ОРИГИНАЛЬНЫЕ СТАТЬИ
RESEARCH ARTICLES

RESTORATION OF DEGRADED DRYLANDS THROUGH EXCLOSURES ENHANCING WOODY SPECIES DIVERSITY AND SOIL NUTRIENTS IN THE HIGHLANDS OF TIGRAY, NORTHERN ETHIOPIA

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Exclusion of grazing animals and tree plantations were among the methods used for the rehabilitation of degraded lands in tropical semiarid areas. Exclosures can foster secondary forest succession by improving soil conditions, attracting seed-dispersal agents and modifying microclimate for understory growth. This paper compares the woody species diversity and soil chemical properties under exclosure with increasing age and grazing land at different slope positions. The study has been conducted in northern Ethiopia from 12 exclosure sites paired each with adjacent grazing land with four treatments replicated three times. In the entire study 216 plots were examined of which 108 were in exclosures and 108 in communal grazing lands.There were four age classes and three slope positions in each of the landuses. Vegetation data were collected using plots measuring 100 m^2. Soils for physicochemical properties were collected from the four corners and center of 5 × 5m plots which was inside the 10 × 10m plot. A total of 61 woody plant species belonging to 41 families were recorded. Diversity and species richness were higher in the exclosures than in grazing lands. Among exclosures these parameters were higher in exclosures older than 30 years and at the foot of the slope. Grazing lands, the youngest exclosures and upper elevation gradient recorded lower values. Chemical soil properties were significantly higher in the exclosures, among them in the oldest exclosures and at foot elevation (except for P) than these were in the grazing land, the youngest exclosures and upper parts of slopes respectively. Exclosures are instrumental to improve the woody species diversity and soil chemical properties in the drylands.

Key words: chemical soil properties, exclosure, slope position, woody diversity

Introduction

Land degradation is a widespread problem throughout sub-saharan Africa and its restoration is a challenge for the management of many semi-arid areas (Yayneshet et al., 2009). Extensive deforestation and conversion of natural forests into agricultural land is the main cause of land use change in Ethiopia. The FAO (2007) estimated a deforestation rate of 1410 km^2 and the World Bank (2001) found 620 km^2 per year. The forest cover of the total area of Ethiopia shrunk from 65% to 2.2% (Berry, 2003). 90% of the total forest reduction was in the highlands, which accounted 5.6% deforestation. These changes have negatively affected the physical and chemical soil properties as well as the bioavailability of soil nutrients (Solomon et al., 2002). Moreover, the relatively early and extensive deforestation in Ethiopia has eroded the biological diversity to such an extent that some plants are faced with local extinction (Yirdaw, 2001). Land degradation affects the livelihood of the rural population and is a major threat to sustainable land use (Hurni et al., 2005) by enhancing degradation of vegetation cover, soil and nutrient depletion in Ethiopia (Haileslassie et al., 2005).

Forests and the benefits they provide in the form of environmental protection, firewood, food and income have an important and critical role in enabling to secure a stable and adequate food supply. Deforestation and land degradation, however, are reducing the capacity of forests and the land to improve environmental conditions and to provide other benefits (Tadesse, 2001). Furthermore, land degradation exacerbates drought and desertification (Sonneveld & Keyzer, 2002). Soil erosion has accelerated on the Ethiopian highlands due to deforestation, cultivation of marginal lands, uncontrolled grazing and higher demand for fuelwood by the local communities (Reusing et al., 2000). This has led to a loss of the fertile top soil through erosion and nutrient depletion and resulted in a low plant diversity and agricultural productivity. Farmers can sustainably use their natural resources by introducing proper plant species on the steep slopes and degraded areas to improve soil fertility. Those species can be used as a source of forage

for livestock and pollen for bees. This would increase the flexibility in the management of land use, fodder and livestock hence enabling households to make a living and diversify sources of livelihood but also address land degradation (Mekonen & Tesfahunegn, 2011). An improved vegetation cover has assisted to increase soil cover thus decreasing losses of soil moisture through evapotranspiration. Better soil cover has also been vital in facilitating improved water infiltration while decreasing soil erosion and increased litter deposition and carbon sequestration that would upgrade fertility to increase productivity (Wairore et al., 2015). Although soil erosion is prevalent throughout Ethiopia, this problem is particularly severe in Tigray region, which urges the need to implement integrated soil and water conservation measures (Tadesse, 2001).

In response of the land degradation, the government of Ethiopia has initiated a number of projects including soil and water conservation works and establishment of exclosures (Nedessa et al., 2005). Exclosures are areas closed off from the interference of human and domestic animals with the goal of promoting natural regeneration of plants and reducing land degradation of formerly degraded communal grazing lands (Seyoum et al., 2015). Exclosures are usually established in steep, eroded, and degraded areas that have been used for grazing in the past (Descheemaeker et al., 2006). Priority areas for establishing exclosures are normally identified as a joint initiative of local communities and governmental and nongovernmental organisations (Descheemaeker et al., 2006). Exclosure is protecting the degraded land from tree cutting and free grazing of domestic animals (Mengistu et al., 2005). In most cases, for establishing of an exclosure, this area should be abandoned as a result of being unsuitable for human and animal use (Nedessa et al., 2005). According to Lemenih & Kassa (2014) exclosure involves protecting areas mainly through social fencing from any form of cultivation, cutting trees and shrubs, or grazing by livestock. There are common management interventions in addition to protection that involves planting of seedlings (exotic or indigenous species), aerial seeding and construction of soil and water conservation structures to speed up succession through the modification of microclimatic and soil conditions. As a result, diverse woody and non-woody plant species re-emerge, landscape greenness increases, soil erosion declines, sediment deposition downstream declines and water infiltration and stream discharge increase (Yami et al., 2006; Babulo et al., 2008; Mekuria & Aynekulu, 2011).

Grazing impacts on soil properties depends on grazing intensity, with moderate grazing of 33 years compared with an ungrazed control, higher values were found for pH, available P, and Mg in ungrazed sites compared to the grazed ones (Ajorlo et al., 2011). The concentrations of available P, total N, Ca, Mg, and K decreased after 1.5 years of heavy grazing compared with an ungrazed control in a tropical pasture (Ajorlo et al., 2011). In addition, heavy grazing resulted in lower water infiltration (Hiernaux et al., 1999) and higher soil loss (Tadesse & Penden, 2002) compared with moderately grazed sites. In Tunisia, Jeddi & Chaieb (2010) documented that 12-year exclosures enhance the total plant cover, dry matter yield, species richness, and contents of organic soil matter, total nitrogen and water infiltration rate compared with continually grazed area. Similarly, Cheng et al. (2011) indicated that 20-year exclusion of livestock grazing significantly increased aboveground and belowground biomass and species richness for five different communities compared with that before exclusion of livestock grazing in a typical steppe of the Loess plateau, northwest China. Additional case studies conducted on exclosures in the central and northern highlands of Ethiopia. So, it was discovered that exclosures had twice more plant species richness and diversity value as compared with communal grazing lands after 22 years of exclosure establishment (Mengistu et al., 2005). And the richness of 13 woody species increased after 8 years of exclosure establishment (Birhane et al., 2006). Also, an increase in organic soil matter, total N and available P after 10 years of exclosure establishment was found (Mekuria et al., 2007). Finally, a considerable decrease in soil loss was reported after the establishment of exclosures in communal grazing lands (Descheemaeker et al., 2006; Girmay et al., 2009; Mekuria et al., 2009). Although there have been studies that compared the effect of exclosures on plant diversity and soil with adjacent open grazing lands, most of them are patchy and considering a single area. Studies on the effect of age of exclosures on plant diversity and soil property are few. Therefore this study provides information on the status of woody plant species diversity in 12 exclosures as compared with the adjacent grazing land in the highlands of Tigray, northern Ethiopia. This research was conducted to understand the role of exclosure in restoration of woody plant species diversity and soil chemical properties in two land use types with increasing age of exclosures at different slope gradients. This paper tries to address the following hypotheses: Availability of nutrients are not significantly different between exclosures and adjacent grazing land with increasing age of exclosure and elevation gradient; and: Woody species diversity is not significantly different between exclosures and

grazing land with increasing age of exclosure and elevation gradient.

Material and Methods

Description of the Study Area

The study was conducted in the highlands of Tigray region in four zones and four districts representing 12 exclosures and adjacent open grazing sites (Fig. 1). The distance between the exclosure and the adjacent grazing land was in the range of 50 to 100 m. The districts, namely Tahtay Maychew, Degua Temben, Atsibi Wenberta and Enda Mehoni, were 273 km, 50 km, 71 and 129 km away from the capital city of the region, Mekelle respectively.

All sites have a tropical semi-arid climate. The altitude of the study sites ranged from 2232 to 2937 m a.s.l. (Table 1). The rainy season usually occurs between June and September (Fig. 2), the growing season varying between 90 and 120 days.

Soils of the study sites were classified into four major groups: Luvisols (Alfisols), Regosols (Entisols), Cambisols (Inceptisols) and Calcisols (Aridisols) (WRB, 2006), but the sites were dominanted by Luvisols (Alfisols) and Cambisols (Inceptisols). The common woody vegetation species in exclosures and in adjacent grazing lands included *Acacia etbaica* Schweinf., *Acacia seyal* (Del.), *Becium grandiflorum* (Lam.) Pichi-Serm., *Euclea racemosa* subsp. *schimperi* (A. DC.) F. White and *Maytenus arbutifolia* (Hochst. ex. A. Rich) Wilczek (Mekuria, 2010). The livelihood of the households in the study area was a mixed crop livestock farming system. Major land uses in the study area included cultivated lands (between 9 and 33% of the area), forest-lands (3% to 58%), exclosures (3% to16%), communal grazing lands (6% to 39%) and others (20% to 41%) (Mekuria, 2010). There were seven main cultivated crops namely Tef (*Eragrostis teff* (Zucc.) Trotter), Bread wheat (*Triticum aestivum* L.), Maize (*Zea mays* L.), Sorghum (*Sorghum bicolor* (L.) Moench), Barly (*Hordeum vulgare* L.), Faba bean (*Vicia faba* L.) and Hanfets[1]. The major animal populations were cattle, goats, sheeps, donkeys, camels, mules and horses.

[1] Hanfets is a popular mixture of wheat and barley grown in the highlands of Eritrea and Tigray (Northern Ethiopia).

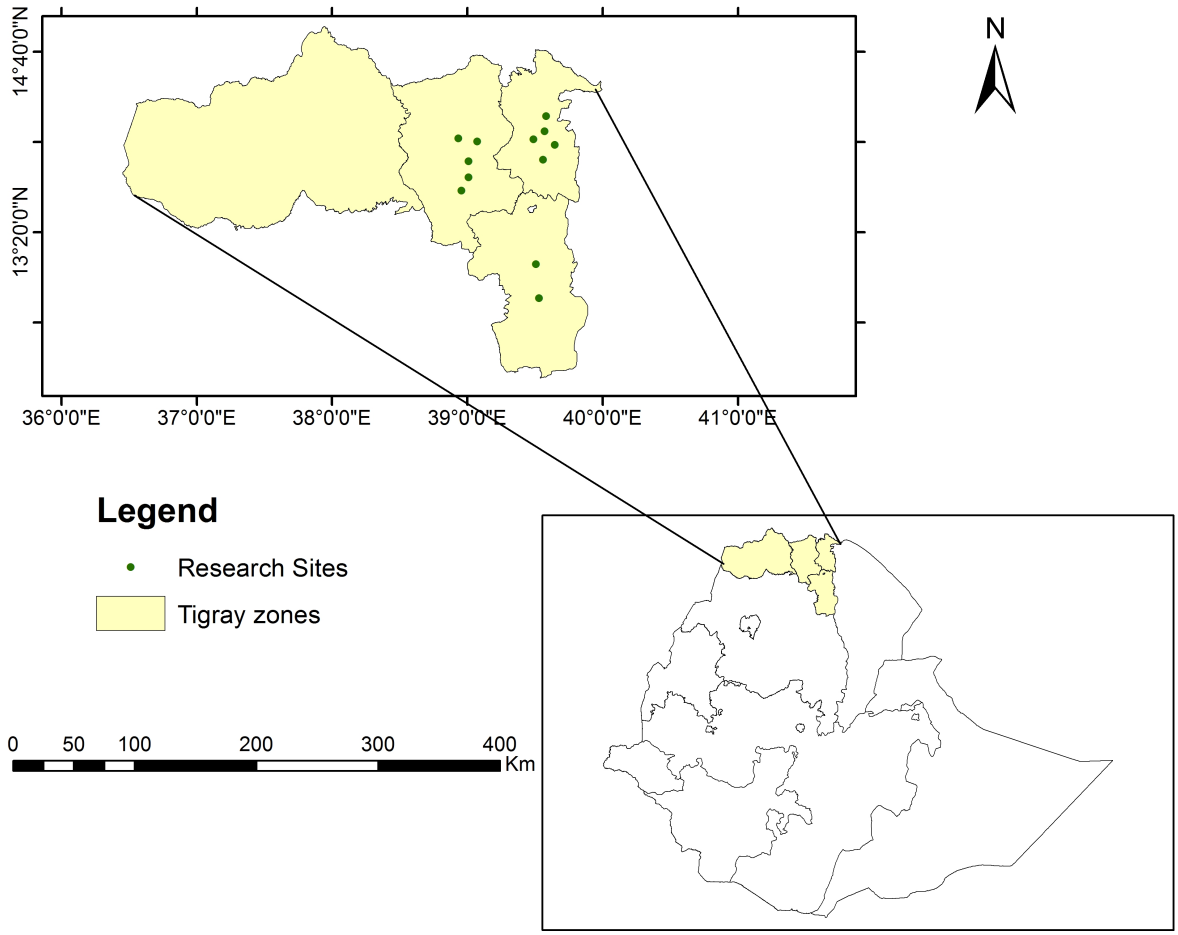

Fig. 1. Location of the study sites in the highlands of Tigray, North Ethiopia.

