Original Research Article

Potential of Agroforestry Practices on Woody Species Diversity and the Conservation of Indigenous Trees in Northern Ethiopia

Abstract

Human activities such as expanding farmland, producing charcoal, and harvesting construction materials and fuel wood are major contributors to forest degradation and biodiversity loss in Northern Ethiopia. This study aimed to assess the diversity, composition, and threat levels of woody species in Homegarden Agroforestry (HGAF), Parkland Agroforestry (PLAF), and Woodlot Agroforestry (WLAF) to prioritize their conservation.The study involved 45 sample plots, with 15 plots each for WLAF (10m x 10m), HGAF (20m x 10m), and PLAF (50m x 100m). Data on woody species were analyzed using Past version 2.17c and SPSS version 20. The results identified 36, 26, and 21 woody plant species from 31, 23, and 19 genera, and 22, 16, and 15 families in HGAF, PLAF, and WLAF, respectively.Significant differences ($p < 0.001$) were found among the agroforestry practices in terms of tree density, species richness, species abundance, and Shannon diversity, though species evenness did not vary. The Importance Value Index (IVI) highlighted the top species in HGAF as *A. etbaica* (75.2%), *F. albida* (33.1%), and *A. seyal* (30.6%). Species with low IVI values, such as *B. polystachya* (1.56%), *R. vulgaris* (1.57%), *G. ferruginea* (1.62%), and *C. aurantiifolia* (0.90%), require significant conservation efforts. In PLAF, the key species were *F. albida* (96.5%), *A. seyal* (223.3%), and *C. africana* (23.2%). In WLAF, *E. globulus* (61.8%), *A. seyal* (8.83%), and *C. edulis* (31.4%) were the most abundant, frequent, and dominant.Trees and shrubs in HGAF and WLAF had smaller stem diameters compared to those in PLAF. However, WLAF had greater tree height and basal area (BA, m^2) than both HGAF and PLAF, with HGAF also showing a higher BA than PLAF ($p \leq 0.05$).The study concluded that HGAF and PLAFare vital for sustaining local livelihoods, providing food, and conserving biodiversity. These agroforestry systems enhance natural forests and help prevent the extinction of woody species. Therefore, developing and enhancing HGAF, and PLAF in densely populated landscapes should be integral to biodiversity conservation strategies.

Introduction

Deforestation which is mainly associated with human pressure has been a major problem for quite a long time with serious consequences for northern Ethiopia, in particular, (Esser et al., 2002). Some drivers of deforestation and associated biodiversity loss include agricultural expansion, charcoal making, fuel-wood collection, illegal logging, fire, and the need for wood construction. These consequences include decline or loss of biodiversity, degradation of land and water bodies, possible negative effects on the local,regional, and global climatic conditions as well asnegative impacts on the welfare of human beings(Nyssen et al., 2009; Temesgen et al., 2014).Thus, small remnant forests,woodlands, or shrublands have become restricted toinaccessible areas such as hillsides, mountaintops,and around churches, monasteries, mosques, orgraveyards, particularly in the northern parts of thecountry.

Tigray is one region that has fallen victim to the land degradation problem in the northern parts of the country. In Tigray, the severelydegraded lands can be typically characterized byheavily eroded or nutrient-deficient soils, hydrologicalinstability, reduced primary productivity, and loss ofbiological diversity(Gashaw, 2018; Nyssen et al., 2009; Temesgen et al., 2014). The floral, faunal, and microbialdiversity of these areas could be reduced, to theextent that they might be changed into wastelands.Past reforestation/afforestation programs in suchareas have been unsuccessful due to either totalfailure or low survival rate of planted species(Mehari, 2005).Several major factors such as unavailability or lowavailability of propagules, low soil nutrient availability,absence of fungal/bacterial root symbionts orunsuitability of the microhabitats for plantestablishment in general and seasonal droughtmay be attributed to such failures(Yirdaw et al., 2017).

To circumvent these problems, Agroforestry practices, which integrate trees into agricultural systems, offer significant potential for climate change mitigation and biodiversity enhancement in arid environments(Negash & Kanninen, 2013). Different agroforestry practices have different potentials to conserve woody species diversityand climate change mitigation depending on site characteristics, geographical location, and management practice. Agroforestry has been acknowledged as one of the most promising land use types for the conserve biodiversity and climate change mitigation besides its several benefits through supporting people's livelihoods via offering energy, food and fiber (Eyasu et al., 2020; Kumar & Nair, 2004).

