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Assessment of Plant Species Composition and Diversity in Home garden Agroforestry Practices Across Agro-Ecological Zones of Dara district, Southern Ethiopia.

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Abstract

*Home garden agroforestry systems support biodiversity conservation and rural livelihoods, yet their ecological patterns may vary across agro-ecological zones. This study assessed the effects of agro-ecological variation on plant diversity, species composition, beta diversity, and vegetation structure in Dara District, Southern Ethiopia. 63 home gardens were systematically sampled using 10 m × 10 m plots for woody species and 1 m × 1 m subplots for herbaceous vegetation. Species diversity was assessed using Shannon–Wiener, Simpson, and evenness indices, while beta diversity was evaluated using the Sørensen similarity index. Structural attributes (diameter at breast height, height, basal area, stem density, and Importance Value Index (IVI), were calculated. Differences among agro-ecological zones were tested using ANOVA and Kruskal–Wallis tests at $p < 0.05$. A total of 214 plant species representing 80 families were recorded, with Asteraceae comprising the largest proportion (7.94%). Herbaceous species accounted for 45% of the flora, followed by trees (27%) and shrubs (21%). Exotic species (56.5%) were more abundant than indigenous species (43.5%). Midland home gardens had the highest species richness (25.86 ± 7.80), Shannon diversity (2.52 ± 0.31), and evenness (0.79 ± 0.07). Beta diversity indicated substantial species turnover, with the greatest dissimilarity between lowland and highland zones (0.65). Structural attributes generally increased with elevation, whereas stem density did not differ significantly. *Ensete ventricosum* had the highest IVI, while regeneration was limited, particularly in highlands. Agro-ecology-specific management is therefore needed to conserve indigenous species and improve regeneration.*

Keywords: *Agro-ecology; Ethiopia; Home garden; Plant diversity; Species composition*

1. Introduction

Biodiversity loss, ecosystem degradation, and climate change represent interconnected global environmental challenges that threaten ecosystem functioning, human well-being, and the long-term sustainability of agricultural systems. Global assessments indicate that land-use change, agricultural expansion, intensification, habitat fragmentation, and climate change are among the dominant drivers of biodiversity decline, with particularly severe impacts in tropical regions where species-rich ecosystems are increasingly converted into agricultural landscapes (IPBES, 2019 ; Díaz et al., 2019). These changes have resulted in the degradation of ecosystem functions, including pollination, soil fertility regulation, carbon storage, and other ecosystem services essential for sustainable food production (IPBES, 2019 ; Dainese et al., 2019).

In this context, agroforestry systems have gained global recognition as nature-based solutions that integrate trees, crops, and livestock within agricultural landscapes, enhancing habitat complexity, conserving biodiversity, improving ecosystem service delivery, and contributing to climate change mitigation through biomass and soil carbon sequestration (Jose, 2009; Mbow et al., 2014; Kuyah et al., 2019; Mathieu and Rivest, 2025). Evidence from global syntheses demonstrates that agroforestry can increase biodiversity and multifunctionality compared with conventional agricultural systems while supporting climate resilience and sustainable livelihoods (Kuyah et al., 2019; (Kuyah et al., 2019; Mathieu and Rivest, 2025). Among agroforestry practices, home garden agroforestry is considered one of the most diverse and sustainable land-use systems because it supports complex, multi-layered vegetation while simultaneously providing food, income, fuelwood, medicinal resources, and other ecosystem services (Kumar and Nair, 2004; Galluzzi et al., 2010; Abebe et al., 2013).

Plant species composition and diversity are fundamental ecological attributes for understanding the structure, function, and sustainability of agroforestry ecosystems. Species composition describes the identity, abundance, dominance, and distribution patterns of plant species within a given ecosystem, whereas plant diversity reflects species richness, evenness, and relative abundance within communities (Magurran, 2004). Assessing these attributes provides valuable insights into ecosystem stability, conservation value, and management intensity. Plant diversity in home gardens is influenced by both environmental and socio-economic factors, including altitude, rainfall, temperature, soil characteristics, household preferences, market access, and management practices (Thompson et al.,

2010 Kehlenbeck et al., 2011). Previous studies in Ethiopia and other tropical regions have shown that plant diversity varies considerably across agro-ecological zones, with mid-altitude areas often supporting greater species richness because of more favorable environmental conditions (Abebe et al., 2013 ;Senbeta et al., 2013). However, the composition and diversity of home garden vegetation are also shaped by household characteristics, cultural preferences, market demand, and access to planting materials (Kumarand Nair, 2004; Kehlenbeck et al., 2011).

Ethiopia is one of Africa's biodiversity hotspots and possesses rich plant genetic resources maintained within diverse traditional agroforestry practices. In southern Ethiopia, particularly in the Sidama Region, home garden agroforestry is characterized by integrated production of enset (*Ensete ventricosum*), coffee (*Coffea arabica*), fruit trees, multipurpose woody species, vegetables, medicinal plants, and ornamental crops, forming highly diversified production systems that contribute to household food security, livelihood resilience, and biodiversity conservation (Hylander et al., 2013). However, increasing population pressure, land fragmentation, climate variability, and changing land-use practices are placing growing pressure on these traditional systems and may reduce their biodiversity and ecological resilience.

Although home garden agroforestry in southern Ethiopia has been widely studied, previous research has mainly focused on crop diversity, woody species composition, livelihood contributions, or general system characterization. Comprehensive assessments that include the entire plant community—including trees, shrubs, herbs, climbers, and cultivated species—across contrasting agro-ecological zones remain limited. Furthermore, little is known about how agro-ecological variation influences species richness, diversity, abundance, community composition, similarity, and stand structure within smallholder-managed home gardens. Recent studies have highlighted the need for more comprehensive biodiversity assessments in Ethiopian agroforestry practices, particularly across environmental gradients (Mekonnen et al., 2023) . This knowledge gap is especially evident in Dara District of the Sidama Region, where diverse agro-ecological conditions have not been systematically investigated despite the long-standing importance of home garden agroforestry.

Therefore, this study aims to:(i) assess plant species composition across agro-ecological zones in home garden agroforestry practices,(ii) compare plant species diversity among agro-ecological zone of home gardens of the study , (iii) assess species similarity along agro-ecological gradients and(iv)

assess the stand structure of woody plant species within the study area . The findings of this study will contribute to a better understanding of biodiversity patterns in home garden agroforestry practice and support the development of sustainable management strategies for smallholder farming systems in heterogeneous landscapes.