Table 1. Specific study site age, altitude and geographic location

Specific site	Zone	District	Age(year)	Altitude (m)	Geographic location
Adihintaweinai	East	Atsbi wonberta	<10	2201–2312	39°038′60″–39°050′52″ East 13°012′75″–14°04′41″ North
Halla	South east	Degua Tembien	<10	2232–2937	38°030′17″–38°040′57″ East 13°054′3″–14°020′30″ North
Melgim	East	Atsbi wonberta	<10	2264–2343	39°038′60″–39°050′52″ East 13°012′75″–14°04′41″ North
Endagebriel	East	Atsbi wonberta	10–20	2248–2351	39°038′60″–39°050′52″ East 13°012′75″–14°04′41″ North
Gurzoemni	Central	Tahtay Maichew	10–20	2244–2322	38°030′17″–38°040′57″ East 13°054′3″–14°020′30″ North
Mezewle	East	Atsbi wonberta	10–20	2325–2411	39°038′60″–39°050′52″ East 13°054′3″–14°020′30″ North
Adikolakul	South east	Degua Tembien	20–30	2180–2214	38°030′17″–38°040′57″ East 13°054′3″–14°020′30″ North
Suhulkoma	East	Atsbi wonberta	20–30	2295–2347	39°038′60″–39°050′52″ East 13°012′75″–14°04′41″ North
Wereriba	South east	Doguetembien	20–30	2200–2358	13°016′23″–13°047′44″ East 39°03′17″–39°024′48″North
Gratselim	South east	Degua Tembien	30–40	2369–2458	38°030′17″–38°040′57″ East 13°054′3″–14°020′30″ North
Kerenadidemsash	South	Endamekoni	30–40	2314–2419	39°016′52″–39°035′31″ East 12°038′4″–12°051′39″ North
Maibiati	South east	Degua Tembien	30–40	2358–2429	38°030′17″–38°040′57″ East 13°054′3″–14°020′30″ North

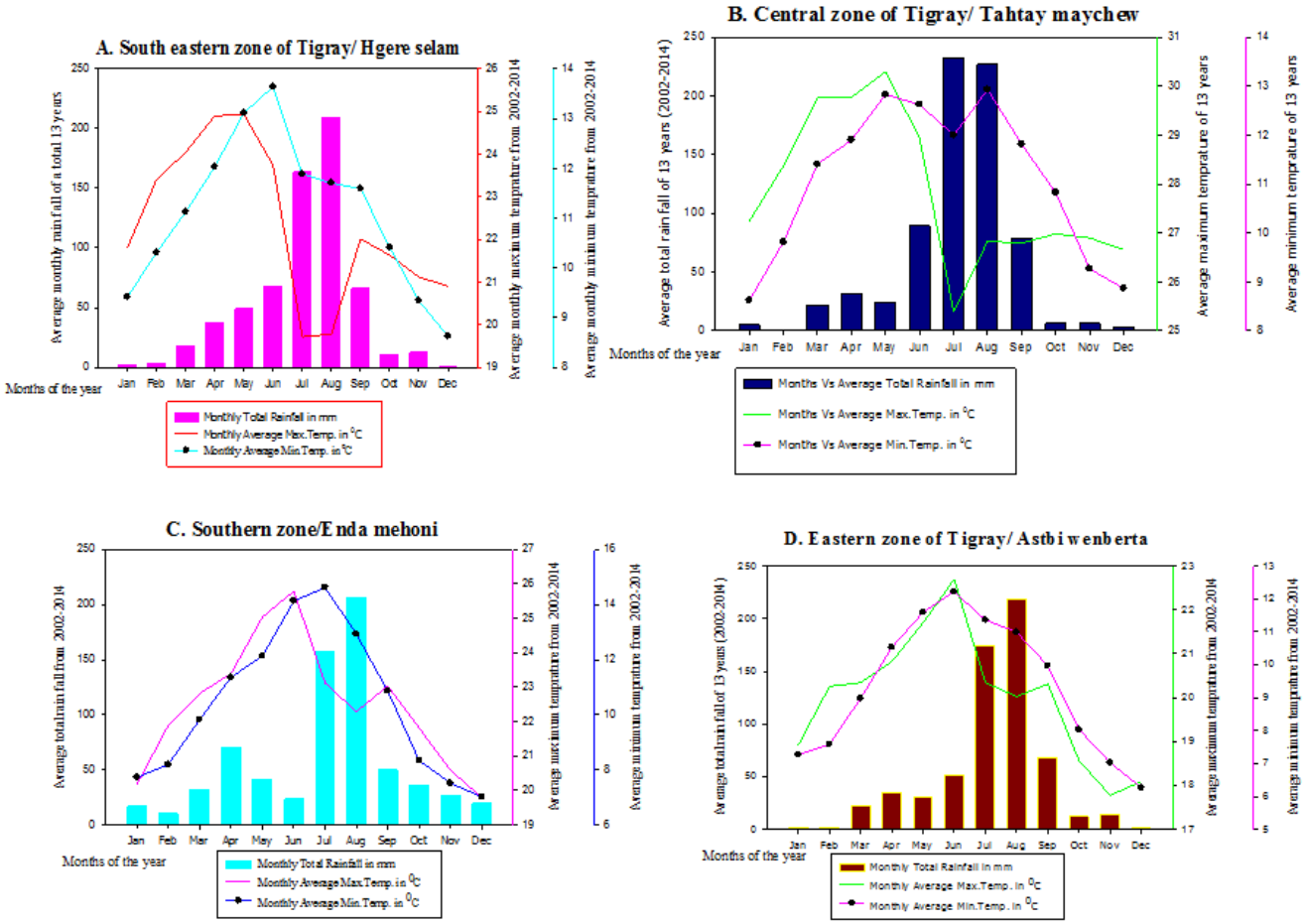

Fig. 2. Monthly average temperature and rain fall of the study area (A, B, C and D) from 2002 to 2014 (EMA, 2014).

Exclosure is a method of rehabilitating land by protecting an area from the interference of animals and human encroachment for a limited period of time, depending on site capacity and vegetation re-establishment (Seyoum et al., 2015). The grazing lands are areas open for continuously grazing by livestock.The exclosures are mainly covered by trees, shrubs and the ground by grass. The life forms of woody plants in the exclosures were 35.1% trees and 39.73% were shrubs, while the rest (25.17%) were woody herbs and climbers. The life forms in the open grazing lands were 83.37% shrubs and 5.7% were trees, while the rest (10.93%) were woody herbs; shrubs significantly outnumbered the trees in the exclosures. The abundance of the naturally regenerated woody plants in the exclosures was 91.03% while 8.9% was found artificially planted but no planted seedling was observed in the open grazing lands. The abundant species in the exclosures were composed of naturally regenerated species.

Experimental layout and design

There were 12 exclosure sites having adjacent grazing land, divided into four age classes and three slope gradients to study the age, slope and land use effect on woody species diversity and chemical soil properties. The first age group had less than ten years old exclosures with triplicate sites (Halla, Meligim and Gidimihantaweynay), the second age group was 10 to 20 years old exclosures with triplicate sites (Gurzoemni, Mezewle and Endagebriel), and the third age group had 20 to 30 years old exclosures with triplicate sites (Addikolakul, Wereriba and Shul-koma). The fourth group had more than 30 years old exclosures with triplicate sites (Maybe'ati, Wadrat and Endaarbaetuenssat).

The role of the exclosure on the soil fertility and the diversity of woody plant species were studied by taking soil and the identitiy of woody plant species and number of plants, under the different ages of paired exclosures and adjacent grazing lands. The experiment was composed of 12 experimental units with four treatments replicated three times. In the entire study 216 plots (12 × 3 small plots × 3 slope positions × 2 pair exclosures and adjacent grazing lands) were examined of which 108 were in exclosures and 108 in communal grazing lands. In each exclosure and grazing land randomly established three transects spaced at a minimum distance of 75 m (Fig. 3). The number of transects were based on vegetation density, spatial heterogeneity of vegetation, and area of the site. To avoid edge effects, the first transect were laid 30–50 m inside the exclosures and grazing lands. Transects were parallel to each other and to the topography of the landscape. In each transect, three slope positions were delineated and a sampling plot measuring 10 × 10 m was established. In each plot, 5 × 5 m subplots for physical and chemical soil analysis were developed (Fig. 3). Each of the study sites were divided into 3 slope gradients: upper slope (US), middle slope (MS) and foot slope (FS). The US position is the uppermost portion of each study site and it can receive little or no overland flow but may contribute runoff to down slope areas. The MS position receives overland flow from the upper slope and contributes runoff to the FS. The FS represents the lowest part of each study site and receives overland flow from both mid and upper slopes.

Plant and soil sampling methods

Plant and soil samples were collected from October 2013 to January 2014 for a total of four months from four types of exclosures and adjacent surrounding grazed land. All woody plants were sampled for diversity in 10 × 10 m quadrates (100 m^2) for trees and shrubs from both sites. The plants were identified in the field and verified using reference books such as Bekele-Tesemma (2007), Hedberg et al. (2003), Hedberg & Edwards (1989), and Edwards et al. (1995, 2000). All woody plants (trees and shrubs) found in each plot were counted. Each plant height, diameter at breast height (DBH), diameter at stump height (DSH) and plant number were recorded. The abundance (total number of woody species in a given area), density (number of individuals of a species in an area per ha) and frequency (number of times a species recorded in a given number of plots) of woody species were calculated.

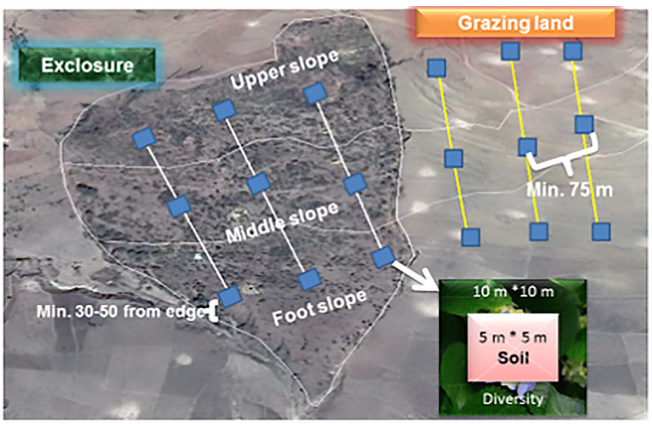

Fig. 3. Experimental designs of the soil and vegetation sampling in one replicate of an exclosure with its paired communal grazing land.

Soil samples were collected from 5 × 5 m subplots nested within the 10 Ч 10 m at the centre of the main plots. A total of 216 soil samples were collected. The soil samples from each plot were taken from the four corners and the centre of a square plot at 50 cm soil depths following an «X» pattern of the main plot to form one composite sample in order to determine organic carbon, pH, EC, N, K and P of the soil in exclosures and adjacent grazing lands. The five soil samples measured 300 g, each collected from 50 m depth in each 25 m^2 plots, were mixed and form 1500 g in total and make a single composite sample to represent the sample plot. From the composite sample 1 kg soil was taken and put into plastic bags, secured, labeled and brought to the soil laboratory. Soil samples were analysed for pH and electrical conductivity on 1:2.5, soil: water suspension method. The organic matter was analysed using the Walkley-Black method (Van Ranst et al., 1999), the total nitrogen content by the Kjeldahl method (Bremmery & Mulvaney, 1982). The available potassium and texture were analysed with flame spectrophotometer and hydrometer method (Gee & Bauder, 1982). The available P was determined using the Olson method (Olsen & Sommers, 1982).

Statistical analyses

The number and abundance of the woody species diversity (Dominance (D), Shannon (H), Simpson (1-D), Evenness (E^H/S) with ages of the exclosures, adjacent grazing land and slope positions were analysed using the PAST software package, version 1.91. The differences in soil parameters between an exclosure and its adjacent communal grazing land at different age groups and landscape position were assessed using ANOVA with Tukey HSD test after checking normality test. Statistical package for social sciences (SPSS) version 20 was used to analyse the chemical soil properties.