Despite the emerging and promising socio-economic and ecological importance of agroforestry practices in Northern Ethiopia, very little or virtually no systematic and scientific studies have been made. With the fact that woody species are disappearing at an alarming rate and thus, the role of agroforestry systems as a conservation tool and climate change mitigation needs to be further explored (Eyasu et al., 2020). As a result, documented information on agroforestry practices is scanty or completely lacking. Therefore, this study aimsto explore the extent of diversity, and composition, and identify threatened tree species for the conservation priority of woody species in the agroforestry practices and manner of population structure, as well as the regeneration status of woody species.

METHODS AND MATERIALS

Description of the study sites

The research was carried out in three different areas in the eastern zone of the Tigray region, northern Ethiopia: Ganta-Afeshum (Simret), Hawzen (Freweyni), and Kilte-Awlaelo (AbrehaWeatsbeha). These areas are situated between 13° 30′–14° 15′ N latitude and 39° 15′–39° 45′ E longitude**Error! Reference source not found.**. The characteristics of the three traditional agroforestry systems in the Tigray Region, Northern Ethiopia are outlined in the studyTable 1.

Site selection and layout

Three specific land uses - homegarden agroforestry (HGAF), parkland agroforestry (PLAF), and woodlot (WLAF) - with similar biophysical conditions were intentionally chosen from each study site to prevent differences in species composition that could arise from variations in altitude. WLAF, HGAF, and PLAF are three distinct concepts associated with agroforestry practices.

WLAF:A**woodlot**is a small area of woodland, typically privately owned, that is managed to produce timber, fuelwood, or other forest products(Nair et al., 2021). Woodlots are often used for personal recreation, wildlife habitat, and conservation.

HGAF: integrating trees, shrubs, and crops within a small-scale farming system around people's homes. It is a traditional practice in many cultures worldwide, where edible and non-edible plants are grown together for subsistence or commercial purposes. Home gardens provide diverse products, improve nutritional security, enhance microclimate, and contribute to soil fertility and biodiversity conservation (Nair, 1993).

PLAF: refers to an agricultural system combining scattered trees or tree clusters with annual or perennial crops in open spaces. This approach is commonly observed in semi-arid regions where trees provide shade, shelter, and other benefits to the crops. The trees' deep root systems help access groundwater, prevent erosion, and enrich the soil. Parkland agroforestry can improve crop yields, diversify income sources, and increase resilience to climate variability.

Sampling system, design

Three sites were purposely chosen based on the presence of HGAF, WLAF, and PLAF. A survey of tree species was conducted in sample plots of 10m x 10m for WLAF, 20m x 10m for HGAF, and 50m x 100m for PLAF. The inventory of tree species was carried out in 15 plots for each agroforestry practice, totaling 45 sample plots.

Data collection

To assess the diversity and dominance of woody species in different agroforestry practices, biometric parameters such as diameter at breast height (DBH)and height were measured on all the trees within each plot. For multi-stemmed woody species each stem was measured separately andthe equivalent diameter of the plant was calculated asthe square root of the sum of diameters of all stemsper plant(Snowdon et al., 2002). Tree/shrub in the study area was defined as woody plants withDBH 2.5 cm and height 1.5m. Specifically, trees were defined as awoody perennial plant with a single main stem or in case of coppiceseveral stems and has a more or less definite crown. While shrubs werewoody perennial plants, often without a definite crown, several stemsgrowing from the same root.The saplings and seedlings were counted within sub-plots in the main plot, from the corners, and in the middle(Linger, 2014; Mekonnen et al., 2014).

Data analysis

Species diversity across various agroforestry (AF) practices was assessed using metrics such as species richness, the Shannon diversity index (H'), and the Shannon equitability or evenness index (E). The important value index (IVI) for each species with a diameter at breast height (DBH) of at least 2.5 cm was calculated by summing its relative abundance, relative dominance, and relative frequency.

Statistical analysis

The independent variables in the study were HGAFs, PLAF, and EX, while the dependent variables included vegetation data. Differences between means were analyzed using a one-factor ANOVA at a significance level of $p \leq 0.05$. Statistical analyses were conducted using Past version 2.17c and SPSS version 20. The normality of the data distribution was assessed with the Shapiro-Wilk test.

Result and discussion

Woody species composition, diversity, and evenness

A combined total of 36, 26, and 21 woody plant species from 31, 23, and 19 different genera and 22, 16, and 15 families were identified in the HGAF, PLAF, and WLAF respectively, as presented in The frequency of indigenous trees in plots varied, with *A. etbaica*, *F. albida*, and *A. seyal* being the three most common indigenous tree species in HGAFs (n=15)

Table 4. These indigenous species are highly favored by farmers in the study areas for purposes such as fuelwood, fodder, soil fertility, bee forage, medicine, shade, timber/poles, ornamental use, and soil conservation. In PLAF, the three most frequently found indigenous tree species were *F. albida*, *A. seyal*, and *C. Africana* (n=15)**Table** 5, and these species are also highly preferred by farmers in the study areas for soil fertility, fodder, food/fruit, fuelwood, soil conservation, bee forage, shade, and timber/poles. Similarly, in WLAF, *E. globulus*, *A. seyal*, and *C. edulis* were among the frequently found indigenous species (n=15)**Table** 6, and these indigenous woody species were also planted or retained by farmers for purposes such as fuelwood, timber/poles, food/fruit, soil fertility, soil conservation, bee forage, and shade.

