

Research Article

Determinant Factor of Plant Species Diversity in the Organic Agriculture-Dominated System of Gedeo Zone, Southern Ethiopia

Abiyot Mebrate ¹, Tadesse Kippie,¹ and Nigussie Zeray²

¹Department of Natural Resource Management, College of Agriculture and Natural Resources, Dilla University, Dilla, Ethiopia

²Departments of Agricultural Economics, College of Agriculture and Natural Resources, Dilla University, Dilla, Ethiopia

Correspondence should be addressed to Abiyot Mebrate; abiyotgeno@gmail.com

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Agricultural intensification is a major challenge for biodiversity conservation in many parts of the world. Organic agriculture is perceived as a possible solution for biodiversity conservation in agriculture dominant systems. This study aimed at investigating the current status of plant species diversity and its determinants in organic agriculture-dominated areas of Gedeo zone, Southern Ethiopia. Multistage sampling procedures were used to obtain 108 households from three agroecological zones of the study area, and plant species data were collected from the quadrants laid in farms of sampled farmers. Besides, diversity management practice data were collected using focus group discussion. A total of 234 plant species belonging to 82 plant families were identified. Most (69.2%) of species in the system were native. The mean value of richness and Shannon index evenness for the whole system was 10.36, 2.06, and 0.89 for highland midland and lowland agroecological zones, respectively, which is relatively high compared with other agriculture-dominated systems in the tropics. The diversity of overall plant species were significantly affected by both agroecological zones and the wealth status of farmers. Midland and lowland agroecological zones had the highest richness values for total plant species than highland. Similarly, highest richness was recorded among farmers of rich and medium wealth classes than poor. The diversity of tree species was significantly affected by both agroecological zone and wealth status of farmer households. The lowland agroecological zone had a significantly higher number of tree species than midland and lowland agroecological zones, while the rich farmer had higher tree diversity compared to medium and poor farmers. The study also identified that diversity of shrubs were significantly influenced by agroecological zone. The midland agroecological had a significantly higher number of shrubs diversity compared to lowland and highland agroecological zones. In this study, herbaceous species diversity was not influenced by both agroecological zone and farmer wealth class. The function of plant species and indigenous plant species maintenance practice had its own effect on plant species diversity in the study area, since the area is dominated with organic agriculture. Therefore, to maintain the current status of the system and to improve the farmer's livelihood, development planners may need to design agroecological-based plant species conservation strategies that give due consideration for indigenous plant species conservation practices and function of plant species.

1. Introduction

Biodiversity is an important symbol to measure the environmental quality and degree of ecological civilization [1]. It is central to ecosystem function and the provision of ecosystem services [2, 3] and a critical resource that humanity simply cannot afford to destroy [4]. Despite the moral, cultural and economic reasons for conserving biodiversity and its ecosystem services, biodiversity is being lost and

degraded at an unprecedented rate as a result of human activities [5]. Land-use change, farm management practices [6], and intensification are assumed to be the major drivers of the current biodiversity loss [7]. Plants are among the organisms more strongly influenced by agricultural management practices [8]. Up to 1 million species threatened with extinction, many within decades, and 25% of species threatened with extinction across terrestrial, freshwater, and marine vertebrate, invertebrate, and plant groups that have

been studied in sufficient detail [5]. One of the earliest global studies also estimated that 15–37% was “committed to extinction” by 2015 [9]. Hence, the conservation of biodiversity should become a fundamental part of agricultural landscapes to achieve global conservation goals [10].

Small-scale sustainable farming such as organic farming can provide a variety of ecosystem services including biodiversity and agrobiodiversity conservation and soil management [11, 12]. It relies on ecological processes, biodiversity, and cycles adapted to local conditions, rather than the use of inputs with adverse effects, and it combines tradition, innovation, and science to benefit the shared environment and promote fair relationships and good quality of life for all involved [13]. The most common practices in organic systems include soil fertility replenishment using locally available organic fertilizers, use of nitrogen-fixing legumes, cover crops, crop rotations, and crop diversification to reduce the risk of crop failure [14, 15]. All these practices directly contribute to plant conservation in the agricultural landscape. In Ethiopia, due to its diversity in agroecological habitats inhabited by diverse ethnic groups, all aforementioned organic agriculture practices are common in many parts of the country in general [16, 17] and Gedeo zone, Southern Ethiopia in particular [18, 19].

The Gedeo agricultural system is characterized as organic production systems that use organic agricultural inputs throughout the system [18, 20, 21]. As a result, the system is the producer of a large variety of organic products such as enset (*Ensete ventricosum* (Welw.) Cheesman) food, which is staple for about 20 million people in Southern Ethiopia [22], coffee, fruits, vegetables, honey, timber, highland sheep, and a variety of crops [23]. Among many organic agricultural products, Yirgacheffe and Sidama brand coffee are certified organic [19, 20, 24]. Getachew and Abiyot [25] also confirmed that 23 primary cooperatives with 36,000 small holder farmers (which are members of Yirgacheffe coffee farmer union) are certified in both organic and fair-trade certificates from international labeling organizations (ILO) and 40% of Ethiopia’s premium grade coffee provided from this system. The organic practices in Gedeo zone are based on indigenous farming practices, shaped by centuries of experience and adapted to the specific locality, and have a strong influence on the landscape. Thus, biodiversity conservation is a part of the culture, history, and spirituality of Gedeo peoples [18].

In agriculture dominant areas, plant diversity may be directly or indirectly associated with environmental and socioeconomic status of farmers. For both conservation purposes and ecological studies, it is important to identify the major factors that influence biodiversity in organic agriculture dominant indigenous systems. Few studies have explored the diversity of woody plant species in the home garden level [19, 26, 27], and no attempt has been made to assess the overall plant species diversity and its influencing factors in the system. Hence, this study aimed at assessing the diversity of plant species and investigating the influencing factors of diversity in organic agriculture-dominated indigenous systems of Gedeo zone, Southern Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area. The study was conducted in the Gedeo zone of the Southern Nations, Nationalities, and Peoples Regional State (SNNPRs) of Ethiopia (Figure 1). The Gedeo is named for the Gedeo people presently living in Gedeo zone. Astronomically, Gedeo zone is situated at 5° 50' 26"–6° 12' 48" N, 38° 03' 02"–38° 18' 59" E [28]. Topographically, the area is undulated and mountainous with 76.81% of land having more than 10% slope [29]. Because of its diverse topographic features, Gedeo zone has a complex and diverse climatic condition. Its altitude ranges from 1450 to 3200 meters above the sea level. The zone lies in inter-tropical convergence zone, receiving rainfall from two sources, the Atlantic and monsoon currents. Hence, the rainfall pattern of the zone is bimodal, of which it falls much between March to May and August to October [18]. It receives a mean annual rainfall of 1500 mm lay within the range of 1200–1800 mm. The mean monthly temperature is 21.5°C, laying within the range 18–25°C. Agroecologically, Gedeo zone comprises of 26% Dega (highland with altitude range 2500–3200 masl), 65% Woina Dega (midland with altitude range 1750–2500 masl), and 9% Kola (lowland with altitude range <1750 masl) [18, 29].

The total population of zone is estimated to be about 1102,445 with a population density of 822 inhabitants per square kilometer which is much higher than the country average (72 people per square km) [30]. The soil of the study area was described as very deep, well drained, red brownish to dark reddish brown, and classified as Eutric Nitisols [31]. According to FAO [32] soil classification, the dominant soil type covering 67% of the total area of the zone is Chromic Luvisols, followed by Haplic Nitisols accounting for 26% of the total area of the zone. The remaining area is covered with Haplic Luvisols (1.8%), Eutric Vertisols (1.9%), Haplic Nitisols (0.01%), and Rhodic Nitisols (3.4%).

