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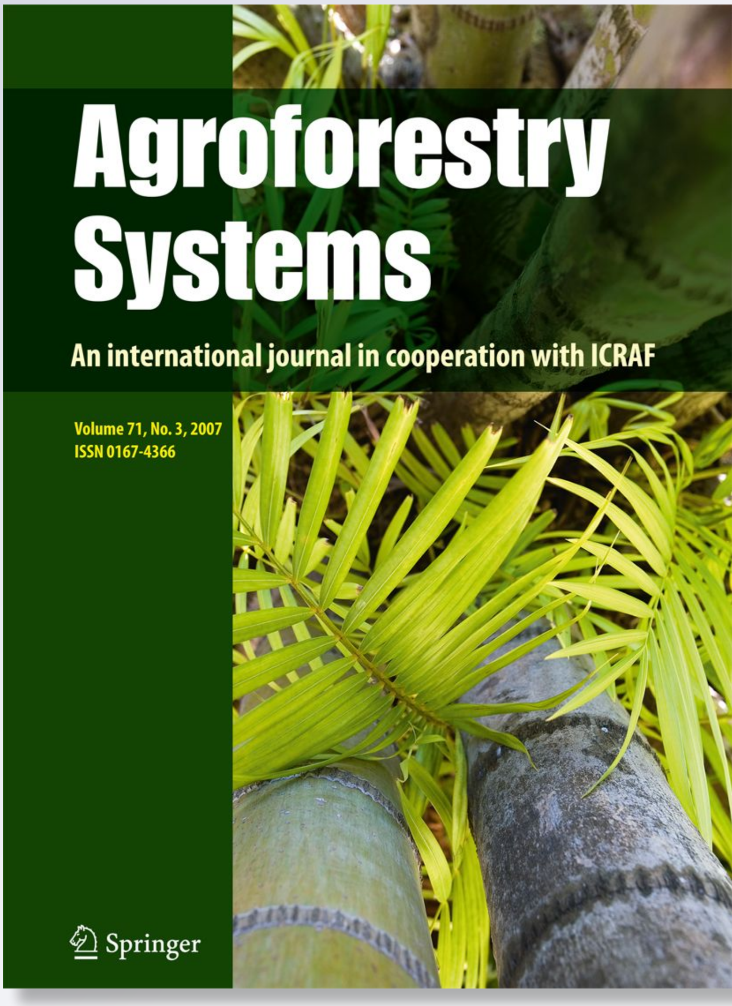

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Abstract Trees are important components of agricultural landscapes in different parts of Ethiopia, and information on their type, diversity and distribution in sub-humid agroecologies is essential for designing interventions. A study was conducted to evaluate tree diversity and their spatial patterns in agricultural landscapes under different land use categories in four selected sub-humid sites in Western Oromia, Ethiopia. Tree inventory was conducted on 100 homesteads (19 ha), 18 crop lands (35 ha) and 11 grazing lands (5.5 ha) belonging to 100 randomly selected households. A total of 82 tree species were identified: 67 in the homesteads, 52 in the crop lands and 29 in the grazing lands. The density of trees varied from 68 trees per ha in crop lands to 801 trees per ha in homesteads. Diversity indices revealed that homestead was the most diverse with Shannon index of 2.42, and Simpson index of 0.84. The density of trees among the tree communities in the four sites varied from 133 in Bako Tibe to 476 in Jima Arjo, but not any one of the sites had more diverse tree community as revealed by the Rènyi diversity profiles analysis. The three dominant tree species in the agricultural landscapes were *Eucalyptus camaldulensis, Vernonia amygdalina* and *Cordia africana*. Pearson correlation analysis showed that high tree species density, richness and diversity had high association with homesteads than with crop lands and grazing lands. It also revealed significant positive correlations between land size and evenness, and latitude and evenness whereas there were significant negative correlations between family size and Shannon diversity index, and land size and tree density. The majority (81.6%) of the trees were established through plantation and only 18.4% were regenerated naturally. The proportion of planted trees varied from 68% in Gobu Seyo to 94.1% in Guto Gida. The study showed that agricultural landscapes harbour high diversity of tree species with a spatial pattern, and increasing the tree cover with focus in the crop lands is essential for improved resilience of the agricultural systems and for *circa-situm* conservation of biodiversity.

Keywords Crop land · Evenness · Grazing land · Homestead · Richness

D. Samuel
Bako Agricultural Research Center, Oromia Agricultural Research Institute, Bako, Ethiopia

A. Derero (✉)
Ethiopian Environment and Forest Research Institute, Addis Ababa, Ethiopia
e-mail: abaynehdd@yahoo.com

Z. Kebebew
Jimma University, Jimma, Ethiopia

K. M. Hadgu
World Agroforestry Centre, ICRAF Ethiopia, Addis Ababa, Ethiopia

Introduction

Ethiopia is endowed with ecosystems diversity and natural vegetation which is categorized in twelve types (Friis et al. 2010). However, most of the natural ecosystem has been under human influence, and the landscape now comprises of mosaics of agricultural fields (with and without trees), remnant and regenerated natural vegetation and settlement areas. Such alteration of natural ecosystems and loss of biodiversity have significant impacts on ecosystem functions and reduce opportunities to avert production related risks (Power and Flecker 2001). Moreover, population growth and associated increasing demands are causing pronounced reductions in forest and tree covers.

Despite this, trees in most of the tropics remain important elements in most of the human dominated agricultural landscapes for various goods and services. Empirical evidences also suggest that the diverse perennial vegetation in agricultural landscapes has greater significance in nutrient cycling as compared to annual crops (Sharma 1997), and specifically trees provide a wide range of important products and service functions. The distribution pattern of various vegetation structures and the mixture with diverse tree-based farming are also interesting features about floristic and eco-diversity at a landscape level (Backes 2001). Woody species diversity, thus, contributes to ecosystem productivity and sustainability under conditions of heterogeneity in species traits and environmental characteristics in agricultural landscapes (Kindt et al. 2004). Furthermore, the trees in landscape mosaics enhance ecological quality of landscapes as well as provide habitat and greater landscape connectivity through buffer zones, corridors, and stepping stones for dispersal of plant and animal species (Perfecto and Vandermeer 2002; Schroth et al. 2004).

