Journal of Forestry and Natural Resources (JFNR)

Volume 2, Issue No. 1

May, 2022

Research Article

Effects of wealth status on home-garden’s biomass and soil carbon stocks: The case of midland kebeles of Ofa district, Wolaita Zone, Southern Ethiopia

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Abstract

Home garden agroforestry has been practiced in various parts of the tropics, and is known to provide a wider ecosystem services for smallholder farmers. Several studies have been conducted on the biodiversity and socio-economic importance of home garden agroforestry in different parts of Ethiopia, however, empirical studies are limited on home garden's carbon stocks storage in reference to socioeconomic factors. The objective of this study was, therefore, to identify the effects of household’s wealth status on the home garden's biomass and soil organic carbon stocks at midland kebeles of Ofa district, Wolaita Zone, Southern Ethiopia. Three kebeles were purposively selected from the district based on the existence and extensive practice of home garden agroforestry. A total of 73 sample plots with 10m×10m were established on home gardens of randomly selected households across wealth classes, representing 14 for rich, 27 for medium, and 32 for poor. In each main plot, all woody species above 2.5 cm dbh were inventoried. Also, three nested 1m×1m subplots were used to collect litter and soil samples. Already developed allometric equations were used for estimation of above and belowground biomass. A total of 146 soil samples for soil physicochemical analysis, and the same size samples were collected separately for bulk density determination, and 73 samples for litter. The mean total carbon stocks (biomass plus soil, 0-60cm) was significantly higher in home gardens of the rich and medium households (respectively 232 ± 22 Mg C ha^{-1} and 207±19Mg C ha^{-1}) than poor households (130 ± 13 Mg C ha^{-1}). The soil organic carbon (SOC) accounted for 68%, 71% and 82% of the total carbon stock in rich, medium and poor households’ home gardens. SOC stock was positively correlated (Spearman R^2=0.65) with total biomass carbon stock. This study revealed that wealth status of households affects carbon stocks in home garden agroforestry in Southern Ethiopia.

Key words: carbon stocks, climate change mitigation, home garden, wealth status, woody species

1. Introduction

Global warming is real and there is a growing interest in the role of different land use systems in stabilizing atmospheric carbon dioxide (CO_2) concentration (IPCC 2014). Increasing the size of the global terrestrial sink is one of the strategies for reduction of CO_2 in the atmosphere. Currently, agroforestry system is more attracting attention to achieve higher amount of carbon stock in the biomass than grasslands, agricultural fallows, and permanent shrub (Roshetko et al. 2002). There has been growing interest in agroforestry systems owing to their large potential for climate change mitigation and their roles to mitigate household food security (Minang et al. 2012; Nair 2012). It has a potential to sequester greater amount of carbon to offset emissions caused by deforestation and forest degradation (Takimoto et al. 2008; Gupta et al. 2009).[1] Different studies in tropics and subtropics revealed that agroforestry practices stored significant amount of carbon in their biomass and soil (e.g., Montagnini and Nair 2004).

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Received 24 January, 2023
Accepted 26 May, 2023

A home garden is one of agroforestry practices with various ecosystem services. It is defined as "a complex sustainable land use system that combines multiple farming components, such as annual and perennial crops and invariably livestock of the homestead and provides environmental services, household needs, and employment and income generation opportunities to the households, the whole tree-crop-animal unit being intensively managed by family labor" (Weerahewa et al. 2012). Home garden is most commonly practiced throughout the tropics and named differently to different places such as household or homestead farms, multi-strata tree gardens, compound farms, backyard gardens, village forest gardens, dooryard gardens, and house gardens (Mattson et al. 2013).

The most common agroforestry practices that are practiced in different parts of Ethiopia include: scattered trees in croplands or parkland agroforestry practiced in large parts of the Ethiopian agricultural landscapes (Hoekstra et al. 1990; Mahari Alebachew 2012), home gardens are practiced in many parts of the southern and south western regions of Ethiopia (Tesfaye Abebe 2000; Mesele Negash et al. 2005), Coffee based agroforestry systems practiced in southern, southwestern and eastern regions of Ethiopia (Demel Teketay and Assefa Tegineh 1991; Mesele Negash et al. 2005; Diriba Muleta et al. 2008).

Agroforestry practices contributed to the sustainable development of Agriculture and promoted economic progress in Ethiopia. It is also believed to contribute for the sustainable Development Goals of the United Nations in various ways. Home garden have a potential to provide productive functions including fuel wood, pole, fodder for animals, improve soil fertility (Poschen 1986; Tesfaye Abebe 2000). Additionally, agroforestry practices also play important roles in adaptation and mitigation of climate change (Tesfaye Feyera 2011; Abiot Molla 2013; Mesele Negash 2013).

The adaptation and mitigation of climate change roles of agroforestry depends on socio-economic factors such as wealth status (Winnas et al. 2015). Wealth status impact is mainly depicted due to the fact that its influence on farm size, tree density and diversity and management of agroforestry practices in different parts of Ethiopia (Zemede Asfaw and Zerihun Woldu 1997; Zebene Asfaw 2003; Abebaw Zeleke 2006). Besides, the amount of carbon stored in the agroforestry practices depend on climatic and edaphic factors (Islam et al. 2015; Unruh et al. 1993), size and age of the holding (Saha et al. 2009).

Home garden agroforestry practice stores higher amounts of carbon than other agricultural systems in the above and belowground biomass and soils (Schroth et al. 2011; Mattsson et al. 2013). The enhanced soil organic carbon sequestration in these systems was attributed to the carbon assimilated by the woody perennial plants, which is transported below-ground to support root growth and organic matter turnover processes (Kumar 2006; Makumba et al. 2007; Beedy et al. 2010). However, such a huge benefits of home garden agroforestry are not addressed well, and the system face problem of changing in to monoculture system in southern Ethiopia (Mersha Gebrehiwot 2013; Tesfaye Abebe et al. 2013).

Previous studies on home garden agroforestry of Wolaita zone, southern Ethiopia assessed the structure, diversity and income contribution of home garden agroforestry for the smallholder farmers (Talamos Seta et al.2013; Mathewos Agize et al. 2016). However, the empirical scientific evidence is lacking regarding how socio-economic factors such as households' wealth status influence biomass and soil organic carbon stocks in agroforestry system. The overall objective of this study was therefore to evaluate the effect of households' wealth status on the home garden's biomass and soil organic carbon stocks and the relationship between them in the midland kebeles of Ofa district, Wolaita zone, southern Ethiopia. We hypothesized that both biomass carbon and soil organic carbon (SOC) stocks would differ among the wealth status of households because of the difference in tree/shrub density; that soil organic carbon stock is significantly related to biomass carbon stocks in home garden because of the high inputs of tree/shrub litter fall.

2. Materials and Methods

2.1 Description of the study area

The study was carried out in the Ofa district, Wolaita Zone, Southern Ethiopia geographically located between 6°42' and 6°49' N latitude and 37°28' and 37°34' E longitude (Figure 1). The total land area of the district is 38,537 ha, comprising cultivated land (44.8%), agroforestry (23.4%), forest land (1.9%), grazing land (13.4%), settlement (11.0%) and other lands (5.4%) (Elias Bojago et al. 2022). Ofa district is one of the most densely populated areas in Ethiopia, with an average density of 450 person's km^{-2} (Elias Bojago et al. 2022). The elevation ranges from 1450 to 2800 ma.s.l. The annual rainfall ranges between 660-1549 mm and temperature ranges from 14 to 34°c (Figure 2).

Ranges of soil types are found in Woliata Zone, but the dominant soil type of the study sites are Nitisols. According to Ethiopian Agro climatic zone classification, the selected district has three major Agro climatic zones, kolla (lowland), Weyna dega (midland) and Dega (highland), accounting for 31%, 48%, and 21% of the district's area, respectively (Elias Bojago et al. 2022). The selected kebeles (Galako, Okoto Sere and Zamo) for this study are located in the mid land (woyna dega) of the district.

The home garden of the present study site is *Tree-enset-coffee* based and woody species such as *Millettia ferruginea*, *Persea americana*, *Croton macrostachyus*, and *Cordia africana* are mainly dominated the upper story while *Enset ventricosum* (*Enset* or *Uta*) and *Coffea arabica* dominate the middle story.

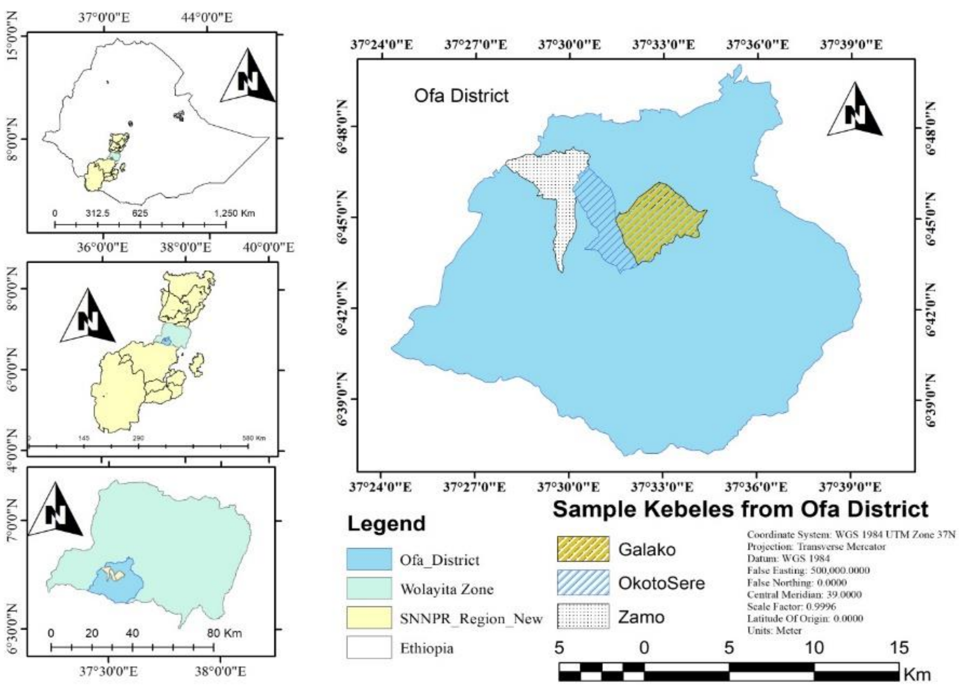


Figure 1. Map of the study Area

2.2 Specific sites selection

Reconnaissance survey was conducted before the actual survey to have an impression and obtain basic information of the study sites. From the study district, three kebeles (smallest administrative unit) were purposively selected for this research based on extensive existence of home garden system. Then, nine villages, three from each selected kebele were selected randomly for this study. In all selected kebeles, *Tree-enset-coffee* based home garden agroforestry was commonly practiced

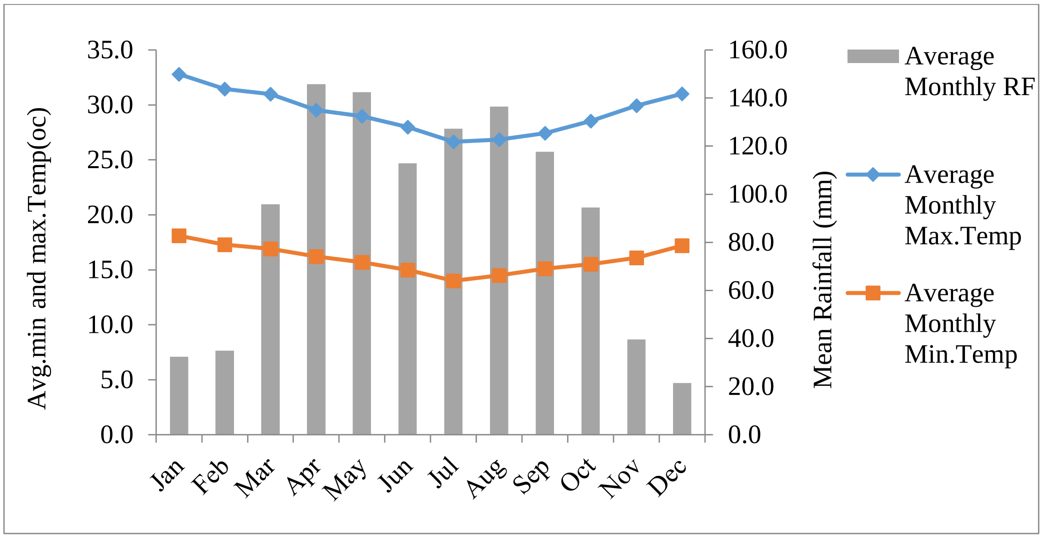


Figure 2. Climate diagram on mean monthly rainfall (mm), mean monthly minimum and maximum temperature (°C) of the Ofa district during the period of 1988-2015 (Source: National Meteorological Agency SNNPR Metrological Center, Hawassa, 2017)

2.3 Key informants selection and wealth status classification

Key informants (KIs) were used to stratify the wealth classes in the study site. In the current study, key informants (KIs) are persons who have lived in the study sites for at least 50 years and are knowledgeable about their localities. To select key informants snowball method was employed. In this method, to select individual farmers who could identify key informants, village tour was made. During village walk, five farmers were randomly asked to give the name of five key informants whom they know best in the study sites. At each village, out of 25 key informants suggested, five top ranking or the most frequently appeared were selected to categorize households (HHs) into different wealth categories. Therefore, in total 45 key informants were selected from the 9 villages.

The purpose of key informant selection was to stratify the households into different wealth categories (poor, medium and rich) based on their own local criteria. The list of required farmers of each village was collected from the Kebele administrative offices. Key informants then set the wealth criteria to categorized households in to different wealth classes. Finally, key informants categorized HHs living in each village into three wealth classes of rich, medium and poor according to the set criteria (see Table 1).

Table 1. Local criteria for wealth ranking based on key informants

	Wealth categories		
Criteria	Poor	Medium	Rich
Land holding (ha)	up to 0.5	up to 1	up to 2 and more
Ox	no ox	1 or a pair of oxen	> a pair of oxen
Cow	no cow	2 cow	> 3 cow
Goat and sheep	0-1	2-4	> 5 goat or sheep
Donkey	0 donkey	1 donkey	≥1 donkey
Mule	no mule	no mule	1 mule
Chicken	1-4	5-10	>11

Mature enset	20-30	80-100	200-1000
No of corrugated iron sheet of the house	0	1	>1

2.4 Sampling techniques

Stratified random sampling technique was employed to collect data from the study sites. Stratification was based on the wealth status of households. Accordingly, three wealth statuses were identified (poor, medium and rich) based on their own local criteria (Table 1). The total of 14, 27 and 32 sample plots were inventoried in rich, medium and poor household farms respectively. The numbers of sample plots required for this study were determined by the pragmatic approach as a result; 10% farmers from each wealth class at each village were randomly selected using lottery method based on their relative proportion. A total of 73 households/farmers across the three wealth classes were selected, comprising 14 rich, 27 medium and 32 poor households (see Table 2).

Table 2. Summary of kebeles, villages and HHs at each wealth class selected for this study

Kebeles	No of Villages	Selected villages	Total No of HHs	HHs in wealth class			Sampled HHs			Total sample
				Rich	Medium	Poor	Rich	Medium	Poor	
Zamo	10	Wonago	60	10	20	30	1	2	3	6
		Zogisa	76	10	28	38	1	3	4	8
		Chana	71	9	26	36	1	3	4	8
Okoto Sere	11	Gayo	82	18	28	36	2	3	4	9
		Shoya	63	8	25	30	1	3	3	7
		Kanko	82	17	37	28	2	4	3	9
Galako	8	Damala	72	18	27	27	2	3	3	8
		Ambe	86	20	29	37	2	3	4	9
		Mani'sa	84	19	28	37	2	3	4	9
Total	29		676	129	248	299	14	27	32	73

2.5 Species inventory

An inventory of all trees/shrubs including coffee and enset (*Ensete ventricosum)* grown on the home garden agroforestry within 10m x 10m plot was conducted. The sample plots were located randomly within selected home garden agroforestry. Trees/shrubs with diameter at breast height (d, at 1.3 m aboveground)) ≥2.5cm, and total height and dominant height in the case of enset (h) ≥1.5 m were measured. For coffee plants, stem diameter at stump height (at 40cm aboveground) and for enset, the basal diameter of the pseudo stem (at 10cm height, d_{10}) were measured (Mesele Negash and Starr 2015). All stem diameter measurements were taken in two perpendicular directions and the average value was used in subsequent calculations. In the case of multi-stemmed plants, each stem was measured and the equivalent diameter of the plant calculated by equation (1) as the square root of the sum of diameters of all stems per plant (Snowdon et al. 2002). Local name of the plants were recorded in field and identification was done using published volumes of Flora of Ethiopia and Eritrea. The summary of biometric characteristics inventoried are shown in Table 3.

$$d_{e=}\sqrt{\sum_{i=1}^{n} d_i^2}$$

Where: d_e is diameter equivalent (at breast or stump Height) (cm) and d_i is diameter of the i^{th} stem at the measurement height (cm).

A total number of 2718 individuals were recorded in the survey. The variation in diameter and height among the wealth status was not significant (Table 3).

Table 3. Statistical summary of studied home garden agroforestry practice across wealth categories in midland kebeles of Ofa district, Wolaita Zone, Southern Ethiopia

Stand characteristics	Rich (n=14)	Medium (n=27)	Poor (n=32)
D_{10}, cm	32.6±6.6[a]	29.4±4.6[a]	31.7±5[a]
D_{40}, cm	8.0±1.1[a]	6.5±0.7[a]	6.9±2.3[a]
D, cm	18.5±4.6[a]	19.6±3.0[a]	16±4.6[a]
H, m	7.8±1.5[a]	7.37±0.5[a]	7.23±0.9[a]

Different letters show significant differences among groups at 5% level of significance D_{10}= diameter at 10 cm height for enset, D_{40}=diameter at 40 cm height for coffee, D=diameter at breast height, H=height (dominant height in the case of enset).

2.6 Litter and soil sampling

Litter and soil samples were collected from three 1m x 1m sub-plots selected randomly from the four corners and the center of each 10m x 10m plots using a lottery method. Litter sub-samples from each plot were composited and fresh weights were measured on the site using spring balance. Then, a 100 g sub-samples were sun-dried and taken to laboratory to oven-dry at 70 °C for 24 h and determined fresh to dry weight ratio. A total of composited 146 samples were collected from 0-30 cm and 30-60 cm depths using soil augur with 7.5 cm diameter for SOC determination and the same amount of soil samples were separately collected for bulk density determination with 5 cm core samplers. The samples for SOC were dried, ground and then sieved with a 2 mm sieve. The bulk density samples were oven-dried at 105 °C for 48 h and weighed, and the weight of >2 mm and <2 mm fractions were recorded

2.7 Determination of biomass

Biomass carbon stocks for each plot (Mg ha^{-1}) were calculated as the product of dry matter biomass and carbon content. For trees, coffee and enset plants the biomass was calculated using the plot inventory data (d, d_{40}, d_{10} and h) and allometric biomass functions. For the aboveground biomass of trees, the allometric equation (2) developed by Kuyah et al. (2012a) was used.

$$AGB = 0.091 \times d^{2.472};\ R^2 = 0.98,\ n = 72$$

Where AGB is the aboveground biomass (kg dry matter/plant) and d is diameter at breast height (cm). This equation was developed for trees in agroforestry systems in western Kenya having similar climatic and soil condition as those in our study area. For estimating the aboveground biomass of coffee and enset plants the allometric equations (3 and 4) developed in the Gedeo agroforestry system, southern Ethiopia by Mesele Negash et al. (2013a) were used.

$$AGB_{\text{coffee, kg/plant}} = 0.147 d^2_{40};\ R^2 = 0.80;\ n = 31$$

Where d_{40} is stem diameter (cm) of the coffee plant at 40 cm height.

$$\ln (AGB_{enset}) = -6.57 + 2.316 \ln (d_{10}) + 0.124 \ln (h);\ R^2 = 0.91,\ n = 40$$

Where d_{10} is the basal diameter (cm) of the enset pseudo stem at 10 cm height and h is total height (m).

Belowground biomass of the tree and coffee plants were calculated using the generic equation (5) developed by Kuyah et al. (2012b)

$$BGB = 0.490 AGB^{0.923};\ R^2=0.95;\ n = 72$$

Where BGB is the belowground biomass (kg dry matter/plant) and AGB is aboveground biomass (kg dry matter/ plant).

Below ground biomass of enset was calculated using the allometric equation (6) developed by Mesele Negash et al. (2013a)

$$BGB_{enset}= 7(x10^{-6})\ d_{10}^{4.083};\ R^2= 0.68,\ n = 40$$

Where d_{10} is the basal diameter (cm) of the enset pseudo stem at 10 cm height.

The dry biomass of litter was calculated using the equation of Pearson et al. (2005)

$$LB = \frac{W\,Field}{A} \times \frac{W\,sub{-}sample\,(dry)}{W\,sub{-}sample\,(fresh)} \times \frac{1}{10000}$$

Where: LB is Litter biomass (Mg ha^{-1}), W field is weight of wet field sample of litter sampled within an area of size 1 m^2 (g), A is size of the area in which litter was collected (ha), W sub-sample (dry) is weight of the oven-dry sub-sample of litter was taken to the laboratory to determine moisture content (g), and W sub-sample (fresh) is weight of the fresh sub-sample of litter was taken to the laboratory to determine moisture content (g).

SOC stocks (Mg ha^{-1}) were calculated as the product of C content (%), bulk density (g<2 mm cm^{-3}) and soil depth (cm). To estimate SOC, first the bulk density was determined. The presence of rock fragments over or underestimate the SOC stock (Throop et al. 2012). This requires accurate estimation of the amount of rock fragments for SOC stock calculation. The estimation was made following Pearson et al. (2005).

$$BDsoil = \frac{ODW}{CV - (\frac{Mcoarsefrag}{Densrock\,frag})}$$

where: BD soil is soil bulk density (g $cm^{-3,}$ > 2 mm coarse fragments), ODW is oven dry weight of soil (<2mm fraction) (g), CV is soil core volume (cm^3), Mcoarse frag is mass of coarse fragments (g), and Densrock frag is density of rock fragments (g cm^{-3}) = 2.65 g cm^{-3}.

The SOC stock values for the two depths (0–30 cm and 30–60 cm) were summed to give the SOC stock for the entire 0–60 cm depth. Home garden total C stocks are defined as the sum of the total biomass carbon and SOC stocks (0–60 cm).

2.8 Determination of biomass, litter and soil carbon content

The carbon content in the tree biomass was calculated by multiplying tree biomass by 48% C content, which was determined for trees grown in agroforestry systems in Kenya (Kuyah et al. 2012a). The C contents of 49% for coffee and 47% for enset biomass were used (Mesele Negash et al. 2013a). The C content (%) of the litter samples were calculated from organic matter contents determined through loss-on-ignition (LOI; ignition at 550°C for 2 h) and litter organic matter fraction was calculated according to Allen et al. (1986). While the carbon content of the soil samples was determined using the Walkley-Black method in soil laboratory (Walkley-Black 1934).

