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Plant Diversity and Conservation Role of Three Indigenous Agroforestry Systems of Southeastern Rift-Valley Landscapes, Ethiopia

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Abstract: Woody and non-woody plant species conservation is one of the ecosystem services provided by agroforestry (AF) systems across the agricultural landscapes. Little attention has been paid to assessing the conservation of plant diversity in AF systems. This study was, thus, aimed at investigating plant species diversity, structure, and composition of three AF systems in Gedeo zone of south-eastern rift–valley agricultural landscape of Ethiopia. The study was conducted in three agroforestry systems, namely, enset based, coffee–enset based (C–E based AF), and coffee–fruit trees–enset based (C–Ft–E based AF) agroforestry systems. Twenty farms representative of each AF system were randomly selected, and inventory of the floristic diversity was employed in a 10 m × 10 m sample plot per farm. A total of 52 perennial woody and non-woody plant species belonging to 30 families were recorded. Of all species identified, 33 (63.5%) were native, of which two species, namely *Millettia ferruginea* (Hochst.) Baker and *Erythrina brucei* Schweinf., were registered as endemic. The highest proportion of native species was recorded in enset based AF (93.3%), and the least were in C–Ft–E based AF (59%). According to the IUCN Red List and local criteria, 13 species were recorded as being of interest for conservation in all AF systems. The woody species *Prunus africana* was identified as both vulnerable by IUCN Red List and rare for 25% of species that least occur. The Shannon diversity index and richness showed that C–Ft–E based AF systems were significantly different from the two remaining AF systems. However, the species abundance and evenness did not show significant differences between the three AF systems. In general, retaining such numbers of woody and non-woody perennial plant species richness under the AF systems of the present study underlines their potential for biodiversity conservation.

Keywords: plant diversity; indigenous agroforestry system; coffee; enset; native species

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1. Introduction

The tropics are seeing an unprecedented rate of deforestation and forest degradation, which is seriously endangering both the forests and the livelihoods of those who rely on them for their resources [1,2]. The consequences of the accelerated tropical forest degradation exert and exacerbate a significant negative impact on agricultural productivity, global climate change, and biodiversity [2]. To reduce such negative impacts, adoption of an agroforestry (AF) system could be one option. Agroforestry systems have a great contribution in maintaining noticeable levels of biodiversity between natural forests and agricultural land uses; they may therefore increase connectivity between fragmented forest habitats and landscapes [3].

As reported by several studies, AF systems have multiple contributions to biodiversity conservation through: arranging and providing additional supportive habitats for species that do not tolerate high levels of disturbance [4]; conserving gene pools of native tree species in fragmented landscapes and conserving and enhancing biodiversity [5–7]; playing an important role in increasing microbial, avian, and faunal diversities [8]; soil conservation and allowing water to recharge, thereby preventing habitat degradation and habitat loss; protecting against the pressure on forest degradation and deforestation in the surrounding natural habitat; and construction of a corridor and stepping stones for perseverance of floral and faunal species through connecting different fragmented habitats in the landscape [4,9,10]. In general, the native and non-native perennial woody and non–woody species could provide several functions: economic benefits such as firewood, timber, wood for different purposes (local construction, farm implements, and household utensils), fodder, food, and medicine; environmental benefits such as erosion control and soil fertility improvements; and finally ecological improvements such as biodiversity conservation [11–13].

Different AF systems show different diversity status based on their richness, abundance, and frequency of plant species [12]. Considering the number of plant species as a measure to categorize the species richness status in different AF systems of tropical and subtropical countries, indigenous AF systems have the highest number of species, followed by coffee systems, tree–crop systems, and cocoa systems. Different management practices in each AF system may result in differences in species richness among these AF systems [14]. The four tropical AF systems with the highest recorded number of plant species are: (1) homegardens in west Java, Indonesia; (2) homegardens in Chagga, at the border of Tanzania and Kenya; (3) trees on agricultural land on Mount Kenya; and (4) traditional homegardens, in south-west Bangladesh [15–17].

There are also some studies conducted in Ethiopia focusing on the contribution of AF systems as refuges for plant species. The reports indicated that there are between 17 (mainly in fruit tree AF systems) and 429 (in various AF systems) plant species growing, and therefore, the systems are very important in biodiversity conservation of the native species [14]. Species richness in Ethiopia showed a variation among the different AF practices and regions of the country. For instance, the highest plant species richness was reported in southern Ethiopia, ranging from 50 to 198 plant species [18–20] followed by south-west Ethiopia with 149 plant species [21], central Ethiopia from 27 to 114 plant species [22–24], and the least was recorded in north Ethiopia with 17–40 plant species [25,26]. Reports specifically from south-eastern Ethiopia revealed that the indigenous AF systems of the region are rich in plant species diversity. Accordingly, [23] reported that there are 90 woody species, including native tree species such as *Juniperus procera* Hochst. ex Endl., *Olea europaea* subsp. *cuspidata* (Wall. ex G. Don) Cif., *Podocarpus falcatus* (Thunb.) R. Br. ex Mirb., *Acacia tortilis* (Forssk.) Hayne, *Acacia etbaica* Schweinf., and *Hagenia abyssinica* J.F. Gmel.

AF practice in the Gedeo zone of southern Ethiopia is known as ancient and indigenous in nature. The Gedeo agroforestry system has been in place for centuries and is an important part of the local culture and economy [27]. The Gedeo indigenous agroforestry system is characterized by rich production potential as well as ecosystem services and is thus known for being a self-sustaining and self-regulating land-use system [28]. The systems are characterized by a mixture of trees, shrubs, and annuals that grow in a diverse form and look like intact and continuous vegetation cover [28]. Due to this reason, the practice is known to be an exemplary land-use system and an ideal AF demonstration site in the region.

Studies were conducted earlier in Dilla Zuria district and reported the role of agroforestry systems in conserving native and non-native plant species. The list of native and non-native plant species reported by the present study and other authors is displayed in Table 1.

Table 1. Summary of list of native and non-native woody plant species reported from different sites of Dilla Zuria district of the Gedeo zone, Ethiopia.

Number	Scientific Name	Origin	Reference
1	*Acokanthera schimperi* (A.Dc) Schweinf.	Native	[29]
2	*Albizia grandibracteata* Taub.	Native	Present study
3	*Albizia gummifera* (J.F. Gmel.) C.A.Sm	Native	Present study
4	*Annona chrysophylla* Bojer	Non-native	Present study
5	*Annona reticulate* Sieber ex A.DC.	Non-native	[30]
6	*Apodytes dimidiata* E. Mey. ex Arn.	Native	[29]
7	*Arundinaria alpine* K.Schum.	Native	[30]
8	*Azadirachta indica* var.	Non-native	Present study
9	*Bersama abyssinica* Fresen	Native	Present study
10	*Bridelia atroviridis* Muell.Arg.	Native	[29]
11	*Bridelia micrantha* (Hochst.) Baill.	Native	Present study
12	*Brucea* sp.	Native	[30]
13	*Cadaba longifolia* DC.	Non-native	[29]
14	*Calpurnia aurea* (Aiton) Benth.	Native	[29]
15	*Canthium oligocarpum* Hiern	Native	[30]
16	*Carica papaya* L.	Non-native	Present study
17	*Carissa spinarum* L.	Native	[29]
18	*Casimiroa edulis* Lal lave and Lex	Non-native	Present study
19	*Cassipourea malosana* (Baker) Alst	Native	Present study
20	*Catha edulis* (Vahl) Forssk. ex Endl.	Native	Present study
21	*Celtis africana N.L.* Burm	Native	Present study
22	*Celtis* sp.	Native	Present study
23	*Chionanthus mildbraedii* (Gilg and G.Schellenb.) Stearn	Native	[29]
24	*Citrus* limon (L.) Osbeck	Non-native	Present study
25	*Citrus sinensis* (L.) Osbeck	Non-native	Present study
26	*Clausena anisata* (Willd.) Benth.	Native	Present study
27	*Clutia abyssinica* Jaub. and Spach.	Native	[29]
28	*Combretum adenogonium* Steud.ex A.Rich.	Native	[29]
29	*Combretum molle* (Klotzsch) Engl. and Diels	Native	[29]
30	*Cordia africana* Lam.	Native	Present study
31	*Coffea arabica* L.	Native	Present study
32	*Croton macrostachyus* Hochst. ex Delile	Native	Present study
33	*Cupressus lusitanica* Miller.	Non-native	Present study
34	*Dalbergia lactea* Vatke	Native	[29]
35	*Dichrostachys cinerea* (L.) Wight and Arrn.	Native	[29]
36	*Diospyros abyssinica* (Hiern.) F. White	Native	[29]
37	*Dodonaea angustifolia* L.f.	Native	[29]
38	*Dovyalis abyssinica* (A.Rich.) Warb.	Native	Present study
39	*Dracaena steudneri* Schweinf. Ex Engl.	Native	Present study
40	*Ensete ventricosum* (Welw.) Cheesman	Native	Present study
41	*Ehretia cymosa* Thonn.	Native	[29]
42	*Ekebergia capensis* Sparrm	Native	[29]
43	*Erythrina brucei* Schweinf.	Native	Present study
44	*Eucalyptus camaldulensis* Dehnh	Non-native	Present study
45	*Eucalyptus globules* Labill.	Non-native	Present study
46	*Eucalyptus grandis* W.Hill ex Maiden	Non-native	Present study
47	*Euclea racemosa* L.	Native	[29]
48	*Euphorbia abyssinica* J.F.Gmel.	Native	Present study
49	*Euphorbia candelabrum* Welw	Native	[29]
50	*Euphorbia tirucalli* L.	Native	[29]
51	*Faidherbia albida* (Delile) A.Chev.	Native	Present study
52	*Faurea rochetiana* (A.Rich.) Chiov. ex Pic.Serm.	Native	[29]
53	*Faurea speciosa* Welw	Native	[30]
54	*Ficus elastica* Roxb. ex Hornem.	Native	Present study
55	*Ficus ovata* Vahl.	Native	[29]
56	*Ficus sur* Forssk.	Native	Present study
57	*Ficus sycomorus* L.	Native	[29]
58	*Ficus thonningii* Blume	Native	[29]
59	*Ficus vasta* Forssk.	Native	Present study
60	*Grevillea robusta* A. Cunn. ex R. Br.	Non-native	Present study
61	*Hagenia abyssinica* (Bruce) J.F.Gmel.	Native	Present study
62	*Hibiscus macranthus* Hochst.ex A. Rich.	Native	[29]
63	*Jacaranda mimosifolia* D.Don	Non-native	Present study
64	*Justicia schimperiana* (Hochst. ex Nees) T.Anderson	Native	[29]
65	*Lantana camara* L.	Non-native	[29]
66	*Lepisanthes senegalensis* (Poir.) Leenh.	Native	[29]
67	*Leucaena leucocephala* (Lam.) de Wit	Non-native	Present study
68	*Maesa lanceolata* Forssk.	Native	[29]
69	*Mangifera indica* L.	Non-native	Present study
70	*Manilkara butugi* Chiov.	Native	[29]
71	*Maytenus arbutifolia* (Hochst. ex A.Rich.) R.Wilczek	Native	[29]
72	*Maytenus senegalensis* (Lam.) Exell	Native	Present study
73	*Melia azedarach* L.	Non-native	Present study
74	*Millettia ferruginea* (Hochst.) Baker	Native	Present study
75	*Mimusops kummel* Bruce ex A.DC.	Native	[29]
76	*Musa acuminata* Colla	Non-native	Present study
77	*Ochna schweinfurthiana* F.Hoffim.	Native	[29]
78	*Olea welwitschii* (Knobl.) Gilg and Schellenb.	Native	[29]