Diversity of woody species in agricultural landscapes also plays an important role in conserving biodiversity (Harvey and Haber 1999). To enhance multi-functionality and sustainable benefits (e.g., ecological, socially and economic), it is important to increase and manage diversity of tree species in the agricultural landscapes. In addition, decisions on land use and land management, and their consequences on agricultural landscapes play significant roles on biodiversity maintenance (Polasky et al. 2003). Spatial pattern of tree diversity along ecological gradients and land use categories may give evidence-based information for making appropriate decisions for improved conservation and management of biodiversity in different landscapes. Moreover, woody species diversity is essential for making sustainable development in Ethiopia and other tropical countries (Shumba 2001). However, limited studies were carried out so far on diversity of plant species in agricultural landscapes in Ethiopia (e.g. Asfaw and Hulten 2003; Abebe 2005; Endale et al. 2017). Hence, it is vital to assess and evaluate stocking levels of tree plants diversity that are grown or maintained in different niches. The present study, thus, focused on characterization of tree diversity and their spatial distribution patterns on agricultural landscapes in Western Oromia, Ethiopia.

Materials and methods

Study site description

The study was conducted in West Shewa and East Wollega administrative zones of Western Oromia Regional State, Ethiopia. More specifically, there were four study sites: (i) Oda Haro Kebele (the smallest unit of local government) in Bako Tibe Woreda (equivalent to a district) in West Shewa zone; and (ii) Wayu Kumba Kebele in Jimma Arjo Woreda (iii) Uke Badiya Kebele in Guto Gida Woreda, and (iv) Ongobo Bakanisa Kebele in Gobu Seyo Woreda of East Wollega (Fig. 1). Hereafter they are referred to as Bako Tibe, Jimma Arjo, Guto Gida and Gobu Seyo site. The sampled Bako Tibe sites are located around 9°04′N and 37°2′E and between 1630 and 1850 m a.s.l., Jima Arjo around 8°77′N and 36° 57′E and between 2030 and 2210 m a.s.l, Guto Gida around 9°39′N and 36°54′E and between 1320 and 1400 m a.s.l, and Gobu Seyo around 9°09′N and 36° 99′E and between 1640 and 1900 m a.s.l.

The study area is characterized by rugged landscapes with hills and valleys, and is dominated by sub-humid areas, which are subdivided into warm lowlands (‘Kola’) and tepid mid highlands (‘Woina-dega’). Some areas within river gorges have warmer moist lowland climates, whereas areas towards higher altitudes have prevalent tepid humid/moist climates. The annual rainfall in the study area follows

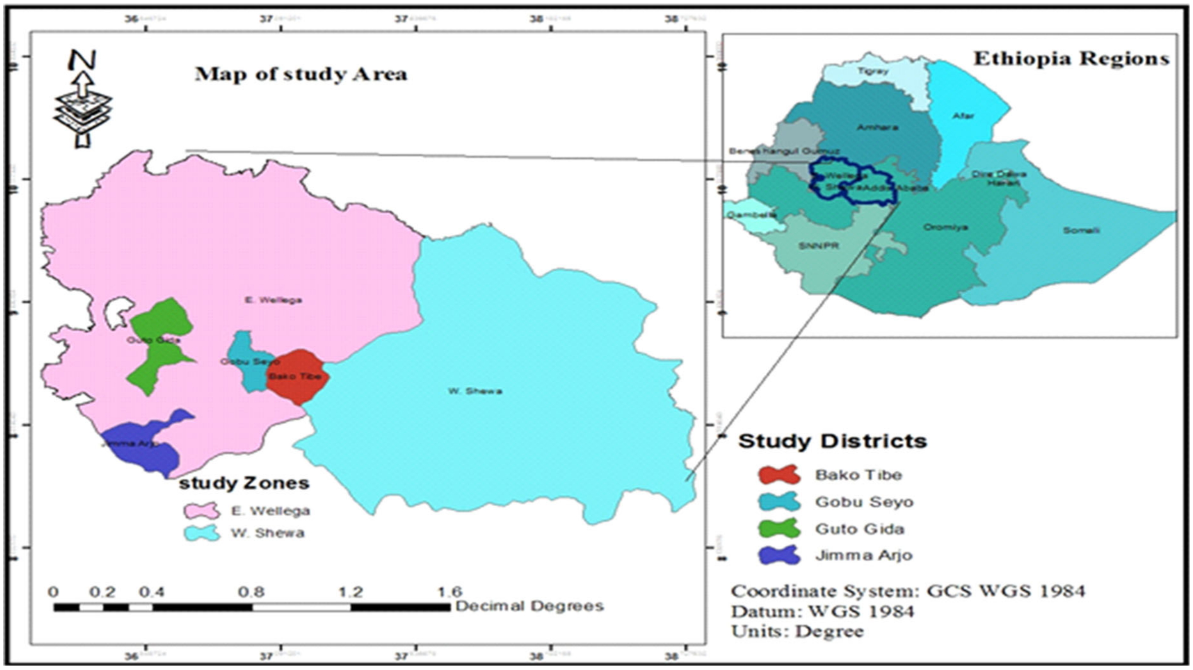

Fig. 1 Location of the study areas in West Shewa and East Wollega Zones in Western Oromia, Ethiopia

unimodal rainfall regime which is characterized by one distinct rainfall peak (August- September) and with the driest season observed between November and February. The mean annual rainfall is 2000 mm in Gobu Seyo and Bako Tibe 1320 mm, whereas it ranges from 1400 to 2000 mm in Jimma Arjo, and from 1600 to 2000 mm in Guto Gida. The mean annual temperature is greater than 15 °C in Guto Gida but it ranges from 15 to 20 °C in Jimma Arjo, 15 to 20 °C in Gobu Seyo and 14.1 to 28.3 °C in Bako Tibe (http://www.oromiyaa.com).

Agriculture is the major livelihood source of the inhabitants in the study area. The farming system is diverse and includes mixed (crop-livestock) farming systems, alley intercropping and mono-cropping (Kiptot et al. 2013). The dominant crops grown in the area are *Zea mays*. The common crops in the area include *Sorghum bicolor*, *Eragrostis tef* and *Guizotia* abyssinica with their relative importance varying with altitude and microclimate. In addition, the area is observed with diversity and heterogeneous types of tree species across the north–south and east-south transects as well as by altitude (Teshome 2014). Commonly found native trees in the agricultural landscapes in the study area include *Croton macrostachyus*, different *Ficus* species, *Cordia africana* and *Acacia abyssinica*. In addition, exotic woodlots, such as that of *Eucalyptus camaldulensis* are common in the study area.

Sampling design

The tree inventory was nested on the farmland area owned by households that were surveyed for socioeconomic characterization by Iiyama et al. (2017). We then selected randomly 25 households per each site (i.e., total of 100 households from the four sites). In each site, five households were selected randomly for a complete inventory of all existing trees in all the land use categories owned by the households. In the remaining, 20 households, inventories were made only on the main homestead areas.

