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ON

ECOLOGICAL EFFECTS OF PLANTATIONS OF EXOTIC TREE SPECIES ON THE UNDERSTORY OF NATIVE VEGETATION IN YERER FOREST, OROMIA REGIONAL STATE, CENTRAL ETHIOPIA.

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YADESA BETO EJETA

A Dissertation submitted to the Department of Plant Biology and Biodiversity Management

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A Thesis Presented to the Graduate Programmes of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Plant Biology & Biodiversity Management

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DEDICATION

This dissertation is dedicated to my Father Beto Ejeta and Mother Nagasse Kalbesa who paid too much sacrifice for my today's life. I also dedicate this paper to my wife, Zinashi Tefari, and my sons' Bikila Yadesa, Chala Yadesa, Jabesa Yadesa, and Nimona Yadesa who bring lots of happiness to my life.

Ecological effects of plantations of exotic tree species on the understory of native vegetation in Yerer forest, Oromia regional state, central Ethiopia.

Yadesa Beto Ejeta, Ph.D. Dissertation

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This doctoral dissertation is consists of four independent components.

List of components:

Component I: **Floristic composition, diversity, structure, and regeneration status of woody species in Yerer Mountain natural forest**

Component II: **Effect of plantations of exotic tree species on the understory of native vegetation species composition, diversity, and density in Yerer forest, central Ethiopia**

Component III: **Effect of different land-use systems on the soil seed bank species composition and density in Yerer forest and surrounding areas**

Component IV: **Effect of Different Land Use Systems on Soil Physico-Chemical properties in Yerer forest and surrounding areas**

The ideas and realization of all the above-mentioned components are entirely my own. The fieldwork activities, methods of data collection, and analysis for all the components were carried out by me. The writing part of all the components was also done by me.

Ecological effects of plantations of exotic tree species on the understory of native vegetation in Yerer forest, Oromia regional state, central Ethiopia.

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ABSTRACT

A study on the effects of plantations of exotic tree species (Eucalyptus globulus, Cupressus lusitanica, Grevillea robusta, and Pinus patula) on native species both in the above and below ground with compared adjacent natural forest was conducted in the central high land of Ethiopia, in Yerer forest. The aim of the study was to investigate and document the effects of plantations of exotic tree species on the above and belowground native vegetation composition, diversity and density, and soil properties in Yerer forest of central Ethiopia. A systematic sampling design was employed to collect vegetation and soil data in all land-use systems. The vegetation and soil data were collected from a total of *20 transect lines and 60 quadrats, each with a 20 m x 20 m (400m^2) area established,* that distributed equal 12 quadrats for each five forest land-use systems. *Within each quadrat, five sub-quadrats with 2m x 2m (for seedling and sapling), and 1m x 1m (for herbaceous, and soil samples) were used for data collection.* In the study, there are three parts, the first part focussing on one of the land uses, the natural forest. In which, a *total of 93 woody species in 46 families were identified from 122 quadrats* along 22 transect lines *in the natural forest only. In the natural forest, the distribution of the density of seedlings > saplings > mature trees, which indicates woody species had s healthy regeneration profiles. In the natural forest, five plant community types were identified with varying degrees of species diversity, richness, and evenness. The species composition similarity coefficients among five plant communities ranged from 36-78%. In the second part, the five forest land-use systems with four plantations of exotic tree species (Eucalyptus globulus, Cuppressus lustanica, Grevillea robusta,* and *Pinus patula) and adjacent natural forest. From 60 quadrats, a total of 211 native species in 59 families, represented by 134 herbs and 77 woody species were recorded. Among the 211 identified native species, 32 species (15.17%) were commonly observed in all five forest* *land-use systems (LUS) 66 species (36.49%) only in a single forest (*36 species only in a natural forest, and 30 species only in exotic tree plantations), *while the rest species were recorded in between two to four forest LUS. The overall native vegetation composition in different forest land-use systems (LUS) ranged from 71 to 181 species. The overall aboveground vegetation species composition in similarity indices among five forest land-use systems (LUSs) ranged from 0.26 – 0.49. The third part focusing on eight land-use systems (natural forest, Eucalyptus globulus, Cuppressus lustanica, Grevillea robusta, Pinus patula, grassland, grazing land, and cropland)* to study the soil seed bank composition and density, and soil properties. *From a total of 96 quadrats,* along 32 transect lines, *the soil seed bank results showed, a total of 98 plant species belonging to 42 families and 84 genera were identified. In all the different land-use systems a total seed bank composition, and seed density* $/m^2$ *ranging between 29 to 57, and 1625 to 3250, respectively. General, The seed bank species composition, and density revealed a significant variation as a function of land-use systems. The analysis of variance (ANOVA) for the majority of soil physical and chemical properties variables of sand particle size, MC, BD, PD, SP, OC, TN, Avial. P, soil pH, EC, CEC, and exchangeable bases (Ca, Mg, K, Na) were showed that a significant variation among land-use systems at* ($P<0.0001$)*. The study results confirmed that plantations with different exotic tree species showed variability in their effect on the understory native species composition, diversity, density, and natural regeneration status. The changes in land use systems under similar climatic conditions significantly influenced the belowground native species composition and density, and soil property.*

Keywords: exotic tree plantations, land-use systems, native species, soil properties, soil seed bank, Yerer forest

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List of Acronyms

%	percent
a.s.l.	Above sea level
ANOVA	Analysis Of Variance
Aval. P	Available phosphorous
BD	Bulk density
BS	Base Saturation (%)
C: N ratio	the ratio of carbon to nitrogen
CEC	cation exchange capacity
cm	Centimeter
cm^3	Centimeter cubic
cmol(+)/kg soil	centimoles of positive charge per kilogram of soil
CV	Coefficient Variation
d/t	different
DBH	diameter at breast height
DM	Dry matter
DOM	Dead Organic Matter
dS	DeciSiemen
E	East
EARO	Ethiopia Agriculture Research Organization
EC	Electrical conductivity
EPRDF	Ethiopia People Republic Democratic Front
EWNHS	Ethiopian Wildlife and Natural History Society

Exch. Ca	Exchangeable Calcium
Exch. K	Exchangeable Potassium
Exch. Mg	Exchangeable Magnesium
Exch. Na	Exchangeable Sodium
FAO	Food and Agricultural Organization of the United Nations
FRA,	Forest Resource Assessment
GDP	Gross Domestic Production
GHGs	Greenhouse Gasses
GLM	General Linear Model
gm	Gram
GPS	Global Positioning System
ha	Hectare
IBC	Institute of Biodiversity Conservation
IPCC	Intergovernmental Panel on Climate Change
IVI	Important Value Index
JCS	Jaccard's Similarity Coefficient
kg	Kilogram
Km	Kilometer
LSD	Least Significant Mean
LULC	Land-use land cover
LULCC	Land-use land cover change
LUS	land-use system
m	Meter

m.a.s.l.	Meter above sea level
m^2	Meter square
MC	Moisture content
MEA	Millennium Ecosystem Assessment
MEA	Millennium Ecosystem Assessment
mg	Milligram
mm	Millimeter
N	North
ns	not significant
OC	organic carbon
^{O}C	Celsius degree
OFWE	Oromia Forest and Wildlife Enterprise
P	Probability statistical significance testing
PD	Particle density
PFM	Participatory Forest Management
R^2	R-Square
S	South
SAS	Statistical Analysis Software
SB	Seed bank
Sd	Standard deviation
SIGN	Significant
SOC	Soil Organic Carbon
SOM	Soil organic matter

SP	Soil porosity
SSB	Soil seed bank
TN	Total nitrogen
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
W	West

1. INTRODUCTION

1.1. Background

Land-use change is the main component of environmental change that alters biodiversity, soil properties, and water resources in terms of quality and quantity, and these, in turn, influence the interaction of a community of organisms with their physical environment (Foley et al., 2005; Newbold et al., 2015). A huge proportion of the world's forest land has been transformed into other land-use systems for the sake of different human needs. However, the outcome of the transformation of forest land-use to other land-use has generally led to environmental degradation (Foley et al., 2005). The world faces severe environmental, social, and economic challenges of unprecedented complexity by the factors of forest degradation and deforestation, biodiversity loss, soil degradation, and climate change (UN General Assembly 2011). Forest degradation and deforestation are worldwide environmental problems resulting from human activities that threatened the sustainability of Earth's life support systems (Lubchenco et.al., 1991). In developing countries, several socioeconomic and environmental challenges have strongly affected the capacity of forests to provide ecosystem services through deforestation and forest degradation (Demel Tektay 2001).

Land use and land cover change (LULCC) are related to great negative effects on ecosystems at nearby, local, national, and worldwide scales. Human land use and its influence on the land cover are a major driver of the distribution and functioning of ecosystems, and delivery of ecosystem services (Ellis, 2011). Land use and land cover change have some fundamental differences. Land use is defined as a series of operations or activities on land, carried out by humans, intending to obtain products and/or benefits through using land resources, for example, settlement, institutional, business, industrial, recreation, wildlife habitat (park), agriculture, and other relatively natural land use (Anderson et al., 1976; Bouma, 1997, Di Gregorio and Jansen 1998, FAO, 2010). Whereas, Land cover refers to the surface of land cover with physical and biological material found on the ground, for instance, vegetation cover with natural or planted, man-made constructions or human-created structures (buildings, infrastructure, etc.), water bodies, minerals (rocks, sand), and bare soil (FAO, 2000; Di Gregorio and Jansen 1998). The analysis of land-use change is essential to the analysis of the relationship between people and land. Land-use change is described as a process by which human activities converting the natural landscape from one land-use to another land-use objective, mainly based on the socio-economic functions (Bouma, 1997, Di Gregorio and Jansen 1998). Land cover change in any country results in several natural and anthropological driving forces (Meyer and Turner, 1994). The land use information is very important to design solutions for the existing identified natural resource management problems.

The changes of land use and land cover changes related to human socio-economics activities are happening speedily in global landscapes. High rates of deforestation and forest fragmentation are the consequences of observed LULCC, which lead to biodiversity loss (Millenium Ecosystem Assessment, 2005). Biodiversity becomes decreased by changing undisturbed land to more intensive disturbed land-use forms like continuous cultivating, overgrazing (Ellis, 2011). The loss of forest cover and biodiversity due to human pressure could be a developing concern in numerous parts of the world (Singh et al., 1997; Hegde and Enters, 2000). Loss of forest cover and plant biodiversity may seriously jeopardize/ risk to the ecological functioning of forest ecosystems (i.e. forest processes such as decomposition of organic matter, soil nutrient cycling, and water retention), and consequently the ability of the forest to provide socio-economic benefits *(*Millenium Ecosystem Assessment, 2005; Duffy, 2009*).* Deforestation, forest degradation, and forest fragmentation are continuing the global phenomenon events, but they are severe in the tropical region due to intensive anthropogenic activities (Wright, 2005). In vast human-dominated landscapes, the rapid conversion of tropical forests to agriculture, development activities, and other land-uses has resulted in the consequences of tropical biodiversity loss (Gibson et al., 2011). The deforestation, forest degradation, and depletion of other natural resources (soils, water) in the tropical region are closely associated with drought, soil fertility loss, climate change, and crop yield loss, which led to affecting the lives of millions of people (Brook et al., 2006).

Ethiopia has lost the majority of forest resources by forest degradation, and conversion of forest land-use to other non-forest land-uses especially during the 20th century (USAID, 2008). Declining areas of natural forests in Ethiopia stimulated special plantings with fast-growing tree species to supplement the local wood materials through compensatory plantation forests (FAO 2010; FRA 2015). Establishment of forest plantations through planting and/or deliberate seeding with fast-growing and short rotation periods of tree species which are characterized as even-aged monoculture forest stands (FAO 2010). Afforestation and reforestation programs have helped to reverse the decline of natural forest resources cover (Lalisa Duguma, and Hager, 2009). At the same time, afforestation and reforestation have also led to increasing forest coverage in some areas which resulted in reducing the national net forest loss by lowering human pressure on natural forests.

Forest plantations with fast-growing exotic tree species in Ethiopia are commonly carried out in monoculture form. The most common plantations of fast-growing exotic tree species in Ethiopia are *Cupressus lusitanica*, *Eucalyptus globulus*, *Eucalyptus camaldulensis*, *Grevillea robusta*, *Pinus patula*, *Pinus radiata*, and *Casuarina cunninghamiana*. According to FAO (2000), FRA (2000) report, among the plantations of fast-growing exotic tree species in Ethiopia, *Eucalyptus globulus* species is estimated to cover about 93% of the total plantation area. Accordingly, among the monoculture plantations of exotic tree species (*Eucalyptus globulus*, *Eucalyptus camaldulensis*, *Cupressus lusitanica*, *Pinus patula*, and *Grevillea robusta*) in Yerer area, *Eucalyptus globulus plantation is covered dominantly about 54%, followed by Cupressus lusitanica plantation (29%).*

1.2. Statement of the problem

Yerer Mountain natural forest is one of the protected dry montane forests in the central highlands of Ethiopia administrated under Oromia Wildlife and forest enterprise. To develop a proper forest management plan and strategies accurate scientific data on existing forest resources is an essential requirement (FAO, 2007). So far, there has not been scientifically documented information on the woody floristic composition, regeneration status, and vegetation structure of species in the natural forest. The lack of such basic information is one of the serious problems that hamper sufficient conservation of the Yerer Mountain natural forest area.

In addition, there is an ongoing expansion of plantations of fast-growing exotic tree species by farmers, enterprises, private, and government institutions. However, the environmental impacts of plantations of different exotic tree species in different areas have two major debates among scholars concerning positive or negative effects (Sasikumar et al., 2002, Florentine and Fox, 2003, Muluneh Mengist et. al. 2011). Thus, there has been studies' identifying the problems on the impacts of fast-growing exotic tree species on associated biodiversity and environment:

1) Some fast-growing exotic tree species result in a negative impact on the above and below ground native flora composition, diversity, and natural regeneration status via shade effect (particularly light-demanding plant species), space competition in both horizontal and vertical ways (native woody species space colonization), and allelopathic effects. These factors contribute to creating unfavorable environmental conditions to hinder the native species diversity and regeneration status (Feyera Senbeta *et al*., 2002, Sasikumar et al., 2002; Florentine and Fox, 2003, Jiregna Gindaba et al., 2004, Bajwa and Nazi, 2005).

2) Some researchers (Bone et al. 1997; Lugo, 1997; Feyera Senbeta and Demel Teketay, 2001; Hartley 2002; Cusack and Montagnini 2004) argued that exotic tree species plantation on degraded land through afforestation and/or reforestation programs could have a positive effect to native plant species restoration by creating favorable environmental conditions to native plant natural regeneration. Exotic tree species plantation also creates opportunities to native plant composition and diversity via seeds and fruits dispersal by attracting dispersal agents, particularly birds and mammals

(Yitebitu Moges, 1998; Feyera Senbeta *et al.* 2002; Carnus et al. 2006; Getachew Tesfaye and Abiyot Berhanu, 2006, Brockerhoff et al. 2008).

3) Fast-growing exotic tree species, particularly *Eucalyptus* species negatively affect soil physical, and chemical properties, through soil acidification, nutrient depletion, less valuable soil organic matter (Evans, 1992; FAO, 2001, El-Khawas and Shehata, 2005; Forrester et al., 2006). Generally, the expansion of exotic tree species plantation in reforestation and afforestation programs are one of the highly criticized forest policy developing in Ethiopia, mainly due to unclear concise reasons decision concerning to their impacts on environmental, and native biodiversity.

For future appropriate native vegetation restoration under different land-use systems, information on the existing of soil seed bank potential is very important, because the different land-use system has a different influence on seed banks composition, distribution and density change under similar climatic condition, due to the complex interaction between human activities and the existing natural biological resources (Feyera Senbeta and Demel Teketay, 2002; Getachew Tesfaye and Abiyot Berhanu, 2006). However, currently, there is limited information about the effect of different land-use systems (LUS) on soil seed bank composition and density in Yerer forest and surrounding areas.

Different scholars were reported to contradict ideas on the impact of plantations of exotic tree species on soil physical and chemical properties change as increases (positive), decreases (negative), or negligible (neutral) effect. To understand the effect of human activities on the soil properties by land-use system change is fundamental to understanding local soil change and sustainable development. However, data about the impact of land-use systems on soil properties in Yerer forest and encompassing areas is still too inadequate to recommend the ideal reasonable management and sustainable utilization of land resources for the forthcoming area.

1.3. Objectives, research questions, and hypotheses

The main research objectives, questions, and hypotheses of the present study were:

Objective 1. To identify and documents the woody species floristic composition, diversity, and natural regeneration status in Yerer Mountain natural Forest.

Research question 1. What is the potential of floristic compositions of woody species, diversity, and natural regeneration status in Yerer Mountain natural Forest?

Hypothesis 1. Ho: there is abnormal natural regeneration of woody species in Yerer mountain natural forest

Ha: there is a healthy natural regeneration of woody species in Yerer mountain natural forest

Objective 2. To determine the species richness, abundance, and composition of naturally regenerated native species under the introduced plantations of tree species.

Research question 2. What are the species richness, abundance, and composition of naturally regenerated native species under the introduced plantations of tree species?

Hypothesis 2. Ho: There are no differences in species richness, abundance, and composition of naturally regenerated native species under the introduced plantations of tree species

Ha: There are variations of species richness, abundance, and composition of naturally regenerated native species under the introduced plantations of tree species

Objective 3. To determine the soil seed bank composition and seed density under different land-use systems (LUS)

Research question 3. What are the soil seed bank composition and seed density under different land-use systems (LUS)?

Hypothesis 3. Ho: There are no variations of soil seed bank composition and seed density under different land-use systems (LUS)

Ha: There are variations of soil seed bank composition and seed density under different land-use systems (LUS)

Objective 4. To determine the soil Physico-chemical properties under different land-use systems (LUS).

Research question 4. What are the soil Physico-chemical properties under different land-use systems (LUS)?

Hypothesis 4. Ho: The soil Physico-chemical properties under different land-use systems (LUS) are no change

Ha: The soil Physico-chemical properties under different land-use systems (LUS) are varies

1.4. Significance of the study

The study generated scientifically organized information on 1) the native woody composition, diversity, and natural regenerated status of Yerer Mountain natural forest, 2) the native vegetation composition, diversity, density, and natural regeneration of woody under different plantations of exotic tree species, 3) the soil seed bank composition and density change under different land-use systems of Yerer forest and surrounding areas, and 4) the selected soil physico-chemical properties change under different land-use systems of Yerer forest and surrounding areas. In the study area, scientifically organized information provide by primary data collection, statistical data analysis, interpretation, and formal writing with justification.

2. LITERATURE REVIEW

2.1. Natural Vegetation of Ethiopia

Vegetation is assemblages of plants growing together in a particular area and covers the ground or in other words the collective plant cover of an area (Jenning et al., 2003*).* Vegetation is an overall term, without explicit reference to specific taxa, life form, structure, spatial degree, or any other particular botanical or geographic features. The simplest concept of vegetation types has been based on physiognomy, i.e. the general physical structure and appearance of the vegetation (Jennings et al., 2003). The vegetation cover of a given area has developed in a definite structure and composition, because of the long period of interaction between biotic and abiotic factors. The pattern of dispersion and vertical characterization of vegetation fluctuate due to various environmental conditions, latitude, and topography of the region. These, in turn, influence the distribution and type of plants and animals in the forest (Jennings et al., 2003).

Ethiopia is situated in the Horn of Africa, with extraordinarily differing landscapes with diverse physiographic characteristics. The country is endowed with a rich diversity of flora and fauna being rich in endemic (IBC, 2014). The country's flora and fauna are distributed over the highest elevation range from the pinnacle of mountains over 4000 m a.s.l. to one of the lowest and hottest climatic regions on earth is the Dallol depression which found at 116 m below sea level (Ensermu Kelbesa et al., 1992; Sebsebe Demissew et al. 2003; IBC 2009). This variation in altitude has made suitable environmental conditions for supporting a different variety of vegetation according to their ecological growth requirements. Extraordinary varieties in elevation are directly reflected the different forms of vegetation established in Ethiopia. The flora of Ethiopia encompasses around 6027 vascular plant species with 12 % endemic ones (Ensermu Kelbesa and Sebsebe Demissew, 2014), these species disseminations placed the country as the fifth largest floral composition in tropical Africa.

Ethiopia is one of the few countries in Africa continent where almost all major significant kinds of natural vegetation are characterized, ranging from thorny bushes, and tropical forests to mountain grasslands because of its wide variety in climate, topography, moisture, and soils. The vegetation resources of Ethiopia, including woodlands, forests, bushlands, and grasslands have been studied by many researchers, and institutions (FAO, 2010; Tamrat Bekele 1994; Sebsebe Demissew et al., 1996, Friis and Sebsebe Demissew, 2001; Tadesse Wolde Mariam, 2003; IBC 2005). According to the recent revision of vegetation type of Ethiopia by Friis et al 2010, there are 12 vegetation types identified mainly based on altitude and/or climatic variables, these are (1) Dry evergreen Afromontane forest and grassland complex, (2) Moist evergreen Afromontane forest, (3) Afroalpine belt vegetation, (4) Riverine vegetation, (5) *Combretum-Terminalia* woodland and wooded grassland, (6) *Acacia-Commiphora* woodland and bushland, (7) Wooded grassland of the western Gambela region, (8) Desert and semi-desert scrubland, (9) Transitional rainforest, (10) Ericaceous belt, (11) Fresh-water lakes (including lake shores, marsh, and floodplain vegetation), and (12) Salt-water lakes (including salt-lake shores, marsh, and pan vegetation). Among the twelve vegetation types of Ethiopia, four are found in the dryland regions of the country: i) *Combretum-Terminalia* woodland and wooded grassland, (ii) *Acacia-Commiphora* woodland and bushland, (iii) Desert and semi-desert scrubland, and (iv) Riverine vegetation. The Ethiopian highlands contribute to more than 50% of the land area with Afromontane vegetation; of which dry montane forests are covered the largest portion (Tamrat Bekele, 1994).