2. Materials and Methods

The study was conducted in Dara District, Sidama National Regional State, southern Ethiopia, located approximately 350 km south of Addis Ababa and 45 km south of Hawassa, between 6°30'–6°50' N latitude and 38°10'–38°30' E longitude. The district covers about 27,000 ha and extends from 900 to 2,900 m above sea level, encompassing three major agro-ecological zones: lowland (Kolla, <1500 m), midland (Woina Dega, 1500–2300 m), and highland (Dega, >2300 m). The district receives a mean annual rainfall of 1,200–1,600 mm, mainly from March to September, while mean annual temperatures range from 12.6 to 25°C. The pronounced variation in altitude, climate, and landscape conditions creates diverse soil environments, vegetation assemblages, and farming practices, making Dara District an appropriate ecological setting for assessing variation in plant diversity, vegetation structure, and carbon storage potential of home garden agroforestry systems (Yeshitila and Awas, 2020; Abebe and Asfaw, 2023 ;Jiso, Tafese, 2025). Such environmental gradients are important drivers of species composition, functional diversity, and ecosystem carbon dynamics in tropical agroforestry landscapes (Maryo et al., 2023).

Home garden agroforestry is a dominant traditional land-use system in Dara District, characterized by the integration of multipurpose trees, *Ensete ventricosum*, *Coffea arabica*, fruit trees, medicinal plants, vegetables, and other useful species within household-managed plots. These diverse agroforestry systems play significant roles in conserving plant biodiversity, improving soil fertility, enhancing carbon sequestration, and supporting rural livelihoods through the provision of food, income, fuelwood, fodder, and other ecosystem services (Abebe and Asfaw, 2023;Semere et al., 2024;Setota et al., 2024).Agriculture in the district is primarily based on mixed crop–livestock farming systems, where crops such as maize, barley, wheat, potatoes, and Enset are cultivated alongside livestock production (Digesa, 2023).However, increasing land pressure, agricultural intensification, and climate variability pose potential threats to the ecological functions and biodiversity of traditional agroforestry systems. Therefore, Dara District provides an ideal landscape for investigating how agro-

ecological variation influences plant diversity, ecosystem services, and carbon sequestration potential of home garden agroforestry systems.

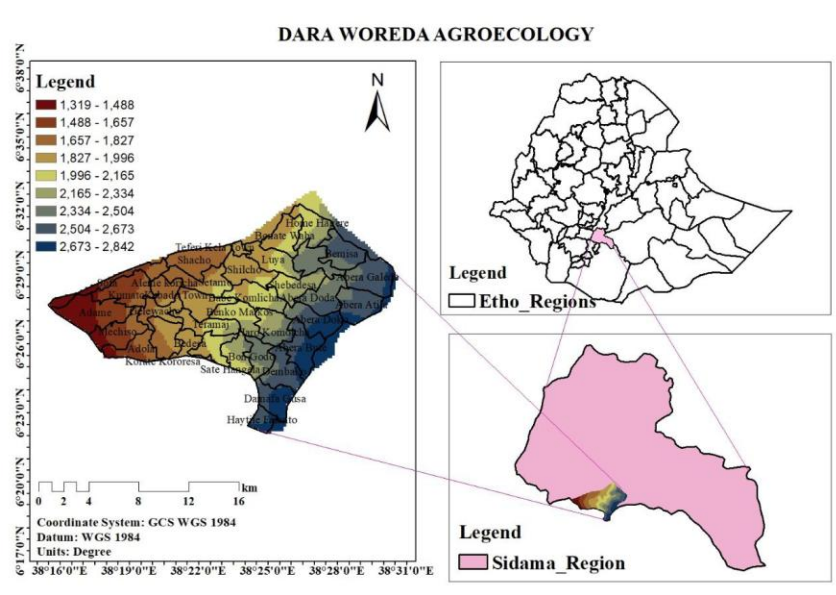


Fig. 1. Locational map of the study area.

These diverse agroforestry systems play significant roles in conserving plant biodiversity, improving soil fertility, enhancing carbon sequestration, and supporting rural livelihoods through the provision of food, income, fuelwood, fodder, and other ecosystem services (Abebe and Asfaw, 2023; Semere et al., 2024; Setota et al., 2024). Agriculture in the district is primarily based on mixed crop–livestock farming systems, where crops such as maize, barley, wheat, potatoes, and Enset are cultivated alongside livestock production (Digesa, 2023). However, increasing land pressure, agricultural intensification, and climate variability pose potential threats to the ecological functions and biodiversity of traditional agroforestry systems. Therefore, Dara District provides an ideal landscape for investigating how agro-ecological variation influences plant diversity, ecosystem services, and carbon sequestration potential of home garden agroforestry systems.

2.2. Research Design and Method

2.2.1. Research Design

This study employed a comparative cross-sectional research design. The comparative cross-sectional research design was employed to assess plant species diversity in home garden agroforestry practices across contrasting agro-ecological zones of the study area. A comparative cross-sectional design is

well suited for ecological and biodiversity studies because it enables the simultaneous assessment of vegetation characteristics across multiple environmental gradients within a defined period, facilitating comparisons of species diversity, composition, and structural attributes among ecological strata (Creswell, 2018). Such designs are widely applied in agroforestry and vegetation ecology to evaluate spatial variation in biodiversity and to identify environmental factors associated with species distribution and community structure (Kumar and Nair, 2004; Jose, 2009).

The study used quantitative approach for, vegetation inventory. Quantitative ecological data were collected through systematic field inventories of selected home gardens, recording plant species identity, abundance, diameter, height, and other structural attributes. These data enabled the estimation of standard biodiversity metrics, including species richness, Shannon–Wiener diversity index, Simpson diversity index, species evenness, and the Important Value Index (IVI), which are internationally recognized indicators for assessing plant diversity, community structure, and species ecological importance (Magurran, 2004; Martin Kent, 2012).