Data collection

Complete inventory of tree was conducted on different agricultural landscape in the selected four study sites. Three major land use categories, which were common in the agricultural landscapes, were considered in the study:

(1) Homestead (HS)—the land use adjacent to the main house of the household that is fenced normally by live and/or dead fence, and in which gardening and farming is practiced. Homestead consists of homestead boundary, homestead alley/hedgerow, intercropping with annual crops; and perennial crops in homesteads, the homestead interior and woodlots.
(2) Crop land (CL)—the land use in which crops are planted separately in block arrangements. Trees can be found scattered, along soil conservation structures, as alleys/hedgerows, as boundary plantings or as woodlots.
(3) Grazing land (GL)—the land used for growing grass and grazing the livestock, and in which trees can be found scattered or as boundary plantings.

All encountered trees (woody perennials but coffee) were identified, their number of stems counted, and their diameter at breast height (> 2 cm DBH) and height (> 2 m height) measured as per the method described in Abate et al. (2006). Height and diameter at breast height (DBH) were measured using Clinometer and diameter tape, respectively. Scientific names of every plant species encountered in each farmland were recorded. Vernacular names of the plant species were also recorded whenever possible. For those tree species which were difficult to identify in the field, plant specimens were collected, pressed and brought to the National Herbarium of Ethiopia, Addis Ababa University for taxonomic identification. Voucher specimens used during the plant identification were kept at the herbarium.

Data analysis

Density (D) was computed by converting the total number of individuals to equivalent numbers per hectare. Dominance/basal area (DO) was calculated as the sum of the basal areas (BA) of the individual tree species in m^2 per ha. Relative density (RD) and relative basal area (RDO) were computed for each tree species on pooled data from all the sites, and their summation (RD + RDO) was used to identify the most dominant species in the system. Descriptive statistics on abundance, density, and basal area of each species per site, and density of trees per land use category was computed.

In addition, the heterogeneity of the tree species was determined using Shannon–Weiner diversity (H′), Simpson (1-D) and Evenness indices (E) (Magurran 2004). Sørenson's similarity coefficient was also used to quantify similarity (Krebs 1989). The diversity and similarity indices were computed using the Biodiversity R software within the R 3.2.2 environment (Kindt and Coe 2005; Kindt 2016).

Rarefaction curve, which is defined as the statistical expectation of the number of species in a survey as a function of the accumulated number of individuals or samples (Colwell 2009; Gotelli and Colwell 2011), was constructed using EstimateS (Colwell 2013) for each land use category. Furthermore, Rènyi diversity profiles were computed to compare the diversity of tree communities in the four sites. The Rényi diversity and evenness profiles allow separating the influence of species richness and the evenness on diversity (Kindt et al. 2001).

In addition, SPSS 20 was used for Pearson correlation analysis between density, richness and diversity indices; and land use categories, land size, family size, geographical location and altitude. Before the analysis, the data was checked in Q–Q plot for any outliers and no outlier was detected in the data.

Results

Tree species abundance, richness and diversity

A total of 82 woody species belonging to 37 families were recorded across the study sites. From a total of 13,307 individual trees counted, 4608 were observed in Jimma Arjo, 2829 in Bako Tibe, 3455 in Gobu Seyo and 2415 in Guto Gida. Of the total individual trees, ten tree species accounted for 85.1% (Table 1). The four dominant plant families in the landscape were tree species that belong to Asteraceae family (28%), Myrtaceae (21%), Fabaceae (16%), and Euphorbiaceae (14%). Among the total number of species, only 28% were exotic, while the remaining 72% were indigenous (Appendix 1). Of all the species, *Vernonia amygdalina, Eucalyptus camaldulensis* and *Justicia schimperiana* were the most abundant tree species with 57.06 (25.6%), 46.81 (21%) and 18.13 (8.1%) individuals per ha, respectively. However, the three dominant tree species in

Table 1 The top ten dominant tree species and their mean abundance, density and basal area in the agricultural landscapes in the four study sites in Western Oromia, Ethiopia

Species	Rank	Mean (± SD)		
		Abundance	Density/ha	Basal area (m^2/ha)
Eucalyptus camaldulensis	1	698 (240)	51 (35)	181,371 (110,019)
Vernonia amygdalina	2	851 (284)	65 (46)	56,204 (30,430)
Cordia africana	3	95 (39)	6 (3)	71,978 (58,636)
Croton macrostachyus	4	95 (100)	8 (11)	49,989 (54,131)
Justicia schimperiana	5	270 (514)	28 (52)	330 (584)
Calpurnia aurea	6	249 (239)	16 (15)	3294 (2927)
Jatropha curcas	7	181 (361)	16 (0)	8900 (17,800)
Ficus vasta	8	2 (2)	0 (0)	39,170 (36,840)
Sesbania sesban	9	162 (179)	12 (12)	3124 (3539)
Ricinus communis	10	148 (236)	15 (30)	4149 (7153)
Others (72 species)		576	39	204,427

The full list of the species and their rank is given in Appendix 1

terms of the relative density and relative basal area were *Eucalyptus camaldulensis, Vernonia amygdalina* and *Cordia africana* (Table 1).

The total number of tree species recorded at the agricultural landscapes in Jimma Arjo, Bako Tibe, Gobu Seyo and Guto Gida were 41, 44, 47 and 38, respectively. The highest species richness was obtained in the cropland land use category for the first several hundreds of individuals (49 species at 1640 individuals), but, after that it was surpassed by the homestead land use category owing to its very high number of individuals (66 species at 10,024 individuals) (Fig. 2).

The total land holding size of the 100 households was 59.67 ha. The proportion of the different land use categories were 19.24 ha (32.2%) homesteads 34.93 ha (58.5%) crop lands and (23%) and 5.5 ha (9.2%) grazing lands, (Table 2). The homestead trees were found as boundary plantings (62 species), intercropping with annual crops (15 species), intercropping with coffee and other perennial crops (18 species), inside the homestead area without intercropping (38 species) and as woodlots of *Eucalyptus camaldulensis*. The crop lands constitute trees in boundaries (36 species), intercropping with annual crops (30 species), intercropping with coffee and other perennial crops (16 species) and woodlots of *Eucalyptus camaldulensis*. The trees in the grazing

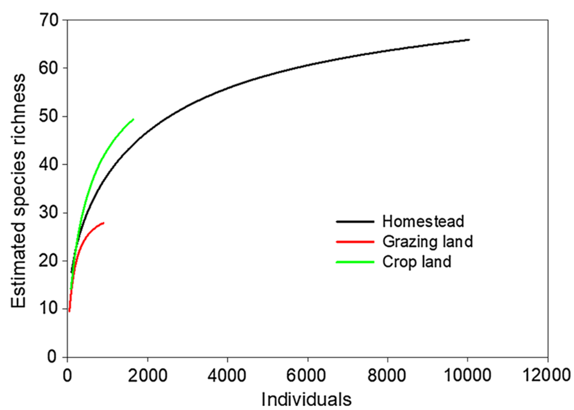

Fig. 2 Rarefaction curves showing tree species richness differences among land use categories in the four sites in Western Oromia

lands were found along boundaries (4 species) and inside the field (29 species).