. The predominant plant families in all agroforestry practices belonged to the Fabaceae family, constituting 41% (9 out of 22) in HGAF, 56% (9 out of 16) in PLAF, and 40% (6 out of 15) in WLAF. In HGAF, each of the families comprised 9% of the total, namely Anacardiaceae, Euphorbiaceae, Lamiaceae, Myrtaceae, Oleaceae, and Rhamnaceae. Conversely, in PLAF, Celastraceae and Euphorbiaceae accounted for 12.5% of the total. Euphorbiaceae represented 13.3% in WLAF.Inside HGAF, the percentages for tree, shrub, shrub/tree, climber/shrub, and herb/shrub species were 31, 39, 22, 3, and 5 respectively

Table 4. Meanwhile, in PLAF, these percentages were 35, 42, 12, 4, and 7 for the corresponding species**Table** 5. For WLAF, the percentages were 29, 43, 10, 5, and 13 for the same species**Table** 6.

The percentage of Indigenous woody species in HGAF, PLAF, and WLAF was 78% (28 out of 36 species), 92% (24 out of 26 species), and 86% (18 out of 21 species) respectively, with the remaining species being non-native. The largest number of indigenous woody species was found in PLAF, followed by WLAF and HGAF.

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The analysis of variance revealed highly significant differences ($p < 0.001$) among various agroforestry practices regarding mean values for tree density, species richness, species abundance, and Shannon diversity, as indicated in Table 3. However, species evenness did not vary across the different agroforestry practices.

Specifically, woodlot agroforestry (WLAF) exhibited significantly lower species richness and Shannon diversity compared to both homegarden agroforestry (HGAF) and parkland agroforestry (PLAF). This trend may be attributed to farmers in the study area favoring specific species, such as Eucalyptus spp., for targeted purposes within woodlot agroforestry.

In contrast, tree density per hectare and species abundance were notably greater in WLAF than in HGAF and PLAF. This can be explained by the closer spacing of trees in woodlot agroforestry, which is primarily designed for producing fuelwood and construction materials. Conversely, in homegarden and parkland systems, trees are interplanted with crops and livestock feed, resulting in wider spacing compared to woodlot agroforestry.

Importance value index (IVI)

The IVI showed that *A.etbaica*(75.2%), *F. albida*(33.1%) and *A. seyal*(30.6%) were the top three important species in HGAFs (Table 5). Whereas, *B.polystachya*(1.56%), *R. vulgaris* (1.57%), *G.ferruginea*(1.62%) and *C.aurantiifolia*(0.90%) and other with low IVI value need high conservation effort. While in PLAF, the most important three woody species were F. albida (96.5%), *A.seyal*(223.3%) and *C.africana*(23.2%) respectivelyTable 5. InWLAF*E. globulus* (61.8%), *A.seyal*(8.83%) and *C. edulis*(31.4%) were relatively recorded as abundant, frequent, and dominant species.

Woody species with a highly important value index (IVI) is considered more important than those with low IVI. This is likely due to their wider economic role (Talemos et al., 2013) and the ecological requirement of the life strategy of the species (Neelo et al., 2015). IVI is also an important parameter that reveals the prioritizing of species for conservation (Berhanu et al., 2017; Regassa et al., 2017; Sambaré et al., 2011; Zegeye et al., 2011). Species with high IVI value need low priority for conservation effort whereas those with low IVI value need high conservation effort.

Therefore, the indigenous woody species in HGAFs, PLAF, and WLAF that had low IVI (<10%) values need conservation priority.

Stand characteristics DBH distribution

The stand characteristics showed significant differences ($p < 0.05$) among various agroforestry practices, particularly in terms of height, diameter, and basal area, as detailed in Table 7. Trees and shrubs in HGAF and WLAF exhibited significantly smaller stem diameters compared to those in PLAF. However, WLAF had notably greater tree height and basal area (BA, m^2) than both HGAF and PLAF, while HGAF also demonstrated a higher BA than PLAF ($p \leq 0.05$).

The reduced height of trees in HGAF and PLAF compared to WLAF may be attributed to the frequent management practices employed by farmers, including pruning and pollarding. Conversely, PLAF displayed significantly larger diameters at breast height (DBH), likely due to the natural retention of trees within that system.