Results and Discussion

Woody plant species composition in exclosures and grazing lands at different age and slope gradient

In total there were noted 61 woody plant species, representing 41 families, and 51% were trees and 49% were shrubs (Appendix 1). Among these plant species 8% were planted while the rest, 92% plants, were naturally grown. In the exclosures there were 60 plant species and 40 plant families, of which 53% were trees and 47% shrubs, while the grazing land had 28 plant species that belongs to 21 plant families (Appendix 2 and 3). So, from the total species found in the study area 32 species were only found in exclosures. This study is in agreement with research done in exclosures and open grazing land in Tigray where 39 plants were found in both exclosures and open grazing land, of which 31 plants were naturally found and 8 were planted (Birhane, 2002). The same author found 27 plant species and 18 families in exclosures, of those 37% trees and 52% shrubs, but the open grazing land had 14 plant species of 12 families and 50% were either trees or shrubs. Another study found 56 woody trees and shrubs belonging to 28 families in both disturbed and undisturbed areas, the undisturbed areas had 47 woody species belonging to 26 families and 42 woody species belonging to 24 families in disturbed areas (Dejenie, 2011). The foot slope had 56 plants representing 39 families, 52% trees and 48% shrubs (Appendix 4), while the middle slope had 49 plant species of 32 families, 51% trees and 49% shrubs (Appendix 5). The upper slope had 42 plant species of 28 families; from those 48% were trees and 52% were shrubs (Appendix 6). Exclosures less than 10 years old had 18 plant species of 12 families, of which 67% were shrubs (Appendix 7), at the same time exclosures with an age between 10 and 20 years old had 23 plant species representing 12 families and 57% were trees (Appendix 8), while exclosures with an age between 20 and 30 years old had 36 plant species of 27 families and 53% were shrubs (Appendix 9). Exclosures older than 30 years had 49 plant species of 36 families, with 51% trees and 49% shrubs and had a higher species richness than in exclosures of the other three age groups (Appendix 10).

Woody plant species diversity in exclosures and grazing lands at different age and slope gradient

In the study area 61 plant species from 41 plant families were found, which is more than the result found in exclosures and open areas in eastern Tigray (Birhane, 2002). The exclosures had a higher diversity, high species richness and these were less evenly distributed, whereas grazing land had a low species richness and the species were evenly distributed (Table 2).

The plant density and abundance of plants were higher in exclosures and lower in grazing land (Appendix 2 and 3), which is in agreement with exclosures in eastern Tigray (Birhane, 2002). The exclosures in this study had a higher diversity than the exclosures in central and northern Ethiopian (Mengistu et al., 2005). Undisturbed sites have a higher diversity than disturbed sites in the Awash National Park in central Ethiopia (Molla et al., 2009). The establishment of exclosures improved the composition, density, richness, and diversity of woody species in comparison to open adjacent sites.

Woody species were substantially richer in exclosures than in open areas, indicating the importance of exclosures for the conservation of biological diversity (Mengistu et al., 2005). Diversity is the most widely used criterion to assess the conservation potential and ecological value of a site (Magurran, 2004). Moreover, it is an important element in resource management planning. This especially holds true for rare and endangered species (Jama & Zeila, 2005). Exclosures are supposed to contribute to the conservation of biological diversity. The higher Shannon diversity indices in the exclosures indicate a higher species diversity in the exclosures than in the open site (Getachew, 2014). The relatively high diversity values of exclosures compared with that of the open areas in turn indicates the importance of exclosure practices for the conservation of genetic resources of the woody species, particularly rare and unique species that are under heavy threat of extinction. Old age exclosures had a higher plants diversity, high species richness and these were also evenly distributed (Table 2), which is in line with Mekuria (2013), who indicated that the oldest exclosures had a higher diversity and species richness than the youngest exclosures. There was a significant difference in plant diversity along the slope gradients ($p < 0.05$). The foot slope of the mountain had a high diversity and plants were evenly distributed. The diversity was higher for the foot slopes followed by the middle and upper slope. This result contradicts to Mekuria (2013), who found a higher diversity at the upper slope.

Woody plants frequency, abundance and density in exclosures and grazing lands at different age and slope gradient

In the study area *Euclea racemosa* L., *Maytenus arbutifolia* (Lam.) Exell, *Becium grandiflorum* (Lam.) Pic. Serm., *Acacia seyal* Delile and *Juniperus procera* Hochst. ex Endl. were the most frequently found, while *Clutia lanceolata* Forssk., *Diplostigma canescens* K. Schum., *Justicia schimperiana* (Hochst. ex Nees) T. Anderson, *Morus alba* L., *Berberis holstii* Engl. and *Pittosporum viridiflorum* Sims were found the least frequently. Individuals of species from the plant families Fabaceae, Celastraceae, Ebenaceae and Lamiaceae were found frequently, while Acanthaceae, Asclepiadaceae and Pittosporaceae had a low frequency (Appendix 1–10). *Dodonaea angustifolia* L. f., *Becium grandiflorum*, *Euclea racemosa* and *Acacia etbaica* Schweinf. had a higher abundance and density of individuals while *Clutia lanceolata*, *Justicia schimperiana* and *Morus alba* had a low abundance and density. Exclosures of the age group more than 30 years old and the foot slope had a higher plant frequency, abundance and density while grazing land of the age group less than 10 years old and upper elevation recorded the lowest (Table 3). The density of woody plants in central and northern Ethiopia were found higher in exclosures, while lower in open area (Mengistu et al., 2005).

Table 2. Diversity of plants in exclosures and adjacent grazing lands with increasing age of exclosures and slope gradient

		Taxa_S	Individuals	Dominance_D	Simpson1-D	Shannon_H	Evenness_e^H/S
Land use	Exclosure	60	4589	0.1022	0.8978	2.847	0.2872
	Grazing	28	1425	0.1193	0.8807	2.512	0.4402
Age (year)	< 10	18	1066	0.1952	0.8048	2.033	0.4243
	10-20	23	1764	0.1757	0.8243	2.208	0.3954
	20-30	37	1469	0.1269	0.8731	2.501	0.3297
	>30	49	1702	0.05767	0.9423	3.181	0.4913
Slope position	Foot	56	2255	0.07922	0.9208	3.036	0.3718
	Middle	49	1967	0.09916	0.9008	2.773	0.3267
	Upper	42	1776	0.1087	0.8913	2.654	0.3383

Table 3. Woody plants frequency, abundance and density in exclosures and adjacent grazing land with increasing with age of exclosures and slope position

Factors	Parameters	Frequency (FR)	Percent (%)	Abundance (AB)	Density (DE)
Land use	Exclosure	699	100	4589	4267.8
	Open area	292	100	1425	1325.3
Age grouops	>30	328	100	1702	3233.8
	20–30	266	100	1466	2785.4
	10–20	231	100	1764	3351.6
	<10	166	100	1066	2025.4
Slope	Foot	408	100	2255	3157.0
	Middle	317	100	1967	2753.8
	Upper	266	100	1776	2486.4

Availability of nutrients in exclosures and grazing lands with increasing age of exclosures and elevation gradient

The chemical soil properties of exclosures were significantly more favourable for plant development than of grazing land (Table 4). This result is supported by Mekuria (2010). Grazing impact on soil properties depends on the grazing intensity. An ungrazed site of 33 years old had higher values of pH, available P and Mg compared to a moderately grazed site (Ajorlo *et al., 2011*) and the concentrations of available P, total N, Ca, Mg, and K decreased after 1.5 years of heavy grazing, compared with an ungrazed control in a tropical pasture. The texture had no significant difference in all age groups and elevation except among exclosures and adjacent grazing land. The chemical soil properties at older age exclosures had values of pH, EC, P, N, K, OC, OM better for plant development than the three young age groups of exclosures. The availability of chemical soil properties decreased with decreasing age of the exclosures. This shows a better result for plant development than by Minal & Anil (2012), who noted the following data: pH (5.1–6.1), EC (dsm^{-1}) (0.22–0.28), OC % (0.32–0.04) and P ($mg \times kg^{-1}$) (4.2–7.7). The foot of a slope had better chemical soil properties than the middle and upper slope and EC was significantly higher at the foot slope and followed by middle and upper slope respectively which is in agreement with Mekuria (2010), who found higher nutrients at the foot slope. Except for EC the middle and upper slopes had no significantly different values ($p > 0.05$).

Conclusions

Diversity and species richness were higher in the exclosures than in grazing lands. Among exclosures these parameters were higher in exclosures older than 30 years and at the foot of the slope. The grazing land, the youngest exclosures and the upper slope had a lower species richness and diversity. The contents of chemical soil properties showed a significant difference and were the highest in the oldest exclosures and at the foot slope. The open grazing land, the youngest exclosures and the upper slope showed poor chemical properties. Exclosures can have multiple importances in improving soil and plants diversity. Exclosures have environmental, social and economic benefits to the local communities. Even though the exclosure management regime has a potential to rehabilitate the degraded areas, integrating soil and water conservation measures and indigenous

Table 4. Soil properties in exclosures and adjacent grazing lands with increasing age of exclosures and elevation gradient

		Mean pH	Mean EC	Mean P	Mean K	Mean % N	Mean % OC	Mean % OM
Land uses	Exclosure	7.752 ± 0.035a	15.898 ± 0.382a	9.143 ± 0.455a	8.80 ± 0.296a	0.565 ± 0.010a	1.727 ± 0.057a	2.977 ± 0.099a
	Gl	7.295 ± 0.035b	9.424 ± 0.382b	2.918 ± 0.455b	3.748 ± 0.295b	0.275 ± 0.010b	0.339 ± 0.057b	0.584 ± 0.099b
Age groups	<10	7.240 ± 0.053c	10.402 ± 0.646b	2.214 ± 0.676c	3.857 ± 0.496c	0.345 ± 0.023b	0.442 ± 0.113c	0.762 ± 0.196c
	10–20	7.492 ± 0.053b	11.989 ± 0.646b	5.747 ± 0.676b	6.146 ± 0.496b	0.403 ± 0.023b	0.952 ± 0.113b	1.642 ± 0.196b
	20–30	7.606 ± 0.053ab	12.414 ± 0.646b	6.169 ± 0.676b	6.71 ± 0.496ab	0.428 ± 0.023ab	1.250 ± 0.113ab	2.154 ± 0.196ab
	>30	7.757 ± 0.053a	15.838 ± 0.646a	9.993 ± 0.676a	8.37 ± 0.501a	0.503 ± 0.023a	1.487 ± 0.113a	2.564 ± 0.196a
Elevation	Foot	7.718 ± 0.048a	14.281 ± 0.588a	7.205 ± 0.661a	6.664 ± 0.471a	0.478 ± 0.020a	1.221 ± 0.107a	2.106 ± 0.184a
	Middle	7.506 ± 0.048b	12.450 ± 0.588ab	5.759 ± 0.661a	6.396 ± 0.467a	0.409 ± 0.020b	1.035 ± 0.107ab	1.784 ± 0.184ab
	Upper	7.348 ± 0.048b	11.252 ± 0.588c	5.128 ± 0.661a	5.733 ± 0.467a	0.372 ± 0.020b	0.842 ± 0.107b	1.451 ± 0.184b

Means in the same column followed by same letter do not differ significantly at $P < 0.05$, mean value three replications ± SE, with units of Av.P = ppm, Av.K = pmm, EC = ms/m, Gl = Grazing land

enrichment planting in the exclosures could be a better method of management to accelerate the rehabilitation process of the exclosures and to increase the diversity and density of woody plant species in the exclosures. Additional research is needed to establish the interactive relationships among soil properties, soil fertilities, survival rate and growth rate of woody plant species in the exclosures.

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Appendix 1. AB, DE, FR, LF, trees and shrubs of all woody plants (P = 0.000)