Tree density, species richness and diversity were different among the different land use categories. The highest mean tree density was found in homesteads, and the overall mean tree density across all the land use categories was 642 (± 820) (Table 2). The highest tree species richness (67) was also recorded in homesteads, and the average number of trees per homestead was 7.7, ranging from a treeless condition to 20 tree species. Similarly, the highest values of diversity (Shannon and Simpson indices) were recorded in homesteads. This was substantiated by

Table 2 Tree density and tree species diversity among the different land use categories in the four farmland sites sampled in Oromia, Ethiopia

No	Land use category	No. of HH	Total area (ha)	Mean density (± SD)	Species richness	Shannon diversity index	Evenness index	Simpson diversity (1-D)
1	Homestead ($n = 100$)	100	19.24	801 (866)	67	2.42	0.575	0.843
2	Crop land ($n = 18$)	18	34.93	68 (114)	52	1.84	0.465	0.621
3	Grazing land ($n = 11$)	11	5.5	112 (170)	29	1.80	0.534	0.712
	Total ($n = 129$)	100	59.67	642 (820)	82	2.58	0.586	0.867

the rarefaction curves which was indicated by the steepest slopes in rarefaction curves of the homestead land use category (Fig. 2).

The tree density varied from 133 trees per ha in Bako Tibe to 476 trees per ha in Jimma Arjo, whereas tree species richness varied from 38 in Guto Gida to 47 in Gobu Seyo (Table 3). Analysis of Shannon diversity index revealed that Gobu Seyo site had the highest value among the four study sites, which could be attributed to the high evenness in the abundance of tree species in Gobu Seyo site as compared to the other three study sites (Table 3).

Figure 3 shows that the Rènyi diversity profiles for both diversity (Fig. 3a) and evenness values (Fig. 3b) of the four sites (communities) intersected at some point. Thus, the four sites could not be ranked with the Rènyi evenness profiles.

Similarity in species composition

According to the Sørensen coefficients of similarity percentage analysis, tree species composition between any two land use categories varied from 34.2 to 39.6 (Table 4). The Sørensen coefficients of similarity showed that the highest similarity of tree species composition was between homesteads and crop fields than between the other combinations of the land use system.

Community diameter and height structures

Seven height-classes were recognized arbitrarily (Fig. 4a). The majority (82%) of the individuals had a height of 10 m and below. The pattern of the total number of individuals in each successive height varies from site to site, for example, the number of small trees (2–5 m) is smaller compared to the next height class (5–10 m) in Bako Tibe, but this is the

Table 3 Tree species abundance, richness, evenness and diversity in the four study sites in Western Oromia, Ethiopia

Study sites	Abundance	Total area (ha)	Density	Species richness	Shannon diversity index	Evenness index	Simpson diversity (1-D)
Jimma Arjo ($n = 34$)	4608	9.67	476	41	2.13	0.575	0.832
Bako Tibe ($n = 32$)	2829	21.26	133	44	2.14	0.565	0.808
Gobu Seyo ($n = 34$)	3455	17.23	201	47	2.28	0.593	0.841
Guto Gida ($n = 29$)	2415	11.46	211	38	2.11	0.581	0.815
Total ($n = 129$)	13,307	59.62	223	82	2.58	0.586	0.867

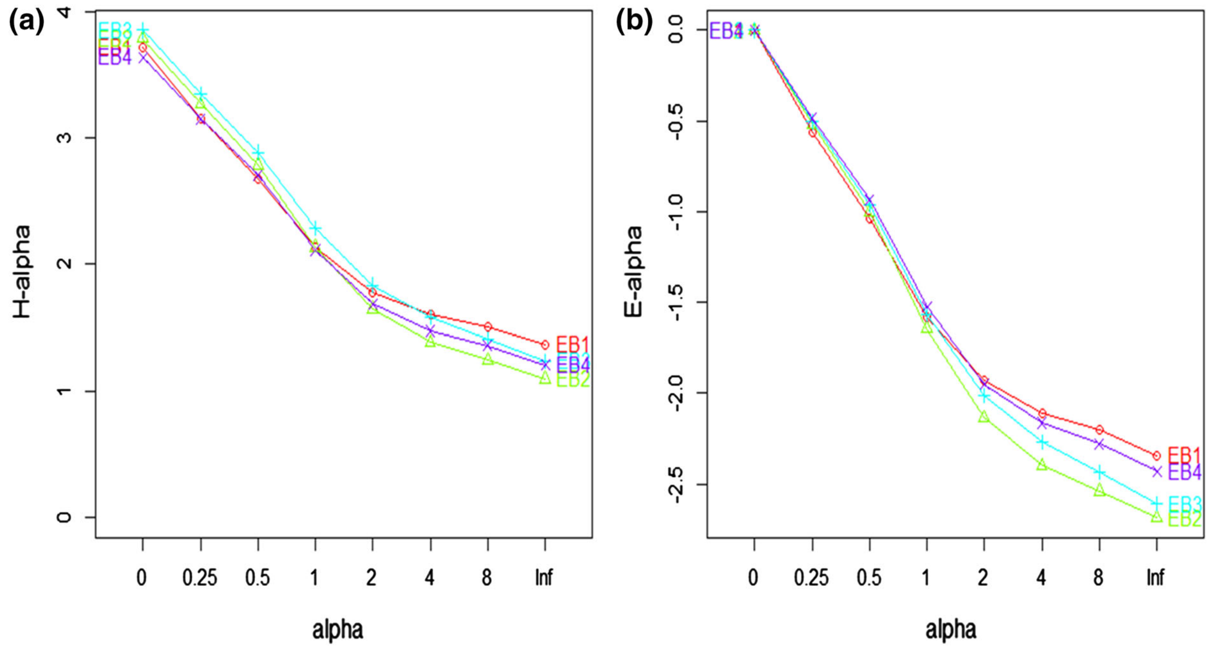

Fig. 3 Rènyi diversity profile (**a**) and evenness profile **b** for the tree communities in four study sites in Western Oromia. *EB1* Jimma Arjo; *EB2* Bako Tibe; *EB3* Gobu Seyo; *EB4* Guto Gida

Table 4 Sørensen similarity percentage in tree species composition among land use categories in the agricultural landscapes in the four study sites in Western Oromia, Ethiopia

Land use category	Crop land	Grazing land
Homestead	39.6	34.2
Crop land	–	39.1

reverse in the rest of the sites. In addition, six arbitrary diameter-classes were constructed (Fig. 4b). About 86% of the trees had DBH of 20 cm and below. The total number of trees in each DBH class decreased steadily with the increasing tree diameter for three of the sites, but the number of trees for Jimma Arjo sites shows sharp drop from the first to the second class, but the second and third dbh classes are represented by similar number of individuals. Generally, both the dbh and height structures show similarity to and deviation from inverted J-curve.

