

# Floristic composition and diversity of Homegarden Agroforestry systems in the Lowlands of Tigray, North-Ethiopia

## Abstract

To reverse the challenges of land degradation, through improved vegetation composition and access to feed and wood, communities in northern Ethiopia started to establish homegarden agroforestry decades ago. However, there was information gap on the floristic composition and diversity of the homegarden agroforestry systems in northern Ethiopia, particularly in the lowlands of Tigray region. Hence, this study aimed at filling the gap. Fifteen homegarden agroforestry farms from fifteen farming households (One homegarden agroforestry farm from each household) were selected purposely. Floristic composition and diversity were estimated through Shannon diversity index, richness, evenness and density estimations. Twenty eight (28) woody species which belong to 17 families were recorded on the home-garden Agroforestry. Fabaceae and Combretaceae were found to be the most dominant families whereas 10 of the 17 families represented each by only one species. The density of the woody species in the homegarden agroforestry was 201 stems ha<sup>-1</sup> from which 56.8% was contributed by *Cordia africana*, *Ziziphus spina-christi* and *Anogeisusleiocarpus*. The Shannon diversity index and evenness of the homegarden farms were 2.52 and 0.75 respectively. In terms of the importance value index (IVI) of the species in the homegarden agroforestry, *Cordia africana* (64.76%) and *Ziziphus spina-christi* (45.30%) were the top ranking species. Generally, the present study revealed that the homegarden agroforestry systems are comparable to other homegarden agroforestry systems in Ethiopia in terms of floristic composition and diversity. Hence, both governmental and private sectors should play their role for the promotion of homegarden agroforestry systems in the study area, and in areas with similar biophysical and social setup. Moreover, afforestation and reforestation programs have to be continued for those species with low density, frequency and dominance in the study area.

**Key words:** Homegarden Agroforestry, floristic composition, diversity, Lowlands

## 1. Introduction

Land degradation, accelerated soil erosion and deforestation are serious problems in Ethiopia (Haregeweyn et al., 2012; Teka, 2017; Teka et al., 2014). Tigray (north Ethiopia) where the study area is located is one of the regions in Ethiopia is characterized by severely degraded soils, low productivity and loss of biodiversity (Birhane et al., 2006; Teka, 2017; Teka et al., 2014). To overcome the problem, various environmental rehabilitation efforts have been promoted and implemented in the last decades. Establishment of Agroforestry systems such as home-garden agroforestry are among many interventions (Guyassa and Raj, 2013).

Different researchers defined home-garden agroforestry a land use system involving deliberate management of multipurpose trees and shrubs in intimate association with annual and perennial agricultural crops and invariably livestock within the compounds of individual houses, the whole tree-crop, and animal unit is being intensively managed by family labor (Gautam et al., 2004; Kumar and Nair, 2006; Weerahewa et al., 2012). Studies from different locations of the globe such as Dixon (1995), Pandey (2002), Marland (2004), Lemma et al. (2006), Jose (2009), Alem (2013), Duguma et al. (2010), Negash et al. (2015) and Kim et al. (2016), indicated positive impacts of home garden agroforestry on plant diversity restoration, carbon sequestration and soil fertility improvement.

Agroforestry is also found to enhance biodiversity by providing habitats for species (Jose, 2009; Guyassa and Raj, 2013; Negash et al., 2013; Bajigo and Tadesse, 2015), and conserving native species (Harvey and Villalobos, 2007). More than 3000 tree species have been documented in tropical Agroforestry systems (Simons and Leakey, 2004). Agroforestry also provides many ecosystem services such as soil and water conservation, and watershed protection (Pandey, 2002; Jose, 2009), and soil fertility improvement (Negash, 2013).

In north Ethiopia (Tigray) where the study is located, few studies (e.g. Darcha et al., 2015; Guyassa and Raj, 2013; Haileselasie and Hiwot, 2012) on the contribution of home-garden Agroforestry systems to ecological restoration were conducted in different sites. However, the focus of these studies was on the mid to highland areas (elevation greater than 1500 m a.s.l) with less intention to the lowlands (elevation less than 1500 m a.s.l). The socio-economic conditions, political and historical contexts, and level of management are different in these different agro-ecologies (Guyassa and Raj, 2013). Moreover, the effect of land use conversion is variable, and

depends on soil type, land-use history and topography. However, the homegardens in north-Ethiopian lowlands were not adequately evaluated and documented. Furthermore, Quantifying the role of home-garden Agroforestry systems for ecological restoration is critical to help decide whether additional home-garden Agroforestry systems should be established in the area, and areas with similar biophysical and socio-economic setup. Hence, this study aimed at inventorying the woody species composition and diversity of homegarden agroforestry systems in Tselemti district, Northern Ethiopia.