R.no	Plants of the Tigray highlands	Vernacular name	Family	LF	FR	%	AB	DE
1	*Abutilon longicuspe* Hochst. ex A. Rich.	Tsa'eda embwak	Malvaceae	S	7	0.7	10	5.0
2	*Acaia decurrens* Willd.	Dikerens	Fabaceae	T	13	1.3	59	29.5
3	*Acacia etbaica* Schweinf.	Seraw	Fabaceae	T	53	5.3	439	219.5
4	*Acacia lahai* Benth.	Lahai	Fabaceae	T	6	0.6	27	13.5
5	*Acacia saligna* (Labill.) Wendl.	Acacha	Fabaceae	T	24	2.4	195	97.5
6	*Acokanthera schimpri* (A. DC.) Schweinf.	Mebt'a	Apocynaceae	T	11	1.1	99	49.5
7	*Acacia seyal* Delile	Tsa'eda che'a	Fabaceae	T	65	6.6	223	111.5
8	*Aloe vera* (*A. barbadensis*) (L.) Burm. f.	E'are	Aloeaceae	S	16	1.6	163	81.5
9	*Becium grandiflorum* (Lam.) Pic. Serm.	Tebeb	Lamiaceae	S	77	7.8	853	426.5
10	*Berberis holstii* Engl.	Zinkila	Berberidaceae	S	1	0.1	4	2.0
11	*Buddleja polystachya* Fresen.	Metere	Loganiaceae	S	9	0.9	10	5.0
12	*Calpurinia aurea* (Aiton) Benth.	Htsawts	Fabaceae	S	41	4.1	177	88.5
13	*Cadaba farinosa* Forssk.	Taum chena	Capparidaceae	S	7	0.7	16	8.0
14	*Carissa spinarum* L.	Agam	Apocynaceae	S	26	2.6	35	17.5
15	*Clutia lanceolata* Forssk.	Bokokot	Euphorbiaceae	S	1	0.1	1	0.5
16	*Leucas oligocephala* Hook. f.	Swakerni	Labiatae	S	17	1.7	170	85.0
17	*Cordia africana* Lam.	Aqui	Boraginaceae	T	2	0.2	2	1.0
18	*Croton macrostachyus* Hochst. ex Delile	Tanbuque	Euphorbiaceae	T	17	1.7	33	16.5
19	*Cupressus lusitanica* Mill.	Tsihidi ferenji	Cupressaceae	T	8	0.8	30	15.0
20	*Diospyros abyssinica* (Hiern) F. White	Kumel a'awaf	Ebenaceae	T	2	0.2	2	1.0
21	*Diplostigma canescens* K. Schum.	Halengi	Asclepiadaceae	S	1	0.1	2	1.0
22	*Dichrostachys cinerea* (L.) Wight & Arn.	Gonnok	Fabaceae	S	2	0.2	5	2.5
23	*Dovyalis abyssinica* (A. Rich.) Warb.	Aihada	Flacourtiaceae	S	3	0.3	3	1.5
24	*Dodonaea angustifolia* L. f.	Tahsos	Sapindaceae	S	55	5.5	1060	530.0
25	*Ekebergia capensis* Sparrm.	Kot	Meliaceae	T	4	0.4	10	5.0
26	*Erica arborea* L.	Shanto	Ericaceae	S	2	0.2	2	1.0
27	*Euphorbia abyssinica* J.F. Gmel.	Kolkual	Euphorbiaceae	T	13	1.3	41	20.5
28	*Eucalyptus camaldulensis* Dehnh.	Keyh bahr zaf	Myrtaceae	T	37	3.7	191	95.5
29	*Eucalyptus globulus* Labill.	Tsa'eda bahr zaf	Myrtaceae	T	17	1.7	58	29.0
30	*Euclea racemosa* L.	Kuli'aw	Ebenaceae	S	94	9.5	847	423.5
31	*Ficus vasta* Forssk.	Da'aro	Moraceae	T	2	0.2	2	1.0
32	*Grewia ferruginea* Hochst. ex A. Rich.	Tsimkuya	Tiliaceae	S	3	0.3	6	3.0
33	*Grevillea robusta* A.Cunn. ex R. Br.	Gravila	Proteaceae	T	3	0.3	8	4.0
34	*Juniperus procera* Hochst. ex Endl.	Tsihidi habesha	Cupressaceae	T	65	6.6	256	128.0
35	*Justicia schimperiana* (Hochst. ex Nees) T. Anderson	Shim'aya	Acanthaceae	S	1	0.1	1	0.5
36	*Maytenus arbutifolia* (Hochst. ex A. Rich.) R. Wilczek	Atat	Celastraceae	S	81	8.2	364	182.0
37	*Maytenus senegalensis* (Lam.) Exell	Argudi/kebkeb	Celastraceae	T	16	1.6	24	12.0
38	*Morus alba* L.	Yferenj injori	Moraceae	T	1	0.1	1	0.5
39	*Myrica salicifolia* Hochst. ex A. Rich.	Nihibi	Myricaceae	S	8	0.8	16	8.0
40	*Nuxia congesta* R. Br. ex Fresen.	Atkaro	Buddleiaceae	T	6	0.6	8	4.0
41	*Olea europaea* L.	Awli'a	Oleaceae	T	30	3.0	72	36.0
42	*Olinia rochetiana* A. Juss.	Shgmesrhi	Oliniaceae	S	10	1.0	60	30.0
43	*Oncoba spinosa* Forssk.	Eqot	Flacourtiaceae	T	7	0.7	18	9.0
44	*Opuntia ficus indica* (L.) Mill.	Beles	Cactaceae	S	7	0.7	65	32.5
45	*Osyris quadripartita* Salzm. ex Decne.	Kerets	Loranthaceae	T	2	0.2	2	1.0
46	*Otostegia integrifolia* Benth.	Mesaguh/ chi'andog	Lamiaceae	S	6	0.6	23	11.5
47	*Phytolacca dodecandra* L'Hér.	Shimiti	Phytolaccaceae	S	7	0.7	13	6.5
48	*Pittosporum viridiflorum* Sims	Chequente	Pittosporaceae	T	1	0.1	3	1.5
49	*Prunus africana* (Hook. f.) Kalkman	Tikur incheti	Rosaceae	T	5	0.5	20	10.0
50	*Psydrax schimperiana* (A. Rich.) Bridson	Zahak	Rubiaceae	T	2	0.2	2	1.0
51	*Rhus glutinosa* Hochst. ex A. Rich.	Mengi	Anacardiaceae	T	15	1.5	38	19.0
52	*Rhamnus prinoids* L'Hér.	Gesho	Rhamnaceae	S	9	0.9	46	23.0
53	*Rhus retinorrhoea* Steud. ex A. Rich.	Teta'alo	Anacardiaceae	T	7	0.7	11	5.5
54	*Rhoicissus tridentata* (L. f.) Wild & R.B. Drumm.	Karshiro	Vitaceae	S	7	0.7	18	9.0
55	*Rosa abyssinica* R. Br.	Konteftefe	Rosaceae	S	3	0.3	6	3.0
56	*Rumex nervosus* Vahl	Hakot	Polygonaceae	S	10	1.0	34	17.0
57	*Salix mucronata* (*S. subserrata*) Thunb.	Kwaa	Salicaceae	T	5	0.5	17	8.5
58	*Schinus molle* L.	Qundo berbere	Anacardiaceae	T	8	0.8	20	10.0
59	*Senna singueana* (Delile) Lock	Hambhambo	Fabaceae	S	23	2.3	65	32.5
60	*Stereospermum kunthianum* Cham.	Argzana	Bignoniaceae	T	5	0.5	13	6.5
61	*Vernonia amygdalina* Delile	Grawa	Asteraceae	S	5	0.5	15	7.5
	Total				991	100	6014	3007

Family frequency		
Family	FR	%
Acanthaceae	1	0.1
Aloeaceae	16	1.6
Anacardiaceae	30	3.0
Apocynaceae	37	3.7
Asclepiadaceae	1	0.1
Asteraceae	5	0.5
Berberidaceae	2	0.2
Bignoniaceae	5	0.5
Boraginaceae	2	0.2
Buddleiaceae	6	0.6
Cactaceae	7	0.7
Capparidaceae	7	0.7
Celastraceae	97	9.8
Combretaceae	17	1.7
Cupressaceae	73	7.4
Ebenaceae	96	9.7
Ericaceae	2	0.2
Euphorbiaceae	31	3.1
Fabaceae	227	22.9
Flacourtiaceae	10	1.0
Lamiaceae	81	8.2
Loganiaceae	9	0.9
Loranthaceae	2	0.2
Malvaceae	7	0.7
Meliaceae	4	0.4
Moraceae	3	0.3
Myricaceae	8	0.8
Myrtaceae	54	5.4
Oleaceae	29	2.9
Oliniaceae	11	1.1
Phytolaccaceae	7	0.7
Pittosporaceae	1	0.1
Polygonaceae	11	1.1
Proteaceae	3	0.3
Rhamnaceae	9	0.9
Rosaceae	8	0.8
Rubiaceae	2	0.2
Salicaceae	5	0.5
Sapindaceae	55	5.5
Tiliaceae	3	0.3
Vitaceae	7	0.7
Total	991	100.0

Hereafter: AB – Abundance, FR – Frequency, LF – Life form (S – shrub, T – tree), DE – density.

Appendix 2. AB, DE, FR, LF, trees and shrubs of woody plants in exclosures (P = 0.000)

R.no	Plant species in exclosures	Vernacular name	Family	LF	FR	%	AB	DE
1	*Abutilon longicuspe* Hochst. ex A. Rich.	Tsa'eda embwak	Malvaceae	S	6	0.9	9	8.4
2	*Acaia decurrens* Willd.	Dikerens	Fabaceae	T	13	1.9	59	54.9
3	*Acacia etbaica* Schweinf.	Seraw	Fabaceae	T	28	4.0	326	303.2
4	*Acacia lahai* Benth.	Lahai	Fabaceae	T	6	0.9	27	25.1
5	*Acacia saligna* (Labill.) Wendl.	Acacha	Fabaceae	T	24	3.4	195	181.4
6	*Acokanthera schimpri* (A. DC.) Schweinf.	Mebti'a	Apocynaceae	T	10	1.4	97	90.2
7	*Acacia seyal* Delile	Tsa'eda che'a	Fabaceae	T	44	6.3	173	160.9
8	*Aloe vera* (*A. barbadensis*) (L.) Burm. f.	E'are	Aloeaceae	S	4	0.6	14	13.0
9	*Becium grandiflorum* (Lam.) Pic. Serm.	Tebeb	Lamiaceae	S	53	7.6	708	658.4
10	*Berberis holstii* Engl.	Zinkila	Berberidaceae	S	1	0.1	4	3.7
11	*Buddleja polystachya* Fresen.	Metere	Loganiaceae	S	5	0.7	6	5.6
12	*Calpurinia aurea* (Aiton) Benth.	Htsawts	Fabaceae	S	22	3.1	122	113.5
13	*Cadaba farinosa* Forssk.	T'aum chena	Capparidaceae	S	4	0.6	11	10.2
14	*Carissa spinarum* L.	Agam	Apocynaceae	S	22	3.1	29	27.0
15	*Clutia lanceolata* Forssk.	Bokokot	Euphorbiaceae	S	1	0.1	1	0.9
16	*Leucas oligocephala* Hook. f.	Swakerni	Labiatae	S	12	1.7	137	127.4
17	*Cordia africana* Lam.	Aqui	Boraginaceae	T	2	0.3	2	1.9
18	*Croton macrostachyus* Hochst. ex Delile	Tanbuque	Euphorbiaceae	T	12	1.7	27	25.1
19	*Cupressus lusitanica* Mill.	Tsihidi ferengi	Cupressaceae	T	7	1.0	29	27.0
20	*Diospyros abyssinica*(Hiern) F. White	Kumel a'awaf	Ebenaceae	T	2	0.3	2	1.9
21	*Diplostigma canescens* K. Schum.	Halengi	Asclepiadaceae	S	1	0.1	2	1.9
22	*Dichrostachys cinerea* (L.) Wight & Arn.	Gonnok	Fabaceae	S	2	0.3	5	4.7
23	*Dovyalis abyssinica* (A. Rich.) Warb.	Aihada	Flacourtiaceae	S	3	0.4	3	2.8
24	*Dodonaea angustifolia* L. f.	Tahsos	Sapindaceae	S	49	7.0	1038	965.3
25	*Ekebergia capensis* Sparrm.	Kot	Meliaceae	T	4	0.6	10	9.3
26	*Erica arborea* L.	Shanto	Ericaceae	S	1	0.1	1	0.9
27	*Euphorbia abyssinica* J.F. Gmel.	Kolkual	Euphorbiaceae	T	13	1.9	41	38.1
28	*Eucalyptus camaldulensis* Dehnh.	Keyh bahr zaf	Myrtaceae	T	17	2.4	76	70.7
29	*Eucalyptus globulus* Labill.	Tsa'eda bahr zaf	Myrtaceae	T	5	0.7	24	22.3
30	*Euclea racemosa* L.	Kuli'aw	Ebenaceae	S	51	7.3	466	433.4
31	*Ficus vasta* Forssk.	Da'aro	Moraceae	T	2	0.3	2	1.9
32	*Grewia ferruginea* Hochst. ex A. Rich.	Tsimkuya	Tiliaceae	S	3	0.4	6	5.6
33	*Grevillea robusta* A. Cunn. ex R. Br.	Gravila	Proteaceae	T	3	0.4	8	7.4
34	*Juniperus procera* Hochst. ex Endl.	Tsihidi habesha	Cupressaceae	T	43	6.2	196	182.3
35	*Justicia schimperiana* (Hochst. ex Nees) T. Anderson	Shim'aya	Acanthaceae	S	1	0.1	1	0.9
36	*Maytenus arbutifolia* (Hochst. ex A. Rich.) R. Wilczek	Atat	Celastraceae	S	60	8.6	265	246.5
37	*Maytenus senegalensis* (Lam.) Exell	Argudi	Celastraceae	T	9	1.3	15	14.0
38	*Morus alba* L.	Yferenj injori	Moraceae	T	1	0.1	1	0.9
39	*Myrica salicifolia* Hochst. ex A. Rich.	Nihibi	Myricaceae	S	8	1.1	16	14.9
40	*Nuxia congesta* R. Br. ex Fresen.	Atkaro	Buddleiaceae	T	5	0.7	6	5.6
41	*Olea europaea* L.	Awli'a	Oleaceae	T	27	3.9	68	63.2
42	*Olinia rochetiana* A. Juss.	Beye/Shimesrhi	Oliniaceae	S	7	1.0	57	53.0
43	*Oncoba spinosa* Forssk.	Eqot	Flacourtiaceae	T	7	1.0	18	16.7
44	*Osyris quadripartita* Salzm. ex Decne.	Kerets	Loranthaceae	T	2	0.3	2	1.9
45	*Otostegia integrifolia* Benth.	Chi'andog	Lamiaceae	S	6	0.9	23	21.4
46	*Phytolacca dodecandra* L'Hér.	Shimiti	Phytolaccaceae	S	7	1.0	13	12.1
47	*Pittosporum viridiflorum* Sims	Chequente	Pittosporaceae	T	1	0.1	3	2.8
48	*Prunus africana* (Hook. f.) Kalkman	Tikur incheti	Rosaceae	T	5	0.7	20	18.6
49	*Psydrax schimperiana* (A. Rich.) Bridson	Zahak	Rubiaceae	T	1	0.1	1	0.9
50	*Rhus glutinosa* Hochst. ex A. Rich.	Mengi	Anacardiaceae	T	15	2.1	38	35.3
51	*Rhamnus prinoids* L'Hér.	Gesho	Rhamnaceae	S	9	1.3	46	42.8
52	*Rhus retinorrhoea* Steud. ex A. Rich.	Teta'alo	Anacardiaceae	T	7	1.0	11	10.2
53	*Rhoicissus tridentata* (L. f.) Wild & R.B. Drumm.	Karshiro	Vitaceae	S	7	1.0	18	16.7
54	*Rosa abyssinica* R. Br.	Konteftefe	Rosaceae	S	3	0.4	6	5.6
55	*Rumex nervosus* Vahl	Hakot	Polygonaceae	S	3	0.4	8	7.4
56	*Salix mucronata* (*S. subserrata*) Thunb.	Kwaa	Salicaceae	T	5	0.7	17	15.8
57	*Schinus molle* L.	Qundo berbere	Anacardiaceae	T	8	1.1	20	18.6
58	*Senna singueana* (Delile) Lock	Hambhambo	Fabaceae	S	10	1.4	32	29.8
59	*Stereospermum kunthianum* Cham.	Argzana	Bignoniaceae	T	5	0.7	13	12.1
60	*Vernonia amygdalina* Delile	Grawa	Asteraceae	T	5	0.7	15	14.0
	Total				699	100	4589	4267.8