Montane ecosystems refer to any ecosystem found in mountains or hilly areas having a high altitude. Montane ecosystems are strongly affected by climate, which gets colder as elevation increases, and hotter as elevation decreases in lowland areas. On the other hand, the montane forest is termed as hill evergreen forests (Tadesse Wolde Mariam, 2003; Friis et al., 2010). The dry evergreen montane forest is one of a very complex vegetation type occurring in the climate of hotter to moist conditions in the altitudinal range 1500 – 3200 m.a.s.l of Ethiopia. The dry evergreen montane forest area receives an annual rainfall of 700 mm to 1500 mm with an annual temperature between 14^0C and 25^0C. Dry evergreen montane natural vegetation is characterized under the long dry seasons (4-8 months) and short rainy period. It is found in the central and western parts of Shewa, Gojam, Wello, and Tigray plateaus (Friis, 1992; Zerihun Woldu 1999; IBC 2007). The upper limit of montane vegetation is the vegetation lands with a transition of shrubs and grasses before spread at the high elevation grasslands. Dry evergreen montane forest & grassland complicated vegetation type is categorized by trees of varied sizes and wide-ranging grasslands that are wealthy in legumes. Common tree species include *Juniperus procera, Olea europaea* subsp. *Cuspidate, Celtis africana, Euphorbia ampliphylla, Mimusops kummel,* and *Ekebergia capensis*. Typical shrubs include *Dracaena spp., Carissa edulis,* and *Rosa abyssinica*, while common grass species belong to the genera *Hyparrhenia, Eragrostis, Panicum, Sporobolus, Eleusine,* and *Pennisetum,* and the legumes genera include *Trifolium, Eriosema,* and *Crotalaria spp*. The forest–grassland ecotone is occupied by tree forest including *Acacia* woodland with *A. abyssinica, A.*

negrii, and *A. pilispina of* the commonest trees (Sebsebe Demissew et al., 1996, Friis and Sebsebe Demissew, 2001, IBC, 2005).

2.2. Remnant and Secondary Natural Forests

2.2.1. The contribution of remnant natural forests in maintain plant biodiversity

Remnant vegetation can be defined as vegetation patches of native trees, shrubs, and grasses those still left from vegetation disappearance by different factors. Remnant vegetation includes all kinds of native natural vegetation counting grasslands, woodlands, dryland forests, rainforests, and it happens on all land tenures, which are owned by both privately and publicly (Sandor and Chazdon, 2014). Remnant trees are spared from cutting when forests are cleared for agricultural or grazing. According to Sandor and Chazdon (2014) reported, the shrinkage of remnant native natural forests has a clear negative consequence on the species diversity, composition, and ecology of the nearby woody vegetation.

A remnant natural habitat is described as an ecological community containing native flora and fauna or biological integrity that has not been significantly disturbed by human intervention destructive activities like farming, overgrazing, selective tree cutting for logging, forest fragmentation, firing, etc., but to replicate itself over time (Sandor and Chazdon, 2014). Most of the natural forests in Ethiopia have disappeared and fragmented into small patches due to continuous deforestation, which is going on at a very alarming rate with an annual loss ranging from 80,000 to 200,000 ha (FAO 2007; Temesgen Mekonnen et. al., 2015). The rates of deforestation and forest degradation activities have accelerated the loss of biological diversity. Conversion of natural areas into intensive land use under cultivation and settlement in central highlands of Ethiopia has left small to medium isolated montane forests as remnant forest areas around mountains. Remnant forest areas are only small remaining patches that it found generally at restricted inaccessible areas to harvest, mountainous or hilly areas, and sacred places (monasteries, churches, and mosques) (Alemayehu Wassie et al., 2005). The biological diversity measurement is naturally emphasizes on the species level and species diversity, which indicates the most important indices for sustainable land use practice to reverse the deterioration of biodiversity by evaluating ecosystems' situation at different scales (Shackelton, 2000).

The natural forests of Ethiopia have decreased continuously at an alarming rate by different human intervention factors in the past few decades. The remnant forests and woodlands are under continuous pressure as a result of high population growth **(**FAO, 2010; Kidane Mengistu 2002). High population growth and the associated ever-increasing demand on natural forests for various forest products and agricultural land have put the remnant forest patches on the verge of disappearance (Tamrat Bekele 1994). Therefore, the persistence of the remnant forest patches and their indigenous species in many areas are threatened. Fragmentation and habitat loss could influence the structure and regeneration of the remnant forests (Cabin et al. 2002). However, the different literature reviews indicated that the remnant flora of Ethiopia is still considered to be rich both in species diversity and endemism.

The remnant natural forest resources play a critical role in supporting the livelihood of rural people of Ethiopia, particularly in meeting daily subsistence basic needs. Remnant forests are diverse in shape, size, and composition, and take the form of parks, wooded buffers, greenways, and conservation-oriented natural areas (MEA, 2005). Presently, the country government is doing to manage and conserve the remnant natural forest resources for the objective of various cultural, economic, social, and environmental benefits in the form of community participatory forest management (PFM) strategy (MEA, 2005; Mammo Siraj et.a., 2016). Participatory Forest Management (PFM) is a mechanism to protect forests and enhance the livelihoods of communities who use and benefit from them in the process (FAO 1996). Forest management is currently supposed as an activity aiming each to sustaining wood production and providing firewood for both household consumption and marketing, local food, other goods, and services to bordering local people (FAO 1996).

2.2.2. The contribution of Secondary natural forests in maintain plant biodiversity

A secondary forest is a forest that has been destructed by human activities without conversion to another land use and has regenerated naturally or artificially through planting (FAO, FRA 2000). Not all secondary forests provide an equivalent worth to sustaining biodiversity, or goods and services, as similar to the primary forest within the same location. Secondary forests are showing a major difference in forest structure, canopy size, species composition, and stems density from the adjacent primary forests on the same sites (FAO, 2010). The most undisturbed secondary forests are dominated by the upper story (30 m) layer of tree species like *Juniperus procera*, and sometimes mixed with *Podocarpus falcatus*. The secondary plant communities are within the process of succeeding toward the state of primary natural forests (Tang et.al. 2007).

The larger portions of the existing forests of Ethiopia are secondary, due to the widespread human influence, which occurs everywhere. Three types of secondary forests are identified. The post-fire secondary vegetation established under the effect of frequent fire, and mainly found in the woodland and bushlands regions **(**FAO, 2010; Kidane Mengistu 2002). The post-extraction secondary forests develop largely through natural processes after a significant disturbance of the original natural stand by commercial utilization and other human activities such as cutting for fuel-wood and construction materials and clearance for cultivation. The post-extraction secondary forests occur in the areas of the three major high forest formations of Ethiopia: moist evergreen montane forests, dry evergreen montane forests, and moist evergreen lowland forests (FAO, 2010, Kidane Mengistu 2002). The post-extraction secondary forests occur at a higher altitude between 2300 - 3200 m, in areas with a more or less pronounced dry period of up to 5 months and an annual rainfall of around 1000 mm. Due to the relative dominance of *Juniperus procera*, these forests are also called *Juniper* forests (FAO, 2010).

The post-fire secondary forests are found in lowland areas within woodland and bushland that are largely restricted to the agro-pastoral and pastoral areas. The lowland of woodland areas is intensely used for grazing in the pastoral area by nomadic tribes in different regions. Fire is the major tool being used by the local people as a means of pastoral land management. A recent study of different workers findings in Gambella region showed that fire has a strong influence on promoting the dominant plant species particularly grasses while suppressing some woody species by burning particularly during the winter season, thus consequence changing the dense forest to "open wooded grassland" (Minassie Gashaw et. al.2000, Kidane Mengistu 2002). The post-extraction secondary forests are located in the Dry evergreen montane forest areas, between 2000 and 3500 m. *Junipers procera* is the dominant tree species, which forms the non-continuous upper story at a height of up to 40 m, in well-protected areas. The ground floor in the lower altitudes often consists of shrubs and a fair regeneration of *Juniperus* and/or *Podocarpus* in closed areas **(**MOA, 1998; Kidane Mengistu 2002).

2.3. Plant Community

Plant community can be defined in different ways by different authors, some of these: Plant communities are defined as the recognizable units of vegetation in a uniform environment with a relatively uniform floristic composition and vegetation structure that is distinct from the surrounding vegetation (Mueller-Dombois and Ellenberg 1974; Kent and Coker, 1992). Plant communities are "the collecting or associating of similar plant species occur together on the landscape due to sharing a common character of ecological growth requirements within a nominated physical environmental unit that interact with each other by acting as complementarities, the competition of similar resources, and dependence" (Kent and Coker, 1992; Callaway and Walker, 1997). However, the components of each plant community are influenced by topography, climate, soil type, and human disturbance within a designated geographic unit.

Studies of plant communities in a forest help to design appropriate management and conservation measures to treat individual communities based on their finding problems. Plant communities are described largely by species similarity (species presence) or species dissimilarity (absence). The classification and recognition of plant communities in a forest help to design and recommend appropriate management regimes for individual community types based on their result as separate unit management regimes (Mueller-

Dombois and Ellenberg 1974; Kent and Coker, 1992). A more understanding of the individual plant community of a forest helps to plan and implementing conservation strategies and sustainable utilization of plant resources. Different studies showed that the species heterogeneity variations of plant communities in spatial and temporal across landscapes. The individual plant community's species compositions of a forest are more express their relationships to one another than any other characteristics in the area (Kent and Coker, 1992).

The classification of plant communities is based on forest features such as complete floristic composition, floristic structure, and relative species abundances. The plant communities' categories are mostly based on the physical physiognomy or appearance, and growth form of the vegetation in the area. Because they have similar requirements for existence in terms of environmental factors such as light, temperature, water, drainage, and soil (Mueller-Dombois and Ellenberg, 1974). The description of the plant community comprises the analysis of species diversity, evenness, and similarity index.

2.4. Floristic Composition, diversity, and structure of vegetation

The floristic composition and structure studies are essential because of their value in understanding the extent of plant diversity, managing endangered and socio-economic significance species (WCMC 1992, Segawa, and Nkuutu, 2006). Ethiopia has diverse physiographic features which helped the nation is endowed with a great variety of vegetation types. In Ethiopia, the floral resources found in different areas as vegetation types include forests, woodlands, grassland, and bushlands. Several scholars have investigated and provided substantial contributions to describing the flora of Ethiopia from the beginning of the 19th century to the mid of the 20th century (Sebsebe Demissew et al. 1996; Zerihun Woldu, 1999; Friis and Sebsebe Demissew, 2001; Sebsebe Demissew et al. 2011).

The investigations of Ethiopia's floral resources were carried out in different parts of the country and contributed to generating valuable botanical information for Ethiopian flora. The distribution and richness of taxa (species and subspecies) are highly variable in the flora area (Ethiopia and Eritrea). The flora of Ethiopia and Eritrea registered 243 families of vascular plants in the flora area, of which 175 were found in both Ethiopia and Eritrea, 63 only in Ethiopia, and five only in Eritrea (Ensermu Kelbessa and Sebsebe Demissew, 2014). In general about 6027 plant taxa at species and subspecies levels were recorded in the Flora area (3,875 taxa in Ethiopia only, 270 taxa in Eritrea only, and 1882 taxa common to both countries). Among the recorded plant taxa in the flora Fabaceae, Poaceae and Asteraceae are the top three families having 678, 609, and 472 taxa, respectively (Ensermu Kelbessa and Sebsebe Demissew, 2014). These results of flora species richness and diversity put Ethiopia as one of the top 25 biodiversity-rich countries in the world (Abiyou Tilahun et al., 2015).

Species diversity is how a biological taxon is spatially arranged. By different workers, studies on plant species composition, diversity, and regeneration status are very important issues for identifying and prioritizing conservation activities to targeted species (Lovett *et al*., 2000; Myers *et al*., 2000). In the floristic study, species diversity is one of the most significant indices used for evaluating the sustainability of forest communities (Kent and Coker, 1992). The species diversity capacities study is very important to provide information on a key indicator of species for the welfare of the ecosystem management (Heywood, 1995; Shakelton, 2000). The two main factors taken into account when measuring species diversity are the total number of species in the community or habitat (species richness) and the total number of individual species per unit area (species evenness) within the sample or community (Kent and Coker, 1992; Krebs, 1999). It is a widely used index that combines richness and evenness (Krebs, 1999). The species richness index is of great importance in assessing taxonomic and ecological values of habitats. The plant species diversity and evenness are calculated commonly by using the Shannon-Wiener diversity index, which naturally varies between 1.5 and 3.5 and rarely exceeds 4.5 (Kent and Coker, 1992).

Generally, species diversity is the product of species richness and evenness or equitability. Species diversity index provides information about species rarity, endemism, and commonness. Species diversity can be measured in different approaches at the level of alpha, beta and gamma diversity. Alpha diversity (α) refers to the number of species within a sample area or community. Beta diversity (β) is a measure of the rate and extent of change or difference in species composition between two adjacent sample areas (habitats) or communities. Among plant species, diversity study level beta diversity (β) is sometimes called habitat diversity because it represents differences in plant species composition among different areas or environments (Kent and Coker, 1992). On the other hand, gamma diversity (γ) is a diversity of a larger spatial unit, such as a landscape. The similarity index measures the degree of similarity between different habitats or communities regarding the composition of species (Kent and Coker, 1992).

2.5. Natural regeneration status of native woody species

Natural regeneration on forest lands is a natural succession of forest on temporarily unstocked lands that are considered as forest (FAO, FRA 2000). Natural regeneration is the process by which an ecosystem impacted by natural or anthropogenic disturbances recovers its total or partial biodiversity, its structure and functioning, through the successional sequence over time. Regeneration is a key ecological process and a central component of forest ecosystem dynamics and restoration of degraded forest lands. Species composition, diversity, and structure of understory vegetation are key to providing complex structures and conserving indigenous floras within forests (Halpern, Spies 1995, Thomas et. al., 1999). Sustainable forest utilization is only possible if adequate information on the regeneration dynamics and factors influencing important canopy tree species are available (Harrington et al., 1997). Therefore, the effectiveness to maintain and expand forests will depend mainly on the success of natural regeneration of the component woody species.

The population structure is characterized by the presence of a sufficient population of seedlings, saplings, and adults which indicate successful regeneration of individual species of a forest. Regeneration studies have significant implications on the conservation and restoration of degraded natural forests (Getachew Tesfaye *et al.*, 2010). The regeneration status of woody species can be predicted by the age structure of their populations. The study of the regeneration status of forests contributes to planning, conservation, and decision-making in forest resources management programs (Pokhriyal et al., 2010). Densities of seedlings and saplings are considered an indicator of the regeneration potential of a forest.

Concerning the natural regeneration status of woody species in a forest, some species are a healthy regeneration status, and graphical showed normal inverted J-shaped population structure, while others species showed that critical regeneration problems which need conservation measure. A species is considered in a good regeneration status if the number of seedlings is greater than saplings which in turn is greater than a tree (seedlings > saplings > tree); fair regeneration is a condition of a species where the number of seedlings is greater than the number of saplings and the number of saplings is also less than the number of trees (seedlings > saplings < tree); poor regeneration is a status of regeneration where the density of sapling is greater than seedlings. A species is considered not regenerating if it survives only in the adult stage and a species has newly arrived if it presents only in the seedling stage (Pokhriyal et al., 2010). A good understanding of factors promoting or hampering the seedling establishment of tree species could help in the future restoration of degraded landscapes through an appropriate management system. Managers need to be aware of the regeneration status of native species in human-modified forests to determine the structure and composition of future communities (Chazdon, 2014).

2.6. Plantation forest

2.6.1. Historical background of plantation forest establishment

In Ethiopia, about 85% of the total population (rural people) directly depend on agriculture and live in rural areas (Krause et. al. 2007). In most developing countries, particularly Ethiopia, people's relationships with forests and trees are inseparably interlinked and interdependent (FAO 2003). The forest resources are playing a central, vital, and diverse multiple roles in sustainably supporting millions of rural livelihoods. Forest resources provide a significant role in economic, social, and ecological benefits (e.g., decrease soil degradation) (Mulugeta Lemenih, Tadesse WoldeMariam 2010).

However, from time to time the rapidly increasing human population in Ethiopia has led to changes in land-use types to fulfill their basic needs by conversion of forestland to agriculture, grassland, settlement, and overexploited for construction materials, fuelwood, and furniture making. These resulted in the natural forests of Ethiopia to have continuously dwindled at an alarming rate (Reusing, 1998; FAO, 2006). In Ethiopia, the natural forests that once covered 40% of land cover at the beginning of the 1900s have been declining both in size and quality to approximately 2.7% due to continued deforestation (Pohjonen and Pukkala, 1990, FAO, 2010).

The consequences of deforestation followed by continuous cultivation, overgrazing, and overexploitation of the resources have caused a decline in the loss of forest ecosystem functions in terms of economic and social benefits, and ecological services (such as regulation of local climate, maintenance of water quality, and supply erosion control, soil fertility improvement, nutrient cycling, wildlife habitats, biological diversity conservation) (FRA 2000, Eshetu Yirdaw, 2002, Lal, 2003). The continuity of forest resource degradation and deforestation has resulted in major challenges to the economic, social, and environmental development in Ethiopia (MEA, 2005). To avert the deforestation, forest degradation, and environmental degradation rate, and their consequence, the Ethiopian government has been working in one way to protect the existing natural forests, and in another way as an alternative measure to launching and promoting tree plantations in the country.

Biomass is currently the fourth largest energy source in the world and the main source in Ethiopia. However, due to natural forest degradation in quality and quantity, and deforestation has led to a shortage of fuelwood from the forests in the country (FAO, 2010, Woldeamlak Bewket, and Stroosnijder, 2003). To cope with the expanding shortage of wood, mainly fuelwood, Ethiopia launched and endorsed plantation forest programs with fast-growing exotic tree species. Accordingly, to relieve the shortage of wood caused by extensive deforestation, *Eucalyptus* was introduced into Ethiopia in 1894- 1895 from Australia during the reign of Emperor Menelik II (Pohjonen and Pukkala, 1990). Nowadays the genus of *Eucalyptus* species is amongst the most successful of the introduced plantation species, being quickly adopted by farmers, and widely distributed and planted all across Ethiopia including large areas of land previously allocated to food production. The establishment of exotic plantations on degraded land has been a slowly growing land use in Ethiopia since tree planting started over a century ago.

However, the formation of large-scale forest plantations did not begin until the 1970s in Ethiopia (Pohjonen, 1989). The motivation of forest plantation expansion is attributed to their fast growth, coppicing ability, and fewer management requirements, the unpalatability of leaves by animals, and their adaptability to a wide range of environmental conditions to grow (Turnbull and Pryor, 1978). In the 1970s, the plantation areas with *Eucalyptus* species around Addis Ababa city were about 15,000 ha and in other parts of the country, approximately 76,000 ha of plantations were established. Between 1975 and 1994, further new plantations were established mainly in periurban areas with aid from different international donors (AfDB, DANIDA, SIDA, UNSO, WFP, and WB) (Leykun Berhanu, 2005; FAO, 2006). *Eucalyptus* plantation is a major land use that was established by the Ethiopian government to address the growing demand for wood products (Ermias Teferi, et.al. 2016), and the expansion of plantation land use has significantly contributed to an increase in total forest plantation cover from an estimated 190,000 ha in 1990 to approximately 972,000 ha in 2010 (Daniel Jaleta et. al. 2016).

Plantation forests are increasing rapidly in the country to avert deforestation and degradation of natural forests, along with providing various goods and services. Forest plantations are defined as forest stands that have been established artificially with exotic or indigenous species and that have a minimum area requirement of 0.5 ha, have a tree crown cover of at least 10% of the land cover, and a total height of mature trees above 5 m (FAO, 2001). In another way, plantation forests are defined as the cultivated forest ecosystems established by planting and/or seeding in the process of afforestation and reforestation for wood biomass production, soil and water conservation, wind protection, and also carbon sequestration (FAO, 2000, FRA 2000).

Plantation forests are either introduced exotic species or indigenous species that are established with even-aged, single-species monocultures of the same species or mixed species. Forest plantation could be established through two processes: afforestation, and reforestation (FAO, 2012). In Ethiopia case, afforestation and reforestation were announced by the governmental policy in 1974 (Poschen 1987), the objectives of plantations include: (1) to fulfill the increasing demand of biomass or fuel woods, poles, and construction material for household consumptions and marketing; (2) to relieve the pressure on remnants of the native forests; and (3) to promote soil and water conservation and rehabilitation of degraded land. Reforestation is the re-establishment of forest artificially by planting after temporary (< 10 years) conditions on land with less than 10%

canopy cover forest (FAO, FRA 2000). Afforestation is the conversion of non-forest land use (for more than 10 years) into forest land use or with the increase of canopy cover to the 10% defined threshold for forest (FAO, FRA 2000).

In Africa countries, Ethiopia is one of the longest histories in forest plantations. In Ethiopia, reforestation and afforestation activities began over a century ago (Mulugeta Lemenih and Bongers 2010). Among fast-growing exotic tree species, at the end of the 19th century, *Eucalyptus* species were introduced to satisfy the high demand for firewood. Farmers prefer planting *Eucalyptus* over other species for its rapid wood production and coppice-based management (Jagger and Ponder, 2000; Tesfaye Abebe 2005, Zenebe Mekonnen et al. 2007). Plantation forests and especially *Eucalyptus* are keys to wood production in Ethiopia. Currently, the documented data showed that approximately fifty-five (55) *Eucalyptus* species are available in Ethiopia. However, the most common and widespread *Eucalyptus* species include *Eucalyptus globulus*, *Eucalyptus camaldulensis*, *Eucalyptus saligna*, *Eucalyptus grandis*, and *Eucalyptus tereticornis.* Planting *Eucalyptus* is expanding from state-owned forest enterprises and projects to community woodlots, household, and farm field boundaries (FAO, 2000; FAO, 2005). The *Eucalyptus* trees particularly *Eucalyptus globulus*, and *Eucalyptus camaldulensis* species were planted on lands that had been transformed from natural forest and marginalized land because of overgrazing and poor land management practices. Afforestation with an appropriate choice of tree species is important. The species in question should be suitable for use in reclamation and rehabilitation. Currently, there is much interest in the usage of plantation trees with different species to recover degraded and marginal agricultural lands in different areas (Evans, 1999).