## 2. Materials and Methods

### 2.1. The Study Area

The study was conducted at Sekota-mariam peasant association (PA) in Tselemti District, North Western Zone of Tigray, north-Ethiopia (Figure 1). The study site was purposely selected based on the availability of homegarden agroforestry system and accessibility of the peasant association (PA) for the study. It is located at 13°05' latitude and 38°18' longitude, and has an altitude of 1350 meter above sea level (m a.s.l). Areas characterized by an elevation less than 1500 but greater than 500 m a.s.l are classified as lowland or locally called 'Kolla' (Hurni et al., 2016).

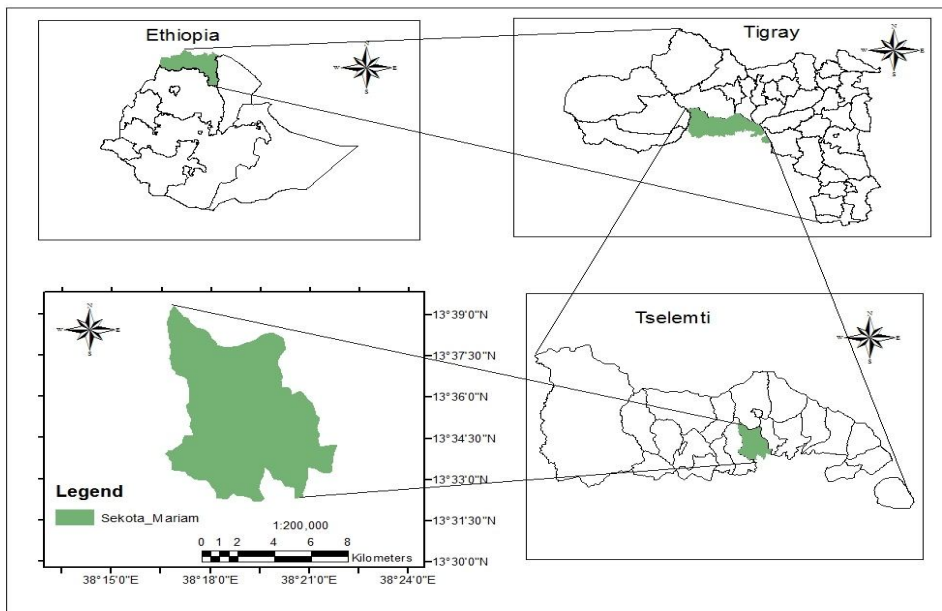


Figure1. Location map of the study area

The study area is characterized by dry semi-arid lowland plains (MOA, 2000). The mean temperature ranges from 15.6 °C in January to 38.6 °C in April. While, the annual rainfall ranges from 350 to 750 mm per year and falls from mid-June to early September (*Livelihood Profile, Tigray Region, Ethiopia, 2007*).

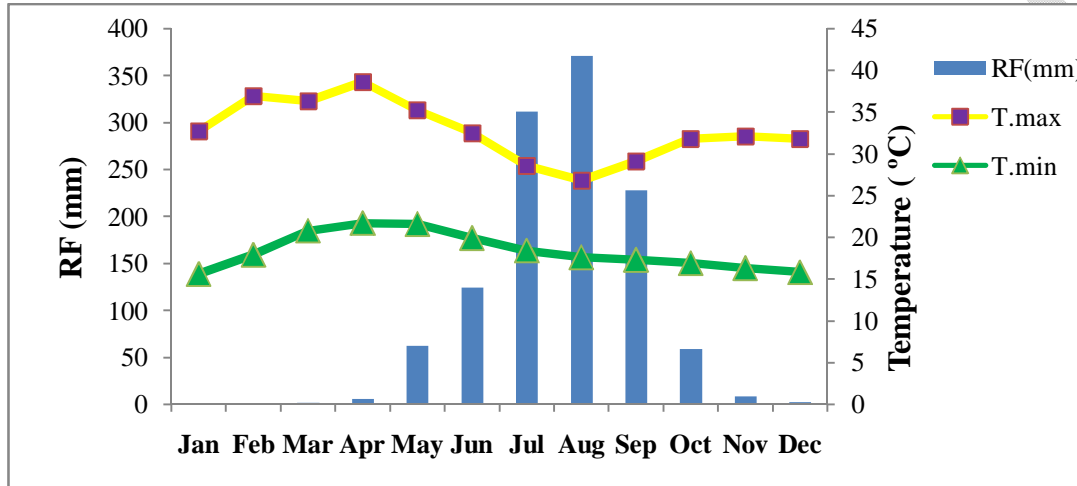


Figure 2. Mean monthly temperature (Years in range) of the study area (Source: Tigray meteorological services center).