2.9 Statistical analyses

Evaluation of normality (Shapiro-Wilk test) and equality of variance (Levene's test) assumptions were done to check the data prior to further statistical analysis. The size and variation in the carbon stocks for each home garden were described by the mean and standard deviation. To test for differences in biomass carbon and SOC stocks among the three wealth categories, one-way ANOVA was performed ($\alpha = 0.05$). To find out the effect of wealth status and soil depths on soil organic carbon stock two-way ANOVA was performed. Spearman correlation test was conducted to examine the relationship between biomass and soil organic carbon stocks. All statistical tests were performed by using Statistical Package for Social Science (SPSS) software version 16.0.

3. Results

3.1 Biomass carbon stocks

The above and belowground carbon stocks in the studied home garden among the three wealth categories are shown in Table 4. The above ground biomass carbon accounted for 75%, 72% and 74% of the total biomass carbon stocks for rich, medium and poor households, respectively. The total biomass carbon stock in the home gardens of poor household was lower than the rich and medium households by 69% and 62%, respectively. Trees contributed 85-94% of the total biomass carbon stocks across the wealth categories. Coffee accounted for 8.3%, 7% and 3.7% of total biomass for home gardens of rich, medium and poor households, respectively.

While enset contributed 6%, 4% and 2% to the total biomass of rich, medium and poor households, respectively. Litter shared 2.6%, 3.2% and 3.3% to the total above ground biomass carbon stock for rich, medium and poor households, respectively.

Table 4. Mean (±SD) above and belowground biomass carbon stocks (Mg ha^{-1}) among the three wealth categories of the studied home gardens

Biomass component	Rich (n=14)	Medium (n=27)	Poor (n=32)
AGBC	56 ± 16.0^{b}	43 ± 11.0^{b}	17 ± 1.0^{a}
BGBC	19 ± 5.7^{b}	17 ± 2.0^{b}	6 ± 3.4^{a}
TBC	75 ± 18.0^{b}	60 ± 17.0^{b}	23 ± 9.0^{a}

Different letters indicate significance differences and similar letters among wealth categories groups non-significantly different at 5 % level of significance; AGBC=Aboveground biomass carbon stock, BGBC=Belowground biomass carbon stock, TBC=total biomass carbon stock

3.2 Soil organic carbon stocks

The soil organic carbon stock (Mg ha^{-1}, 0-60cm) did not differ between the home gardens of rich and medium households, but both of them significantly varied from poor households (p<0.05) (Table 5). The total soil organic carbon stock in the home gardens of poor household was lower than rich and medium households by 32% and 27%, respectively. The soil organic carbon stock was highest for rich households and least for the poor households. Higher SOC stock was found in surface soil (depth 0-30cm) than sub-surface layer (30-60 cm) in all wealth categories, and the difference was significant along the soil depths (Table 5). The surface soil layer contributed 53% of the total SOC in home garden of rich household, 56% for the medium and 58% for the poor. The SOC stocks of the sub-surface followed similar trend that of the surface layers across the wealth categories.

Table 5. Mean (±SD) soil organic carbon stock (Mg ha^{-1}) of the studied home gardens among wealth categories

Depth, cm	Wealth categories		
	Rich (n=14)	Medium (n=27)	Poor (n=32)
0-30	84 ± 12^{bB}	83 ± 11^{bB}	63 ± 13^{aB}
30-60	73 ± 10^{bA}	64 ± 14^{bA}	44 ± 12^{aA}
Total (0-60)	157 ± 21^{b}	147 ± 19^{b}	107 ± 11^{a}

Within each soil layer, different small letter superscripts show significant differences among groups in row at 5 % level of significance and between soil depths (0-30 and 30-60cm) different capital letter superscripts show significant differences among groups in column at 5 % level of significance.

The SOC showed significant variation within soil depths and among wealth categories (p< 0.05) but the interaction effect did not differ (p> 0.05) (Table 6).

Table 6. Mixed model effects of soil depth and wealth categories on SOC stock in the study sites

Source of variation	Df	MS	p-value
Depth	1	8236.680	0.00
Wealth status	2	8941.265	0.00
Depth*Wealth status	2	210.123	0.635
Error	140	461.237	

MS mean square, df degree of freedom

3.3 Home garden total carbon stock

The total carbon stock (in biomass and soil) did not significantly differ between home gardens of rich and medium households, but both of them significantly varied from the poor households (p<0.05). The highest home garden total carbon stocks was recorded for rich (232±22 Mg C ha^{-1}), followed by medium (207±19Mg C ha^{-1}) and poor households (130±13Mg C ha^{-1}) (Figure 3). The total carbon stock in the home gardens of poor household was lower than the rich and medium households, by 43% and 37% respectively. The highest variation in total C stock was observed in the home gardens of rich (ranged 120–357.4 Mg C ha^{-1}), followed by medium (83.5–314.8 Mg ha^{-1}), and the poor households (43.9–225.3 Mg ha^{-1}). The soil

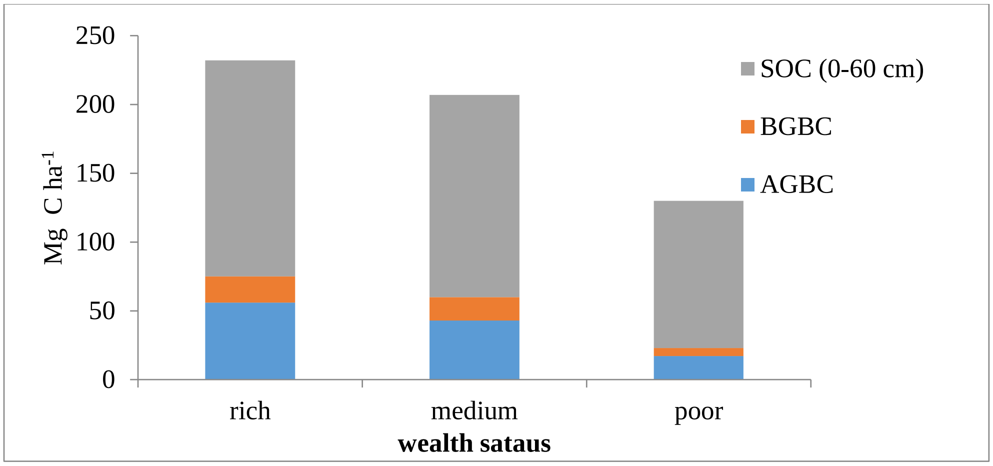
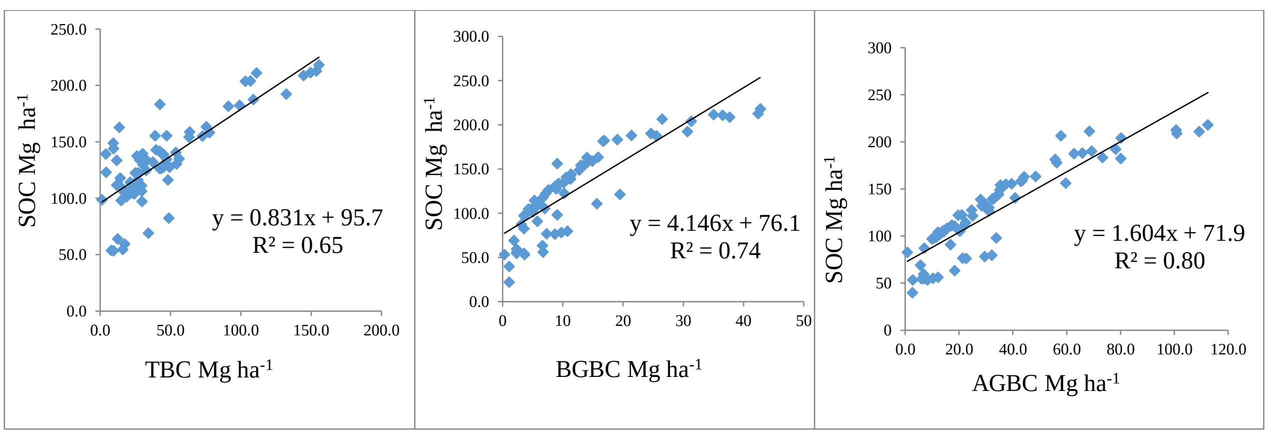


Figure 3. Total home garden carbon stocks across wealth categories. AGBC= aboveground biomass carbon stock, BGBC= belowground biomass carbon stock

As we hypothesized, the results of the correlation analysis revealed a significant and positive relationship between biomass components and SOC stocks. The total biomass carbon stock explained 65% of the total variation in SOC stock while aboveground and belowground biomass carbon stocks explained 80% and 74% of the total variations in SOC stocks, respectively (Figure 4 a-c).



(a) (b) (c)

Figure 4. Spearman correlation between (a) total biomass, (b) belowground biomass and (c) aboveground biomass carbon stocks with SOC stocks for the studied home garden

4. Discussion

4.1 Biomass carbon stocks

This study revealed that wealth status of households affect biomass carbon stocks in the home garden agroforestry in southern Ethiopia. We attribute high total biomass carbon stock in the home garden of rich and medium households to the high plant biomass and basal area. In our study, trees accounted for most of the total biomass C stocks (89 % on average). Study conducted in different parts of Ethiopia confirmed that wealth status of households affect tree density in agroforestry practices (Zebene Asfaw 2003; Worku Belayhun 2011; Getahun Yakob et al. 2014; Getahun Haile et al. 2017). Poor farmers in the studied area focus only on a few selected species which provide direct benefits such as fruit trees and coffee. If the farmers have small size of land holding then, they do not prepare to plant large numbers of tree in their farm since their available land is reserved for corps for home consumption. This tree density may affect the biomass carbon stocks. Study conducted by Wang *et al.* (2011) showed that stand structural parameters have significant positive relationship with aboveground carbon stocks. The high biomass carbon stocks across the three wealth status suggest the significant potential of the systems to store and enhance terrestrial carbon content. The total biomass C stocks across the three wealth status were within the range reported for tropical agroforestry systems (12–228 Mg C ha^{-1}) (Albrecht and Kandji 2003).

4.2 Soil organic carbon stocks

The amount of SOC in the studied home garden agroforestry was significantly affected by difference in the wealth status of households. The high SOC stocks for rich and medium households could be related to high litter inputs from high number of perennial components such as tree, coffee and enset. Litterfall contributes to the return of organic matter to the soil (Liang et al. 2011). This was in agreement with studies in Kerala, where home garden’s with high number of stems resulted high soil organic carbon than home gardens with low number of stems (Saha et al. 2009). James et al. (2009) asserts that number of stem is an important factor for soil organic carbon stock in home garden as it is directly related to the carbon sequestration. Other studies elsewhere showed similar results (e.g., Fernandez et al. 2010). Strong correlation between total biomass and SOC stocks were also shown in our study.

Soil organic carbon plays a great role in the global carbon cycle and C pools (Sundarapandian et al. 2015). We attribute the high SOC stocks in present home garden agroforestry to the high proportion of tree and shrubs in the system. The SOC stock of the present study was lower than indigenous agroforestry systems of the south-eastern Rift Valley escarpment of Ethiopia (Mesele Negash and Mike Starr 2015). However, it was higher than those reported in home garden of Rangpur district, in Bangladesh (Jaman et al. 2016). The 0-30 cm depth SOC stocks in the current agroforestry system was higher than the ones reported for coffee agroforestry systems elsewhere in the tropics (Ekwe Dossa et al. 2008; van Noordwijk et al. 2002). Soil organic carbon content decreased with increase in the soil depth. This might be due to the higher presence of organic matter on the surface soil layer than the sub-surface layer (Yimer et al. 2015). The result was consistent with other studies conducted in the different parts of Ethiopia (e.g., Aklilu Bajigo et al. 2015; Mesele Negash and Mike Starr 2015) and elsewhere in tropics (e.g. Ekwe Dossa et al. 2008; van Noordwijk et al. 2002).

4.3 Home garden total carbon stock

Home garden agroforestry across the three wealth status of study site had a high potential to store carbon both in biomass and soil. A high proportion of the total C stock in home garden agroforestry system in the present study is in the soil. The SOC (0−60 cm) to total biomass C ratio for the studied home garden agroforestry was 2:1 for rich households, 2.5:1 for medium households and 4.6:1 for the poor households. The total carbon stock in the studied home garden across the three wealth status was higher than the reports of home garden agroforestry practice of Gunnuno watershed (Aklilu Bajigo et al. 2015) and lower than Gedeo agroforestry in South-eastern Rift Valley escarpment of Ethiopia (Mesele Negash and Mike Starr 2015). Maintaining of higher carbon stock levels of home garden agroforestry also ensures the productivity of the system.

4.4 Relationship between biomass and soil organic carbon stocks

There was significant and positive relationship between biomass and soil organic carbon stocks in the studied home garden agroforestry. We attribute this to home garden with the high number of stems, which accumulate high organic matter from root, litter and aboveground biomass have a high potential to store carbon in the soil. This was in line with study conducted by Mekuria Wolde et al. (2009), reported that soil organic carbon stock increases in ecosystems as aboveground biomass increases. A study conducted in Rangpur district, in Bangladesh showed a positive and significant relationship between tree biomass and soil organic carbon (R^2=0.94) (Jaman et al. 2016). This finding was also in conformity with studies conducted in Kerala, India that revealed home gardens with higher biomass had higher soil organic carbon than home gardens with lower biomass (Saha et al. 2009). Moreover, Joneidi (2013), reported that belowground biomass was positively correlated with soil organic carbon in his study (r=0.84, $p<0.05$). Therefore, climate change mitigation efforts on smallholder farms should also be considered the socio-economic factors affecting carbon accumulation of the system.

5 Conclusions

The home garden agroforestry of the study area is not only providing productive and protective services for smallholders, but also important for serving as carbon sinks to help in climate change mitigation. The result of this study confirms that wealth status of households in the study area affected home garden's biomass and soil organic carbon stocks. The home gardens of rich and medium households had higher biomass and soil organic carbon stock than poor households. The variation in carbon stocks (biomass and soil) between rich and medium households is not significant, but poor households are significantly different from both rich and medium households. This is in association with high number of stems, which results in high litter fall production and biomass in the home gardens of rich and medium households. Biomass carbon stocks were found to be strongly correlated with soil organic carbons. Thus, climate change mitigation efforts on smallholder farms should also consider the socioeconomic factors such as wealth status for enhancing climate change mitigation role of the agroforestry system.

6 Recommendations

Based on this study, the following points have been forwarded as recommendations

- The high carbon stocks of the system indicates that it has a significant carbon sequestration and climate change mitigation role so, farmers should be benefited from carbon credit schemes to maintain this agroforestry system through the implementation of payment for environmental services.
- Further research should be conducted on other socioeconomic factors other than wealth status that may affect the carbon stocks in home garden agroforestry system.
- The policy makers, stakeholders, researchers and extension practitioners should further work on enhancing the awareness about the role of home garden agroforestry on climate change adaptation and mitigation.

Acknowledgements

The first Author would like to thank Federal Democratic Republic Ministry of Education (MoE) and Wondo Genet College of Forestry and Natural Resources for providing me financial support. I would like to extend my grate appreciation to Zamo, Okoto and Galako kebele farmers for giving permission for their farms. My gratitude goes to my beloved wife Nestanet Lemma and My brother Yasin Darcho for their generous support on field work.

Funding

This study was supported by Federal Democratic Republic Ministry of Education (MoE)

Competing interest

The authors declare that they have no competing interests

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Research Article

Response of enset (*ensete ventricosum (welw.) cheesman)* to different application rates of potassium application in Hula District, Sidama region, Ethiopia

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Abstract

Field experiment was conducted in Hula district, Sidama region, Ethiopia to investigate the response of *enset* to potassium (K) fertilizer for two years (2016-2018). The treatments were: Control (0),80, 150 and 200 kg K/ha as KCl along with the recommended nutrients to the area; 20 kg P/ha, 11.15 kg S/ha and 0.57 kg B/ha as NPS+B; and 138 kg N/ha as Urea and NPS+B. Application of K in two consecutive years increased *enset* production and enabled the *enset* to reach the second edible stage (*etancho*) in two year and four months after transplanting. Thus, *enset* matured two years earlier as compared to the farmers' experience, which takes four years to reach this stage and crops in control plots matured at one year later stage (*malancho*) than those with K application. Application of K also increased the growth, dry matter and yield (*Kocho* and *bulla*) of *enset* as compared to the control plants. Among the treatments, twice application of 80 kg K/ha during the life of *enset* significantly ($p< 0.05$) increased the growth, yields and net benefits of *enset* production than the other treatments as indicated by the highest marginal rate of return. Hence, twice application of 80 kg K/ha is recommended for the study area.

Key words: Growth parameters, *kocho* and *bula* yields, maturity, agro-ecology

1. Introduction

Enset (*Enseteventricosum* (Welw.) Cheesman) is a perennial horticultural plant that is cultivated from home vicinity to far fields and it is usually called "false banana". It has several hundred landraces (clones), having different characteristics and uses (Mohammed et al. 2013). According to Brandt et al. (1997) *enset* is a staple crop for an estimated 15-20 million people in Ethiopia and a reliable food source where failure of annual crops is common (Dalbato 2000; Mikias et al. 2010).

Thus, *enset* cultivation is one of the tremendous potentials of the country to nourish the rapidly increasing part of population, particularly those below food poverty line. Moreover, e*nset* provides a range of services such as, forage (Funte et al. 2010), fiber (Tsehaye and Kebebew, 2006) and traditional medicine (Nyunja et al. 2009), construction and soil protection.*Enset* grows at altitudes between 1500- 3100 m above sea level (Tsegaye and Struik 2003). Rainfall above 1100 mm, temperature [1] between 16 and 20°C, and fertile soils are good conditions for *enset* production and productivity. Among these growth determinants, soil fertility is the major one

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Received 23 May, 2023
Accepted 26 May, 2023

(Tsegaye and Struik 2001). Moreover, adequate moisture plays a great role for the growth and productivityof *enset*, though *enset* has remarkable capacity to withstand heat. Brandt et al. (1997) and Shank and Ertiro (1996) reported that it is adapted to ample rainfall areas.

Enset is distributed in the wild throughout much of central, eastern and southern Africa (Brandt et al. 1997). However, its cultivation, domestication and farming system is established in Ethiopia (Brandt, 1996). Supporting this, CSA and MoA (1994) reported that about183,765.87 ha of land is cultivated with *enset* of which 57.38% is found in the southern parts of Ethiopia.

Enset requires high amount of organic matter for desirable production and productivity (Haile and Abay 2012). However, limitation in the number of livestock in *enset* growing areas is causing reduction in the amountof animal dung (Ayele 1975). This situation calls for the use of chemical fertilizers to tackle the problem (Forsido et al. 2013). Supporting this, a research conducted at Areka south Ethiopia, indicated vigorous growth and prompted maturity when 138 kg N/ha and 20 kg P/hawere applied twice throughout the life of *enset* (Ayalew and Yeshitila 2011). Until recently, there has been a general perception that soils of Ethiopia contain sufficient amount of potassium based on the report by Murphy (1968). Thus, fertilizer extension program in Ethiopia did not include potassium until 2014. However, national soil fertility survey conducted by Ethiopian Soil Information System (EthioSIS) found vast areas, especially highland vertisols and acidic soils in the country, that respond to potassium fertilization (EthioSIS 2014). These findings indicate the importance of potassium application to increase crop yield in the different agricultural areas. Thisresearch was therefore aimed at evaluating the response of *enset* to potassium application in Sidama region, Ethiopia and to determine the rate and frequency of K application to *enset* for optimum growth and productivity.

2. Materials and methods

2.1 Description of the study area

The study was conducted in Hula district, Sidama region, Ethiopia (Figure 1) from 2016 - 2018. Sidama administrative region is located between 5°45’- 6°45’ N latitude and 38°39°E longitude, covering a total area of 6,538.17 km^2 (SZPEDD, 2004). The regional capital, Hawassa, is located in the northern tip of Sidama region, at a distance of 275 km from Addis Ababa. As per traditional agro-ecological zone classification of Ethiopia, the districtis characterized by tepid to cool humid mid highlands and the type of soil was nitisol. The experimental site was located at 6º33.0’64’’N and 38°28.8’20"E; and at an altitude of 2502 masl.

2.2 Soil sampling, preparation and analysis

A composite sample was taken from a total of twelve systematic random soil samples (0-50 cm) collected prior to land clearing and preparation. The sampling depth was chosen to be 0-50 cm since the study planned to explore the K status within the enset rooting depth. The samples were air-dried and passed through 2 mm sieve to remove large particles, debris and stones (Tan, 1996). Particle size analysis was performed using the Bouyoucous hydrometer method (Bouyoucos 1951) and the textural classes were categorized using United State Department of Agriculture soil textural triangle.

The pH was determined in 1:2.5 soil-water suspensions using a glass electrode (Jackson, 1973). Electrical conductivity was determined from the saturation extract (l:5 soil water ratio) of soils (Gupta, 2009). Organic carbon (OC) was determined following wet oxidation method of Walkley and Black (1934). Total nitrogen (N) was determined by Kjeldhal method (Bremner and Mulvaney, 1982). Mehlich III extractant was used to extract, phosphorus (P), exchangeable potassium (K), calcium (Ca), magnesium (Mg), sulfur (S) and boron (B) (Mehlich 1984). Cation exchange capacity (CEC) was determined using ammonium acetate method (Sumner and Miller, 1996).

2.3 Experimental design and field management

Field trials were conducted in three consecutive years (2016-2018). The experiment was laid out in a randomized complete block design (RCBD) with three replications. The treatments included: 0, 80, 150 and 200 kg K/ha as KCl. One hundred eight seedlings of *enset* suckers were transplanted a year after sprouting to the main field at a depth of 20 cm.

Muriates of potash (KCl) were split applied two times per year. Recommended levels of P (20 kg/ha), N (138 kg/ha) (Ayalew and Yeshitila 2011), S (11.15 kg/ha) and B (0.57 kg/ha) were also used. Application times were once for P while twice for N per year. Inter and intra row spacing was 2 × 2 m. Urea and NPS+B were used as sources of N while only NPS+B was used as a source of P,S and B. The fertilizers were applied in a circular band (side dress) at a depth of 3 to 5 cm after one month of planting and then yearly as per treatments as suggested by Borges et al. (2002). All the other agronomic managements (weeding, cultivation etc.,) were carried out properly and equally for all the treatments.

2.4 Plant sampling and agronomic data collection

Prior to harvesting, a total of thirty six enset plants were sampled randomly from the experimental site (Tsegaye and Struik 2003). Plant and pseudostem height, pseudostem circumference, leaf length and the leaf width were measured using a tape meter. Moreover, all the fully expanded and green leaves were counted starting from the emergence of new leaves until the time of harvest to determine total number of leaves while weighing corms using portable balance.