Family	FR	%
Acanthaceae	1	0.1
Aloeaceae	4	0.6
Anacardiaceae	30	4.3
Apocynaceae	32	4.6
Asclepiadaceae	1	0.1
Asteraceae	5	0.7
Berberidaceae	2	0.3
Bignoniaceae	5	0.7
Boraginaceae	2	0.3
Buddleiaceae	5	0.7
Capparidaceae	4	0.6
Celastraceae	69	9.9
Combretaceae	12	1.7
Cupressaceae	50	7.2
Ebenaceae	53	7.6
Ericaceae	1	0.1
Euphorbiaceae	26	3.7
Fabaceae	149	21.3
Flacourtiaceae	10	1.4
Lamiaceae	58	8.3
Loganiaceae	5	0.7
Loranthaceae	2	0.3
Malvaceae	6	0.9
Meliaceae	4	0.6
Moraceae	3	0.4
Myricaceae	8	1.1
Myrtaceae	22	3.1
Oleaceae	26	3.7
Oliniaceae	8	1.1
Phytolaccaceae	7	1.0
Pittosporaceae	1	0.1
Polygonaceae	3	0.4
Proteaceae	3	0.4
Rhamnaceae	9	1.3
Rosaceae	8	1.1
Rubiaceae	1	0.1
Salicaceae	5	0.7
Sapindaceae	49	7.0
Tiliaceae	3	0.4
Vitaceae	7	1.0
Total	699	100.0

Appendix 3. AB, DE, FR, LF, trees and shrubs of woody plants in grazing land (P = 0.000)

R.no	Plant species of grazing lands	Vernacular name	Family	LF	FR	%	AB	DE	Family frequency		
1	*Abutilon longicuspe* Hochst. ex A. Rich.	Tsa'eda embwak	Malvaceae	S	1	0.3	1	0.9	Families	FR	%
2	*Acacia etbaica* Schweinf.	Seraw	Fabaceae	T	25	8.6	113	105.1	Aloeaceae	12	4.1
3	*Acokanthera schimpri* (A. DC.) Schweinf.	Mebt'a	Apocynaceae	T	1	0.3	2	1.9	Apocynaceae	5	1.7
4	*Acacia seyal* Delile	Tsa'eda che'a	Fabaceae	T	21	7.2	50	46.5	Buddleiaceae	1	0.3
5	*Aloe vera* (L.) Burm. f.	E'are	Aloeaceae	S	12	4.1	149	138.6	Cactaceae	7	2.4
6	*Becium grandiflorum* (Lam.) Pic. Serm.	Tebeb	Lamiaceae	S	24	8.2	145	134.9	Capparidaceae	3	1.0
7	*Buddleja polystachya* Fresen.	Metere	Loganiaceae	S	4	1.4	4	3.7	Celastraceae	28	9.6
8	*Calpurinia aurea* (Aiton) Benth.	Htsawts	Fabaceae	S	19	6.5	55	51.2	Combretaceae	5	1.7
9	*Cadaba farinose* Forssk.	Taum chena	Capparidaceae	S	3	1.0	5	4.7	Cupressaceae	23	7.9
10	*Carissa spinarum* L.	Agam	Apocynaceae	S	4	1.4	6	5.6	Ebenaceae	43	14.7
11	*Leucas oligocephala* Hook. f.	Swakerni	Labiatae	S	5	1.7	33	30.7	Ericaceae	1	0.3
12	*Croton macrostachyus* Hochst. ex Delile	Tanbuque	Euphorbiaceae	T	5	1.7	6	5.6	Euphorbiaceae	5	1.7
13	*Cupressus lusitanica* Mill.	Tsihidi ferenji	Cupressaceae	T	1	0.3	1	0.9	Fabaceae	78	26.7
14	*Dodonaea angustifolia* L. f.	Tahsos	Sapindaceae	S	6	2.1	22	20.5	Lamiaceae	23	7.9
15	*Erica arborea* L.	Shanto	Ericaceae	S	1	0.3	1	0.9	Loganiaceae	4	1.4
16	*Eucalyptus camaldulensis* Dehnh.	Keyh bahr zaf	Myrtaceae	T	20	6.8	115	107.0	Malvaceae	1	0.3
17	*Eucalyptus globulus* Labill.	Tsa'eda bahr zaf	Myrtaceae	T	12	4.1	34	31.6	Myrtaceae	32	11.0
18	*Euclea racemose* L.	Kuli'aw	Ebenaceae	S	43	14.7	381	354.3	Oleaceae	3	1.0
19	*Juniperus procera* Hochst. ex Endl.	Tsihidi habesha	Cupressaceae	T	22	7.5	60	55.8	Oliniaceae	3	1.0
20	*Maytenus arbutifolia* (Hochst. ex A. Rich.) R. Wilczek	Atat	Celastraceae	S	21	7.2	99	92.1	Polygonaceae	8	2.7
21	*Maytenus senegalensis* (Lam.) Exell	Argudi/kebkeb	Celastraceae	T	7	2.4	9	8.4	Rubiaceae	1	0.3
22	*Nuxia congesta* R. Br. ex Fresen.	Atkaro	Buddleiaceae	T	1	0.3	2	1.9	Sapindaceae	6	2.1
23	*Olea europaea* L.	Awli'a	Oleaceae	T	3	1.0	4	3.7	Total	292	100.0
24	*Olinia rochetiana* A. Juss.	Shgmesrhi	Oliniaceae	S	3	1.0	3	2.8			
25	*Opuntia ficus indica* (L.) Mill.	Beles	Cactaceae	S	7	2.4	65	60.5			
26	*Psydrax schimperiana* (A.Rich.) Bridson	Zahak	Rubiaceae	T	1	0.3	1	0.9			
27	*Rumex nervosus* Vahl	Hakot	Polygonaceae	S	7	2.4	26	24.2			
28	*Senna singueana* (Delile) Lock	Hambhambo	Fabaceae	S	13	4.5	33	30.7			
	Total				292	100	1425	1325.3			

Appendix 4. AB, DE, FR, LF, trees and shrubs of woody plants in foot elevation (P = 0.000)

R.no	Plant of foot slope	Vernacular name	Family	LF	FR	%	AB	DE	Family frequency		
1	*Abutilon longicuspe* Hochst. ex A. Rich.	Tsa'eda embwak	Malvaceae	S	2	0.5	2	2.8	Family	FR	%
2	*Acaia decurrens* Willd.	Dikerens	Fabaceae	T	7	1.7	31	43.4	Acanthaceae	1	0.2
3	*Acacia etbaica* Schweinf.	Seraw	Fabaceae	T	18	4.4	126	176.4	Aloeaceae	2	0.5
4	*Acacia lahai* Benth.	Lahai	Fabaceae	T	3	0.7	11	15.4	Anacardiaceae	13	3.2
5	*Acacia saligna* (Labill.) Wendl.	Acacha	Fabaceae	T	10	2.5	72	100.8	Apocynaceae	14	3.4
6	*Acokanthera schimpri* (A. DC.) Schweinf.	Mebti'a	Apocynaceae	T	3	0.7	27	37.8	Asteraceae	3	0.7
7	*Acacia seyal* Delile	Tsa'eda che'a	Fabaceae	T	29	7.1	101	141.4	Berberidaceae	1	0.2
8	*Aloe vera* (*A. barbadensis*) (L.) Burm. f.	E'are	Aloeaceae	S	2	0.5	3	4.2	Bignoniaceae	3	0.7
9	*Becium grandiflorum* (Lam.) Pic. Serm.	Tebeb	Lamiaceae	S	25	6.1	393	550.2	Boraginaceae	2	0.5
10	*Berberis holstii* Engl.	Zinkila	Berberidaceae	S	1	0.2	2	2.8	Buddleiaceae	3	0.7
11	*Buddleja polystachya* Fresen.	Metere	Loganiaceae	S	3	0.7	4	5.6	Cactaceae	3	0.7
12	*Calpurinia aurea* (Aiton) Benth.	Htsawts	Fabaceae	S	14	3.4	41	57.4	Capparidaceae	1	0.2
13	*Cadaba farinosa* Forssk.	T'aum chena	Capparidaceae	S	1	0.2	1	1.4	Celastraceae	35	8.6
14	*Carissa spinarum* L.	Agam	Apocynaceae	S	12	2.9	14	19.6	Combretaceae	7	1.7
15	*Clutia lanceolata* Forssk.	Bokokot	Euphorbiaceae	S	1	0.2	1	1.4	Cupressaceae	26	6.4
16	*Leucas oligocephala* Hook. f.	Swakerni	Labiatae	S	7	1.7	82	114.8	Ebenaceae	30	7.4
17	*Cordia africana* Lam.	Aqui	Boraginaceae	T	2	0.5	2	2.8	Ericaceae	1	0.2
18	*Croton macrostachyus* Hochst. ex Delile	Tanbuque	Euphorbiaceae	T	11	2.7	26	36.4	Euphorbiaceae	19	4.7
19	*Cupressus lusitanica* Mill.	Tsihidi ferenji	Cupressaceae	T	2	0.5	5	7	Fabaceae	96	23.5
20	*Dovyalis abyssinica* (A. Rich.) Warb.	Aihada	Flacourtiaceae	S	1	0.2	1	1.4	Flacourtiaceae	6	1.5
21	*Dodonaea angustifolia* L. f.	Tahsos	Sapindaceae	S	22	5.4	254	355.6	Lamiaceae	29	7.1
22	*Ekebergia capensis* Sparrm.	Kot	Meliaceae	T	3	0.7	4	5.6	Loganiaceae	3	0.7
23	*Erica arborea* L.	Shanto	Ericaceae	S	1	0.2	1	1.4	Malvaceae	2	0.5
24	*Euphorbia abyssinica* J.F. Gmel.	Kolkual	Euphorbiaceae	T	7	1.7	23	32.2	Meliaceae	3	0.7
25	*Eucalyptus camaldulensis* Dehnh.	Keyh bahr zaf	Myrtaceae	T	13	3.2	74	103.6	Moraceae	2	0.5
26	*Eucalyptus globulus* Labill.	Tsa'eda bahir zaf	Myrtaceae	T	7	1.7	22	30.8	Myricaceae	6	1.5
27	*Euclea racemosa* L.	Kuli'aw	Ebenaceae	S	30	7.4	304	425.6	Myrtaceae	20	4.9
28	*Ficus vasta* Forssk.	Da'aro	Moraceae	T	1	0.2	1	1.4	Oleaceae	11	2.7
29	*Grewia ferruginea* Hochst. ex A. Rich.	Tsimkuya	Tiliaceae	S	1	0.2	2	2.8	Oliniaceae	6	1.5
30	*Grevillea robusta* A. Cunn. ex R. Br.	Gravila	Proteaceae	T	2	0.5	7	9.8	Phytolaccaceae	6	1.5
31	*Juniperus procera* Hochst. ex Endl.	Tsihidi habesha	Cupressaceae	T	24	5.9	93	130.2	Pittosporaceae	1	0.2
32	*Justicia schimperiana* (Hochst. ex Nees) T. Anderson	Shim'aya	Acanthaceae	S	1	0.2	1	1.4	Polygonaceae	8	2.0
33	*Maytenus arbutifolia* (Hochst. ex A. Rich.) R. Wilczek	Atat	Celastraceae	S	29	7.1	157	219.8	Proteaceae	2	0.5
34	*Maytenus senegalensis* (Lam.) Exell	Argudi	Celastraceae	T	6	1.5	9	12.6	Rhamnaceae	6	1.5
35	*Morus alba* L.	Yferenj injori	Moraceae	T	1	0.2	1	1.4	Rosaceae	3	0.7
36	*Myrica salicifolia* Hochst. ex A. Rich.	Nihibi	Myricaceae	S	6	1.5	14	19.6	Rubiaceae	2	0.5
37	*Nuxia congesta* R. Br. ex Fresen.	Atkaro	Buddleiaceae	T	3	0.7	4	5.6	Salicaceae	3	0.7
38	*Olea europaea* L.	Awli'a	Oleaceae	T	11	2.7	25	35	Sapindaceae	22	5.4
39	*Olinia rochetiana* A. Juss.	Beye/Shimesrhi	Oliniaceae	S	6	1.5	44	61.6	Tiliaceae	1	0.2
40	*Oncoba spinosa* Forssk.	Eqot	Flacourtiaceae	T	5	1.2	16	22.4	Vitaceae	6	1.5
41	*Opuntia ficus indica* (L.) Mill.	Beles	Cactaceae	S	3	0.7	23	32.2	Total	408	100
42	*Otostegia integrifolia* Benth.	Mesaguh/ chi'andog	Lamiaceae	S	5	1.2	12	16.8			
43	*Phytolacca dodecandra* L'Hér.	Shimiti	Phytolaccaceae	S	6	1.5	12	16.8			
44	*Pittosporum viridiflorum* Sims	Chequente	Pittosporaceae	T	1	0.2	3	4.2			
45	*Prunus africana* (Hook. f.) Kalkman	Tikur incheti	Rosaceae	T	3	0.7	16	22.4			
46	*Psydrax schimperiana* (A. Rich.) Bridson	Zahak	Rubiaceae	S	2	0.5	2	2.8			
47	*Rhus glutinosa* Hochst. ex A. Rich.	Mengi/hatami	Anacardiaceae	T	5	1.2	7	9.8			
48	*Rhamnus prinoids* L'Hér.	Gesho	Rhamnaceae	S	6	1.5	37	51.8			
49	*Rhus retinorrhoea* Steud. ex A. Rich.	Teta'alo	Anacardiaceae	T	2	0.5	4	5.6			
50	*Rhoicissus tridentata* (L. f.) Wild & R.B. Drumm.	Karshiro	Vitaceae	S	6	1.5	17	23.8			
51	*Rumex nervosus* Vahl	Hakot	Polygonaceae	S	7	1.7	27	37.8			
52	*Salix mucronata* (*S. subserrata*) Thunb.	Kwaa	Salicaceae	T	3	0.7	13	18.2			
53	*Schinus molle* L.	Qundo berbere	Anacardiaceae	T	6	1.5	16	22.4			
54	*Senna singueana* (Delile) Lock	Hambhambo	Fabaceae	S	14	3.4	43	60.2			
55	*Stereospermum kunthianum* Cham.	Argzana	Bignoniaceae	T	3	0.7	11	15.4			
56	*Vernonia amygdalina* Delile	Grawa	Asteraceae	T	3	0.7	11	15.4			
	Total				408	100	2255	3157			