The major reference soil groups in the area are Nitisols, Cambisols and Vertisols (TARI, 2002). The area is within a mixed farming zone that produces both food and cash crops along with livestock production. The main crops grown for consumption are sorghum (*Sorghum bicolor*), finger millet (*Eleusine coracana*) and maize (*Zea mays*). Livestock production is a major component of the livelihood system. The main livestock types are cattle, goats and sheep. Livestock are important for draft power and as an income source. The district has a total land size of 717, 000 ha. From this, 80% is planted in cereals, 4% in oil seeds, 2% in pulses and the remaining with vegetables and fruit trees (OOARD, 2014). The district has a total population of 138,858; of which 68750 are women and 70,108 are men (CSA, 2008). The population density is 36 people km<sup>-2</sup>.

## 2.2. Vegetation data sampling

For vegetation survey in the homegarden agroforestry, 15 plots (in this case homegarden agroforestry farms) from 15 farming households (One homegarden agroforestry farm

from each household) were selected purposely. Quadrates were not laid in the homegarden agroforestry, rather the entire area of the homegarden was used as a sampling unit for each farm house hold for vegetation survey (Didita and Mengistu, 2012).The area of the smallest plot, which is 973 m<sup>2</sup> was taken as sampling area for each plot.Complete enumeration of species within each sampling unit was used for vegetation survey (Tolera et al., 2008).

Diameter tape and caliper were used to measure the diameter at breast height (DBH) and diameter at estimated stump height (DSH) of the species. Plant identification was done at the field. The woody species encountered in the plots were identified based on our experience supported by the local residents and district experts. The scientific name of each species was referred from Species list of useful trees and shrubs for Ethiopia (Tesemma, 1993, 2007), and useful trees and shrubs in Eritrea (Bein et al., 1996).

### 2.3.Vegetation data analysis

The vegetation data were analyzed by computing the density, frequency, dominance, diversity indices and importance value index (IVI).

**Density:** was computed by summing up all the individuals from all sample plots and translated to hectare base for all the species. Two sets of density were calculated: density/ha of each species and relative density, which was calculated as the ratio of the density of a given species to the sum total of the density of all species:

$$\text{Relativedensity} = \frac{\text{Density of species A in hectare base}}{\text{Density of all species in hectare base}} * 100 \dots\dots \text{Eq (1)}$$

**Frequency:** It shows the presence or absence of a given species in each sample quadrant. Two sets of frequency were calculated, absolute frequency, which refers to the number of plots in which the woody species encountered and relative frequency, calculated as the ratio of the absolute frequency of a given species to the sum total of the frequency of all species:

$$\text{Relativefrequency} = \frac{\text{Frequency of species A}}{\text{Frequency of all species}} * 100 \dots\dots\dots\text{Eq (2)}$$

**Dominance:**It refers to the degree of coverage of a given species expressed by a space it occupied in a given area. Two sets of dominance were calculated: absolute dominance (the sum of basal areas of the stems in m<sup>2</sup>/ha), and relative dominance: ratio of the total basal

area of a given species to the sum of total stem basal areas of all species. Dominance was calculated for individual stems with diameter > 2.5cm (Worku, 2006):

$$\text{Relativedominance} = \frac{\text{DominanceofspeciesA}}{\text{Dominanceofallspecies}} * 100 \dots\dots \text{Eq (3)}$$

**Basal area (BA)** was computed using the formula:-

$$BA = \frac{\pi d^2}{4} \dots\dots\dots \text{Eq (4)}$$

Where BA= basal area in m<sup>2</sup>; π=3.14; D=diameter

**Importance Value Index (IVI):**

It refers to the relative ecological importance of each species in a given area. It was calculated by summing up the relative dominance, relative density and relative frequency of the species as follows:

$$IVI = Rd + RD + RF \dots\dots\dots \text{(Eq 5)}$$

Where Rd is relative density, RD is relative dominance and RF is relative frequency.

**Diversity indices**

Species diversity was estimated using Shannon Wiener Diversity Index and evenness (Kent & Coker 1992):

$$H' = - \sum_{i=1}^s p_i \ln p_i \dots\dots\dots \text{(eq. 6)}$$

Where:

H' = Shannon diversity index

s = number of species

Pi = the proportion of individuals or the abundance of the ith species expressed as a proportion of the total

ln = natural logarithm

**Evenness:** was calculated using the formula:

$$\text{Evenness (J')} = - \sum_{i=1}^s p_i \ln p_i / \ln s \dots\dots\dots \text{(Eq 7)}$$

Where: S = number of species and ln is a natural log.

### **Species richness**

Species richness can be expressed as number of species per unit area. The sum of all woody species encountered in the plots of the land use systems was used to determine the species richness.