Table 1. *Cont.*

Number	Scientific Name	Origin	Reference
79	*Osyris quadripartita* Salzm. ex Decne.	Native	[29]
80	*Pavetta oliveriana* Heirn	Native	[29]
81	*Persea americana* Mill.	Non-native	Present study
82	*Phyllanthus ovalifolius* Forssk	Native	[29]
83	*Pittosporum viridiflorum* Sims	Native	[29]
84	*Polyscias fulva* Harms	Native	[30]
85	*Pouteria adolfi-friederici* (Engl.) A.Meeuse	Native	[29]
86	*Pouteria alnifolia* (Baker) Pierre	Native	[30]
87	*Prunus africana* (Hook.f.) Kalkman	Native	Present study
88	*Prunus persica* (L.) Batsch	Non-native	[30]
89	*Psidium guajava* L.	Non-native	Present study
90	*Rhamnus prinoides* L. Herit.	Native	Present study
91	*Rhus vulgaris* Meikle	Native	[29]
92	*Ricinus communis* L.	Native	Present study
93	*Sapium ellipticum* (Hochst.) Pax	Native	[29]
94	*Senna siamea (Cassia siamea)* (Lam.) H.S.Irwin and Barneby	Native	Present study
95	*Sesbania sesban* (L.) Merr.	Non-native	Present study
96	*Solanum incanum* L.	Native	[29]
97	*Spathodea campanulata* P.Beauv.	Native	Present study
98	*Spathodea nilotica* Seem.	Native	[29]
99	*Solanum betaceum* Cav.	Non-native	Present study
100	*Solanum macrocarpon* L.	Non-native	[30]
101	*Suregada procera* (Prain) Croizat.	Native	[29]
102	*Syzygium guineense* (Willd.) DC.Subsp.*afromontanum*F. White.	Native	[29]
103	*Terminalia schimperiana* Hochst.	Native	[29]
104	*Trichilia dregeana* Sond.	Native	Present study
105	*Vangueria madagascariensis* J.F.Gmel.	Native	[29]
106	*Vernonia amygdalina* Delile	Native	Present study
107	*Vernonia auriculifera* Hiern.	Native	[29]

Previous studies have been conducted [13,30–34] on management of indigenous AF practices, component interaction, diversity and composition, carbon stocks, and additional ecosystem services of AF systems in the Gedeo zone and other locations. However, studies dealing with the contribution of enset based, coffee–enset (C–E) based and coffee–fruit tree–enset (C–Ft–E) based AF systems to biodiversity conservation in the study area are found to be limited. To fill the gap in scientific knowledge about the function and structure of these systems and their exact extent, more attention is needed.

The overall objective of this study was to assess the contribution of enset based, coffee–enset (C–E) based and coffee–fruit tree–enset (C–Ft–E) based AF systems to biodiversity conservation. The specific objectives were (i) to assess and evaluate the woody and non-woody plant species richness in three indigenous AF systems; (ii) to compare woody and non-woody perennial plant composition, structure, and diversity among three AF systems; (iii) to identify endemic native woody plant species and species of conservation concern; and (iv) to assess the effect of diameter at breast height (DBH) and stem number on the basal area of the AF systems. Research questions were initiated to answer: (a) Could species diversity differ among the three AF systems owing to different management systems? (b) Do the AF systems conserve a significant number of woody and non-woody plant species? (c) How do indigenous agroforestry systems contribute to the maintenance of native, endemic species, and species of conservation concern? The findings of the present study will help managers, conservationists, and scientists to better understand the functional complexity of multistrata AF systems and the diversity status of the species that require local genetic diversity conservation.

2. Materials and Methods

2.1. Study Area and Sites

The study was conducted in the Gedeo zone of the Southern Nations, Nationalities, and Peoples' Regional State of Ethiopia (SNNPRs), more specifically in the Dilla Zuria district (Figure 1). Geographically, it lies between 38°03′02″ and 38°18′59″ E and 5°50′26″ and 6°12′48″ N. The research area's elevation varies from 1544 to 1830 m above sea level. The mean monthly air temperature ranges from 13 to 28 °C, while the annual rainfall ranges from 1127 to 1624 mm, according to meteorological data collected over a period of nine years (2010–2018) [35]. The Gedeo zone has a total area of 134,686 ha, which is divided into various land-use types, including agricultural land (94.5%), AF land used for perennial and annual crops, grassland (1.4%), wetland (0.8%), natural forest (0.5%), plantations (0.1%), and others (pasture land, residential) (2.7%) [36]. According to the traditional agro climatic categorization, the zone has a mid-altitude climate (Dega), which is 37% of the total area; a subtropical climate (Weynadega), which is 62% of the total area; and 1% of the total area with a tropical climate (Kolla). The soil type is nitosol having a deep, reddish-brown color with relatively high organic matter content. These soils are well-drained and fertile [37]. The texture of the soil is predominantly clay. The main economic activity of farmers in the study area is AF-based food and cash crop production. AF is the primary source of income for farmers in the study area, where coffee and fruit production dominate. Livestock husbandry is insignificant in the system except for a few attempts at fattening of oxen, goats, and sheep. The three main AF systems practiced in the study area are: (1) an enset based AF system (mainly practiced in the Sisota site); (2) a coffee–enset based AF system (practiced in the Golla site); and (3) a coffee–fruit trees–enset based AF system (practiced in the Chichu site).

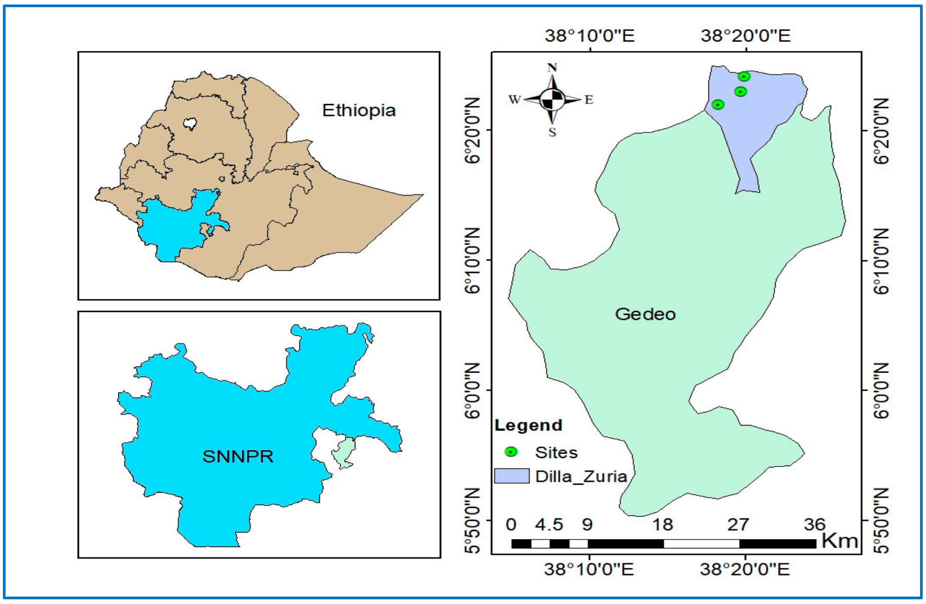

Figure 1. Locations of the study sites in the Dilla Zuria district of the Gedeo zone, Ethiopia.

2.1.1. Indigenous Agroforestry Systems as Focus of the Study

Enset Based Agroforestry

Enset based AF systems are predominantly practiced in central, south-western, and southern Ethiopia [38,39]. Depending on the distribution of other plant species, enset (*Ensete ventricosum* (Welw.) Cheesman), known as false banana, belongs to the Musaceae family and could cover 60–70% of the total area in this system. This perennial species is local and has been tamed as one of the staple food crops in south, central, and southwest Ethiopia. The edible parts of the enset plant include the pseudostem and underground corm. An estimated area of enset cover in Ethiopia is nearly 300,000 ha, yielding approximately 4.4 million tons per year and feeding approximately 20% of the total population of the country [40–42]. As a result, enset farming is considered one of Ethiopia's most resilient traditional farming practices [43,44].

Enset not only provides economic benefits to the farmers, but it also provides a significant environmental service. For instance, micro-climate amelioration, addition of nutrients through litterfall and hence improving the soil fertility and protection of the soil from water erosion and runoff hazards are some of the environmental services. One of the good things about nutrient addition to the soil is that when enset is harvested, most of the biomass remains in the system. This is because the leaves and all the other inedible parts of the enset corm are returned directly to the soil [45,46].

Coffee–Enset Based Agroforestry (C–E Based AF)

One of the traditional agroforestry homegardens in southern Ethiopia is the C–E based AF system [39]. The technology can be effectively used at elevations of 1500 to 2300 m above sea level. It is suggested that the temperature and moisture levels at this height will be favorable for these agroforestry techniques. In southern Ethiopia's AF systems, the two dominant native perennial crops, notably coffee and enset, collectively occupy more than 60% of the available land [33]. Enset is a staple food crop, and coffee serves as a cash crop [33]. According to the National Bank of Ethiopia report, the share of coffee in the country's total merchandise export revenue is 25.1% [47], which means coffee is playing a great role in obtaining hard currency for the country [48].

C–E based AF systems harbor several native woody species, such as *Cordia africana* Lam., *Millettia forginea* (Hochst.) Baker, roots (ginger, sweet potato), and annual crops (maize), which are favorably growing in intimate association with enset and coffee. The perennial woody species are growing in spatial and vertical configurations in this AF system. Generally, these indigenous C–E based AF are all-inclusive farm systems from which households obtain most of their subsistence as well as their cash needs [18]. The average size of C–E based AF as homegarden is estimated to approximately 0.7 hectares per farmer and can support a population of 500–1000 persons per km^2 [49]. Like other AF systems, this system also maintains high species diversity by combining crops, trees, and animals with different uses and production cycles.

Coffee–Fruit Tree –Enset Based Agroforestry (C–Ft–E Based AF)

Components of this AF system include multifunctional tree and shrub species, coffee (*C. arabica* L.), enset, several fruits, annual crops, vegetables, medicinal plants, and animal species. Most of this sort of indigenous AF system is made up of coffee, fruit trees, and enset, with the remainder consisting of vegetables and spices [50]. For each species, the percentage of coffee, fruit trees, and enset is anticipated to range between 20 and 25. In a C–Ft–E based AF system, the fruit trees (e.g., *Persea americana* Mill., *Mangifera indica* L., *Casimiroa edulis* Lal Lave and Lex.), coffee, and enset are shaded by tree species such as *Cordia africana* Lam., *Milletia ferruginea* (Hochst.) Baker, *Ficus vasta* Forssk., and *Ficus sur* Forssk.. Herbaceous plants such as *Zea mays* L., *Musa* spp., *Brassica oleracea* L., and *Ipomoea batatas* (L.) Lam make up the understory [51]. These indigenous C–Ft–E based AF systems are all-inclusive farm systems from which households obtain almost all their subsistence as well as cash needs [18]. Communities practicing this type of AF system were self-sufficient in wood for energy and generated 47% and 45% of their annual income from fruit trees and coffee, respectively [50].