2.2. Sampling Method. In this study, multistage stratified random sampling techniques were applied to generate the required primary data. In the first stage, four Woredas (Bulle, Dilla Zuria, Wonago, and Yirgacheffe) were purposively chosen among the six Woredas found in Gedeo zone. This is for the purpose of capturing the climate variability in different agroecological zones (Figure 1). In the second stage, the kebele (it is the smallest administrative unit, but higher than a village and is often translated as “peasant association;” it consists of about 500 households and 800 hectares of land) of four Woredas was stratified into three agroecological zones, including highland, midland, and lowland. In the third stage, following a simple random sampling technique, totally 9 kebeles (3 kebele from each agroecological zone) were selected. In the fourth stage, after securing a fresh list of the household head, again stratified based on wealth status into rich, medium, and poor using local criteria with the help of key informants, kebele agricultural development agent, and kebele leaders. Local criteria such as landholding size, coffee tree holding (major cash crop), enset plant holding (staple food), and livestock

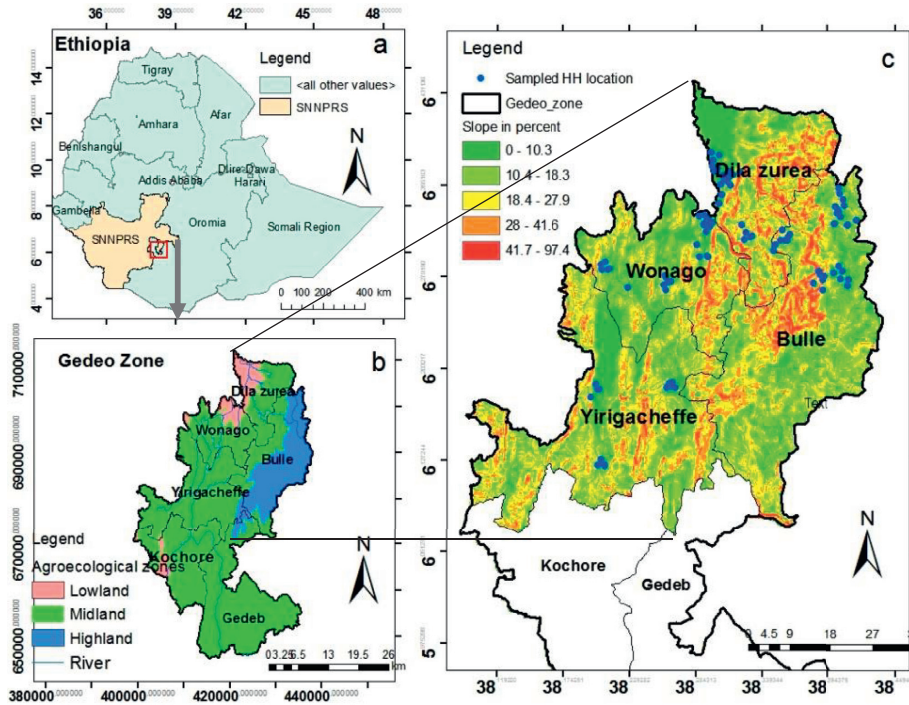


FIGURE 1: Map of the study area. (a) Location of SNNPRS in Ethiopia and location of Gedeo zone in SNNPRS, (b) district in Gedeo zone and agroecological zone classification, and (c) slop of sampled districts and location of sampled households.

holdings were used for the classification of households (Table 1). Finally, a total 108 households (i.e., four HHs from each wealth category, totaling 12 households, and thus 36 households from each agroecological zone) were randomly selected.

2.3. Data Collection. The plant species inventory was conducted in 2010 from the end of April to the beginning of July. The farm of the sampled household was used as a sample plot for plant inventory. Therefore, 10 m × 10 m quadrates were assigned at the central part of a farm using ocular estimation as described by Negash et al. [33] for wood species data collection. Besides main quadrates, 1 × 1 m plot was established for herbaceous species inventory at the center of main quadrates.

Woody species is with diameter at breast height (DBH) > 2.5 cm (at 1.5 m height). DBH was measured using a meter tape. For woody species with DBH below 2.5 cm, only stem count was made to know a number of abundances [34]. For tree species forked below 1.3 m, individual stems were separately measured, and then, average DBH was taken. For coffee plants, the stem diameter at stump height 40 cm was measured, and for enset, the basal diameter of the pseudostem at height of 10 cm was measured as described by Negash et al. [33]. In the case of the multistemmed coffee plant (2–5 stems per plant), each stem was measured, and the equivalent diameter of the plant calculated as the square root of the sum of diameters of all stems per plant is given as follows [35]: $d_{40} = \sqrt{\sum_i^n d_n^2}$, where d_{40} represents the diameter at stem height 40 cm and d_i represents the diameter of the i^{th} stem at 40 cm height.

TABLE 1: Socioeconomic indicator of wealth class in the study area.

Indicator	Wealth class			
	Rich	Medium	Poor	Total
Family size	8.75	7.28	5.28	6.7
Land size (ha)	1.98	0.78	0.36	0.79
Coffee (number)	1922.33	1108.01	426.36	949.5
Enset (number)	1192.6	609.25	251.49	555.95
Number of livestock (TLU*)	3.93	1.55	0.68	1.56

Sources: own survey, 2019 *TLU, tropical livestock unit (it is a standard used to quantify different livestock types and sizes using cattle with body weight of 250 kilograms).

DBH was also calculated as follows: $DBH (cm) = \text{circumference } (C) / \pi$, where $\pi = 3.14$. A cover abundance of each herbaceous species was visually estimated and rated based on the 1–9 scale of Braun Blanquette, as modified by Westhoff and Van der Maarel [36]. Local name of all plant species found in the sample plots were recorded by the help of key informants, and identification of the scientific names of species was carried out using supplementary field guide [37], and for species difficult to identify in the field, specimens were collected and taken to the National Herbarium at Addis Ababa for identification.

Farmers owning the farm were interviewed for local use of plant species, source of species, and diversity affecting factors. Focus group discussion (FGD) also was administered in each of the sample kebele with local leaders, elders, women and local healers, development agents (DAs), and local administration and government line offices to reconcile the information.

2.4. Methods of Data Analysis. The plant species diversity was computed using Shannon's diversity index [38, 39]. $H = -\sum_{i=1}^s (P_i \ln(P_i))$, where H represents Shannon's diversity index, P_i represents the proportion of individuals composed of species i , and s represents the total number of species in the sample quadrant. Species evenness distribution was evaluated using Pielou evenness index (J) expressed as $J = H'/\ln s$, where H' is the diversity index, S is the species number, and \ln is the natural logarithm of total number of species in the population. The Sørensen index (SI) was used to determine beta-diversity of plant species composition similarity among the three agroecological zones. $S_s = 2a/2a + b + c$, where S_s is a Sørensen similarity coefficient, b is the number of species in one plot (farm), c is the number of species in another plot on the transect (agroecology), and a is the number of species in both plots. The dbh value was used to calculate the basal area of plants with $\text{dbh} \geq 2.5$ cm as follows: where BA is the basal area (cm^2).