Appendix 5. AB, DE, FR, LF, trees and shrubs of woody plants in middle elevation (P = 0.000)

R.no	Plants of middle slope	Vernacular name	Family	LF	FR	%	AB	DE
1	*Abutilon longicuspe* Hochst. ex A. Rich.	Tsa'eda embwak	Malvaceae	S	4	1.3	6	8.4
2	*Acaia decurrens* Willd.	Dikerens	Fabaceae	T	3	0.9	15	21
3	*Acacia etbaica* Schweinf.	Seraw	Fabaceae	T	19	6.0	205	287
4	*Acacia lahai* Benth.	Lahai	Fabaceae	T	1	0.3	8	11.2
5	*Acacia saligna* (Labill.) Wendl.	Acacha	Fabaceae	T	8	2.5	64	89.6
6	*Acokanthera schimpri* (A. DC.) Schweinf.	Mebt'a	Apocynaceae	T	4	1.3	44	61.6
7	*Acacia seyal* Delile	Tsa'eda che'a	Fabaceae	S	21	6.6	70	98
8	*Aloe vera* (*A. barbadensis*) (L.) Burm. f.	E'are	Aloeaceae	S	8	2.5	59	82.6
9	*Becium grandiflorum* (Lam.) Pic. Serm.	Tebeb	Lamiaceae	S	28	8.8	236	330.4
10	*Buddleja polystachya* Fresen.	Metere	Loganiaceae	S	3	0.9	3	4.2
11	*Calpurinia aurea* (Aiton) Benth.	Htsawts	Fabaceae	S	16	5.0	86	120.4
12	*Cadaba farinosa* Forssk.	Taum chena	Capparidaceae	S	4	1.3	9	12.6
13	*Carissa spinarum* L.	Agam	Apocynaceae	S	6	1.9	7	9.8
14	*Leucas oligocephala* Hook.f.	Swakerni	Labiatae	S	7	2.2	48	67.2
15	*Croton macrostachyus* Hochst. ex Delile	Tanbuque	Euphorbiaceae	T	4	1.3	5	7
16	*Cupressus lusitanica* Mill.	Tsihidi ferengi	Cupressaceae	T	2	0.6	4	5.6
17	*Dichrostachys cinerea* (L.) Wight & Arn.	Gonnok	Fabaceae	S	1	0.3	3	4.2
18	*Dovyalis abyssinica* (A. Rich.) Warb.	Aihada	Flacourtiaceae	S	1	0.3	1	1.4
19	*Dodonaea angustifolia* L. f.	Tahsos	Sapindaceae	S	19	6.0	413	578.2
20	*Ekebergia capensis* Sparrm.	Kot	Meliaceae	T	1	0.3	6	8.4
21	*Euphorbia abyssinica* J.F. Gmel.	kolqual	Euphorbiaceae	T	3	0.9	12	16.8
22	*Eucalyptus camaldulensis* Dehnh.	Keyh bahr zaf	Myrtaceae	T	14	4.4	72	100.8
23	*Eucalyptus globulus* Labill.	Tsa'eda bahr zaf	Myrtaceae	T	5	1.6	23	32.2
24	*Euclea racemosa* L.	Kuli'aw	Ebenaceae	S	33	10.4	265	371
25	*Ficus vasta* Forssk.	Da'aro	Moraceae	T	1	0.3	1	1.4
26	*Juniperus procera* Hochst. ex Endl.	Tsihidi habesha	Cupressaceae	T	19	6.0	67	93.8
27	*Maytenus arbutifolia* (Hochst. ex A. Rich.) R. Wilczek	Atat	Celastraceae	S	23	7.3	87	121.8
28	*Maytenus senegalensis* (Lam.) Exell	Argudi/kebkeb	Celastraceae	T	5	1.6	6	8.4
29	*Myrica salicifolia* Hochst. ex A. Rich.	Nihibi	Myricaceae	S	2	0.6	2	2.8
30	*Nuxia congesta* R. Br. ex Fresen.	Atkaro	Buddleiaceae	T	2	0.6	3	4.2
31	*Olea europaea* L.	Awli'a	Oleaceae	T	9	2.8	21	29.4
32	*Olinia rochetiana* A. Juss.	Shgmesrhi	Oliniaceae	S	2	0.6	2	2.8
33	*Oncoba spinosa* Forssk.	Eqot	Flacourtiaceae	T	2	0.6	2	2.8
34	*Opuntia ficus indica* (L.) Mill.	Beles	Cactaceae	S	3	0.9	37	51.8
35	*Osyris quadripartita* Salzm. ex Decne.	Kerets	Loranthaceae	T	1	0.3	1	1.4
36	*Otostegia integrifolia* Benth.	Chi'andog	Lamiaceae	S	1	0.3	11	15.4
37	*Phytolacca dodecandra* L'Hér.	Shimiti	Phytolaccaceae	S	1	0.3	1	1.4
38	*Prunus africana* (Hook. f.) Kalkman	Tikur incheti	Rosaceae	T	2	0.6	4	5.6
39	*Rhus glutinosa* Hochst. ex A. Rich.	Mengi	Anacardiaceae	T	5	1.6	7	9.8
40	*Rhamnus prinoids* L'Hér.	Gesho	Rhamnaceae	S	3	0.9	9	12.6
41	*Rhus retinorrhoea* Steud. ex A. Rich.	Teta'alo	Anacardiaceae	T	2	0.6	2	2.8
42	*Rhoicissus tridentata* (L. f.) Wild & R.B. Drumm.	Karshiro	Vitaceae	S	1	0.3	1	1.4
43	*Rosa abyssinica* R. Br.	Konteftefe	Rosaceae	S	2	0.6	5	7
44	*Rumex nervosus* Vahl	Hakot	Polygonaceae	S	1	0.3	1	1.4
45	*Salix mucronata* (*S. subserrata*) Thunb.	Kwaa	Salicaceae	T	2	0.6	4	5.6
46	*Schinus molle* L.	Qundo berbere	Anacardiaceae	T	2	0.6	4	5.6
47	*Senna singueana* (Delile) Lock	Hambhambo	Fabaceae	S	7	2.2	19	26.6
48	*Stereospermum kunthianum* Cham.	Argzana	Bignoniaceae	T	2	0.6	2	2.8
49	*Vernonia amygdalina* Delile	Grawa	Asteraceae	T	2	0.6	4	5.6
	Total				317	100	1967	2753.8

Family frequency		
Family	FR	%
Aloeaceae	8	2.5
Anacardiaceae	9	2.8
Apocynaceae	10	3.2
Asteraceae	2	0.6
Bignoniaceae	2	0.6
Buddleiaceae	2	0.6
Cactaceae	3	0.9
Capparidaceae	4	1.3
Celastraceae	28	8.8
Combretaceae	7	2.2
Cupressaceae	21	6.6
Ebenaceae	33	10.4
Euphorbiaceae	7	2.2
Fabaceae	76	24.0
Flacourtiaceae	3	0.9
Lamiaceae	29	9.1
Loganiaceae	3	0.9
Loranthaceae	1	0.3
Malvaceae	4	1.3
Meliaceae	1	0.3
Moraceae	1	0.3
Myricaceae	2	0.6
Myrtaceae	19	6.0
Oleaceae	9	2.8
Oliniaceae	2	0.6
Phytolaccaceae	1	0.3
Polygonaceae	1	0.3
Rhamnaceae	3	0.9
Rosaceae	4	1.3
Salicaceae	2	0.6
Sapindaceae	19	6.0
Vitaceae	1	0.3
Total	317	100.0

Appendix 6. AB, DE, FR, LF, trees and shrubs of woody plants in upper elevation (P = 0.002)