2.2. Methods

2.2.1. Sampling Design and Data Collection

We compared three different AF types' floristic content, structure, and diversity. This was performed to allow for a more accurate assessment of the relative capacity of agroforests with different crop combinations to conserve biodiversity along altitudinal gradients. A total of 60 AF farms (20 farms from each AF) were randomly chosen from lists of farms along the altitudinal gradients. Additionally, information on the site history, height, slope, GPS location, AF type, and age of each AF farm were recorded.

A nested quadrat with 10 m $\times$ 10 m size was established in each AF farm for the inventory of trees/shrubs, coffee, and enset (Figure 2). Ocular estimate was first employed to divide the farm into equal sections in order to find the location of a quadrat's center. Second, a number was given to every component. Third, a data collection plot was chosen using a random number generator. The size of the quadrats and sampling size coincide with recommended practice in the literature for similar agroforestry farms [14]. In some cases, the size of the quadrant might occupy the whole farm. Due to the small size of some farms, cost, and time-related issues, the size of the quadrant was limited to 100 m^2.

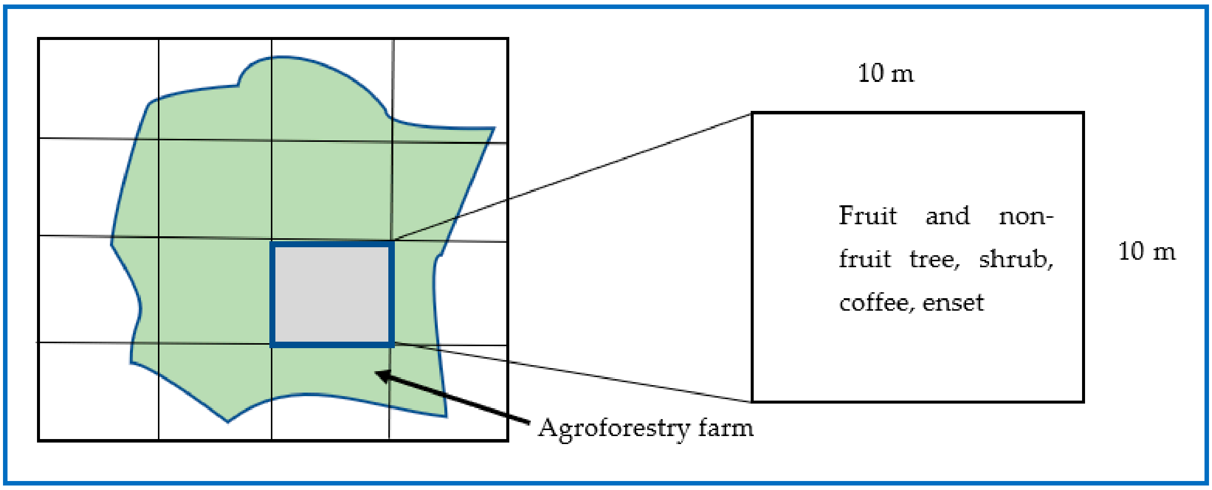

Figure 2. Sample plot layout for inventory of trees, shrubs, coffee, and enset plants (10 × 10 m). See Section 2.2.2 for detail.

2.2.2. Plant Species Inventory

To assess the plant species diversity and composition, an inventory of all the trees (fruit and non-fruit), coffee, and enset plants was carried out. Inventory of non-fruit trees and shrubs, fruit trees, enset, and coffee plants was carried out for the 60 farms (20 farms from each of the three AF systems). An inventory of species that exist out of the 60 sample plots but are still at the selected study sites was also carried out to assess the total number of perennial woody and non-woody plant species. Measurements such as diameter at breast height (DBH, cm ± 0.1) and total height (h, m ± 0.1) of all trees and shrubs (single and multi-stemmed) having a breast height diameter ≥ 2.5 cm and a height ≥ 1.5 m were employed in the 10 × 10 m sample plots on each AF farm [13]. For coffee plants (in enset–coffee and C–Ft–E based AF systems), the stem diameter at stump height (40 cm), d_{40}, was also measured. For enset based AF systems, the basal diameter of the pseudostem (height of 10 cm, d_{10}) of plants one year old or older was measured. Stem diameter (d, d_{10}, and d_{40}) was measured using a caliper in two perpendicular directions, and the average value was used. In the studied AF systems, biodiversity analysis was performed by counting all woody species above 20 cm height, and species were identified by using identification keys and local informants [14]. The reason why we used 20 cm as the minimum height is because plant species above this height are easily identifiable and countable.

2.3. Data Analysis

2.3.1. Stand Characteristics of Plant Species and Diversity Analysis

Tree and stand characteristics were calculated for each agroforestry sample plot in the three studied AF systems. Parameters such as relative frequency, relative abundance, relative dominance, DBH, height, basal area (BA), and stem numbers of the perennial woody and non-woody plant species were determined. One-way ANOVA was carried out to test differences among the three AF systems, followed by post hoc testing by means of the least significant difference (LSD) test. Diversity indices (Shannon diversity index, Pielou's evenness index, and Margalef's richness index) were also calculated. This comparison helped to evaluate the mean differences among AF systems [52]. Levene's test was also conducted to check the homogeneity of variances. For assessing the relationship between some parameters, regression analysis was employed. For multi-stemmed plants, mainly in the case of coffee plants (2 to 12 stems per plant) and mango plants (2–4), each stem was measured, and the equivalent diameter of the plant was calculated as the square root of the sum of squared diameters of all stems per plant [53].

$$de\ or\ de_{40} = \sqrt{\sum_{i}^{n} di^2} \tag{1}$$

where *de* (cm) = equivalent diameter at breast height, de_{40} (cm) = equivalent diameter at 40 cm height, *di* = sum of all squared diameters up to the *i*th stem

The Shannon diversity index [54,55], Pielou's evenness index (J) and Margalef's richness index (D_{mg}) [56] were calculated for each plot. Sorensen's similarity coefficient determined the similarity/dissimilarity between AF systems. Species richness and abundance were followed by Mann–Whitney U-test for multiple comparisons. The following formulas were used for the diversity indices.

$$H' = -\sum_{i=1}^{s} pi\ lnpi \tag{2}$$

where, H' = Shannon Diversity Index, Pi = the abundance of *i*th species expressed as a proportion of total cover [54,56]. As [13] mentioned, the Shannon diversity index is preferred for knowing plant species diversity due to its sensitivity to sample size. It also gives more weight to assessing rare plant species.

$$J = \frac{H'}{H'max} \tag{3}$$

where: J = Pielou's evenness (Equitability) [57], H' = Shannon diversity index and $H'max$ = ln S where "S" is the number of species. J has values between 0 and 1.0, where 1.0 represents a situation in which all species are equally abundant.

$$D_{\mathrm{Mg}} = \frac{(S-1)}{\ln(N)} \tag{4}$$

where D_{Mg} is Margalef's richness index, S = species richness, N = the total number of individuals in the plot

$$Ss = \frac{2a}{2a+b+c} \tag{5}$$

where: Ss = Sorensen's similarity coefficient, a = number of species common to both samples, b = number of species in sample 1 but not in 2, c = number of species in sample 2 but not in 1.

Another very crucial index that is used to investigate the structural role of each plant species in the sampling plots is the important value index percentage (IVI%). It was calculated using the percentages of relative abundance (RA), relative dominance (RD), and relative frequency (RF). Therefore, to investigate the importance value index (IVI%) of each species, we used the following formulas:

IVI (%) = Relative abundance + Relative dominance + Relative frequency,

where

$$Relative\ abundance = \frac{Number\ of\ individual\ s\ of\ woody\ species}{Total\ number\ of\ woody\ individual\ s} \times 100 \tag{6}$$

$$Relative\ dominance = \frac{Basal\ area\ of\ each\ species}{Basal\ area\ of\ all\ species} \times 100 \tag{7}$$

$$Relative\ frequency = \frac{Chance\ to\ find\ each\ species}{Chance\ to\ find\ all\ species} \times 100 \tag{8}$$

2.3.2. Analysis of Species Conservation Concern

Assessing the status of species conservation concerns in order to sustainably maintain the plant species in the studied AF systems is crucial. Species conservation concern (rare, threatened, vulnerable, or least concern) of each studied AF type was identified and then recorded. Geographical distribution, habitat preference, taxonomic ideas that specific scholars decide to apply, and population size are the main factors to take into account and then classify if species are rare [58,59]. To analyze species conservation concerns in our study, three approaches were used: (i) those woody or non-woody species retained in the different agroforestry systems and listed as of the least concern, threatened/vulnerable by IUCN Red Lists [60]; (ii) 25% of species that have the least occurrence in each AF type [56]; and (iii) based on local criteria [61,62]. The local criteria might be based on information from published and unpublished documents. Under this species conservation concern categorization approach, classes made by the Woody Biomass Inventory and Strategic Planning Project were used [61]. The above study has covered about 60% of the area in Ethiopia, and the classification includes those species with a population density below 100,000 individuals in the country.

To test for differences in stand structure, diversity, and richness, a one-way ANOVA followed by post hoc testing was used. Levene's test was also conducted to check the homogeneity of variances. A linear regression analysis was performed to analyze the relationship between some parameters.

All statistical analysis was carried out using Statistical Package for Social Sciences–IBM SPSS version 26 (SPSS Inc. 2019) and Microsoft Window Excel (2016).

3. Results and Discussion

3.1. Plant Diversity and Conservation in Indigenous Agroforestry Systems

3.1.1. Perennial Plant Species Composition

Our results show that "Dilla Zuria" AF systems harbor perennial woody and non-woody plant species diversity. This underlines that conservation of these biological resources should not be restricted to forest areas alone since there has been massive encroachment and pressure from anthropogenic factors [63]. A total of 52 perennial woody and non-woody plant species belonging to 30 families were recorded (Table A1). Out of this number, 31 plant species were recorded from the 60 inventoried sample plots, while the remaining 21 plant species were recorded from the 60 sample plots. The highest number of species richness was recorded in the C–Ft–E based AF system (22 species) (Table A4), whereas the lowest number was recorded in the enset based AF system (15 species) (Table A2). Similar results were found in the Gedeo Zone of Southern Ethiopia, where the enset based AF system had the lowest species richness (26 species compared to the remaining two systems) [13].

The cumulative species richness in the current study sites was within the range of woody and non-woody species recorded in the AF systems of southern Ethiopia (50–120 plant species) [18–20,64] and in central Ethiopia (27–114 species) [22–24]. However, the species richness of the present study was higher than in northern Ethiopia (17–40) [25,26]. In addition, the results of this study showed a higher richness over three AF practices compared to Wenago District of Ethiopia, with 24 woody species belonging to 19 plant families being recorded in the same district of south-eastern rift-valley landscapes but in different sites than the current study [34], and Wolayta zone of southern Ethiopia, 32 woody species belonging to 21 families in enset–coffee based agroforestry systems, in midland of the Sidama zone, Ethiopia [65], with 32 woody species belonging to 19 families, and [66]. Similarly, the species richness of the present study was higher than reported in the coffee-based AF system in eastern Uganda (50 woody species) [67].