2.6.2. Significance of plantation forest

Plantation forest is undoubtedly important in providing extensive benefits at local, national, regional, and global levels. Forest plantations can provide critical positive economic, social, cultural, and environmental or ecological benefits (FAO, 1993). Generally, the importance of forest can be seen in the aspect of forest ecosystem service, and forest resources use. A forest ecosystem could be a forest unit that includes all plants, wild-animals, and micro-organisms (biotic components) of the region that work together with all the inanimate physical (abiotic) elements of the environment, whereas, the benefits provided by forest resources use include economic, social, and cultural values (FAO, 2000; FRA 2000). The benefits derived from forest resources being subject to full production for wood and non-wood products (FAO, 1993). Tree plantations are increasing globally from time to time (Payn et. al., 2015) for various objectives like restoring degraded landscapes (Rappaport, and Montagnini, 2014), managing and conserving native vegetation species (Yang, 2013), sustaining timbers, poles, and pulps products to users (Payn et. al., 2015) or carbon sequestration (Miah, et.al. 2009; and Arias 2011) among others.

The economic benefits of plantation forests are usually measured in monetary terms and may include: income for employment in the sector; the value of the production of goods and services from forests; and the contribution of the sector to the national economy, energy supplies, international trade, and from a commercial point of view, forests provide the raw materials used for wood-based industries (wood products, paper product) (Eshetu Yirdaw 2002). Plantation forests are offering high employment opportunities, both in plantation development and management on field, and raw materials product processing industries (Million Bekele, 2001). Plantation forests are important sources of incomes from non-timber wood products such as fuelwood and charcoal, poles and logs, gums, resins, and oils, sawmilling, medicines, mushrooms, tourism, fodder and forage, fruit, nuts, and honey (Christian et al., 1998; Norton, 1998; Davis et al., 2001).

Additionally, different studies suggest that if the direct consumption of wood products in the forms of fuelwood and charcoal and forest products utilized in other economic sectors such as health, food, and manufacturing and construction activities are considered under the benefits (Million Bekele, 2001). Similarly, other workers also reported that plantation forests could provide revenue to improve the livelihoods of the local communities, as well as strengthening regional and national economies in some nations, like New Zealand, Chile, and Brazil (Nambiar, 1999; Dyck, 2003). Moreover, plantation forests also providing social functions such as fruit and seeds for food, woody and non-wood materials for local construction, fuelwood for cooking and heating, for traditional farm implements, household furniture; medicine; fodder for animals, for tourist attractions, recreation opportunities, and as well as having many other uses (World Bank 2009, Takahashi et al., 2010).

Plantation forests provide ecosystem services. Forest ecosystem provides various services that living organism derives from ecosystem functions that maintain the earth's life-supporting system (FAO, 2000, FRA 2000). The ecosystem service and the natural capital in this regard become critical to the function of the earth's life-supporting system. The ecological functions provided by forest ecosystems include provide habitat for wildlife, rehabilitating lands exhausted from other land uses, diversifying the rural landscape, maintaining biodiversity, protect soil degradation by reducing the chances of floods, nutrient cycling, increases soil fertility, offer watershed management, erosion control, flood and landslide prevention, protection from wind and rain, soil and water conservation, provide shade and shelter (Christian et al., 1998; Norton, 1998; FAO, 2000, FRA 2000, Davis et al., 2001, Million Bekele, 2001). Different workers also reported the ecological services of planted trees to protect soil via the litter layer and leaf canopy, thereby decreasing runoff and erosion by increasing water infiltration rates and reducing temperature and moisture fluctuations (Sanchez, et. al., 1997). There are beneficial effects related to the action of tree roots in forests with the enhancement of soil structure through inputs of organic materials via root decay (Fisher, 1995; Olsson, 2001). Plantation forests may also improve degraded soils by improving soil nutrient status through increased inputs and reduced outputs, while they can increase the availability of nutrients through enhanced nutrient cycling (Rhoades, 1997; Jobbágy and Jackson, 2001).

The establishment of exotic species plantations can have several advantages. The relatively fast growth rate of exotic species provides wood to be used for various purposes. Moreover, recent studies on tropical tree plantations indicate that exotic species may facilitate the regeneration of native species under the canopy and catalyze the subsequent succession processes (EshetuYirdaw, 2002). The potential role of forest plantations in meeting future demands for industrial wood products, for a comprehensive forecast of the supply and demand for wood and wood products (Goldman et al. 2008). In several countries, the substitution of wood supply from the natural forest by plantation forests may help to reduce population pressure on natural forests exploitation in the areas in which unsustainable harvesting of wood is a major cause of forest degradation by partially meet demand from natural forests (FAO, 2000, and FRA 2000).

2.7. Impact of plantation of exotic tree species on native plant biodiversity

On a global level, the natural forest extent changes through the loss of cover and conversion to plantations and other similar land uses. However, several issues have evolved regarding the plantations' forest impact on biodiversity (Stephens and Wagner, 2007). The effect of intensive plantation forest practices on native species composition and diversity is controversial among different scholars (Braun et al., 2017). Generally, different authors indicated that fast-growing exotic tree species plantation could act as both problems (negative effect) and solutions (positive effect) on the understory native plant biodiversity and ecological restoration role (Braun et al., 2017; Kint, 2005). The effects of fast-growing species plantation on undergrowth vegetation composition and diversity differ strongly based on the characteristics of the surrounding landscape (agriculture, savannah, or native forest), uniformity of horizontal (spatial heterogeneity), and vertical (stratification) structural diversity of overstorey tree species and management regimes (Kint, 2005). A better understanding of how plantation forests affect native biodiversity and other ecosystem services are critical to establishing economically, socially, and ecologically sustainable land-use policies (Goldman et al., 2008).

Exotic tree plantation forest is one of the options that can foster secondary forest succession by improving soil conditions, attracting seed-dispersal agents, and modifying microclimate for understory growth (Abrham Abiyu et. al., 2011). Afforestation causes a change in microclimate and land use patterns in the plantation area. Reforestation of exotic tree plantations on degraded land could contribute positively to restore native biota by stabilizing soil properties and creating site conditions suitable for native animals and plants to recolonize (Lugo 1997; Moore and Allen 1999). The conservation of native plant biodiversity for forest landscapes dominated by plantation has become an increasingly important topic, and opportunities to maintain or enhance native plant biodiversity in exotic tree plantation forests need to be recognized and applied. Some studies suggest that exotic tree plantation forests can play an important role in native plant diversity conservation and restoration (Hartley 2002; Cusack and Montagnini 2004; Carnus et al. 2006; Brockerhoff et al., 2008). Similarly, exotic tree plantation forests have been used to catalyze the understory native vegetation succession to restore (Parrotta 1999; Lee et al 2005; Brockerhoff et al 2008). Hence, the regeneration of native tree species under the canopy of exotic tree plantations can be achieved (Lugo, 1997).

The studies of the understory of native plant diversity in exotic tree plantation forests are very important because the understory of native species is the main component of forest ecosystems play the role in many ecological values and processes (Eshetu Yirdaw2001; Roberts 2002; Nagaike et al., 2006). To evaluate the effect of plantation forest on the native plant biodiversity, a primary forest was selected as a reference forest to compare their native plant diversity and regeneration status (Loo et. al., 2017). The diversity of native flora found in exotic tree plantations is lower than in primary forests (Bremer and Farley, 2010; Felton et. al., 2010), and depends on the intensity of plantation use (Newbold et al., 2015). The other researchers also reported that tropical forest plantations are promoted the recruitment, establishment, and succession of native woody species by functioning as foster ecosystems (Parrotta, 1997; Lugo et al., 1993). Similarly, Eshetu Yirdaw (2002) was reported that plantation forests have a potential contribution to catalyzing and fostering a role in the conservation of indigenous plant species, and rehabilitation of degraded forests and their ecosystems.

Large-scale introductions of exotic tree species are deemed one of the major agents of global environmental changes (Pereira et al., 2012). In contrary to the positive effect of exotic tree plantation forests on native vegetation species composition, diversity, and conservation, on the other hand, numerous studies indicated that intensive monocultures of exotic tree plantations are widely viewed in a negative effect mainly concerning biological diversity conservation (Carnus et al., 2003). Some workers believe that the regeneration of indigenous woody species under the canopy of exotic tree plantations could be hampered. This could be attributed primarily related to the knowledge that plants could compete with the existing natural resources (soil nutrient and water) to each other (Rouhi-Moghaddam et. al. 2007). For instance, monoculture form, *Eucalyptus* species plantations have the potential to change the diversity of understory native plant species along with landscapes (Lugo**,** 1997; Souto et al., 2001).

2.8. Effect of land-use systems on soil seed banks composition and diversity

Land use and land cover change have become a central focal point in the current strategies for managing natural resources and monitoring environmental change. Land use is the activities, arrangements, and inputs that people undertaking to the use of lands such as industrial zones, residential zones, and agricultural fields, while, land cover is the existing of biological and physical situations on the ground surface either permanently or temporally, for instance, forest, grassland, crops, etc. (Di Gregorio and Jansen, 1998; FAO 2000). Land use\land cover change is increasingly recognized as an important driver of environmental change on all spatial and temporal scales. It contributes significantly to earth atmosphere interaction, forest fragmentation, and biodiversity loss (Blair and Dockray, 2004). Generally, Land use\land cover change has major impacts on above and below-ground biodiversity, earth climate, and hydrology. The loss of biodiversity due to land use\land cover changes takes place at multiple levels (landscape, ecosystem, and species), and multiple dimensions (structure and function) (Turner et al., 2001).

A major impact of land use\land cover is on biotic resources. For instance, the annual loss of plant species in tropical Africa is high due to the human activities of land-use change from forest-land to agriculture, grazing, and settlement land-use (FAO, 2001). The loss of plant biological diversity can cause decreasing in ecosystem unity and loss of plant genetic resources in the region. The forest resources in tropical areas have suffered great degradation from time to time by anthropogenic actions, and many of it transformed into pasture or cultivated areas. Subsequently, the soil seed bank physiognomies of the areas have been adapted and it’s essential to a better understanding of its consequences on the natural regeneration of forests (Santos et al. 2018). The soil seed bank is strongly affected by anthropogenic actions through land-use systems change.

The soil seed bank is defined as the natural storage of mature viable seeds that exist in the leaf litter, on the soil surface, or buried in the soil of many ecosystems, which represents the memories of the past plant community and serves as a repository for the future production of subsequent generations of plants to enable their survival in the surrounding area (Whittle et.al. 1997, Swaine 2001, Walck, 2005, Fisher, 2009). The soil seed bank is one of all the ecological parts that shape the dynamics of an ecological system in land-use. The soil seed bank plays a crucial role in re-establishing vegetation on degraded land, and in desertification areas (Zhan, 2007, Williams, 2009). However, the viability of vegetation recovers by using the belowground vegetation or seed bank composition and seed density (Duncan, 2009). Thompson and Grime (1979) were recognized that two main seed bank germination viability strategies: transient types, in which seeds remain viable for no more than 1 year, and persistent seeds are seeds that remain in the soils and viable for longer than one year for germination.

An understanding of persistent seed banks is the main vital to understanding several aspects of vegetation management, restoration, and conservation plan development for future activities (Jalili et al. 2003). Soil seed banks contain a higher density of plant groups, such as pioneer trees, shrubs, climbers, grasses, forbs, and non-native species, which may impact future forest composition through competition with newly-emerged tree seedlings (Thompson et al. 2003). Most of the seeds within the soils come from the adjacent parent plants, whereas the remaining seeds within the soils are contributed by plant communities from an extended distance by dispersal agents (Solomon Tefera, 2011).

The soil seed bank assessment contributes baseline knowledge for designing approaches to the restoration and management of disturbed forests (Richter and Stromberg, 2005; Mulugeta Lemenih & Demel Teketay, 2006; Wang et al., 2009). To manage and restore forest vegetation, detailed information on the regeneration ability of the plant species is required, including the availability of seeds, which may differ depending on the nature of land-use systems (Mulugeta Lemenih and Demel Teketay, 2006). Because the soil seed bank is one source of plant seeds (Baskin, 1998), that influence the formation and composition of future forest regeneration, and community structure (Warr et al., 1993). Seed banks reflect the vegetation history of the floristic composition of a particular area. Understanding regeneration mechanisms is also an important first step towards a successful implementation of forest rehabilitation as restoration of degraded forest lands relies much on natural regeneration. Seed rain, soil seed bank, seedling bank, and coppices are the major sources of natural regeneration (Getachew Tesfaye et al., 2010).

Historical land use is a key factor that can influence the soil seed bank composition for a long period (Plue et.al, 2010; Van Calster et.al. 2008). In land-use and forest management practices, the soil seed bank is an important component of vegetation dynamics (Thompson 1987). The seed dispersal and soil seed bank both play important roles in species recruitment and succession (Bakker et.al., 1996; Plue et.al., 2009). The tree plantations can facilitate native species regeneration by attracting seed dispersal agents from nearby native communities (Zamora and Montagnini, 2007). Plantation in afforestation modifies the habitat to affect the structure and species diversity of the soil seed bank and understory vegetation. Soil seed banks represent a stock of regeneration potential in many plant communities as well as represent an important component of ecosystem resilience (González-Alday et.al. 2007). In particular, soil seed banks allow species to bridge temporally unsuitable habitat conditions for germination and establishment (Bossuyt and Honnay, 2008).

2.9. Effect of land-use systems change on soil properties

Understanding the effect of human activities on the soil environment is fundamental to understanding local change and sustainable development (Luo et. al., 2008). Severe declination of soil quality could result in permanent deterioration in the productive capacity of the land quality (Islam and Weil, 2000). Severe deterioration in soil quality may lead to permanent degradation of land productivity, and then, it results in the increment of agricultural production costs to maintain soil fertility (Yifru Abera and Taye Belachew 2011). The main causes for soil degradation are poor agricultural practices, deforestation, and overgrazing, but also fast-growing tree plantations, when poorly planned and managed may lead to soil quality decline (Mulugeta Lemenih et. al. 2004; Bekele Lemma et. al., 2006). The conversion of natural forest to farming led to significant declines in soil physical properties (silt contents, moisture content, and aggregate stability), and soil chemical properties (such as N, P, K, and organic matter), but on the other hand, with these soil properties change, the soil bulk density, sand content, and pH level were increased significantly (Abad et. al., 2014). Mulugeta Lemenih (2004) observed the influences of land-use changes on soil properties and native vegetation potential in the highlands of Ethiopia.

Land-use changes, vegetation composition, and ecosystem development are through modification and/or fragmentation of habitats, cause a decline in biodiversity and lead to degradation of soil and water (Cao. et.al. 2011). The extensive prevalence of environmental deterioration has generated much-expanding interest in the science and practice of ecological restoration that seeks to reinforce the recovery of degraded land in terms of quality and watercourses (Dobson et. al., 1997; Lamb et. al., 2005). Afforestation is generally used as a mechanism to control soil erosion, accelerate vegetation recovery, and improve ecological conditions (Kozlowski, 2002; Li, 2004). The ecological impact of afforestation becomes a strong debate during the afforestation process (Cao et. al., 2010; Jiao et.al. 2012). Plantation on degraded land in the afforestation program a primary measure of intervention to influence soil characteristics such as soil erodibility, soil water content, soil fertility *(*Jiao et. al., 2007*;* Tateno et. al., 2007*).* The previous studies showed that Plantation in afforestation has ecological function on erosion control, catchment-water yield, and soil carbon sequestration (Qiu et.al. 2010; Chang et.al. 2011; and Wang et.al. 2011). Additionally, forest plantations also may improve degraded lands through steadying soils, enhancing soil nutrients, and rising soil organic matter accumulation via increasing the aboveground litter production (Lugo, 1992; Lugo et al., 1993; Parrotta, 1995, Michelsen et al., 1996).

In the past decade, a large part of the natural vegetation had been destroyed and the land turned into farmland, thus aggravating soil erosion and ecological degradation (Zhao et.al. 2013). Changes of forests to rangeland and agricultural lands are one of the most concerns in environmental degradation and world climate change (Wali, 1999). Tropical savanna is a subject issue to the numerous forms of soil and flora degradation, due to different ecological disturbances by anthropogenic factors (like fire, fragmentation, logging, woodcutting, overgrazing), and natural factors (like climatic change) (Savadogo et al., 2008). The ecological disturbances commonly occurred due to the removal of vegetation biomass through a forest fire (Whelan, 1995), or through redistribution and loss of soil layers (Belnap, 1995). Soil erosion is regarded as one of the global environmental problems which cause land degradation and ecosystem disequilibrium (Pimente and Kounang, 1998). Revegetation is an efficient approach to manage soil degradation and improve the ecological system. In the component of vegetation, the presence of grass or trees can reduce runoff and conserve soil and water (Cerdà 1999, Zhou et.al., 2006, Lieskovský and Kenderessy 2014).

Land use/land cover changes are caused by some natural and human driving forces (Meyer and Turner, 1994). Population growth is the most important factor of the human driving force that causes land-use/land cover changes in Ethiopia (Hurni, 1993). Currently, due to population growth, forest lands are degraded and converted to agricultural lands. The impact of land-use change on soil physical and chemical properties might vary for various types of soils, vegetation, and ecological zones. The anthropogenic activities have changed the land-use systems features of the Earth's surface, and soil properties either positively or negatively. Transformation of one land use system into another system and different management practices can affect soil structure, soil organic carbon, and other nutrients reserve (Yeshanew Ashagrie et.al, 2007). Land-use changes such as deforestation, conversion of rangeland to cropland, and cultivation are known to result in changes in soil Physico-chemical and biological properties (Houghton 1999). Generally, land-use changes from one to another particularly the conversion of forest land to cultivation land may vastly deteriorate soil quality.

3. MATERIALS AND METHODS

3.1. The study area description

3.1.1. Location

A field study was conducted in the central highland of Ethiopia, Oromia Regional State, East Shewa Zone, Yerer forest, and surrounding areas. Yerer forest is one of the remnant montane evergreen natural forests and plantation forests with different exotic tree species in the central highland of Ethiopia. The study area is located in the central-eastern part of Ethiopia at 40 km southeast far from Addis Ababa, and 17 km north of Bishoftu town. Yerer forest and surrounding areas is located between 8°52'00" - 8°55'00" N latitude and 38°59'30” - 38°95'15" E longitude, with altitudinal ranges between 2000 and 3105 m.a.s.l. (Figure 1).

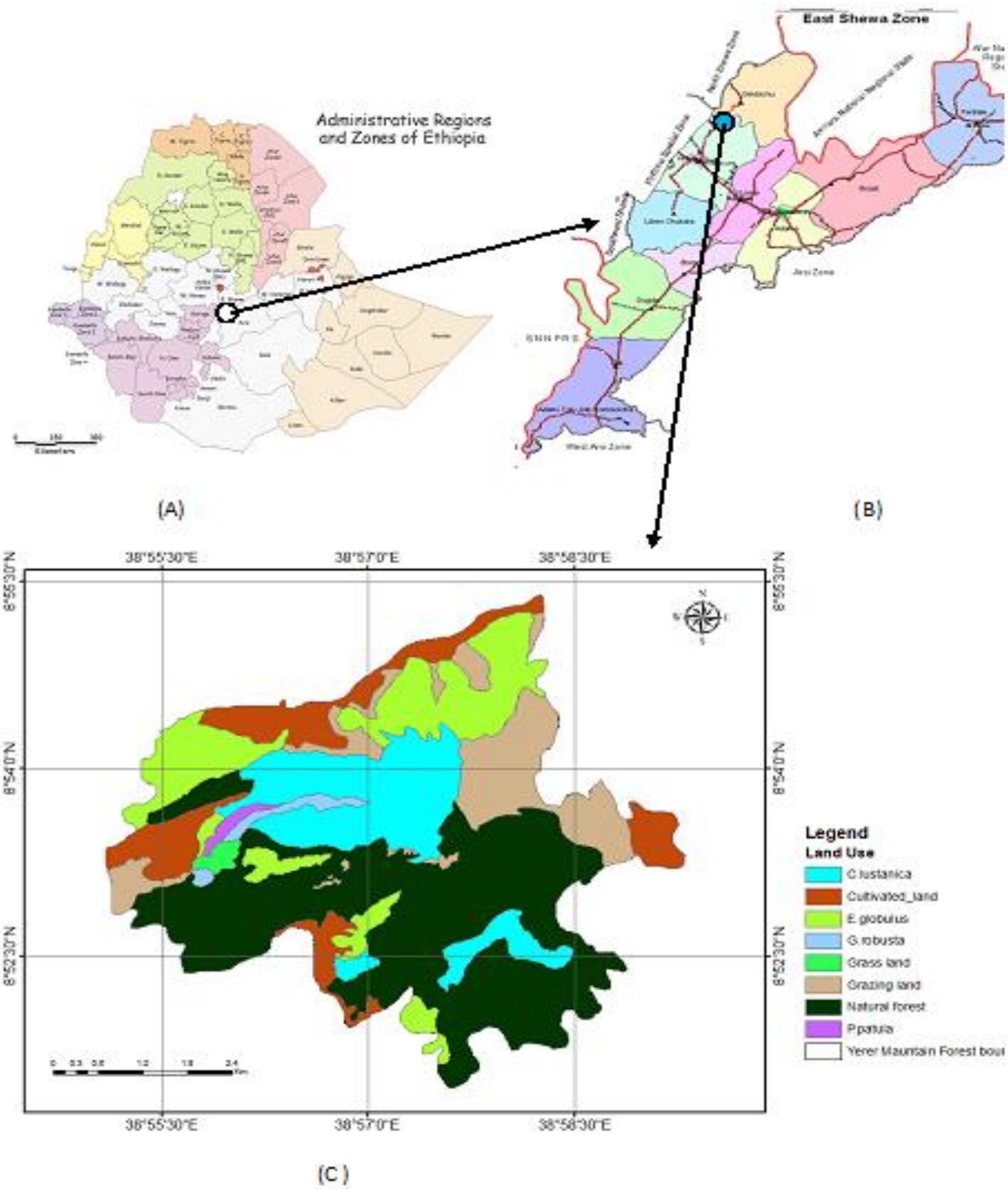

Figure 1: A) Map of Ethiopia, B) Map of East Shewa Zone in Oromia Regional State, C) Map of study area of Yerer forest and Surrounding (developed using ArcGIS 10.4.1 Software).