The community structure of woody species in Homegarden Agroforestry (HGAF), Parkland Agroforestry (PLAF), and Woodlot Agroforestry (WLAF) was analyzed based on the densities of Diameter at Breast Height (DBH) (**Error! Reference source not found.**). The findings indicate that in both HGAF and WLAF, the number of individuals decreases as the DBH increases. This pattern in HGAF and WLAF is likely due to factors such as dense spacing, short harvest rotations, and pollarding practices.

In contrast, the DBH distribution in PLAF does not follow the same trend. This difference is attributed to the retention of large trees in farmers' fields for extended periods, which helps in maintaining soil fertility and providing shade. The overall stand characteristics of HGAF, PLAF, and WLAF offer insights into the regeneration status of these systems.

The DBH class distribution across all size classes shows an inverted J-shaped curve, particularly in HGAF and WLAF. This pattern suggests that most species have a higher number of individuals in the lower DBH classes, with a gradual decrease in numbers as DBH increases. This indicates a healthy recruitment process and dynamic population structure of woody species in the study area (Eyasu et al., 2020; Forest, 2003; Gebrewahid et al., 2019). However, in PLAF, there is a declining trend in new regeneration, highlighting the need for attention to promote regeneration.

Conclusion and recommendation

The study concluded that species richness and diversity were significantly higher in Homegarden Agroforestry (HGAF) and Parkland Agroforestry (PLAF) compared to Woodlot Agroforestry (WLAF). However, WLAF exhibited greater abundance and tree density. HGAF and PLAF are crucial for preserving economically and ecologically valuable tree species such as *F. albida, C. africana, O. europaea, R. prinoides, Z. spina-christi, C. arabica,* and *C. macrostachyus,* which are now rare or scarcely found in the natural forests of the study area.

Therefore, homegardens and PLAF, where farmers are motivated to maintain valuable tree species, serve as vital land uses for conserving many species due to active management by the farmers. However, species with low economic value to farmers are at risk of extinction. Indigenous species with low Importance Value Index (IVI) should be prioritized for conservation through community-based tree management practices.

The study recommends conducting more detailed research involving a larger number of agroforestry practices across different soil and agro-climatic conditions to better understand the conservation status of native species.

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Table 1 Characteristics of the three Indigenous agroforestry systems in the Tigray Region, Northern Ethiopia

Characteristics	Ganta-Afeshum	Hawzen	KilteAwlaelo
Altitude (m a.s.l)	1840-3216	1800-2500	2000-2500
Mean annual rain falls (mm)	600-800	600-900	700
Average minimum and maximum To (oC)	10 to 25	10 to 25	12.6 to 31.1
Dominant soil type	Arensol and Regosol	Andosol	Rigosol and Cambisol
Textural Class	clay to clay loam	clay to clay loam	clay to loamy
Major trees	Juniperus procera; Olea europaea; Cordia africana and Acacia species	Acacia species, Euphorbia,Juniperuspr ocera, Ficus species,Cordiaafricana,	Cordia africana, Acacia etbaica, Faidherbia albida, and Ziziphus spina-christi
Major food and cash crops	Teff, barley, wheat, Maize and pulses	Teff, barley, wheat, Maize and pulses	Teff, Barley, Wheat, Sorghum, Maize, Potato, Tomato, Onion, Cabbage
Major food and cash crops	Teff, barley, wheat, Maize and pulses	Teff, barley, wheat, Maize and pulses	Teff, Barley, Wheat, Sorghum, Maize, Potato, Tomato, Onion, Cabbage

Table 2 Woody species composition of the agroforestry practices in northern Ethiopia

Agroforestry Practice	Species	Genus	Family
HGAF	36	31	22

PLAF	26	23	16
WLAF	21	19	15

Table 3. Mean (SD) tree density, richness, abundance, woody Species diversity index of Shannon, and Shannon Evenness

Agroforestry practices	No obs.	Tree density ha-1	Diversity measurement			
			Species richness	Species abundance	Shannon diversity	Evenness
HGAF	15	735 (±117)[b]	5.53 (±0.54)[a]	29.40 (±4.69)[b]	1.30 (±0.09)[a]	0.73 (±0.04)
PLAF	15	49 (±6.71)[b]	5.13 (±0.74)[a]	24.67 (±3.36)[b]	1.12 (±0.14)[a]	0.70 (±0.03)
WLAF	15	6493 (±945)[a]	3.07 (±0.75)[b]	64.93 (±9.45)[a]	0.32 (±0.12)[b]	0.71 (±0.08)
P-value		***	***	***	***	0.92

Table 4 Woody species Relative Frequency (RF %), Relative Density (RD %), Relative Dominance (RDo %) and Importance Value Index (IVI) in HGAF