## **3. Result and Discussions**

### **3.1. Floristic composition**

As shown in Table 1, twenty eight (28) woody species which belong to 17 families were recorded on the home-garden Agroforestry. This result corresponds with the findings of Guyassa and Raj (2013) for Abreha we Atsbeha watershed (northern Ethiopia) who reported 28 species in home-gardens. However, this was higher than the number of species reported by Mengistu and Asfaw (2016) at Dallo Mena District, South-East Ethiopia (15 species), but lower than those reported by Abebe et al. (2013) at Sidama Zone of southern Ethiopia (120 species), Haileselasie and Hiwot (2012) at home-gardens of Hintalowagerat district of Tigray region (40 species), and Tolera et.al. (2008) at Arsi Negelle district in central Ethiopia (64 species). These differences may be attributed to the variations in environmental conditions and farmers management.

Fabaceae and Combretaceae were the most dominant families at the home-garden Agroforestry system represented by 5 and 3 species respectively and contributed 28.5% of the species composition of the system. However, 10 of the 17 families represented each by only one species. This revealed that the system was dominated by few species.

**Table1: Tree species in home garden Agroforestry**

Species name	Family name	Number of species per Family
<i>Citrus lemon</i>	Rutaceae	Rutaceae=2 species
<i>Cordia africana</i>	Boraginaceae	Boraginaceae=1
<i>Jacaranda mimosifolia</i>	Bignoniaceae	Bignoniaceae=2
<i>Carica papaya</i>	Caricaceae	caricaceae=1
<i>Mangifera indica</i>	Anacardiaceae	Anacardiaceae=1
<i>Psidium gaujava</i>	Myrtaceae	Myrtaceae=1
<i>Acacia polyacantha</i>	Fabaceae	Fabaceae=5
<i>Ziziphus spina-christi</i>	Rhamnaceae	Rhamnaceae=2
<i>Croton macrostachyus</i>	Euphorbiaceae	Euphorbiaceae=1
<i>Citrus aurantifolia</i>	Rutaceae	Rubiaceae=2
<i>Acacia persiciflora</i>	Fabaceae	Combretaceae=2
<i>Gardenia lutea</i>	Rubiaceae	Moraceae=3
<i>Anogeisusleiocarpus</i>	Combretaceae	Meliaceae=1
<i>Fehiderbia albida</i>	Fabaceae	Ebenaceae=1
<i>Ficus vasta</i>	Moraceae	Caesalpinioideae=1
<i>Melia azedarach</i>	Meliaceae	Tiliaceae=1
<i>Acacia seyal</i>	Fabaceae	Burseraceae=1
<i>Terminalia brownii</i>	Combretaceae	
<i>Diospyros mespiliformis</i>	Ebenaceae	
<i>Sterospermumkunthianum</i>	Bignoniaceae	
<i>Ficus ingens</i>	Moraceae	
<i>Cassia singueanea</i>	Caesalpinioideae	
<i>Ziziphus jujube</i>	Rhamnaceae	
<i>Ficus sycomorus</i>	Moraceae	
<i>Grewia ferruginea</i>	Tiliaceae	
<i>Commiphora africana</i>	Burseraceae	
<i>Dichrostachyscinearea</i>	Fabaceae	
<i>Vangueria edulis</i>	Rubiaceae	

### 3.2. Density, diversity indices and richness

The overall density of the woody species in the homegarden agroforestry was 201 stems ha<sup>-1</sup> (Table 2). Density of species in the homegarden varied among species. *Cordia africana*, *Ziziphus spina-christi* and *Anogeisusleiocarpus* were the denser species with 52.7, 37 and 24.6 stems ha<sup>-1</sup> respectively and contributed to 56.8% of the total density in the homegarden agroforestry while 9 species were found to be the least abundant with 0.7 stem ha<sup>-1</sup> each (Table 2). The density on the homegarden agroforestry was found to be higher than that reported by Yakob et al. (2014), 113

stems  $\text{ha}^{-1}$ , for Gimbo district (south west Ethiopia), but lower than that reported by Abebe et al. (2013) which was 475 stems  $\text{ha}^{-1}$  for agroforestry homegarden of Sidama zone, Southern Ethiopia. This difference could be due to difference in planting pattern of the woody species. According to Abebe et al. (2013) for home-gardens in Sidama, and Molla and Kewessa (2015) for home-gardens in Bale zone, woody species abundance largely depends on the planting pattern of the woody species.