Higher plant species richness than the studied AF systems was also recorded in different parts of the country as well as in other tropical countries: 55 woody species for traditional AF practices of Dellomenna district of south-eastern Ethiopia [68], 58 wood species for Gedeo Zone of southern Ethiopia [13], 65 for the coffee based agroforestry in the catacamas landscapes of Honduras [69], 70 woody species for Moneragala district in Sri Lanka [70], 83 species for Nicaragua, 100 species for Yem special district of southern Ethiopia [63], 104 species for Jimma Ganati District in Western Ethiopia [71], 105 woody species for cacao agroforests in San Alejandro, Peruvian Amazon [72], and 191 species for Sudanian Zone of Burkina Faso [73], 289 woody plants from sub-urban areas in Sri Lanka [74], and 459 tree and shrub species around Mt. Kenya in central and eastern Kenya [75]. The higher species richness at these study sites might be related to the scale of area coverage included in the study and the range of agro-climatic zones. Some authors argued that the wider the scale of the study in terms of areal coverage [39] and altitudinal range [76], the better is the probability of getting more additional woody and non-woody plant species adapted to different agro-ecologies. The distance from natural forest areas can also greatly influence the species richness of AF systems. For instance, studies of AF systems in a biodiversity hotspot region of northeast India have shown that tree species richness increases with proximity to natural forests, and the tree species are closely related [77]. AF systems that are structurally complex and vegetatively diverse are thought to have the ability to improve landscape connectedness, lessen edge effects, and preserve relatively high levels of species richness [10]. Ref. [39] reported that the variation in plant species richness in different study areas could also be related to the difference in site characteristics (farm size, altitude), the management strategy of the practitioner, and socioeconomic factors. [34,78] stated that farmers' preferences for the trees and shrubs they choose to plant for various purposes may have an impact on the diversity of species richness in a given AF system. In general, the high woody species richness under AF systems in the present study underlines their potential for biodiversity conservation.

Out of the thirty families recorded in the studied agroforestry systems, three families had a higher number of species: Fabaceae (represented by five species), Myrtaceae (four), and Euphorbiaceae (three). Francoaceae, Rhizophoraceae, Rubiaceae, Anacardiaceae, Lauraceae, Boraginaceae, Rhamnaceae, Asteraceae, Dracaenacea, Caricaceae, Annonaceae, Solanaceae, Cupressaceae, Salicaceae, and Phyllanthaceae, however, were only represented by one species (Table A1). In general, a small number of families (10%) were represented by five, four, and three species while the majority of families (50%) were represented by a single species. The remaining 40% of families were represented by two species. The highest number of perennial woody or non-woody plant species in this study was represented by the family Fabaceae. Similar studies conducted by [13,63,66] also found that the family Fabaceae in different AF systems scored a higher number of species compared to other families. The assessment regarding the origin of the woody and non–woody species across the three AF systems showed that 33 of 52 species (63.5%) were native, while the remaining 19 of 52 species (36.5%) were non-native.

The highest native perennial woody and non-woody plant species number was registered in the enset based AF system with 14 out of 15 species (93.3%) (Figure 3) while the lowest was in the C–Ft–E based AF system with 13 out of 22 species (59%) (Figure 3). This might be due to the fact that practitioners established these AF systems by selectively thinning suppressed trees in natural forests. It has also been a common practice to deliberately keep native trees for the purpose of shading coffee, improving soil fertility, and providing other ecosystem services. For instance, *Millettia ferruginea* (Hochst.) Baker and *Cordia africana* Lam. Have been used as shade for coffee because of their less dense crown and scattered branches. In addition, the practitioners believed that *M. ferruginea* (Hochst.) Baker could improve soil fertility and enhance the productivity of crops and vegetables that grow beneath it [79]. The average native plant species percentage in the present study (63.5%) was higher than in a study reported from 402 homegardens in six regions in south-western Bangladesh, with 247 out of 419 (59%) [16]. However, the average native plant species percentage in the current study was lower than three indigenous AF systems in the Gedeo zone of Southern Ethiopia, where 50 out of 58 species (86%) were reported [13].

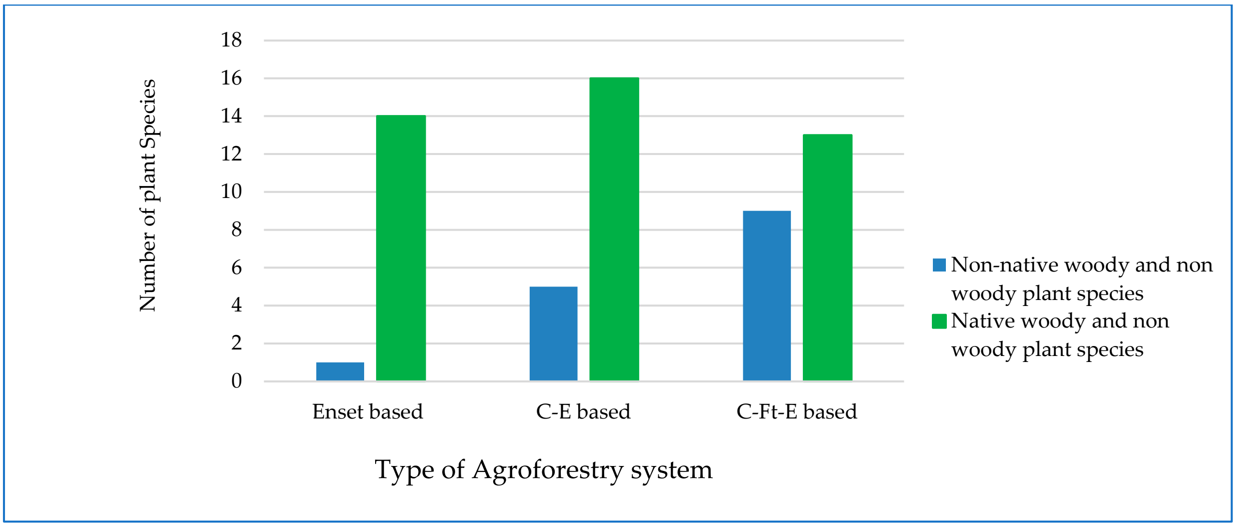

Figure 3. Comparison of the three agroforestry systems in terms of number of woody and non-woody plant species.

However, in the case of C–Ft–E based AF systems, the plots were dominated by non-native fruit species such as *Persea americana* Mill., *Musa acuminata* Colla, *Psidium guajava* L., *Carica papaya* L., and *Mangifera indica* L. The dominance of non-native species in this type of AF might be due to the high number of fruit tree species that were introduced by development missionaries and domesticated for lower-altitude areas [20]. In lower-altitude areas, warmer temperatures are mostly reflected. This type of weather condition might speed up litter decomposition and thus improve soil fertility, which favors the growth of a variety of plants. Introduction of these non-native species might affect the existence of native species, implying that they could be replaced by non-native ones due to a shortage of space for proper growing. These non-native species may also be attractive for the farmers because of their value for consumption and the market. In general, maintaining such a considerable number of tree and shrub species in the studied AF systems, both native and non-native in origin, implies a great role of these indigenous AF systems in the conservation of plant genetic resources. The role of AF systems in maintaining a substantial number of plant species was also reported by [80,81], who conducted research in homegarden AF systems of west Java and east Usambara of Indonesia.

3.1.2. Plant Species Endemism and Conservation Concern

Agroforestry systems can play a great role in the conservation of plant species by providing a variety of habitats for different species. Agroforestry systems can be designed to provide a range of different microclimates, soil types, and other environmental conditions as well as habitat for wildlife and promote the natural regeneration of native species, which can help restore plant diversity in an area [7,82]. Farmers who adopt AF instead of monocultures have less risk of pest and disease attack due to the diversity of plant species in the system, frequent disturbance through crop rotation, tillage, and burning, and minimizing the population of pathogens and their dispersal [83]. In the current study, the role of the three AF systems in the conservation of native and endemic perennial woody and non-woody species was assessed. According to the results, *M. ferruginea* (Hochst.) Baker and *Erythrina brucei* Schweinf were some of the common woody species found across the studied AF systems and were registered as native and endemic. However, it has been argued that the species' distinctiveness expressed in terms of their presence as rare species or endemic species in AF systems is low compared to forest areas because to anthropogenic drivers [10]. The reason for a few endemic woody and non-woody perennial plant species in the present study might therefore be related to anthropogenic activities such as removal of native trees and replacing them with some cash crops and non-native fruit trees.

Species conservation concerns in AF systems are also important issues to deal with. As the inventory from the three AF systems showed, a total of 13 species were listed as species of conservation concern according to the IUCN Red Lists and local criteria. *M. ferruginea* (Hochst.) Baker, *Erythrina brucei* Schweinf., *Dracaena steudneri* Schweinf. Ex Engl., *Senna siamea* (Lam.) H.S.Irwin and Barneby, *Trichilia dregeana* Sond., *Melia azedarach* L., *Azadirachta indica* var., *Albizia grandibracteata* Taub., *Bridelia micrantha* (Hochst.) Baill. were listed under the least concern by the IUCN Red Lists [60]. *Rhamnus prinoides* L. Herit. was listed as both rare for 25% of species that least occur [56] and as having the least number of individuals (\100,000 individuals in the country) as per local criteria [61]. *Prunus Africana* (Hook.f.) Kalkman was listed as both vulnerable by the IUCN Red Lists [60] and rare for 25% of species that least occur [56]. *Albizia gummifera* (J.F. Gmel.) C.A.Sm and *Ficus vasta* Forssk. were listed as rare for 25% of species that least occurred [56]. The number of species listed under the IUCN Red List in the present study (10 out of 52) was higher than reported in south-western Bangladesh (6 out of 419) [16]. In terms of proportion from the total species, the number of Red List species in the current study (25%) was by far higher than that reported in south-western Bangladesh (1.4%). This difference might be due to the physiogeographic situation (distinct type of landscape, landforms, rock type, and evolutionary history of Ethiopia and thus situated in East African highland) as compared to Bangladesh.

The assessment of species in terms of rarity showed that the occurrence of five native species was very limited in certain sample plots. Woody species such as *Combretum* spp., *P. africana* (Hook.f.) Kalkman, *Ficus sur* Forssk., *S. siamea (C. siamea)* (Lam.) H.S.Irwin and Barneby, *and T. dregeana* Sond. occurred only in one sample plot (Figure 4), implying that these species are rare, demand conservation, and need to be maintained by practitioners.

3.1.3. Plant Species Frequency and Important Value Index

Out of the 31 plant species recorded on sample plots, 4 were the most frequent across the inventoried farms. *E. ventricosum* (Welw.) Cheesman was the most frequent plant species, occurring in 60 sample plots, and was followed by *M. ferruginea* (Hochst.) Baker (in 46 sample plots), *Coffea arabica* L. (in 39 sample plots), and *C. africana* Lam. (in 29 sample plots) (Figure 4). A study conducted in a similar zone but under different site conditions reported that *Cordia Africana* Lam. and *M. ferruginea* (Hochst.) Baker were the most frequent perennial woody species [13]. Ref. [68] reported that plant species with a greater economic or ecological value were found to be more frequently distributed across the smallholdings. *M. ferruginea* (Hochst.) Baker also showed a higher frequency. This might be related to the special characteristics of the tree species, such as serving as a shade for *C. Arabica*, being better adapted in the area, and the fact that propagation and management of the species is easy [13]. It also has the ability to improve soil fertility and thus increase productivity [79]. The third most frequent species was *C. arabica* L. The reason might be related to its economic importance and income source for the household, enhancing their livelihood [28,39].