3.1.2. Climate

For the present study, the 31 years of meteorological data (1987 – 2018) of rainfall and temperature were collected from the National Meteorology Service Agency (NMSA). The meteorological data showed that the mean annual rainfall of the study area is 907.33 mm which characterized by a bimodal rainfall having long dry seasons (6-8 months), and the mean annual minimum and maximum temperatures were recorded 11.1 ^{0}C, and 29.5^{0}C, respectively (National Meteorology Service Agency, 2018) (Figure 2). The climate diagram was computed by using R for window version 3.5.1 statistical package (R Development Core Team, 2016). The area obtains the maximum rainfall during the rainy season between June to September and is followed between March and April Months.

Short rains occur at any month of the dry season irregularly, especially between October to May seasons. The average annual minimum, maximum and mean temperatures for 31 years data are 11.1 ^{0}C, 29.5^{0}C, and 20.3^{0}C respectively (Figure 2). The highest mean annual temperature of the study area was 29.5 ^{0}C recorded in May followed by 28.9 ^{0}C in March whereas the lowest mean annual temperature was 11.1 ^{0}C recorded in December followed by 11.6 ^{0}C in November.

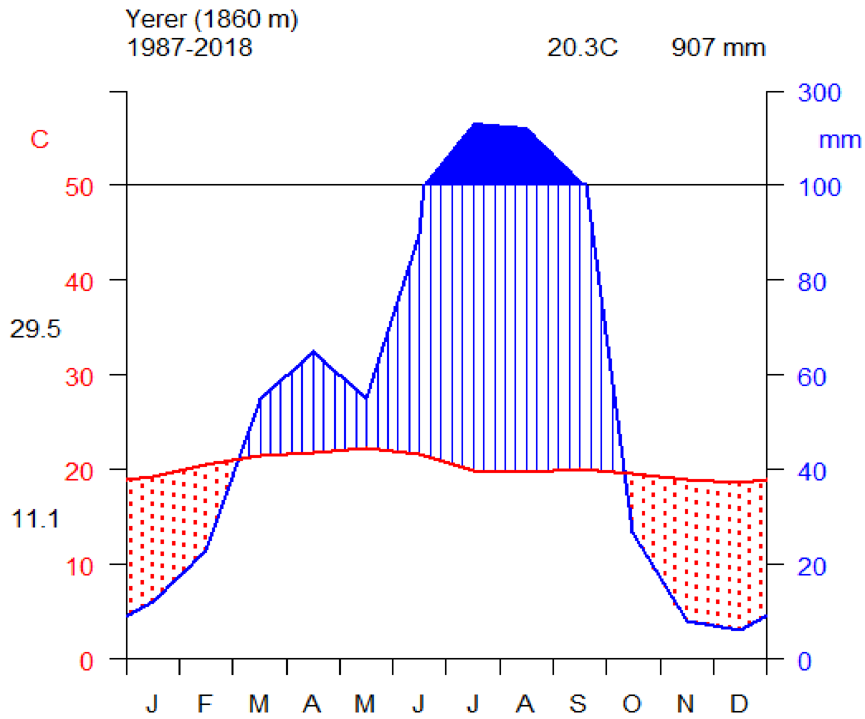

Figure 2: Climadiagram showing rainfall distribution and temperature variation from 1987-2018 at Yerer forest and surrounding areas. Data source: National Meteorological Services Agency (2018)

3.1.3. The natural vegetation of the study area

The vegetation resources (including forests, woodlands, and bushlands) of Ethiopia could be categorized into twelve (12) general groups as described by Friis et al., 2010. Among the described twelve vegetation types of a country's, Dry evergreen Montane forest is one of a very complex vegetation type occurring in the climate of hotter to moist conditions in the altitudinal range 1500 – 3200 m.a.s.l of Ethiopia. The dry evergreen montane forest area receives an annual rainfall of 700 mm to 1500 mm with an annual temperature between 14^{0}C and 25^{0}C (Zerihun Woldu 1999; Friis and Sebsebe Demissew, 2001; Friis et al., 2010). In line with this description, Yerer Mountain natural forest is one of the remnants and secondary natural forests, which is categorized under the Dry evergreen montane forest in the central highlands of Ethiopia.

Yerer Mountain natural forest is consists of a dry montane forest and established plantation forests, and covers an area of 3254 ha of this 1793 ha is plantation forest with exotic and native tree species planted in monoculture and mixed forms, and 1461 ha is covered by natural forest and others. Some tree, shrub and climber species dominate the mixed deciduous forest. Vegetation composition of the Yerer Mountain natural forest is characterized as Dry evergreen Montane forest, which dominated by some tree species of *Juniperus procera*, *Olea europaea* subsp. *cuspidata*, *Ficus sur, Rhus retinorrhoea*, *Olinia rochetiana*, *Rhus vulgaris,* and shrub species of *Carissa spiranum, Dodonaea angustifolia, Myrsine africana, Erica arborea, Hypericum revolutum, Maytenus arbutifolia, Osyris quadripartite, Euclea racemosa*, *Heteromorpha arborescens,* and *Pterolobium stellatum.*

There are nine peaks in Yerer Mountain forest called locally as “Yerer Mucha Sagali” meaning “Yerer with nine breasts” which all rise above 2764 meter altitudes. These nine peaks have their local names. Yerer forest was re-designated in 1999 as administrated by Addis Ababa and Bahir-Dari Fuelwood plant Development Agency” under the Ministry of Agriculture. But from 2009 onwards it is administrated by Oromia Forest and Wildlife Enterprise (OFWE). In the current administrative structure, Yerer forest is shared four districts as Akaki (five villages), Ada’a (two villages), Gimbichu (one village), and Barak (one village) in different areas. It is to be noted that approximately 45% of the area is found in Akaki district.

3.1.4. Farming system

The farmers of the central highland area are practice ‘‘mixed’’ farming systems (i.e. both crop and livestock production activities). Like other parts of the highlands of the country, the majority of the inhabitants overwhelmingly rely on subsistence agriculture as the main economic development source. The major crop types grown in the study area under rainfed include cereal crops such as wheat (*Triticum aestivum*), ‘teff’ (*Eragrostis tef*), barley (*Hordeum vulgare*), pulses such as field lentil (*Lens culinaris*) chickpea (*Cicer arietinum*), and pea (*Pisum sativum*). The average landholdings size in the study area is 1.5 ha. Commonly, the study area is characterized by an average slope of 0.75 to 5.4% which is suitable for agricultural development. Livestock rearing is the main component of farming activity. The majority of rural households possess oxen, cows, heifers, sheep, goats, donkeys, and poultry.

3.1.5. Land-use history in Yerer area

Land-use change

Land-use changes from time to time depending upon socio-economic change. Understanding land-use history is essential to comprehend the magnitude and trend of changes in vegetation, and soil properties (Bouma, 1997, Kettle, et.al. 2000, Turner et. al., 2013). The impact of land-use change on soil physical and chemical properties might vary for various kinds of soils, vegetation, and ecological variables. The major intensification land-use change in the central highlands of the country the area occurs by conversion of natural forest to cropping and grazing land. On the other hand, degraded lands have been converted to plantation forests by reforestation and afforestation program with fast-growing tree species for the socio-economic benefit and land rehabilitation in the area. In the study area, natural forests have been converted to other land-use systems to provide the basic needs of the local people for agriculture and wood products.

The rapid population growth in the Yerer area requires additional farmlands for food crop production leading to the conversion of forest lands and pastureland to the croplands. The forest and grazing land-use systems change started in 1991 with decreased significantly, while arable cropland has increased. Clearing of forests for agricultural production and grazing is widespread in the surrounding Yerer Mountain forest.

Land-use systems

In the Yerer Mountain forest and its surrounding areas, the major land-use systems are natural forest, plantation of different exotic tree species, grassland, grazing land, and cropland. In the present study context which is defined as: Natural forest is the forest land composed primarily of an indigenous tree, shrubs, lianas, climbers, and other herbaceous species may include both closed and open forests. Plantation of exotic tree species is forest stands established artificially by non-native tree or shrub species in reforestation and afforestation program for industrial and non-industrial usage. Grassland is an area where vegetation land dominated by the nearly continuous cover with poaceae family rather than large shrubs or tree species. Grazing land refers to a land covered with vegetation of grass that appropriate for livestock or herbivore grazing or feeding. Cropland refers to land covered with temporary crop production both in single or multiple cropping systems, followed by harvest and leaves a bare soil period (Bouma, 1997, Turner et. al., 2013, Verburg et. al., 2013).

3.1.6. Yerer Mountain forest history

Based on the primary and secondary information collected from community elders and Oromia Forest and Wildlife Enterprise (OFWE), Yerer Mountain natural forest had historically wider four periods of administration trends:

i) Emperor Haile Selassie I (1930-1974)

In Ethiopia, there was a limited attempt by the imperial government to promote forestry in the country and to protect state forests in the early 1960s. During the second half of the 1960s, the imperial government began to show also concern for environmental problems and undertook several initiatives to promote afforestation and soil and water conservation (Dessalegn Rahmato 2001). Historically in the past time, huge forest resources were managed in the form of crown property by emperors and kings fundamentally as sources of fuelwood and timber for the royal families. Such forests were protected and encroachment was forbidden (Dessalegn Rahmato 2001). The first elaborate and modern legislation on forest resources came during Emperor Haile Selassie in 1965 which gave recognition for three forms of forests (namely state forest, private forest, and protected forest) (Sisay Nune 2008). Yerer Mountain natural forest is one of the protected forests among the designated protected forests in Ethiopia. The forest resource management paradigm during Emperor Haile Selassie's administration period was for their economic value mainly as a source of domestic fuelwood and construction material. In addition to the natural forest protection with an attempt was made to reverse the shrinkage of natural forest area, new plantation carried out on farmland in the study area.

Before 1974 people had come from the northern part of the country and settled in the Yerer Mountain natural forest in scattered form. Following the human settlement in and surrounding natural forest, large tracts of the natural landscape have been slowly cleared phase by phase for agricultural activities, grazing land, and domestic consumption of wood products. As the human population increased from time to time in the area, Yerer Mountain's natural forest productivity decreased in quantity and quality by human influence results in deforestation and forest degradation. To compensate for the decrease of the natural forest quantity and quality, as well as to minimize the pressure of local people on it, plantation of exotic tree species (particularly, *Eucalyptus globulus*, and *Pinus patula*), were introduced to the Yerer area in 1957 by the government and planted as sources of fuelwood and construction materials, and buffer the remaining natural forests.

ii) The Derge Regime (1974-1991)

The emperor Haile-Selassie administration system was detached from the authority in 1974 by a committee of 120 military officers of the Derg. The Derg that replaced emperor Haile-Selassie rapidly, and accepted the popular socialist ideological orientation, and nationalized all rural and urban lands. In 1980, Derge announced a new law is known as forest and wildlife conservation and development proclamation No. 192/1980 by accusing the previous emperor Haile-Selassie government of its inappropriate and unintended exploitation of the country's forest resources and specified that the forest cover was deteriorated due to the self-centered interest of the aristocracy (Sisay, 2008). Afterward, the Derge regime developed a policy that communities' mobilized and forced labor campaigns to rehabilitate the degraded land areas with vegetation by reforestation, afforestation, and area closure programs. During the Derge regime (1974-1991), the rapid expansion of large scale and community plantations occurred which resulted in the establishment of large scale plantations mainly for supplying the huge demand for wood products in Ethiopia (Yitebitu Mogos et. al., 2010), particularly in central highlands including Yerer forest and its surrounding area.

Yerer Mountain forest was also designated as part of Ethiopia forest and wildlife conservation development in 1980 year. After the Yerer natural forest felled under the administration of Ethiopia forest and wildlife conservation development, the government policy forced the settled people to leave a forest area. The natural forest then was managed by permanent and temporary employers of local guards. Yerer Mountain Forest had managed with multiple objectives: environmental protection (soil, water, and climate), biodiversity conservation, and sustainable use of the forest resources for economic and social values. On the degraded and deforested parts have been established with even-aged monocultures and mixed plantation by exotic and native species in the areas. The major exotic tree plantation species were: *Eucalyptus globulus, Eucalyptus camadulensis, Cuppressus lusitanica,* and *Pinus patula.* In addition to the exotic tree species, the plantation forest is also carried out by plantation of native species which include: *Juniperus procera*, *Hagenia abyssinica*, and *Podocarpus falcatus*.

iii) During *EPRDF* (1991-2009)

After the fall of the Derg regime in 1991, there was widespread deforestation of forest areas that were designed and managed as state forests and protected forests. The main state forest and protected forests' were devastated in the Yerer area during the war and transition later the downfall of the military Derge in the 1991 year in Ethiopia. Due to the increase in the human population, the degradation of the Yerer Mountain forest mainly occurred due to illegal encroachment by farmers, uncontrolled timber logging, and unregulated collection of non-timber forest products. Yerer Mountain forest area was re-designated and demarcated with 3254 hectares in 1999 as the “Fuelwood plant development” forest area, which was administrated by “Addis Ababa and Bahir-Dari Fuelwood plant Development Agency” under the Ministry of Agriculture. The main objective of Yerer Mountain forest management and conservation was to provide fuelwood, and construction materials to urban and city people to satisfy the energy demand. During this period plantation was expand by reforestation and afforestation programs with fast-growing tree species. Besides, the natural forest resources were managed and protected from external intervention bodies by employers of local guards.

iv) Oromia Forest and Wildlife Enterprise (2009 - present)

The Oromia Forest and Wildlife Enterprise (OFWE) is an autonomous fully government-owned organization established with regulation number 122/2009, issued in July 2009 by the Oromia State Council under the Federal Democratic Republic of Ethiopia. Beginning from 2009 up to present (2021) Yerer forest is re-designated to administrate under the Oromia Forest and Wildlife Enterprise (OFWE). The Yerer forest management objectives by OFWE including to biodiversity, soil, and water conservation; ensure sustainable development and forest resources utilization; supply forest products to the domestic and national markets by enhancing forest industries, and subsequently contribute to regional and national socio-economic development.

Participatory forest management (PFM) was introduced in Oromia Forest and Wildlife Enterprise (OFWE) in 2010 as a new system of forest resources governance to mitigate the persistent problems of forest degradation and deforestation, and to improve better social and economic benefits to local communities. In the Yerer forest, Participatory forest management (PFM) is institutionalized as forest resources management responsibilities, use rights, and benefit-sharing following the legal framework agreement between Oromia Forest and Wildlife Enterprise (OFWE) and a community-based organization (CBO). The main procedure in the CBO establishment process was to assess the forest resources utilization arrangement to identify primary and secondary users who would be allowed to involve as a member of beneficiaries in the communities. Recently, plantation activities were carried out by different exotic and native tree species in, and surround the Yerer forest area. The major plantations of the exotic tree are *Eucalyptus globulus, Cuppressus lustanica, Eucalyptus camandulensis, Eucalyptus saligna, Pinus patula, and Grevillea robusta;* however, the native tree species include *Juniperus procera, Hagenia abyssinica, Podocarpus falcatus, Olea europaea* subsp. *cuspidata,* and *Cordia africana.*

3.1.7. Plantation forest stand characteristics

The present study was conducted in the plantation of four exotic tree species in Yerer adjacent to the natural forest to investigate their effect on the understory of native plant composition, diversity, and regeneration status. The mono plantation exotic tree species forests were comprised of a *Cupressus lusitanica, Eucalyptus globulus, Grevillea robusta,* and *Pinus patula* those considered in this study. The exotic tree species were selected because of their popularity among different exotic tree species plantation development in the region, their crown structure, and the predictable variation of native species composition and density under the canopy.

All of the plantation species were established between 1998-2002 years on agricultural land and degraded forest land that was previously natural forest. The plantations were nearby natural forest in the west, and northwest directions within the distance range of 320-1105m, however, the exotic tree plantation species were 25-926 m apart from each other. Commonly the exotic tree plantation species were established at a spacing of 2.5 m × 2.5 m. However, during the data collection, the density of each exotic tree plantation species was lower than the expected standard tree density per hectare; because of loss, some planted seedlings due to survival rate problem, illegal selective cutting, windfall problems, self-dead, self-thinning especially in the *C. lusitanica,* and *Pinus patula* plantation forests. Concerning to the important characteristics of exotic tree plantation species and adjacent natural forest sites, they have more or less close similar altitudinal range, land slope range, soil nature, and management practices.

3.2.Reconnaissance Survey

Reconnaissance survey of Yerer Mountain forest and surrounding areas were conducted in the second to fourth weeks of December 2016 to obtain an impression of the different land-use systems in the area, to collect information on the accessibility of the studies, to familiarize me with the study area, to get an insight of the forest, topography, and other environmental conditions. During the reconnaissance survey in the study area, eight different land-use systems were identified: five forest land-use systems (natural forest, *Eucalyptus globulus, Cuppressus lustanica, Grevillea robusta,* and *Pinus patula plantations*), and three other land-use systems (grassland, grazing land, and cropland). For vegetation and environmental variables data collection of site selection from eight land-use systems (LUS) were relatively similar in their: topography, altitude, aspect, slope, area free from erosion exposed, and free from a disturbance to avoid the environmental and external intervention factors on above and belowground vegetation composition, diversity, density, natural regeneration status, and soils. The soil sample data was collected from the field in January 2017 for the seed bank, and soil properties determination. The woody plant species and environmental variables field data collections in the whole natural forest were carried out from Mid-January to Mid-June 2017. Whereas, for the comparative study of vegetation composition, diversity, and density among five forest land-use systems (LUS), the field data were collected from Mid-September to November 2018.

3.3.Sampling Design

Following a reconnaissance survey, actual sampling of vegetation, environmental variables, and soils were done focusing on a common appropriate sampling design for every eight land-use systems (LUS). Hence, the systematic sampling design approach was employed to determine the aboveground native vegetation composition, diversity, density, and woody natural regeneration status with line transects laid in each five forest land-use systems (FLUS) by using main quadrat and sub-quadrat sample sizes following Kent and Coker (1992) and Muller-Dombois and Ellenberg (1974) procedure. Moreover, the systematic sampling design was applied for the determination of underground species (soil seed banks) composition and density, and soil Physico-chemical properties with line transect and quadrat sampling for every eight land-use systems (LUS) following Muller-Dombois and Ellenberg (1974). The reason for the preference of a systematic sampling design was to ensure sufficient representative samples of vegetation and soil data from each land-use system (LUS).

The observational research design was focused on four major sets of studies. These are 1) the native woody composition, diversity, structure, and natural regeneration status of the whole Yerer Mountain natural forest, 2) the vegetation composition, diversity, density, and woody natural regeneration status among five forest land-use systems, 3) evaluate the changes in soil seed banks' composition and density under differing land-use systems, and 4) evaluate the selected soil Physico-chemical properties *dynamics under different land-use systems* in the central highlands of Ethiopia. General, the study has consisted of three main components, such as above-ground vegetation, underground vegetation in the soil seed bank, and soil Physico-chemical properties study. In this study, the eight land-use systems (LUS) were considered as treatments because each different land-use system (LUS) and its management practice has a different effect on the local environmental conditions, and the quadrats in each land-use system (LUS) were considered as a replication. Among eight land-use systems (LUS), a natural forest land-use system was used as a control quadrat to serve as a reference point before land-use systems changed to others.

With a systematic sampling technique, the aboveground vegetation assessment within the forest stand was conducted using a line transects survey during the peak of vegetation cover based on the nature of plant growth habits. For woody composition, structural, and regeneration status data collection to the whole natural forest, a total of 122 square quadrats with 400 m^2 areas each were laid at every 100 m distance interval between the consecutive quadrats along 22 transect lines. The transect lines were laid parallel to each other along the altitudinal gradient with 100m spacing between the two adjacent transect lines following the procedure of Esmailzadeh et al**.** (2011).

However, for comparative analysis of above and belowground vegetation composition, diversity, density, and natural regeneration status, and soil properties study in every eight land-use systems (LUS) was also conducted by using the transect lines technique. Accordingly, from 32 transect lines, a total of 96 square quadrats with 20 m x 20 m size each were located at 50 m intervals between the consecutive quadrats along a transect line and 50 m apart between transect lines. Twelve (12) quadrats along 4 transect lines were laid down in every eight land-use systems (LUS) separately to collect the necessary data. The aboveground woody composition, regeneration status, density, and herbaceous data were collected only in plantation exotic tree species and adjacent natural forest, but the soil samples for seed banks and laboratory analysis were collected in all eight land-use systems.

3.4. Sampling procedure and data collection methods

3.4.1. Vegetation sampling and data collection

For vegetation data collection the main square-shaped size of the quadrat of 20 m x 20 m (400 m^2) was used for trees, shrubs, and climbers. In each of the main quadrat, five subquadrats (2 m × 2 m) were established to investigate the natural regeneration status potential of seedlings and saplings of woody species, and five subquadrats of 1 m × 1 m area for herbaceous data collection by arranging four (4) subquadrats at each corner and one (1) subquadrat at the center for each forest land-use systems (LUS) following the procedure described by Muller-Dombois and Ellenberg (1974). The first starting sample quadrat of all line transects in each forest land-use system (LUS) was selected randomly at the peak of altitude and lay down to the bottom. The transect lines were laid separately for the natural forest, and each exotic tree plantation based on their topographical conditions. All sample quadrats on transect lines at starting and ending points were located at least 15 m from each forest stand edge to avoid edge effect.

For the whole Yerer Mountain natural forest floristic study, the data of woody species (trees, shrubs, climbers, seedlings, saplings) composition, and structures (DBH, height, stems density) were collected in each quadrat. However, for vegetation composition, diversity, and density comparative analysis among plantation exotic tree species, and adjacent partial natural forest, the data of vegetation (trees, shrubs, climbers, seedlings, saplings, and herbs) composition, and structures (DBH, height, stems density) were collected in each quadrat. In each quadrat, a complete list of vegetation present were identified the species name, counted the stem density, measured diameter at breast height (DBH), height (H), estimated the canopy cover of individual species, and measured litters depth. The lichens, bryophytes, and vascular epiphytes within each quadrat were also noted on the data collection sheet. Additional, vegetation species that occurred outside of the quadrats within 12m distance surrounding it, species not recorded in the previous sample quadrats were also recorded and identified to produce a comprehensive list of the plant species composition of the study area.