The ecological importance of each species in the given agroecological was demonstrated using parameters such as relative frequency (%), relative abundance (%), relative dominance (%), and importance value index (%). For multiple stems such as coffee, dominance was calculated by measuring root collar diameter of all stem and by summing the square root of the cross-sectional areas of all stems at that height [35]. Relative species dominance was calculated as the ratio of the total BA of the plants of each species to the total sampled area. The relative abundance (RA), relative dominance (RDo), and relative frequency (RF) were calculated as follows:

$$\begin{aligned} \text{RA} &= \frac{\text{Number of individuals of each species}}{\text{Total number of individuals of all species}} \times 100, \\ \text{RDo} &= \frac{\text{Dominance of each species}}{\text{Total dominance of all species}} \times 100, \\ \text{RF} &= \frac{\text{Frequency of each species}}{\text{Total frequency of all species}} \times 100, \end{aligned} \quad (1)$$

Therefore, the importance value index (IVI) indicating the importance of each species in the system was calculated using the formula of Mueller-Dombois and Ellenberg [40]: $\text{IVI} = \text{RD} + \text{RF} + \text{RDo}$.

Descriptive statistics such as mean, %ages range, and standard deviations were used. In the case of the plant species inventory, all data analyses were performed using SPSS version 25. ANOVA was used, and significant differences detected through ANOVA with $p \leq 0.05$ were investigated by comparison of means using Tukey's HSD test.

3. Result and Discussion

3.1. Plant Species Composition. A total of 234 plant species belonged to 82 families were identified from the Gedeo agricultural system (Table 2). The highest numbers of species (151) were recorded in the midland agroecological zone followed by lowland (136) and highland (109). The most

dominant family was Asteraceae represented by 24 plant species (10.3%) followed by families Fabaceae, Poaceae, Solanaceae, Lamiaceae, and Rutaceae, represented by 8–17 species and constituting 7.3, 6.4, 4.7, 4.3, and 3.4%, respectively (Figure 2(a)). Generally, this study identified a greater number of plant species in a human dominant agricultural system than similar studies. For instance, Negash [19] recorded 82 plant species in indigenous agroforestry systems of the southeastern rift valley escarpment. Melese and Daniel [26] recorded 75 plant species in the home garden of Dilla Zuria Woreda, Southern Ethiopia, while Abebe [41] recorded 120 plant species in the home garden systems of Sidama, Southern Ethiopia. There could be many reasons for such high plant species diversity in the agricultural system of Gedeo. The major reason mentioned during the discussion was indigenous diversity management practices developed by the community (Section 3.1). In addition to that, the agricultural practices in the area were chemical-free and organic. Many authors reported that organic agriculture played a great role to maintain plant biodiversity in the agricultural landscape [6, 8]. Moreover, farmers also explained secured property rights both culturally and legally. According to data from GZAD [42], the majority (91%) of farmers in the zone have got a legal land ownership document. Several studies [43, 44] reported the importance of secure land tenure for tree planting and biodiversity conservation. With respect to the habits, the result shows that 53.4% species were herbaceous followed by tree species 26.5%, shrubs 14.1%, and climbers 6% (Figure 2(b)).

Out of all recorded plant species, 162 (69.2%) were native species, while 72 (30.8%) were exotic species (Table 2). The number of native species in the medium wealth class farms and midland agroecological zones was higher than other wealth classes and agroecological zones. The agroecological zone had a significant effect on the exotic species richness ($p < 0.01$), Shannon diversity index ($p < 0.01$), and species evenness ($p < 0.05$) (Table 2). The proportion of native species was highest in midland (78%) and highland (76%) agroecological zones than lowland (67.6%) (Table 2). Decreasing trend of native plant and increasing trend of exotic species from highland to lowland was previously reported [19, 45]. Different mechanisms have been proposed to drive this pattern, including better abiotic growing conditions (higher temperature and more light and nutrients) for introduced species, native plant richness [46], and high adoption rate of society for exotic species, especially fruits and ornamentals in lowland agroecological zone.

As noticed from the discussion, the introduced exotic species including trees for cash earning (e.g., *E. camaldulensis* Dehnh. and *E. globulus* Labill.), fruit trees (e.g., *M. indica*, *Casimiroa edulis* La Llave, and *Persea americana* Mill.), and ornamental herbaceous (e.g., *Rosa abyssinica* Lindley, *Passiflora caerulea* L., and *Dianthus caryophyllus* L.) in the system. The result was in agreement with Abebe et al. [47] and Negash et al. [33] who reported the dominance of exotic tree species in the system, such as fruit crops as major sources of nutrition and income and fast-growing *Eucalyptus* species for pole and fuelwood purposes.

TABLE 2: Origin of plant species along agroecological zone and wealth class of the study area.

Origin	Agroecological zone			Wealth class			Overall
	Highland	Midland	Lowland	Rich	Medium	Poor	
Native	88	118	92	107	123	107	162
Exotic	26	33	44	43	46	29	72
Total	114	151	136	150	169	136	234

Source: own survey data, 2019.

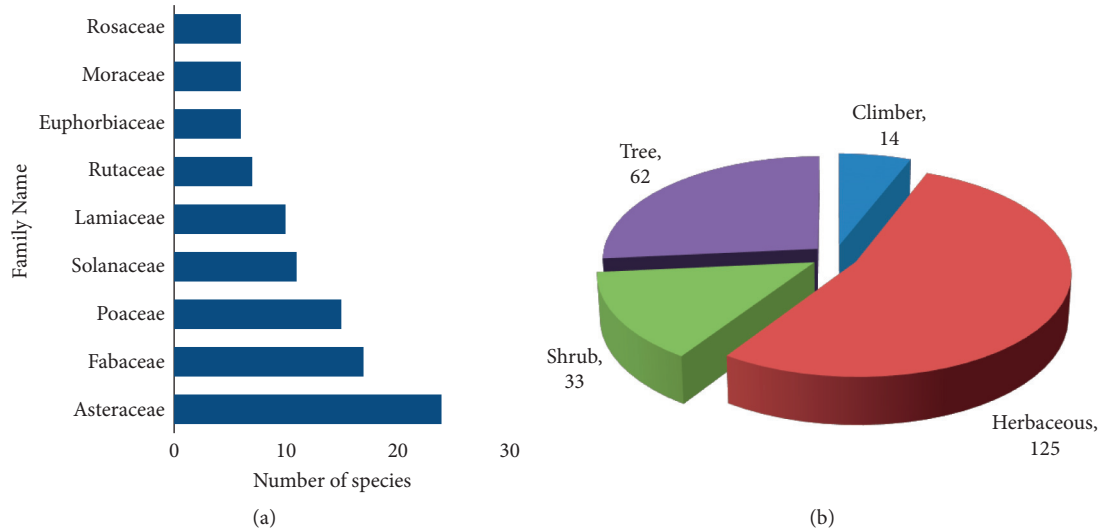


FIGURE 2: (a) Most dominant families of plant species and (b) habitats of plant species in the study area.

Concerning wealth class, exotic species richness ($p < 0.01$), Shannon diversity index ($p < 0.05$), and species evenness ($p < 0.05$) showed significant differences among wealth categories (Table 3). Medium wealth class farmers hosted a large number of total species (169) compared to rich and poor wealth classes. This might be due to the direct involvement of medium farmers in their farm management than the rich farmers. As the farmer explained during the discussion, rich farmers managed their farms by hiring laborers, who not cared for most simple plant species on the farm.

3.2. Species Similarity among Agroecological Zones. The overall Sorensen’s similarity coefficient of the study area ranges 40–64% across the agroecological zones (Table 4). The highest similarity was observed between lowland and midland (64%), followed by highland and midland (59%) agroecological zones. The lowest similarity was observed between lowland and highland (40%) agroecological zones. High similarity indices could be due to environmental homogeneity which mostly brings about uniformity in the weather conditions which results in good plant growth.