R.no	Plant in upper slope	Vernacular name	Family	LF	FR	%	AB	DE
1	*Abutilon longicuspe* Hochst. ex A. Rich.	Tsa'eda embwak	Malvaceae	S	1	0.4	2	2.8
2	*Acaia decurrens* Willd.	Dikerens	Fabaceae	T	3	1.1	13	18.2
3	*Acacia etbaica* Schweinf.	Seraw	Fabaceae	T	16	6.0	108	151.2
4	*Acacia lahai* Benth.	Lahai	Fabaceae	T	2	0.8	8	11.2
5	*Acacia saligna* (Labill.) Wendl.	Acacha	Fabaceae	T	6	2.3	59	82.6
6	*Acokanthera schimpri* (A. DC.) Schweinf.	Mebti'a	Apocynaceae	T	4	1.5	28	39.2
7	*Acacia seyal* Delile	Tsa'eda che'a	Fabaceae	T	15	5.6	52	72.8
8	*Aloe vera* (*A. barbadensis*) (L.) Burm. f.	E'are	Aloeaceae	S	6	2.3	101	141.4
9	*Becium grandiflorum* (Lam.) Pic. Serm.	Tebeb	Lamiaceae	S	23	8.6	224	313.6
10	*Berberis holstii* Engl.	Zinkila	Berberidaceae	S	1	0.4	2	2.8
11	*Buddleja polystachya* Fresen.	Metere	Loganiaceae	S	3	1.1	3	4.2
12	*Calpurinia aurea* (Aiton) Benth.	Htsawts	Fabaceae	S	10	3.8	50	70
13	*Cadaba farinosa* Forssk.	Taum chena	Capparidaceae	S	2	0.8	6	8.4
14	*Carissa spinarum* L.	Agam	Apocynaceae	S	9	3.4	14	19.6
15	*Leucas oligocephala* Hook. f.	Swakerni	Labiatae	S	3	1.1	40	56
16	*Croton macrostachyus* Hochst. ex Delile	Tanbuque	Euphorbiaceae	T	2	0.8	2	2.8
17	*Cupressus lusitanica* Mill.	Tsihidi ferengi	Cupressaceae	T	4	1.5	21	29.4
18	*Diospyros abyssinica*(Hiern) F. White	Kumel a'awaf	Ebenaceae	T	2	0.8	2	2.8
19	*Diplostigma canescens* K. Schum.	Halengi	Asclepiadaceae	S	1	0.4	2	2.8
20	*Dichrostachys cinerea* (L.) Wight & Arn.	Gonnok	Fabaceae	S	1	0.4	2	2.8
21	*Dovyalis abyssinica* (A. Rich.) Warb.	Aihada	Flacourtiaceae	S	1	0.4	1	1.4
22	*Dodonaea angustifolia* L. f.	Tahsos	Sapindaceae	S	14	5.3	393	550.2
23	*Erica arborea* L.	Shanto	Ericaceae	S	1	0.4	1	1.4
24	*Euphorbia abyssinica* J.F. Gmel.	Kolkual	Euphorbiaceae	T	3	1.1	6	8.4
25	*Eucalyptus camaldulensis* Dehnh.	Keyh bahr zaf	Myrtaceae	T	10	3.8	46	64.4
26	*Eucalyptus globulus* Labill.	Tsa'eda bahr zaf	Myrtaceae	T	5	1.9	12	16.8
27	*Euclea racemosa* L.	Kuli'aw	Ebenaceae	S	31	11.7	278	389.2
28	*Grewia ferruginea* Hochst. ex A. Rich.	Tsimkuya	Tiliaceae	S	2	0.8	4	5.6
29	*Grevillea robusta* A. Cunn. ex R. Br.	Gravila	Proteaceae	T	1	0.4	1	1.4
30	*Juniperus procera* Hochst. ex Endl.	Tsihidi habesha	Cupressaceae	T	22	8.3	96	134.4
31	*Maytenus arbutifolia* (Hochst. ex A. Rich.) R. Wilczek	Atat	Celastraceae	S	32	12.0	120	168
32	*Maytenus senegalensis* (Lam.) Exell	Argudi	Celastraceae	T	2	0.8	9	12.6
33	*Nuxia congesta* R. Br. ex Fresen.	Atkaro	Buddleiaceae	T	1	0.4	1	1.4
34	*Olea europaea* L.	Awli'a	Oleaceae	T	9	3.4	26	36.4
35	*Olinia rochetiana* A. Juss.	Shigmesrhi	Oliniaceae	S	3	1.1	14	19.6
36	*Opuntia ficus indica* (L.) Mill.	Beles	Cactaceae	S	1	0.4	5	7
37	*Osyris quadripartita* Salzm. ex Decne.	Kerets	Loranthaceae	T	1	0.4	1	1.4
38	*Rhus glutinosa* Hochst. ex A. Rich.	Mengi	Anacardiaceae	T	5	1.9	8	11.2
39	*Rhus retinorrhoea* Steud. ex A. Rich.	Teta'alo	Anacardiaceae	T	3	1.1	5	7
40	*Rosa abyssinica* R. Br.	Konteftefe	Rosaceae	S	1	0.4	1	1.4
41	*Rumex nervosus* Vahl	Hakot	Polygonaceae	S	2	0.8	6	8.4
42	*Senna singueana* (Delile) Lock	Hambhambo	Fabaceae	S	2	0.8	3	4.2
	Total				266	100	1776	2486.4

Family frequency		
Family	FR	%
Aloeaceae	6	2.3
Anacardiaceae	8	3.0
Apocynaceae	13	4.9
Asclepiadaceae	1	0.4
Berberidaceae	1	0.4
Buddleiaceae	1	0.4
Cactaceae	1	0.4
Capparidaceae	2	0.8
Celastraceae	34	12.8
Combretaceae	3	1.1
Cupressaceae	26	9.8
Ebenaceae	33	12.4
Ericaceae	1	0.4
Euphorbiaceae	5	1.9
Fabaceae	55	20.7
Flacourtiaceae	1	0.4
Lamiaceae	23	8.6
Loganiaceae	3	1.1
Loranthaceae	1	0.4
Malvaceae	1	0.4
Myrtaceae	15	5.6
Oleaceae	9	3.4
Oliniaceae	3	1.1
Polygonaceae	2	0.8
Proteaceae	1	0.4
Rosaceae	1	0.4
Sapindaceae	14	5.3
Tiliaceae	2	0.8
Total	266	100

Appendix 7. AB, DE, FR, LF, trees and shrubs of woody plants in less than 10 age (P = 0.000)

R.no	Plant species in < 10 years old	Vernacular name	Family	LF	FR	%	AB	DE	Family frequency		
1	*Acacia decurrens* Willd.	Dikerens	Fabaceae	T	4	2.4	13	24.7	Family	FR	%
2	*Acacia etbaica* Schweinf.	Seraw	Fabaceae	T	15	9.0	138	262.2	Aloeaceae	4	2.4
3	*Acacia seyal* Delile	Tsa'eda che'a	Fabaceae	T	10	6.0	30	57.0	Apocynaceae	2	1.2
4	*Aloe vera* (*A. barbadensis*) (L.) Burm. f.	E'are	Aloeaceae	S	4	2.4	7	13.3	Celastraceae	16	9.6
5	*Becium grandiflorum* (Lam.) Pic. Serm.	Tebeb	Lamiaceae	S	36	21.7	325	617.5	Combretaceae	3	1.8
6	*Calpurinia aurea* (Aiton) Benth	Htsawts	Fabaceae	S	4	2.4	21	39.9	Cupressaceae	14	8.4
7	*Carissa spinarum* L.	Agam	Apocynaceae	S	2	1.2	2	3.8	Ebenaceae	33	19.9
8	*Leucas oligocephala* Hook. f.	Swakerni	Labiatae	S	3	1.8	15	28.5	Euphorbiaceae	8	4.8
9	*Dodonaea angustifolia* L. f.	Tahsos	Sapindaceae	S	1	0.6	1	1.9	Fabaceae	37	22.3
10	*Euphorbia abyssinica* J.F. Gmel.	kolqual	Euphorbiaceae	T	8	4.8	25	47.5	Lamiaceae	38	22.9
11	*Euclea racemosa* L.	Kuli'aw	Ebenaceae	S	33	19.9	293	556.7	Oliniaceae	1	0.6
12	*Juniperus procera* Hochst. ex Endl.	Tsihidi habesha	Cupressaceae	T	14	8.4	76	144.4	Polygonaceae	9	5.4
13	*Maytenus arbutifolia* (Hochst. ex A. Rich.) R. Wilczek	Atat	Celastraceae	S	11	6.6	40	76.0	Sapindaceae	1	0.6
14	*Maytenus senegalensis* (Lam.) Exell	Argudi	Celastraceae	T	5	3.0	9	17.1	Total	166	100.0
15	*Olinia rochetiana* A. Juss	Beye/Shimesrhi	Oliniaceae	S	1	0.6	14	26.6			
16	*Otostegia integrifolia* Benth.	Mesaguh/chi'andog	Lamiaceae	S	3	1.8	16	30.4			
17	*Rumex nervosus* Vahl	Hakot	Polygonaceae	S	8	4.8	29	55.1			
18	*Senna singueana* (Delile) Lock	Hambhambo	Fabaceae	S	4	2.4	12	22.8			
	Total				166	100	1066	2025.4			

Appendix 8. AB, DE, FR, LF, trees and shrubs of woody plants in between 10 and 20 age (P = 0.000)

R.no	Plant species in between 10 & 20 age	Vernacular name	Family	LF	FR	%	AB	DE	Family frequency		
1	*Acaia decurrens* Willd.	Dikerens	Fabaceae	T	9	3.9	46	87.4	Family	FR	%
2	*Acacia lahai* Benth.	Lahai	Fabaceae	T	6	2.6	27	51.3	Aloeaceae	2	0.9
3	*Acacia saligna* (Labill.) Wendl.	Acacha	Fabaceae	T	21	9.1	179	340.1	Anacardiaceae	1	0.4
4	*Acacia seyal* Delile	Tsa'eda che'a	Fabaceae	T	12	5.2	52	98.8	Celastraceae	35	15.2
5	*Aloe vera* (L.) Burm. f.	E'are	Aloeaceae	S	2	0.9	5	9.5	Cupressaceae	35	15.2
6	*Becium grandiflorum* (Lam.) Pic. Serm.	Tebeb	Lamiaceae	S	10	4.3	81	153.9	Ebenaceae	18	7.8
7	*Calpurinia aurea* (Aiton) Benth.	Htsawts	Fabaceae	S	11	4.8	36	68.4	Euphorbiaceae	5	2.2
8	*Clutia lanceolate* Forssk.	Bokokot	Euphorbiaceae	S	1	0.4	1	1.9	Fabaceae	71	30.7
9	*Croton macrostachyus* Hochst. ex Delile	Tambuque	Euphorbiaceae	T	4	1.7	9	17.1	Lamiaceae	13	5.6
10	*Cupressus lusitanica* Mill.	Tsihidi ferenji	Cupressaceae	T	4	1.7	16	30.4	Myrtaceae	29	12.6
11	*Dichrostachys cinerea* (L.) Wight & Arn.	Gonnok	Fabaceae	S	2	0.9	5	9.5	Oleaceae	1	0.4
12	*Dodonaea angustifolia* L. f.	Tahsos	Sapindaceae	S	20	8.7	636	1208.4	Proteaceae	1	0.4
13	*Eucalyptus camaldulensis* Dehnh.	Keyh bahir zaf	Myrtaceae	T	18	7.8	102	193.8	Sapindaceae	20	8.7
14	*Eucalyptus globulus* Labill.	Tsa'eda bahir zaf	Myrtaceae	T	11	4.8	32	60.8	Total	231	100
15	*Euclea racemose* L.	Kuli'aw	Ebenaceae	S	18	7.8	195	370.5			
16	*Grevillea robusta* A. Cunn. ex R. Br.	Gravilia	Proteaceae	T	1	0.4	4	7.6			
17	*Juniperus procera* Hochst. ex Endl.	Tsihidi habesha	Cupressaceae	T	31	13.4	133	252.7			
18	*Maytenus arbutifolia* (Hochst. ex A. Rich.) R. Wilczek	Atat	Celastraceae	S	32	13.9	169	321.1			
19	*Maytenus senegalensis* (Lam.) Exell	Argudi/kebkeb	Celastraceae	T	3	1.3	4	7.6			
20	*Olea europaea* L.	Awli'a	Oleaceae	T	1	0.4	2	3.8			
21	*Otostegia integrifolia* Benth.	Chi'andog	Lamiaceae	S	3	1.3	7	13.3			
22	*Rhus retinorrhoea* Steud. ex A. Rich.	Teta'alo	Anacardiaceae	T	1	0.4	1	1.9			
23	*Senna singueana* (Delile) Lock	Hambhambo	Fabaceae	S	10	4.3	22	41.8			
	Total				231	100.0	1764	3351.6			

Appendix 9. AB, DE, FR, LF, trees and shrubs of woody plants in between 20 and 30 age (P = 0.007)

R.no	Plant species in between 20 & 30 age	Vernacular name	Family	LF	FR	%	AB	DE
1	*Abutilon longicuspe* Hochst. ex A. Rich.	Tsa'eda embwak	Malvaceae	S	2	0.8	2	3.8
2	*Acacia etbaica* Schweinf.	Seraw	Fabaceae	T	27	10.2	221	419.9
3	*Acacia saligna* (Labill.) Wendl.	Acacha	Fabaceae	T	3	1.1	16	30.4
4	*Acokanthera schimpri* (A. DC.) Schweinf.	Mebti'a	Apocynaceae	T	3	1.1	7	13.3
5	*Acacia seyal* Delile	Tsa'eda cha'a	Fabaceae	T	12	4.5	38	72.2
6	*Aloe vera* (*A. barbadensis*) (L.) Burm. f.	E'are	Aloeaceae	S	2	0.8	9	17.1
7	*Becium grandiflorum* (Lam.) Pic. Serm.	Tebeb	Lamiaceae	S	23	8.6	332	630.8
8	*Berberis holstii* Engl.	Zinkila	Berberidaceae	S	1	0.4	2	3.8
9	*Calpurinia aurea* (Aiton) Benth.	Htsawts	Fabaceae	S	4	1.5	9	17.1
10	*Cadaba farinosa* Forssk.	Taum chena	Capparidaceae	S	6	2.3	15	28.5
11	*Carissa spinarum* L.	Agam	Apocynaceae	S	13	4.9	15	28.5
12	*Leucas oligocephala* Hook. f.	Swakerni	Labiatae	S	9	3.4	91	172.9
13	*Croton macrostachyus* Hochst. ex Delile	Tanbuque	Euphorbiaceae	T	4	1.5	10	19.0
14	*Cupressus lusitanica* Mill.	Tsihidi ferengi	Cupressaceae	T	4	1.5	14	26.6
15	*Diplostigma canescens* K. Schum.	Halengi	Asclepiadaceae	S	1	0.4	2	3.8
16	*Dodonaea angustifolia* L. f.	Tahsos	Sapindaceae	S	24	9.0	253	480.7
17	*Eucalyptus camaldulensis* Dehnh.	Keyh bahir zaf	Myrtaceae	T	2	0.8	2	3.8
18	*Euclea racemose* L.	Kuli'aw	Ebenaceae	S	26	9.8	161	305.9
19	*Grevillea robusta* A. Cunn. ex R. Br.	Gravila	Proteaceae	T	2	0.8	4	7.6
20	*Juniperus procera* Hochst. ex Endl.	Tshdi habesha	Cupressaceae	T	4	1.5	9	17.1
21	*Maytenus arbutifolia* (Hochst. ex A. Rich.) R. Wilczek	Atat	Celastraceae	S	24	9.0	108	205.2
22	*Maytenus senegalensis* (Lam.) Exell	Argudi	Celastraceae	T	5	1.9	7	13.3
23	*Myrica salicifolia* Hochst. ex A. Rich.	Nihibi	Myricaceae	S	4	1.5	8	15.2
24	*Olea europaea* L.	Awli'a	Oleaceae	T	9	3.4	21	39.9
25	*Olinia rochetiana* A. Juss.	Shgmesrhi	Oliniaceae	S	8	3.0	25	47.5
26	*Oncoba spinosa* Forssk.	Eqot	Flacourtiaceae	T	3	1.1	6	11.4
27	*Osyris quadripartite* Salzm. ex Decne.	Kerets	Loranthaceae	T	2	0.8	2	3.8
28	*Phytolacca dodecandra* L'Hér.	Shimiti	Phytolaccaceae	S	4	1.5	8	15.2
29	*Psydrax schimperiana* (A. Rich.) Bridson	Zahak	Rubiaceae	T	2	0.8	2	3.8
30	*Rhus glutinosa* Hochst. ex A. Rich.	Mengi	Anacardiaceae	T	13	4.9	16	30.4
31	*Rhamnus prinoids* L'Hér.	Gesho	Rhamnaceae	S	5	1.9	21	39.9
32	*Rhus retinorrhoea* Steud. ex A. Rich.	Teta'alo	Anacardiaceae	T	1	0.4	1	1.9
33	*Rhoicissus tridentata* (L. f.) Wild & R.B. Drumm.	Karshiro	Vitaceae	S	3	1.1	6	11.4
34	*Rumex nervosus* Vahl	Hakot	Polygonaceae	S	2	0.8	5	9.5
35	*Schinus molle* L.	Qundo berbere	Anacardiaceae	T	4	1.5	6	11.4
36	*Senna singueana* (Delile) Lock	Hambhambo	Fabaceae	S	5	1.9	12	22.8
	Total				266	100.0	1466	2785.4