The important value index (IVI%) of each plant species in the studied AF systems was calculated to determine the significance of each individual species in the system. According to the results, the five plant species with the highest important value index in the C–Ft–E based indigenous AF system were *E. ventricosum* (Welw.) Cheesman, *Coffea arabica* L., *M. acuminata* Colla, *M. indica* L., and *P. americana* Mill., respectively (Table 2). In comparison to the first and third AF systems, the enset based AF system exhibits a higher IVI% for enset species. Besides the lead species, the system includes four more different tree species that are important multipurpose species, namely *M. ferruginea* (Hochst.) Baker, *C. africana* Lam., *Erythrina brucei* Schweinf., and *Croton macrostachyus* Hochst. ex Delile. In the C–E based AF system, besides the lead species of coffee and enset, certain species overlap with the second AF system.

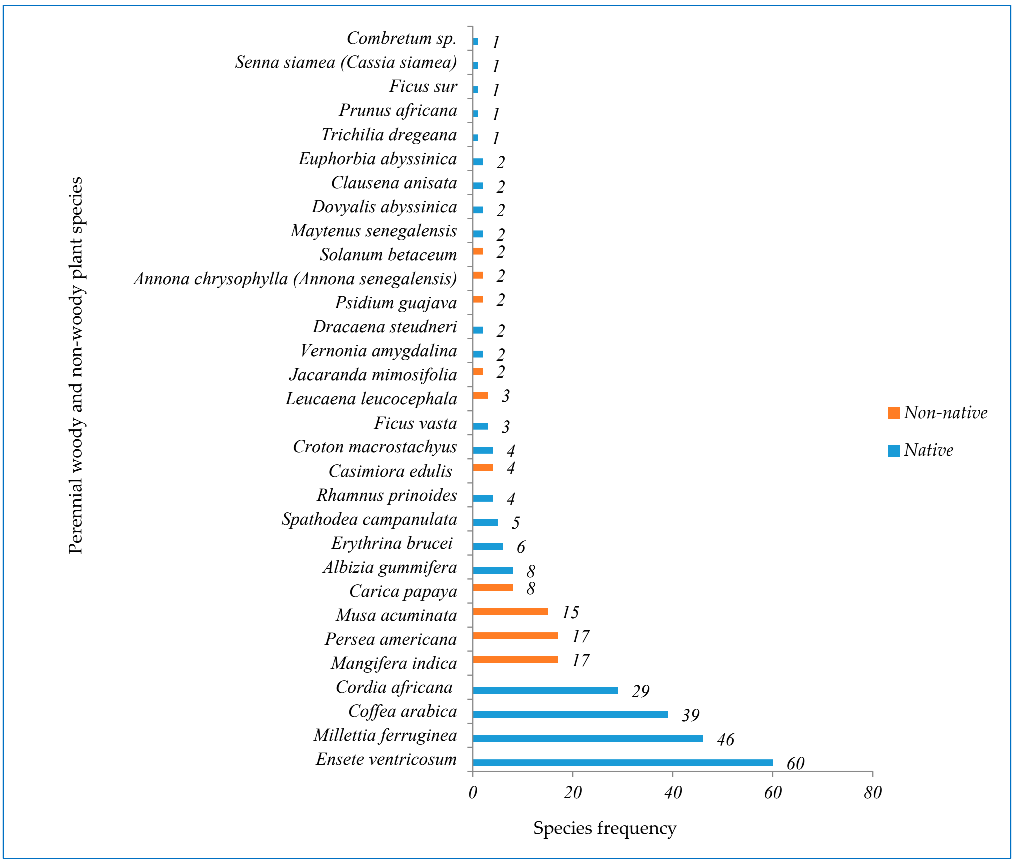

Figure 4. Frequency of woody and non-woody plant species across the three AF systems (60 sample plots) of the study sites.

Table 2. Woody and non woody plant species with the highest important value index percentage (IVI %) in each of the three indigenous AF systems in south-eastern rift-valley landscapes, Ethiopia.

Agroforestry System	Species Scientific Name	IVI%
Enset based	*Ensete ventricosum* (Welw.) Cheesman	204.6
	Millettia ferruginea (Hochst.) Baker	40.9
	Cordia africana Lam.	22.2
	Erythrina brucei Schweinf.	6.1
	Croton macrostachyus Hochst. ex Delile	4.0
Coffee–enset based	*Ensete ventricosum* (Welw.) Cheesman	159.2
	Coffea arabica L.	56.3
	Millettia ferruginea (Hochst.) Baker	23.9
	Cordia africana Lam.	21.3
	Albizia gummifera (J.F. Gmel.) C.A.Sm	6.7
Coffee–fruit tree–enset based	*Ensete ventricosum* (Welw.) Cheesman	103.4
	Coffea arabica L.	46.7
	Musa acuminata Colla.	42.3
	Mangifera indica L.	24.1
	Persea americana Mill.	21.6

The IVI% of *E. ventricosum* (Welw.) Cheesman was recorded the highest across the three AF systems. This was due to the species' high relative frequency, relative abundance, and relative dominance in each AF system. The variation in IVI% for various woody or non-woody species among the AF systems might be related to farmers' species preference, growth performance, and original stocking density of the species in the sample quadrants [65].

Under the C–Ft–E based AF system the majority of the plant species with the highest IVI % were non-native species, specifically fruit trees, whereas in enset based and C–E based AF systems all the species with highest IVI % were the native ones. These results coincide with the report on perennial plant species composition (Section 3.1.1) of this study, which found a higher percentage of native species under enset based and C–E based AF system while the C–Ft–E based AF system had lower numbers of native species.

3.1.4. Stand Structure, Diversity, and Richness Status of Agroforestry Systems

Considering the stem number, basal area, height, and DBH of only enset species in the three AF systems, the enset based AF system showed the highest value, whereas the lowest value for these parameters was found in the C–Ft–E based AF system (Table 3). The mean stem number, BA, and DBH were higher in the C–Ft–E based AF system, whereas the mean height for the woody species was higher in the enset based AF system (Table 4). The least mean values of stem number and basal area for only woody species were recorded in the enset based AF system (Table 4). The computation of these four parameters was also carried out for the mixture of woody and enset species for each AF system. Based on the results, the highest mean stem density was recorded in the C–Ft–E based AF system (71.2 stems), whereas the least was in the enset based AF system (44.6 stems) (Table 5). The highest average basal area, height, and DBH of the perennial woody species and enset together were recorded in the enset based AF system; 317.7 m^2 ha^{-1}, 4.6 m, 26.7 cm, respectively (Table 5). The combined mean perennial woody species stem density (20.8 per 100 m^2 or 2083 stems ha^{-1} when extrapolated to a hectare basis) for all 60 farm plots in the present study was much higher than the reported values by [13], who found stem density of woody species in enset based AF (625 stems ha^{-1}), C–E based AF (1240 ha^{-1}), and fruit–coffee AF systems (1505 ha^{-1}) of south-eastern Ethiopia. Similarly, [39] reported 636 stems ha^{-1} in the enset–coffee–Maize AF systems in southern Ethiopia and 1833 stems ha^{-1} in homegardens in west Java, which are below the mean values of the present study. The greater difference in stem density between our results and those reported by other authors might be due to the fact that the farm owners in the current study have better silvicultural management of the system. Proper lopping, pollarding, pruning and stratified layer planting are some of the good silvicultural management activities practiced by the farm owners. Having stratified layers in the studied AF systems allows growth of different trees/shrubs in some space so that they could have less competition for the above and belowground resources.

Table 3. Mean stem number, basal area (BA), height, and diameter at breast height (DBH) of only enset species for each AF system, followed by SE in parenthesis.

Agroforestry System	n	Stem Number (No/100 m^2)	BA (m^2 ha^{-1})	Height (m)	DBH (cm)
Enset based AF	20	34.7 (2.7) (b)	306.4 (28.8) (b)	4.4 (0.2) (b)	31.0 (1.7) (b)
C–E based AF	20	29.3 (2.8) (b)	207.0 (15.1) (c)	4.1 (0.2) (b)	28.8 (1.8) (ab)
C–Ft–E based AF	20	13.1 (2.0) (a)	81.2 (9.3) (a)	3.6 (0.2) (a)	24.2 (1.4) (a)
p-value		<0.05	<0.05	<0.05	<0.05

C–E based AF: coffee–enset based AF; C–Ft–E based AF: coffee–fruit tree–enset based AF.

Table 4. Mean stem number, basal area (BA), height, and diameter at breast height (DBH) of only woody plant species for each AF system, followed by SE in parenthesis.

Agroforestry System	n	Stem Number (No/100 m^2)	BA (m^2 ha^{-1})	Height (m)	DBH (cm)
Enset based AF	20	9.3 (1.7) (b)	11.3 (2.5) (b)	6.0 (0.8) (b)	11.2 (1.3) (a)
C–E based AF	20	22.0 (1.1) (c)	21.9 (4.1) (bc)	3.6 (0.2) (ac)	8.1 (0.3) (b)
C–Ft–E based AF	20	31.2 (3.5) (a)	53.8 (10.4) (a)	4.2 (0.2) (a)	11.8 (0.5) (a)
p-value		<0.05	<0.05	<0.05	<0.05

C–E based AF: coffee–enset based AF; C–Ft–E based AF: coffee–fruit tree–enset based AF.

Table 5. Mean stem number, basal area (BA), height, and diameter at breast height (DBH) of perennial woody and enset species together for each AF system, followed by SE in parenthesis.

Agroforestry System	N	Stem Number (No/100 m^2)	BA (m^2 ha^{-1})	Height (m)	DBH (cm)
Enset based AF	20	46.9 (3.0) [(b)]	317.7 (28.1) [(b)]	4.6 (0.1) [(a)]	26.7 (1.5) [(b)]
C–E based AF	20	53.8 (2.6) [(b)]	228.5 (14.8) [(c)]	4.3 (0.2) [(a)]	18.9 (0.7) [(c)]
C–Ft–E based AF	20	71.2 (3.2) [(a)]	149.2 (17.6) [(a)]	4.3 (0.1) [(a)]	15.7 (0.7) [(a)]
p-value		<0.05	<0.05	NS	<0.05

Note: similar letter shows not significant difference and different letters indicate significance differences between groups according to LSD multiple test (Fisher LSD test) at $p < 0.05$; NS: not significant. C–E based AF: coffee–enset based AF; C–Ft–E based AF: coffee–fruit tree–enset based AF.

The mean stem density, basal area, height, and DBH of enset species for the ensetbased AF system were significantly different at ($p < 0.05$) from the C–Ft–E based AF system (Table 3). In addition, the enset based AF system showed a significant difference from the C–E based AF only for mean basal area (Table 3). The computed values of only perennial woody species in the three AF systems showed that the C–Ft–E based AF system was significantly different at ($p < 0.05$) from the enset based AF system for their mean stem density, basal area, and DBH (Table 4). However, the mean height of only woody species in enset based AF was significantly different from both C–Ft–E based and C–E based AF systems (Table 4). Under Table 5, the computations for their mean stem density, BA, height and DBH were conducted for all the woody and enset species as a mixture for the three AF systems. The C–Ft–E based AF system was significantly different ($p < 0.05$) from the enset based AF system in terms of mean stem density, BA, and DBH. In addition, C–Ft–E based and enset based AF systems were significantly different from C–E AF systems in terms of BA and DBH. However, the height of the species did not significantly differ among the AF systems (Table 5). The stem density of plant species in AF systems is related to ecological (altitude, rainfall, and temperature) [39] and socioeconomic conditions (marketing, size of land holding) [39,84]. The highest mean BA and mean DBH of plant species were found in the enset based AF system with 317.7 m^2 ha^{-1} and 26.7 cm respectively. The lowest mean BA and mean DBH of species were found in C–Ft–E based AF with 149.2 m^2 ha^{-1} and 15.7 cm, respectively.