The Shannon diversity index value and species evenness of the homegarden agroforestry were found to be 2.52. This was comparable to the findings at Bale zone home garden in Ethiopia ranging from 2.53 to 2.73 (Molla and Kewessa, 2015), at Kerala garden in India, ranging from 1.12 to 3 (Kumar et al., 1994), and home-gardens of Thailand, ranging from 1.9 to 2.7 (Gajaseni and Gajaseni, 1999). However, it was found to be higher than those reported by Guyassa and Raj (2013) for Abreha-we-Atsbeha ( $H = 1.31$ ), Bajigo and Tadesse (2015) for Gununo in Wolayitta Zone ( $H=2.02$ ) and Tolera (2008) for Arsi Negelle in Ethiopia ( $H = 2.22$ ). The richness of the species in the land use system was found to be 5. Moreover, the evenness of homegarden in the study area (0.75) was higher compared to what was reported by Tolera (2008) for Arsi Negelle in Ethiopia (0.64) and Mengistu (2008) at homegarden of western Amhara of Ethiopia ( $H=0.69$ ). However, it was lower compared to the values reported by Molla and Kewessa (2015) for Bale zone, evenness ranging from 0.91 to 0.99.

**Table 2: Species abundance, density, dominance, frequency and importance value index**

Species	Abundance	Density (trees/ha)	Dominance (cm <sup>2</sup> /ha)	Freq.	IVI%
<i>Citrus lemon</i>	15	10.3	1395.1	2	9.7
<i>Cordia africana</i>	77	52.7	16286.2	12	64.8
<i>Jacaranda mimosifolia</i>	1	0.7	110.4	1	1.8
<i>Carica papaya</i>	11	7.5	1512.6	2	8.5
<i>Mangifera indica</i>	8	5.5	875	2	6.6
<i>Psidium gaujava</i>	3	2.1	2829.6	1	6.3
<i>Acacia polyacantha</i>	7	4.8	2590.3	4	11.3
<i>Ziziphus spina-christi</i>	54	37	10789.7	9	45.3
<i>Croton macrostachyus</i>	12	8.2	1891	2	9.4
<i>Citrus aurantifolia</i>	1	0.7	223.4	1	2
<i>Acacia persiciflora</i>	5	3.4	468	1	3.7
<i>Gardenia lutea</i>	2	1.4	394.8	2	3.9
<i>Anogeisusleiocarpus</i>	36	24.7	8218.8	6	31.6
<i>Fehiderbia albida</i>	8	5.5	2753.1	3	10.5
<i>Ficus vasta</i>	1	0.7	950.2	1	3
<i>Melia azedarach</i>	1	0.7	115.4	1	1.8
<i>Acacia seyal</i>	16	11	9230.8	3	22.3
<i>Terminalia brownii</i>	1	0.7	502.6	1	2.4
<i>Diospyros mespiliformis</i>	1	0.7	110.5	1	1.8
<i>Sterospermumkunthianum</i>	5	3.4	2475.9	1	6.5
<i>Ficus ingens</i>	6	4.1	2001	1	6.2
<i>Cassia singueanea</i>	1	0.7	42.8	1	1.7
<i>Ziziphus jujube</i>	4	2.7	507.5	2	4.7
<i>Ficus sycomorus</i>	5	3.4	3439.4	2	9.1
<i>Grewia ferruginea</i>	1	0.7	105.6	1	1.8
<i>Commiphora africana</i>	5	3.4	283.2	1	3.4
<i>Dichrostachyscinearea</i>	6	4.1	1346.6	2	6.6
<i>Vangueria edulis</i>	1	0.7	36.9	1	1.7
Total	294	201	71486	67	

### 3.3. Frequency, dominance and importance value index (IVI)

In homegarden agroforestry, *Cordia africana* and *Ziziphus spina-christi* were the most frequent species encountered in 12 and 9 plots respectively out of the 15 plots, while 14 species were recorded in only one quadrat (Table 2). The two most dominant species were *Cordia africana* (22.78%) and *Ziziphus spina-christi* (15.09%) with 1.63 m<sup>2</sup>/ha and 1.08 m<sup>2</sup>/ha respectively (Table 2). In terms of the importance value index of the species in homegarden agroforestry, *Cordia africana* (64.76%) and *Ziziphus spina-christi* (45.30%) were the top ranking species

(Table 2). This can show us only few species hold the largest value of IVI and so higher difference in ecological importance of each species at the study area.

#### **4. Conclusion**

The results of this study elucidated that the floristic composition, density, diversity indices in the homegarden agroforestry systems of in the lowlands of Tigray region, northern Ethiopia are comparable to many other homegardens of the country. Most of the families were founded to be represented by a single species which shows that the system was dominated by few species and families. The study also revealed that only three species contributed to more than half of the total density in the homegarden agroforestry. In addition, half (14) of the total species were recorded in only one plot where one species was recorded in almost all of the plots. On top of that, the study showed that only few species hold the largest value of Importance Value Index (IVI) and so higher difference in ecological importance of each species at the study area. Both governmental and private sectors should play their role for the promotion of homegarden agroforestry systems in the study area, and in areas with similar biophysical and social setup. Moreover, afforestation and reforestation programs have to be continued for those species with low density, frequency and dominance in the study area.