In each main quadrat, woody species those DBH > 2.5 cm, and height > 3m were considered as a tree, shrubs, and woody climber, whereas species that DBH less than 2.5 cm and height less than 3 m were considered as seedling and sapling. In this study concept the following woody species (tree, shrub, woody climber, seedlings, and saplings), and herbaceous species are defined as: the woody plant is a plant that has hard stems (woody) as its structural tissue, tree refer to woody plants having a dominant single stem with DBH > 2.5cm, and height more than 5 m tall, the shrub is woody plants having the number of stems at or near the base of the plant close to the ground with DBH > 2.5cm, and height between 3 - 5 m tall, the climber is woody plants which use trees and other means to climb over the canopy, the sapling is a young woody plant with DBH $\leq$ 2.5cm and height between 1 - 3 m tall, and the seedling are a younger woody species with diameter $\leq$ 2.5cm, and height $\leq$ 1 m tall were recorded and accounted in each quadrat (Feyera Senbeta and Demel Teketay, 2001, Gillison, 2006). While herbaceous are vascular plants that have no persistent woody stems above ground. This means herbaceous is plants don't have a stem that will remain above the ground when their leaves die.

For woody species, structural analysis, individual species diameter at breast height (DBH), and height (H) were measured in each quadrat. The diameter at breast height (DBH), and height were measured by using a measuring tape (meter tape), and hypsometer, respectively in the main sample quadrats. The woody species of seedlings and saplings' diameter and height were measured simply by using a measuring tape. The diameter at breast height (DBH) of tree, shrub, sapling, and a woody climber was measured at breast height (at1.3m height) from the ground. In cases where the tree or shrubs were branched at breast height (1.3m) or below breast height, the circumference was measured separately for each branch. The diameters of seedlings were measured at a height of 20 cm above the ground. The percent cover-abundance value of individual vegetation species was estimated visually with related to quadrat proportion and record as raw data on the data collection sheet. The litters' depth was measured with a ruler at the center of five replicate of subquadrats and then took the average per the main quadrat.

3.4.2. Soil sampling procedure, sample preparation, and data collection methods for the Soil seed bank

3.4.2.1.Soil sampling and sample preparation

The soil samples were collected in five replicates of quadrats with a 1m x 1m area within each of the main sample quadrat by placing the four (4) subquadrats at each corner and one (1) subquadrat at the center of the main quadrat. The soil samples were collected close to the center of each sub quadrat by carefully digging with a sharp knife by measuring 10 cm x 10 cm surface area. The soil samples were taken in three depth layers, each layer is 5 cm thick (0-5 cm, 5-10 cm, and 10-15 cm), total 15 cm depth. Besides these, the litter layer was also included with the soil samples as the 4th layer because it contained a high number of seeds (Esmailzadeh et al., 2011).

The soil sample collection was completed within two weeks to avoid differences among land-use systems, and any temporal bias in seed availability and composition following the method used by Toledo and Ramos (2011). The collected five soil samples from each main quadrat were combined in their similar depth layer categories and mixed well thoroughly to form a one representative composite soil sample per the main quadrat to reduce variability within the quadrat by avoiding contamination between depth layers. The composited soil sample for each soil layer was again divided into five equal parts and among them; one sample was randomly selected for seedlings emergence trials to further study. The collected soil samples from each land-use system at each depth layer were packed into plastic bags and transport to the study area closer to Oromia Forests and Wildlife Enterprise permanent nursery site to further investigation.

3.4.2.2.Seed Bank analysis

For the assessment of the species composition and density of the seed banks, the study used the seedlings emergence method because of its ability to determine the viable fraction of readily germinable seeds (Espeland et al. 2010). The number of viable seeds in each soil sample was estimated through the germination trial method. This method allows providing a good perspective for managers in using in-situ seed banks as opposed to sowing seed as a source of materials for vegetation restoration efforts.

The seedlings emergence trial was commenced at the beginning of February 2017. The seedlings emergence trial was carried out in the greenhouse in the Oromia Forests and Wildlife Enterprise permanent nursery site adjacent to the study area. The composited soil samples were spread on 20 cm diameter and 8 cm depth circular plastic pots (seedlings emergence trial material) for the germination of the seed banks. Each composite soil sample was placed in a separate tray container concerning soil depth layers' in a non-temperature controlled greenhouse. The trays were watered every day to retain the soil samples moistly. The trial was completed when the emergence of seedlings stopped. The tray was kept and observed until no more seedlings emerged. Seedling recruitment was terminated after six (6) months (from beginning February to end July 2017).

3.4.2.3.Emerged Seedlings in soil seed bank data collection

The emerged seedlings were identified, counted, recorded, and removed/discarded on a two-weekly basis. To avoid the differences in light exposure of seedlings, the place of the trays was altered every two weeks following the technique used by Esmailzadeh et al. (2011).

Plant Identification

Complete lists of species (trees; shrub; climber, seedlings, saplings, and herbaceous) were made for each established quadrat. Seedlings in a seed bank that was difficult to distinguish were transplanted into other germination pots for continued growth until ready to identifiable. Most of the vegetation species were identified by using botanical keys and local knowledge. However, some species that could difficult to identify in the field, the specimens were collected from the field following standard herbarium technique. Specimens of vegetation were collected from the study area, allotted collection numbers, pressed, and dried properly for identification at the National Herbarium of Ethiopia, Addis Ababa University. The collected specimens from the field were identified by comparing with already identified herbarium specimens and using taxonomic keys in the Flora of Ethiopia and Eritrea volumes 1 – 8 (Hedberg and Edwards, 1995; Edwards et al., 1995; 1997; 2000; Hedberg et al., 2003; Hedberg et al., 2004). The voucher specimens were eventually kept at the National Herbarium.

3.4.3. Soil sampling, sample preparation, and laboratory analysis methods

3.4.3.1. Soil sampling and data collection

The soil data were collected from eight land-use systems with five replication in each. For laboratory analysis, the soil samples were collected from five sub-quadrats with a 1m x 1m area by placing four (4) subquadrats at each corner and one (1) subquadrat at the center of the main quadrat of 20m x 20m area in each land-use system. The soil samples were collected from two depth layers of topsoil (0 – 20 cm) layer and subsoil (20 – 40 cm) layer. Soil samples were taken by using a soil auger, at the center of each subquadrat of the 1m x 1m area. The soil samples were collected by using a soil auger in adjusting with the required soil depth layers and by carefully cleaning the equipment at each soil sampling depths, to prevent soil contamination between depth layers, and quadrats. The collected soil samples from two depths separately in five replicated subquadrats within the main quadrat were mixed thoroughly to form a one representative composite soil sample per the main quadrat with respective to their similar soil depth layers. Finally, 1 kg of the representative soil sample from the composite samples was taken for soil laboratory analysis. For soil moisture content determination, the soil samples were taken by using moisture cans, whereas for bulk density the soil samples were taken by using core sampler (cylindrical metal sampler) with the standard dimension size of 0.5 cm diameter and 0.5 cm length form from undisturbed soil.

3.4.3.2. Soil sample preparation

The collected representative soil samples were labeled with appropriate information and transport immediately to the soil laboratory of Hawassa University, Wondo Genet College of Forestry and Natural Resources, for sample preparation and laboratory analysis. Before the analysis, the composite soil samples were air-dried, ground, and sieved to pass through a 2mm size sieve in preparation for laboratory analysis of most soil chemical properties. Again the soil samples were further sieved to pass via a 0.5 mm size sieve for the analysis of total nitrogen in the laboratory (Ranst et al., 1999). Again the soil samples were further sieved to pass via a 0.5 mm size sieve for the analysis of total nitrogen within the laboratory (Ranst et al., 1999).

3.4.3.3. Laboratory analysis methods

Soil Analysis and Laboratory Procedure

The laboratory soil analysis consisted of two major elements which are: 1) soil physical properties (such as soil texture, moisture content, bulk density, particle density, and porosity), and 2) soil chemical properties (organic carbon, total nitrogen, C: N ratio, available phosphorous, soil pH, soil electrical conductivity, Cation exchange capacity, exchangeable bases, and Percent base saturation).

Analysis of soil physical properties

The soil texture classes (% sand, % silt, and % clay) were analyzed by using the Hydrometer method. This method is preferable due to its inexpensiveness, ease, and rapidity to use in a soil laboratory. In the hydrometer method, 40 g of sodium hexametaphosphate and 10 g of sodium carbonate were dissolved to make a volume of 1 liter by adding distilled water to be used as a dispersing agent. 51 grams of air-dried soil sample was added to 50 ml of a dispersing agent and 100 ml of distilling water. The contents were mixed with a glass rod and allow to stand for 30 minutes. Hydrometer and temperature readings were taken after 40 seconds and 3 hours.

Soil moisture content was determined by weighing fresh soil samples in a laboratory immediately from the field fresh sample and again reweighted soil sample after oven-dried at 105 C^0 for 24 hours in the laboratory (Brady and Weil 2002). The moisture content of each sample was computed by subtracting the dried weight of the soil sample from the corresponding knew fresh sample weight. For soil bulk density determination of undisturbed soil samples of known dimensions (length and diameter) volume were taken with a sharp-edged steel cylinder forced manually in the center of the required soil depth. For bulk density determination, the samples were dried in an oven at 105°C (221°F) for a minimum of 48 hours. Subsequently, bulk density was calculated from the measurement of bulk volume used in the core length and the diameter of the cutting edge of the core sampler (Black et. al., 1965).

Soil particle density (g / cm^3) is a mass of soil solids (oven-dry) per unit volume of soil solids. It is easy to measure the mass of a small sample of soil solids but not so easy to accurately measure the volume of soil solids that make up this mass. Therefore, the volume of a known mass of soil solids is determined by indirectly measuring the volume of water displaced by the soil solids in the graduated cylinder. Hence, to determine particle density, 5 gm weight of dry soil sample was taken into a 10 ml graduated measuring cylinder. In another graduated cylinder, 10 ml of distilled water was taken and poured/ transferred into the first graduated cylinder until the volume reaches to 10 ml mark. Finally, particle density was calculated by dividing the weight of the soil solids sample to volume of the soil solids sample (volume of water left in the second cylinder) (Huque and Alam, 2005). Soil particle density = oven-dry soil weight/volume of soil solids. Soil porosity can be calculated from the known values of bulk density and particle densities. Soil porosity was determined by subtracting the ratio of bulk density to particle density from one (1) as Porosity = 1 - (bulk density/particle density) (Huque and Alam, 2005).

Analysis of soil chemical properties

The soil organic carbon (OC) was determined following the Walkley Black wet digestion method as described by Ranst et al. (1999). The total nitrogen level in the soil was determined following the modified Kjeldahl's digestion, distillation, and titration method as described by Ranst et al. (1999). The C: N ratio was determined by dividing the value of organic carbon to the total nitrogen corresponding to each soil sampling depths. The soil available phosphorous content was determined by following the Olsen procedure (Olsen et. al. 1954). The soil pH was measured by using a digital pH meter in a 1:2.5 soil to water supernatant suspension (Jackson, 1973, Van Reeuwijk 1992). The Electric conductivity of the soil samples was determined by using electrical conductivity meter from a 1:1 soil-distill water mixture (20g of soil in 20ml distilled water). The cation exchange capacity (CEC) of soils was determined by saturation with 1N sodium acetate followed by replacement of sodium on the exchange complex with 1N ammonium acetate at pH 7 following the procedure described by Chapman (1965). Sodium level was determined by atomic absorption spectrometry (AAS) and CEC expressed as meq/100g of soils. The exchangeable bases were extracted with 1M ammonium acetate at PH 7.0. Exchangeable Ca and Mg were measured from the extract with atomic absorption spectrophotometer; whereas exchangeable Na and K were determined from the same extraction with a flame photometer (Black et, al., 1965). Percent base saturation (PBS) was determined by dividing total exchangeable bases (Ca, Mg, K, and Na) to the CEC of the soil and multiplied by 100.

3.4.4. Environmental gradient sampling procedure and data collection

The different environmental topographic factors are affecting the patterns of vegetation species distribution (McEwan, et al. 2011). The environmental gradients of altitude, slope, and aspect at each main quadrat were measured. The slope was measured by using clinometers. Altitude and aspect were measures by using GPS (Global positioning system), and Compass to locate the study area, respectively. The slope was measured by using clinometers. The latitude and longitude were taken from the center of each main quadrat and measured by using GPS.

3.5. Data Analysis

3.5.1. Vegetation Data Analysis

3.5.1.1.Vegetation community analysis

The collected woody species and herbaceous data in abundance percent (%) cover were transformed to the appropriate modified 1-9 scale of Braun-Blanquet (van der Maarel, 1979) with R Software library (labdsv) by following the procedure of Roberts (2010). The presence-absence and cover-abundance data, defined here as the proportion of area in a quadrat covered by every species recorded and gathered cover-abundance values in percent from each quadrat (vander Maarel, 1979). Finally, the estimated percent cover-abundance values of individual species was transformed and converted to the Braun-Blanquet 1-9 scale as modified by van der Maarel (1979) as follows: 1: Rare, generally one individual; 2: Occasional or few individuals, with less than 5% cover of the total; 3: Abundant, with less than 5% cover of the total; 4: Very abundant, by less than 5% cover of the total; 5: 5-12% cover of the total area; 6: 12-25% cover of the total area; 7: 25-50%

cover of the total area; 8: 50-75% cover of the total area; and 9: 75-100% cover of the total area.

The vegetation data were classified into homogeneous subgroups employing hierarchical cluster analysis, by using the most common multivariate technique to analyze community ecological data. The hierarchical cluster analysis of plant communities in the forest helps to group a set of observations (vegetation quadrat samples), based on their attributes in species similarities (Kent and Coker 1992, McCune and Grace 2002). All individuals of species recorded in all quadrats were used in the vegetation data analysis. The study area vegetation was grouped into relative homogeneous plant communities /clusters in the statistical analysis of Hierarchical Agglomerative Cluster analysis to obtained dendrogram of communities along with respective quadrats.

Accordingly, an agglomerative hierarchical cluster analysis was performed using PC-ORD for windows version 5.0 (McCune and Mefford, 1999) with R software version 3.5.2 to classify the vegetation into plant community kinds based on the data of species abundance in the individual quadrat. The decision on the number of woody plant communities in the natural forest was based on the determining optimal number of clusters analysis of vegetation data with R software program and then counts the number of elbows from the analyzed output of the quadrated figure. The clustering of community types was identified from the output of the cluster analyzed further distinguished in a synoptic table value. The product of average cover-abundance values of a species and its frequency in the community type were taken as the synoptic values of the species in the community type (van der Maarel et al., 1987). Eventually, each community type was named by two indicator species or dominated species characteristics based on the higher relative magnitude of their indicator values. Indicator species are the species characteristic of each community group found mostly in a single group of typology, and present in the majority of sites belonging to that group.

3.5.1.2.Vegetation Diversity index analysis

For each plant community type, species diversity; richness; and evenness in the aboveground vegetation were calculated using Ecological Methodology software. Species richness, diversity, and evenness were measured using Shannon and Wiener's (1949) diversity index. Shannon - Wiener diversity index is the most common method used to measure species diversity without affected by vegetation sample size, and it describes both species richness and evenness (Krebs, 1989, Kent and Coker, 1992; Krebs, 1999). Shannon -Wiener Diversity Index was used to analyze the species diversity, species richness and evenness of the vegetation as follows:-

Species diversity index (H') - was calculated according to Shannon-Wiener (1949) by using the following formula:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i \qquad \text{……………………………………………………(1)}$$

Where, H' = Shannon diversity index; S = the number of species; Pi = the proportion of individuals or the abundance of the i^{th} species expressed as a proportion of total cover; and ln = log base $_n$ (natural logarithm).

Species richness (R) is measured to know how many numbers of different kinds of species present in each plant community type or forest land-use system (Krebs 1999). The computational formula is as follows:

R **=** **(**S'-1**)/**LnN ……………………………………………………………….. (2)

Where R is species richness; S' is the number of species of that taxonomic group observed and N is the total number of individuals species observed

Species evenness index (J') is a measure of how similar species are in their abundances. The Evenness of species was calculated by dividing H by Hmax as:

J*'*= *H′*/*H′*max or *J'*=*H'*/ln*S* ………………………………………………….…… (3)

Where **J**' *is Species e*venness index, ***H'*** is Shannon-Wiener Diversity Index; ***H′max*** is equal to the natural logarithm of richness in S**,** and ***ln*** = log base $_n$ (natural logarithm); **S** is a total number of species in the study area, Hmax = lnS. Hence, the evenness index tells as an assemblage/accumulation of most species are equally abundant or one that has high evenness.

3.5.1.3. Vegetation structure Analysis

The structural analysis of the vegetation was described by using the following components: DBH and height, basal area, stem density, frequency, Important Value Index (IVI). Woody species density and basal area values were analyzed on a hectare basis.

DBH values of mature woody and sapling species were obtained by indirectly calculated from stems circumference (C) of individual woody measuring at 1.3m from the ground by meter tape, and DBH values of seedlings were calculated from stems circumference (C) measured with tape at 20cm from the ground. Later the diameter was calculated from circumference (C), by using the formula of $\mathbf{d = C/\pi}$ where: d = diameter at breast height (DBH), C = stems circumference, π = 3.14. The derivation of diameter from the circumference measurement technique is simple, fast, economical low-cost, and relatively precise.

Basal area (BA) is the area outline of a woody near the ground surface. The basal area of the woody species is expressed in m^2/ ha (Mueller-Dombois and Ellenberg, 1974). The basal area of the woody species was calculated by using diameter at breast height as used by (Kent and Cooker, 1992). Basal area (BA) = $\pi d^2 / 4$ where: d = diameter at breast height (DBH), π = 3.14. Basal area was computed for all woody species of trees, shrub, and woody climber's species with a DBH > 2.5 cm. Total basal area (m^2) is the sum of the stem cross-sectional area at diameter breast height on a per-hectare basis.

Density: - refer to the counting numbers of individuals of plant species inside the sampling quadrat (Kent and Coker, 1992). Density is computed by converting the counted numbers of individual species from the total quadrats into a hectare basis.

Importance Value Index (IVI) is very important to compare the ecological significance of the individual woody species. The high value of IVI indicates that the species sociological structure in the community is high. Important Value Index (IVI) is considered by ecologists as the most realistic aspect of vegetation study because it combines data of the three parameters such as Relative Density (RD), Relative Dominance (RDO), and Relative Frequency. Hence, IVI was calculated for woody species of the study area following Mueller-Dombosis and Ellenberg (1974) formula: IVI = Relative Density (RD) + Relative Dominance (RDO) + Relative Frequency (RF)

$$RD = \frac{\text{number of all individuals of a species}}{\text{total number of all individuals of the sample}} \times 100$$

$$RDO = \frac{\text{basal area of a species}}{\text{total basal area of the sample}} \times 100$$

$$RF = \frac{\text{the number of quadrats where a species occur}}{\text{total occurrence for all species of the sample}} \times 100$$

Frequency is the number of individual plant species observed or recorded in the total sample quadrats taken in the study area. The frequency distribution of woody species was calculated as follow:

$$\textbf{\% frequency of species} = \frac{\text{No. of quadrats in which species A occurs}}{\text{total No. of quadrats examined}} \times 100$$

3.5.1.4. Regeneration Status

The natural regeneration status of woody species in the forest was determined by comparing the density of seedling with sapling and sapling with matured woody data in the same area (Shankar, 2001; Dhaulkhandi et al., 2008; Tiwari et al., 2010) in the following categories: 1) "good" regeneration, if present in seedling > sapling > mature woody; 2) "fair" fair" regeneration, if present in a number of the seedlings is greater than a number of saplings, but a number of the saplings is less than a number of mature woody; 3) "poor" regeneration, if a plant species survive only at the sapling stage, but not found at seedlings (even if a number of saplings may be less than, more than, or equal to mature); 4) "none" regeneration if a species is absent both in sapling and seedling stages, but present as mature, and 5) "new" regeneration if a species is not found at maturity stage, but found only at sapling and/or seedling stages.

3.5.2. Comparative analysis of native species composition and density under different forest land-use systems

The statistical analysis focused on the difference of native species richness, and density among different forest land-use systems (LUS). One-way analysis of variance (ANOVA) was used to detect variations in species composition (richness) and density. The total numbers of native species composition and density per each quadrat data were used as input for comparative analysis of native species richness and density among forest land-use systems (FLUS) in the study area. One-way analysis of variance (ANOVA) was used to compare mean species richness and mean density of native species among forest land-use systems (LUS). The least significant difference (LSD) test was used for comparisons of the mean values of variables.

3.5.3. Comparative analysis of seed bank composition and density under different land-use systems (LUS)

The species composition and density of seeds in the soil were determined by organizing the data obtained from germinated responses of seedlings. The density of seeds/m^2 was derived from the total number of emerged seedlings in soil samples per germination tray was summed/ added for each sample quadrat of 10cm x 10cm area and convert to m^2 area. Total numbers of seedlings were expressed as seed density per m^2. On the other hand, the underground (soil seeds) species composition and density distribution across the vertical soil depth in each land-use system were analyzed based on the total numbers of germinated seedlings in similar soil layers. The means differences between the total number of species composition and seed density were tested by one-way ANOVA among the eight land-use systems by using SAS software (Version 9.4). The main effects of land-use systems on seed bank species composition and density were tested at a significant level ($P<0.05$). Duncan's multiple range tests were used to compare differences between means of species composition and density between land-use systems. L.S.D. test was used for comparisons among means.

3.5.4. Floristic Composition similarity indices

Floristic composition similarity analysis among communities within a natural forest

Sorensen's similarity index was used to determine the pattern of species turnover among successive communities of Yerer natural forest. The species Similarity analysis among forest communities is described by using the following formula (Kent and Coker, 1992):

Ss = 2a/ (2a+b+c),

Where,

Ss = Sorensen's similarity coefficient

a = Number of species common to both samples;

b = Number of species in sample 1;

c = Number of species in sample 2

Floristic composition similarity analysis among different land-use systems (LUS)

The similarity index of native species among different land-use systems (LUS) was calculated and compared by using Jaccard's Similarity Coefficient (Krebs 1989). Therefore, Jaccard's similarity index/ Coefficient was used to find species similarity among land-use systems by using the following formula:

$$JI = \frac{a}{a + b + c}$$

JI: Jaccard's similarity index, a: number of common species in LUS, b: number of species that exist only in first LUS, c: number of species that exist only in second LUS.