Furthermore, the comparative design facilitated the evaluation of biodiversity patterns across agro-ecological zones by stratifying the study area according to ecological conditions before sample selection. Stratified ecological sampling improves representativeness by ensuring that variation in elevation, climate, and land-use practices is adequately represented, thereby reducing sampling bias and increasing the reliability of biodiversity comparisons (Martin Kent, 2012). The collected data were subsequently analyzed using biodiversity indices and comparative statistical techniques to determine differences in species diversity and composition across agro ecologies. This methodological approach is widely recommended for evaluating agroforestry biodiversity because it allows researchers to link ecological patterns with environmental and management factors influencing species distribution in smallholder farming systems (Kumar and Nair, 2004 ; Jose, 2009).

2.2.2. Sample Size Determination and Justification

A total of 63 home garden agroforestry households was included in this study, comprising 21 households from each of the three agro-environmental zones. The sample size was determined to ensure adequate representation of agro-environmental variability while remaining feasible in terms of field data collection, vegetation inventory, biomass measurement, soil sampling, and socio-ecological surveys. Equal allocation of 21 home gardens to each agro-ecological zone was adopted to ensure

balanced representation and facilitate robust comparisons among lowland, midland, and highland systems. This approach improves the statistical power and precision of comparative analyses by avoiding unequal sample sizes across ecological strata. Although proportional sampling reflects the population distribution of home gardens, it may underrepresent smaller strata and reduce the reliability of between-zone comparisons. Since the primary objective of this study was to evaluate differences in plant diversity, vegetation structure, carbon stocks, and ecosystem services across agro-ecological zones rather than estimate district-wide parameters, equal allocation was considered the most appropriate sampling strategy (Cochran, 1977; Creswell, 2018; Lohr, 2021). Furthermore, the sample size provided adequate replication within each agro-ecological zone to support comparative statistical analyses, including one-way ANOVA, Kruskal–Wallis tests, biodiversity indices, and multivariate analyses. Balanced sample sizes across the three strata improve statistical efficiency, increase the precision of variance estimates, and enhance the ability to detect significant differences among agro-ecological zones (Cochran, 1977).

The adequacy of the proposed sample size is further supported by published studies conducted in Ethiopian home garden agroforestry practices. Previous studies have successfully detected significant differences in plant species diversity, vegetation structure, carbon stocks, and ecosystem services using sample sizes ranging from 40 to 72 home gardens. For example, (Birhane et al., 2020) assessed 60 home gardens in southern Ethiopia and reported significant differences in species richness and carbon stocks along an elevation gradient. Negash and Starr (2015) investigated 45 home gardens in the Ethiopian Rift Valley and identified significant variation in carbon stocks among agroforestry practices. Darcho and Negash, (2023) evaluated 40 home gardens in Wolaita Zone and found significant effects of household wealth on carbon storage, while Tesfaye et al., (2022) examined 72 home gardens across multiple sites and detected significant agro-environmental differences in ecosystem services.

The proposed sample size of 63 home gardens is therefore comparable to, and exceeds the average sample size reported in similar Ethiopian studies. Moreover, the study will be conducted across nine kebeles (three kebeles per agro-environmental zone), providing broader spatial coverage than many previous studies that sampled only three to five kebeles. This wider geographical representation is expected to improve the capture of environmental and socio-ecological heterogeneity, enhance the

robustness of statistical analyses and increase the generalizability of the findings to Home garden agroforestry practice in the study area.

2.2.2. Method of data collection and sampling

The home gardeners were selected from each kebele of the three agro-ecology. Within each agro ecology, 21 plots (63 home gardeners or pilots in total) was randomly selected (Tesfay et al., 2022). To assess the diversity and the composition of plant species in the home garden; first the researcher divided home garden into two equal parts using measuring tape. Then, a number was assigned to each part and finally, one part out of two parts was randomly selected (Betemariyam et al., 2020). From randomly selected part; systematic pilot placement were used in the home gardens where the land was planted with mixed trees and seasonal crops (Park et al., 2019) and the plot was made 10*10 m (Kassa et al., 2022). Square plots was selected ; as they tend to include more of the within-plot heterogeneity and; thus be more representative than circular plots of the same area (Chemeda et al., 2022). In order to determine the diversity of woody species existing in home garden agroforestry practices, woody species inventory was made 10*10 m (Kassa et al., 2022). For woody species (data on species name, number of individuals of each species per quadrat and number of structural layers based on the plant height was collected. Plant species herbs, shrubs, and trees (Kumar, 2023) was encountered in the HGs. Diameter at breast height (DBH) of trees and shrubs was measured using diameter tape and height of plants was measured using measuring poles (for small plants < 3 m) and clinometers for larger plants (height > 3 m: such as trees and shrubs) (Birhanand Amdie, 2019). On each HG woody species seedlings (<2.5 cm diameter and height < 1 m), saplings (2.5 - 5 cm diameter and height 1 -2 m) and matured (>5 cm diameter and height > 2 m) was recorded by complete counting method (Jiangshan et al, 2009, as cited in Mesafnt Minale, 2021). The herbaceous vegetation was collected from five subplots (quadrats of 1m x 1m size) in four cardinal directions North, East, South, West and at the center in each main plot at a distance of 1m from the outside boundary of the main plot. From these five subplots, herbaceous material (<5cm diameter) was sampled using an aluminum/wooden square frame of 1m x 1m. For collection of samples destructive sampling method (Harvest the aboveground biomass of each sampled plant) was used (Gayathri and Raj, 2023). Totally 63 plots were sampled for the plant biodiversity.

Woody and herbaceous species identification and data collection was carried out using knowledgeable people from the local community, researcher and cross check with botanical expert. Woody species nomenclature was carried by using Flora of Ethiopia and Eritrea (Edwards, 2000, Tesfaye Abebe, 2005 ,Regassa, 2016,Tefera and Kim, 2019).Unknown species will be collected, pressed and identified at a recognized herbarium. The geographical location and altitude of each sample home garden was recorded using a GARMIN GPS. Each species recorded in the home gardens was classified by family, habit according to the morphology of the plant in its full growth potential (tree, shrub, herb or climber), domesticity (planted vs. naturally established(Taylor et al., 2010).