2.5 Measurement of fresh weight

Fresh weights of shoot and corm were determined separately. Then, 500 g samples from each were taken, packed in cellulose paper folders and dried at 105°C for 24 h in an oven (Jones, 2001).

2.6 Kocho and bula production

Leaf sheaths were decorticated using a sharp-edged bamboo scraper while pulverizing the corm by sharp edged animal bone and combined with the decayed corm. After fermentation, fresh kocho was squeezed by applying human force till it loses all its moisture content and the weight of squeezed kocho was recorded.

2.7 Plant leaf sampling and analysis

Enset leaves were sampled based on sampling techniques used for banana plant since *enset* and banana have similar leaf morphology (Tsegaye and Struick, 2003). In supernatant solutions, potassium was determined by flame photometer while P was determined by Colorimetry (Housecroft and Constable, 2006). Sulfur and boron were determined by atomic absorption spectrophotometer (AAS).

2.8 Statistical analysis

Using the SAS package (SAS Institute 2012), LSD test (at P = 0.05), ANOVA (one-way analysis of variance) and correlation studies were undertaken according to CIMMYT (1988).

2.9 Economic analysis

Partial budget analysis of selected treatments was done

3. Results

3.1 Some soil physico-chemical properties of the experimental site

The soil was strongly acidic (pH < 5.5) while the textural class was sandy loam (Table 1). According to EthioSiS (2014) available P and total N was low; and S was very low while K contents were optimum. According to Maria and Yost (2006), Calcium contents were high while the magnesium contents were medium. The organic carbon was very low (Landon 2014). In accordance with EthioSIS (2014), the B contents were very low (< 0.5 mg kg^{-1}) while the CEC was high based on Landon (2014).

3.2 Nutrient contents of the *enset* leaf

The nitrogen content was increased from control to T4 and varied from 2.06 to 2.5 (Table 2). Statistically similar contents of N were recorded at T2, T3 and T4 and these contents were significantly (($p<0.05$)) different from that of the control treatment (Table 2). Overall, the N contents in all treatments were below 2.5% and low as proposed by Kalira (1998). The lowest and highest values of P were recorded at T3 and T4 treatments, respectively (Table 2). The P contents varied from 0.34 to 0.47% (Table 2) and itwas sufficient as proposed by Kalira (1998). Sulfur contents of the leaves were statistically similar, varied from 0.12 to 0.22% (Table 2) and were deficient

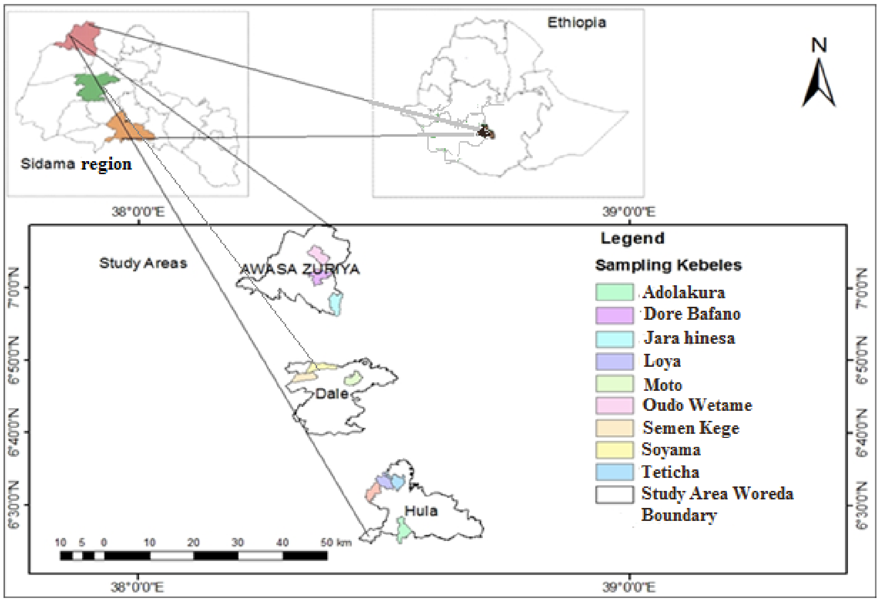

Table 1. Selected physico-chemical characteristics of the experimental soil.

n	Sampling depth	pH (H2O)	OC (%)	CEC (meq/kg)	Total N (%)	Available P	Exchangeable bases mg/kg K	Ca	Mg	S	B	Sand	Clay%	Textural class
1	50 cm	5.40	2.71	26.46	0.12	2.91	240	2039	326	8.22	0.31	60	20	Sandy loam

Table 2. Effect of potassium levels on nutrient contents of *enset* leaves of experimental site.

Treatments (kg K/ha)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B (mg/kg)
Control (0)	2.12^{b}	0.35^{b}	3.10^{c}	0.35^{b}	0.23^{b}	0.12	11^{b}
T2 (80)	2.30^{a}	0.40^{b}	3.60^{b}	0.40^{ab}	0.19^{c}	0.13	9.5^{c}
T3 (150)	2.35^{a}	0.34^{b}	4.10^{a}	0.34^{b}	0.23^{b}	0.16	7.7^{d}
T4 (200)	2.38^{a}	0.47^{a}	4.21^{a}	0.47^{a}	0.25^{b}	0.22	13^{a}
Minimum	2.12	0.34	3.10	0.34	0.19	0.12	7.7
Maximum	2.38	0.47	4.21	0.47	0.25	0.22	13
LSD0.05	0.183	0.03	0.25	0.082	0.05	0.16^{NS}	4.0
SEM±	0.039	0.01	0.14	0.018	0.01	0.02	10

Means within a column followed by the same letter is not significantly different at $p < 0.05$, Total number of leaf samples per experimental site was 12.

according to Kalira (1998). Despite the optimum K status of experimental soils, leaf K concentrations were increased with increasing K application from T2 to T3 (Table 2). It ranged from 3.10 to 4.21% and was sufficient as proposed by Kalira (1998).

Calcium ranged from 0.34 to 0.47% while magnesium varied between 0.19 and 0.25% having statistically similar contents at control, T3 and T4 (Table 2). Leaf Ca and Mg were deficient at all treatments in accordance with Kalira (1998). Boron content varied from 7.7 to 13 mg/kg and the highest values were recorded at T4 (Table2). The concentrations of B in plant leaves decreased with increasing rates of potassium application.

3.2 Effect of applied potassium on vegetative growth parameters

Enset plants were harvested at two years and four months after transplanting. The vegetative growth and number of leaves were increased with increasing level of potassium application (Table 3). The growths were also increased with increasing contents of N, P and K in the leaves of plant (Table 2) as was also reported by Uluro and Mengel (1994). The number of leaves per plant and vegetative growth in controls were significantly different ($p<0.05$) from those with K application. Plant heights ranged from 317 to 514 cm while the pseudostem heights range between 97 and 168 cm. Pseudostem circumferences varied from 121 to 177 cm. On the other hand, total number of leaves ranged from 46 to 74 while leaf lengths fall between 228 and 346 cm. Finally, leaf widths varied from 68 to 86 cm (Table 3).

3.3 Effect of increasing levels of potassium applicationon dry matter production

Above ground dry matter (Shoot)

The shoot dry weights were increased with increasing level of potassium application from T4 to T4 (Figure 2) and also increased with increasing contents of N, P and K in the leaves of plant (Table 2). Significant (P 0.05) differences in shoot dry weights were recorded between the controls and K treated plots (Figure 2). However, the differences among the applied K levels were not significant.

Below ground dry matter (Corm)

The corm dry matter production increased with increasinglevel of applied potassium (Figure 2). Dry weights of controls were statistically different ($p<0.05$) from K treated plots while T3 and T4 were at par. The dry weights were increased with increasing contents of N, P and K in the leaves of plant (Table 2).

Table 3. Effect of different rates of potassium on vegetative parameters.

Treatment (kg/ha)	Plant height, cm	Pseudostem, height, cm	Pseudotesm circumference, cm	3rd leaf length, cm	3rd Leaf width, cm	Total number of leaves
Control (0)	317^b	97^b	121^b	228^b	68^b	46^b
T2 (80)	467^a	152^a	165^a	322^a	82^a	67^a
T3 (150)	497^a	166^a	172^a	313^a	85^a	71^a
T4 (200)	514^a	168^a	177^a	345^a	86^a	74^a
Minimum	317	97	121	228	68	46
Maximum	514	168	177	345	86	74
$LSD_{0.05}$	61	27.2	19.5	50.8	6.5	8.2
SEM±	18	7.2	5.5	12.1	1.7	2.5
CV%	17.2	22.3	16	19.8	8.4	19.4

Means within a column followed by the same letter(s) is/are not significantly different at p< 0.05. Total number of leaf samples per experimentalsite was 12.

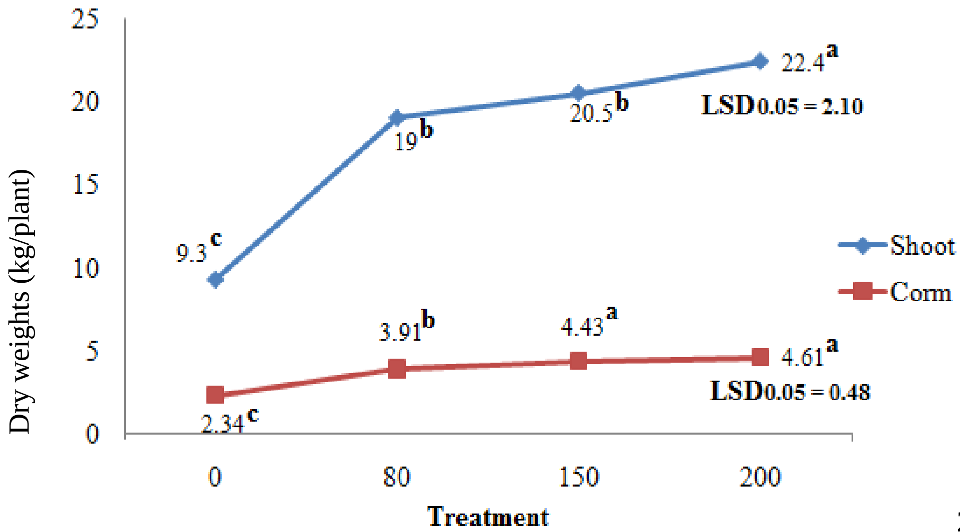

Figure 2. Effect of increasing rates of potassium on above and below ground dry weights. Means with the same letters are not significantly different at $p < 0.05$.

3.4 Maturity and yields of enset

Enset crops with K application reached the second edible stage (Sidamic term: etancho) in two year and four months after transplanting. Thus, it matured two years earlier as compared to the farmers' experience in the area, which takes four years to reach this stage. On the other hand, crops in control plots matured at one year later stage (Sidamic term: malancho) than those with K application. *Enset* yields were increased with increasing levels of applied potassium and significant differences ($p<0.05$) in yield were recorded between controls and the K applied treatments (Table 4). Yields were also increased with increasing contents of N, P and K in the leaves of plant (Table 2). Among the treatments, T4 resulted in the highest dry squeezed (36.8 kg/plant) weights of *kocho*. On the other hand, the lowest dry or squeezed (15.2 kg/plant) weights were recorded at control. Lastly, squeezed *kocho* yields at T2, T3 and T4 were higher by 49.5, 54 and 58.6%, respectively than yields obtained from control (Table 4). The highest *bula* weight (1.9 kg/plant) was recorded at T4 while recording the lowest (0.8 kg/plant) at control. The *bula* yields at T2, T3 and T4 were higher by 50, 52.9 and 57.9%, respectively than yields obtained from the control.

3.5 A cross-correlation among total dry matter, yields, potassium rates and leaf nutrient contents

The results of cross-correlation showed strong positive relationships between K rates and leaf K contents, *kocho and bula* yields and total DM (Table 5). Additionally, K rates showed strong positive associations with leaf percent N and P. Moreover intermediate negative correlations existed between B, K rates and K. Leaf K correlated positively and strongly with *kocho, bula* and total DM (Table 5). Leaf N correlated positively and strongly with *kocho* and *bula* yield while correlating strongly and positively only with total DM. It also correlated positively and intermediately with percent P. The leaf percent P correlated positively and intermediately with *kocho* and total DM while correlating positively and strongly with *bula* yield. Overall, the *kocho* and *bula* yields and total DM correlated strongly and positively with each other.

Table 4. Effects of increasing rates of potassium on *kocho* and *bula* yields.

Treatment(kg K/ha)	Squeezed *Kocho*	*Bula*	% Increase in squeezed *kocho* yield over control kg/plant	% Increase in *bula* yield over control
Control (0)	15.2^{c}	0.8^{c}	-	-
T2 (80)	30.1^{b}	1.6^{b}	49.5	50.0
T3 (150)	33.1^{b}	1.7^{b}	54.1	52.9
T4 (200)	36.8^{a}	1.9^{a}	58.7	57.9
$LSD_{0.05}$	3.7	0.2	-	-
SEM±	1.6	0.1	-	-
CV%	12.8	14.8	-	-

Means in a column followed by the same letter(s) is/are not significantly different at $p<0.05$.

Table 5. Cross correlation among *enset* leaf nutrient content, K rates, yields and total dry matter.

Parameter	N	K	P	S	B	K rates	Kocho yield	Bula yield	Total DM
N	1								
K	0.675*	1							
P	0.675*	0.687*	1						
S	0.339	0.418	0.241	1					
B	-0.479	-0.646*	-0.218	-0.211	1				
K rates	0.748**	0.962*****	0.778***	0.411	-0.654*	1			
Kocho yield	0.879****	0.865****	0.717**	0.286	-0.705*	0.914*****	1		
Bula yield	0.868****	0.863****	0.745**	0.278	-0.694*	0.904*****	0.991*****	1	
Total DM	0.899*****	0.899*****	0.669*	0.336	-0.726**	0.898*****	0.992*****	0.986*****	1

*Significant at $p<0.05$; ** $p<0.01$; *** $p<0.005$; **** $p<0.001$; ***** $p<0.0001$.

3.6 Economic analysis

The results of partial budget and economic analysis pertaining to the data on fermented and squeezed *kocho* and *bula* (Tables 6 to 9) showed that the highest marginalrate of return was obtained from K application at 80 kg K/ha while the highest net benefits were obtained from 200 kg K/ha in the district.

4. Discussion

The low pH of experimental site soil indicates the leaching loss of crop nutrients. Moreover, the low total N, available P, S and B contents could also reduce crop growth and yield (Kochet al. 2019).

Table 6. Economic Analysis of squeezed *kocho* yield.

Variable	Hula district			
	T_1	T_2	T_3	T_4
Total yield (t/ha)	38	75.25	82.75	92
Adjusted yield (t/ha)	34.2	67.73	74.5	82.8
Value in birr	205200	406380	447000	496800
Cost of KCl applied in birr	-	2775	5203	6937
Cost that vary birr	-	2775	5203	6937
Net benefits birr	205200	403605	441797	489863

T_1= Control or no K, T_2 = 80 kg K/ha, T_3 =150 kg K/ha, T_4 =200 kg K/ha.

Table 7. Partial budget analysis data of squeezed *kocho*.

Treatment		Hula district		
		Cost that vary (birr/ha)	Net Benefits (birr/ha)	Marginal rate ofreturn (%)
T1	Control	0	205200	-
T2	80	2775	403605	7149
T3	150	5203	441797	1573
T4	200	6937	489863	2772

T_1= Control or no K, T_2 = 80 kg K/ha, T_3 =150 kg K/ha, T_4 =200 kg K/ha.

Table 8. Economic Analysis of *bula* yield.

	Hula district			
	T_1	T_2	T_3	T_4
Total yield	2	4	4.25	4.75
Adjusted yield	1.8	3.6	3.83	4.3
Value in birr	126000	252000	268100	301000
Cost of KCl applied in birr	-	2775	5202.8	6937
Cost that vary birr	-	2775	5203	6937
Net benefits birr	126000	249225	262897	294063

T_1= Control or no K, T_2 = 80 kg K/ha, T_3 =150 kg K/ha, T_4 =200 kg K/ha.

Table 9. Partial budget analysis data of *bula* yield.

Treatment		Cost (birr/ha)	Net Benefits (birr/ha)	Marginal rate of return (%)
T1	Control	0	126000	-
T2	80	2775	249225	4440.5
T3	150	5203	262897	563.1
T4	200	6937	294063	1797.3

T1= Control or no K, T2 = 80 kg K/ha, T3 =150 kg K/ha, T4 =200 kg K/ha.

potassium in balanced nutrition as was also reported by MoA and ATA (2012). An increase of yield revealed that K promotes carbohydrate production when applied along with limiting nutrients as was also reported by White et al. (1974). This was confirmed by an increase of limiting nutrients concentrations; N, P and K in the leaves of *enset* plant with increasing levels of K application as was also reported by Uloro and Mengel (1994). This indicated the need for further investigation to determine site and crop type based critical K levels for different crops. Application of potassium also increased the maturity of *enset*. Thus, the results call for K recommendation in order to boast crop productivity. On the other hand, leaf Ca (< 0.50%) and Mg (< 0.20%) was deficient probably due to the antagonistic effect of K on the uptake of Ca and Mg (IPNI, 1998). Furthermore, due to B deficiency in the soil, increased growth caused by K reduced B concentration via dilution (Mengel and Kirkby 2001). The results of cross-correlations that strong positive relationships existed between K rates, yields and total DM; and leaf K, N and P contents indicated an increase of nutrient contents in *enset* leaves and yield with increasing K levels (Table 4). Positive relationship existed among K rates and leaf percent N is convincing, since leaf N contents increase with increasing K levels (IPNI, 1998) while positive correlation with percent leaf P indicated that applied P level was low to be affected by K levels. An intermediate negative correlation existedbetween B and K rates; and B and K indicates the dilution effect of increasing biomass production on boron (Mengeland Kirkby 2001).

5. Conclusion

Further site and crop specific investigations on critical levels of available K and application of K along with limiting nutrients in the study area are vital to increase *enset* yield. Hence, application of 80 kg K/ha two times throughout the life of *enset* is recommended since significant ($p<0.05$) growth, yield increase and marginal rate of return were obtained from this rate.

Conflict of Interests

The authors have not declared any conflict of interests.

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Research Article

Woody Species Diversity across Agricultural Land Use in Dale Wabara District, West Oromia Region, Ethiopia

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Abstract

Sustainable farming practices have a potential for conserving biodiversity and also providing wood resources for local community in such it is a good solution to reduce deforestation and forest degradation. Different land uses encompass various types of biological diversity. This study was initiated to assess woody species diversity across different land use types in Dale Wabara district, West Oromia Region, Ethiopia. In three kebeles a total of 45 quadrates were laid on different land use types; 15 quadrates in each lowest administrative unit with three replications for each land use to get vegetation data by selecting households randomly. Plots size of 10 m × 10 m for woodlot, complete enumeration with about 900 m^2 plot size for homegarden, 20 m x 25 m for coffee farm, 40 m x 40 m for grazing land and 50 m × 50 m for crop fields was drown. Species richness, diversity, evenness, frequency and important value index were analyzed between land use types. The study result showed that a total of 50 woody species belonging to 27 families were identified from these three kebeles. Fabaceae was the most dominant family with 7 and 14% species followed by Moraceae with 4 and 8% species. From the total identified species 78% were trees and 22% shrubs. The result of one-way ANOVA showed that the diversity of woody species significantly vary across land use types ($F_{(4, 10)}$ = 86.1, P< 0.001). The highest species diversity was recorded in homegarden (H'=2.796) followed by grazing land (H'=2.624). In general, agroforestry practices have a role for biodiversity conservation. Therefore, trees on farm land needs due attention to maintain woody species diversity within the system by farmers in order to more augment biodiversity conservation.

Key words: agroforestry practices, biodiversity, homegarden, land use types, woody species

1. Introduction

Attention and deliberate inclusion of trees in agricultural landscape has been a common practice among farmers for a very long time and the farming communities have played important roles in conserving crop and tree diversity (Oke and Jamala 2013). Tropical agricultural landscape including Ethiopia encompasses different land use types among which agroforestry practices are the major component. It is indicative of the complex, multi-layer structure of the natural forest with rich plant diversity and is shaped by deliberate planting or retention, and assisted regeneration of useful woody species (Kumar and Nair, 2004). [1]Agroforestry is a dynamic ecologically based natural resources management system through

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Received November 11, 2022
Accepted 26 May, 2023

integration of trees on farms that diversifies agricultural landscapes and sustains production for increased social, economic, and environmental benefits for land users at all levels (ICRAF 2002). The concept of agroforestry puts woody perennials, including trees and shrubs as pillars for the system/practice (Mengistu and Asfaw 2016). It is growing/cultivation of trees and of non-tree crops or animals on the same piece of land which provides diverse output from the same land units. These land use types conserve different types of plant species in pieces of land and minimizes the impacts of communities in the natural forests (Mengistu and Asfaw 2016). It was credited as a sustainable farming practice that uses and conserves biodiversity and limits agricultural expansion into natural forests in Ethiopia (Khumalo et al. 2012). Different types of traditional agroforestry practices are found in different parts of the country. Some of the practices includes: coffee shade tree systems, scattered trees on the farm land, home gardens, woodlots, and trees on grazing lands (Asfaw 2003; Tesfaye 2005). Many woody species of trees are deliberately preserved, and their regeneration is assisted in the agricultural environment because of their specific use (Bishaw and Abdelkadir 2003). Meanwhile, different land uses encompass various types of biological diversity. Among several of them, woody species are one of the dominant types basically grown naturally or manually (Mengistu and Asfaw 2016).

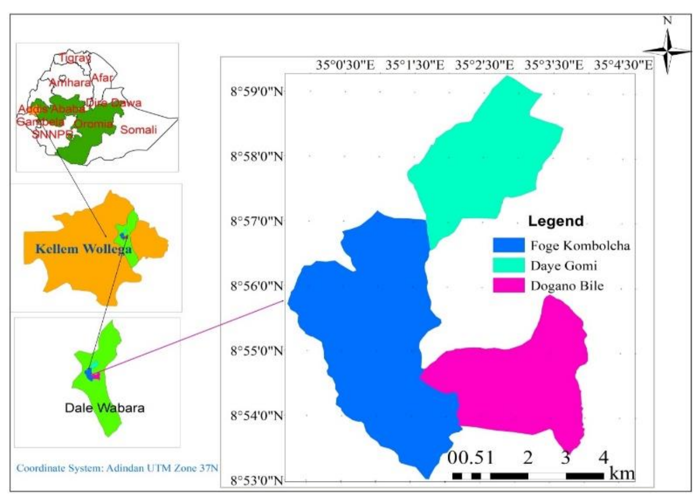
Study of the biological structure of agroforestry systems indicated by the number and abundance of species helps to identify plant diversity to increase their abundance and productivity (Hamilton, 2005). For the purpose of determining the role that governments can play in achieving the essential solutions and conservation strategies for biodiversity, it is crucial to identify the diversity potential of woody species across different land use types. Such issue is important for conservation intervention in agro-ecosystems of the smallholder farmers in general and that of the land use systems in particular.