3.3. Influence of Agroecological Zone and Wealth Status on Plant Diversity. The results revealed that the average species richness for the whole agricultural system was 10.32 with range 8.75–11.11 per quadrant (Table 4). The richness of total

plant species was significantly affected by both agroecological zones ($p < 0.01$) and wealth status of the farmers ($p < 0.1$). Midland (11.11) and lowland (11.11) agroecological zones had the highest richness values than highland (Table 5). As shown in Figure 3, the result of this study revealed a decreasing trend with increasing altitude. This is comparable with Negash et al. [33] who reported a decreasing trend in richness with increasing elevation in the southeastern rift valley escarpment, Ethiopia. Conversely, Haile et al. [48] have found an increasing trend of tree and shrub species richness with increasing altitudinal gradients in smallholder agricultural management units in Central Ethiopia. Concerning the wealth status of farmers, higher plant species richness was recorded in rich (10.89) and medium (10.56) wealth classes compared to poor wealth class (9.53). Based on their experience, participants of the focus group discussion underlined the reason that large farm holdings and several plots of land have given the advantage to wealthy farmers to diversify various plants in their farm. Our result is in line with [48–50] that higher plant species richness found in wealthy farmers was related to larger land holdings.

The average Shannon diversity index for the whole agricultural system ranged from 1.94 to 2.13 with mean diversity 2.06, which was higher compared to other agriculture dominated systems in the tropics. The value of Shannon index for total plant species was significantly affected by agroecological zone ($p < 0.1$) (Table 5). Midland (2.13) and

TABLE 3: Diversity indices F value native and exotic species as influenced by agroecological zone and wealth class.

Factor	Origin of species	F value for diversity indices		
		Beta diversity (S)	Shannon (H')	Evenness (J)
Agroecological zone	Native	11.01***	3.781*	0.466
	Exotic	23.50***	18.547***	5.540**
Wealth class	Native	0.15 ns	1.418 ns	4.054*
	Exotic	10.195***	8.205**	5.418**

Source: own survey data, 2019. *, **, and *** mean significant at the 10%, 5%, and 1% probability levels, respectively. ns, not significant.

TABLE 4: Species composition similarity among agroecological zones and wealth category using Sorensen's similarity index in the study area.

Agroecological zones	Highland	Midland	Lowland
Highland	0		
Midland	0.59	0	
Lowland	0.40	0.64	0

Source: own survey data, 2019.

TABLE 5: Richness (s), Shannon (H'), and evenness (J) of total plant species across the agroecological zones and wealth status of farmer in the study area.

Parameters	Agroecological zone			Wealth class			Overall
	Highland	Midland	Lowland	Rich	Medium	Poor	
Overall species richness (S)	8.75 ± 1.32	11.11 ± 1.53	11.11 ± 3.19	10.89 ± 3.28	10.56 ± 1.59	9.53 ± 1.92	10.32 ± 2.42
Sign	14.99***			4.06*			
Overall Shannon index (H')	1.94 ± 0.23	2.13 ± 0.21	2.11 ± 0.41	2.07 ± 0.40	2.07 ± 0.24	2.05 ± 0.25	2.06 ± 0.30
Sign	4.49*			0.37 ns			
Overall evenness (J)	0.90 ± 0.07	0.89 ± 0.06	0.89 ± 0.09	0.88 ± 0.07	0.88 ± 0.09	0.92 ± 0.05	0.89 ± 0.73
Sign	0.197 ns			2.69*			
Tree species richness (S)	1.31 ± 0.86b	2.53 ± 0.84ab	3.54 ± 1.67a	3.10 ± 2.02a	2.29 ± 1.11b	1.99 ± 0.90 b	3.01 ± 1.02
Sign	38.236***			10.049***			
Tree Shannon index (H')	0.68 ± 0.24b	0.89 ± 0.25 b	1.11 ± 0.39a	1.10 ± 0.45a	0.98 ± 0.24a	0.80 ± 0.23 b	0.96 ± 34
Sign	9.745***			3.957*			
Tree evenness (J)	0.77 ± 0.20b	0.96 ± 0.06a	0.94 ± 0.07a	0.89 ± 0.15b	0.95 ± 0.07a	0.95 ± 0.08a	0.93 ± 0.11
Sign	21.045***			13.615***			
Shrubs species richness (S)	1.99 ± 0.74b	2.82 ± 0.63a	2.14 ± 0.89ab	2.43 ± 0.79	2.31 ± 0.78	2.21 ± 0.95	2.69 ± 0.65
Sign	11.942***			0.827 ns			
Shrubs Shannon index (H')	0.66 ± 0.11ab	0.58 ± 0.21b	0.71 ± 0.32a	0.60 ± 0.23	0.63 ± 0.25	0.73 ± 0.25	0.64 ± 0.24
Sign	2.675*			2.2 ns			
Shrubs evenness (J)	0.94 ± 0.07a	0.74 ± 0.15b	0.73 ± 0.23 b	0.74 ± 0.21b	0.78 ± 0.19b	0.89 ± 0.10a	0.79 ± 0.17
Sign	13.73***			6.677**			
Herbaceous spp. richness (S)	5.33 ± 0.93	5.44 ± 1.42	5.22 ± 1.61	5.06 ± 1.51	5.53 ± 0.97	5.42 ± 1.46	5.38 ± 1.24
Sign	0.236 ns			1.167 ns			
Herbaceous Shannon (H')	1.50 ± 0.23	1.49 ± 0.31	1.44 ± 0.39	1.43 ± 0.38	1.49 ± 0.25	1.51 ± 0.29	1.48 ± 0.27
Sign	0.401 ns			0.675 ns			
Herbaceous evenness (J)	0.90 ± 0.08	0.89 ± 0.09	0.89 ± 0.12	0.90 ± 0.09	0.88 ± 0.12	0.91 ± 0.07	0.90 ± 0.10
Sign	0.038 ns			0.921 ns			

Source: own survey data, 2019. *, **, and *** mean significant at the 10%, 5%, and 1% probability levels, respectively. ns, not significant; ±SD.

lowland (2.11) agroecological zones had the highest Shannon index than highland (1.94). This could happen because the Shannon diversity index is usually associated with an increase in species richness [46, 51]. This result is comparable to the Shannon index value of species recorded in enset-coffee-based home gardens of Southern Ethiopia [41]. In this study, the wealth status of the farmer had no statistically significant effect on the Shannon diversity index. On the contrary, the total plant species evenness did not show a significant difference among agroecological zones.

The richness, Shannon index, and evenness of tree and shrub species were significantly affected by both agroecological zone and wealth status of farmer households. Farmers in lowland agroecological zone had significantly ($p < 0.01$) higher number of tree species (3.54) than midland (2.53) and lowland (1.31) agroecological zones. Likewise, the midland agroecological had a significantly ($p < 0.01$) higher number (2.82) of shrubs followed by lowland (2.14) and highland (1.99) agroecological zones. This is logical for the study area that lowland agroecological zone is highly