2.3. Data Analysis

All data were organized and processed using Microsoft Excel, and statistical analyses were conducted in SPSS 20 version. Prior to inferential analysis, data were tested for normality (Shapiro–Wilk test) and homogeneity of variance (Levene’s test). Differences in diversity indices(Mean of species richness, Shannon diversity index ,Simpson index and Evenness) and structural variables(diameter at breast height (DBH), height, basal area (BA), and stem density) among agro-ecological zones were evaluated using one-way analysis of variance (AN OVA) for normally distributed data(stem density) and the Kruskal–Wallis test for non-parametric data((DBH), height, basal area (BA)). Where significant differences were detected, post hoc comparisons were performed using Tukey’s HSD or Dunn’s test. Statistical significance was declared at $p < 0.05$.

Species dominance and ecological importance were evaluated using the Importance Value Index (IVI), calculated as the sum of relative density, relative frequency, and relative dominance for each species. Regeneration status was analyzed by classifying individuals into seedling, sapling, and mature stages. To quantify plant species diversity, commonly used ecological diversity indices was computed. The Shannon–Wiener diversity index (H') was used to assess species diversity, considering both species richness and evenness. It was calculated using the formula:

$$H' = - \sum_{i=1}^s P_i \ln(P_i) \dots\dots\dots \text{Eq. (1)}$$

Where p_i represents the proportion of individuals belonging to the i th species and S is the total number of species (Shannon and Weaver, 1949). Species evenness (E) was also calculated to determine how evenly individuals are distributed among species using the equation:

$$\text{Equitability (evenness)} J = \frac{H'}{H'_{\max}} = \frac{-\sum_{i=1}^S p_i \ln(p_i)}{\ln S} \dots\dots\dots \text{Eq. (2)}$$

In addition, the Simpson's diversity index (D) was calculated to measure species dominance within the Home garden agroforestry practice (Simpson, 1949). These indices helped to compare biodiversity patterns among different agro-ecological zones.

$$D = \frac{1}{\sum_{i=1}^S p_i^2} \dots\dots\dots \text{Eq. (3)}$$

Where D =Simpson's index of species diversity S = number of species; P_i
= proportion of total sample belonging to the i^{th} species.

The Sørensen coefficient of similarity (S_s) (M.Kent, Coker, 1992, as cited in Maryo et al., 2023) was used to calculate the species similarities of across three agro-ecological zones

Sørensen coefficient of similarity (S_s) was defined by

$$(S_s) = \frac{2a}{2a+b+c} \dots\dots\dots \text{Eq. (4)}$$

Where, S is Sørensen's similarity index.

C is the number of species common to both sites.

A is the number of species present in one of the sites to be compared.

B is the number of species present on the other site. The coefficient values range from 0 (complete dissimilarity) to 1 (total similarity) (Kent and Coker, 1992, as cited in Edo et al., 2024).

The Important Value Index (IVI) was calculated for woody species to determine their ecological significance within the home garden practice. IVI integrates three structural parameters: relative

density (RD), relative frequency (RF), and relative dominance (RDo). These parameters was calculated as follows (Kent and Coker, 1992,as cited in Edo et al., 2024):

$$\text{The Important Value Index (IVI)} = (\text{RD}) + (\text{RF}) + (\text{RDo}) \text{ ----- equation(5)}$$

$$\text{Relative Density (RD)} = (\text{Number of individuals of a species} / \text{Total number of individuals of all species}) \times 100 \text{----- equation (a)}$$

$$\text{Relative Frequency (RF)} = (\text{Frequency of a species} / \text{Sum of frequencies of all species}) \times 100 \text{----- equation (b)}$$

$$\text{Relative Dominance (RDo)} = (\text{Basal area of a species} / \text{Total basal area of all species}) \times 100 \text{----- equation (c)}$$

The IVI then be calculated as:

Basal area (BA) of woody species was computed from the diameter at breast height (DBH) measurements using the formula:

Where, DBH is the diameter at breast height (1.3 m above ground level). Basal area values was expressed in square meters per hectare ($\text{m}^2 \text{ha}^{-1}$).

To compare biodiversity an indicator among agro-ecological zones, one-way analysis of variance (ANOVA) was employed was fulfilled the assumptions of normality and homogeneity of variance. Prior to analysis, the normality of data distribution was checked using the Shapiro–Wilk test, and homogeneity of variance was tested using Levene’s test. Differences among means were considered statistically significant at $p < 0.05$.

Finally, plant species were categorized by growth form (tree, shrub, herb, climber and epiphyte), origin (exotic and indigenous), and regeneration status (seedlings, saplings, and Matured). While frequency distributions and percentage values was calculated to describe vegetation structure and regeneration patterns across the agro-ecological zones. Graphs, tables, and charts were s developed using Microsoft Excel and SPSS version 20 to organize data and visually present species diversity, structural composition, and regeneration status of plant species in the studied home garden agroforestry practices.

3. Results

3.1. Plant Species Composition

3.1.1. Floristic composition

A total of 214 plant species representing 80 families were recorded in the 63 home gardens. The flora was dominated by Asteraceae (7.94%), followed by Euphorbiaceae (6.54%), while Fabaceae and Lamiaceae each contributed 13 species (6.07%). Most of the remaining families were represented by only a few species, indicating a broad but uneven taxonomic composition of the home garden flora.

3.1.2. Plant Species growth form

The growth-form distribution of plant species showed a clear dominance of herbaceous species, which accounted for 45% of the total. Trees represented the second largest group at 27%, followed by shrubs at 21%. Climbers contributed a relatively small proportion of 7%, while epiphytes were nearly absent (1%). This distribution indicates that the vegetation structure is largely dominated by low-growing and short-lived species (herbs), with comparatively fewer woody components (trees and shrubs). The minimal presence of climbers and absence of epiphytes suggest limited vertical stratification and reduced habitat complexity in the study area (Fig 2).

Regarding origin of plant species: out of 214 plant species recorded, 121 species (56.5%) were exotic, while 93 species (43.5%) were indigenous to the study area. The number of exotic species exceeded that of indigenous species by 28 species.