In Ethiopia, documentation of agroforestry practices are very limited and has been concentrated especially in southern parts of the country (Zebene 2003; Tesfaye 2005; Tesfaye et al. 2010; Mathewos et al. 2013; Bajigo and Tadesse 2015; Wari et al. 2019). Information on agroforestry practices across different land use types (mainly homegarden, shade tree-coffee farm, trees on grazing land, trees on crop fields and woodlot) and its potentials have not been evaluated in the western parts. Therefore, this study was intended to assess woody species diversity across land use types in agricultural landscapes of Dale Wabara district, West Oromia Region, Ethiopia to contribute to filling the existing gaps.

2. Materials and Methods

2.1 Description of study area

The study was conducted in Dale Wabara District, Kellem Wollega Zone West Ethiopia (Figure 1). The district is located in between 35°0'30" to 35°4'30"E and 8°53'0" to 8°59'0"N. The study site is located at about 585 km from the capital city, Addis Ababa and has an altitude of 1850-2200 m.a.s.l. Nitosols is the major soil types of the study site. Agro-climatic zone of the study site is characterized to be wet Weina-Dega 98 % and moist Kola 2% with minimum annual



temperature of 20ºC and maximum 25ºC with annual rain fall ranges from 1200–1800 mm

(Dale Wabara District Agricultural Office, 20019).

Figure 1: Map of the study area

Agricultural activities of the study kebeles

The dominant farming activities in the study area are mixed farming systems. Due to their wide range of uses, valuable trees like *Cordia africana*, *Albizia gummifera*, and *Eucalyptus camaldulensis* are included in farms through retention or planting by farmers in agroforestry systems, which is the normal method of using agricultural land. The most land use type on which woody plants grown by farmers of the district are: home-garden, crop field, grazing lands, coffee farm and woodlots are more common. The major economic activities are livestock rearing and crop production. Among crop production like, maize, millet, teff, sorghum, coffee and wheat are highly produced in the area and cows, sheep, oxen and goats are common livestock. Whereas coffee, livestock and teff are the main source of income which accounts about 32%, 20% and 16% respectively in the study area (Dale Wabara District Agricultural Office 2019)

2.2. Methods

2.2.1 Sampling technique for woody vegetation inventory

Multi-stage sampling techniques were followed, with the help of experts and informants to select sample *kebele*. In the first stage the Dale Wabara district was divided into different category based on percentage of agroforestry coverage. This is obtained from the total area of the district, the area covered by agroforestry and then converted to percentage. Accordingly, it was categorized as high, medium and low percent of agroforestry cover. In the second stage, three *kebeles* were selected randomly by assigning random number to every *kebeles* from each category. Then Foge Kombolcha from high, Dogano Bile from medium and Daye Gomi from low agroforestry coverage were selected. Plots for homegardens, crop fields, coffee farms, grazing land, and woodlots were set out in three chosen kebeles by randomly selecting five (5) households in Foge Kombolcha, seven (7) households in Dogano Bile and 8 (eight) households in Daye Gomi, totally 20 (twenty) households through allocating random number. Households were randomized for random selection of sample plot for inventory. Accordingly, 15 plots in each *kebeles* in three replications for each land use including homegarden were laid out and totally 45 plots in three *kebeles* following (Abreha and Gebrekidan 2014). The sample sizes per land use type were found to be sufficient according to the plot number-species accumulation curve done after data collection following (Bajigo and Tadesse 2015). This is mostly due to plant incorporated in agricultural land is identical in species component due to farmers intensive species preference to include in their farm land unlike that of natural forest which have heterogeneity in plant species requiring large sample size. Here the distribution of the five land use types among household is not equal. Therefore, for the replication of land use the number of household randomly selected for inventory was different. As a result, the number of plots inventoried from each household in each *Kebele* was variable. During inventory, when the 1st household has only three or two of the five different land use, for the left land use the next randomly selected household was used for inventory to have equal replication. It was interesting to note that, to reduce bias, farmers also replicated for each land uses.

A total of nine sample plots for each land use types including homegarden were surveyed with sample size of 10 m × 10 m for woodlots according to Senbeta et al. (2002) and Ponce-Hernandez et al. (2004), for homegarden a complete enumeration with about 30 m × 30 m (Tolera et al., 2008), 20 m x 25 m for coffee farm (Negawo and Beyene, 2017), 40 m x 40 m for grazing land following Nikiema (2005) and for crop fields 50 m × 50 m Tadesse et al. (2019) because of the low density of trees in crop field. A large sample plot area was used since it was less likely to get woody species from small plots in this land use (Tolera et al., 2008).

2.2.2 Woody species inventory

In each sample plot, local name, number of woody species, diameter at breast height (DBH) and tree height were collected. DBH and tree height of woody plants were measured by using diameter tape and clinometer, respectively. The data were collected from woody species with DBH greater than or equal to five centimeters (≥ 5 cm) diameter at breast height (DBH at 1.3 m) and height ≥ 3m. This size was taken into account because of woody species less than this size is less available in agricultural land due to the fact that, farmers' intensive management to increase the land uses efficiency. With the help of a local Para taxonomist, species were identified using a guide book Flora of Ethiopia and Eritrea (Hedberg *et al*. 2004) and useful trees and shrubs for Ethiopia (Bekele 2007).

2.2.3 Data analysis

Inventory data were analyzed by Microsoft Excel and the outputs were used to determine population structures like basal area, importance value index (IVI) and frequency of woody species (Dibaba et al. 2014). The status of woody species in household's farms was examined by computing the diversity, species richness and evenness values. Accordingly, the following are the details of methods and steps used for analyzing the vegetation data.

The sum of all species encountered in each study area (through counting the total number of species) was used to determine the species richness of the study area (Giday et al. 2019).

Diversity was calculated by using the equation:

$$\mathrm{H}' = -\sum_{\mathrm{i}=1}^{\mathrm{S}} pi \ln pi$$

Where: H′= the Shannon Diversity Index, S the number of species, Pi = the proportion of individuals or the abundance of the i^{th} species expressed as a Proportion of the total, Pi = n*i* /N, ni number of individuals of species "i" N = total number of individuals of all species, ln log base e

A higher value of H' indicates high species diversity in the sample (Magurran 2004).

Shannon's evenness was calculated as:

$$\mathrm{j}' = \frac{\mathrm{H}'}{\mathrm{H}_{\max}} = \frac{\mathrm{H}'}{\ln \mathrm{S}} \text{ with } \mathrm{H}' = \mathrm{H}_{\max} = \ln \mathrm{S}$$

While, H' is Shannon index, j' = evenness
S = species richness
Equitability assumes a value between 0 and 1 with 1 being complete evenness (Magurran 2004).

Frequency was calculated as:

$$\text{Frequency} = \frac{\text{Number of plots in which species occur}}{\text{Total number of plots}} \text{x100}$$

Basal area was computed for each woody species as:

$$BA = \frac{\pi(\,DBH^2\,)}{4}$$

Where, π = 3.14, BA = basal area (m2), DBH = diameter at breast height (cm)

Similarity Indices: Was computed by the following formula:

$$\mathrm{S_s} = \frac{2\mathrm{a}}{2\mathrm{a}+\mathrm{b}+\mathrm{c}}$$

Where Ss - is Sorensen similarity coefficient, c is number of species common to both samples, a is number of species distinctive (found only) in sample 1, and b is number of species distinctive (found only) in sample 2.

Important Value Index was calculated as follows:
IVI (%) = Relative abundance + Relative dominance + Relative frequency

$$\text{Relative abundance} = \frac{\text{Number of individual}\mathbf{s}\text{ of woody species}}{\text{Total number of woody individual s}} \text{ x100}$$

$$\text{Relative dominance} = \frac{\text{Dominance of woody species}}{\text{Total dominance of all woody species}} \text{ x100}$$

$$\text{Relative frequency} = \frac{\text{Frequency of woody species}}{\text{Frequency of all woody species}} \text{ x100}$$

2.3 Statistical Analysis

One-way ANOVA was used using R software version 3.5.3. Significant differences detected through ANOVA with P<0.05 were investigated by comparison of means using Tukey's HSD test. During analysis woody species inventoried in each plots were converted to /ha to manage the variation in plot size of the land use types.

3. Results and discussion

3.1 Species composition

A total of 50 woody species belonging to 27 families were identified and recorded in the study area. Current study identified that *Croton macrostachyus, Albizia gummifera, Cordia africana, Vernonia amygdalina, Carica papaya, Grevillea robusta, Catha edulis, Eucalyptus camaldulensis, Cupressus lusitanica, Acacia lahai, Albizia schimperiana,* and *ficus vasta* were the most dominant species in the study site. Fabaceae was the dominant family represented by 7 species and it accounts (14%) following by Moraceae (8%), Euphorbiaceae, Myrtaceae and Bignoniaceae each account (6%). This result was in line with the result in Sub-Humid Lowlands of Ethiopia (Tadesse et al., 2019) and study in Wolayitta Zone of Ethiopia (Bajigo and Tadesse 2015) who reported that, Fabaceae family is the dominant family of the woody species recorded.

The results also revealed that, 37 (74%) of these species were indigenous while the remaining 13 species (26%) were exotic. This result is comparable with the result of Molla and Kewessa, (2015) who reported that from the identified species indigenous were the highest percent than exotic in traditional agroforestry practices of Dellomenna district, south eastern Ethiopia. Current study results showed that from the total 50 species, 39 (78%) were trees and 11 (22%) were shrubs which indicate that the largest portion of identified woody species were trees. This study was consistent with the study result of Wari et al. (2019), who reported that the identified woody species were dominated by trees.

Among recorded woody species, 23 species were found in home-garden, 16 in grazing land, 14 crop field, 18 in coffee farm and 4 in the woodlot. This indicates that, homegarden has got the highest woody plant species richness than other land use types in the overall study sites. Homegarden of Foge Komolcha has the highest woody species richness than other land use (16) followed by grazing lands of Foge Kombolcha (13) and Dogano Bile (12) when comparing species richness at kebele level. This is in line with the result of (Tolera et al. 2008; Fikir et al. 2018) who reported that, higher number of woody plant species found in homegardens than other land use types. However, the woody species richness of this land use is low as compared to Wari et al. (2019) in South western Ethiopia (39) and higher than (Mangistu and Asfaw 2016) in Dallo Mena Woredas of Bale zone South East Ethiopia.

From total woody species recorded in current study, four species were identified in woodlot which was much lower than other land uses in terms of species richness. This might be due to dominance of single species which affect the opportunity of other species occurrence. For instance, the intensity of light reaching the forest floor may differ in accordance with the density of crown cover, and this may influence understory plants colonization (Senbeta et al. 2002). The current study revealed that diversity of woody species varied from site to site. The variation could be due to differences in farm management, socioeconomic status, farmers' tree species preference and environmental factors. According to Schorth and Harvey (2007), different groups of species respond in different ways to various habitat types, management practices and landscape. Correspondingly, there were distinct differences in the level of species abundance and richness among the agroforestry types (Negash et al., 2012). Study in Southern Ethiopia shows that, due to the most important factors like local socioeconomic and physical conditions, there is variation in tree species richness on farm (Abebe et al. 2013). According to Tesfaye et al. (2014), there are more tree species in home compounds and fences than far away from homesteads due to day to day management and supervision by farmers. Results in Sub-humid lowlands of Ethiopia also indicate that, the accumulation of a greater number of species in homegardens compared to other land use is attributed to the planting preference of exotic species in homegardens (Tadesse et al., 2019). Similar to this results in South-East Ethiopia identified that, in the homegarden agroforestry practice, farmers manage both exotic and native trees/shrubs species (Mangistu and Asfaw 2016).

3.1.1 Similarity Indices

The similarities in woody species composition were compared among the land uses (Table 1). It measures the degree to which the species composition of different systems is alike (Guyassa et al. 2014). The highest similarity in woody species compositions (73.33%) was recorded between crop fields and grazing lands, while the lowest (18.18%) was between woodlots and coffee farms. Similar result with the result of Guyassa and Raj (2013) who identified that, the Sorensen coefficient of similarity estimated for crop land and grazing is greater as compared with others.

The relatively high similarity in woody species composition between grazing land and crop field could be due to the high number of common species found in both systems than other land use types. This is because of trees found in both systems were mostly composed from ruminants of forest species. The similarity index result of Dogano Bile and Foge Kombolcha sites were highest (64.61%) whereas it was lowest in Daye Gomi and Foge Kombolcha sites (55.17%) (Table 2). In home-garden-coffee farm, home-garden-woodlot, crop field-woodlot, grazing land-woodlot and coffee farm-woodlot this index were low comparing with others. This implies that, they have less overlapping species with each other which could be resulted from farmer's tree selection on different land uses for different purposes. This might be explained by the fact that farmers intensive species selection for different uses on different land use types might lead to low similarity index between land use types (Mengistu and Asfaw, 2016).

Table 1: Similarity indexes of woody species among land use types.

	Sorensen similarity index in percent (%)			
Land use type	Homegarden	Grazing land	Crop field	Coffee farm
Homegarden	-	-	-	-
Grazing land	42.72	-	-	-
Crop field	57.43	73.33	-	-
Coffee farm	38.28	43.53	43.05	-
Woodlot	34.78	20	33.33	18.18

Table 2: Percent of Sorenson similarity index in three sites

Site	Daye Gomi (%)	Dogano Bile (%)
Dogano Bile	64.4	-
Foge Kombolcha	55.17	64.61

3.2 Woody species diversity

The Shannon diversity index across land use types were varied from 2.796 to 0.304 and species evenness varied from 0.946 to 0.219 (Table 3). It is important to note that during analysis woody species inventoried in each plots were converted to /ha to manage the variation in plot size of the land use types since Shannon diversity index is sensitive to different plot sizes.

Table 3: Woody species richness, diversity and evenness across land use types of study area

Land use type	Species richness	Species diversity (H')	Species evenness (j')
Crop field	14	2.163	0.819
Grazing land	16	2.624	0.946
Coffee farm	18	0.742	0.257
Homegarden	23	2.796	0.892

Woodlot	4	0.304	0.219

The result of one-way ANOVA showed that the diversity of woody species significantly vary across land use types ($F_{(4,10)}$ = 86.1, P< 0.001) Figure 2). The highest species diversity was recorded in homegarden (H'=2.796) followed by grazing land (H'=2.624) and crop field (H'=2.163). Woodlot has the lowest Shannon index than other land use types. This result is in line with study result in Wolayitta Zone indicating homegarden has the highest species diversity than other land use types (Bajigo and Tadesse, 2015). Evenness indices were highest in grazing land (j'= 0.946). It was interesting to note that despite grazing land has lower number of species than homegarden, it hosts evenly distributed species throughout its ecosystem. This contributed to high evenness index in this system.

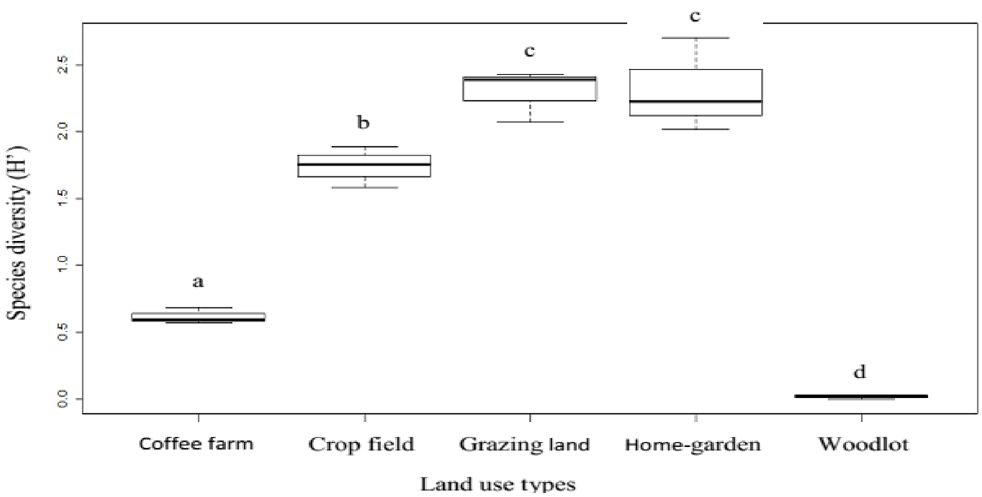


Figure 2: A boxplot showing the woody species diversity across land use types. The different small letters on boxplot indicate the significant differences in diversity among land use types.

The higher diversity indexes in homegarden could be due to difference in distribution of number of individuals and species richness as a result of variation in woody species efficiency, the difference in agroforestry practices, and planting site preference. This could be the case, because Shannon diversity index is usually associated with an increase in species richness (Abebe et al. 2010). According to Agidie et al. (2013), some farmers prefer to plant trees around their home to protect them from the livestock by family members. Studies in North Western Ethiopia indicated that the highest species diversity is due to the highest species richness (Giday et al. 2019). Even though the highest species evenness is also the case for the highest species diversity this may be not usually in where there is low number of species with evenly distributed in the system. According to Abebe et al. (2013), the composition, diversity and density of tree are influenced by physical and socioeconomic factors. Other findings also show, the higher woody species diversity around homesteads is due to the higher soil fertility from animal manure around this area contributes the higher performance of trees and shrubs (Felix et al., 2018; Giday et al. 2019) and also the daily follow up by farmers (Tesfaye et al. 2014).

Comparing different land use types in terms of Shannon diversity indices, there was no statistically significance difference between homegarden and grazing land agroforestry practices in the study area. Variation was observed when comparing coffee farm with crop field, grazing land, homegarden, and comparing woodlot with crop field, grazing land and homegarden which was statistically significant (p<0.001). There was statistically significant difference (p<0.05) in diversity indices when comparing woodlot-coffee farm, grazing land-crop field and home-garden-crop field. Between woodlot and coffee farm, it was lowest at woodlot and highest in coffee farm, whereas between grazing land-crop field and homegarden-crop field it was lowest in both comparisons at crop field. Results in Wolayitta Zone and Sub-humid lowlands of Ethiopia indicate, diversity index is significantly higher in homegarden than crop field (Bajigo and Tadesse 2015; Tadesse et al. 2019). This might be caused from farmer's continuous cultivation of crop field for crop production which affects the distribution of woody species across this system.

During comparisons, similar pattern of variation was also found for evenness values across different land use types. Comparing evenness indices of coffee farm with grazing land, home-garden and crop field it was highest in those land uses and lowest in coffee farm. The results also indicated that when comparing evenness indices of woodlot with crop field, grazing land, homegarden and coffee farm, it was lowest at woodlot than those land uses (j'= 0.219). These difference was statistically significant ($p<0.001$). However, comparing crop field with grazing land and home-garden, the evenness indices were highest in grazing land and homegarden and lowest in crop field which was statistically significant ($p<0.05$) and while there was no significant difference among home-garden and grazing land. The results were similar with the result of Fikir et al. (2018) who identified that, similar pattern of variation was also found for evenness values among land uses.

Comparing current study results at three kebele, as the result of Shannon diversity index shows, Foge Kombolcha was more diversified followed by Dogano Bile and Daye Gomi in homegarden agroforestry of study sites, where species evenness ranges between 0.974 and 0.896 (Table 4). The result was higher in both species diversity and evenness than home-garden of Gununo Watershed in Wolayitta zone (Bajigo and Tadesse, 2015) and in the South-central highlands of Ethiopia (Tolera et al. 2008) while lower in diversity index and higher in evenness index than study in East Shewa zone of Ethiopia (H'=3.05, j'= 0.34) (Yemenzwork 2014).

Table 4: Woody species richness, diversity and evenness in three kebele sites

Land use	Site	Species richness (No.)	Species diversity (H')	Species evenness (j')
	Dogano Bile	7	1.580	0.802
Crop field	Foge Kombolcha	8	1.754	0.823
	Daye Gomi	10	1.889	0.821
	Dogano Bile	12	2.388	0.961
Grazing land	Foge Kombolcha	13	2.428	0.944
	Daye Gomi	9	2.071	0.942
	Dogano Bile	9	0.597	0.271
Coffee farm	Foge Kombolcha	7	0.684	0.352
	Daye Gomi	8	0.572	0.275
	Dogano Bile	12	2.227	0.896
Homegarden	Foge Kombolcha	16	2.700	0.974
	Daye Gomi	9	2.016	0.917
	Dogano Bile	2	0.021	0.031
Woodlot	Foge Kombolcha	2	0.000	0.000

Daye Gomi	3	0.025	0.036

In grazing land, the highest diversity was recorded in Foge Kombolcha than Dogano Bile and Daye Gomi site with evenness index varying from 0.961 to 0.942. This result was higher in both species diversity and evenness index than result in Tigray region of Ethiopia (Guyassa and Raj 2013), when it was lower than the study result of South Western Ethiopia in species diversity and more or less higher than in evenness index (Wari et al., 2019).

The highest species diversity was recorded in the crop field of Daye Gomi than in Foge Kombolcha and Dogano Bile sites and evenness index of woody species ranged between 0.823 and 0.802. The result shows that, when comparing crop field with home-garden and grazing land, both index was low in this land use type. This could be resulted from very scattered and ununiformed (low evenness) distribution of species in this land use type (Guyassa and Raj 2013). Study in South-central highlands of Ethiopia indicate, Shannon diversity indices and evenness indices is higher in natural forest than crop fields and home-gardens due to the uniform distribution (high evenness) of species (Tolera et al. 2008). This result was higher in both Shannon diversity index and evenness index than study result in Tigray region of Ethiopia (Guyassa and Raj, 2013). However, it was lower in Shannon diversity index and higher evenness index in crop field of the South-central highlands of Ethiopia (Tolera et al. 2008) and Enda Mekhoni Wereda in Tigray region of North Ethiopia (Guyassa et al. 2014).

In Foge Kombolcha site, woody species diversity is higher than Dogano Bile and Daye Gomi while evenness index ranges from 0.352 to 0.271 in coffee farm land use type. The lowest species diversity in coffee farms in relation to other land use types may be explained in terms of uneven distribution of shade tree species and large percent domination of coffee shrubs in the study area. The result was in line with Wari et al. (2019) who reported that, single species (*Coffea arabica*) dominated the coffee farm and less shade tree species number. According to Mengistu and Asfaw (2016), due to farmer's activity to increase the land use efficiency like intensive thinning of other plant species in order to reduce competition from the coffee, lower species diversity is recorded from coffee farm agroforestry practices; and these activities might affect and limit the number of woody species grown in the system. Study in South East Ethiopia indicate that, in shade grown coffee agroforestry practice, about large percent of the practice are covered by coffee shrubs and other important shade tree species which are highly familiar and positive interaction with coffee plants are only found (Mengistu and Asfaw 2016). This result indicates higher diversity index and lower evenness index than study result in South East Ethiopia, while it was lower in both Shannon index than the result recorded in South West Ethiopia (Tadesse et al. 2014).