The mean basal area and DBH of all species significantly differed ($p < 0.05$) between based the three agroforestry systems (Table 5). According to the computed mean basal area values for each species, *E. ventricosum* (Welw.) Cheesman (58.6%), *M. acuminata* Colla (11.8%), and *C. arabica* L. (7.0%) in C-Ft-E based (Table A4) and *E. ventricosum* (Welw.) Cheesman (96.1%), *Cordia africana* (1.4%), and *Croton macrostachyus* (0.4%) in enset based (Table A2) had the highest relative dominance. Under the C–E based AF system *E. ventricosum* (89.8%), *C. africana* Lam. (3.8%), and *C. arabica* L. (2.7%) showed the highest relative dominance (Table A3). The share of native plant species in terms of relative dominance was 80%, 99.9%, and 99.5% in C–Ft–E based, enset based, and C–E based AF systems, respectively. The results revealed that native species almost fully dominate the horizontal space, especially in enset based and C–E based AF systems. The average stem number (2083.3 stems ha^{-1}) and BA (29 m^2 ha^{-1}) of perennial woody species recorded in the present study was higher than reported in other indigenous fruit–coffee AF systems of south-eastern Ethiopia with 1505 stems ha^{-1} and BA of 11.7 m^2 ha^{-1} [13], in coffee-based agroforests in Guinea between 1071 and 1239 stems ha^{-1} and BA of 22.15 m^2 ha^{-1} [85], and in cocoa agroforest and mixed food agroforest in south-eastern Ghana with 125 stems ha^{-1} and BA of 8.4 m^2 ha^{-1} [86]. The greater difference in stem number and basal area between this investigation and those reported by other authors might be related to the tendency of the farmers to maintain more native trees from previous forest land and plant more coffee and non-native fruit trees.

The relationship between BA and DBH and between BA and stem number was assessed using regression analysis. The assessment was conducted for enset species, woody species separately, and mixtures of woody and enset species in the three AF systems. As the results displayed in the regression graph, the correlation between BA and DBH by separate computing of woody species and enset was from very low to low, respectively (Figures 5A and 6A). The mean BA of enset and woody species separately within the AF systems was somehow affected by stem number, although the correlation was low with values of r^2 = 0.31 and r^2 = 0.23, respectively (Figures 5B and 6B). The mean BA increased with increasing mean DBH, with a correlation of r^2 = 0.6 for a mixture of woody and enset species (Figure 7A). However, no correlation was found between BA and stem number (Figure 7B). The reason might be the mixing of woody and enset, which increases the density of the stand and thus the possibility of a smaller diameter of enset species.

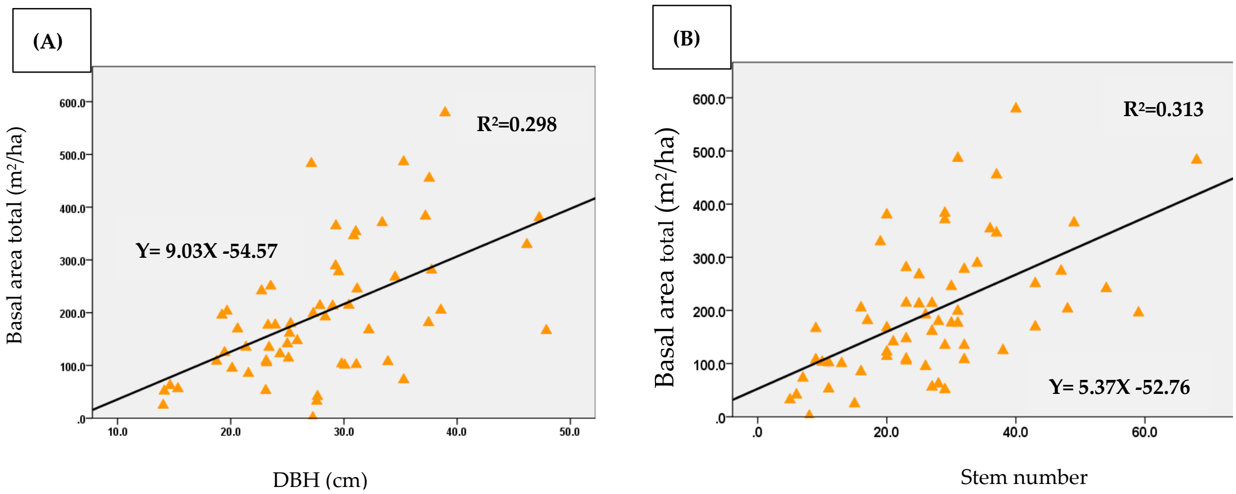

Figure 5. Relationship between DBH and BA (**A**); stem number and BA (**B**) for the enset species of the three studied AF systems.

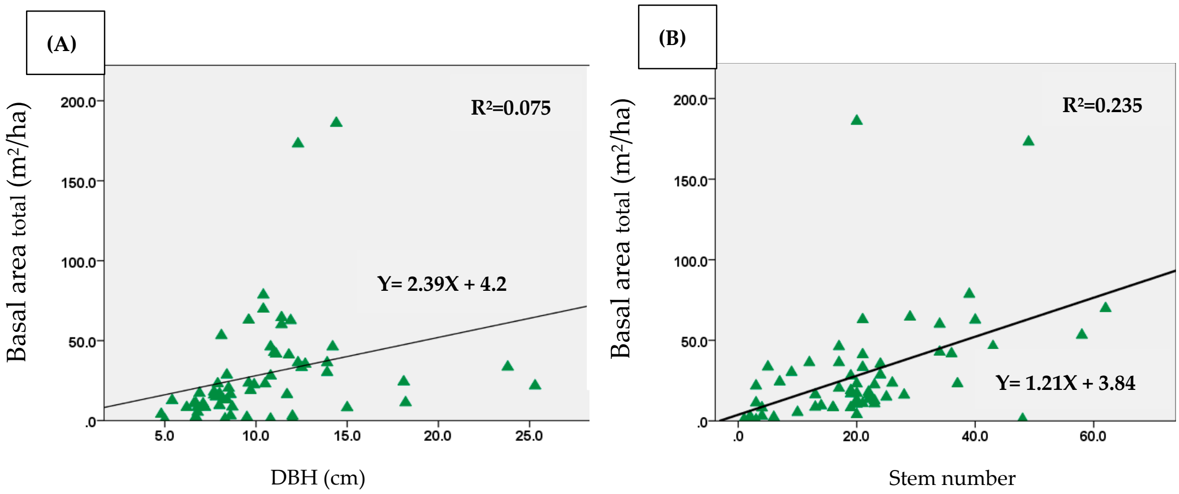

Figure 6. Relationship between basal area and diameter at breast height (DBH) (**A**); basal area and stem number (**B**) for the woody species of the three studied AF systems.

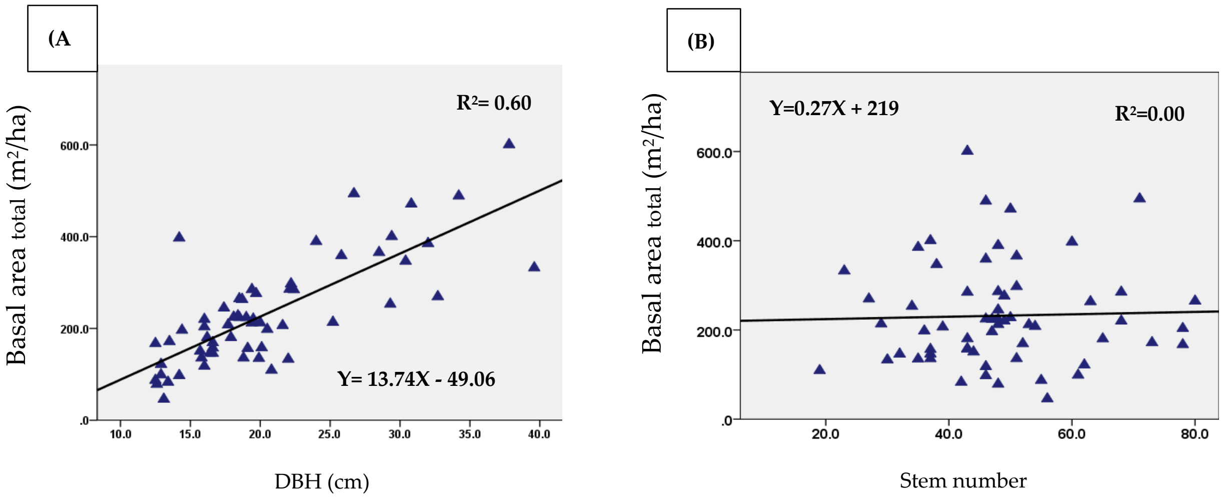

Figure 7. Relationship between diameter at breast height (DBH) and basal area (**A**); stem number and basal area (**B**) for the woody and enset species of the three studied AF systems.

Diversity indices such as Shannon diversity index, Margalef's richness index, and Pielou's Eveness index helped us analyze and evaluate the relationships of species distributed among the three studied AF systems. According to the results, C–E based AF systems showed higher species abundance (51.3), whereas enset based AF systems showed lower (44.6). The highest diversity index and richness were, however, observed in the C–Ft–E based AF systems, whereas the lowest was in the enset based AF systems.

The species mean abundance and Pielou's Eveness index values between the AF systems were not significantly different (Table 6). Shannon's diversity and Margalef's richness index of species was significantly different ($p < 0.05$) between the three AF systems. The high richness index in C–Ft–E based AF might be related to proximity to main roads [33,39] and favorable environmental conditions like temperature [13]. For instance, the temperature in the C–Ft–E based AF system (>25 °C) was slightly warmer compared to the remaining two systems with 13–28 °C. This warmer weather condition, coupled with a high amount of rainfall, might provide favorable conditions for plants to survive easily and grow faster. This might motivate the practitioners to incorporate additional woody and non-woody species (in our case, mainly high-value fruit trees and coffee, enset, and other native species) to receive more benefits out of them. [20] also reported greater species richness in the C–Ft–E based AF system might be related to the incorporation of various native and non-native woody species along a vertical stratum.

Table 6. Mean ± SD. of woody and non-woody plant species abundance, Shannon diversity index (H′), Margalef's richness index (D_{mg}), and Pielou's evenness (J) of study plots under the three AF systems.

Agroforestry System	N	Abundance per 100 m^2	Shannon Diversity Index	Margalef's Richness Index	Pielou's Eveness Index
Enset based AF	20	44.6 (3.0) $^{(a)}$	0.7 ± 0.2 $^{(b)}$	0.6 ± 0.2 $^{(b)}$	0.6 ± 0.1 $^{(a)}$
C–E based AF	20	51.3 (2.6) $^{(a)}$	1.0 ± 0.1 $^{(c)}$	1.0 ± 0.3 $^{(c)}$	0.6 ± 0.1 $^{(a)}$
C–Ft–E based AF	20	48.5 (3.2) $^{(a)}$	1.1 ± 0.2 $^{(a)}$	1.2 ± 0.3 $^{(a)}$	0.6 ± 0.1 $^{(a)}$
p-value		NS	<0.05	<0.05	NS

Note: Same letter shows not significant difference and different letters indicate significance differences between groups according to LSD multiple test (Fisher LSD test) at $p < 0.05$; NS: not significant. C–E based AF: coffee–enset based AF; C–Ft–E based AF: coffee–fruit tree–enset based AF.