Factors influencing tree density, richness and diversity

Land use category was found to be a very important factor influencing tree species density, richness and diversity. Results showed that there was higher density, richness and diversity in homesteads as compared to the rest of the land use categories (Table 5). Family size had negative relationship with the Shannon diversity index. In addition, the Pearson correlation analysis also revealed that there was significant negative relationship between farmland size and tree density. In addition, the correlation analysis showed that farms in western locations tended to harbour higher tree density, and higher altitude areas showed lesser species evenness.

Mode of regeneration of the tree species

Results show that 85.6 and 18.4% from the total trees encountered were established through plantation and natural regeneration, respectively (Table 6). Results show that for all sites the predominant mode of regeneration is plantation. Depending on abundance, *Vernonia amygdalina* is the most abundant tree species that was planted followed by *Eucalyptus camaldulensis, Justicia schimperiana, Jatropha curcas, Sesbania sesban, Ricinus communis, Erythrina brucei, Morus alba, Calpurnia aurea, Mangifera indica* and *Cordia africana*. And from maintained tree species *Calpurnia aurea* was the most abundant

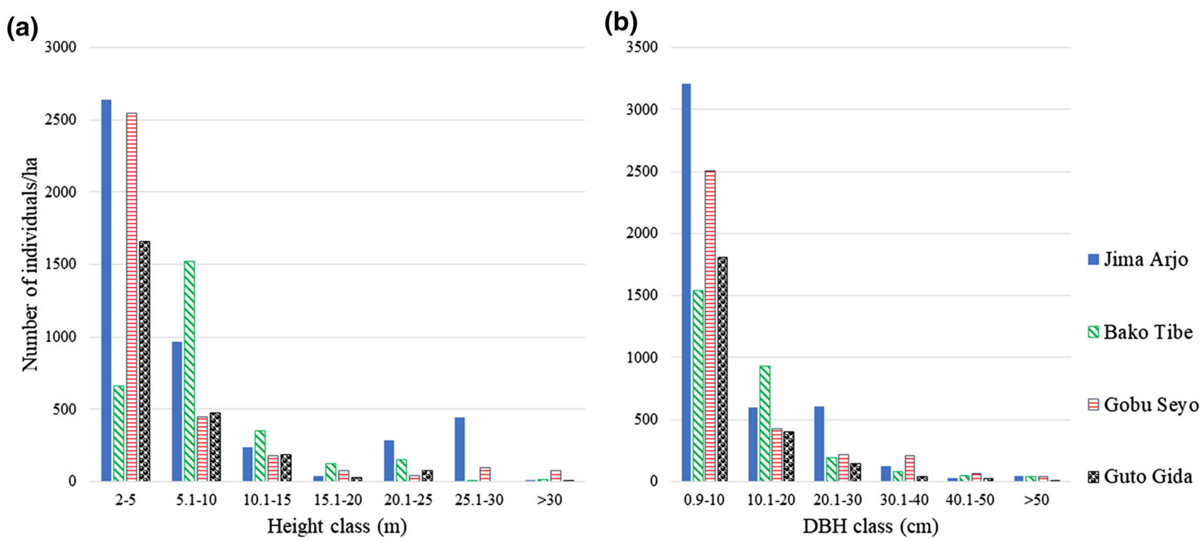

Fig. 4 Tree community height and diameter structures in four study sites in the subhumid Oromia, Ethiopia

Table 5 Pearson correlation analysis between biophysical and socioeconomic factors and species parameters in the four study sites in Oromia, Ethiopia ($n = 188$)

Variables	Density	Richness	Shannon diversity	Evenness
Land use category dummy (homestead = 1, others = 2)	− 0.370**	− 0.507**	− 0.414**	− 0.155*
Land size	− 0.273**	0.047	0.132	0.149*
Family size	− 0.052	− 0.090	− 0.182*	− 0.242**
Longitude	− 0.186*	− 0.091	− 0.087	0.001
Latitude	− 0.040	0.027	0.123	0.189**
Altitude	0.038	0.002	− 0.091	− 0.179*

*Correlation is significant at the 0.05 level

**Correlation is significant at the 0.01 level

Table 6 The mode of regeneration and tree establishment in the agricultural landscapes in the selected four sites in Western Oromia

Study sites	Abundance			Proportions across sites (%)		Proportions per site (%)	
	Planted	Retained	Total	Planted	Retained	Planted	Retained
Jimma Arjo	3747	861	4608	34.5	35.1	81.3	18.7
Bako Tibe	2493	336	2829	23.0	13.7	88.1	11.9
Gobu Seyo	2339	1116	3455	21.6	45.5	67.7	32.3
Guto Gida	2273	142	2415	20.9	5.8	94.1	5.9
Total	10,852	2455	13,307	100.0	100.0	81.6	18.4

followed by *Vernonia auriculifera, Croton macrostachyus, Ricinus communis, Cordia africana, Albizia gummifera, Eucalyptus camaldulensis, Maesa lanceolata, Vernonia amygdalina, Syzygium guineense subsp guineense* and *Deinbollia kilimandscharica*.

Discussion

The number of species recorded, 82 tree species on about 60 ha, is a little higher compared to a similar extensive study which was conducted in semi-arid areas in Ethiopia and reported 77 tree species on a total area of 76 ha (Endale et al. 2017). But it was much lower compared to anther extensive study in the Mount Kenya area that reported 297 tree species on 60 ha of farms belonging to smallholders (Lengkeek et al. 2005). The marked differences between the Kenyan and the Ethiopian cases in species richness may relate to differences in site characteristics. The total number of tree species recorded per site ranged from 38 to 47 species which agrees to the tree species range as reported by Endale et al. (2017). The differences among the sites in species richness could apparently be attributed to differences in tree planting and management experiences, agroecological conditions, human impact on natural ecosystems, distance to forest areas and the like.

About 85% of all the recorded tree species belong to only 10 tree species which indicates that only few tree species dominate the agricultural landscape of the study area. Similar studies conducted in Mukono district in Central Uganda also reported about 50% of all the recorded species belong to only 10 tree species (Boffa et al. 2008). Of the abundant tree species in the study area, *Vernonia amygdalina* is the most abundant tree species owing to its wide use as live fence (Duguma and Hager 2010), its multiple domestic uses and easy propagation. The second abundant species, *Eucalyptus camaldulensis*, is widely planted in woodlots and serves as 'cash crop' for the smallholders.