3.5.5. Comparative analysis of soil Physico-chemical properties under different land-use systems (LUS)

All quantitative field soil data were analyzed by the General linear model (GLM) analysis of variance (ANOVA). Statistical difference in soil Physico-chemical properties among land-use systems was analyzed by a two-way analysis of variance (ANOVA) at $p<0.05$ significant levels. The least significant difference (LSD) test and Pearson’s correlation coefficient analysis were employed to assess the mean difference and the association between soil variables, respectively. Means comparisons were used to soil properties change interpretation and explanation among eight land-use systems in the study area.

4. RESULT

4.1. Floristic composition, diversity, and structure of woody species

4.1.1. Floristic Composition

A total of 93 woody species (trees, shrubs, and woody climbers) were identified from the Yerer natural forest, which belongs to 46 families and 73 genera. Out of the total woody species, 86 were identified at the species level, 7 specimens at the subspecies level (See Appendix 1). Of these plant species 13 were endemic, 79 were indigenous, and 1 introduced woody species. Three native woody species and one introduced species were observed outside the sampling quadrats at a distance ranging from 7 to 12 meters. These woody species were *Otostegia tomentosa* subsp. *ambigiens*, *Solanecio gigas*, *Paullinia pinnata*, and *Cajanus cajan.* Fabaceae family was the most dominant contributing fourteen species (15.05 %) to the total species followed by Lamiaceae, and Asteraceae with eight (8.60 %), and six species (6.45 %), respectively. Moreover, among the identified woody species in a natural forest, eight families each consists of three species, six families each consists of two species, and twenty-nine families each consists of one species (Figure 3).

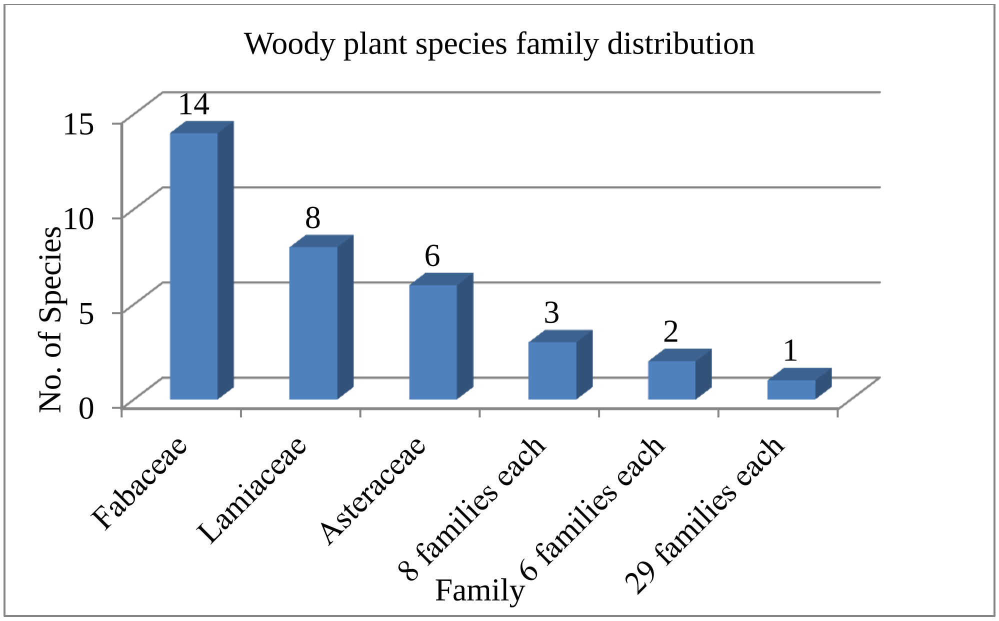

Figure 3: Woody plant species families' distribution in Yerer natural forest

4.1.2. Woody species Growth Form Proportion

Of the total 93 woody species, 25 species (26.88%) were trees, 55 species (59.14%) were shrubs, and 13 species (13.98%) were climber (Figure 4).

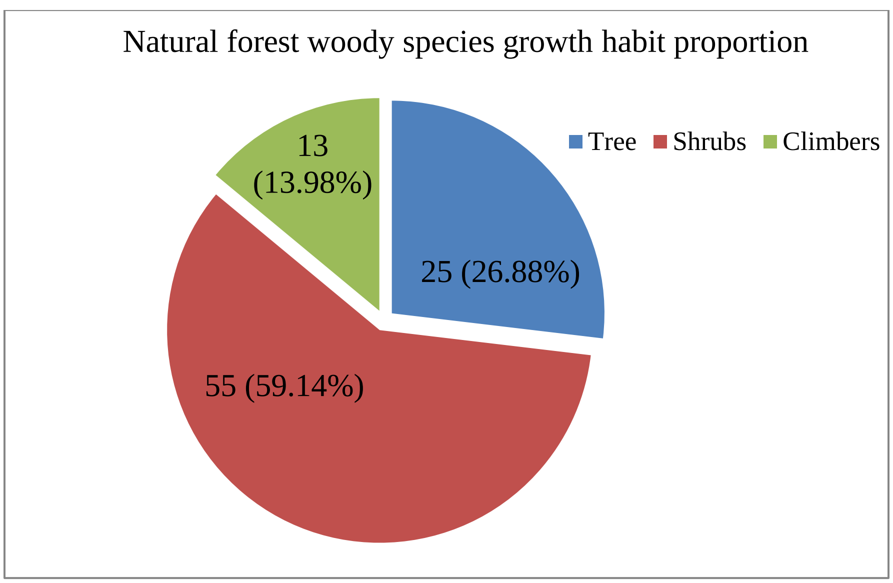

Figure 4: Distribution of woody species in their growth habit in the natural forest

4.1.3. The species accumulation curve

The species accumulation curve is concerned with the accumulation rates of new species over the sampled area and depends on species identity. Accordingly, the result of the species accumulation curve plotted for the species recorded in Yerer natural forest revealed that sufficient numbers of quadrats were laid to confirm the presence of rich species composition (93 species). The number of species composition increases vertically from area sample quadrats of 1 to 37with increasing the number of quadrats (Figure5).

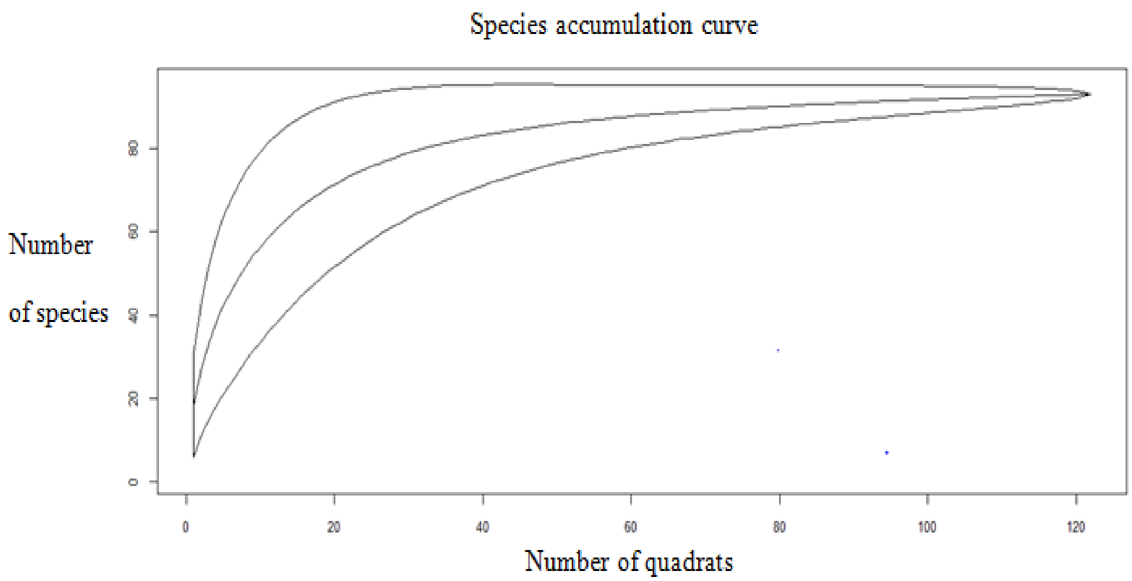

Figure 5: Woody species accumulation curve of Yerer natural forest

One of the primary goals of field vegetation ecology studies is to estimate how many species of a given taxon occur in an area. The majority of 84 (90%) woody species were recorded between quadrat 1 and quadrat 71 in the study site. The total number of species richness becomes continuous after 117 quadrats with increasing the number of sample quadrats, which leading to the low probability of encountering more species with increasing sample areas.

4.1.4. Woody plant Communities Classification

The hierarchical classification of the plant species into different communities has been done by dendrogram hierarchical classification using a similarity ratio. The vegetation classification was employed by using the individual plant species cover-abundance value estimation with reference to the sample quadrat size. The decision on the number of plant communities in the natural forest was based on the determining optimal number of clusters analysis of vegetation data with R software program and then counts the number of the elbow from the analyzed output of plotted figure.

Cluster dendrogram

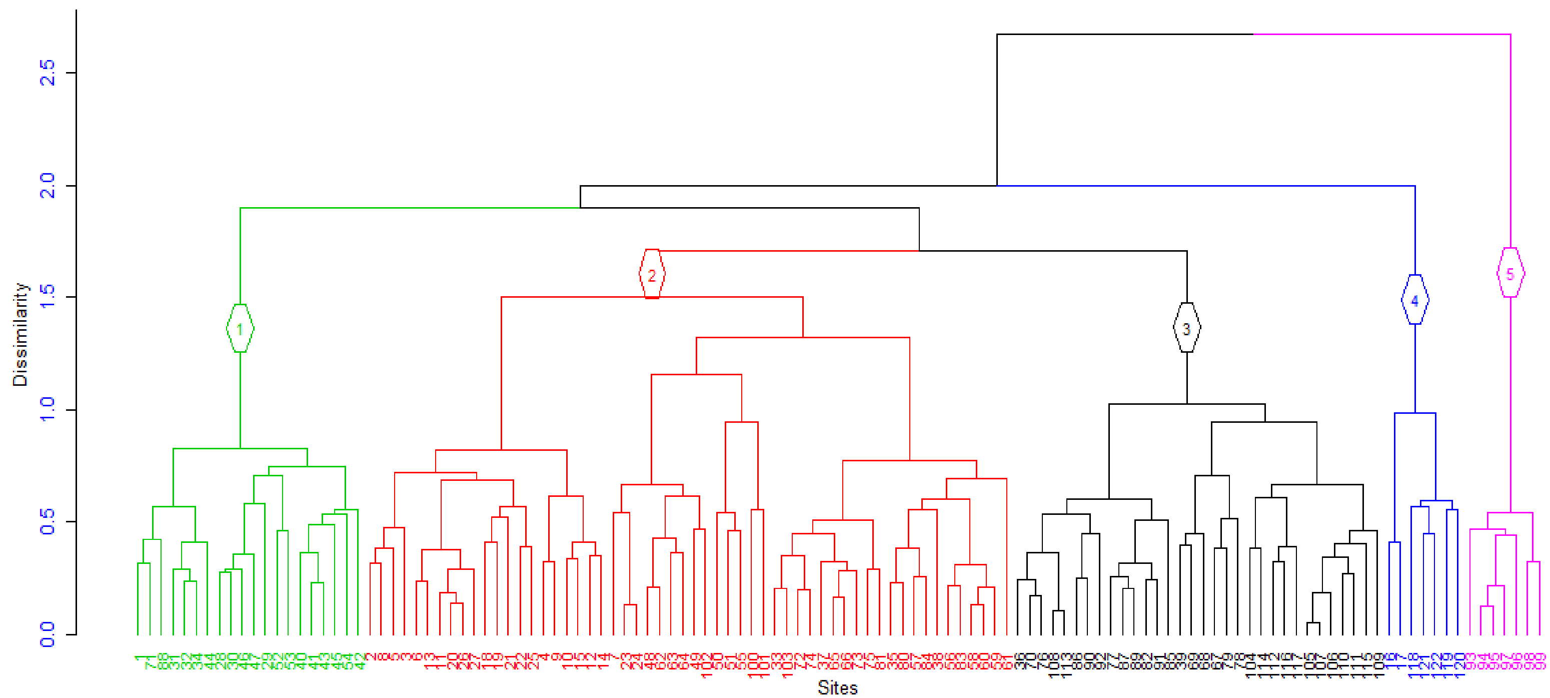

Figure 6: Dendrogram of the woody plant hierarchical cluster analysis showing sample quadrats in the community types in the natural forest

Five plant community types were identified from the cluster analysis (Figure 6**)**. The name for each community type was given after two dominant woody species (trees and /or shrubs) occurring in each community (group) using the relative magnitude of the highest mean cover-abundance within the cluster as a criterion for naming them. A list of the community types along with their synoptic-cover abundance values of all 64 species having a synoptic value greater than or equal to 1.0 at least in one community type was given in Appendix 2. Each plant community type was described based on their altitudinal, and slope distribution range, the number of quadrats consisted and woody species composition in their growth habit categories (tree, shrub, and woody climber) (Table 1). The five different types of classified communities were described as follows.

Community Representative list

C1-(community 1) = *Juniperus procera - Myrsine africana*

C2-(community 2) = *Ficus sur - Pterolobium stellatum*

C3-(community 3) = *Carissa spinarum - Maytenus arbutifolia*

C4-(community 4) = *Olea europaea - Euclea racemosa*

C5-(community 5) = *Erica arborea - Hypericum revolutum*

1. ***Juniperus procera - Myrsine africana* community type**

This community type is distributed between the altitudinal range of 2448-2754 m a.s.l, and the slope gradient range of 22-65%. The community is comprised of 20 (16.39%) quadrats and 43 (46.24%) species out of the total identified woody species in the forest (Table 1). This community consists of a total of 14 indicator species (5 trees, 8 shrubs, and 1 climber species) those having cover-abundance greater than or equal to 1.0 (See Appendix 2). The most important/ dominant species in this community include: *Juniperus procera, Rhus retinorrhoea, Maesa lanceolata, Olinia rochetiana,* and *Pittosporum viridiflorum* are tree species, *Myrsine africana, Rosa abyssincia, Osyris quadripartite, Rhus vulgaris, Dodonaea angustifolia, Buddleja polystachya, Dombeya torrida* subsp. *torrid,* and *Clerodendrum myricoides* are shrub species, and *Periploca linearifolia* is climber species. The major importance species of *Juniperus procera, Myrsine africana, Rosa abyssincia, Dodonaea angustifolia,* and *Rhus retinorrhoea* are constancy species/common species that occurs in all forest communities but dominantly found in this community type.

Table 1: The communities, sample quadrats, and species composition distribution with their altitudinal and slope ranges

Community type	Community name	No. of quadrats	%age	Quadrat lists	No. of species Composition					Altitudinal range (m.a.s.l.)	Slope range
					Tree	Shrub	Climber	Total	%age		
C1	*Juniperus procera - Myrsine africana*	20	16.39	1, 71, 88, 31, 32, 34, 44, 28, 30, 46, 47, 29, 52, 53, 40, 41, 43, 45, 54, 42	9	24	10	43	46.24	2448-2754	22-65%
C2	*Ficus sur - Pterolobium stellatum*	56	45.90	2, 8, 5, 3, 6, 13, 11, 20, 26, 27, 18, 19, 21, 22, 25, 4, 9, 10, 15, 12,14, 7, 23, 24, 48, 62, 63, 64, 49, 102, 50, 51, 55, 100, 101,	26	31	11	68	73.12	2294-2763	9-65%

				33, 103, 72, 74, 37, 65, 66, 73,75, 81, 35, 80, 57, 84, 38, 56, 83, 58, 60, 59, 61							
C3	*Carissa spinarum - Maytenus arbutifolia*	32	26.23	36,70,76,106,113,86,90,92,77,87,89, 82,91, 85,39,69, 67,79,78,104,114,112,116,117,105,107,108,110,111,115,109	21	29	10	60	64.52	2330-2575	5-55%
C4	*Olea europaea - Euclea racemosa*	7	5.74	16,17,118,121,122,119,120	19	35	9	63	67.74	2265-2309	11-26%
C5	*Erica arborea - Hypericum revolutum*	7	5.74	93, 94, 95, 97,96, 98, 99	10	21	0	31	33.33	2964-3103	20-44%

2. *Ficus sur - Pterolobium stellatum* community type

This community is distributed within the altitudinal range between 2294 and 2763 m a.s.l, where the slope gradient ranges from 9% - 65%. This community is characterized by medium to high altitude, steep slope, valley, and partial mountainous topography. As compared to other the rest four forest communities this community contains the largest number of 56 quadrats (45.90%), and 68 species composition (73.12%) of the total identified species in the area (Table 1). It also contains the largest number of indicator species those having a cover-abundance value greater than one, and the most species richest community. This community consists of a total of 35 indicator species (14 trees, 14 shrubs, and 7 climber species) those having cover-abundance greater than or equal to 1.0 (See Appendix2).

In this community, the most dominant species include: *Ficus sur, Croton macrostachyus, Salix mucronata*, *Vernonia amygdalina, Acacia abyssinica Hagenia abyssinica,* and *Ficus cycomorus* are tree species, and *Pterolobium stellatu*, *Bersama abyssinica*, *Vernonia auriculifera, Dovyalis abyssinica, Rubus apetalus* , and *Grewia ferruginea* are shrub species. The important climber species of this community are *Clematis longicauda*, *Helinus mystacinus, Stephania abyssinica, and Clematis simensis. Phoenix reclinata*, *Millettia ferruginea*, and *Podocarpus falcatus* are diagnostic species/characteristic species that occur only in this community type. The indicator species of *Calpurnia aurea* and *Rumex nervosus* are constancy species/common species that occur in all forest communities but dominantly found in this community type. This richness of woody species might be resulted due to the wide variation of 469 m between the lower and upper altitudinal range, and composed of a larger number of quadrats. The majority of quadrats

(55%) belonged to the stream /riverine areas, and the rest of the quadrats are found in the terrestrial land also might be contributing to handling many different species under the community.

3. *Carissa spinarum - Maytenus arbutifolia* community type

This community is found in the range of 2330-2575 m. a.s.l. and a slope varies from flat (5%) to steep 55%. This community consists of 32 quadrats (26.23%) and 60 species composition (64.52%) out of the total identified species. The indicator species having cover-abundance greater than or equal to 1.0 are 1 tree and 5 shrub species. The only tree species found in this community is *Prunus africana*, however, the shrub species include *Carissa spinarum, Maytenus arbutifolia, Heteromorpha arborescens, Rhamnus stadd,* and *Otostegia integrifolia* (See Table 1 & Appendix 2).

Table 2: Synoptic table cover-abundance values of woody species

Species Name	**Communities**					Growth habit
	C1	C2	C3	C4	C5	
Juniperus procera	**8.05**	3.86	2.45	5.42	1	T
Myrsine africana	**6.9**	3.14	1.66	4.77	1.71	S
Rosa abyssincia	**6.8**	4.29	4.45	1.92	2.14	S
Osyris quadripartita	**6.5**	0	5.68	5	0	S
Rhus retinorrhoea	**6.1**	1.29	4.68	5.19	1.43	T
Maesa lanceolata	**5.65**	2	0.52	0.23	0	T
Rhus vulgaris	**5.6**	3.57	5.19	3.27	0	S
Pittosporum viridiflorum	**5.2**	1.71	4.97	2.12	0	T

Ficus sur Forssk.	0	**6.43**	`1	0.27	0.71	T
Pterolobium stellatum	0.3	**5.14**	0.69	0.46	0	S
Bersama abyssinica	0	**4.57**	1.26	1.27	0	S
Vernonia auriculifera	1.65	**4.43**	0	0.19	0	S
Croton macrostachyus	0.7	**4.39**	0.65	0.35	0	T
Phoenix reclinata	0	**3.29**	0	0	0	T
Millettia ferruginea	0	**1**	0	0	0	T
Podocarpus falcatus	0	**1**	0	0	0	T
Carissa spinarum	4.6	1	**7.13**	6.19	0	S
Maytenus arbutifolia.	5.8	3.57	**6.29**	5.08	0.71	S
Prunus africana	0.55	2.43	**6.18**	3.15	0.71	T
Heteromorpha trifoliata	0.25	0	**5.81**	2.35	0	S
Olea europaea subsp. cuspidata	3.3	2.71	3.56	**7.19**	0	T
Euclea racemosa subsp. schimperi	0.65	2.14	1.31	**6.62**	0	S
Jasminum grandiflorum subsp. *floribundum*	1.95	2.14	2.32	**6.35**	0	C
Erica arborea	5.65	0	0.23	0	**8.71**	S
Hypericum revolutum	2	0	0	0.19	**8.57**	S
Inula confertiflora	0	0	0	0.38	**6.57**	S
Hypericum quartinianum	0.35	1	0.13	0	**5.71**	S
Lippia adoensis	2.9	1.14	0.97	0	**5.43**	S

(Refer Appendix 2 for the entire 64 woody species of a synoptic table)

4. ***Olea europaea - Euclea racemosa* community type**

This community type compared to the rest three communities (C1, C2, and C3) has the least number of quadrats i.e. 7 quadrats which account for 5.74%, but the high composition of 63 species (67.74%) are associated with this community type. However, among 63 woody species composition, only 3 indicator species (1 tree, and 1 shrub, and 1 climber species) those having cover-abundance greater than or equal to 1.0 were found in this community (Tables 1 & 2).

5. ***Erica arborea - Hypericum revolutum* community type**

This community type is found relatively at a higher elevation between the altitudinal ranges of 2964 and 3103 m a.s.l. as compared to the rest communities in the area, and its slope gradient was varied within 20% - 44%. This community type contains 7 quadrats (5.74%) and 31 species (33.33%) (Table1 & 2). This community consists of a total of 6 indicator species (only shrub species) those having cover-abundance greater than or equal to 1.0. The major dominance of shrub species in this community includes *Hypericum revolutum, Inula confertiflora, Erica arborea, Lippia adoensis, Solanum marginatum, and Hypericum quartinianum*.

4.1.5. Woody Species Diversity, Richness and Evenness of plant community types in natural forest

The Shannon – Wiener diversity index (H') was computed for each plant community type. The different values of diversity index (H') for the communities reflect the difference in their species richness and evenness (Table 3). However, the evenness (equitability) was measured with the relative abundance of various species found in the individual community.