Family	FR	%
Aloeaceae	2	0.8
Anacardiaceae	18	6.8
Apocynaceae	16	6.0
Asclepiadaceae	1	0.4
Berberidaceae	1	0.4
Capparidaceae	6	2.3
Celastraceae	29	10.9
Combretaceae	9	3.4
Cupressaceae	8	3.0
Ebenaceae	26	9.8
Euphorbiaceae	4	1.5
Fabaceae	51	19.2
Flacourtiaceae	3	1.1
Lamiaceae	23	8.6
Loranthaceae	2	0.8
Malvaceae	2	0.8
Myricaceae	4	1.5
Myrtaceae	2	0.8
Oleaceae	9	3.4
Oliniaceae	8	3.0
Phytolaccaceae	4	1.5
Polygonaceae	2	0.8
Proteaceae	2	0.8
Rhamnaceae	5	1.9
Rubiaceae	2	0.8
Sapindaceae	24	9.0
Vitaceae	3	1.1
Total	266	100

Appendix 10. AB, DE, FR, LF, trees and shrubs of woody plants in greater than 30 age (P = 0.000)

R.no	Plant in greater than 30 years old	Vernacular name	Family	LF	FR	%	AB	DE
1	*Abutilon longicuspe* Hochst. ex A. Rich.	Tsa'eda embwak	Malvaceae	S	5	1.5	8	15.2
2	*Acacia etbaica* Schweinf.	Seraw	Fabaceae	T	10	3.0	80	152.0
3	*Acokanthera schimpri* (A. DC.) Schweinf.	Mebt'a	Apocynaceae	T	8	2.4	92	174.8
4	*Acacia seyal* Delile	Tsa'eda che'a	Fabaceae	T	32	9.8	103	195.7
5	*Aloe vera* (*A. barbadensis*) (L.) Burm. f.	E'are	Aloeaceae	S	8	2.4	142	269.8
6	*Becium grandiflorum* (Lam.) Pic. Serm.	Tebeb	Lamiaceae	S	7	2.1	115	218.5
7	*Berberis holstii* Engl.	Zinkila	Berberidaceae	S	1	0.3	2	3.8
8	*Buddleja polystachya* Fresen.	Metere	Loganiaceae	S	9	2.7	10	19.0
9	*Calpurinia aurea* (Aiton) Benth.	Htsawts	Fabaceae	S	22	6.7	111	210.9
10	*Cadaba farinosa* Forssk.	T'aum chena	Capparidaceae	S	1	0.3	1	1.9
11	*Carissa spinarum* L.	Agam	Apocynaceae	S	11	3.4	15	28.5
12	*Leucas oligocephala* Hook. f.	Swakerni	Labiatae	S	5	1.5	64	121.6
13	*Cordia africana* Lam.	Aqui	Boraginaceae	T	2	0.6	2	3.8
14	*Croton macrostachyus* Hochst. ex Delile	Tanbuque	Euphorbiaceae	T	9	2.7	14	26.6
15	*Diospyros abyssinica* (Hiern) F. White	Kumel a'awaf	Ebenaceae	T	2	0.6	2	3.8
16	*Dovyalis abyssinica* (A. Rich.) Warb.	Aihada	Flacourtiaceae	S	3	0.9	3	5.7
17	*Dodonaea angustifolia* L. f.	Tahsos	Sapindaceae	S	10	3.0	170	323.0
18	*Ekebergia capensis* Sparrm.	Kot	Meliaceae	T	4	1.2	10	19.0
19	*Erica arborea* L.	Shanto	Ericaceae	S	2	0.6	2	3.8
20	*Euphorbia abyssinica* J.F. Gmel.	Kolkual	Euphorbiaceae	T	5	1.5	16	30.4
21	*Eucalyptus camaldulensis* Dehnh.	Keyh bahr zaf	Myrtaceae	T	17	5.2	87	165.3
22	*Eucalyptus globulus* Labill.	Tsa'eda bahr zaf	Myrtaceae	T	6	1.8	26	49.4
23	*Euclea racemosa* L.	Kuli'aw	Ebenaceae	S	17	5.2	200	380.0
24	*Ficus vasta* Forssk.	Da'aro	Moraceae	T	2	0.6	2	3.8
25	*Grewia ferruginea* Hochst. ex A. Rich.	Tsimkuya	Tiliaceae	S	3	0.9	6	11.4
26	*Juniperus procera* Hochst. ex Endl.	Tsihidi habesha	Cupressaceae	T	16	4.9	38	72.2
27	*Justicia schimperiana* (Hochst. ex Nees) T. Anderson	Shim'aya	Acanthaceae	S	1	0.3	1	1.9
28	*Maytenus arbutifolia* (Hochst. ex A. Rich.) R. Wilczek	Atat	Celastraceae	S	14	4.3	47	89.3
29	*Maytenus senegalensis* (Lam.) Exell	Argudi	Celastraceae	T	3	0.9	5	9.5
30	*Morus alba* L.	Yferenj injori	Moraceae	T	1	0.3	1	1.9
31	*Myrica salicifolia* Hochst. ex A. Rich.	Nihibi	Myricaceae	S	4	1.2	8	15.2
32	*Nuxia congesta* R. Br. ex Fresen.	Atkaro	Buddleiaceae	T	6	1.8	8	15.2
33	*Olea europaea* L.	Awli'a	Oleaceae	T	19	5.8	49	93.1
34	*Olinia rochetiana* A. Juss.	Shigmesrhi	Oliniaceae	S	2	0.6	21	39.9
35	*Oncoba spinosa* Forssk.	Eqot	Flacourtiaceae	T	4	1.2	12	22.8
36	*Opuntia ficus indica* (L.) Mill.	Beles	Cactaceae	S	7	2.1	65	123.5
37	*Phytolacca dodecandra* L'Hér.	Shimiti	Phytolaccaceae	S	3	0.9	5	9.5
38	*Pittosporum viridiflorum* Sims	Chequente	Pittosporaceae	T	1	0.3	3	5.7
39	*Prunus africana* (Hook. f.) Kalkman	Tikur incheti	Rosaceae	T	5	1.5	20	38.0
40	*Rhus glutinosa* Hochst. ex A. Rich.	Mengi	Anacardiaceae	T	2	0.6	6	11.4
41	*Rhamnus prinoids* L'Hér.	Gesho	Rhamnaceae	S	4	1.2	25	47.5
42	*Rhus retinorrhoea* Steud. ex A. Rich.	Teta'alo	Anacardiaceae	T	5	1.5	9	17.1
43	*Rhoicissus tridentata* (L. f.) Wild & R.B. Drumm.	Karshiro	Vitaceae	S	4	1.2	12	22.8
44	*Rosa abyssinica* R. Br.	Konteftefe	Rosaceae	S	3	0.9	6	11.4
45	*Salix mucronata* (*S. subserrata*) Thunb.	Kwaa	Salicaceae	T	5	1.5	17	32.3
46	*Schinus molle* L.	Qundo berbere	Anacardiaceae	T	4	1.2	14	26.6
47	*Senna singueana* (Delile) Lock	Hambhambo	Fabaceae	S	4	1.2	19	36.1
48	*Stereospermum kunthianum* Cham.	Argzana	Bignoniaceae	T	5	1.5	13	24.7
49	*Vernonia amygdalina* Delile	Grawa	Asteraceae	T	5	1.5	15	28.5
	Total				328	100	1702	3233.8

Family	FR	%
Acanthaceae	1	0.3
Aloeaceae	8	2.4
Anacardiaceae	11	3.4
Apocynaceae	19	5.8
Asteraceae	5	1.5
Berberidaceae	1	0.3
Bignoniaceae	5	1.5
Boraginaceae	2	0.6
Buddleiaceae	6	1.8
Cactaceae	7	2.1
Capparidaceae	1	0.3
Celastraceae	17	5.2
Combretaceae	5	1.5
Cupressaceae	16	4.9
Ebenaceae	19	5.8
Ericaceae	2	0.6
Euphorbiaceae	14	4.3
Fabaceae	68	20.7
Flacourtiaceae	7	2.1
Lamiaceae	7	2.1
Loganiaceae	9	2.7
Malvaceae	5	1.5
Meliaceae	4	1.2
Moraceae	3	0.9
Myricaceae	4	1.2
Myrtaceae	23	7.0
Oleaceae	19	5.8
Oliniaceae	2	0.6
Phytolaccaceae	3	0.9
Pittosporaceae	1	0.3
Rhamnaceae	4	1.2
Rosaceae	8	2.4
Salicaceae	5	1.5
Sapindaceae	10	3.0
Tiliaceae	3	0.9
Vitaceae	4	1.2
Total	328	100

ВОССТАНОВЛЕНИЕ НАРУШЕННЫХ ЗАСУШЛИВЫХ ЗЕМЕЛЬ ПУТЕМ ИЗЪЯТИЯ ИХ ИЗ ХОЗЯЙСТВЕННОЙ ДЕЯТЕЛЬНОСТИ, ПОВЫШАЮЩЕГО РАЗНООБРАЗИЕ ДРЕВЕСНЫХ ВИДОВ И ПОЧВЕННОЕ ПИТАНИЕ, В ВЫСОКОГОРЬЯХ ТИГРАЯ, СЕВЕРНАЯ ЭФИОПИЯ

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Изъятие пастбищных животных и посадок деревьев было одним из методов, используемых для восстановления деградированных земель в тропических полузасушливых областях. Изъятые земли могут способствовать вторичной сукцессии лесов, улучшая почвенные условия, привлекая агентов для распространения семян и изменяя микроклимат для развития подроста. В этой статье сравнивается разнообразие древесных пород и химические свойства почв на участках изъятых из использования в разное время и на пастбищах на склонах разной экспозиции. Исследование было проведено в Северной Эфиопии на 12 участков, изъятых из использования, и на таком же количестве выпасаемых участков, расположенных в непосредственной близости, с четырьмя обработками и в трех повторностях. В ходе работы было исследовано 216 участков, из которых 108 находились на исключенных из хозяйственной деятельности участках и 108 – на общинных пастбищах. В каждой группе участков было выделено четыре класса по возрасту и три – по экспозиции склона. Данные о растительности были собраны на участках размером 100 **м²**. Образцы почвы для определения ее физико-химических свойств были собраны из четырех углов и центра участков размером 5 × 5 м, которые находились внутри участков размером 10 × 10 м. В общей сложности был зарегистрирован 61 вид древесных растений из 41 семейства. Разнообразие и видовое богатство были выше на участках, изъятых из сельскохозяйственной деятельности, чем на пастбищах. Среди неиспользуемых участков эти параметры были выше на тех, которые были изъяты из хозяйственной деятельности более 30 лет назад и которые расположены у подножий склонов. Пастбища, недавно изъятые из пользования участки и расположенные на вершине склонов показали наиболее низкие значения этих параметров. Химические свойства почвы были значительно благоприятнее для растительности на изъятых из пользования участках, а среди них - на участках, имеющих самый большой возраст и расположенных у подножия склонов (за исключением содержания фосфора) по сравнению со значениями этих показателей на пастбищах, на недавно изъятых из пользования участках и расположенных на верхних частях склонов. Таким образом, изымаемые из хозяйственного использования участки играют важную роль в повышении разнообразия древесных пород и улучшения химических свойств почвы в засушливых областях.

Ключевые слова: изъятые из хозяйственной деятельности участки, разнообразие древесных растений, химические свойства почвы, экспозиция склона