Among the different land use catergories, homesteads tend to harbour more species with increased sample size as depicted in the the rarefaction curves, which takes care of differences in sample sizes (Moreno-Calles et al. 2010; Chao and Jost 2012). Results may show that species richness in agricultural fields are mainly influenced by human activities including planting, protection and management practices. A similar study by Tolera (2006) in Arsi Negele, Ethiopia, also documented that the highest tree species richness was recorded in homegardens as compared to crop fields and the natural forest. In the crop lands and grazing lands, patterns of species richness could be influnecd by most of the illegal tree cuttings and assocaited with less tree planting.

The Rènyi diversity profiles of the four sites intersected indicating that not any one of the sites had more diverse tree community; when a given community is more diverse than the other, its diversity profile will be everwhere above the diversity profile of the other (Kindt et al. 2006).

Due to both human impact and natural differences in the sites, only 11 tree species identified were shared by all the sites. The highest Sørensen coefficients of similarity between the two closest sites (Bako Tibe and Gobu Seyo) may depict that the differences in species composition influenced by the natural causes may be stronger than by the human impacted agricultural landscapes. Similarly, other studies (Tolera 2006) reported that the contribution of tree species to the soil seed flora decline from time to time because of continuous cultivations.

Different tree species were most abundant in different sites: *Vernonia amygdalina* in Jimma Arjo and Gobu Seyo, *Eucalyptus camaldulensis* in Bako Tibe, and *Jatropha curcas* in Guto Gida. This could be attributed to farmer's contexts, management and agroecological conditions which determine on the dominant tree species in the agricultural landscapes. Because of plantations, management and agroecological conditions *Jatropha curcas* is another dominant tree species in Guto Gida which is a low lying and hot area compared to the other study sites.

In terms of basal area, the dominance of *Eucalyptus camaldulensis* at three of the sites except at Bako Tibe where *Cordia africana* had the highest basal area, is because *E. camaldulensis* can grow to big tree compared to the other abundant species *Vernonia amygdalina* and *Jatropha curcas*.

The density of trees per hectare in this study was between 133 and 476 and had an average value of 223. The results agree with other studies (Duguma and Hagar 2010) which were reported from the central highland of Ethiopia. However, Abebe (2005) reported high density of trees per hectare in Sidama homegarden, ranging from 86 to 1082 with an average value of 475. In the Kandyan gardens of Sri Lanka, a study by Perera and Rajapaske (1991) reported that number of trees, with a diameter of 5 centimetres and above, range from 92 to 3736 trees per hectare and 70% of them containing 500–1500 trees per hectare.

The existence of significant association of higher density, richness and diversity to homesteads as compared to the rest of the major land use categories is due to higher tree planting and seedling protection in the homestead areas. The significant negative relationship between farmland size and tree density may be households with larger sizes plant high density plantations such as woodlots. Other studies also reported positive relationship between farm size and tree species richness per farm and farm size in southern Ethiopia (Asfaw and Hulten 2003; Abebe 2005).

Results on community diameter and height structures followed inverted J-curve in two of the sites and deviations in the other two apparently owing to the mixed nature of regeneration, which involved both planting and natural regeneration. Unlike community structures in natural forests and woodlots, which usually are uneven aged and tend to have community structures with inverse J-distribution (Derero et al. 2003; Isango 2007), and such deviations of the population structure of farmland trees were expected.

Tree species owned by most of the households (85.6%) in the study area were planted by the farmers than naturally grown ones. The farmers established the major tree species, such as, *Vernonia amygdalina* and *Eucalyptus camaldulensis* through planting in the system. This indicates that the local community in the study area has wealth of experiences in tree planting and consider it as major mode of tree regeneration. Other studies also indicated that *Eucalyptus globulus and Eucalyptus camaldulensis*, which are also the results of planting and coppice management, are major species found at the central highland of Ethiopia by Duguma and Hagar (2010).

Conclusions

The study has generated important information on tree diversity and their spatial patterns on agricultural landscapes in homesteads, crop lands and grazing lands in four selected sub-humid sites in Western Oromia, Ethiopia. It has identified 82 tree species on about 60 ha of land that are found distributed in various numbers and proportions in the three land use categories, homesteads being the most diverse and with the highest tree density. It also identified that although there is marked difference in density of trees among the tree communities in the four sites, there was no clear distinction in the diversity profile of the communities. The tree species that are valued apparently for their multiple utilities are the most dominant tree species in the agricultural landscape, and they include *Eucalyptus camaldulensis, Vernonia amygdalina* and *Cordia africana*. Land size, family size and location (latitude) have showed some level of significant association with some of the tree species parameters including evenness, diversity index and density. The trees in the farming systems are established mainly through plantation indicating the important role smallholders have in shaping up tree diversity and spatial patterns. Thus, in the face of the existing competition for land for the cultivations of annual crops and perennials, the agricultural landscapes in Western Oromia still have a considerable number of diverse tree species and, play a vital role in the *circa-situm* conservation of biodiversity in general and conservation of trees. While there is a need to optimize the boundary plantings and intercropping in the homesteads with high valued trees and optimum management, it is essential to increase the tree cover in the farming systems with focus in the crop lands. The woodlots are identified both in the homesteads and croplands, and they also require improvements and diversification. This system optimization and diversification will improve the resilience and long-term productivity of the agricultural systems.

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Appendix 1

Table 7.

Table 7 List of all tree species, origin, and number of individuals encountered in the different land use categories, and computed density, basal area and relative values in four study sites in sub-humid Oromia