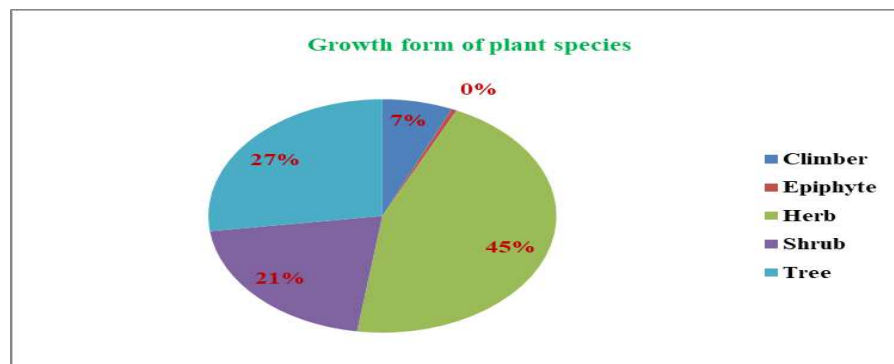


Fig.2. Growth form of plant species of the study area

3.2 Plant Species Diversity

Species richness and diversity indices showed clear variation across agro-ecological zones (Table 2). The Kruskal-Wallis test revealed that species richness differed significantly among agro-ecologies ($p = 0.002$). The highest mean species richness was recorded in the midland agro-ecology (25.86 ± 7.80), which was significantly higher than both lowland (21.00 ± 6.31) and highland (18.24 ± 2.78), as indicated by different superscript letters.

Similarly, Shannon diversity index showed a highly significant variation across agro-ecological zones ($p < 0.001$), with the midland agro-ecology exhibiting the highest diversity (2.52 ± 0.31). The Simpson diversity index also differed significantly among agro-ecologies ($p = 0.001$), with higher values in midland systems. In addition, species evenness showed significant variation across agro-ecologies ($p = 0.042$). Midland agro-ecology exhibited the highest evenness (0.79 ± 0.07), while lowland and highland agro-ecologies showed relatively lower evenness values.

Table 1. Species richness and diversity indices across agro-ecological zones.

Agro-ecology	Mean of species richness	Shannon(Mean $\pm$ SD)	Simpson(Mean $\pm$ SD)	Evenness(Mean $\pm$ SD)
Lowland	21 $\pm$ 6.31 ^a	2.17 $\pm$ 0.48 ^a	0.83 $\pm$ 0.07 ^a	0.65 $\pm$ 0.14 ^a
Midland	25.86 $\pm$ 7.8 ^b	2.52 $\pm$ 0.31 ^b	0.86 $\pm$ 0.06 ^b	0.79 $\pm$ 0.07 ^b
Highland	18.24 $\pm$ 2.78 ^a	2.08 $\pm$ 0.25 ^a	0.77 $\pm$ 0.15 ^a	0.64 $\pm$ 0.09 ^a
p-value	0.002	0.00	0.001	0.042

Note: Values are Mean $\pm$ SD, different superscript letter (a,b) within the same column indicate statically significant difference among agro-ecological zones at $p < 0.05$. Significance was determined using the Kruskal-Wallis test followed by pairwise comparison.

3.3 Dissimilarity and Similarity index of Plant Species among Agro-ecological Zones

Fig 3 presents the pairwise species dissimilarity and similarity indices among three agro-ecological zones. The lowland-midland pair showed the highest similarity (0.57) and the lowest dissimilarity (0.43). In contrast, the lowland-highland pair exhibited the highest dissimilarity index (0.65) and the lowest similarity (0.35). The midland-highland pair showed intermediate values, with a dissimilarity index of 0.55 and similarity of 0.45.

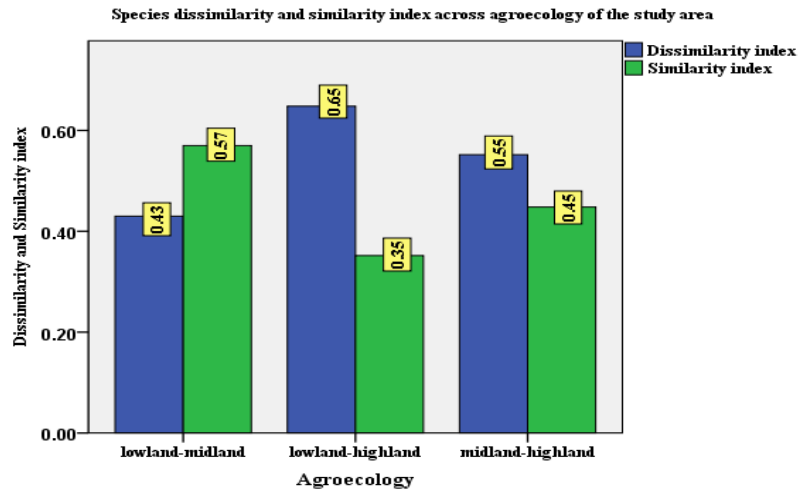


Fig 3. Plant species dissimilarity and similarity of the study area

The midland-highland pair shows intermediate values, with a dissimilarity index of 0.55 and similarity of 0.45. This indicates a moderate level of species replacement, suggesting that although these zones share some ecological characteristics, environmental filtering and microclimatic differences still contribute to noticeable compositional differences.

3.4. Stand structure of woody species of the study area

3.4.1 Stand structure of woody species (stem density, DBH, Height and Basal area)

A total of 63 plots were assessed for woody-species structural characteristics, including diameter at breast height (DBH), height, basal area, and stem density. Based on normality tests, Kruskal–Wallis H tests were applied to DBH, height, and basal area, while stem density was analyzed using one-way ANOVA.

DBH differed significantly among agro-ecological zones ($\chi^2 = 7.152$, $p = 0.028$), with the highest mean rank in the highland (282.98), followed by the midland (268.48) and lowland (237.82). Mean DBH ranged from 13.45 ± 22.55 cm in the lowland to 15.42 ± 13.17 cm in the highland. Similarly, woody-species height varied highly significantly among zones ($\chi^2 = 18.092$, $p < 0.001$), with mean ranks increasing from lowland (221.74) to midland (274.94) and highland (290.96). Mean height was 6.82 ± 10.52 m, 8.61 ± 10.26 m, and 8.16 ± 7.79 m in the lowland, midland, and highland, respectively.

Basal area also differed significantly among zones ($\chi^2 = 7.152$, $p = 0.028$), with mean ranks of 237.82, 268.48, and 282.98 for lowland, midland, and highland, respectively. However, mean basal area remained low (0.03–0.05 m²/ha). Stem density showed no significant difference ($F = 1.254$, $p = 0.293$), despite increasing from $7,171.43 \pm 3,196.74$ stems/ha in the lowland to $8,683.38 \pm 3,235.48$ stems/ha in the highland.