No	Vencular name	Scientific name	Family	ToEt	Life Form	RF (%)	RD (%)	Rdo (%)	IVI
1	Seraw	*Acacia etbaica*Schweinf.	Fabaceae	I	S	13.33	44.52	17.31	75.17
2	Momona	*Faidherbia albida* (Delile) A.Chev.	Fabaceae	I	T	6.67	4.47	21.95	33.09
3	Keyh/Tsaeda Chea	*Acacia seyal* Del.	Fabaceae	I	T	1.33	8.05	21.25	30.64
4	Keyhbahrzaf	*Eucalyptus camaldulensis*Dehnh.	Myrtaceae	E	T	6.67	8.5	6.03	21.19

5	Beles	*Opuntia ficus-indica* (L.) Miller.	Cactaceae	E	S	4	7.16	0	11.16
6	Awuhi	*Cordia africana* Lam.	Boraginaceae	I	T	4	0.67	4.55	9.22
7	Awulie	*Olea europaea* subsp. Cuspidata	Oleaceae	I	T	4	1.12	2.4	7.51
8	Ere	*Aloe vera* (L.) Burm.f.	Aloaceae	I	SH	2.67	3.8	0.89	7.36
9	Kincheb	*Euphorbia tirucalli* L.	Euphorbiaceae	I	ST	1.33	0.22	5.74	7.29
10	Kolkal	*Euphorbia candelabrum* Kotschy	Euphorbiaceae	I	T	2.67	1.34	3.22	7.23
11	Shibaka	*Ficus thonningii* Blume	Moraceae	I	ST	1.33	0.45	5.32	7.11
12	Tahases	*Dodonaoea angustifolia*L.f.	Sapindaceae	I	S	4	1.12	1.12	6.24
13	Hambohambo	*Senna singueana* (Del.) Lock	Fabaceae	I	ST	4	1.79	0	5.79
14	Abatere	*Jasminum abyssinicum*Hochets. Ex DC.	Oleaceae	I	CS	2.67	0.45	2.31	5.43
15	Lihay	*Acacia lahai*Steud. &Hochst. ex Benth.	Fabaceae	I	ST	1.33	0.22	3.64	5.19
16	Tebeb	*Beciumgrandiforum* (Benth.) Pichiserm	Lamiaceae	I	SH	2.67	2.46	0	5.13
17	Nim	*Azadirachta indica* A. Juss.	Meliaceae	E	T	2.67	0.89	1.23	4.8
18	Gesho	*Rhamnus prinoides*L'Herit.	Rhamnaceae	I	S	2.67	2.01	0	4.68
19	Kebkeb	*Maytenus senegalensis* (Lam.) Exell	Celastraceae	I	S	2.67	0.89	0.95	4.51
20	Gravella	*Grevillea robusta* R. Br.	Proteaceae	E	T	2.67	1.34	0.45	4.46
21	Gaba	*Ziziphus spina-christi* L.	Rhamnaceae	I	T	2.67	1.34	0	4.01
22	Gonek	*Dichrostachys cinerea* (L.) Wight & Arn.	Fabaceae	I	ST	2.67	1.12	0.17	3.96
23	Egam	*Carissa edulis* (Forssk.) Vahl	Apocynaceae	I	S	2.67	1.12	0.17	3.96
24	Lusuniya	*Luceanaleucocerphala* Lam.	Fabaceae	E	S	2.67	0.89	0.17	3.73

25	E'ka	*Agave sisalana* Perro ex Eng.	Agavaceae	I	S	1.33	0.67	0	2
26	Siwakerni	*Leucas abyssinica* (Benth.) Briq.	Lamiaceae	I	S	1.33	0.67	0	2
27	Zeytuhun	*Psidium guajava* L.	Myrtaceae	E	TS	1.33	0.45	0.14	1.92
28	Kuliaw	*Euclea racemosa* Murr.	Ebenaceae	I	S	1.33	0.22	0.3	1.86
29	Mango	*Mangifera indica* L.	Anacardiaceae	E	S	1.33	0.22	0.24	1.79
30	Buna	*Coffea arabica* L.	Rubiaceae	I	S	1.33	0.45	0	1.78
31	Tseliemchea	*Acacia tortilis* (Frossk.) Hayne	Fabaceae	I	T	1.33	0.22	0.16	1.72
32	Akacha	*Acacia saligna* (Labill.) Wendl.	Fabaceae	E	T	1.33	0.22	0.1	1.66
33	bokrilomin	*Citrus aurantiifolia* (Christm.) Swingle	Rutaceae	I	S	1.33	0.22	0.1	1.66
34	Tsinkuya	*Grewia ferruginea*Hochst. ex A. Rich.	Tiliaceae	I	TS	1.33	0.22	0.07	1.62
35	Atami	*Rhus vulgaris* Meikle	Anacardiaceae	I	S	1.33	0.22	0.01	1.57
36	Metere	*Buddlejapolystachya*Fresen.	Loganiaceae	I	ST	1.33	0.22	0	1.56