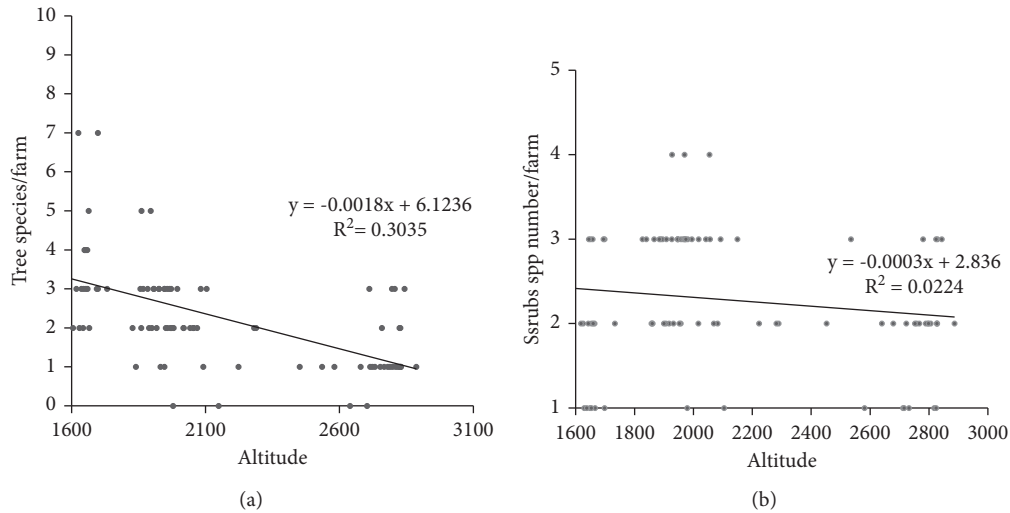


FIGURE 3: The altitude gradient against to tree species richness (a) and shrub species richness (b).

occupied by fruits and shade trees, while the midland is mostly occupied by the coffee plant (which is categorized as shrubs) and shade trees. Generally, the lower and middle agroecological zones are characterized by intensive trees and shrubs management practices compared to the highland agroecological zone.

The tree species richness was higher at rich farmers (3.10) followed by medium (2.29) and poor (1.99) wealth classes (Table 3). The reason for higher tree species diversity for the rich household is due to the fact that rich households have a larger farm size than medium and poor households. Hence, the more land a household owns, the higher the chance is to grow more trees in their land. The finding of this study is in line with Giday et al. [52] and Aklilu et al. [53] who reported that tree species richness increases as farm size increases. Asfaw and Hulten [54] and Abebe [41] also reported a positive relationship between farm size and tree species richness per farm and a similar relationship between wealth status and farm size in Southern Ethiopia. On the other hand, all diversity measure parameters for herbaceous species were not significantly affected by agroecological zones and wealth status of farmers.

3.4. The Local Use of Plant Species. Utilization of the products is one of ecological and socioeconomic factors that influence the species diversity in the agricultural system [55–57]. The plant species were stated by the households as sources of primarily food, forage, enhancing soil fertility, construction materials, fuelwood, medicine, and other products of the commercial value (Figure 4(a)). Food (fruits, root crops, vegetables, and cereals) is the most important end-use category. Out of the total recorded species, 60 species (25.6%) were used as food, out of which 9 were tree, 5 shrubs, 8 climbers, and 38 herbaceous. Another important category also was soil fertility that out of recorded species 55 (23.5%) were used for soil fertility. This might be due to the organic soil fertility management practices in the study area [19, 21]. Most of the plant species in the system were chosen for their

multifunction benefits. As shown in Figure 4(b), out of all plant species recorded, 87 species were mentioned as having one use type, 86 species having two use types, 38 species with three use types, and 10 species with four use types. Among all species, enset has multiple uses including staple food, soil fertility, construction materials (rope and house roof), and forage medicine [18, 55]. HHs in western Ethiopia mentioned that most of the woody and herbaceous perennial species were used for more than one purpose [58].

The respondents have also identified three herbaceous species including Daka-Seri ansicho (*Oxalis anthelmintica*), partinume (*Parthenium hysterophorus* L.), and agaro (*Rutidosperma subuuta*) as harmful (invasive) species. Two of the former are exotic and a latter one is endemic. Such species were highly abundant in lowland and midland agroecological zones than highland. This supports the finding of Talemoss et al. [45] that there was high abundance of partinume (*Parthenium hysterophorus* L.) at lowland of Gedeo zone. The occurrence of such invasive species in these areas might be due to the suitability of the environment for their development. Darka [59] also found that elevation was found to have a significant negative effect on the number of invasive species; thus, invasions were less prone to occur at higher elevations.

3.5. Important Value. Their variation in species, an importance value index, was observed among the agroecological zones. *Coffea arabica* L. contributes the most important value index in midland (75.26%) and lowland (52.88%) agroecological zones (Table 6). This may be due to the significant role of *Coffea arabica* in the livelihoods of the Gedeo people. The most important wood species with high importance value index in the lowland agroecological zone are economically valuable species such as *Coffea arabica* L., *Mangifera indica* L., and *Persea americana* Mill. Whereas, at midland agroecological zone, most of the species with high-value indices were native trees useful for soil conservation, shade and compatibility with other food crops such as are

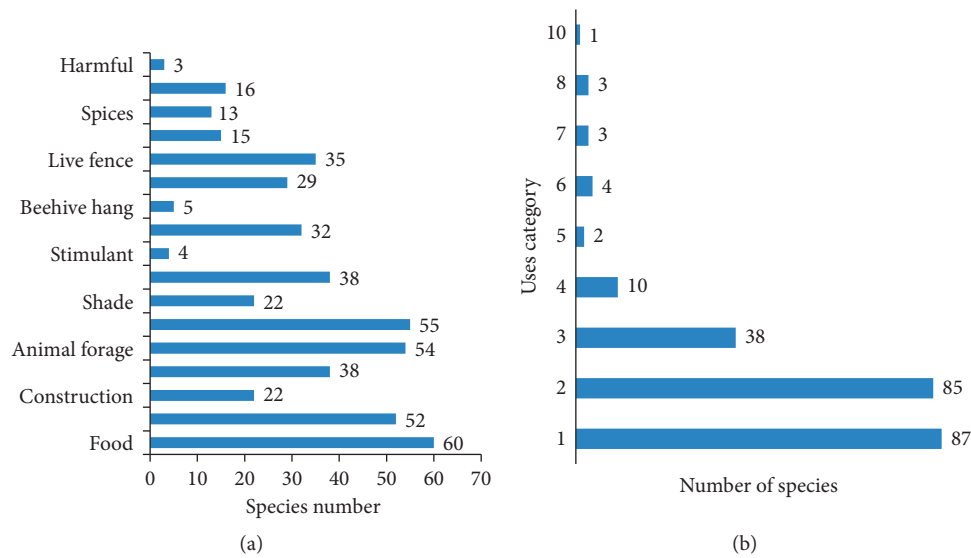


FIGURE 4: Local uses (a) and use category (b) of plant species recorded in the study area.

TABLE 6: Frequency, abundance, and dominance and importance value index of major woody species in agroecological zone of the study area.