Species name	Vernacular name	Origin	Family	HS	CL	GL	Density	RD	BA	RBA	RD + RBA	Rank
Acacia abyssinica Hochst. ex Benth.	Laaftoo (Or)	I	Fabaceae	10	7	8	0.42	0.19	171.54	0.41	0.6	32
Acacia seyal Del.	Doddota (Or)	I	Fabaceae	1	0	0	0.02	0.01	17.06	0.04	0.05	65
Albizia gummifera (J.F.Gmel.) C.A.Sm.	Mukarbaa (Imala) (Or)	I	Fabaceae	35	52	12	1.66	0.74	1820.68	4.36	5.1	11
Allophylus abyssinicus (Hochst.) Radlkofer	Malqaqqoo (Or)	I	Sapindaceae	1	0	0	0.02	0.01	15.22	0.04	0.05	66
Annona senegalensis Pers.	Gishxaa (Goraa) (Or)	I	Annonaceae	0	1	0	0.02	0.01	0.22	0	0.01	76
Anogeissus leiocarpa (DC.) Guill. & Perr.	Mokkii (Or)	I	Combretaceae	1	0	0	0.02	0.01	23.22	0.06	0.07	63
Apodytes dimidiata E.Mey.ex Arn	Wandabiyoo (Or)	I	Icacinaceae	3	0	0	0.05	0.02	52.37	0.13	0.15	52
Bersama abyssinica Fresen.	Lolchiisaa (Or)	I	Melianthaceae	11	0	10	0.35	0.16	8.17	0.02	0.18	49
Bridelia micrantha (Hochst.) Baill.	Galaanoo (Or)	I	Euphorbiaceae	1	3	3	0.12	0.05	182.09	0.44	0.49	37
Brucea antidysenterica Lam	Qomanyoo (Or)	I	Simaroubaceae	16	3	3	0.37	0.17	7.15	0.02	0.19	48
Buddleja polystachya Fresen.	Anfaarree (Or)	I	Loganiaceae	0	23	0	0.39	0.17	35.78	0.09	0.26	43
Caesalpinia decapetala (Roth) Alston.	Qonxirii (Or)	E	Leguminoseae	0	6	0	0.1	0.05	0.38	0	0.05	67
Cajanus cajan (Linn.) Millsp.	Atara gugee (Or)	E	Fabaceae	0	4	0	0.07	0.03	1.08	0	0.03	72
Calliandra calothyrsus Meissn	Kaalaandaraa (Or)	E	Mimosaceae	0	1	0	0.02	0.01	1.68	0	0.01	77
Calpurnia aurea (Ait.) Benth.	Ceekaa (Or)	I	Fabaceae	157	277	562	16.71	7.48	220.83	0.53	8.01	6
Carica papaya Linn.	Paappaayyaa (Or)	E	Caricaceae	0	21	0	0.35	0.16	83.45	0.2	0.36	40
Casimiroa edulis La Llave	Kaazmiir (Amr) (Kookii) (Or)	E	Rutaceae	0	12	0	0.2	0.09	45.97	0.11	0.2	47
Casuarina equisetifolia L.	Shiwaashuwwee (Or)	E	Casuarinaceae	0	1	0	0.02	0.01	0.40	0	0.01	78
Catha edulis Forsk.	Caatii (Or)	I	Celastraceae	33	3	0	0.6	0.27	18.20	0.04	0.31	41
Celtis africana Burm.f.	Cayii (Or)	I	Celtidaceae	4	11	1	0.27	0.12	571.77	1.37	1.49	21
Citrus aurantifolia (Christm.)	Loomii (Or)	E	Rutaceae	0	1	0	0.02	0.01	1.48	0	0.01	79
Citrus reticulate Blanco.	Mandariinii (Or)	E	Rutaceae	2	0	0	0.03	0.02	4.51	0.01	0.03	73
Citrus sinensis (L.) Osbeck.	Burtukaana (Or)	E	Rutaceae	2	0	5	0.12	0.05	9.94	0.02	0.07	62
Combretum collinum Fresen.	Dhandhansa (Or)	I	Combretaceae	6	1	8	0.25	0.11	169.15	0.41	0.52	35
Combretum molle R.Br. ex G.Don.	Adda-jaboo (Rukeensa) (Qanqalcha) (Or)	I	Combretaceae	12	4	11	0.45	0.2	617.62	1.48	1.68	19
Cordia africana Lam.	Waddeessa (Or)	I	Boraginaceae	55	315	11	6.39	2.86	4825.76	11.55	14.41	3
Croton macrostachyus Hochst. ex Delile	Bakkanniisa (Or)	I	Euphorbiaceae	88	171	122	6.39	2.86	3351.52	8.02	10.88	4
Cupressus lusitanica Mill.	Gaattiraa (Or)	E	Cupressaceae	5	93	0	1.64	0.74	199.51	0.48	1.22	24
Deinbollia kilimandscharica Taub.	Dabaqqaa (Or)	I	Sapindaceae	9	3	20	0.54	0.24	696.79	1.67	1.91	17
Delonix regia (Hook.) Raf.	Muka Dirre-Daawaa (Or)	E	Fabaceae	0	4	0	0.07	0.03	14.41	0.03	0.06	64

Table 7 continued

Species name	Vernacular name	Origin	Family	HS	CL	GL	Density	RD	BA	RBA	RD + RBA	Rank
Dombeya torrida (J.F. Gmel.)	Daannisa (Shakshak) (Or)	I	Sterculiaceae	1	0	0	0.02	0.01	13.48	0.03	0.04	69
Ehretia cymosa Thonn.	Ulaagaa (Or)	I	Boraginaceae	4	18	1	0.39	0.17	127.78	0.31	0.48	38
Ekebergia capensis Sparrm.	Somboo (Or)	I	Meliaceae	3	4	0	0.12	0.05	38.11	0.09	0.14	54
Entada abyssinica Steud. ex A.Rich.	Ambaltaa (Doosheet) (Or)	I	Fabaceae	2	2	0	0.07	0.03	58.71	0.14	0.17	50
Erythrina abyssinica Lam. ex DC	Beeroo (Or)	I	Fabaceae	4	19	0	0.39	0.17	165.18	0.4	0.57	33
Erythrina brucei Schweinf.	Waleensuu (Or)	I	Fabaceae	4	306	0	5.2	2.33	1148.13	2.75	5.08	12
Eucalyptus camaldulensis Dehnh.	Baargamoo diimaa (Or)	E	Myrtaceae	1140	1558	93	46.81	20.97	12160.06	29.12	50.09	1
Euphorbia abyssinica J. F. Gmel.	Adaamii (Or)	I	Euphorbiaceae	0	2	0	0.03	0.02	1.48	0	0.02	74
Euphorbia tirucalli L.	Aannoo Cadaa) (Or)	I	Euphorbiaceae	0	119	0	2	0.89	28.75	0.07	0.96	26
Faurea rochetiana (A.Rich.) Chiov. ex Pic. Serm.	Gaarrii (Or)	I	Proteaceae	0	0	5	0.08	0.04	212.36	0.51	0.55	34
Ficus ovata Vahl	Qilinxoo (Or)	I	Moraceae	0	5	0	0.08	0.04	15.85	0.04	0.08	60
Ficus sur Forssk.	Harbuu (Or)	I	Moraceae	1	0	0	0.02	0.01	11.85	0.03	0.04	70
Ficus sycomorus L.	Odaa (Or)	I	Moraceae	5	8	0	0.22	0.1	1162.57	2.78	2.88	14
Ficus thonningii Blume	Dambii (Or)	I	Moraceae	2	6	0	0.13	0.06	77.80	0.19	0.25	44
Ficus vasta Forssk.	Qilxuu (Or)	I	Moraceae	4	2	3	0.15	0.07	2626.14	6.29	6.36	8
Gardenia ternifolia Schum. & Thonn.	Gaambeella (Or)	I	Rubiaceae	5	3	1	0.15	0.07	83.87	0.2	0.27	42
Grevillea robusta A. Cunn. ex R. Br.	Giraaviiliyaa (Or)	E	Proteaceae	1	98	0	1.66	0.74	80.52	0.19	0.93	27
Grewia bicolor Juss.	Harooressa (Or) (Safaa) (Amh)	I	Tiliaceae	3	0	0	0.05	0.02	33.49	0.08	0.1	56
Grewia ferruginea Hochst. ex A.Rich.	Dhoqonuu (Or)	I	Tiliaceae	1	13	2	0.27	0.12	8.97	0.02	0.14	55
Jacaranda mimosifolia D. Don	Jaakaraandaa (Or)	E	Bignoniaceae	0	19	0	0.32	0.14	152.84	0.37	0.51	36
Jatropha curcas Linn.	Jaatiroovaa (Qobboo) (Or)	E	Euphorbiaceae	0	722	0	12.11	5.43	596.70	1.43	6.86	7
Justicia schimperiana (Hochst. ex Nees) T. Anderson.	Dhummuugaa (Or)	I	Acanthaceae	12	1069	0	18.13	8.12	22.12	0.05	8.17	5
Leucaena pallida Britton & Rose	Lukiinaa (Or)	E	Fabaceae	0	24	0	0.4	0.18	10.57	0.03	0.21	46
Maesa lanceolata Forssk.	Abbayyii (Or)	I	Myrsinaceae	40	21	5	1.11	0.5	53.86	0.13	0.63	31
Mangifera indica L.	Maangoo (Or)	E	Anacardiaceae	3	173	8	3.09	1.38	1543.81	3.7	5.08	13
Maytenus arbutifolia (Hochst. ex A.Rich.)	Kombolcha (Or)	I	Celastraceae	3	0	0	0.05	0.02	31.09	0.07	0.09	58
Melia azedarach L.	Niimii (Miimmii) (Or)	E	Meliaceae	0	53	0	0.89	0.4	300.18	0.72	1.12	25
Millettia ferruginea (Hochst.)	Sootalloo (Or)	I	Fabaceae	1	3	0	0.07	0.03	49.29	0.12	0.15	53
Morus alba L.	Injoorrii Faranjii (Goraa) (Or)	E	Moraceae	0	258	0	4.33	1.94	226.84	0.54	2.48	16