In relation to other site, relatively higher levels of diversity were recorded in woodlot of Daye Gomi followed by Dogano Bile while it was zero in Foge Kombolcha site. This result was similar with the result of Bajigo and Tadesse (2015) who reported that, since the woodlot is composed of single species, the diversity index was relatively zero. Species diversity index and evenness index were ranges between 0.025 to 0.000 and 0.036 to 0.000 respectively. The study result show that, the diversity index and evenness index of this land use type was lower in all sites than other land use types. This result was in agreement with those of Wari et al. (2019) who reported that, woodlots composed of some woody species, and the diversity index was relatively lower in all sites than other land use types. The same to this, current study identified woodlots are dominated by a single species mostly *Eucalypus* species and *Grevillea robusta* which was consistent with the result of (Bajigo and Tadesse, 2015) in Wolayitta zone of Ethiopia. Additionally, grazing land was more diversified followed by home-garden and crop field in Dogano Bile site. This result was in line with the study result of Wari et al. (2019), who reported that grazing land recorded highest species diversity than other land use system. Homegarden of Foge Kombolcha was more diversified than other land use types in overall study site whereas species diversity of grazing land in each sites were higher than coffee farm, homegarden, woodlot and crop field except with Foge Kombolcha and Dogano Bile site homegarden.

Generally, this study showed that, species diversity and richness varies across different land uses. The land use types did also show clear differences when evenness indices are considered. This could be due to difference in topography, functions of species, nutrient and moisture availability, management activity and factors related to socioeconomic of the farmers. According to Nuberg et al. (2009), the variations of species diversity among different area is due to variation in topographic variables, moisture and nutrient availability. The study result in Southern Ethiopia showed that altitude have significant effects on total species richness, composition and diversity and identified that, diversity of tree decreases with increasing altitude. As altitude increase there is high rainfall and minimum temperature which restricts plant growth (Tefera et al., 2016). Similarly, result in South Eastern Rift Valley of Ethiopia indicate, the variation in species richness probably was due to differences in altitude and farmers' tree management practices. They report that, farmers in enset agroforestry give more emphasis to managing *Enset ventricosum* with native woody species. Due to this they practice thinning to create more space for growing this species (Negash *et al*. 2012).

High species diversity is often associated with important ecological services such as nutrient cycling, soil and water conservation, and resilience under anthropogenic pressure (Jose, 2009). According to Faye et al. (2011), the most important functions of tree species are essential products like food, medicines, animal fodder, and fuel wood followed by environmental services which include soil fertility improvement, soil/water conservation, shade and sale products to generate revenue. Frequently existed woody species are fast growing, shade tree, tolerable for different managements and those provide different uses (Bajigo and Tadesse 2015). For instance, *Eucalyptus* is ranked higher than all other trees based on its growth performance, the availability of saplings at local extension offices, and its overall multi functionality (Tefera et al. 2014).

3.3 Structure of woody species

Frequency

The current study showed that more percentage of woody species were frequently observed within frequency class '1' in crop field, coffee farm, woodlot and home-garden, whereas, frequency classes '2' in grazing land (Table 5). This result was in line with (Tefera et al., 2016; Wari et al., 2019) who reported that most of trees and shrubs species were recorded in the frequency class 'A'. The least number of species were recorded for frequency class 1 (6.25%), 3 (5.55%) and class 4 (8.76%) in grazing land, coffee farm and home-garden land use types, respectively.

Table 5: Woody species frequency class percentage in different land uses

	Frequency class				
Land use types	1 (0-20%)	2 (21-40%)	3 (41-60%)	4 (61-80%)	5 (81-100%)
Grazing land	6.25	62.5	18.75	12.5	-
Crop field	42.85	35.71	21.42	-	-
Coffee farm	66.67	16.66	5.55	-	11.01
Woodlot	67.7	15.5	-	16.86	-
Homegarden	34.78	34.71	21.75	8.76	-

The most frequently observed woody species in grazing land were *Acacia lahai* (66.66%) and *Croton macrostachyus* (55.05%) respectively; while *Terminalia laxiflora* (22.2%) was the least frequent in the overall study area. Where *A. lahai* (67.16%) and *Maesa lanceolate*

(60.37%), in Foge Kombolcha; *A. lahai* (56.4%), *C. macrostachyus* (53.2%) and *Ficus vasta* (45.46%) were the most frequent species in Dogano Bile site. *Vernonia auriculifera* (71.3%) and *Buddleia polystachya* (64.21%) were the most frequented woody species in Daye Gomi grazing land. Most of these species were frequently cited in other grazing land (Wari et al., 2019). In homegarden the most frequently woody species were *Catha edulis* (77.32%) and *Carica papaya* (55.58%) where *Olea africana* (11.12%) was the least frequent in the overall study site. *Cupressus lusitanica* (72.6%) and *Grevillea robusta* (65.08%) in Foge Kombolcha site; *Citrus sinensis* (86.42%) and *Juniperus procera* (82.7%) in Dogano Bile site whereas in Daye Gomi site *C. edulis* (85.77%) and *Vernonia amygdalina* (78.04%) were the most frequently observed woody species in home-garden agroforestry system. Most of these woody species also frequently cited by (Mekonen et al., 2015; Tefera et al., 2016; Wari et al., 2019). In crop field, *Cordia africana* (55.63%), *Eucalyptus camaldulensis* and *V. amygdalina* both (44.57% each) were frequently observed in overall sites. Where in Dogano Bile site *C. macrostachyus* (66.45%) and *C. africana* (60.8%); while in Foge Kombolcha, *C. africana* (57.11%), *C. macrostachyus* (53.8%) and *E. camaldulensis* (48.62%), whereas in Daye Gomi site, *C. africana* (60.8%) and *V. amygdalina* (59.42%) were frequently found. These woody species frequently observed in another crop field. For instance, *A. gumifera and C. africana* in South western Ethiopia (Wari et al., 2019) and *C. macrostachyus* is the most frequent woody species encountered in crop fields of south central highlands of Ethiopia (Tolera et al., 2008). *C. macrostachyus*, *E. camaldulensis* and *V. amygdalina* were frequent woody species cited by Duguma and Hager (2010).

Coffea arabica (100%), *Albizia schimperiana* (57.53%), *V. auriculifera* (51%) and *C.africana* (48.03%) were the most frequently woody species encountered in coffee farms of the study area. Other studies in South East Ethiopia identified that *C. arabica* is the most frequently observed woody species in coffee farm (Mengistu and Asfaw, 2016). According to study result in Eastern Uganda, *C. africana* is the most frequent tree species encountered in coffee farm agroforestry system (Negawo and Beyene 2017). The only frequently observed woody species in class '5' and no species were recorded in frequency class '4' in this land use type. In woodlot, the most frequently observed woody species was *E. camaldulensis* in the study area. It was 66.67% frequency in the overall study sites, while 100% in Dogano Bile and Daye Gomi sites. *G. robusta* next to *E. camaldulensis* was the frequent woody species encountered during inventory with frequency of 33.33% in overall study sites and 100% in Foge Kombolcha site. Similar with the result of Wari et al. (2019) who reported that, *E. camaldulensis* was the most frequently observed species during the survey in woodlots. The frequency distribution of woody species on different land use types in the present study was variable. Study in South Eastern Ethiopia showed that, the frequency distribution of tree species on farms is variable (Molla and Kewessa 2015). This might be due to their values on land use types. As one would expect, tree species with a greater economic or ecological value or both were found to be frequently distributed across the farms (Molla and Kewessa, 2015).

3.3.1 Importance value index (IVI)

Importance value index (IVI) measures the overall importance of a species and gives an indication of the ecological success of a species in a particular area (Molla and Kewessa 2015). Species with high IVI is associated with the land uses and based on farmer's species preference which is linked with species market demand and service value. Especially in agroforestry practices, species with higher IVI are associated with framers species preference and product value (Mengistu and Asfaw, 2016). In this study the IVI showed that, *V. auriculifera*, *C. edulis*, *V. amygdalina* and *C. papaya* have high IVI due to their relatively high relative abundance 11.67%, 10.58%, 10% and 7.05%, respectively. *E. camaldulensis* (90.5%), *C. africana* (32.91%), *F. vasta* (23.6%) and *C. macrostachyus* (19.29%) have high relative dominance and hence contributed highest IVI value in the study area. According to Kent and Coker (1992), important value index indicates the extent of the dominance, occurrence and abundance of a given species in relation to other associated species in an area. The dominance of these species could be associated to their higher economic roles in the system. The study result of Mekonnen et al. (2014) showed that species with multiple uses showed higher IVI.

The most important woody species in the five land use types of the study area with highest IVI's was presented in (Table 6). Of all species, *E. camaldulensis* (134.46%), *C. arabica* (52.64%), *C. africana* (47.24%), *F. vasta* (34.26%) and *G. robusta* (19.27%) were the top ranking in woodlot, coffee farm, crop field, grazing land and homegarden respectively. As the current study indicated, the species with higher IVI were most important woody species in land use types of study area. For home-garden agroforestry practices the highest IVI value is covered by species which provide higher income for the farmers, while in the case of coffee agroforestry practice, about large percent of the practice were covered by coffee shrub and other important shade tree species which are highly familiar and positive interaction with coffee plants. Due to this in coffee farm *C. arabica* contributed the highest IVI because of its high relative frequency than shade tree. According to Mengistu and Asfaw (2016), in home-garden agroforestry practice, woody species with highest IVI are fruit tree species and other high market value species whereas, in shade grown coffee agroforestry practice woody species with the highest IVI are *C. arabica* and few other shade tree species.

Table 6: The top five woody species with the highest IVI values in land use types.

Land use types	Species name	IVI
Homegarden	*G. robusta*	**19.27**
	C. papaya	19.17
	V. amygdalina	18.04
	C. lusitanica	17.53
	C. edulis	16.85
Grazing land	*F. vasta*	**34.26**
	C. macrostachyus	31.72
	Acacia species	28.51
	V. amygdalina	21.78
	M. lanceolate	16.03
Crop field	*C. africana*	**47.24**
	C. macrostachyus	32.26
	A. gummifera	28.16
	V. amygdalina	19.74
	E. camaldulensis	13.41
Coffee farm	*C. Arabica*	**52.64**
	A. schimperiana	35.56
	C. africana	23.62
	Acacia species	11.17
	V. auriculifera	10.85
Woodlot	*E. camaldulensis*	**134.46**
	G. robusta	54.30

This study identified that, *A. schimperiana* and *Acacia* species were most preferred woody species for coffee shades as they have thin and small leaves which allow an appropriate amount of light to reach the coffee trees. These results were in line with the result of Ango et al. (2014) who reported that, woody species with thin, small and elongated leaves are most preferred species as shade for coffee. Especially, *V. auriculifera* was preferred species during early establishment of coffee farm on treeless field until permanent shade tree species grown enough due to their fast growing habit in study area. Study results of Wari et al. (2019) also identified that, small trees and shrubs were used for shade when farmers convert other land uses and/or treeless field to coffee farm due to fast growing and soil fertility improvement. In crop field *C. africana*, *A. gumifera*, *C. macrostachyus* and others were the most important woody species found. During informant interview, they pointed out that, these tree species were incorporated for their multiple uses like nutrient cycling and crop protection besides to other economic uses. Study result of Agidie et al. (2013) in upper Blue Nile basin of Ethiopia showed, *C. africana* is preferable for timber, farm equipment and fodder while *C. macrostachyus* is useful for its fuel, fence, soil improvement and shade. They identified that, these species are widely found on farmlands, homesteads and farm boundary and has no any harmful effect to crops. According to Schroth et al. (2001), the incorporation of shade trees on crop field is frequently shown to positively affect and nutritional status through improved light regulation and nutrient cycling.

In homegarden agroforestry system *G. robusta, V. amygdalina, C. lusitanica, C. papaya and C. edulis* were the most important woody species recorded in this system. The current study identified that some of species were exotic, fruit trees and cash crops which have mostly economic value. This finding was in line with the result of Tolera et al. (2008) who reported, species occurred in homegarden were mostly exotic trees such as *Eucalyptus* and *Cupressus* spp., fruit trees and cash crops such as chat (*C. edulis*), which are all species of economic or nutritional importance for farmers. In woodlot land use type, *E. camaldulensis* and *G. robusta* were the most important woody species recorded in the study area. Other study in South Western Ethiopia showed that *E. camandulensis, C. lusitanica* and *G. robusta* were the most important woody species identified in woodlot land use type (Wari et al., 2019). *E. camaldulensis* was species dominating woodlots in the study area due to its multiuse like for pole, fencing, fire wood and market value. According to Agidie et al. (2013), farmers prefer *E. camaldulensis* for its multipurpose uses (poles, fuel and charcoal, construction and farm implements) and its contribution to income generation. Current study also revealed the most important woody species in grazing land were *F. vasta*, *C. macrostachyus, V. amygdalina, M. lanceolate* and *A. lahai*. Trees on grazing land play an interactive role in animal production by providing shade and fodder (Agidie et al., 2013). Especially key informant mentioned that, trees like *F. vasta, V. amygdalina, A. lahai and C. africana* were help as supplementary feed during dry months. According to Duguma and Hager (2010), *V. amygdalina* is the highly preferred species for animal feed.

3.3.2 Distribution of DBH and Height Classes

3.3.2.1 Density

The density of woody species was analyzed in the overall study sites. As the result indicates woodlots were higher than other land use types in number of woody plants per hectare (Table 7). Next to woodlot coffee farm and homegarden have higher woody plant density respectively.

Table 7: Density of woody plant in the study area

Study area	Density per hectare				
	Homegarden	Grazing land	Crop field	Coffee farm	Woodlot
Site	1043.17	659.69	305.3	1971.52	6507
Dogano Bile	893	615	296	1021.7	4521.52
Foge Kombolcha	1103.64	519.3	401.4	2058	5641.61
Daye Gomi	962	502.17	187	1103	4031

3.3.2.2 Distribution of DBH

Distribution of all individuals in different DBH size classes was analyzed and classified into 5 classes as A (5-15cm), B (15.1-25cm), C (25.1-35cm), D (35.1-45cm), E (45.1-55), F (>55cm). DBH class distribution of all individuals in different size class showed an inverted J-shape distribution in overall land use types of study area (Figure 3). This result was similar with the result of (Dibaba et al., 2014; Mengistu and Asfaw, 2016; Wari et al., 2019). Out of the total woody species, 49.03% were distributed in “A” diameter class and 25.6% were distributed in B diameter classes. This indicates most of individual species have lowest DBH size in most of land use types. This might be due to farmer’s tree selection, the tree characteristics, replacement of aged tree species by productive young and high resource competition within the system. Farmers were very sensitive for the land and very much selective for the tree species grown on their field. For instance in home-garden most of the trees grown were fruit trees which have small diameter. According to Mengistu and Asfaw (2016), due to farmers intensive tree selection most of trees grown in their field are fruit tree species which are not that much larger in diameter.

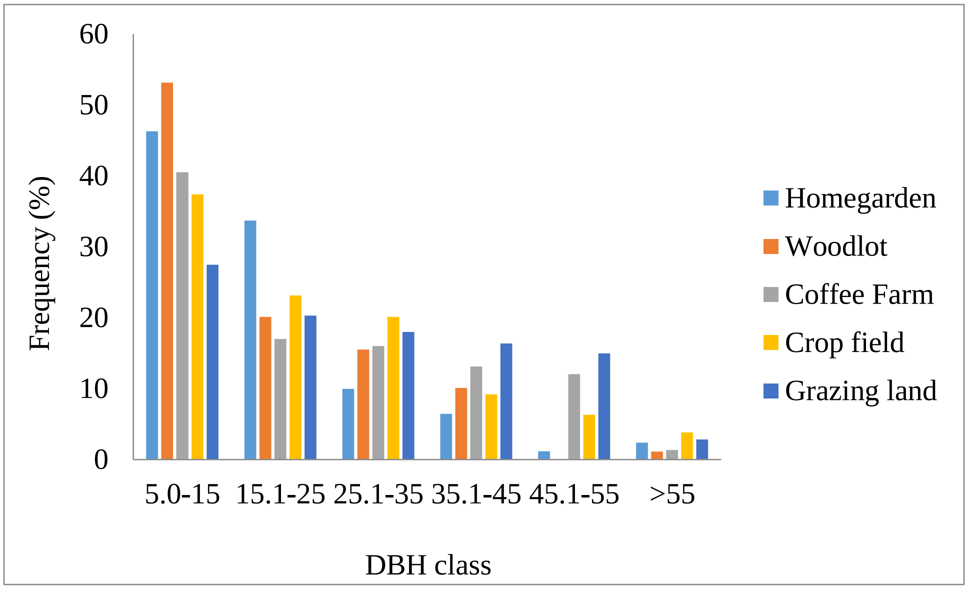


Figure 3: DBH class distribution of woody species in different land use type

In case of coffee farm, the system is dominated by coffee shrubs and very limited individual of shade tree components. Due to selective thinning limited tree species are grown on the larger area without competition for many years and results in higher DBH for few shade trees like *A. schimperiana, C. africana* and *Acacia* species in this system. Study result of Soto-Pinto et al. (2001) identified that, most of shade components were in the range of <20 cm DBH and most of the trees had height of ≤ 15m in coffee farms. Therefore, there was higher tree abundance at both the lower diameter and height classes in the system (Likassa and Gure, 2017). In grazing land there was more small sized and few large sized woody species found. In this system large sized tree species like *F. vasta, C. macrostachyus* and *Acacia* species were maintained specially to serve as shade during dry season. These species contributed highest DBH in this land use types. In case of woodlot, key informants explained, *Eucalyptus* were mostly planted in high densities for the requirement of straight poles which lead to resource competition and may results in low diameter.

3.3.2.3 Height classes distribution of woody species

From all system all individuals with ≥3 m height woody species identified during inventory and were categorized in to height classes. Based on the height, all species were classified into three height classes as 3 to 10 m lower height class, 10 to 17 m medium height class, and ≥17 m upper height class (Figure 4). The study results showed that woody species had highest frequency percentage of lower height class distribution across homegarden, coffee farm and crop field. This could be resulted from woody species management by farmers for different purposes.

According to Mengistu and Asfaw (2016), in homegarden and crop field in order to reduce shade and minimize light competition from the under growth plants the height of trees are managed repeatedly which affects height growth. Additionally, the majority of trees cultivated in this system were multi-purpose tree species whose height was controlled to collect wood for fence, house construction, farm equipment, animal feed, firewood, and also for sales.

Figure 4: Height class distribution of woody species in different land use types.

This result was in line with the result of Yakob et al. (2014). In case of coffee farm, the system was covered by very few shade trees and more coffee shrubs with small height in the study area. Woodlots were mostly dominated by higher heights. According to key informants, woody species produced in woodlots were mostly needed with sufficient heights for construction items like poles. This result was similar with the result of Wari et al. (2019) who reported that, woodlots are purposely required for woody products and it is dominated by higher height woody plants in overall study sites.

4. Conclusion and Recommendation

Farmers have got the tradition of integrating and managing woody species in different land use types. This could be seen as an opportunity which promotes local peoples interest in conservation and maintenance of such locally important species through agroforestry systems. They include woody plants into their farmlands through retention of remnant or naturally regenerated plants and/or undertaking plantation activities. In the present investigation, there was considerable significant variation in woody species diversities among different land use types of the study area. Accordingly, the study concluded that home-gardens host more diverse woody species followed by grazing land and crop field while lowest species diversity was recorded in woodlot.

Generally, traditional agroforestry practices in which woody species integrated and managed with indigenous knowledge could be potential for biodiversity conservation; and one option to address the problems of deforestation and related resource degradations in the current study area. The results of the present study confirm that, agroforestry practices can play a significant role in conservation of woody species diversity. Moreover, the presence of woody species in these systems may favor the survival of other organisms and hence contribute to wider conservation of biological diversity.

In order to manage integrated plant species on farmlands and sustain the existing woody species, it is necessary that more concrete efforts and interventions in conservation are required to retain woody species on farmlands to increase diversity. This is more important for improvement of the traditional agroforestry practices in which multi-purpose tree species are included for providing varies forest products and in doing so reducing pressures from existing forest besides to contributing to biodiversity conservation. Therefore, attention should be given to trees on farmlands and related land use types.

Acknowledgments

The authors would like to give thanks to almighty God who extends our life to this. We are very much grateful to Dr Debissa Lemessa for unreserved guidance and invaluable contributions to this research. Perhaps, special thanks to the local farmers, woreda level natural resource conservation experts and Jimma University for facilitating all required process.

Conflicts of interest: We (the authors) declare that they have no conflicts of interest.

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Research Article

The Status of Selected Essential Plant Micronutrients under Enset (*Ensete Ventricosum* (Welw.) Cheesman) Farming Systems in Sidama Region, Ethiopia

Kibreselassie Daniel Auge

Abstract

Information regarding micronutrients' status under enset farming system soils is rare. Thus, the objective of this study was to assess the status of micronutrients in soils under an enset farming system and their relationship with soil properties in Hula, Dale and Hawassa-Zuriya districts of Sidama region, Ethiopia. Soil samples were collected from Woinadega (warm subtropical climate) and 'Dega' (wet and cool temperate climate) agro-ecologies using stratified random sampling technique. The acidic reaction was high, medium and low in Hula, Dale and Hawassa-Zuriya districts, respectively. The lowest (2.0 mg/kg) Zinc, the highest (259 mg/kg) and the lowest (15 mg/kg) Manganese ($P<0.0001$) were recorded in Hawassa-Zuriya, Dale and Hawassa-Zuriyadistricts, respectively. The highest (0.0028) iron (214 mg/kg) and copper (2.0 mg/kg) were determined in a Hula district. Boron was low (0.5-0.8 mg/kg) in a Hula district while optimum (0.8-2 mg/kg) in Dale and Hawassa-Zuriya districts. Zinc was optimum in Hawassa-Zuriya while high in Dale and Hula districts. Manganese was very low (<60 mg/kg) in Hawassa-Zuriya district while optimum (100-300 mg/kg) in Dale and Hula districts. Iron (25-300 mg/kg) and Cu (0.9-2.0 mg/kg) were optimum in the districts. Positive correlations occurred between Boron, pH and CEC; Cu, Mn and CEC and SOM, and the micronutrients while pH and micronutrients such as Fe and Zn; and phosphorus and zinc correlated negatively. Agro-ecological and soil type variations influenced the size of essential plant micronutrients across the districts with the lowering effect from the low to high altitudes except for Boron. Hence, it is concluded that there should be soil micronutrients management to tackle the altitudinal variation effects that lowers their level in soils.