The Shannon diversity index values in the present study for C–Ft–E based (1.1) and C–E based AF (1.0) were comparable with studies conducted in enset–coffee–Maize–Khat AF (1.15) in Sidama region of southern Ethiopia [39] and in Kerala homegarden agroforestry (1.2) in India [71]. However, our results were lower than values reported by [68] in traditional AF practices (2.2) of the Dellomenna district of south-eastern Ethiopia; Ref. [87] in homegarden AF (1.8) of southern Gonder of Ethiopia [65] and in homegarden AF (2.23) of Wolayitta Zone, Ethiopia. The lower diversity index values of the present study compared to the above-mentioned reports were due to the medium evenness index values across all small holdings of the investigated AF plots. This implies that species diversity is to be affected by the abundance and equitability of the species within the sample plots. The results of this study in terms of Pielou's Eveness index (with a mean value of 0.6) were also comparable with other results: in enset coffee AF and fruit coffee AF (0.6) of similar study zones like ours but with different study sites [13], in enset–coffee–Maize–Chat–Pineapple AF (0.55) in Sidama area of Southern Ethiopia [18], and in homegardens of Kerala (from 0.24 to 0.71) of Southern India [71].

The equitability of the woody species was almost the same across all the AF systems. The result of a one-way ANOVA followed by post hoc testing (Fisher's LSD test) (n = 20) showed that the difference in mean Pielou's Eveness index between the studied AF systems was not significant. The mean Pielou's Eveness index value of 0.6 implies a situation in which species are moderately distributed in each plot of the AF systems, or, in other words, the relative homogeneity of the species in the sample plots was 60% of the maximum possible even population across all smallholdings. According to the analysis of Sorensen's similarity index for the three AF systems, the highest species similarity was observed between C–Ft–E based AF and C–E based AF with a value of 67% (14 woody species out of 28), while the least was between the C–Ft–E based AF and enset based AF system with a value of 48% (9 woody species out of 28). The species similarity between enset based AF and C–E based AF was a little higher than the latter relatively with a value of 57% (10 woody species out of 25).

3.1.5. Relationship of Altitude with Species Richness and Species Abundance

Altitude is one of the important variables that could exert an effect on habitat quality and thus influence species richness, composition, and diversity. This is because altitude affects changes in the availability of relevant resources for plant growth, for instance, heat and water [13,88]. Regression analysis was performed to evaluate the relationship between altitude and species richness and abundance. The graphs representing all the three studied AF systems are displayed in Figure 8A,B. Our results showed that both the mean Margalef's species richness index and abundance were decreasing as altitude increased. The correlation between mean species richness and altitude was r^2 = 0.33 whereas the correlation between mean species abundance and altitude was r^2 = 0.31 (Figure 8B). From the results, we could understand that altitude was more related to species richness than species abundance, although both have very low correlation values.

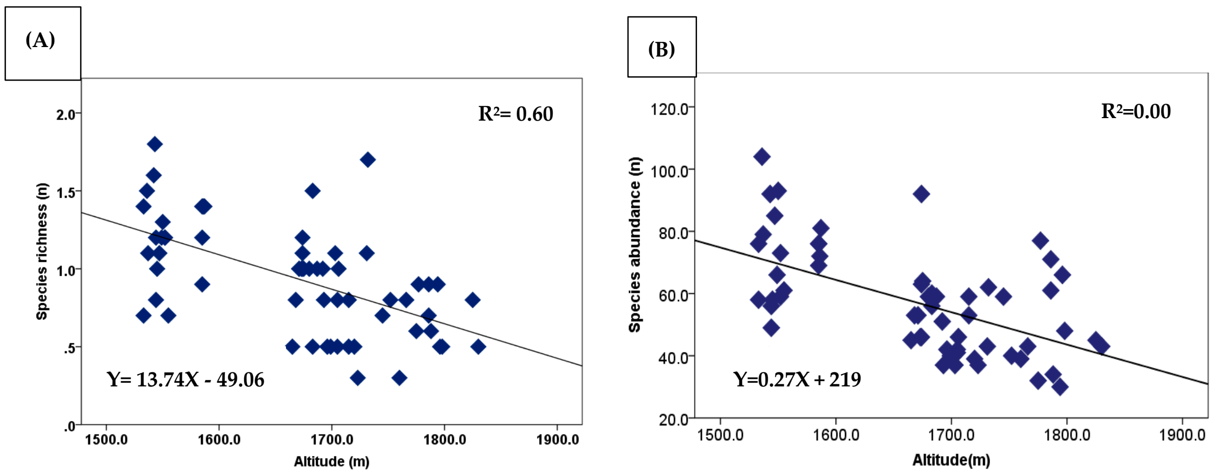

Figure 8. Relationship between altitude and Margalef's species richness index (**A**), altitude and species abundance (**B**) under the three studied AF systems.

The results of the present study are in line with other reports, such as [89], who observed a decreasing trend of plant species richness as altitude increased in the northeastern Tibetan Plateau, China. However, contradicting results were reported by [39,90], in which an increasing trend of species richness with increasing altitude was observed. These studies were conducted in the Qinghai-Tibetan Plateau, China and southern Ethiopia, respectively. The reason for increasing species richness with altitude in these studies might be related to different factors. For instance, the study conducted by the first author included all altitudinal ranges (from 320 to 5200 m.a.s.l.). Therefore, increasing species richness with altitude was possible because, at higher altitudes, the impact of livestock on destructing plant species is very low compared to the lower altitudes. The second author also reported an increasing enset species richness with altitude but not for all species. This increase might be due to enset species preferring an altitudinal range between 2000 and 2500 m asl. Whether to obtain an increasing or decreasing trend of species richness with altitude is greatly affected by the scale of the study, for instance, the altitudinal range [76]. The author articulated that if a survey of the entire altitudinal gradient is conducted, the pattern shows a hump shape, implying that an increasing trend of species richness up to a certain altitude range and then started to decrease. But if the survey is conducted on a narrow scale of altitudinal gradient, the pattern changes progressively to a monotonically decreasing trend of species richness with increasing altitude. Therefore, from the above idea, we could understand that the relationship between species richness and altitude could be either negative or positive, depending on the situation.

Species richness and abundance could also be affected by other factors such as the educational level of the landowner, land ownership, slope and extension access [25], and farm size [18,25]. As farmers become more aware, well-educated, own larger land size and obtain better access to extension service, their tendency to grow more trees becomes high. In addition, the possibility of incorporating diverse fruit and non-fruit trees would be higher. Edaphic factors such as soil conditions could positively or negatively affect species richness and evenness [91]. For instance, a study conducted by [92] revealed that species richness was negatively correlated with phosphorus availability and species evenness was negatively correlated with the ratio of organic carbon to total nitrogen in soil.

4. Conclusions and Recommendations

Agricultural landscapes that integrate AF systems show great potential for maintaining woody and non-woody species diversity, as forest lands do. The studied AF systems are playing a great role in conserving woody and non-woody species. The higher percentage of native plant species in the present study is an indicator of the sustainability of the system for conserving the plant species. Dominance of non-native fruit tree species in C–Ft–E based AF was observed. If such dominance continues in the AF systems, it could be a threat to the maintenance of native plant species in the future. Conserving plant species that are categorized as conservation concerns according to the IUCN Red List and local criteria implies how strong AF systems can serve as a refuge for species. In general, this study offers an opportunity to evaluate the status of the AF systems and provide scientific information on the conservation potential of the systems for endemic native species. It also further contributes to the development of a national policy concerning the conservation of biodiversity. Some native tree species were found to be rare, although they are dominant in other areas. For instance, species such as *Trichilia dregeana* Sond., *Ficus sur* Forssk., *Prunes africana* (Hook.f.) Kalkman, and *Combretum species* were some of them. Therefore, a special conservation priority coupled with wise utilization of native plant species should be implemented by the community to maintain their presence. The government, non-governmental organizations, and other concerned stakeholders should promote different AF practices to conserve native woody and non-woody plant species through circa situm conservation. Since the current study was conducted on a limited AF site, further research on a broader scale is needed to explore the potential of the systems to accommodate more native and endangered taxa.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d16010064/s1, Table S1: List of woody and non-woody plant species in the three indigenous agroforestry systems of southeastern rift-valley landscapes, Ethiopia; Height, Diameter at breast height (DBH); calculations of Shannon diversity index, Pielou's evenness index, and Margalef's rich ness index, and Abundance of each plot; Table S2: Summarized values of Shannon diversity index, Pielou's evenness index, and Margalef's rich ness index, and Abundance of woody and non-woody plant species for each study site.

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Conflicts of Interest: We declare that there are no conflicts of interest.

Appendix A

Table A1. List of perennial woody and non-woody plant species recorded across the three studied AF systems of our study sites.

Number	Vernacular Name	Scientific Name	Family	Origin
1	Gorbe	*Albizia gummifera* (J.F. Gmel.) C.A.Sm	Fabaceae	Native
2	Geshita	*Annona chrysophylla* Bojer	Annonaceae	Non-native
3	Papaya	*Carica papaya* L.	Caricaceae	Non-native
4	Abukere	*Casimiroa edulis* Lal lave and Lex	Rutaceae	Non-native
5	Godere	*Clausena anisata* (Willd.) Benth.	Rutaceae	Native
6	NI	*Combretum* sp.	Combretaceae	Native
7	Wedesa	*Cordia africana* Lam.	Boraginaceae	Native
8	Buno	*Coffea arabica* L.	Rubiaceae	Native
9	Mokonisa	*Croton macrostachyus* Hochst. ex Delile	Euphorbiaceae	Native
10	NI	*Dovyalis abyssinica* (A.Rich.) Warb.	Salicaceae	Native
11	Cho'e	*Dracaena steudneri* Schweinf. Ex Engl.	Dracaenaceae	Native
12	Ensete	*Ensete ventricosum* (Welw.) Cheesman	Musaceae	Native
13	Welale/Gedogna	*Erythrina brucei* Schweinf.	Leguminosae	Native
14	Kulkal	*Euphorbia abyssinica* J.F.Gmel.	Euphorbiaceae	Native
15	wagela	*Ficus sur* Forssk.	Moraceae	Native
16	Kilto	*Ficus vasta* Forssk.	Moraceae	Native
17	NI	*Jacaranda mimosifolia* D.Don	Bignoniaceae	Non-native
18	Lusina	*Leucaena leucocephala* (Lam.) de Wit	Mimosoideae	Non-native
19	Mango	*Mangifera indica* L.	Anacardiaceae	Non-native
20	Kobo/gulo	*Maytenus senegalensis* (Lam.) Exell	Celastraceae	Native