Table 5 Woody species Relative Frequency (RF %), Relative Density (RD %), Relative Dominance (RDo%) and Importance Value Index (IVI) in PLAF

No.	Vencular name	Scientific name	Family	To	Life	RF (%)	RD (%)	Rdo (%)	IVI
1	Momena	*Faidherbia albida* (Delile) A.Chev.	Fabaceae	I	T	1.61	31.47	63.43	96.5
2	Keyih/TsaedaC	*Acacia seyal* Del.	Fabaceae	I	T	17.74	19.29	12.15	49.1

No.	Vencular name	Scientific name	Family	To	Life	RF (%)	RD (%)	Rdo (%)	IVI
	hea								
3	Awuhi	*Cordia africana* Lam.	Boraginaceae	I	T	11.29	3.05	8.83	23.1
4	Hambohabo	*Senna singueana* (Del.) Lock	Fabaceae	I	ST	8.06	13.7 1	0.00	21.7
5	Kinchib	*Euphorbia tirucalli* L.	Euphorbiaceae	I	ST	1.61	7.11	5.87	14.5
6	Tselemchea	*Acacia tortilis* (Frossk.) Hayne	Fabaceae	I	T	6.45	1.52	5.48	13.4
7	Hohot	*Rumex nervosus* Vahl	Polygonaceae	I	S	6.45	6.09	0.00	12.5
8	Kebkeb	*Maytenus senegalensis* (Lam.) Exell	Celastraceae	I	S	6.45	5.08	0.37	11.9
9	Seraw	*Acacia etbaica*Schweinf.	Fabaceae	I	S	4.84	0.51	0.87	6.22
10	Gaba	*Ziziphus spina-christi* L.	Rhamnaceae	I	T	4.84	1.02	0.34	6.19
11	Gonek	*Dichrostachys cinerea* (L.) Wight & Arn.	Fabaceae	I	ST	3.23	2.54	0.03	5.79
12	Kuliaw	*Euclea racemosa* Murr.	Ebenaceae	I	S	1.61	3.05	0.40	5.06
13	Akacha	*Acacia saligna* (Labill.) Wendl.	Fabaceae	I	T	1.61	2.03	0.44	4.08
14	Keyhbahrzaf	*Eucalyptus camaldulensis*Dehnh.	Myrtaceae	E	T	1.61	1.02	0.88	3.51
15	Beles	*Opuntia ficus-indica* (L.) Miller.	Cactaceae	E	S	3.23	0.00	0.00	3.23

No.	Vencular name	Scientific name	Family	To	Life	RF (%)	RD (%)	Rdo (%)	IVI
16	Ere	*Aloe vera* (L.) Burm.f.	Aloaceae	I	SH	3.23	0.00	0.00	3.23
17	Tambuk	*Croton macrostachyus* Del.	Euphorbiaceae	I	T	1.61	0.51	0.90	3.02
18	Dander	*Carduus nyassanus* (S. Moore) R.E. Fries	Asteraceae	I	HS	1.61	1.02	0.00	2.63
19	Shewit hagay	*Parkinsonia aculeata* L.	Fabaceae	I	S	1.61	0.51	0.02	2.14
20	Daero	*Ficus vastaForssk*	Moraceae	I	T	1.61	0.51	0.00	2.12
21	Alendia	*Ormocarpum pubescens* (Hochst.) Cuf. ex Gillet	Fabaceae	I	S	1.61	0.00	0.00	1.61
22	A'ndel	*Capparis tomentosa* Lam.	Capparidaceae	I	CS	1.61	0.00	0.00	1.61
23	A'nka	*Commiphorahabessinica* (Berg) Engl.	Burseraceae	I	S	1.61	0.00	0.00	1.61
24	Atat	*Maytenusarbutifolia* (A. Rich.) Wilczek	Celastraceae	I	S	1.61	0.00	0.00	1.61
25	Egam	*Carissa edulis* (Forssk.) Vahl	Apocynaceae	I	S	1.61	0.00	0.00	1.61
26	Gindae	*Calotropis procera* (Ait.) Ait. f.	Asclepiadaceae	I	S	1.61	0.00	0.00	1.61

Table 6 Woody species Relative Frequency (RF%), Relative Density (RD%), Relative Dominance (RDo%), and Importance Value Index (IVI) in WLAF