Key words: enset, Ethiopia, soil nutrients, soil organic matter

1. Introduction

Enset (Ensete ventricosum (Welw.) Cheesman) is a part of sustainable production system and has been cultivated in Ethiopia since ancient times (Garedew et al. 2017). It is among the domesticated cultigens (Khoury et al. 2016) and referred to as false banana. Enset is commonly known as false banana because it differs from domesticated bananas in that the mature plant does not produce edible fruit (USDA Agricultural Research Service, 2015).

[1] It is most commonly grown in home-gardens, frequently intercropped with peas or beans,

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Received 18 May, 2022
Accepted 26 May, 2023

which is suitable to compensate the low protein level in enset foods (Abebe et al. 2010).

Micronutrients are elements (Fe, Mn, Zn, Cu, B, Mo and Cl) required by crops in small quantities and known to be essential for plant growth. Plants require them for protein and auxin production (Zn), as constituent of cytochrome oxidase (Cu), photosynthesis (Fe), germination of pollen grains and growth of pollen tubes, and formation of seed, cell walls, and protein (B), conversion of nitrates to ammonium within the plant and process of N fixation by legume nodules (Mo), in several enzymatic reactions, in the synthesis of chlorophyll, carbon assimilation and nitrogen metabolism (Mn) (Arokiyaraje et al. 2011).

Soil pH is a valuable soil property since it affects the wide range of soil chemical and biological processes, including nutrient availability and microbial activity (Neina 2019). In highly acidic soils, manganese, iron, copper and zinc can become more available while phosphorus and most micronutrients become less available in highly alkaline pH (Jensen, 2010). Soil organic matter plays an important role by improving physical and chemical properties of soils and/or by buffering nutrient supply (Viventsova et al. 2005). The CEC is a chemical property of a soil that describes soils' capacity to supply nutrient cations to the soil solution for plant uptake and it is highly associated with clay minerals and organic matter (OM) content of soil (Cornell University Cooperative Extension, 2007).

When there are large quantities of crop available micronutrients in soils, they harm crops because of their interaction with other nutrients (Yadav and Meena 2009). Hence, maximizing agricultural production needs, among others, a balanced use of micronutrients (Patel and Singh 2009). It also requires giving due attention to their relation with soil properties since it could help one to understand their function during the micronutrients application. In line with this, Wondwosen and Sheleme (2011) reported the importance of micronutrient application through balanced fertilization while giving due attention to soil factors such as organic matter content, adsorptive surface, soil pH, lime content, soil texture, topography and nutrient interactions in the soil (Eyob et al. 2015). In view of the above considerations, knowledge of the status of micronutrients and their relationship with some soil physic-chemical properties become very important to revise the fertilizer package to boost crop productivity.

According to the research report by Desta (1983), micronutrients deficiency was not serious problem in Ethiopian soils. As a result, sufficient efforts are not made to reveal what on the ground. It also brought about to come up with a conclusion that remarkable deficiency of micronutrients doesn't occur until recently. In spite of this assumption, most recent studies confirmed that certain soil micronutrients were deficient in soils of Ethiopia, which limits crop productivity. Supporting this, Teklu et al. (2007) reported the deficiencies of Mo, Cu, and Zn in Ethiopian Nitisols while Yifru and Mesifn (2013) was reporting the deficiency of Fe and Zn in almost all soil samples collected from the Vertisols of central Ethiopia. Regardless these facts, special attention had been given only to macronutrients such as N and P in Ethiopia and it seems to block further strive to see the relationship of soil properties with plant micronutrients in soils. Owing to these reports, an attempt to find out the status and the relationship between soil factors and micronutrients are scarce in Sidama, Ethiopia especially in the soils under enset farms.

Therefore, a clearer understanding of the micronutrients status and their relationships with other physico-chemical properties are required to enable effective management of micronutrient supply and use. Therefore, this study was aimed to assess the status of some micronutrients and their relationship with selected physico-chemical properties under enset farming system in Sidama region, Ethiopia.

2. Materials and Methods

2.1 Study Area

The study was conducted in Hawassa-Zuriya, Dale and Hula districts of Sidama region, Ethiopia (Figure 1) in 2020/21. Sidama region is located within 5°45'- 6°45'N latitude and 38°-39° E longitude, covering a total area of 6,538.17 sq km of which 97.71% is land and 2.29% is covered by water (SZPEDD 2004). It is bordered by Gedeo administrative zone in the south, Bilate River, which separates it from Wolayita zone in the west and Oromiya regional state in the north and southeast. The region lies in the area varying from low land (warm to hot) to highland (warm to cold). The regional capital, Hawassa, which is located in the northern tip of the region, has a distance of 275 km from Addis Ababa. The sampling sites are located between 038°20'7.8" - 038°32'36.5"E and 06°28'15.5" - 07°04'50.3"N. Altitudes vary from 1710 – 1732, 1720 - 1798 and 2684 – 2783 m.a.s.l in Hawassa-Zuriya, Dale and Hula districts, respectively. A total of nine 'kebeles' (peasant associations) were selected, of which 3 were from Hawassa-Zuria, 3 from Dale and 3 from Hula district.

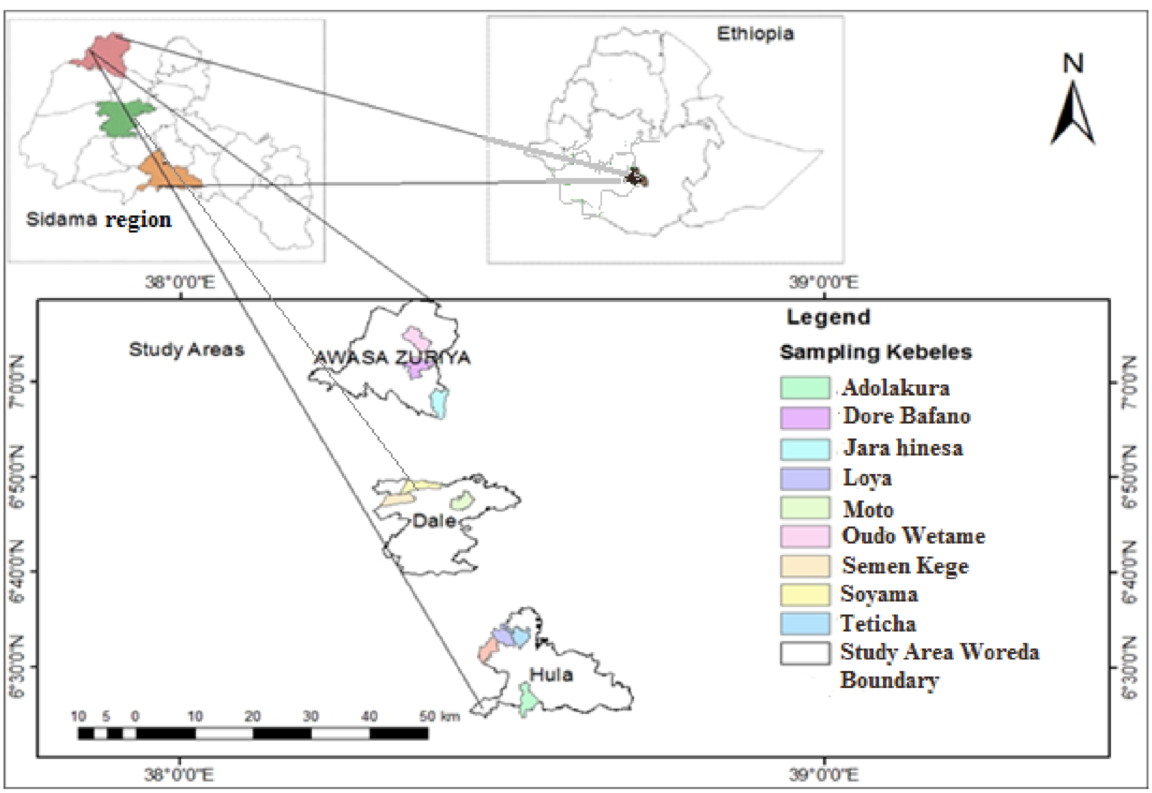

Figure 1. Map of study districts and soil sampling 'kebeles' in the study districts.

2.1.1 Climate and soil management

The Hula district has temperature range of 10-18 ^{o}C. The rainfall pattern of the area is bimodal and receives 1100-1400 mm per annum. The long rainy season begins from July and ends in September and the short rainy season begins in March and ends in May (Gebre-Egizabher 2022). The mean annual temperature in Dale district ranges between 9.6°C and 29.2°C. The area has a bimodal rainfall pattern with the peaks ranging from April to May and August to October. The mean annual rainfall of the area is 1102 mm per year (Kewessa et al. 2015). The mean minimum and maximum monthly temperature of Hawassa-Zuriya district is 13.8 °C and 27.8 °C, respectively (NMA 2017). The mean annual total rainfall is 935 mm with main wet season from April to September. In the districts, application of high amount organic fertilizers (household refuses, farmyard manure and compost) is common with inconsiderable removal of enset's residue from the farm.

2.2 Soil Sampling

In the present study, sample districts from the region were randomly selected because nearly all areas in the region have good potential for enset production irrespective of productivity variation due to rainfall and altitude discrepancy. Following this, enset farms of the representative farmers in the 'kebeles' were selected using systematic sampling method and each field was divided into three strata 12 m long in the direction from home vicinity to far located fields based on enset' growth variations. Since the study planned to explore the micronutrients status within the enset rooting depth, 50 cm depth for each core was bored randomly from each stratum using an auger and samples were collected in plastic pail. Core samples collected in plastic pail were then placed on a plastic sheet with an area of 3 m^2 and thoroughly mixed. Then, about 1 kg sample was taken and kept in a polyethylene plastic bag and labelled. Finally, eighty one composite soil sample (12 cores) was taken based on the method outlined by Rikard (2008) in November 2020 from the districts and kebeles (3 woredas*3 kebeles* 3 farmers field*3 strata) were collected in November 2020. Before laboratory analysis, samples were air-dried at room temperature, grounded using mortar and pestle, homogenized, and passed through a 2 mm sieve. Lastly, samples were stored in clean and dry area at room temperature until the time of use.

2.3 Physico-chemical analysis

Particle size analysis was performed using the Bouyoucous hydrometer method (Bouyoucos, 1951). Bulk density was determined by core method (Blacke 1965). The pH was determined in 1:2.5 soil-water suspensions using a glass electrode (Jackson 1973). Organic carbon was determined by wet oxidation method (Walkley and Black 1934). Soil organic matter (SOM) was estimated by multiplying the soil organic carbon by 1.72 (Baldock and Skjemstad 1999). Cation exchange capacity (CEC) was determined using ammonium acetate method (Sumner and Miller, 1996). Available phosphorus was determined using the Olsen method (Olsen and Sommers, 1982). Micronutrients were extracted using Mehlich III extractant (Mehlich 1984) and determined by inductively coupled plasma-atomic emission spectrometry (ICP-AES). The different values for the various soil fertility parameters were rated using the EthioSIS adopted critical levels (Ethiosis 2014). The soil samples were analyzed at Horticoop

Ethiopia (Horticultural) PLC in Addis Ababa and at Hawassa College of Teacher Education.

2.3.1 Critical limits of micronutrients

The critical limits of micronutrients contents as proposed by EThioSIS (2014) for elements extracted with Mehilich 3.

Table 1. Critical limits of soil micronutrients

Micronutrient	Concentration (mg kg^{-1})	Status	Micronutrient	Concentration (mg kg^{-1})	Status
Zn	<1	Very low	Mn	<60	Very low
	1-1.5	Critical level		60-100	Critical level
	1.5-10	Optimum		100-300	Optimum
	10-20	High		300-500	High
	>20	Very high		>500	Very high
Fe	-	Very low	Cu	<0.5	Very low
	25	Critical level		0.5-1	Critical level
	25-300	Optimum		0.9-20	Optimum
	300-400	High		20-30	High
	>400	Very high		>30	Very high
B	<0.5	Very low			
	0.5-0.8	Critical level			
	0.8-2	Optimum			
	2-4	High			
	>4	Very high			

Source: EThioSiS (2014)

2.4 Statistical Analysis

Data analyses were performed with the statistical analysis system (SAS Institute, 2012). The soil data generated were subjected to analyses of variance (ANOVA) using the general linear model procedure. Tukey's Studentized Range (HSD) means comparison test was used to determine the differences among soil samples of different districts based on the measured micronutrients and other soil properties at p = 0.05. The simple correlation analyses of data were computed in relation to the micronutrients amount with physico-chemical properties of soil under study.

3. Results

3.1 Soil Physical Properties

Selected physical properties are summarized in Tables 1. The proportions of sand, silt and clay varied from 14 to 56, 16 to 45 and 17 to 50% for Hawassa-Zuriya, Dale and Hula districts, respectively. The results indicate that most of the soils contained relatively higher proportion of clay as compared to silt and sand, but among the districts, Hula had the highest sand contents (Table 1). Percentage of clay fraction in Dale and Hula districts was the highest (55.6%) while only 22.2% of the studied soils in Hawassa-Zuriya. Bulk densities (g/cm^3) of the soils of

Hawassa-Zuriya, Dale and Hula districts varied from 0.71 to 0.94, 0.87 to 1.22 and 0.87 to 1.08, respectively. The mean bulk density of Hawassa-Zuriya was the lowest and statistically different (p =0.0022) from that of Dale and Hula districts.

3.2 Soil Chemical Properties

Selected chemical properties determined in the soils are summarized in Table 1. The soil pH values of Hawassa-Zuriya, Dale and Hula districts varied from 6.2 to 7.5, 6.3 to 7.6 and 4.7 to 5.4, respectively. According to EThioSiS rating (2014), the pH ranged from strongly acidic to moderately alkaline and all soil samples from Hula district were strongly acidic in reaction. Percent SOM ranged from 2.1 to 7.1% and was observed to increase with decreasing pH.

The Cation exchange capacity ranged between 17.4 and 46.4 meq/100 soil g and the values were not significantly different across the districts. According to the CEC (meq/100 soil g) rating by Landon (1984): infertility (<4), minimum value (5-15), optimum (15-25), high (25-40), very high (>40). Hence, the CEC values varied from optimum to very high. Available phosphorus content varied from 7.10 to 140.20, 1.10 to 7.32 and 0.23 to 8.40 mg/kg for Hawassa-Zuriya, Dale and Hula districts, respectively. The mean values of P was 45.20, 3.80, 3.04 mg/kg in Hawassa-Zuriya, Dale and Hula districts, respectively. There were significant differences (p =0.0083) in available phosphorus across sites (Table 1).

3.3 Soil Micronutrients

The level of micronutrients is shown in Table 3 below. Available zinc ranged from 4.5 to 32.7 mg/kg while the mean values were 2.0, 13.8 and 11.4 mg/kg in Hawassa-Zuriya, Dale and Hula districts, respectively. Crop available manganese in the soils ranged from 55.7 to 334.4 mg/kg and the mean values were 15.1, 197.3 and 259.4 mg/kg, respectively for Hawassa-Zuriya, Hula and Dale districts. Among the districts, the Dale district had the highest (259 mg/kg) Mn (p <0.0001) content while the lowest Mn was determined in Hawassa-Zuriya district.

Crop available iron ranged from 79.5 to 290.0 mg/kg having the mean values of 128, 149 and 214 mg/kg for the soils of Hawassa-Zuriya, Dale and Hula districts, respectively. Significantly (p =0.0028) higher mean iron (214 mg/kg) was determined in the Hula district than the Dale and Hawassa-Zuriya districts. Copper ranged from 0.3 to 2.8 mg/kg and the mean values in the soils of Hawassa-Zuriya, Dale and Hula districts were 1.2, 1.5 and 2.0 mg/kg, respectively. The contents of copper in the Hawassa-Zuriya and Dale districts were statistically similar while the contents were statistically and significantly (p <0.0001) different from Cu contents in the Hula soils. The highest mean copper was recorded in the Hula district. Boron ranged from 0.01 to 1.9 mg/kg while the mean values in the soils of Hawassa-Zuriya, Dale and Hula districts were 1.2, 0.9 and 0.5 mg/kg, respectively. Statistically different and higher B contents were determined in Dale district than the Hula and Hawassa-Zuriya districts.

4. Discussion

4.1 Soil Physical Properties

The wide variability of sand proportion among the districts might be due to the differences in soil mineralogy (Auge et al. 2017) and the extent to which silt and clay size particles are washed by the soil erosion. On the other hand, the high clay proportions recorded in Dale and Hula districts indicates that the soils are well covered by the canopy of enset crops and organic matter as these districts have more enset coverage than Hawassa-Zuriya district.

Table 2. Descriptive statistics of selected soil properties under enset farming system in Sidama region.

District	Descriptive Statistics	Phosphorus (mg/kg)	pH (H_2O)	SOM (%)	Bulk density (g/cm^3)	CEC (cmol/kg)	Soil texture (%)		
							Sand	Clay	Silt
Hawassa-Zuriya (N = 27)	Mean	45.20[a]	7.0[a]	2.9[a]	0.83[a]	28.30	32.0	34.0	33.6[a]
	StdDev	44.60	0.4	0.8	0.08	8.99	12.9	10.4	4.7
	Minimum	7.10	6.2	2.1	0.71	17.40	14.0	20.0	30.0
	Maximum	92.20	7.5	4.8	0.94	43.40	50.0	48.0	45.0
Dale (N = 27)	Mean	3.80[b]	6.9[a]	4.5[b]	0.97[b]	30.90	31.3	39.8	26.7[ab]
	StdDev	2.00	0.4	1.0	0.10	6.03	7.9	6.8	6.6
	Minimum	1.10	6.3	3.4	0.87	27.10	19.0	30.0	19.0
	Maximum	7.32	7.6	6.6	1.22	46.40	44.0	50.0	38.0
Hula (N = 27)	Mean	3.04[b]	5.1[b]	5.4[b]	0.95[b]	32.00	37.9	36.4	24.8[b]
	StdDev	3.00	0.3	1.0	0.06	5.30	11.4	11.3	6.9
	Minimum	0.23	4.7	4.4	0.87	26.0	26.0	17.0	16.0
	Maximum	8.40	5.4	7.1	1.08	42.6	56.0	46.0	40.0
Total (81)	Mean	17.30	6.6	4.3	0.92	30.4	33.7	36.7	28.3
	StdDev	31.92	0.9	1.4	0.10	6.90	10.9	9.60	7.0
	Minimum	2.10	4.7	2.1	0.71	17.4	14.0	17.0	16.0
	Maximum	92.20	7.6	7.1	1.22	46.4	56.0	50.0	45.0
	F value	7.84**	23.1****	16.4****	8**	0.66NS	0.98NS	0.8NS	5*

N =number of total samples per district, **** =p<0.0001, *** =p<0.001, ** =p<0. 01, * =p<0.05, NS =non-significant, Means within a column having similar letters are not statistical significant at $p \leq 0.05$, StdDev =standard deviation, F value =statistical F test

Table 3. Descriptive statistics of micronutrients in the soils under enset farming system in Sidama Region

District	Descriptive statistics	Zinc	Manganese	Iron	Copper	Boron
			(mg/kg)			
Awassa-Zuriya (N = 27)	Mean	2.0^{b}	15^{c}	128^{b}	1.2^{b}	1.20^{a}
	StdDev	0.9	9	71	50.0	0.70
	Minimum	1.4	56	80	0.3	0.01
	Maximum	7.7	260	231	2.4	1.10
Dale (N = 27)	Mean	13.8^{a}	259^{a}	149^{b}	1.5^{b}	0.90^{ab}
	StdDev	5.6	46	17	0.5	0.40
	Minimum	8.8	203.4	113	1.1	0.30
	Maximum	25.4	334.4	168	2.6	1.90
Hula (N = 27)	Mean	11.4^{a}	197.3^{b}	214^{a}	2.0^{a}	0.50^{b}
	StdDev	4.3	40.1	41	0.6	0.40
	Minimum	4.5	125.7	153	0.9	0.10
	Maximum	17.6	243.0	290	2.8	1.20
Total (81)	Mean	9.1	157.3	164	46.7	0.80
	StdDev	6.5	111.1	60	70.4	0.60
	Minimum	4.5	55.7	80	0.3	0.01
	Maximum	32.7	334.4	290	2.8	1.90
	F value	20.5^{****}	114.0^{****}	7.6^{*}	65^{****}	4.4^{*}

N=number of total samples per district, **** =p<0.0001, *** = p<0.001, * = p<0.05, Means within a column having similar letters are not Statistical significant at p≤0.05, StdDev = standard deviation, F value = statistical F test.

This result agrees with the finding of Chakoro and Mekuria (2015) who reported the effects of organic matter and crop canopy in reducing erosion and the resulting effect on soils' clay.

The bulk density of Hawassa-Zuria soils was lower than those in Dale and Hula districts and it could be due to the lowest mean sand proportion in the soils of the district. This is in line with the report by Sakin et al. (2011) that negative correlation exists between the bulk density and the sand content of soils. On the other hand, bulk density values less than one indicated that the studied soils were of organic soils (Sakin and Deliboran 2011; Sakim 2012).

4.2 Soil Chemical Properties

The significant variations observed among the mean pH of the districts could be due to the differences in topographic position (Dessalegn et al. 2014), degree of removal of basic cations by crop harvest (Hartemink 2006; Sisay 2019) and prevailing micro-climate condition like rainfall intensity (Dessalegn et al. 2014). On the other hand, strong and moderate acidic reactions determined in soils of Hula district could be due to the heavy rains it experiences and the resulting accelerated leaching of the exchangeable bases. Cation exchange capacity (CEC) increased with increasing contents of clay and SOM. This was because of the negative sites which attracts positively charged ions (Kibreselassie and Suh-Yong

2020). Hence, the moderate to very high range of CEC indicated that soils are capable of keeping the micronutrients from leaching down a profile.

Significantly high variations of percent SOM in the studied soils among the districts could be due to agro ecological differences among the districts. This has been manifested by an increase in SOM with decreasing pH and with increasing elevation from Hawassa-Zuriya to Hula district (section 2.1). In line with this, Jeffrey et al. (2002) reported an increase of SOM and a decrease of pH with increasing elevation.

Phosphorus contents varied noticeably among the districts. These variations could be due to the different soil management practices, inherent soil fertility status and type and rate of organic fertilizers used in enset farming system (Fixen and Grove 1990). Besides, variation in parent material, degree of P-fixation, soil pH and slope gradient may also contribute to the difference in available P contents (Abate et al. 2016).

4.3 Status of Micronutrients in the Soils

Significant variations of zinc, boron and copper across the districts reveal that soils were different in chemical properties and the variation could be due to variations in the animal manure applied, the rain fall status and topography. The topography and rainfall effects are based on soil erosion processes and matter transport which flushes the top fertile soils. On the other hand, since manure reduces runoff, the loss of micronutrients is seldom as compared to soils containing low level of manure. This is in line with the report by Primus et al. (2017) that animal manure, rain fall amount, and topography affect the level of micronutrients in soils.