Table 2. Comparison of stand structural variables woody species across agro-ecological zones of the study area

Variable	Agro ecology	N	Mean± Std	Mean rank	x ²	p-value	Significant
DBH (cm)	Lowland	21	13.45±22.55	237.82	7.152	0.028	Yes
	Midland	21	14.41 ±18.77	268.48			
	Highland	21	15.42 ±13.17	282.98			
Height (m)	Lowland	21	6.82±10.32	221.74	18.092	0	Yes
	Midland	21	8.61± 10.26	274.94			
	Highland	21	8.16±7.79	290.96			
Basal area (m ² /ha)	Lowland	21	0.05 ±0.33	237.82	7.152	0.028	Yes
	Midland	21	0.04 ±0.31	268.48			
	Highland	21	0.03 ±0.05	282.98			
Number of stem(ha ⁻¹)	Lowland	21	7171.43±3196.74	-	F=1.254	0.293	No
	Midland	21	7523.81±2926.76	-			
	Highland	21	8633.33 ±3235.48	-			

Note: DBH, Height and Basal area were analyzed using the Kruskal-Wallis H test (reported as χ^2) with $p < 0.05$ and stem density (ha⁻¹) was analyzed using one way ANOVA (reported as F with $p > 0.05$).

3.4.2. Stand structure of woody species (Important Value Index (IVI))

Table 3 presents the ten woody species with the highest Importance Value Index (IVI), calculated from relative density (RD), relative frequency (RF), and relative dominance (RDo). *Ensete ventricosum* (Welw.) Cheesman was the most structurally important species, recording the highest

RD (52.82%), RF (11.38%), and RDo (23.58%), and consequently the highest IVI (87.78%). Its high relative density indicates that it constituted more than half of the recorded individuals, while its frequency and dominance demonstrate its widespread occurrence and substantial contribution to basal area.

Persea americana Mill. and *Cordia africana* Lam. ranked second and third, with IVI values of 22.28% and 21.72%, respectively, indicating substantial structural importance. *Eucalyptus globulus* Labill. (21.26%) and *Coffea arabica* L. (20.45%) also showed relatively high IVI values. Although *C. arabica* had relatively high density (10.50%), its low dominance (2.13%) suggests that it was represented mainly by smaller individuals and contributed comparatively little to total basal area.

Table 3. Presents the top ten woody species ranked based on Importance Value Index (IVI) and includes : relative density (RD), relative frequency (RF), relative dominance (RDo) of the study area.

S/No	SPECIES	RD(%)	RF(%)	RDo(%)	IVI(%)
1	<i>Ensete ventricosum</i> (Welw.) Cheesman	52.82	11.38	23.58	87.78
2	<i>Persea americana</i> Mill.	1.91	6.61	13.77	22.28
3	<i>Cordia africana</i> Lam.	2.06	5.78	13.87	21.72
4	<i>Eucalyptus globulus</i> Labill.	2.31	9.70	9.25	21.26
5	<i>Coffea arabica</i> L.	10.50	7.82	2.13	20.45
6	<i>Euphorbia abyssinica</i> Gmel.	8.03	6.47	3.50	18.00
7	<i>Ficus sur</i>	0.07	0.64	16.29	16.99
8	<i>Hagenia abyssinica</i> (Bruce) J.F. Gmel.	0.91	5.22	9.49	15.63
9	<i>Musa x paradisiaca</i> L.	5.65	4.35	3.77	13.77
10	<i>Juniperus procera</i> Hochst. ex Engl.	1.90	5.54	6.19	13.63

Source: Survey data, 2025, Note: RF=Relative Frequency, RD=Relative Density, RDo=Relative Dominance, IVI=Important Value Index

Euphorbia abyssinica Gmel., *Ficus sur*, and *Hagenia abyssinica* (Bruce) J.F. Gmel. exhibited intermediate IVI values (15.63–18.00%). Notably, *F. sur* had extremely low density (0.07%) but high dominance (16.29%), indicating that its few individuals were relatively large and contributed substantially to basal area. *Musa × paradisiaca* L. (13.77%) and *Juniperus procera* Hochst. ex Engl. (13.63%) had the lowest IVI among the top ten species. Overall, the marked variation in IVI indicates

an uneven woody-species structure, characterized by strong dominance of *E. ventricosum* alongside several species with complementary structural roles.

3.4.3. Stand structure of woody species (Regeneration Status)

The bar chart (Fig 4) illustrates the regeneration status of woody plant species across three agro-ecological zones, categorized into seedlings, saplings, and mature individuals. Overall, the total counts show a clear dominance of mature individuals (2624), followed by saplings (1229) and seedlings (1035). This pattern indicates a population structure skewed toward older individuals, suggesting potential regeneration limitations. Across agro-ecologies, the lowland zone exhibits relatively balanced regeneration, with 521 seedlings, 431 saplings, and 556 mature individuals. In the midland area, the number of mature individuals (965) is substantially higher than both saplings (455) and seedlings (317). The highland shows the lowest regeneration pattern, with very low seedling count (197) compared to saplings (343) and a much higher number of mature individuals (1103). Comparatively, seedling density decreases along the agro-ecological gradient from lowland to highland, while mature individuals increase. This suggests that environmental conditions and/or management practices vary significantly across agro-ecologies, influencing regeneration dynamics.