No.	Vencular name	Scientific name	Family	To Ethiopia	Life Form	RF (%)	RD (%)	Rdo (%)	IVI
1	Bahrzaf	*Eucalyptus globulus* Labill.	Myrtaceae	E	T	34.0	91.5	97.68	223
2	Keyh/Tsaedachea	*Acacia seyal* Del.	Fabaceae	I	T	6.82	0.93	1.09	8.8
3	Egam	*Carissa edulis* (Forssk.) Vahl	Apocynaceae	I	S	6.82	1.03	0.00	7.8
4	Tahases	*Dodonaoea angustifolia*L.f.	Sapindaceae	I	S	4.55	0.51	0.10	5.1
5	Habi tsel iem	*Jasminum floribundum*	Oleaceae	I	CS	4.55	0.41	0.00	4.9
6	Jatrofa	*Jatropha curcas* L.	Euphorbiaceae	E	S	4.55	0.41	0.00	4.9
7	Kebkeb	*Maytenus senegalensis* (Lam.) Exell	Celastraceae	I	S	4.55	0.31	0.00	4.8
8	Seraw	*Acacia etbaica*Schweinf.	Fabaceae	I	S	4.55	0.31	0.00	4.8
9	Momona	*Faidherbia albida* (Delile) A.Chev.	Fabaceae	I	T	2.27	0.10	1.13	3.5
10	Tebeb	*Beciumgrandiforum* (Benth.) Pichiserm	Lamiaceae	I	SH	2.27	1.13	0.00	3.4
11	Hambohambo	*Senna singueana* (Del.) Lock	Fabaceae	I	ST	2.27	1.03	0.00	3.3

No.	Vencular name	Scientific name	Family	To Ethiopia	Life Form	RF (%)	RD (%)	Rdo (%)	IVI
12	Kuliaw	*Euclea racemosa* Murr.	Ebenaceae	I	S	2.27	0.82	0.00	3.1
13	Ere	*Aloe vera* (L.) Burm.f.	Aloaceae	I	SH	2.27	0.41	0.00	2.6
14	Dander	*Carduus nyassanus* (S. Moore) R.E. Fries	Asteraceae	I	SH	2.27	0.21	0.00	2.4
15	Hitsawuts	*Calpurnia aurea* (Ait.) Benth.	Fabaceae	I	S	2.27	0.21	0.00	2.4
16	Chea	*Acacia abyssinica*Hochst.	Fabaceae	I	T	2.27	0.10	0.00	2.3
17	Gesho	*Rhamnus prinoides*L'Herit.	Rhamnaceae	I	S	2.27	0.10	0.00	2.3
18	Gulie	*Ricinus communis* L.	Euphorbiaceae	I	S	2.27	0.10	0.00	2.3
19	Tselim Berbere	*Schinus molle* L.	Anacardiaceae	E	T	2.27	0.10	0.00	2.3
20	Tsihdi	*Juniperus procera*Hochst. Ex Endl.	Cupressaceae	I	T	2.27	0.10	0.00	2.3
21	Tsinkuya	*Grewia ferruginea*Hochst. ex A. Rich.	Tiliaceae	I	TS	2.27	0.10	0.00	2.3

Table 7. Stand structure of agroforestry practices in Eastern Tigray, Ethiopia

Agroforestry practices	Mean (SD) Stand characteristics

	Height (m)	DBH (cm)$_{Av.}$	BA (m2)/ha
HGAF	6.31 (4.9)^{b}	14.8 (7.19)^{b}	31.29 (23.4)^{b}
PLAF	7.76 (4.2)^{b}	32.33 (8.72)^{a}	3.47 (2.32)^{c}
WLAF	12.75 (5.98)^{a}	12.73 (3.33)^{b}	77.41 (62.72)^{a}
P value	<0.001	<0.001	<0.001