Table 3: Shannon-Weiner diversity, richness, and evenness index of plant community types

Community Type	Altitudinal range (m)	Total No. of quadrat	Species Richness	Species diversity (H’)	Species evenness (J)
1	2448-2754	20	43	3.32	0.88
2	2294-2763	56	68	3.98	0.94
3	2330-2575	32	60	3.41	0.84
4	2265-2309	7	62	3.42	0.83
5	2964-3103	7	31	2.82	0.82

The Shanon-Wiener diversity index shows that different species diversity and richness values in the natural forest were varied among five communities. The species diversity, and richness of community two > community four > community three > community one > community five (Table 3). Generally, community two has the highest species diversity and richness followed by community four; however, community 5 has the least species diversity and richness values in the study area. The highest species evenness was observed in community two, followed by community one, and the least species evenness was observed in community five of the natural forest.

4.1.6. Floristic Species Similarity among plant community types of natural forest

According to Sorenson's similarity coefficient, community types two and four were the highest, while, community types one and five were the least similarities in Yerer's natural forest. The distribution of plant species among the communities indicates different similarity patterns (Table 4).

Table 4: Sorensen's similarity coefficient (Sc) among five communities.

	C1	C2	C3	C4	C5
C1	0				
C2	0.6	0			
C3	0.76	0.75	0		
C4	0.63	0.78	0.74	0	
C5	0.36	0.59	0.42	0.54	0

The Sorenson's coefficient of similarity results indicates that the degree of common species shared between communities two and four (78%), one and three (76%), two and three (75%), and three and four (74%) were high and relatively have similar weight. However, the least degree of species similarity was observed between communities one and five (36%) and followed by communities three and five (42%).

4.1.7. Vegetation Structure of natural forest

4.1.7.1. Diameter at Breast Height (DBH), and Height (H) distribution

DBH class distribution

The distribution of woody species density with DBH ≥2.5 cm in Yerer Mountain natural forest were categorized in to seven DBH classes as follow: 2.5-10, 10.1-20, 20.1-30, 30.1-40, 40.1-50, 50.1-60, and > 60 cm. The woody species DBH was recorded in the range between 2.55 to 73.45cm. The distribution of individual woody species with their DBH classes was presented in (Figure 7).

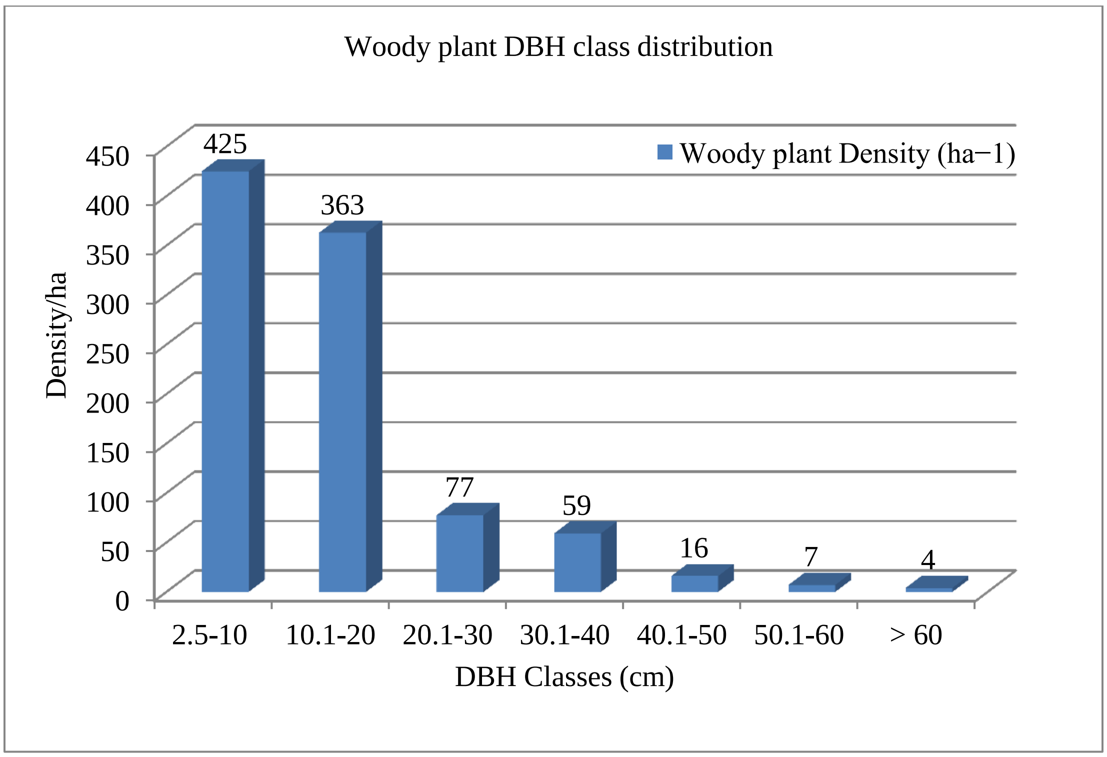

Figure 7: Woody plant DBH class distribution in Yerer natural forest

Individuals with the DBH class size of 2.5-10 cm were covered by about 44.69 % of the density of the total stem and followed by 10.1-20 cm, 20.1-30 cm, and 30.1-40 cm in the order of 38.17%, 8.10%, and 6.20%, respectively. The second-highest number of stems was recorded within the Dbh class of 10.1-20cm which accounts for 38.17%, while the least number of stems was recorded in the Dbh class of above 60cm, which share about 0.42% out of the density of the total stem. The general pattern of DBH class distribution of woody species was showed an inverted J-shape.; which means the highest numbers of individuals were found in the diameter class of 2.5–10 cm declining with increasing diameter.

Height class distribution

In the study area, each woody plant species height was measured and categorized into six classes as follows: 2-5, 5.1-10, 10.1-15, 15.1-20, 20.1-25, and >25m (Figure 8). Woody plant height was recorded in the range of 2.5 to 27.5 m.

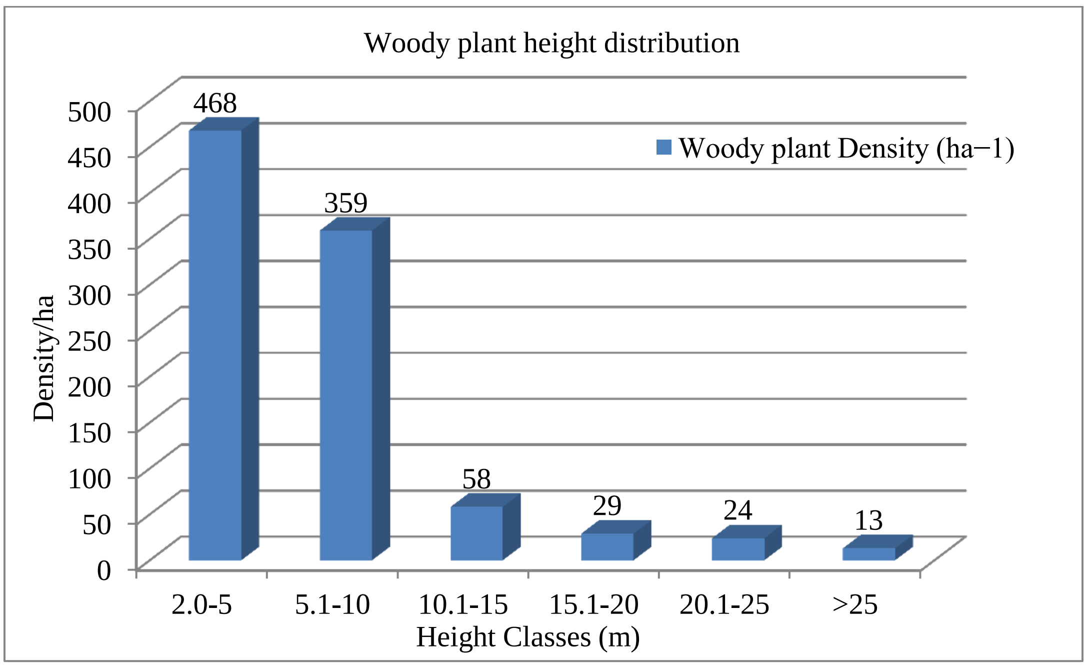

Figure 8: Woody plant height class distribution in Yerer natural forest

In Yerer's natural forest, the highest height distribution is mainly dominated by shrubs (height< 5m) and followed by trees (height > 5m). The results showed that the largest numbers of stems were recorded in the height class of 2– 5 m which accounts for about 49.21%, and secondly followed by a 5.1 – 10 m height class that shares about 37.75%. The lowest numbers of stems were recorded within the height classes of more than 25 m, which account for 1.37%.

4.1.7.2. Density and Frequency

The density of Woody Species

The density of woody species is one of the most important structural parameters to be considered during vegetation structure description. The total density of woody species with DBH greater than 2.5 cm in Yerer natural forest is 951/ha. The highest woody species density was recorded in the lower DBH class of 2.5-10.0cm and height class of 2.0-5.0m and followed by 10.1-20.0cm DBH and 5.1-10.0m height classes (See above Figures 6 and 7).

Frequency of Woody Species

Frequency is defined as the probability or chance of finding a particular species in a total sample quadrat. In the Yerer natural forest, the overall frequency of individual woody species varied between 2 and 114 quadrats. This means some woody species are observed within a minimum of 2 quadrats and a maximum of 114 quadrats in a natural forest. Results from the calculated frequency values of various woody species were categorized into five frequency classes as: 1.0 – 20.0, 20.1 – 40.0, 40.1 – 60.0, 60.1 – 80.0, 80.1 – 100.0, 100.1 – 120.0 (Figure 9).

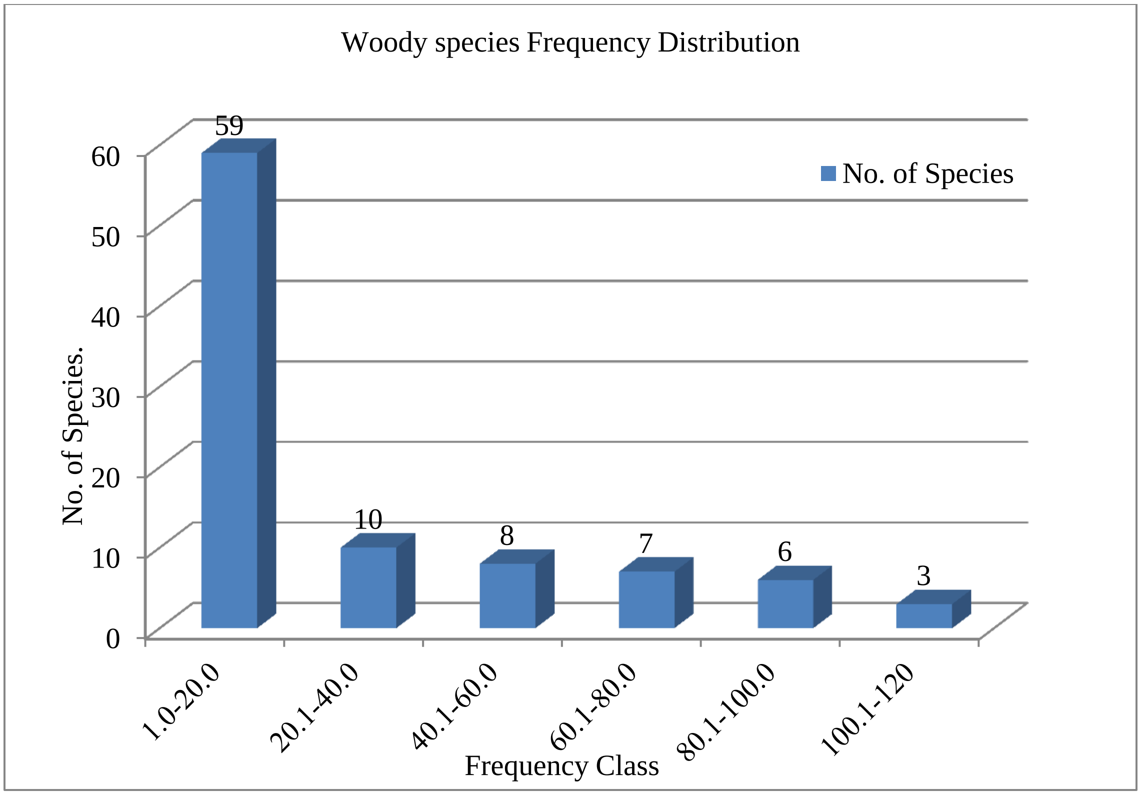

Figure 9: Woody species frequency class distribution in Yerer natural forest

The most frequent species were *Juniperus procera* (93%), *Myrsine africana* (87%), *Carissa spinarum* (84%), *Dodonaea angustifolia* (80%), and *Maytenus arbutifolia* (76%). *On the other hand*, *Acacia tortilis* subsp. *spirocarpa*, *Acacia seyal*, *Bersama abyssinica*, *Dregea schimperi*, *Acacia albida* (*Faidherbia albida*), *Podocarpus falcatus*, and *Salix mucronata* species were the least frequently (2.46%) each. The highest frequencies of woody species were observed in the first frequency class of 1.0-20.0.

4.1.7.3. Basal area (BA)

The total basal area of woody species in Yerer natural forest was 46.82 $m^2 \cdot ha^{-1}$ for DBH > 2.5 cm. The highest basal area of woody plants (11.24m^2/ha) was observed in the DBH class of 10.1-20 cm, followed by the DBH class of 20.1-30 cm with a 10.82m^2/ha basal area (Figure

10). The least basal area of the woody plant (2.17m^2/ha) was recorded in the DBH class of > 60cm.

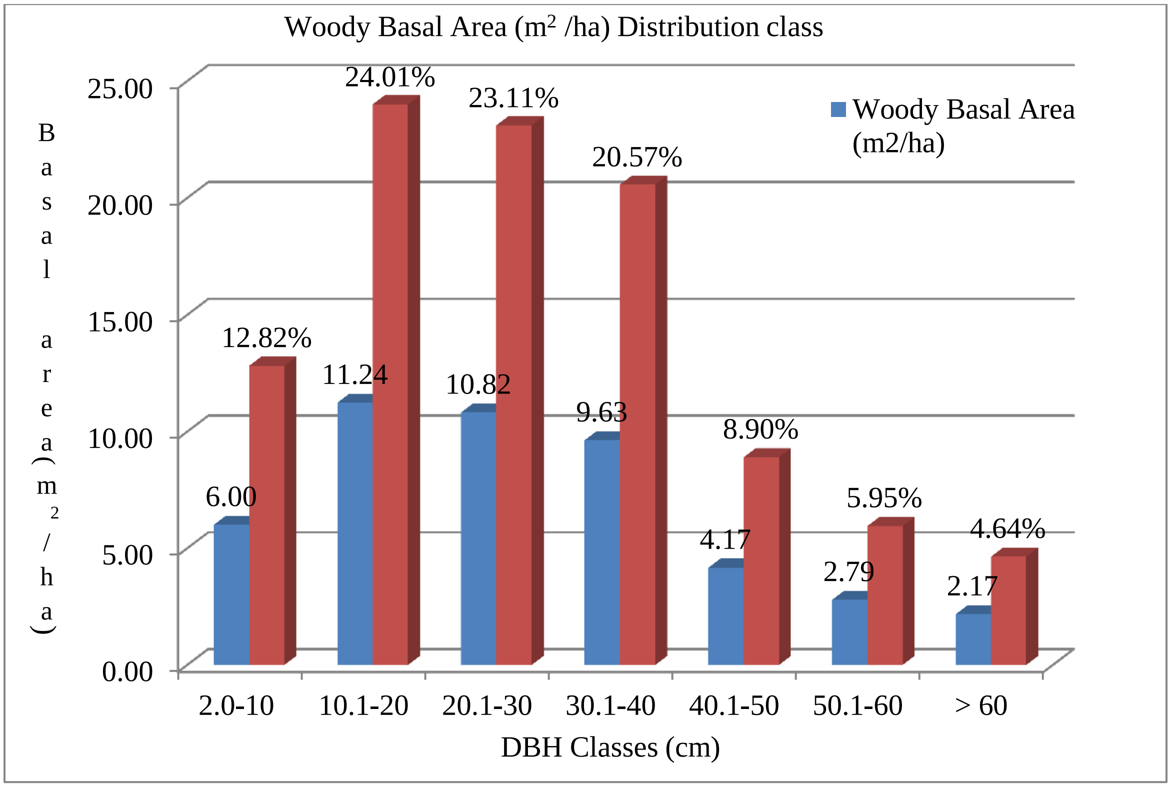

Figure 10: Woody basal area class distribution in Yerer natural forest

4.1.7.4. Important Value Index (IVI)

The species with the highest IVI values reflect the most dominant species in the particular vegetation. The analysis of IVI values of the study area showed that the natural forest is dominated by some woody plant species including *Juniperus procera* (45.36), *Myrsine africana* (19.05), *Carissa spinarum* (18.73), *Dodonaea angustifolia* (17.73), and *Olea europaea* subsp. *Cuspidata* (17.02). These five top of species whose IVI greater than 16 were contributed about 117.89 IVI or 39.30 % of the total IVI of the study area species (See Table 5 and Figure 11).

Table 5: The major dominance of 10 top woody plant species of importance value index (IVI)

Species Name	Relative frequency (RF)	Relative density (RDen)	Relative dominance (RDom)	Importance Value Index (IVI)	%age of IVI
Juniperus procera	5.91	10.46	28.99	45.36	15.12
Myrsine africana	5.50	8.20	5.35	19.05	6.35
Carissa spinarum	5.29	8.52	4.93	18.73	6.24
Dodonaea angustifolia	5.03	7.99	4.71	17.73	5.91
Olea europaea subsp. *cuspidata*	3.27	6.62	7.13	17.02	5.67
Maytenus arbutifolia	4.82	3.89	6.64	15.35	5.12
Osyris quadripartita	4.56	5.15	4.21	13.93	4.64
Rhus retinorrhoea	4.51	2.84	5.01	12.36	4.12
Rhus vulgaris	4.67	2.73	4.23	11.63	3.88
Rosa abyssincia	4.25	3.89	2.34	10.48	3.49

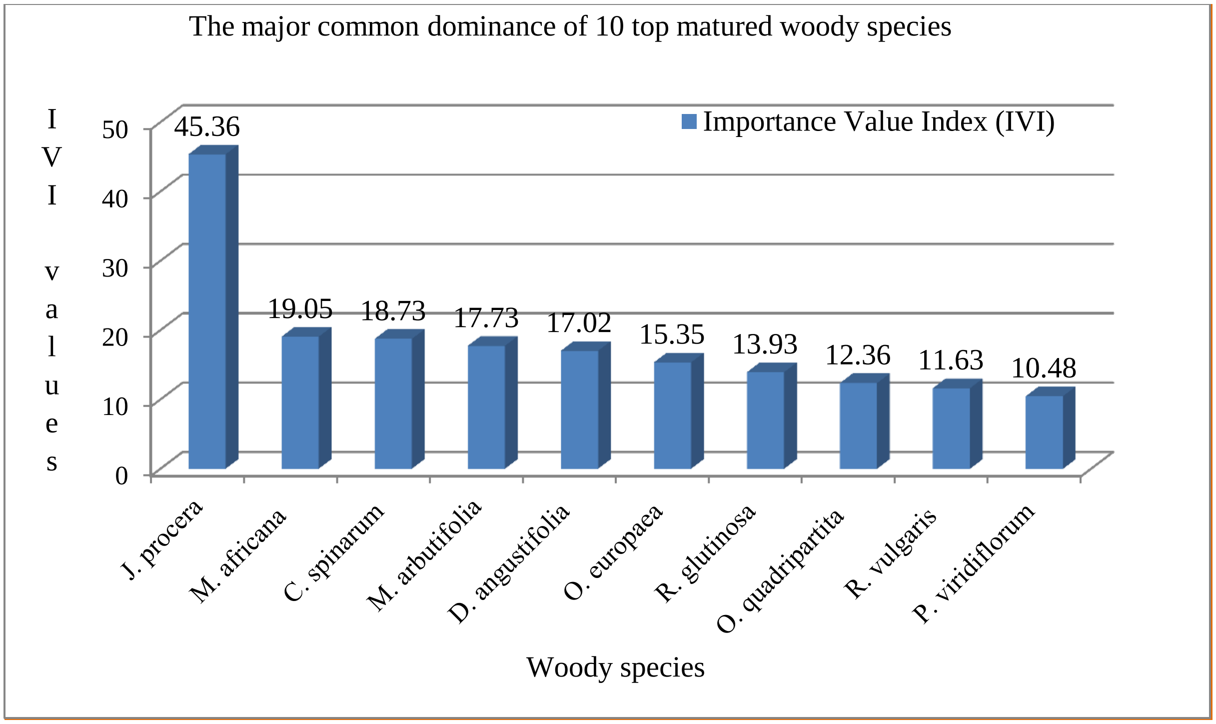

Figure 11: the major common dominance of 10 top woody species in Yerer natural forest

The highest IVI values of woody species were occurred due to their high values of relative frequency, relative dominance, and relative density. The Important value indices (IVI) of species are good indicators for the prioritization of species conservation.

4.1.8. Regeneration status of woody plants in Yerer natural forest

Understanding the natural regeneration status or recruitment potential of woody species (seedlings and saplings abundance) is one of the major importances to confirm the individual woody species conservation in the forest. A total of 84 woody species were found at the regeneration status of seedlings and sapling levels in natural forests. Accordingly, a total of 1354 (39.67%) seedlings/ha, 1108 (32.46%) saplings/ha, and 951 (27.86%) mature individuals/ha were recorded in the natural forest (Figure 12). The present study results showed that the population of seedlings and saplings were greater than mature individuals of woody species. The ratio of seedling and sapling to the matured parent woody plant was 1.42: 1 and 1.17: 1, respectively.