Scientific name	Lowland agroecological zone			
	RA	RF	RD	IVI
<i>Coffea arabica</i> L.	39.106	13.757	0.022	52.885
<i>Mangifera indica</i> L.	8.101	7.937	17.750	33.788
<i>Persea americana</i> Mill.	4.190	6.878	15.258	26.326
<i>Millettia ferruginea</i> (Hochst.) Bak.**	4.469	4.762	5.472	14.704
<i>Eucalyptus camaldulensis</i> Dehnh.	4.190	3.175	6.999	14.363
<i>Albizia gummifera</i> (J. F. Gmel.) C. A	1.676	3.175	6.538	11.389
<i>Acacia senegal</i> (L.) Wild.	0.279	0.529	10.397	11.206
<i>Grevillea robusta</i> R. Br.	2.793	2.116	4.703	9.613
<i>Cordia africana</i> Lam.	1.117	2.116	4.679	7.913
<i>Acacia abyssinica</i> Hochst. ex Benth	1.117	2.116	3.234	6.467
Midland agroecological zone				
<i>Coffea arabica</i> L.	56.053	19.162	0.050	75.264
<i>Millettia ferruginea</i> (Hochst.) Bak.**	6.053	7.784	11.571	25.408
<i>Cordia africana</i> Lam.	2.105	4.192	13.765	20.062
<i>Persea americana</i> Mill.	1.316	2.994	8.977	13.287
<i>Ficus sur</i> Forssk.	1.053	2.395	8.415	11.863
<i>Mangifera indica</i> L.	1.842	2.395	6.302	10.540
<i>Ficus elastica</i> Roxb. ex Hornem.	0.000	0.000	0.000	10.287
<i>Trichilia emetica</i> Vahl	1.053	2.395	5.726	9.174
<i>Croton macrostachyus</i> Del.	0.789	1.796	4.262	6.847
<i>Cupressus lusitanica</i> Mill.	2.368	2.395	1.560	6.323
Highland agroecological zone				
<i>Eucalyptus globulus</i> Labill.	23.364	13.592	34.096	71.052
<i>Malus sylvestris</i> Mill.	5.607	4.854	45.350	55.812
<i>Erythrina brucei</i> Schweinf.**	4.206	8.738	1.647	14.590
<i>Vernonia myriantha</i> Hook. f.	5.607	7.767	0.009	13.383
<i>Coffea arabica</i> L.	8.411	4.854	0.004	13.270
<i>Hagenia abyssinica</i> (Bruce) J. F. Gmel.	1.869	3.883	2.476	8.229
<i>Arundinaria alpina</i> K. Schum.	1.869	3.883	2.281	8.034
<i>Solanecio gigas</i> (Vatke) C. Jeffrey	2.336	4.854	0.577	7.768
<i>Justicia schimperiana</i> (Hochst. ex Nees)	3.738	3.883	0.035	7.657
<i>Vernonia amygdalina</i> Del.	2.804	3.883	0.007	6.694

Source: own data analysis, 2019.

Milletia ferruginea (Hochst.) (25.41%) and *Cordia africana* Lam. (20.06%). Similar studies have also reported the popularity of those species in the study area [18, 19, 29]. In the highland agroecological zone, *Eucalyptus globulus* Labill. (71.05%) recorded the highest important value index followed by *Malus sylvestris* Mill. (52.81%) and *Erythrina brucei* Schweinf. (14.59%). The highest importance value for *Eucalyptus globulus* may be explained by (1) multiple purposes such as fuelwood, timber, cash crop, boundary demarcation, and fencing, (2) bridge the widening gap between demand and supply of wood specifically at the highland agroecological zone, and (3) farmer response and a coping strategy for expanding soil acidity in the area [60, 61].

3.6. Diversity Management Practices. Maintenance of diversity and multiple cropping practices is one of the major characteristics, given much emphasis in the Gedeo community. The community has long devised on-farm and off-farm plant diversity management systems locally called “baabo” and “woyyo” systems, respectively. The baabo system (on-farm diversity maintenance practice) is the management practices of plant species in the farmland (fichcha). It enforces all community members to manage native tree species in harmony with major crops such as coffee and enset in the farm and ethical use and maintenance of plant species and other natural resources. Hence, this was the motto of the community that “Existence in Gedeo means having three at once: enset-coffee and trees.” Beside enset-coffee and native trees, it was observed that there were several crops such as fruit trees, green leafy vegetables, cereals root crops, spices, and condiments cultivated. There were several reasons as to why farmers maintain high agrobiodiversity in the farm level. As shown in Figure 5 that the reasons for the conservation of diversity were to maintain soil fertility, control diseases and pests, and facilitate vertical and horizontal variations, thus allowing cultivation of crops adapted to light and shade. In addition to that, farmers apply specially tailored farming methods to optimize their use of the limited farming lands in the rugged topography and maintain the efficiency of crop production and crop diversity. Moreover, diversification permits phased harvesting of crops within different maturity periods, as insurance (the failure of one crop does not mean the failure of all crops, and the remaining one or two crops out of the two or three planted that remained serves as an insurance to the farmer.

On the other hand, the woyyo system is off-farm diversity management practices. It is the preservation practices of some susceptible plant species in conservation areas and the protection of particular ecosystems or habitats for traditional purposes. As described by farmer, the woyyo comprises “songgo” (social gathering place), “woyyo” (sacred forest grove at the pick of the mountain), ambba (forest grove at the memorial place of significant historical events), hiressa (rest place), and qarra (unburial dead casting places). As reported by farmers, the management of these resources are shaped around local rules and regulations. These rules and regulations are most often protected by religious or

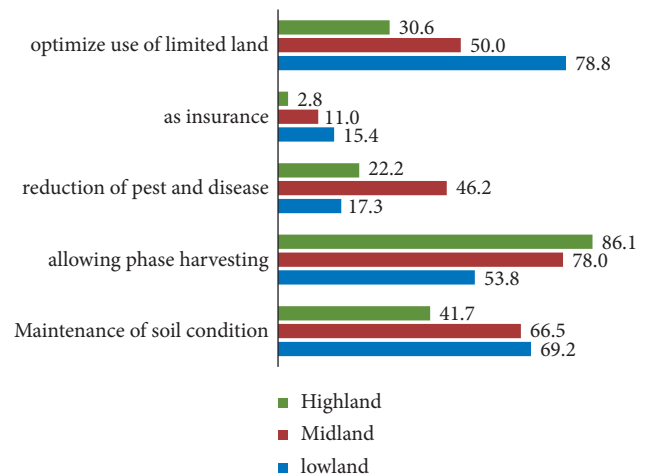


FIGURE 5: Farmers reason for conserving plant diversity in the same farm.

cultural beliefs and superstitions and enforced prohibitions called fago. Such practices might be the secret for the sustainability of the system for millennia despite political and religious-based pressure to obliterate the system [21]. According to Tadesse [18], the indigenous system of the Gedeo agricultural system is time-tested example of sustainable agriculture that exists today. Hence, the practice is congruent to the organic agriculture requirement.

4. Conclusion and Recommendations

The study shows that in the study area, a total of 234 plant species belonging to 82 families were recorded, of which 69% species were native. The species richness and Shannon index value of total plant species were significantly influenced by agroecological zone. Midland and lowland agroecological zones had the highest value of species richness and Shannon index than highland. The richness, Shannon index, and evenness of tree species were significantly affected by both agroecological zone and wealth status of farmer households. Farmers in the lowland agroecological zone had a significantly higher number of tree species than midland and lowland agroecological zones. Likewise, the tree species' richness was higher at rich wealth class farmers compared to medium and poor. This could be due to the fact that rich households have a larger farm size than medium and poor households. Moreover, availability of a plant species largely determines its utilization. The study also identified that all diversity parameters of shrubs were significantly influenced by agroecological zones. The midland agroecological had a significantly higher number of shrub diversity compared to lowland and highland agroecological zones. In this study, herbaceous species diversity was not affected by both agroecological zone and farmer wealth class.

Moreover, the function of plant species also had its own effect on plant species diversity in the study area, since the area is dominated by organic agriculture. The result of the study shows that in the study area, *Coffea arabica* L. contributes the most important value index at midland

and lowland agroecological zones. This may be due to the significant role of *Coffea arabica* in the livelihoods of the Gedeo people. On the other hand, in the highland agroecological zone, *Eucalyptus globulus* Labill. recorded the highest important value index. The highest importance value for *Eucalyptus globulus* may be explained by multiple purposes of trees such as fuelwood, timber, cash crop, boundary demarcation, fencing, and a coping strategy for expanding soil acidity in the highland agroecological zone.