Table A1. *Cont.*

Number	Vernacular Name	Scientific Name	Family	Origin
21	Tatato	*Millettia ferruginea* (Hochst.) Baker	Leguminosae	Native
22	Muse	*Musa acuminata* Colla	Musaceae	Non-native
23	Avocato	*Persea americana* Mill.	Lauraceae	Non-native
24	Gorbe	*Prunus africana* (Hook.f.) Kalkman	Rosaceae	Native
25	Sholla	*Psidium guajava* L.	Myrtaceae	Non-native
26	Gesho	*Rhamnus prinoides* L. Herit.	Rhamnaceae	Native
27	NI	*Senna siamea (Cassia siamea)* (Lam.) H.S.Irwin and Barneby	Fabaceae	Native
28	Timatim zaf	*Solanum betaceum* Cav.	Solanaceae	Non-native
29	NI	*Spathodea campanulata* P.Beauv.	Bignoniaceae	Native
30	NI	*Trichilia dregeana* Sond.	Meliaceae	Native
31	Hebicha	*Vernonia amygdalina* Delile	Asteraceae	Native
List of perennial woody and non-woody plant species recorded out of the study plots				
32	NI	*Albizia grandibracteata* Taub.	Fabaceae	Native
33	NI	*Azadirachta indica* var.	Meliaceae	Non-native
34	Tibero/Sessa	*Bersama abyssinica* Fresen	Francoaceae	Native
35	Yebelo	*Bridelia micrantha* (Hochst.) Baill.	Phyllanthaceae	Native
36	Tilo	*Cassipourea malosana* (Baker) Alst	Rhizophoraceae	Native
37	Chate	*Catha edulis* (Vahl) Forssk. ex Endl.	Celastraceae	Native
38	Motokomo	*Celtis africana* Burm.f.	Ulmaceae	Native
39	Motokomo	*Celtis* sp.	Ulmaceae	Native
40	Lomie	*Citrus limon* (L.) Osbeck	Rutaceae	Non-native
41	Birtukan	*Citrus sinensis* (L.) Osbeck	Rutaceae	Non-native
42	NI	*Cupressus lusitanica* Miller.	Cupressaceae	Non-native
43	Bahirzaf	*Eucalyptus camaldulensis* Dehnh.	Myrtaceae	Non-native
44	Bahirzaf	*Eucalyptus globules* Labill.	Myrtaceae	Non-native
45	Bahirzaf	*Eucalyptus grandis* W.Hill ex Maiden	Myrtaceae	Non-native
46	NI	*Grevillea robusta* A. Cunn. ex R. Br.	Proteaceae	Non-native
47	NI	*Faidherbia albida* (Delile) A.Chev.	Fabaceae	Native
48	Kilto	*Ficus elastica* Roxb. ex Hornem.	Moraceae	Native
49	NI	*Hagenia abyssinica* (Bruce) J.F.Gmel.	Rosaceae	Native
50	NI	*Melia azedarach* L.	Meliaceae	Non-native
51	NI	*Ricinus communis* L.	Euphorbiaceae	Native
52	NI	*Sesbania sesban* (L.) Merr.	Fabaceae	Non-native

Table A2. List of perennial woody and non-woody plant species and their important value index under enset based indigenous AF, south-eastern rift-valley landscapes, Ethiopia.

Scientific Name	Family	Fre n	RF (%)	Tot Dom	RD (%)	AB	RA (%)	IVI (%)
Albizia gummifera (J.F. Gmel.) C.A.Sm	Fabaceae	2.0	3.0	0.2	0.3	6.0	0.6	3.9
Combretum sp.	Combretaceae	1.0	1.5	0.0	0.0	4.0	0.4	1.9
Cordia africana Lam.	Boraginaceae	11.0	16.7	0.9	1.4	39.0	4.1	22.2
Crot macrostachyus Hochst. ex Delile	Euphorbiacee	2.0	3.0	0.2	0.4	6.0	0.6	4.0
Dovyalis abyssinica (A.Rich.) Warb.	Salicaceae	1.0	1.5	0.0	0.0	3.0	0.3	1.9
Dracaena steudneri Schweinf. ex Engl	Dracaenaceae	1.0	1.5	0.0	0.0	11.0	1.2	2.7
Ensete ventricosum (Welw.) Cheesman	Musaceae	20.0	30.3	61.3	96.1	743.0	78.2	204.6
Erythrina brucei Schweinf.	Leguminosae	3.0	4.5	0.0	0.1	14.0	1.5	6.1
Maytenus senegalensis (Lam.) Exell	Celastraceae	1.0	1.5	0.0	0.0	1.0	0.1	1.6
Millettia ferruginea (Hochst.) Baker	Leguminosae	19.0	28.8	0.9	1.3	102.0	10.7	40.9
Prunus africana (Hook.f.) Kalkman	Rosaceae	1.0	1.5	0.0	0.0	4.0	0.4	1.9
Rhamnus prinoides L. Herit.	Rhamnaceae	1.0	1.5	0.0	0.0	6.0	0.6	2.1
Senna siamea (Cassia siamea) (Lam.) H.S.Irwin and Barneby	Fabaceae	1.0	1.5	0.0	0.0	4.0	0.4	2.0
Solanum betaceum Cav.	Solanaceae	1.0	1.5	0.0	0.0	3.0	0.3	1.9
Vernonia amygdalina Delile	Asteraceae	1.0	1.5	0.2	0.3	4.0	0.4	2.2

Fre: frequency; RF: relative frequency; Tot Dom: total dominance; RD: relative dominance; AB: abundance; RA: relative abundance; IVI: important value index.

Table A3. List of perennial woody and non-woody plant species and their important value index under C–E based indigenous AF system, south-eastern rift-valley landscapes, Ethiopia.

Scientific Name	Family	Fre n	RF (%)	Tot Dom	RD (%)	AB	RA (%)	IVI (%)
Albizia gummifera (J.F. Gmel.) C.A.Sm	Fabaceae	5.0	5.2	0.1	0.3	14.0	1.1	6.7
Clausena anisata (Willd.) Benth.	Rutaceae	2.0	2.1	0.0	0.1	8.0	0.7	2.8
Coffea arabica L.	Rubiaceae	20.0	20.8	1.3	2.7	400.0	32.7	56.3
Cordia africana Lam.	Boraginaceae	13.0	13.5	1.7	3.8	48.0	3.9	21.3
Croton macrostachyus Hochst. ex Delile	Euphorbiacee	2.0	2.1	0.0	0.1	8.0	0.7	2.8
Dovyalis abyssinica	Salicaceae	1.0	1.0	0.0	0.0	2.0	0.2	1.2
Dracaena steudneri Schweinf. Ex Engl.	Dracaenaceae	1.0	1.0	0.0	0.0	8.0	0.7	1.7
Ensete ventricosum (Welw.) Cheesman	Musaceae	20.0	20.8	41.3	89.8	594.0	48.6	159.2
Erythrina brucei Schweinf.	Leguminosae	3.0	3.1	0.0	0.0	13.0	1.1	4.2
Euphorbia abyssinica J.F.Gmel.	Euphorbiaceae	2.0	2.1	0.0	0.0	6.0	0.5	2.6
Ficus sur Forssk.	Moraceae	1.0	1.0	0.1	0.3	2.0	0.2	1.5
Ficus vasta Forssk.	Moraceae	1.0	1.0	0.1	0.2	1.0	0.1	1.4
Jacaranda mimosifolia D.Don	Bignoniaceae	1.0	1.0	0.0	0.1	5.0	0.4	1.5
Leucaena leucocephala (Lam.) de Wit	Mimosoideae	1.0	1.0	0.0	0.0	5.0	0.4	1.5
Mangifera indica L.	Anacardiaceae	1.5	1.55	0.1	0.2	4.0	0.3	2.1
Millettia ferruginea (Hochst.) Baker	Leguminosae	19.0	28.8	0.9	1.3	102.0	10.7	40.9
Persea americana Mill.	Lauraceae	1.0	1.0	0.0	0.0	0.0	0.0	1.0
Psidium guajava L.	Myrtaceae	2.0	2.0	0.0	0.0	10.0	0.4	1.6
Rhamnus prinoides L. Herit.	Rhamnaceae	2.0	2.1	0.0	0.0	16.0	1.3	3.4
Spathodea campanulata P.Beauv.	Bignoniaceae	1.5	1.55	0.1	0.2	4.0	0.3	2.1
Vernonia amygdalina Delile	Asteraceae	1.0	1.0	0.0	0.0	4.0	0.3	1.4

Fre: frequency; RF: relative frequency; Tot Dom: total dominance; RD: relative dominance; AB: abundance; RA: relative abundance; IVI: important value index.

Table A4. List of perennial woody and non-woody plant species and their important value index under C–Ft–E based AF system, south-eastern rift-valley landscapes, Ethiopia.

Scientific Name	Family	Fre n	RF (%)	Tot Dom	RD (%)	AB	RA (%)	IVI (%)
Albizia gummifera (J.F. Gmel.) C.A.Sm	Fabaceae	1	0.8	0.0	0.0	4.0	0.3	1.1
Annona chrysophylla Bojer	Annonaceae	2	1.5	0.0	0.2	22.0	1.8	3.5
Casimiroa edulis Lal lave and Lex	Rutaceae	4	3.1	0.0	0.0	11.0	0.9	4.0
Carica papaya L.	Caricaceae	8	6.2	0.1	0.2	22.0	1.8	8.2
Coffea arabica L.	Rubiaceae	19	14.6	2.0	7.0	310.0	25.1	46.7
Cordia africana Lam.	Boraginaceae	5	3.8	0.1	0.5	16.0	1.3	5.7
Ensete ventricosum (Welw.) Cheesman	Musaceae	20	15.4	16.9	58.6	363.0	29.4	103.4
Erythrina brucei Schweinf.	Leguminosae	1	0.8	0.0	0.2	2.0	0.2	1.1
Ficus sur Forssk.	Moraceae	1	0.75	1.5	5.15	1	0.1	6.0
Ficus vasta Forssk.	Moraceae	1	0.75	1.5	5.15	1.0	0.1	6.0
Leucaena leucocephala (Lam.) de Wit	Mimosoideae	1	0.8	0.0	0.0	2.0	0.2	0.9
Mangifera indica L.	Anacardiaceae	16	12.3	0.9	3.1	108.0	8.8	24.1
Maytenus senegalensis (Lam.) Exell	Celastraceae	1	0.8	0.0	0.0	2.0	0.2	0.9
Millettia ferruginea (Hochst.) Baker	Leguminosae	12	9.2	0.6	2.1	64.0	5.2	16.6
Musa acuminata Colla	Musaceae	15	11.5	3.4	11.8	234.0	19.0	42.3
Persea americana Mill.	Lauraceae	16	12.3	1.3	4.5	59.0	4.8	21.6
Prunus africana (Hook.f.) Kalkman	Rosaceae	0	0.0	0.0	0.0	0.0	0.0	0.0
Psidium guajava L.	Myrtaceae	1	0.8	0.0	0.0	1.0	0.1	0.9
Rhamnus prinoides L. Herit.	Rhamnaceae	1	0.8	0.0	0.0	4.0	0.3	1.1
Solanum betaceum Cav.	Solanaceae	1	0.8	0.0	0.0	1.0	0.1	0.9
Spathodea campanulata P.Beauv.	Bignoniaceae	3	2.3	0.4	1.5	5.0	0.4	4.2
Trichilia dregeana Sond.	Meliaceae	1	0.8	0.0	0.0	1.0	0.1	0.9

Fre: frequency; RF: relative frequency; Tot Dom: total dominance; RD: relative dominance; AB: abundance; RA: relative abundance; IVI: important value index.

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