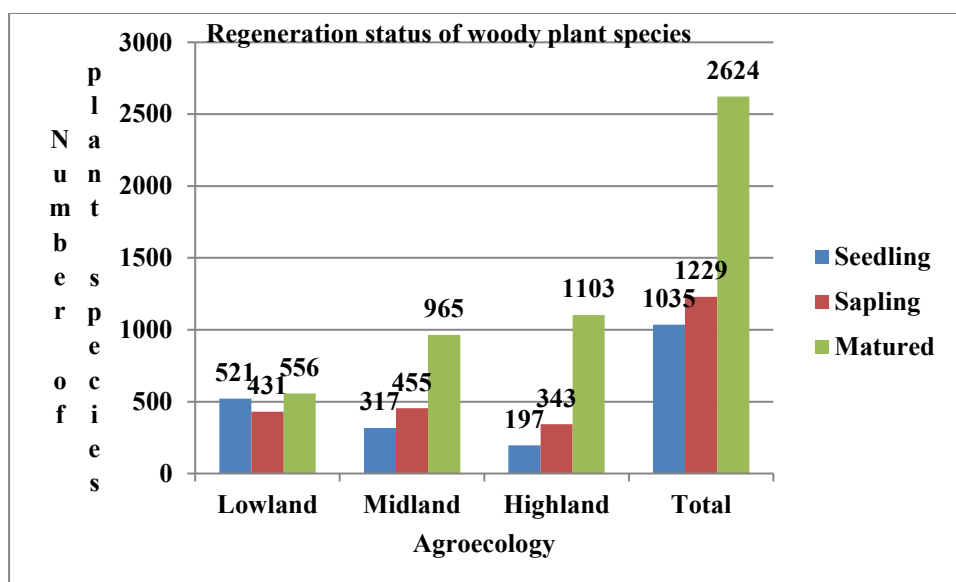


Fig. 4. Regeneration status of woody plant species

4. Discussion

4.1 Plant Species Composition

4.1.1 Floristic composition

The 214 plant species belonging to 80 families recorded in the present study demonstrate that home garden agroforestry practice in the study area are important reservoirs of plant biodiversity. This high species richness is consistent with previous studies showing that tropical home gardens maintain diverse plant assemblages through the integration of trees, shrubs, crops, and herbs that support both biodiversity conservation and rural livelihoods (Kumar and Nair, 2004; Tesfaye Abebe, 2005).

The dominance of Asteraceae (7.94%), followed by Euphorbiaceae (6.54%), Fabaceae, and Lamiaceae (6.07% each), agrees with findings from Ethiopian and other tropical home gardens, where these families are common because of their broad ecological adaptability and multiple uses, including food, medicine, fodder, and soil fertility improvement (Tefaye Abebe, 2005; Tolera et al., 2008). Although a few families contributed many species, most families were represented by only one or a few species, reflecting the selective management practices of farmers and the heterogeneous nature of home garden agroforestry practices.

4.1.2 Growth form and origin

The dominance of herbaceous species (45%), followed by trees (27%) and shrubs (21%), suggests that home gardens in the study area are managed primarily for food production through annual crops, vegetables, and medicinal plants. This pattern agrees with previous studies in tropical home gardens, where herbaceous species are favored because they provide rapid economic returns and efficient land use (Kumar and Nair, 2004; Tesfaye Abebe, 2005). In contrast, tree-dominated home gardens with more complex vertical structure have been reported from parts of India and Sri Lanka (Kumar and Nair, 2004). The low proportion of climbers (7%) and absence of epiphytes further indicate limited vertical stratification.

The higher proportion of exotic species (56.5%) than indigenous species (43.5%) is consistent with studies from Ethiopian home gardens, where farmers preferentially cultivate introduced species for their high productivity, market value, and multiple uses (Tefaye Abebe, 2005; Tolera et al., 2008). However, this contrasts with traditional home gardens in parts of Sri Lanka and Indonesia, where indigenous species remain dominant because of strong conservation and cultural practices (Kehlenbeck et al., 2007). Nevertheless, the considerable proportion of indigenous species recorded highlights the important role of home gardens in conserving native plant diversity alongside economically important exotic species.

4.2. Plant Species Diversity

The significantly higher species richness and diversity in the midland agro-ecology indicate that this zone provides more favorable conditions for sustaining diverse home garden vegetation. This finding agrees with previous studies showing that intermediate agro-ecological zones often support greater plant diversity due to favorable climate, soil conditions, and diverse management practices (Kumar and Nair, 2004; Tesfaye Abebe, 2005; Tolera et al., 2008). The higher Shannon, Simpson, and evenness indices in the midland zone suggest a more balanced and less species-dominated plant community, consistent with findings from tropical home gardens (Galluzzi et al., 2010; Kehlenbeck et al., 2007).

The lower diversity observed in the lowland and highland agro-ecologies contrasts with studies reporting greater diversity in lowland systems, highlighting the influence of local environmental conditions and household management on plant diversity (Kumar and Nair, 2004). In the lowland

zone, higher temperatures and moisture stress may limit species establishment and survival, while in the highland zone, cooler temperatures and potential frost risks may constrain species diversity. Overall, these results demonstrate that agro-ecological variation is a major determinant of plant diversity in home garden agroforestry practices.

4.3 Species Similarity and Dissimilarity

The observed variation in species composition among agro-ecological zones indicates that altitude is a major driver of species turnover in the study area. The higher similarity between the lowland and midland zones (0.57) reflects comparable environmental conditions and management practices, whereas the greater dissimilarity between the lowland and highland zones (0.65) suggests that increasing elevation and associated climatic differences limit species overlap. This finding is consistent with studies showing that environmental gradients strongly shape plant community composition and increase beta diversity along altitudinal gradients (Rahbek et al., 2019). The intermediate similarity between the midland and highland zones (0.45) further indicates gradual species replacement driven by environmental heterogeneity, highlighting the importance of conserving home gardens across different agro-ecological zones to maintain regional plant biodiversity. The pairwise dissimilarity values (0.43-0.65) demonstrate moderate to strong species turnover, emphasizing the complementary conservation value of home gardens across altitudinal gradients.

4.4 Stand Structure of Woody Species

4.4.1 DBH, Height, Basal Area, and Stem Density

The significant differences in DBH, tree height, and basal area among agro-ecological zones indicate that elevation plays an important role in shaping the structural development of woody species in home garden agroforestry practices. The larger DBH and taller trees observed in the highland are consistent with previous studies, which reported that favorable climatic conditions, greater soil moisture availability, and lower environmental stress at higher elevations promote tree growth and biomass accumulation (Kuyah et al., 2016 ; Zomer et al., 2022). patterns have also been reported in Ethiopian agroforestry practices (Negash et al., 2023).

However, the generally low basal area values across all zones (0.03-0.05 m²/ha) indicate that woody species contribute relatively little to the total basal area compared to natural forests or more tree-dominated agroforestry systems. This may reflect the predominant focus on herbaceous crops in these home gardens, with woody species serving supplementary rather than dominant roles.