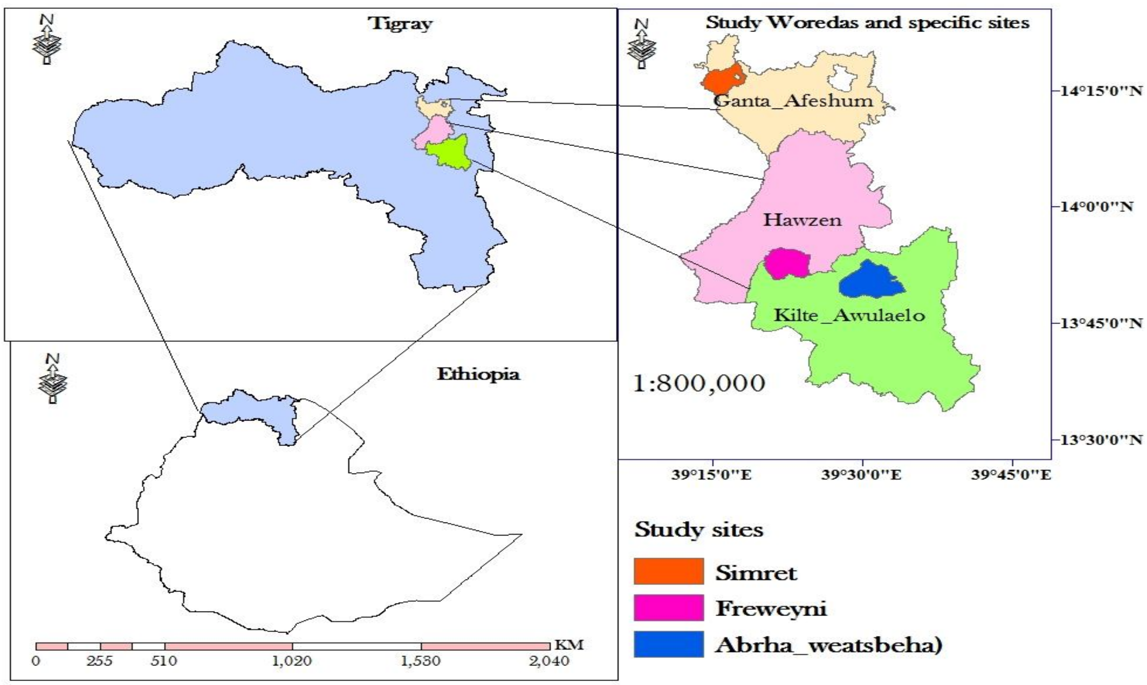

Figure 1: Map of the study area

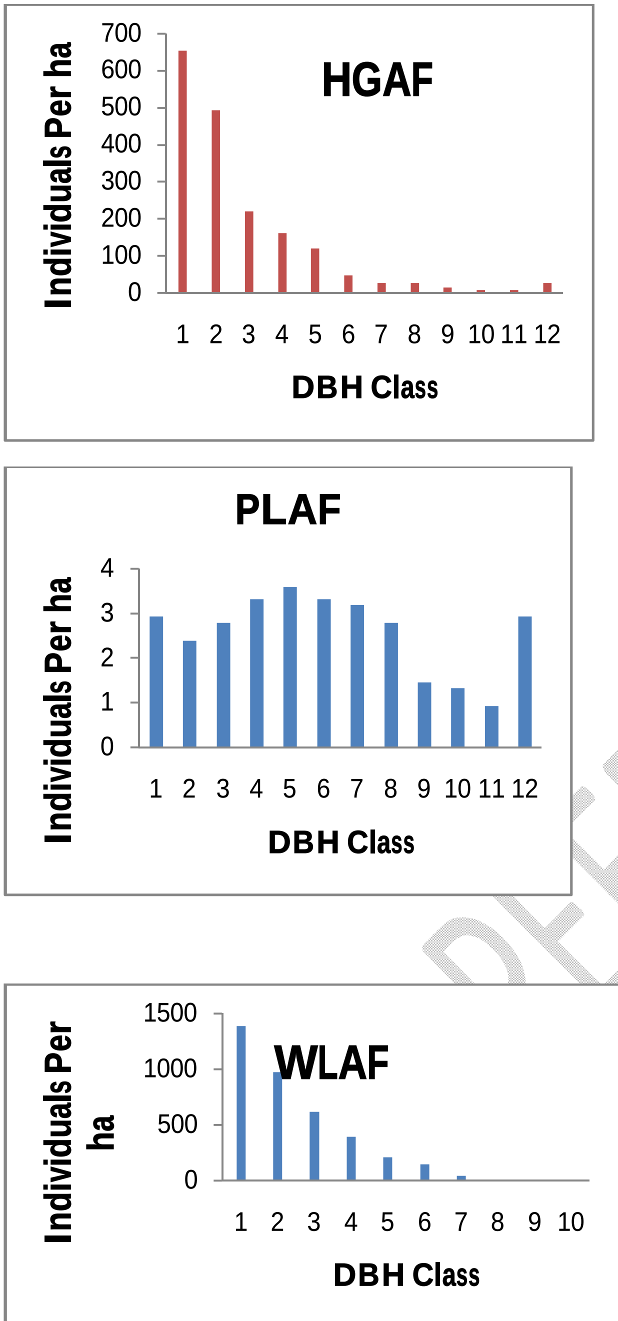

Figure 2 Diameter class (cm) distribution of woody species per hectare encountered in agroforestry practices1=2.50 - 7.49, 2=7.50 - 12.49, 3=12.50 - 17.49, 4=17.50 - 22.49, 5=22.50 - 27.49, 6=27.50 - 32.49, 7=32.50 - 37.49, 8=37.50 - 42.49, 9=42.50 - 47.49, 10=47.50 - 52.49, 11=52.50 - 57.49, 12=57.50+.