#### **References**

- Abebe, T., Sterck, F. J., Wiersum, K. F., Bongers, F. (2013): Diversity, composition and density of trees and shrubs in agroforestry home gardens in Southern Ethiopia. *Agroforestry systems*. 87(6), 1283-1293.
- Abera, G., Wolde-Meskel, E. (2013): Soil properties, and soil organic carbon stocks of tropical Andosol under different land uses. *Open Journal of Soil Science*. 3, 153-162
- Alem, S. M. (2013): Effect of Plantation Forests on Soil Chemical Properties, Soil Temperature and regeneration of Woody Plants: A Comparative Analysis. PhD Dissertation. Mendel University in Brno, Czech Republic.

- Araujo, A. S., Leite, L. F., De Freitas Iwata, B., De Andrade Lira, M., Xavier, G. R., Figueiredo, M. D. (2012): Microbiological process in agroforestry systems. A review. *Agronomy for Sustainable Development*. 32(1), 215-226.
- Awasthi, K. D., Singh, B. R., Sitaula, B. K. (2005): Profile carbon and nutrient levels and management effect on soil quality indicators in the Mardi watershed of Nepal. *Acta Agriculturae Scandinavica Section B-Soil and Plant*. 55(3), 192-204.
- Bajigo, A., Tadesse, M. (2015): Woody Species Diversity of Traditional Agroforestry Practices in Gununo Watershed in Wolayitta Zone, Ethiopia. *Forest Res*. 4(155), 2.
- Bein, E., Habte, B., Jaber, A., Birnie, A., Tengnas, B. (1996): Useful Trees and Shrubs in Eritrea. Identification, Propagation and Management for Agricultural and Pastoral Communities. Regional soil conservation unit, RSCU/SIDA, Nairobi.
- Birhane, E., Teketay, D., Barklund, P. (2006): Actual and potential contribution of exclosures to enhance biodiversity of woody species in the drylands of Eastern Tigray. *Journal of Drylands*. 1(2), 134-147.
- CSA. (2008): Summary and statistical report of the 2007 population and housing census results. Population size by age and sex. Central Statistical Agency of Ethiopia: Addis Ababa.
- Darcha, G., Birhane, E., Abadi, N. (2015): Woody Species Diversity in *Oxytenanthera abyssinica* Based Homestead Agroforestry Systems of Serako, Northern Ethiopia. *Journal of Natural Sciences Research*. 5 (9): 18 – 26.
- Didita, M and Mengistu, B. (2012). The role of homegarden Agroforestry in plant diversity conservation in Bale. Forestry and forest products in Ethiopia. Proceedings of the national work shop on forestry research technologies. Ethiopian Institute Agricultural Research (EIAR). Addis Ababa, Ethiopia.
- Dixon, R. K. (1995): Agroforestry systems: sources of sinks of greenhouse gases? *Agroforestry systems*. 31(2), 99-116.
- Duguma, L. A., Hager, H., Sieghardt, M. (2010): Effects of land use types on soil chemical properties in smallholder farmers of central highland Ethiopia. *Ekológia (Bratislava)*, *Ekológia (Bratislava)*. 29(1), 1-14.
- Gajaseni, N., Gajaseni, J. (1999): Ecological rationalities of the traditional home garden system in the Chao Phraya Basin, Thailand. *Agroforestry Systems*. 46 (1): 3–23.