In contrast, stem density did not differ significantly among agro-ecological zones, suggesting that stem abundance is influenced more by farmers' management practices and planting preferences than by environmental gradients. Comparable findings have been reported by Rahn(2023), although other studies have documented higher stem densities at higher elevations due to greater tree retention and natural regeneration (Mbow et al., 2021).Overall, the results suggest that agro-ecological variation primarily affects tree size and stand structure rather than stem abundance in the home garden agroforestry practice of the study area.

4.4.2. Importance Value Index (IVI)

The exceptionally high Importance Value Index of *Ensete ventricosum* (IVI = 87.78%) confirms its dominant ecological role in the home garden agroforestry practice of Dara District. Its high relative density, frequency, and dominance reflect its widespread cultivation and multifunctional importance as a staple food crop, livestock feed, fiber source, and drought-resilient species. This finding agrees with recent studies from southern Ethiopia, which identified *E. ventricosum* as the structural and functional backbone of traditional home gardens because of its outstanding contribution to household food security, income, and resilience to climate variability (Borrell et al., 2020). Its overwhelming dominance also reflects farmers' deliberate management and preference rather than natural ecological succession.

The relatively high IVI values of *Persea americana* (22.28%), *Cordia africana* (21.72%), *Eucalyptus globulus* (21.26%), and *Coffea arabica* (20.45%) indicate their important ecological and socioeconomic roles within the agroforestry practice. Similar findings have been reported in Ethiopian home gardens, where these species are widely retained for fruit production, timber, fuelwood, shade, and income generation, resulting in high structural importance (Negash, 2013). The low dominance but high density of *C. arabica* observed in this study reflects the cultivation of numerous small-sized individuals beneath the tree canopy, a pattern commonly reported in coffee-

based agroforestry practices of Ethiopia. Conversely, species such as *Ficus sur* exhibited low density (0.07%) but high dominance (16.29%), indicating the presence of a few large trees contributing substantially to stand basal area. Similar structural patterns have been documented in tropical agroforestry practices, where remnant indigenous trees are intentionally retained for shade, soil fertility improvement, and biodiversity conservation despite their low abundance (Jose, 2009; Kuyah et al., 2021).

The marked variation in IVI among species indicates an uneven community structure dominated by a few economically valuable species. This pattern is consistent with previous studies showing that Ethiopian home gardens are shaped primarily by farmers' management objectives and livelihood needs rather than by natural forest dynamics, resulting in the dominance of multipurpose species while maintaining a diverse assemblage of less abundant plants (Kumar and Nair, 2004; Negash, 2013).

4.4.3 Regeneration Status

The regeneration pattern observed in this study, where mature individuals (2624) greatly outnumbered saplings (1229) and seedlings (1035), indicates an uneven population structure and suggests regeneration constraints in the home garden agroforestry practice of Dara District. Similar patterns have been reported in Ethiopian agroforestry and dry Afromontane forests, where limited recruitment has been linked to intensive harvesting, grazing pressure, and poor seedling establishment (Negash, 2013). Such a population structure may reduce the long-term sustainability of woody species if recruitment remains insufficient.

The relatively higher seedling abundance in the lowland zone (521 seedlings) suggests more favorable regeneration conditions, whereas the highland zone exhibited poor regeneration, characterized by very few seedlings (197) despite a large number of mature trees (1103). This finding agrees with recent studies showing that regeneration success varies across agro-ecological gradients due to differences in temperature, soil moisture, light availability, and management practices (Kuyah et al., 2021). However, it contrasts with reports from some humid Ethiopian highland forests, where cooler and wetter conditions promoted higher seedling recruitment (Asefa et al., 2020), indicating that local management practices may exert a stronger influence than climate alone.

The declining seedling abundance from lowland to highland suggests that targeted management interventions, including protection of natural regeneration, enrichment planting, and reduced disturbance, are needed to enhance the long-term persistence of woody species in the study area. The regeneration deficit observed across all zones, but particularly in the highland, calls for urgent conservation and management actions to ensure the sustainability of these important agroforestry systems.

5. Conclusion

This study demonstrates that home garden agroforestry systems in Dara District are important reservoirs of plant biodiversity and provide essential ecological and livelihood benefits. A total of 214 plant species belonging to 80 families were recorded, with Asteraceae, Euphorbiaceae, and Fabaceae being the most species-rich families. Agro-ecological variation strongly influenced plant diversity, with the midland zone recording the highest species richness (25.86 ± 7.80), Shannon diversity (2.52 ± 0.31), and evenness (0.79 ± 0.07). The substantial species turnover along the altitudinal gradient, particularly the high dissimilarity between lowland and highland zones (0.65), confirms elevation as an important driver of plant community composition.

Vegetation structure was dominated by herbaceous species (45%), followed by trees (27%) and shrubs (21%). The predominance of exotic species (56.5%) over indigenous species (43.5%) indicates increasing farmer preference for introduced species, mainly because of their economic and livelihood benefits, but may also have implications for long-term biodiversity conservation. *Ensete ventricosum* had the highest Importance Value Index ($IVI = 87.78$), followed by *Persea americana* (22.28) and *Cordia africana* (21.72), highlighting the ecological and socioeconomic importance of key multipurpose species. Significant variation in DBH, height, and basal area across agro-ecological zones further indicates that environmental gradients influence vegetation structure, whereas stem density remained relatively stable.

The regeneration status raises concerns about the long-term sustainability of these systems. Mature individuals (2,624) substantially outnumbered saplings (1,229) and seedlings (1,035), with the highland zone showing the most pronounced recruitment limitation, where only 197 seedlings were recorded compared with 1,103 mature individuals. This pattern suggests the need for immediate interventions to enhance natural regeneration and maintain future plant populations.

Accordingly, management should prioritize enrichment planting with indigenous trees and shrubs, conservation of rare species, species selection suited to specific agro-ecological conditions, and improved regeneration practices, particularly in highland areas. Farmers should also be supported to diversify income through high-value multipurpose species, stronger market linkages, cooperatives, and climate-smart practices. At the institutional level, agroforestry should be integrated into regional land-use, biodiversity, and climate strategies. Strengthened extension services, community seed networks, farmer training, secure land tenure, and gender- and youth-inclusive participation are also essential. Coordinated action among farmers, researchers, extension agents, and policymakers will be critical for maintaining biodiversity, strengthening livelihoods, and enhancing the resilience and long-term sustainability of home garden agroforestry systems in southern Ethiopia.

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