Generally, the Gedeo agricultural system provides the habitat for a range of plant species in the human dominant agricultural system. For such diversity, the role of indigenous plant species maintenance practice played a great role which is shaped by centuries of experience and adapted to the specific locality. Thus, biodiversity conservation is a part of the culture, history, and spirituality of Gedeo peoples. Therefore, to maintain the current status of the system and to improve the farmer's livelihood, development planners may need to design agroecological-based plant species conservation strategies that give due consideration for indigenous plant species conservation practices and function of plant species.

Data Availability

All data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

- [1] W. Xiaotian and C. Xingpeng, "An evaluation index system of China's development level of ecological civilization," *Sustainability*, vol. 11, pp. 1–13, 2019.
- [2] E. G. Brockerhoff, L. Barbaro, B. Castagnyrol et al., "Forest biodiversity, ecosystem functioning and the provision of ecosystem services," *Biodiversity & Conservation*, vol. 26, no. 13, pp. 3005–3035, 2017.
- [3] S. Quijas and P. Balvanera, "Biodiversity and ecosystem services," in *Encyclopedia of Biodiversity*, S. A. Levin, Ed., vol. 1, pp. 341–356, Academic Press, Waltham, MA, USA, 2nd edition, 2013.
- [4] UNEP (United Nations Environmental Programme), *The Environmental Food Crisis: The Environment's Role in Averting Future Food Crises (A UNEP Rapid Response Assessment)*, UNEP, Nairobi, Kenya, 2009.
- [5] UNSD (United Nations Sustainable Development), *Nature's Dangerous Decline 'unprecedented'; Species Extinction Rates 'accelerating' UN Report*, UNEP, Nairobi, Kenya, 2019.
- [6] J. Bengtsson, J. Ahnström, and A.-C. Weibull, "The effects of organic agriculture on biodiversity and abundance: a meta-analysis," *Journal of Applied Ecology*, vol. 42, no. 2, pp. 261–269, 2005.
- [7] M. Joyce and K. Haskins, *Plant Reintroduction in a Changing Climate: Promises and Perils*, Island Press, Washington, DC, USA, 2012.
- [8] R. J. Fuller, L. R. Norton, R. E. Feber et al., "Benefits of organic farming to biodiversity vary among taxa," *Biology Letters*, vol. 1, no. 4, pp. 431–434, 2005.
- [9] C. D. Thomas, S. E. Williams, A. Cameron et al., "Biodiversity conservation: uncertainty in predictions of extinction risk/ Effects of changes in climate and land use/Climate change and extinction risk (reply)," *Nature*, vol. 427, pp. 145–148, 2004.
- [10] L. J. Martin, J. E. Quinn, E. C. Ellis et al., "Conservation opportunities across the world's anthromes," *Diversity and Distributions*, vol. 20, no. 7, pp. 745–755, 2014.
- [11] A. White, "Economy of change: -e organic market as a model for agricultural development in india," 2007, <http://digitalcollections.sit.edu/cgi/viewcontent.cgi?article=1212&context>.
- [12] S. Wymann Von Dach, R. Romeo, A. Vita, M. Wurzinger, and T. Kohler, *Mountain Farming Is Family Farming: A Contribution from Mountain Areas to the International Year of Family Farming 2014*, FA, the Centre for Development and Environment of the University of Bern and the Centre for Development Research of the University of Natural Resources and Life Sciences, Vienna, Austria, 2013.
- [13] IFOAM (International Federation of Organic Agriculture Movements), *Guidelines for Public Support to Organic Agriculture*, IFOAM, Bonn, Germany, 1st edition, 2017.
- [14] P. Sullivan, "Drought resistant soil. Fayetteville, arkansas: appropriate technology transfer for rural areas – national sustainable agriculture information service," 2002, <http://attra.ncat.org/attra-ub/PDF/drought.pdf>.
- [15] N. E.-H. Scialabba and M. Müller-Lindenlauf, "Organic agriculture and climate change," *Renewable Agriculture and Food Systems*, vol. 25, no. 2, pp. 158–169, 2010.
- [16] K. Menale, Z. Precious, P. John, and K. Gunnar, *Sustainable Agricultural Practices and Agricultural Productivity in Ethiopia: Does Agroecology Matter?*, Environment for development, London, UK, 2011.
- [17] Feed the Future, "Conservation agriculture experience sharing and networking event. Jointly organized by the agricultural knowledge, learning, documentation and policy (akldp) project, agriprofocus and the canadian food grains bank (crgb)," 2017, <http://agriprofocus.com/ethiopia-agroecologyplatform>.
- [18] K. Tadesse, *Five Thousand Years of Sustainability? A Case Study on Gedeo Land Use (Southern Ethiopia)*, Treemail Publishers, Heelsum, Netherlands, 2002.
- [19] M. Negash, "The Indigenous agroforestry systems of the South-Eastern Rift Valley Escarpment, Ethiopia: their biodiversity, carbon stocks, and litterfall," Tropical Forestry Reports No. 44. Doctoral Thesis, University of Helsinki, Helsinki, Finland, 2013.
- [20] A. Abdu and T. A. Gedeo, "Highland home garden agroforestry system- case study," in *Farmers' Strategies for*