- Gautam, R., Sthapit, B., Shrestha, P. (2004): Home gardens in Nepal. Proceedings of a national workshop, Local Initiatives for Biodiversity, Research and Development (LI-BIRD). Pokhara, Nepal.
- Grossman, R., Reinsch, T. (2002): Bulk density and linear extensibility. *Methods of Soil Analysis: Part 4 Physical Methods (methods of soil)*, 201-228.
- Guyassa, E., Raj, A. J. (2013): Assessment of biodiversity in cropland agroforestry and its role in livelihood development in dryland areas: A case study from Tigray region, Ethiopia. *Journal of Agricultural Technology*. 9(4), 829-844.
- Haileselassie, T. H., Hiwot, M. T. (2012): Agroforestry practices and flora composition in backyards in Hiwane, HintaloWejerat of Tigray, Northern Ethiopia. *International Journal of Biodiversity and Conservation*. 4(7), 294-303.
- Harcombe, R. (1980): Soil nutrient loss as a factor in early tropical secondary succession. *Biotropica*. 12, 8±15.
- Haregeweyn, N., Berhe, A., Tsunekawa, A., Tsubo, M., Meshesha, D. T. (2012): Integrated Watershed Management as an Effective Approach to Curb Land Degradation: A Case Study of the Enabered Watershed in Northern Ethiopia. *Environmental Management*. 50, 1219–1233.
- Harvey, C. A., Villalobos, J. A. G. (2007): Agroforestry systems conserve species-rich but modified assemblages of tropical birds and bats. *Biodiversity and Conservation*. 16(8), 2257-2292.
- Houba, V., Vander, L., Novazamsky, I., Walinga, I. (1989): Plant and Soil Analysis procedures. Department of Soil Science and Plant Nutrition Agric. Univ. Wageningen, Netherlands.
- Hurni, H., Berhe, W. A., Chadhokar, P., Daniel, D., Gete, Z., Grunder, M., Kassaye, G. (2016): Soil and Water Conservation in Ethiopia: Guidelines for Development Agents. Second revised edition. Bern, Switzerland: Centre for Development and Environment (CDE), University of Bern, with Bern Open Publishing (BOP). 134 pp.
- Jackson, M. (1958): *Soil Chemical Analysis*. 6th ed. Prentice; Halls, Inc., Englewood cliffs: New Jorsey. p.498.
- Jha, M. N., Gupta, M. K., Raina, A. K. (2001): Carbon Sequestration: Forest soil and land use management. *Annals of Forestry*. 9, 249-256.
- Jose, S. (2009): Agroforestry for ecosystem services and environmental benefits: an overview. *Agroforestry systems*. 76(1), 1-10.

- Kim, D. G., Terefe, B., Girma, S., Kedir, H., Morkie, N., Woldie, T. M. (2016): Conversion of home garden agroforestry to crop fields reduced soil carbon and nitrogen stocks in Southern Ethiopia. *Agroforestry systems*. 90(2), 251-264.
- Kumar, B. M., George, S. J., Chinnamani, S. (1994): Diversity, structure and standing stock of wood in the home gardens of Kerala in peninsular India, *Agroforestry Systems*. 25 (3), 243–262.
- Kumar, B. M., Nair, P. K. R. (2006): *Tropical Home Gardens: A Time-Tested Example of Sustainable Agroforestry*. Environmental Experts, India.
- Labata, M. M., Aranico, E. C., Tabaranza, A. C. E., Patricio, J. H. P., Amparado, Jr. R. F. (2012): Carbon stock assessment of three selected agroforestry systems in Bukidnon, Philippines. *Advances in Environmental Sciences*, 4(1).
- Lemma, B., Kleja, D. B., Nilsson, I., Olsson, M. (2006): Soil carbon sequestration under different exotic tree species in the southwestern highlands of Ethiopia. *Geoderma*. 136(3), 886-898.
- Livelihood Profile, Tigray Region, Ethiopia. (2007): Draft Adiabo Lowland Livelihood Zone. Pp. 5. [www.heaweb.org/download/file/fid/357](http://www.heaweb.org/download/file/fid/357)
- Marland, G., Garten, C. T., Post, W. M., West, T. O. (2004): Studies on enhancing carbon sequestration in soils. *Energy*. 29(9), 1643-1650.
- Mengistu, B., Asfaw, Z. (2016): Woody Species Diversity and Structure of Agroforestry and Adjacent Land Uses in Dallo Mena District, South-East Ethiopia. *Natural Resources*. 7 (10), 515-534.
- MOA (Ministry of Agriculture). (2000): *Agro ecological Zones of Ethiopia*, Natural Resource Management and Regulatory Department, Addis Ababa.
- Moges, A., Holden, N. M. (2008): Soil fertility in relation to slope position and agricultural land use: a case study of Umbulo Catchment in Southern Ethiopia. *Environmental management*. 42(5), 753-763.
- Molla, A., Kewessa, G. (2015): Woody Species Diversity in Traditional Agroforestry Practices of Dellomenna District, Southeastern Ethiopia: Implication for Maintaining Native Woody Species. *International Journal of Biodiversity*. <http://dx.doi.org/10.1155/2015/643031>
- Negash, M., Starr, M. (2015): Biomass and soil carbon stocks of indigenous agroforestry systems on the south-eastern Rift Valley escarpment, Ethiopia. *Plant and soil*. 393(1-2), 95-107.
- November, E., Aerts, R., Behailu, M., Muys, B. (2002): Species list Tigrinya – Scientific. Technical note 2002/4. Forest Rehabilitation Project, Mekelle University, Ethiopia and K.U. Leuven, Belgium. Pp.10.