Within the districts, variance of zinc could be due to variations in SOM contents of the soils; i.e., an increase in zinc content with increasing SOM. Supporting this, a report by Brock et al. (2005) indicated an increase of zinc content as a function of the applied animal manure. This might be due to the chelation and mineralization effect of high organic matter level that increases the solubility of Zn. The finding is in line with Iratkar et al. (2014) who reported the high availability of zinc when SOM level increases. The statistically different and lower Zn contents were determined in Hawassa-Zuriya district than the Dale and Hula districts. This could be due to the calcareous nature of Hawassa-Zuriya soils that was indicated by pH (7.0) and low (2.9%) SOM. It can also be attributed to the adverse effect of high available phosphorus content (129.6 mg/kg) on zinc. This is supported by the finding of Rengel (2015) that an increase in soil pH negatively affects, especially above 6.5, the extractability and plant availability of soil Zn. The effect of high available phosphorus is in line with Yang et al. (2011) who reported that Zn extractability from soil is negatively related to phosphate. In the present study, the optimum status of Zn in soils of Hawassa-Zuriya district while high in Dale and Hula districts is convincing since enset protects the soil from erosion and degradation because of its canopy leaves, and high accumulation of applied manure as was also reported by Tamire and Argaw (2015). In accordance with EThioSiS (2014), the level of zinc was optimum in Hawassa-Zuriya district while high in the Dale and Hula districts.

The very high variations of Mn in Hawassa-Zuriya district could be due to the variations in parent materials of soils and the resulting mineralogy. Significantly different from those of other districts and the highest (259 mg/kg) content of Mn found in Dale district could be attributed to tropical weather condition of the district and the weathering of primary Mn containing ferromagnetism minerals that form secondary minerals such as pyrolusite (MnO_2) (Schaefer et al 2017).

On the other hand, the lowest (15 mg/kg) Mn content of the Hawassa-Zuriya soils could be due to the statistically different and the lowest value of SOM (2.9%) determined compared to those of the other districts (Chabra et al. 1996). Moreover, it could also be due to the dry and well-aerated features of the soils since high concentrations of Mn occur in poorly drained and reduced environments (Rengel, 2015). In accordance with EthioSiS (2014), the mean Manganese level of Hawassa-Zuriya district soils was very low (<60 mg/kg) while optimum (100-300 mg/kg) in the Dale and and Hula districts. The very low Mn is the indicative of the need for its fertility in the area.

The very high variations of Fe in Hawassa-Zuriya could be due to variations in soils' mineralogy. Significantly different and higher mean iron (214 mg/kg) determined in the Hula district could be due to the high acidic reaction (pH =5.1) in the district which increases the solubility of iron as was also reported by Kumar and Babel (2011). In the study, concentrations of Fe fall in optimum range (25-300 mg/kg) in all districts.

The within Hawassa-Zuriya and Dale district variations of Cu could be attributed to variations in mineralogy and parent materials of the soils. In the study, the highest mean copper in the Hula district soils could be due to the low pH (5.1) and high SOM (5.4%). This is supported by Iratkar et al. (2014) who reported the available copper increase with increasing contents of SOM. On the other hand, statistically similar and low Cu contents determined in Hawassa-Zuriya and the Dale district could be due to the comparatively high and statistically similar pH of soils in the districts. In the present study, concentrations of Cu fall in the optimum range (0.9-2.0 mg/kg) and this is convincing since enset protects the soil from erosion and degradation because of its canopy leaves, accumulation of decomposing SOM and application of manure as to the report by (Tamire and Argaw 2015).

The very high variations of B could be attributed to variations in the landscape positions, management practices, soil type and mineralogy, and parent materials of the soils. The lower boron contents found in the soils of Hula district than in the soils of Hawassa-Zuriya could be due to acidic and sandy nature of the soils, and aggravated leaching of mobile borate ions by high rainfall from the root zone and vise-versa. This is in line with the finding of Oyinlola and Chude (2010), and Fekadu (2020) who reported the leaching of boron in acidic and sandy soils where heavy rain is common. According to EthioSiS (2014), B was low (0.5-0.8 mg/kg) in the soils of Hula district while optimum (0.8-2 mg/kg) in the soils of Dale and Hawassa-Zuriya districts. The low B contents in Hula district soils shows that Hula requires B fertility.

4.4. Correlations among the Micronutrients and Selected Soil Properties

Results pertaining to the correlation studies between micronutrients and selected properties of soils showed positive and significant correlations. Boron correlated positively and significantly ($r = 0.3995$, $p < 0.039$) with pH and CEC ($r = 0.4164$, $p < 0.031$) indicating that leaching loss of B is seldom when pH increases and it also revealed that the CEC of the soils is pH dependent and increases with increasing concentration of hydroxide ions in the soils (Dora, 2019). Significant and positive correlation existed between CEC and Mn ($r = 0.5350$, $p < 0.004$), and CEC and Cu ($r = 0.4263$, $p < 0.027$) showing that an increase in CEC increases the availability of these micronutrients due to more availability of exchange sites on soil colloids (Domingues et al., 2020). Positive correlations occurred between SOM and micronutrients (except for

Zn) while statistically significant relationships existed between SOM and Mn ($r = 0.4271$, $p<0.026$), and SOM and Cu ($r = 0.5920$, $p = 0.0011$). This is in line with the report by Kaleem et al. (2010) that the available Fe, Mn, Cu and Zn positively and significantly correlated with soil organic matter. These positive associations are convincing since SOM supplies soluble chelating agents which chelate the micronutrients, releases them slowly and increases their availability (Kumar and Babel, 2011). With regard to positive correlation between Cu and SOM, it could also be said that soils of the study area are not high in organic matter like soils of peat and mucks areas since these held Cu^{++} or Cu^{+++} more tightly and thereby cause the deficiency (Mathayo et al. 2016).

Statistically significant and negative correlation between pH and micronutrients such as Fe ($r = -0.6683$, $p=0.0001$) and insignificant negative correlation with Cu indicated that the solubility of these micronutrients decreases with increasing pH. Here, negative correlation of Fe with pH shows the iron reducing effect of the lowering pH, from non-available (non-toxic) Fe^{3+} into plant-available Fe^{2+} ions and vice versa (Rengel 2015). On the other hand, the decrease in plant available forms of micronutrients with increasing pH may result from poor solubility of the given chemical form of the nutrient (Takala 2019).

Although not statistically significant, positive association between clay and the micronutrients shows that the availability of micronutrients increases with increasing clay content. Supporting this, Doug (2004) reported that fine textured soils with higher amounts of clay are less likely to be low in plant available micronutrients. Statistically significant and negative correlation occurred between phosphorus and zinc ($r = 0.6949$, $p<0.0001$). This revealed that in the soils where available phosphorus is high, available Zn becomes low because of the 'phosphorus induced zinc deficiency' (Nguyen et al, 2019). Besides, statistically significant and positive correlation ($r = 0.6642$, $p = 0.0002$) existed between Zn and B indicates that compounds which constitute them solubilise in the same pH range. Furthermore, significant and positive association occurred between Mn and B ($r = 0.5574$, $p = 0.0025$), and Fe and Cu ($r = 0.4820$, $p = 0.011$) also show that compounds containing these pairs of micronutrients solubilise in the same pH range.

Statistically significant and negative correlation between pH and Altitudes ($r = -0.9329$, $p<0.0001$) indicated that the hydrogen ion concentration in the soils increased with an increasing altitude while decreasing with a decreasing altitude. This means, pH decreases with increasing altitude and vice versa. This is in line with the report that higher precipitation increases the leaching of basic cations while increasing the hydrogen ions (Shazia et al. 2014). Positive association of SOM with altitudes ($r = 0.6527$, $p=0.0002$) showed that the decomposition rate of SOM slowed as an altitude increases and decomposition hastened with a decreasing altitude. The result agrees with Charan et al. (2013) who reported an increase of SOM content when altitude increases. The positive correlation of Fe and Cu with altitudes showed the solubilising of iron and Cu chemical forms (compounds) by the low pH (soil reaction). Even though insignificant, the negative correlation of B with Altitudes showed the decreasing of B with an increasing altitude. This could be due to the leaching loss of B, in the forms of boric acid (H_3BO_3), which dominates in soil solutions below pH 7.0; by the heavy rains in high altitude areas (Quaggio et al. 2003).

Table 4. Pearson cross - correlation matrix between micronutrients and selected soil properties and altitudes

	pH	SOM	CEC	Clay	P	Zn	Mn	Fe	Cu	B	Alt
pH	1	-0.5008**	0.4829*	-0.0195	0.3485	-0.7701***	0.0694	-0.6683***	-0.3576	0.3995*	-0.9329****
SOM		1	0.4829*	0.0626	-0.4585*	-0.0234	0.4271*	0.3513	0.5920**	0.2304	0.6527****
CEC			1	0.1861	-0.3085	0.0315	0.5350**	-0.0692	0.4263*	0.4164*	0.1729
Clay				1	0.0240	0.0512	0.3117	0.1916	0.0425	0.1472	-0.0225
P					1	-0.6949****	-0.5716**	0.0979	-0.1629	0.1579	-0.3410
Zn						1	-0.0833	0.2911	0.1631	0.6642***	-0.2123
Mn							1	-0.0907	0.3418	0.5574**	0.0341
Fe								1	0.4820*	-0.0427	0.6662****
Cu									1	0.3590	0.5331***
B										1	-0.2571
Alt											1

*Denotes significant at $p<0.05$, ** denotes significant at $p<0.01$, *** denotes significant at $p<0.001$, ****denotes significant at $p <0.0001$, Bd =Bulk density, p =phosphorus, Zn =zinc, Mn =manganese, Fe = iron, Cu =copper, B =boron, Alt = Altitude.

5. Conclusion

The effect of mean soil pH on Zn, B and copper contents show that the micronutrients management must be on the basis of soils' pH management. The very low Mn content determined in Hawassa-Zuriya, which is probably due to the rapid decomposition of added manure, indicates the importance of manure management to raise the soil Mn level so as to come up with economically sound yield. The low B content determined in Hula implied the importance of boron management while giving due attention to the narrow range occurring between optimum and deficiency. From the correlation study, the positive relationship among pH, CEC and available B; the positive relationship among CEC, SOM, Mn and Cu show the importance of very slight increase in pH during lime application. This indicates the importance of SOM management in order to increase the Mn and Cu contents of the soils. On the other hand, significant and negative correlation existed among pH, Fe and Zn indicated the effect of decreasing pH on an availability of Fe and Zn. Hence, pH decreases as altitude increases, and the availability of these micronutrients becomes high as compared to low altitude areas. Thus this indicates the importance of Fe and Zn management in low altitude areas. Finally, it is concluded that people engaged in enset production/agricultural activities should apply phosphorus based on soil's zinc content.

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Research Article

Habitat Characteristics of Wildlife Species in Pandam Wildlife Game Reserve, Plateau State, Nigeria

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Abstract

The paper assessed the vegetation composition and structure within the existing habitats in Pamdam Wildlife Game Reserve. Line transects (2 km each) were laid 1 km apart; Savannah Woodland (SW), Riparian Forest (RF) and Swamp Land (SL). A total of 48 (50 x 50 m^2) sample plots established on 12 transect lines were delineated at 500 m intervals. Tree species of Dbh ≥10 cm was identified and enumerated (individuals /ha). Shrubs [individuals /m^2] and herbs [individuals/m^2] were enumerated in 5 x 5 m^2 and 1 x 1 m^2 quadrats, respectively. Data were analyzed using descriptive statistics and ANOVA at $\alpha_{0.05}$. Simpson's (D) and Shannon-Weiner (H') indices were estimated for trees and understorey. Density of trees (188 individuals /ha), shrubs (162), and herbs (1012) were the highest in SW and the least in RF (respectively 80, 86, and 567) were recorded. Tree species with highest Important Value Index (IVIs) were *Parinari curatellifolia* (12.9%), *Vitex doniana* (14.0%) and *Mitragyna inermis* (27.1%) in SW, RF and SL, respectively. The D and H' were the highest for trees and shrubs in SW while they were the least in RF. The study revealed that especially conservation attention for the particular habitat so as to maintain persistent wildlife population in the reserve.

Keywords: habitat, soil parameters vegetation components, Nigeria

1. Introduction

Habitat relationships are paramount to determining the ecosystem productivity, function, and sustainability of wild animals. It is thus defined as the retinue of ecosystem resources that are integral to wild animal habituation and productivity **(**Sinclair *et al*. 2005). It is an area that harbors a particular or defined state of vegetation type, in terms of quality and quantity. Habitat portrays functional components that uniquely define an organism in a particular manner that suit the animal in question.

A habitat depot's coverage of an area marked and occupied by wild animals comprises features like water bodies, food, soil formation, and type, as well as the associated vegetation (Dalle *et al*. 2014). [1] For instance, the slope or level of terrain, water sources, and soil properties may influence the distribution of animals and plants development and growth (Yang *et al*. 2009; Wu et al. 2023).

Game Reserve protects the integrity of the natural environment and also serves as the

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Received 25 July, 2022
Accepted 26 May, 2023

cornerstone for biodiversity conservation and their biomass and soil (e.g., Montagnini and Nair 2004). It is among the sites for biodiversity conservation in Nigeria and the whole world. Game Reserve is the most feasible strategy to manage and conserve biodiversity (Thomas and Middleton 2003). Game Reserve harbor most of our remaining forest vegetation and fauna species which play key roles in climate change, habitat structure, biodiversity conservation, and ecotourism (Yager *et al.* 2015; Odunlami and Ijeomah 2016; Maradana and Owk 2016).

Game Reserve vegetation diversity and structure are important to range ecologists to assess the capacity of habitat in forage resources production (Schoenholtz *et al.* 2000; Maradana and Owk 2016; Saka *et al*. 2018). Habitat losses in several Game Reserve occasioned by degradation in range structure had drastically impacted negatively on wildlife populations' especially mammalian herbivores, which form a crucial trophic level in the food chain.

Game Reserve ecosystems at all levels have high and productive surface areas and are acknowledged to harbor a notable portion of global biological resources (Baraloto *et al*. 2013). According to Tyowua *et al.* (2012), wildlife studies are considerably valued when assessments incorporate their habitat. However, the primary limiting component that affects wild animal population changes is the quality and size of the habitat. Sustainable management ofGame Reserve-ecosystems demands a comprehensive insight into its resources. This could be available mostly through knowledge of the forest ecosystem. The evaluation and management of woody plants and the understorey ecosystem should be continuous, considering they are vital variables of vegetation composition (Attua and Pabi 2013).

The roles of plants in Game Reserve ecosystems are numerous. Its' covers aid fauna prey species with protection. Habitat composition contributes to carbon sequestration, nutrient cycling, and organic matter composition (Pan *et al*. 2011). Vegetation is the major constituent of wildlife habitat component that can directly influence cover and food availability and indirectly detect water availability and quality. However, anthropogenic threats such as agricultural expansion, settlement, and extractive forest use around the research site lead to vegetation degradation and loss in wildlife habitat, ultimately deteriorating wildlife habitat quality. A change in plant species composition and structure in a wildlife habitat corresponds to a change in wild faunal composition (McNear Jr 2013; Fu *et al*. 2015). Mammalian herbivores dwell in all major terrestrial ecosystems on Earth (Ripple *et al*. 2015) and require large home ranges (Berger 2004). Hence, they are also referred to as important species that require large and suitable habitats for their conservation and management (Isasi-Catala 2011). Despite the fact that mammals require large, extensive, quality wildlife habitats and that their habitats are under immense pressure, studies on the vegetation-wildlife relationship are limited in number and scope. Most studies focused either on floral diversity or wildlife species, with a clear link between habitat vegetation composition and structure and wildlife species. Therefore, the present study is aimed at evaluating the floristic composition (tree and understory (shrubs and herbs)) and structure of the Game Reserve.

2. Material and Methods

2.1 Description of the study area

The African Union (AU) pioneered the setting up of reserves, including Pandam WildlifeGame Reserve, Plateau State, Nigeria, which was established in 1972. Pandam Wildlife Game Reserve is a swamp, and wooded Guinea-savannah habitat located in the northcentral of Nigeria (8º 35' N and 8º 55' N and 8º 00' E and 10º 00' E) (Figure 1; Ezealor 2002). The PWP protects a forested area of 327.54 km^2, with an important water source (a Y-shaped lake being the major tributary of River Benue) for much of the Qu'apam Local Government Area. The elevation range of the Game Reserve (from 91 to 206 m above sea level) results in three diverse ranges of habitat. The Savannah-woodland is dominated by *Parinari curatellifolia, Combretum nigricans*, and *Vitellaria paradoxa;* Swamp land *Mitragyna inermis*, *Acacia nilotica*, and Riparian Forest mostly along the tributaries of the banks of the Pandam Lake, dominated by *Vitex doniana*, *Erythrophleum suaveolens*, *Rauvolfia vomitoria*, *Prosopis africana*, and *Elais guinensis*. The soil is ferruginous and lies over sedimentary rocks (Akosim *et al*. 2004). The mean annual rainfall ranges from about 1000 to 1500 mm (Samson 2016). The annual mean temperature of the Game Reserve is 39°C. The reserve is surrounded by areas of high human population density and intense agricultural practice. Human activities encroaching on the Game Reserve have led to high levels of habitat degradation through unmanaged logging, charcoal production, and livestock grazing. The perimeter wire fence erected at the early time of the Game Reserve creation (1973), to help preserve the ecosystem while protecting neighboring communities from damage caused by wildlife, has been pulled down.

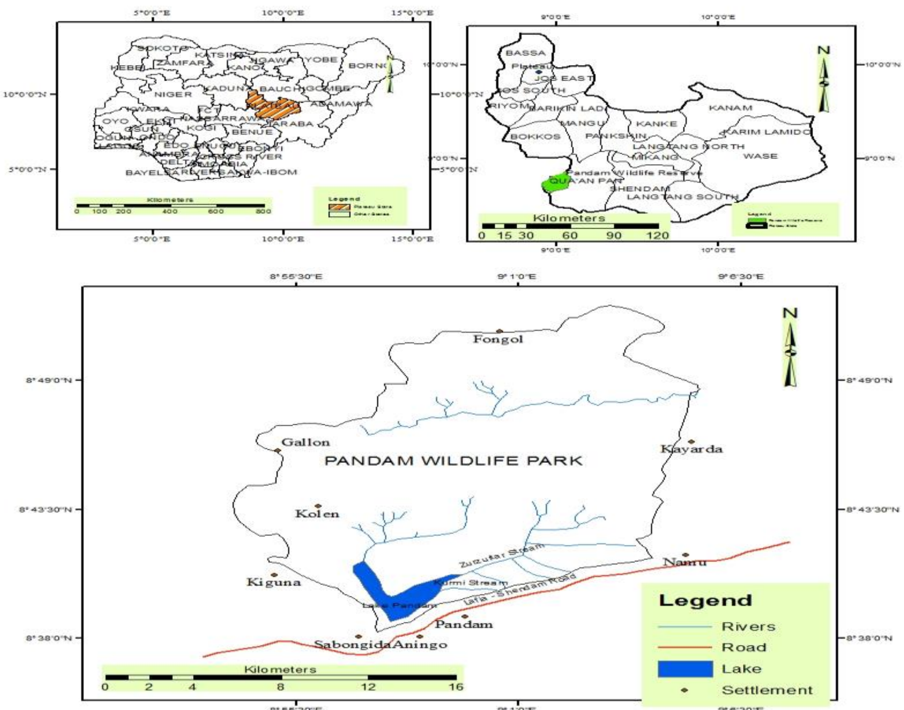

Figure 1: Study area Map

2.2 Data collection procedure and analyses

We surveyed the three existing habitats in Pandam Game Reserve using a total of 48 plots established on 12 transect lines. Line transects of 2 km in length, each spaced 1km apart, were established across three different habitat types (savannah woodland (SW), riparian forest (RF), and swamp land (SL)). Proportional to the size of each habitat type, a total of 4, 3 and 3 transects were established in savannah woodland, riparian forest and swamp land, respectively. On each transect, a total of four (50 x 50 m^2) sample plots spaced at 500m intervals were established. In each plot, tree species of Dbh ≥10 cm at 1.3 m above the ground were identified and enumerated (number/ha). Trees were identified according to the International Plant Nomenclature Index (IPNI, 2008). Nested quadrats were laid at the center and four corners of each plot and used to estimate the density of shrubs [/m^2] and herbs [/m^2] in 5 x 5 m^2 and 1 x 1 m^2 quadrat, respectively.

2.3 Data Analysis

Important value index was calculated on the basis of RF, RD and RDo

$$RF = \frac{Frequency\ of\ a\ species}{Total\ frequency\ of\ all\ species} \times 100$$

$$RD = \frac{Number\ of\ a\ species}{Total\ Number\ of\ all\ species} \times 100$$

$$RD_0 = \frac{Summation\ basal\ area\ of\ all\ trees\ of\ a\ species}{Summation\ of\ basal\ area\ of\ all\ trees} \times 100$$

$$IVI = \frac{(RD + RF + RDo)}{3}$$

RF Relative frequency, RD Species relative density, RDo Species relative dominance, IVI Species importance value index

Diversity indices such as Simpson (1-D) index and Shannon-Wiener (*H'*) index (Magurran, 2004), Evenness (E_H), and Margalef Index (*MI*) were computed to compare the plant diversity among habitat types and for the pooled diversity using equations 6 to 10 below.
The overall diversity index and the diversity among habitat types were computed using Simpson's diversity index formula below (equation 7)

$$D^S = 1 - \sum \frac{n_i(n_i - 1)}{N(N - 1)}$$

Likewise the overall diversity index and the diversity among habitat types were also computed using Shannon-Wiener Index (H') formula below (equation 8) – The index depends on species richness and evenness.

$$H' = -\sum \left(\frac{n_i}{N} \times ln\frac{n_i}{N}\right)$$

Pilou evenness (*J*) was used compares the actual diversity value among habitat types and the pooled

$$J = \frac{H'}{H_{max}}$$

In addition the Margalef's index (MI) among habitat types and for the overall was also computed using the equation below

$$MI = \frac{n - 1}{lnN}$$

Where ni is the number of individuals of amount (biomass) of each the *i* species and *N* is the total number of individuals (or biomass) for the site.

3. Results

3.1 Family representation of plant species of Pandam WildlifeGame Reserve

A total of 37 families were recorded in the plant life forms; out of this number, tree species were represented by 20 (54.05%), shrubs 11 (27.03%) and herbs 7 (18.92%) families. The tree species result revealed that 12 families had just a species each, while 3 families had 7, 6, 4, and 3 species, respectively. Also, 2 families had 2 species each. The dominant family was Fabaceae with 7 species (16.67%), followed by Combretaceae with 6 species (14.29%), and the least were Bombacaceae, Caesalpiniodeae, Leguminosae, Simaroubaceae, Anacardiaceae, Ochnaceae, Celastraceae, Apocynaceae, Sterculiaceae, Myrtaceae, Sapotaceae and Verbenaceae with one species each (Figure 2).