Table 7 continued

Species name	Vernacular name	Origin	Family	HS	CL	GL	Density	RD	BA	RBA	RD + RBA	Rank
Ocimum lamiifolium Hochst. ex Benth.	Ancabbii (Or)	I	Lamiaceae	0	13	0	0.22	0.1	1.24	0	0.1	57
Olea europaea L.	Ejersa (Or)	I	Oleaceae	3	4	2	0.15	0.07	607.24	1.45	1.52	20
Olinia rochetiana Juss.	Digaajjaa (Or)	I	Oliniaceae	0	1	0	0.02	0.01	17.06	0.04	0.05	68
Persea americana Mill.	Avokaadoo (Or)	E	Lauraceae	0	58	0	0.97	0.44	92.90	0.22	0.66	30
Piliostigma thonningii (Schumach.)	Liilluu (Or) Yeqollaa Waanzaa (Amh)	I	Fabaceae	10	6	0	0.27	0.12	243.49	0.58	0.7	28
Pittosporum viridiflorum Sims.	Soolee (Or)	I	Pittosporaceae	0	2	0	0.03	0.02	0.19	0	0.02	75
Premna schimperi Engl.	Urgeessaa (Or)	I	Verbenaceae	2	6	2	0.17	0.08	5.55	0.01	0.09	59
Prunus persica (L.)	Kookii (Or)	E	Rosaceae	0	8	0	0.13	0.06	8.92	0.02	0.08	61
Psidium guajava Linn.	Zayituunaa (Or)	E	Myrtaceae	0	1	0	0.02	0.01	0.56	0	0.01	80
Rhus vulgaris Meikle	Xaaxessaa (Or)	I	Anacardiaceae	0	0	2	0.03	0.02	7.79	0.02	0.04	71
Ricinus communis L.	Qobboo (Or)	I	Euphorbiaceae	0	593	0	9.95	4.46	278.18	0.67	5.13	10
Sapium ellipticum (Hochst.) Pax	Bosoqa (Or)	I	Euphorbiaceae	0	1	4	0.08	0.04	263.49	0.63	0.67	29
Schrebera alata (Hochst.) Welw.	Qasammee (Or)	I	Oleaceae	1	0	0	0.02	0.01	66.74	0.16	0.17	51
Sesbania sesban (Linn.) Merr.	Sasbaaniyaa (Or)	I	Fabaceae	75	572	0	10.85	4.86	209.43	0.5	5.36	9
Spathodea nilotica Seem.	Ispaatoodaa (Or)	E	Bignoniaceae	1	6	0	0.12	0.05	80.64	0.19	0.24	45
Stereospermum kunthianum Cham.	Botoroo (Or) Waashintee (Amh)	I	Bignoniaceae	11	8	6	0.42	0.19	496.52	1.19	1.38	23
Syzygium guineense (Willd.) DC. Subsp. *afromontanum* F.White	Baddeessaa (Or)	I	Myrtaceae	10	3	8	0.35	0.16	725.14	1.74	1.9	18
Syzygium guineense (Willd.) DC. subsp. *guineense*	Goosuu (Or)	I	Myrtaceae	2	8	26	0.6	0.27	499.68	1.2	1.47	22
Terminalia laxiflora Engl. & Diels.	Warakkee (Or)	I	Combretaceae	5	0	0	0.08	0.04	139.30	0.33	0.37	39
Vangueria apiculate K. Schum.	Buruurii (Or)	I	Rubiaceae	0	1	0	0.02	0.01	0.70	0	0.01	81
Vepris nobilis (Delile) Mziray	Hadheessa (Or)	I	Rutaceae	0	1	0	0.02	0.01	0.16	0	0.01	82
Vernonia amygdalina Del.	Eebicha (Or)	I	Asteraceae	32	3370	0	57.06	25.57	3768.19	9.02	34.59	2
Vernonia auriculifera Hiern.	Reejjii (Or)	I	Asteraceae	43	75	218	5.64	2.52	41.71	0.1	2.62	15
Total				1886	10259	1162	223.24	100	41765.16	100	200	

I indigenous, *E* exotic, *Or* Oromifa, *Amh* amharic, *HS* homestead, *CL* crop land, *GL* grazing land, *RD* relative density, *BA* basal area, *RBA* relative basal area, rank is based on RD + RBD

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