- Adapting to and Mitigating Climate Variability and Change through Agroforestry in Ethiopia and Kenya*, pp. 45–50, Oregon state university, Corvallis, OR, USA, 2013.
- [21] L. Abiyot, *The Dynamics of Indigenous Knowledge Pertaining to Agroforestry Systems of Gedeo: Implications for Sustainability*, PhD dissertation, University of South Africa, Pretoria, South Africa, 2013.
- [22] J. S. Borrell, M. K. Biswas, M. Goodwin et al., “Enset in Ethiopia: a poorly characterized but resilient starch staple,” *Annals of Botany*, vol. 123, no. 5, pp. 747–766, 2019.
- [23] G. H. Lummina, “Can agroecological practices feed the world?: the bio- and eco-economic paradigm in agri-food production,” in *Agroecology, Ecosystems, and Sustainability*, pp. 309–325, Taylor and Francis Group London and, New York, NY, USA, 2015.
- [24] Y. Kodama, “New role of cooperatives in Ethiopia: the case of Ethiopian coffee farmers cooperatives,” *African Study Monographs, Suppl.* vol. 35, pp. 87–108, 2007.
- [25] M. Getachew and M. Abiyot, “Production and ecological potentials of Gedeo’s indigenous agroforestry practices in southern Ethiopia,” *Journal of Resources Development and Management*, vol. 30, pp. 68–76, 2017.
- [26] M. Mengitu and F. Daniel, “Plant species diversity and composition of the homegardens in Dilla zuriya woreda, Gedeo zone, SNNPRS, Ethiopia,” *Plant*, vol. 3, no. 6, pp. 80–86, 2015.
- [27] T. Yirefu, A. Wendawek, and T. Bogale, “Woody plants species diversity of home garden agroforestry in three agroecological zones of Dilla Zuria District, Gedeo Zone, Southern Ethiopia,” *International Journal of Fauna and Biological Studies*, vol. 3, no. 3, pp. 98–106, 2016.
- [28] T. Bogale, *Agroforestry practice in Gedeo zone, Ethiopia: a geographical analysis*, PhD Dissertation, Punjab University, Chandigarh, India, 2007.
- [29] G. Birhane and M. Melesse, “Evaluation of land use patterns across agro-ecological and slopeclasses using GIS and remote sensing: the case of Gedeo Zone, Southern Ethiopia,” *International Journal of Advanced Remote Sensing and GIS*, vol. 4, no. 1, pp. 1385–1399, 2015.
- [30] CSA (Central Statistics Agency), *Population Projection of Ethiopia for All Regions at Wereda Level from 2014–2017*, Central Statistical Authority, Addis Ababa, Ethiopia, 2013.
- [31] MoA (Ministry of Agriculture), *Land use System and Soil Conditions of Ethiopia*, p. 148, Land Use Study and Rural Technology Promotion, Addis Ababa, Ethiopia, 1995.
- [32] FAO (Food and Agriculture Organization), *Fertilizer and Plant Nutrition Guide*, p. 6, FAO, Rome, Italy, 1984.
- [33] M. Negash, E. Yirdaw, E. Yirdaw, and O. Luukkanen, “Potential of indigenous multistrata agroforests for maintaining native floristic diversity in the south-eastern Rift Valley escarpment, Ethiopia,” *Agroforestry Systems*, vol. 85, no. 1, pp. 9–28, 2012.
- [34] T. Abed and N. C. Stephens, *Tree Measurement Manual for Farm Foresters*, National Forest Inventory, Bureau of Rural Sciences, Canberra, Australia, 2nd edition, 2003.
- [35] P. Snowdon, J. Raison, H. Keith, P. Ritson, P. Grierson, and M. Adams, “Protocol for sampling tree and stand biomass. National carbon accounting system,” Technical report no. 31, Australian Greenhouse Office, Canberra, Australia, 2002.
- [36] V. Westhoff and E. Van der Maarel, “The braun-blanquet approach,” in *Ordination and Classification of Communities*, R. H. Whittaker, Ed., Springer, Dordrecht, Netherlands, pp. 617–726, 1973.
- [37] A. Bekele Tesemma, *Useful Trees and Shrubs of Ethiopia: Identification, Propagation and Management for 17 Agroclimatic Zones*, World Agroforestry Centre, Kenya, East Africa, 2007.
- [38] C. E. Shannon and W. Weaver, *The Mathematical Theory of Communication*, The University of Illinois Press, Champaign, IL, USA, 1949.
- [39] K. Ma and Y. M. Xing Ming, “Measurement of biotic community diversity I & Agr; diversity (Part 2),” *Biodiversity Science*, vol. 02, no. 4, pp. 231–239, 1994.
- [40] D. Mueller-Dombois and H. Ellenberg, *Aims and Methods of Vegetation Ecology*, p. 547, John Wiley & Sons, Hoboken, NJ, USA, 1974.
- [41] T. Abebe, *Diversity in Homegarden Agroforestry Systems of Southern Ethiopia. Tropical Resource Management Paper No. 59, Erosion and Soil & Water Conservation Group*, p. p119, Dept. of Environmental Sciences, Wageningen University and Research Centre, Wageningen, Netherlands, 2005.
- [42] GZAD (Gedeo Zone Agricultural Department), *Annual Report for the Year of 2018*, GZAD, Muscat, Oman, 2019.
- [43] R. L. Brown, L. A. J. Reilly, and R. K. Peet, *Species richness: Small scale*, pp. 1–9, Wiley Online Library, New York, NY, USA, 2016.
- [44] B. B. Walters, “Do property rights matter for conservation? Family land, forests and trees in Saint Lucia, West Indies,” *Human Ecology*, vol. 40, no. 6, pp. 863–878, 2012.
- [45] S. Talemso, A. Abreham, M. Fisseha, and B. Alemayehu, “Distribution status and the impact of parthenium weed (*Parthenium hysterophorus* L.) at Gedeo Zone (Southern Ethiopia),” *African Journal of Agricultural Research*, vol. 8, no. 4, pp. 386–397, 2013.
- [46] M. G. Gantchoff, C. M. Wilton, and J. L. Belant, “Factors influencing exotic species richness in Argentina’s national parks,” *PeerJ*, vol. 6, p. e5514, 2018.
- [47] T. Abebe, K. F. Wiersum, and F. Bongers, “Spatial and temporal variation in crop diversity in agroforestry homegardens of Southern Ethiopia,” *Agroforestry Systems*, vol. 78, no. 3, pp. 309–322, 2010.
- [48] G. Haile, M. Lemenih, F. Senbeta, and F. Itanna, “Plant diversity and determinant factors across smallholder agricultural management units in Central Ethiopia,” *Agroforestry Systems*, vol. 91, no. 4, pp. 677–695, 2016.
- [49] B. Torres, C. Vasco, S. Günter, and T. Knoke, “Determinants of agricultural diversification in a hotspot area: evidence from colonist and indigenous communities in the Sumaco Biosphere Reserve, Ecuadorian Amazon,” *Sustainability*, vol. 10, no. 5, p. 1432, 2018.
- [50] K. Sichoongwe, L. Mapemba, G. Tembo, and D. Ng’ong’ola, “The determinants and extent of crop diversification among smallholder farmers: a case study of southern province Zambia,” *Journal of Agricultural Science*, vol. 6, no. 11, 2014.
- [51] L. Deng, G. Zeng, C. Fan et al., “Response of rhizosphere microbial community structure and diversity to heavy metal co-pollution in arable soil,” *Applied Microbiology and Biotechnology*, vol. 99, no. 19, pp. 8259–8269, 2015.
- [52] K. Giday, F. Debebe, F. Debebe, A. J. Raj, and D. Gebremeskel, “Studies on farmland woody species diversity and their socioeconomic importance in Northwestern Ethiopia,” *Tropical Plant Research*, vol. 6, no. 2, pp. 241–249, 2019.
- [53] A. Aklilu, A. Belayneh, W. Alemayehu, M. H. Kiros, A. Ermias, and M. Jeremias, “Agroforestry practices and farmers’ perception in koga watershed, Upper Blue Nile Basin, Ethiopia,” *Agriculture and Forestry*, vol. 59, no. 3, pp. 75–89, 2013.
- [54] Z. Asfaw and H. Hulten, “Tree diversity management in the traditional agroforestry land-use of Sidama, southern

- Ethiopia,” *Acta Universitatis Agriculturae Sueciae Silvestria*, vol. 263, no. 1, pp. 1–28, 2003.
- [55] C. Li, X. Chen, A. Jiang, M.-B. Lee, C. Mammides, and E. Goodale, “Socioeconomic determinants of crop diversity and its effect on farmer income in Guangxi, southern China,” *Agriculture*, vol. 11, no. 4, p. 336, 2021.
- [56] P. F. McCord, M. Cox, M. Schmitt-Harsh, and T. Evans, “Crop diversification as a smallholder livelihood strategy within semi-arid agricultural systems near Mount Kenya,” *Land Use Policy*, vol. 42, pp. 738–750, 2015.
- [57] W. Willett, J. Rockström, B. Loken et al., “Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems,” *The Lancet*, vol. 393, no. 10170, pp. 447–492, 2019.
- [58] T. Eguale, A. Abdu, K. Asia, S. Yowhan, and N. Florent, “Contrasting species diversity and values in home gardens and traditional parkland agroforestry systems in Ethiopian Sub-Humid Lowlands,” *Forest@*, vol. 10, p. 266, 2019.
- [59] S. J. Dark, “The biogeography of invasive alien plants in California: an application of GIS and spatial regression analysis,” *Diversity and Distributions*, vol. 10, no. 1, pp. 1–9, 2004.
- [60] FAO (Food and Agriculture Organization), “The socio-economic and environmental issues of eucalyptus in eastern Africa,” *Addis Ababa, Ethiopia*, vol. 46, 2009.
- [61] S. Kidanu, *Using eucalyptus for soil and water conservation on the highland vertisols of Ethiopia*, PhD Dissertation, Wageningen University, Wageningen, Netherlands, 2004.