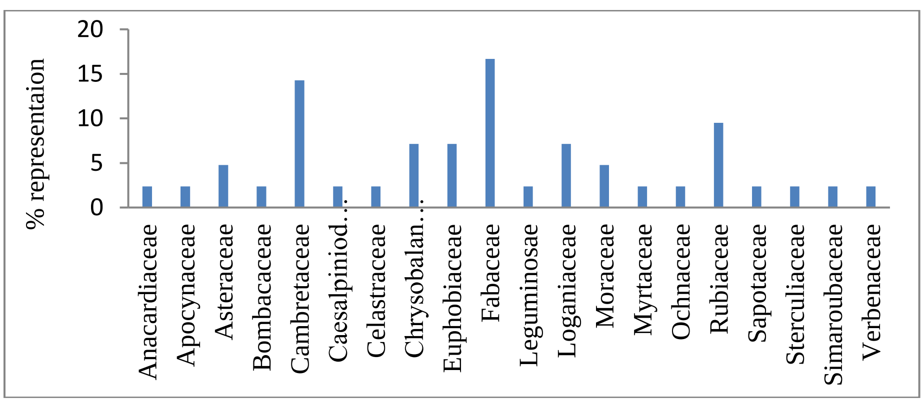

Figure 2: Family representations of tree species in Pandam Wildlife Game Reserve

For the shrub species recorded, the family Malvaceae was most dominant with 3 species (21.43), followed by Arecaceae and Fabaceae with 2 species each (14.29%) and the least dominant families were; Mimosoideae, Connaraceae, Asteraceae, Vitaceae, Euphorbiaceae, and Sapotaceae with a species each (Figure 3). Among the herb species, Poaceae was the most dominant with 13 species (54.17%), followed by the family Cyperaceae with 4 species (16.67%) and the least dominant families were; Acanthaceae, Euphorbiaceae, Amaranthaceae, and Melastomataceae with a species each (Figure 4).

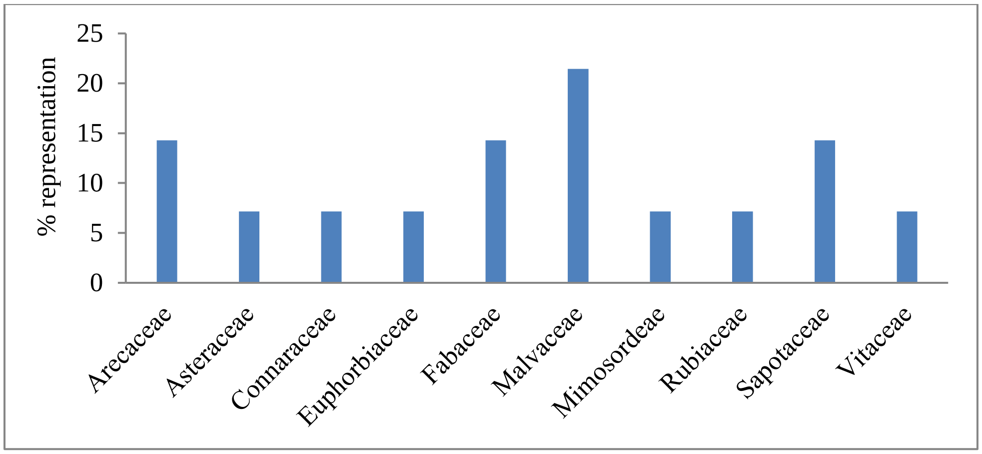

Figure 3: Family representations of shrubs species in Pandam Wildlife Game Reserve

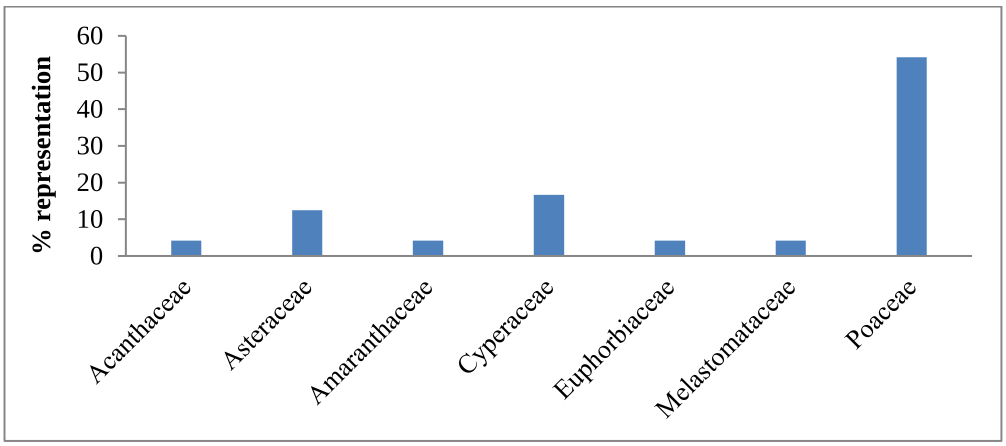

Figure 4: Family representations of herbs species in Pandam Wildlife Game Reserve

3.2 Tree and understorey species composition and structure

A total of 6,451 individuals of plant species in 37 families were recorded; of these, 1,338 (20.74%) were trees, 738 (11.44%) were shrubs and 4,375 (67.82%) were herbs. Out of the total of 80 species, 42 (20 families) were trees, 24 (7 families) were herbs and 14 (10 families) were shrubs (Table 1).

Table 1: Plant species richness distribution according to life forms in Pandam Wildlife Game Reserve

S/No.	LF	FI	Total	Families
1	Tree	42	42	20
2	Shrubs	14	14	10
3	Herbs	24	24	7
	Total	80	80	37

Note: LF – Life form, FI – fully identified

Table 2: Tree species composition based on Importance Value Index across the habitats in Pandam Wildlife Game Reserve.

		Habitats											
S/N	Species	Savannah woodland				Riparian forest				Swamp Land			
		RF	RD	RD_O	IVI	RF	RD	RD_O	IVI	RF	RD	RD_O	IVI
1	*Acacia nilotica*	2.020	1.047	1.547	1.538	1.058	3.226	1.520	1.935	5.405	5.102	11.230	7.246
2	*Anogeissus leiocarpa*	2.020	2.618	5.368	3.335	0	0	0	0	2.703	1.020	2.096	1.940
3	*Anthocleista djalonensis*	1.010	0.262	0.276	0.516	2.646	3.226	1.294	2.389	2.703	1.020	0.216	1.313
4	*Antidesma venosum*	1.010	0.262	0.261	0.511	0	0	0	0	2.703	1.020	0.598	1.440
5	*Bombax costatum*	1.010	0.524	1.142	0.892	0	0	0	0	0	0	0	0
6	*Borassus aethiopum*	0	0	0	0	3.704	4.839	6.071	4.871	2.703	1.020	2.096	1.940
7	*Burkea africana*	5.050	5.236	6.844	5.710	0	0	0	0	2.703	1.020	0.329	1.411
8	*Combretum nigricans*	7.070	15.183	8.963	10.405	6.878	6.452	2.814	5.381	0	0	0	0
9	*Combretum spp*	4.040	2.094	1.235	2.456	0	0	0	0	5.405	8.163	2.624	5.397
10	*Combretum zenkeri*	0	0	0	0	1.587	3.226	0.586	1.800	0	0	0	0
11	*Crossopteryx febrifuga*	5.050	2.356	1.234	2.880	0	0	0	0	2.703	1.020	0.788	1.504
12	*Dialium guineense*	0	0	0	0	0	0	0	0	5.405	2.041	0.979	2.808
13	*Daniellia oliveri*	4.040	7.068	9.220	6.779	9.524	8.065	5.701	7.763	2.703	1.020	2.731	2.151
14	*Elaeis guineensis*	0	0	0	0	0	0	0	0	5.405	2.041	2.984	3.477
15	*Erythrophleum suaveolens*	0	0	0	0	0	0	0	0	5.405	6.122	20.694	10.740
16	*Ficus asperifolia*	1.010	0.524	0.404	0.646	0	0	0	0	0	0	0	0
17	*Ficus sur*	0	0	0	0	1.058	3.226	1.370	1.885	0	0	0	0
18	*Hannoa undulata*	1.010	0.524	0.734	0.756	0	0	0	0	5.405	2.041	0.509	2.652
19	*Hymenocardia acida*	1.010	1.047	0.127	0.728	0	0	0	0	2.703	1.020	0.376	1.366
20	*Lannea schimperiana*	7.070	3.665	6.699	5.811	0	0	0	0	5.405	2.041	1.046	2.831
21	*Lophira lanceolata*	2.020	0.785	1.391	1.399	0	0	0	0	0	0	0	0
22	*Maytenus senegalensis*	1.010	0.262	0.177	0.483	0	0	0	0	0	0	0	0
23	*Maranthes polyandra*	8.080	9.424	6.918	8.141	9.524	8.065	3.722	7.104	0	0	0	0
24	*Mitragyna inermis*	1.010	0.262	0.270	0.514	0	0	0	0	10.811	43.878	26.711	27.133
25	*Pachystegia rufa*	0	0	0	0	2.116	3.226	1.480	2.274	0	0	0	0
26	*Parinari curatellifolia*	7.070	16.492	14.996	12.854	0	0	0	0	0	0	0	0
27	*Parinari polyanda*	1.010	1.310	2.143	1.488	0	0	0	0	0	0	0	0
28	*Parkia biglobosa*	2.020	1.310	2.467	1.670	0	0	0	0	0	0	0	0
29	*Prosopis africana*	2.020	0.524	0.937	1.160	2.646	3.226	13.198	6.357	5.405	2.041	1.796	3.081

30	*Pterocarpus erinaceus*	4.040	3.665	3.526	3.744	0	0	0	0	2.703	1.020	1.138	1.620
31	*Rauvolfia vomitoria*	0	0	0	0	13.757	4.839	7.458	8.685	0	0	0	0
32	*Sarcocephalus latifolius*	1.010	0.262	0.114	0.462	1.058	3.226	0.417	1.442	5.405	2.041	1.001	2.816
33	*Sterculia setigera*	2.020	0.524	0.546	1.030	0	0	0	0	2.703	1.020	1.284	1.669
34	*Strychnos innocua*	5.050	4.712	1.898	3.887	0	0	0	0	0	0	0	0
35	*Strychnos spinosa*	1.010	0.262	0.481	0.584	0	0	0	0	0	0	0	0
36	*Syzygium guineensis*	2.020	1.047	1.951	1.673	0	0	0	0	2.703	1.020	6.805	3.509
37	*Terminalia avicennioides*	2.020	1.832	1.800	1.884	5.291	6.452	2.859	4.867	0	0	0	0
38	*Terminalia schimperiana*	6.060	4.712	3.232	4.668	2.646	3.226	2.384	2.752	0	0	0	0
39	*Uapaca togoensis*	1.010	0.262	0.321	0.531	0	0	0	0	0	0	0	0
40	*Detarium micocarpum*	0	0	0	0	0	0	0	0	2.703	3.061	9.451	5.072
41	*Vitellaria paradoxa*	5.050	4.450	8.013	5.838	0	0	0	0	1.587	4.839	0.891	2.439
42	*Vitex doniana*	4.040	5.497	7.791	5.776	17.460	11.290	13.135	13.962	8.108	10.204	10.782	9.698

Note that RF- Relative frequency, RD- relative density, RD_O relative dominance and IVI- Important Value Index

Table 3: Understorey (herbs and shrubs) species composition of Pandam Wildlife Game Reserve.

	Species	Habitats		
		SW N/m^2	RF N/m^2	SL N/m^2
Herbs	*Acroceras zizanioides*	60	0	0
	Andropogon tectorum	110	160	80
	Asystasia gangetica	68	20	60
	Brachiaria brizantha	59	68	45
	Eragrostis cilianensis	68	0	74
	Eragrostis ciliaris	48	0	60
	Eragrostis tremula	73	68	47
	Imperata cylindrica	80	80	89
	Leersia hexandra	120	50	0
	Leptochloa caerulescens	70	60	201
	Oplismenus burmannii	87	0	60
	Paspalum conjugatum	92	48	52
	Paspalum scrobiculatun	80	54	0
	Pennisectum pedicellatum	0	50	80
	Aspilia africana	201	47	39
	Aspilia bussei	89	0	60
	Cyathula prostrate	63	47	80
	Heterotis rotundifolia	53	0	78
	Vernonia galamensis	79	78	0
	Vernonia cinerea	72	48	54
	Cyperus alternifolius	89	25	60
	Cyperus esculentus	100	100	66
	Cyperus difformis	109	48	89
	Scleria verrucose	80	0	0
Shrubs	*Acacia gourmaensis*	12	0	10
	Borassus aethiopum	40	11	15
	Byrsocarpus coccineus	30	13	0
	Chromolaena odorata	20	0	13
	Cissus populnea	41	0	10
	Flueggea virosa	34	14	14
	Gardenia aqualla	24	9	0
	Mimosa diplotricha	17	12	18
	Mimosa invisa	41	20	7
	Pachystela brevipes	14	14	17
	Raphia sudanica	13	0	19
	Sida rhombifolia	14	0	9
	Triumfetta rhomboidei	60	84	18
	Waltheria indica	20	17	14

SW: Savannah woodland, RF: Riparian forest, SL: Swamp land

The result in Table 2 depicts the tree species' relative frequency (RF), relative density (RD), and relative dominance (RD_O) and Important Value Index (IVI) across the habitats. In Savannah Woodland (SW), RF, RD, RD_O and IVI values ranged from 1.01 to 8.08%, 0.26 to 16.49%, 0.13 to 15.00% and 0.48% to 12.85%, respectively. Within the Riparian Forest RF, RD, RDO and IVI values ranged from 0.53 to 17.46%), (1.61 to 11.29%), 0.36 to 14.10%) and IVI 1.44% to 13.96% respectively. In the Swamp land (SL) RF, RD, RDO and IVI values ranged from 2.70 to 10.81%, 1.02 to 43.88%, 0.21 to 26.71%, and 1.31% to 27.13% respectively.

The most occurring tree species in savannah woodland was *Maranthes polyandra* with the highest relative frequency of 8.08%, in riparian forest *Vitex doniana* occurred most with a relative frequency of 17.46% and in swamp land, *Mitragyna inermis* was the most occurring tree species with the relative frequency of 10.81%. *Parinari curatellifolia* was the most populous tree species in the savannah woodland with an RD value of 16.49%, while *Vitex doniana* (11.29%) was the most populous tree species in the riparian forest and *Mitragyna inermis* with an RD value of 43.88% being the most populous tree species in the swamp land of theGame Reserve. Tree species dominance in savannah woodland revealed that *Parinari curatellifolia* was the highest with an RD_O value of 15.00%, while in riparian forest *Erythrophleum suaveolens* had the highest RD_O value of 14.10%, and *Mitragyna inermis* had an RD_O value of 26.71% in swamp land. The Important Value Index (IVI) provides knowledge on important species in a floristic community. Based on the IVI, *Parinari curatellifolia* was the most dominant tree species in savannah woodland with an IVI of 12.85 and riparian forest *Vitex doniana* with an IVI of 13.96, and *Mitragyna inermis* in swamp land with IVI value of 27.13 (Table 2).

3.3 Trees /understorey (herbs and shrubs) species diversity across habitats of Pandam WildlifeGame Reserve

The result of trees, herbs, and shrubs' species diversity is given in Tables 4 to 6. Several trees and density were higher in SW (33,188) and least in RF (15, 80). Simpson index (D) and Shannon-wiener (H') were also highest in SW (D = 0.92, H' =2.97), followed by SL (D = 0.88, H' =2.63) and the least in RF (D = 0.80, H' =1.97) (Table 4).
The number, density and diversity of shrub species given in Table 5 revealed a higher abundance in SW (14, 162), followed by SL (12, 116) and the least in RF (9, 86). Simpson index (D) and Shannon-wiener (H') were also highest in SW (D = 0.91, H' = 2.52), followed by SL (D = 0.91, H' = 2.45) and the least in RF (D = 0.77, H' = 1.85). The herb species number, density and diversity indicated the highest dominance in SW (23, 1012), followed by SL (19, 702) and the least was RF (17, 567). Simpson index (D) and Shannon-wiener (H') were also highest in SW (D = 0.95, H' = 3.08), followed by SL (D = 0.94, H' = 2.86) and the least in RF (D = 0.93, H' = 2.7) (Table 6).

Table 4: Tree species number, density, and diversity indices across habitats of Pandam Wildlife Game Reserve.

Parameters	Savannah Woodland	Riparian Forest	Swamp Land	Pooled
Taxa_S	33	15	24	42
Individuals	716	296	362	1338
Number Individuals ha^{-1}	188	80	96	202
Dominance_D	0.08	0.20	0.12	0.06
Simpson_1-D	0.92	0.80	0.88	0.94
Shannon_H	2.97	1.97	2.63	3.19
Evenness_e^H/S	0.54	0.48	0.58	0.58
Margalef	4.87	2.46	3.90	5.70

Table 5: Shrubs species number, density, and diversity indices across habitats of Pandam WildlifeGame Reserve.

Parameter	Savannah Woodland	Riparian Forest	Swamp Land
Taxa	14	9	12
Individuals	380	194	164
Density	162	86	116
Dominance	0.09	0.23	0.09
Simpson	0.91	0.77	0.91
Shannon	2.52	1.85	2.44
Evenness	0.88	0.71	0.96
Margalef	2.19	1.52	2.15

Table 6: Herbaceous species number, density, and diversity indices acros habitats of Pandam WildlifeGame Reserve.

Parameter	Savannah Woodland	Riparian Forest	Swamp Land
Taxa	23	17	19
Individuals	1950	1051	1374
Density	1012	567	702
Dominance	0.05	0.07	0.06
Simpson	0.95	0.93	0.94
Shannon	3.08	2.73	2.86
Evenness	0.95	0.90	0.92
Margalef	2.90	2.30	2.49

4. Discussion

4.1 Plant species composition, Important Value Index (IVI), and family representation

This study revealed a clear distinction between the savannah woodland, riparian forest, and swamp land in terms of tree and understorey species distribution in the Game Reserve. There was a discernible pattern of plant existence for tree species as one moved from savannah woodland to the riparian forest and understorey species from savannah woodland to swamp land. Information on habitat characteristics is relevant to plant ecology as it also describes the state of vegetation in line with wildlife species' habituation, abundance, and survival. The composition of varied plant species indicates the structure of the habitat.

The IVI reveals the ecological importance of a species in a given ecosystem and is thussed for prioritising species conservation strategies (Kacholi 2013). The IVI value thus ranges from 0.00 to 3.00 (or 300%). The high IVI exhibited by *Parinari curatellifolia*, *Combretum nigricans*, *Maranthes polyandra*, and *Daniellia oliveri* at savannah woodland; *Vitex doniana*, *Rauvolfia vomitoria*, *Erythrophleum suaveolens* and *Daniellia oliveri* at the riparian forest; and *Mitragyna inermis*, *Erythrophleum suaveolens*, *Vitex doniana* and *Acacia nilotica* at swamp land is largely due to its higher species density compared to other species at different habitats of theGame Reserve. The occurrence of many species with lower IVI values in the Game Reserve is an indication that the majority of species were rare in the forest. This finding is also supported by the frequency of the family distribution of plants. However, the top five important families of plants recorded in the reserve were in line with the reports of some researchers like Maradana and Owk (2016) and Wakawa *et al.* (2017). The dominance of the two families Fabaceae and Poaceae were mainly due to high species abundance in trees and herbs species. Generally, trees belonging to these families are widespread in the subtropics and tropical forests, and play significant roles in the socio-economic life of people, improve soil fertility, serve as forage resources, and are rich in medicinal values (Addo-Fordjour *et al*. 2009; Aladesanmi *et al.* 2017; Wakawa *et al.* 2017). The rare number of species encountered in theGame Reserve confirms the commonly acclaimed notion that most of the species in the altered ecological forest are rare, rather than common (Magurran 2004). The rarity may be due to anthropogenic disturbance in the Game Reserve, especially logging and charcoal production that occurred at its peak in late 2017 up to 2018 within the research period.

4.2 Plant species density and diversity

Tree species diversity in both guinea savannah and tropical forest differ, even within the same forest (Steege *et al.* 2000; Neumann and Starlinger 2001). The tree species diversity assessed with Simpson (D) and Shannon-Weiner (*H'*) was found to be higher in savannah woodland with 2.97. Diversity indices measured for understorey (herbs and shrubs) species were also found to be higher (D- 3.0: H'-2.25) in savannah woodland. Species diversity measures the composition and assemblage of species which indicates their relative abundance (Gotelli and Chao 2013). The decrease in tree species diversity indices from riparian forest to swamp land suggests that tree distribution and composition declined with the corresponding effect by land-use type. Evidence of logging especially in the riparian part of the Game Reserve was high. Understorey composition also decreased in riparian forest to swamp land and was dominant in the savannah woodland, suggesting that herbs especially are favored by undisturbed areas (Ares *et al*. 2010). The value for tree species determined by the Shannon-Weiner index reflected a moderate diversity in the Game Reserve. The values, however, compare favourably with the values of Bello *et al.* (2013) in Kogo Forest, Wakawa *et al.* (2017) in Sahelien forest in Yobe State, and Asinwa *et al*. (2018) in Ogun River Watershed. The values are less compared with David (2014), Maradana and Owk (2016), and Aladesanmi *et al.* (2017). The stand density (202 trees ha^{-1}) of the Pandam Wildlife Game Reserve (PWP) is low compared with Duran *et al.* (2006) with a value of 347 trees ha^{-1}; Kessler *et al.* (2005) obtained 544 trees ha^{-1}. In any given forest, lower tree stands in an area usually reflect the higher composition of understorey vegetation (Pardini *et al*., 2005). This was evident in the Game Reserve as reflected high diversity of understorey species.

5. Conclusion

Protected Areas like Game Reserve require a continuous update of information on the status and trend of habitat components. This research presents methods for evaluating floristic diversity and structure. Savannah woodland habitat is the most diverse in tree and shrub species and understory herb species, which corresponds to better cover and foraging opportunities for the wildlife species in the game reserve. This calls for especially conservation attention for the particular habitat so as to maintain persistent wildlife population in the reserve. However, to make apply sound wildlife habitat management prescriptions there is also a need for further study on the relationship between floristic diversity and structure and wildlife species population abundance.

Funding: The research jointly sponsored by the team

Acknowledgement: we would like to acknowledge the support provided by the Pandam Wildlife Game
Reserve, Jos Plateau State, Nigeria and the University of Agriculture, Makurdi for the encouragement.

Conflict of interest: No conflict of interest

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