- Olsen, S. R., Sommers, L. E. (1982): Phosphorus. In: Page, A. L., Miller, L. H., Keeney, D. R. (Eds.), *Methods of Soil Analysis. Part 2. Chemical and microbiological properties. Agronomy Monograph, second ed., vol. 9, American Society of Agronomy, Madison, WI, 403-430.*
- OOARD (Office of Agriculture and Rural Development). (2014): Annual report of Office of the agricultural and rural development of Tselemti Woreda, Tselemti.
- Pandey, D. N. (2002): Carbon sequestration in agroforestry systems. *Climate policy*. 2(4), 367-377.
- Pearson, T. R., Brown, S. L., Birdsey, R. A. (2007): Measurement guidelines for the sequestration of forest carbon. General Technical Report NRS-18. Northern Research Station. United States Department of Agriculture.
- Pinho, R. C., Alfaia, S. S., Miller R. P., Uguen, K., Magalhães, L. D., Ayres, M., Freitas, V., Trancoso, R. (2011): Islands of fertility: soil improvement under indigenous home gardens in the savannas of Roraima, Brazil. *Agroforestry Systems*. 81 (3), 235–247.
- Radersma, S., Grierson, P. F. (2004): Phosphorus mobilization in agroforestry: Organic anions, phosphatase activity and phosphorus fractions in the rhizosphere. *Plant and Soil*. [259 \(1-2\)](#), 209-219.
- Shannon, C. E., Weaver, W. (1963): *The mathematical theory of communication*. Urbana: University of Illinois Press.
- Simons, A. J., Leakey, R. R. B. (2004): Tree domestication in tropical agroforestry. *Agroforestry systems*. 61, 167-181.
- Singh, B. R., Wele, A. D., Lal, R. (2010): Soil carbon sequestration under chronosequences of agroforestry and agricultural lands in Southern Ethiopia. 19<sup>th</sup> World Congress of Soil Science. Norwegian University of Life Sciences.
- TARI (Tigray Agricultural Research Institute). (2002): Spatial stratification of agro ecologies in Tigray, Mekelle.
- Teka, K. (2017): Identification of Erosion Prone Areas at Macro-Watershed Level for Regional Development Planning in Northern Ethiopia. *Journal of the Drylands*. 7 (1), 598 – 609.
- Teka, K., Van Rompaey A., Poesen J., Van Bruyssel S., Deckers J., Amare, A. (2014): Spatial Analysis of Land Cover Changes in Eastern Tigray (Ethiopia) from 1965 till 2007: are there Signs of a Forest Transition? *Land Degrad. Develop.* DOI: 10.1002/ldr.2275.

- Tesemma, A. (1993): Useful Trees and Shrubs for Ethiopia. Identification, Propagation and Management for Agricultural and Pastoral Communities. Technical handbook No 5. Regional soil conservation unit. Swedish international development authority.
- Tesemma, A. (2007): Useful trees of Ethiopia: identification, propagation and management in 17 agro ecological zones. Nairobi: RELMA in ICRAF Project, 552p.
- Tolera, M., Asfaw, Z., Lemenih, M., Karlton, E. (2008): Woody species diversity in a changing landscape in the south-central highlands of Ethiopia. *Agriculture, ecosystems & environment*. 128(1), 52-58.
- Van reeuwijk, L. P. (1992): Procedures for Soil Analysis, 3rd edition. International Soil Reference Centre Wageningen (ISRIC), Netherlands, Wageningen.
- Walkley, A., Black, I. A. (1934): Chromic acid titration for determination of soil organic matter. *Soil Science*. 63, 239 - 251.
- Wang, G., Welham, C., Feng, C., Chen, L., Cao, F. (2015): Enhanced Soil Carbon Storage under Agroforestry and Afforestation in Subtropical China. *Forests*. 6, 2307-2323.
- Weerahewa, J., Pushpa kumara, G., Silva, P., Daulagala, C., Punyawardena, R., Premalal, S., Miah, G., Roy, J., Jana, S., Marambe, B. (2012): Are home garden ecosystems resilient to climate change? An analysis of the adaptation strategies of home gardeners in Sri Lanka. *APN Science Bulletin*. 2, 22–27.
- Wei, X., Shao, M., Gale, W., Li, L. (2014): Global pattern of soil carbon losses due to the conversion of forests to agricultural land. *Sci Rep*. 4, 40 – 62.
- Worku, A. G. (2006): Population Status and Socio-economic Importance of Gum and Resin Bearing Species in Borana Lowlands, southern Ethiopia. Msc thesis, Addis Ababa University.
- Yakob, G., Asfaw, Z., Zewdie, S. (2014): Wood Production and Management of Woody Species in Homegardens Agroforestry: The Case of Smallholder Farmers in Gimbo District, South West Ethiopia. *International Journal of Natural Sciences Research*. 2(10), 165-175.
- Yimer, F., Alemu, G., Abdelkadir, A. (2015): Soil property variations in relation to enclosure and open grazing land use types in the Central Rift Valley area of Ethiopia. *Environmental Systems Research*. 4(1), 17.

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