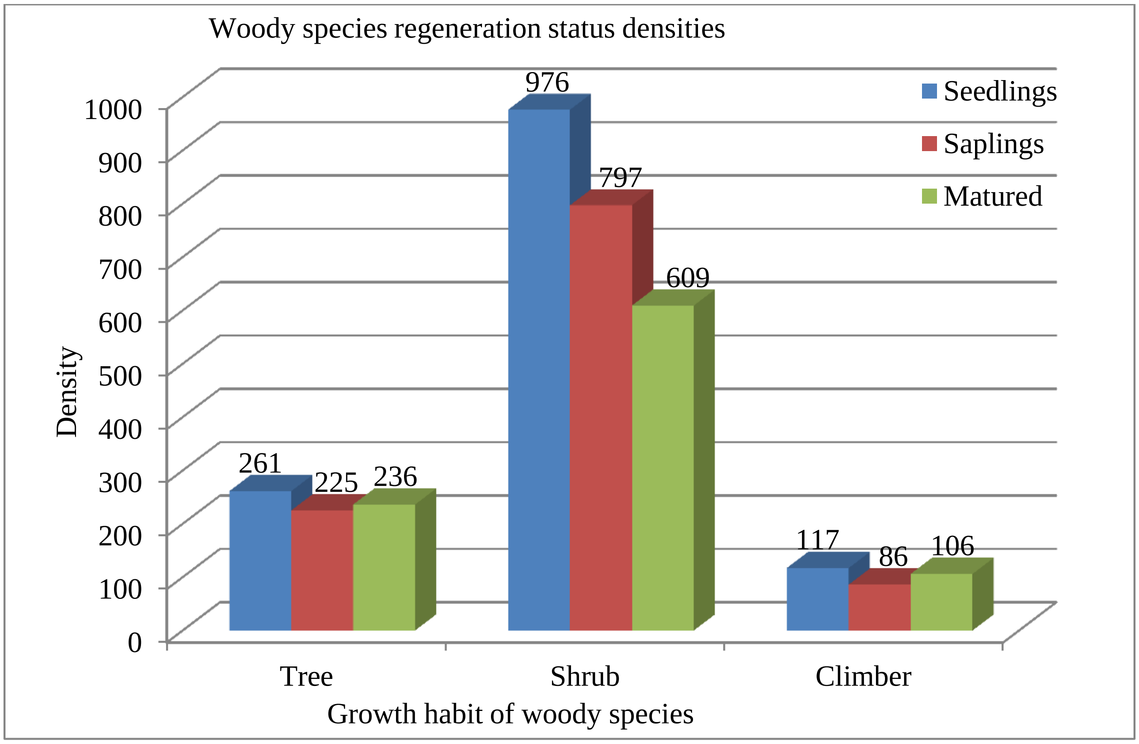

Figure 12: Seedlings, saplings, and matured woody species distribution in Yerer natural forest

Concerning to woody growth habit distribution in the natural forest, the field assessment results on the regeneration status revealed that tree and woody climber densities of seedlings > matured woody > saplings density. However, shrub species were composed of high population densities of seedlings > saplings > matured woody in the study area. The major dominance of woody species that have more than 50 seedlings and saplings each population densities per hectare includes *Myrsine africana*, *Dodonaea angustifolia*, *Carissa spinarum*, *Juniperus procera*, and *Maytenus arbutifolia* that contribute 47.34% of seedlings, and 49.64% of saplings population densities.

The “poor” regenerating categories of woody species consisted of 8 species, such as *Salix mucronata*, *Pterolobium stellatum*, *Croton macrostachyus*, *Podocarpus falcatus*, *Millettia ferruginea*, *Rumex nervosus*, *Solanum marginatum*, and *Cussonia arborea*. The natural regeneration status of these species in the forest indicated that they require urgent conservation measures. The “none” regenerating categories of woody species those not found at both seedlings and saplings stages, but present at maturity stage consisted of 9 species, such as *Grewia ferruginea*, *Vernonia amygdalina*, *Solanecio gigas*, *Embelia schimperi*, *Phoenix reclinata*, *Bersama abyssinica*, *Ekebergia capensis*, *Acacia albida*, and *Cordia africana.*

4.2. Effects of plantations of exotic tree species on understory native vegetation species composition and diversity

4.2.1. Plantations of exotic tree species structure

The current investigation was emphasized on mono plantations of four exotic tree species (*Cupressus lusitanica*, *Eucalyptus globulus*, *Grevillea robusta*, and *Pinus patula*) in Yerer area adjacent to the natural forest. The location of all forest land-use systems are laid between 2352 -2586 m.a.s.l., and 3 – 22% altitudinal and slope range, respectively. The mean height range of the plantation species was recorded between 8.69 and 19.93 m. The highest mean height was registered in *Pinus patula* (19.38m) and followed by *Eucalyptus globulus* (17.97m). On the other hand, the lowest mean height was registered in Natural forest (8.69 m), followed by *Grevillea robusta* (9.72 m). The mean woody Diameter at breast height (DBH) range of forest stands was recorded between 13.37 and 23.92 cm. The highest mean DBH was registered in *Pinus patula* (23.92 cm) and followed by *Cupressus lusitanica* (22.43 cm). The lowest mean Diameter at breast height (DBH) of forest stand was observed in *Grevillea robusta* (13.37 cm) and followed by natural forest (16.93 cm) (See Table 6).

The mean woody basal area range of forest stands was recorded between 20.04 and 62.69m^2/ha. The highest mean basal area was recorded in Natural forest (62.69m^2/ha) and followed by *Pinus patula* (53.28 m^2/ha). The lowest mean basal area of forest stand was observed in *Grevillea robusta* (20.04 m^2/ha) and followed by *Eucalyptus globulus* (44.56 m^2/ha). The mean litter's depth range of forest stands was recorded between 1.3 and 4.2 cm. The highest and lowest mean litters' depth of forest stands were recorded in *Pinus patula* (4.2 cm) and *Eucalyptus globulus* (1.3 cm). The mean Crown/ canopy cover range of forest stands was recorded between 61 and 87% at *Eucalyptus globulus* and Natural forest, respectively.

Table 6: Plantations of exotic tree species structure

Forest LUS/ Treatments	Distance from natural forest (m)	Range of altitude (m)	Slope range (%)	Area (ha)	Age range (yr)	Mean height (m)	Mean dbh (cm)	Mean basal area (m2 ha-1)	Tree density ha-1	Average litter depth (cm)	Crown/ canopy cover (%)
Cupressus lusitanica	320	2509-2586	10-38%	487	9-16	15.54	22.43	51.59	911	2.6	74
Eucalyptus globulus	1105	2389-2515	10-31%	918	9-14	17.97	21.14	44.56	963	1.3	61
Grevillea robusta	470	2381-2492	3-31%	4.87	8-13	9.72	13.37	20.04	727	1.8	68
Pinus patula	560	2464-2497	12-33%	9.73	9-14	19.93	23.92	54.28	867	4.2	81
Natural forest	-	2352-2545	12-42%	1158	+30	8.69	16.93	62.69	1716	2.9	87

DBH and Height Class Distribution

Growth performance of forest stand

In general, the diameter and height growth of woody species varies among different plantation exotic tree species throughout the study area. The frequency distribution of different diameter and height classes of woody plants in the different plantation exotic tree species and natural forest were presented in Figure 13 and Figure 14.

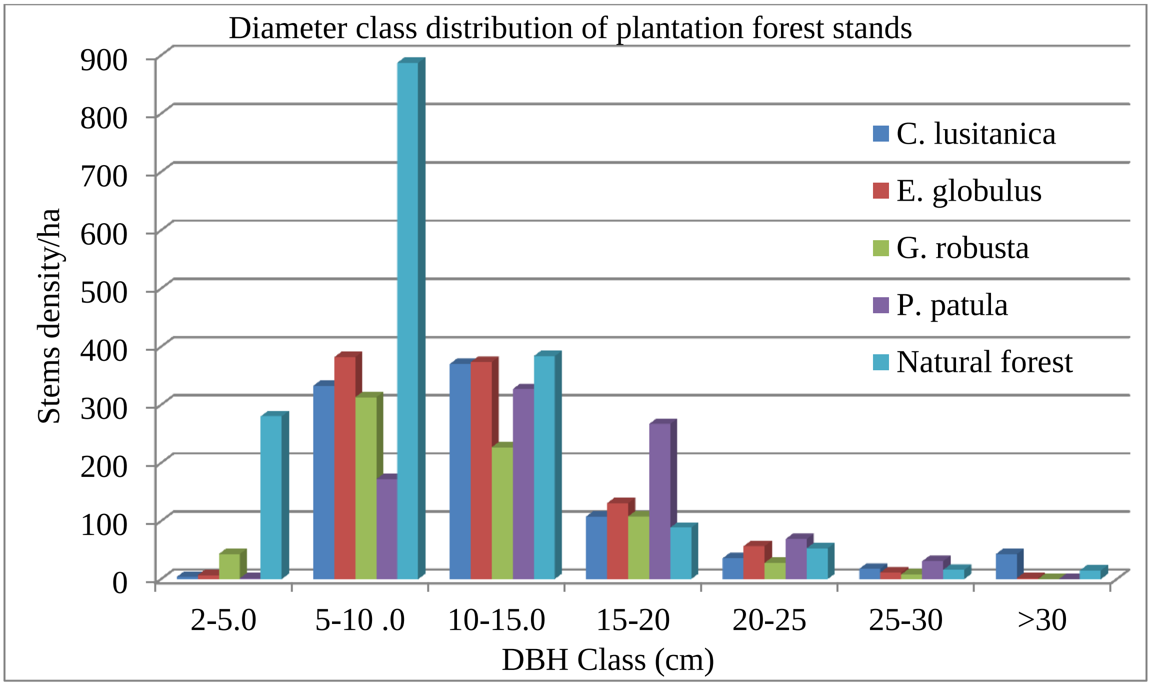

Figure 13: Diameter class distribution of plantation exotic tree species and natural forest

In all forest land-use systems, the majority of stem densities were found in the lower diameter class distributions of 5-10 cm and 10-15 cm (See Figure 13). The majority of stem densities of natural forest and *Grevillea robusta* were laid in the DBH class of 5-10 cm. The highest stem densities of *Eucalyptus globulus* and *Cupressus lusitanica* were laid in the DBH class distributions of 5-10 cm and 10-15 cm, whereas, the highest stem densities of *Pinus patula* was observed in 10-15cm and followed by 15-20cm DBH class.

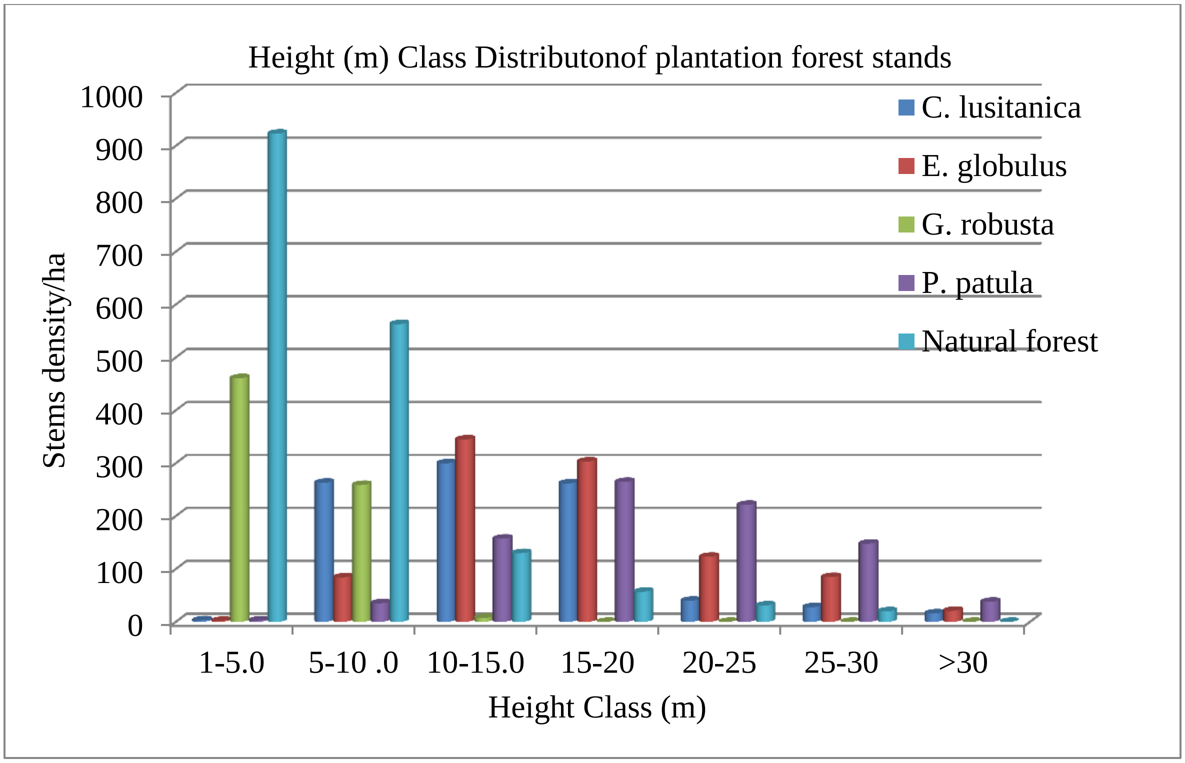

Figure 14: Height class distribution of plantation forest and adjacent natural forest

The majority stems densities of natural forest and *Grevillea robusta* were felled in the lower height class distributions of 1-5 m. The highest stem densities of *Cupressus lusitanica* and *Eucalyptus globulus* were laid in the height class of 10-15 m, whereas, the highest stem densities of *Pinus patula* were observed in 15-20 m class. A small number of individuals of *Cupressus lusitanica*, *Eucalyptus globulus*, and *Pinus patula* was found in the height class of 1-5 m.

4.2.2. Native vegetation composition under different forest land-use systems

In a total of 60 sample quadrats, a total of 211 native vegetation species belonging to 59 families, and 153 genera were recorded in four plantation exotic tree species and adjacent natural forest. To simplify the study description, native vegetation species composition is classified into five growth habit categories, i.e. tree, shrub, climber, herb, and fern. In these groups, the maximum number of native vegetation species was observed at the herb category and followed by shrub growth habits. Of the total 211 native vegetation species, 132 herb species (62.56%), 46 shrub species (21.80%), 21 tree species (9.95%), 10 climber species (4.74%), and 2 fern species (0.95%) were identified in all five forest land-use systems (LUS) (See Table 7, and Appendix 3).

Table 7: The total above-ground native species composition across different forest LUS in their growth habit in the study area

Land-use Systems (LUS)	No. of Native plant Spp. composition in their growth habit						Total species richness	Spp. richness Contribution (%)
	Tree	Shrub	Climber	Total woody Spp.	Herb	Fern		
Natural forest	21	35	10	66	113	2	181	85.78
C. lusitanica	7	20	5	32	54	1	87	41.23
E.globulus	3	16	3	22	49	1	71	33.65
G.robusta	6	22	3	31	70	0	101	47.87
P.patula	6	17	4	27	52	0	79	37.44
In all 4 plantation forest LUS	8	36	9	53	120	2	175	82.94

Under the four exotic tree plantation species alone, a total of 175 native species, representing 54 families and 134 genera, of which 56.87% herbs, 17.06% shrubs, 3.79% tree, 4.27% climber, and 0.95% fern species were recorded (See Appendix 3).

The highest number of woody and herb species were observed in the natural forest; however, the lowest number of woody species and herbs were recorded under *the Eucalyptus globulus* plantation forest.

4.2.3. Effect of different forest LUS on native vegetation species composition, density, and distribution

The native vegetation species composition in different forest land-use systems (LUS) ranged from 71 to 181 species. The total number of species recorded in forest land-use systems were ranked as Natural forest (181) > *Grevillea robusta* (101) > *Cupressus lusitanica* (87) > *Pinus patula* (79) > *Eucalyptus globulus* (71) plantation forest (Table 7 and Figure 15). Among all forest land-use systems, the results indicated that the highest species richness was observed in natural forests. However, among plantation exotic tree species, the highest number of species were recorded in *Grevillea robusta* and followed by *Cupressus lusitanica* plantation forest. Whereas, among the five forest land-use systems (LUS), the lowest species richness was observed in the *Eucalyptus globulus* and followed by *the Pinus patula* plantation forest.

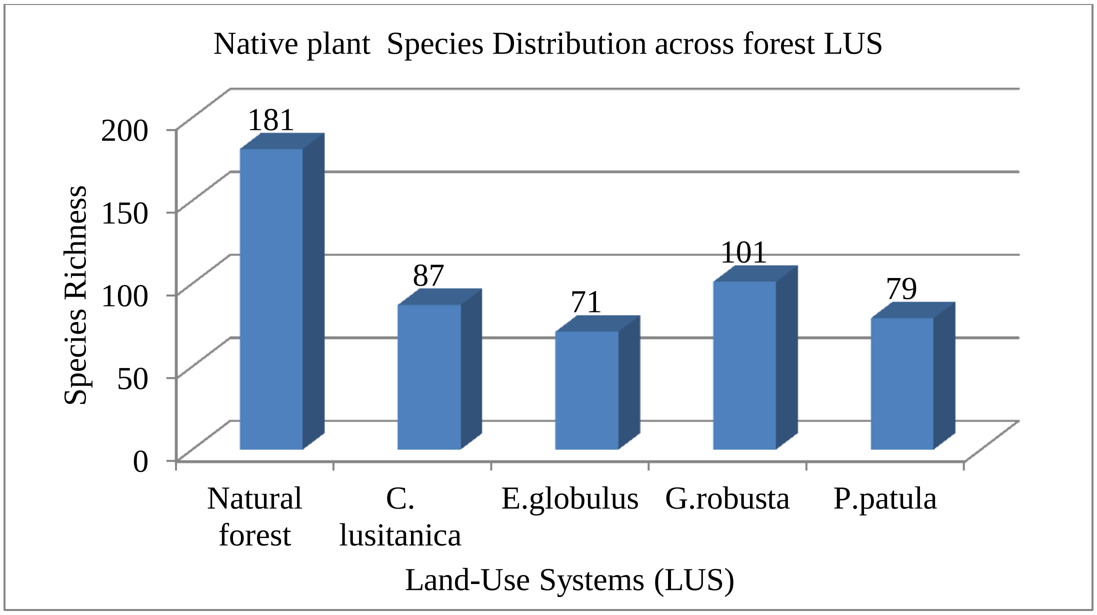

Figure 15: Native species distribution under different forest land-use systems (LUS)

The overall mean values of the number of native species composition /sample quadrat under different plantation exotic tree species and natural forest land-use systems varied between the range of 12 to 58 species. The analysis of variance (ANOVA) for several native species composition /quadrat was revealed that a significant variation among all forest land-use systems at ($P<0.0001$). The distribution of the number of native species composition /quadrat under natural forest, *Cupressus lusitanica*, *Grevillea robusta*, Pinus *patula,* and *Eucalyptus globulus* in the order of 58, 42, 33, 24, and 12, respectively.

Table 8: Mean values of native species composition and density/ quadrat under different land-use systems (LUS)

Land-use Systems (LUS)	Mean No. of species/quadrat	Mean plant density/ quadrat	No. of species/quadrat		Plant density/ quadrat	
			Minimum	Maximum	Minimum	Maximum
Natural forest	58a	33136a	52	59	23716	38560
C. lusitanica	33c	16863c	28	42	12117	25354
E.globulus	12e	10281d	6	17	2472	22194
G.robusta	42b	20405b	38	53	11343	39391
P.patula	24d	12424d	17	37	9702	18922
LSD	4.57	2854.8				
CV	16.35	31.69				
SIGN	0.0001***	0.0001***				

Note: Means for land-use systems within a column followed by the same letter are not significantly different from each other at $p < 0.05$.

KEYS: ***** = Significant at P<0.05, ****** = highly significant at P<0.01, ******* = very highly significant at P<0.001, and **ns** = Non-significant (at P> 0.05).

The overall mean values of species density/quadrat distribution under different four exotic tree plantation species and adjacent natural forest land-use systems varied in the range of 1028 to 3313. The maximum and minimum mean values of species density/quadrat were observed in natural forest and *Eucalyptus globulus,* respectively

(See Table 8 above). The analysis of Variance (ANOVA) made for the distribution of species density/quadrat under natural forest, *Grevillea robusta, Cupressus lusitanica, and E.globulus* showed significant variations at (P< 0.0001). However, the ANOVA test showed that a non-significant variation between *E.globulus* and *P. patula* plantation.

4.2.4. Effect of different forest LUS on native species diversity, richness, and evenness

The overall woody species richness values in all forest LUS were arranged in the order of natural forest > *Grevillea robusta* > *Cupressus lusitanica* > *Pinus patula* > *Eucalyptus globulus* plantations (Table 9).

Table 9: Shannon-Weiner diversity index values under different forest LUS in the study area

Land-use Systems (LUS)	Species Richness (R')	Species Diversity (H')	Species evenness (J)	No. of genus	No. of families
Natural forest	181	4.91	0.95	139	54
C. lusitanica	87	4.27	0.92	75	38
E.globulus	71	3.61	0.83	61	31
G.robusta	101	4.35	0.94	82	41
P.patula	79	3.95	0.90	67	40

The natural forest land-use system had the highest species richness (181) while the *Eucalyptus globulus* plantation forest (71) exhibited the least species richness. The overall observed species richness (175) in plantations of the four exotic tree species was lower than the natural forest (181). Among plantation forest stands, the *Grevillea* *robusta* plantation stand was more native species richness (101) than the other plantation forest stands in the study area.

The overall native species diversity indices (*H′*) of all forest land-use systems were ranked as natural forest (4.91) > *Grevillea robusta* (4.35) > *Cupressus lusitanica* (4.27) > *Pinus patula* (3.95) > *Eucalyptus globulus* (3.61) plantation forest (Table 9). The natural forest land-use system had the highest species diversity followed by *Grevillea robusta* and *Cupressus lusitanica* plantation forests.

The species evenness distribution across forest land-use systems were arranged in the order of natural forest (0.95) > *Grevillea robusta* (0.94) > *Cupressus lusitanica* (0.92) > *Pinus patula* (0.90) > *Eucalyptus globulus* (0.83) plantation forest. The highest species evenness was observed in a natural forest, however, the least species evenness was observed in *Eucalyptus globulus* plantation forest. The species evenness between natural forest and *Grevillea robusta* and between *Cupressus lusitanica* and *Pinus patula* plantation forests were close uniformly distributed. Among plantation forest stands, the highest species evenness was observed in *Grevillea robusta* than the other plantation forest stands.

4.2.5. Effect of different forest LUS on the composition and density of native woody species regeneration

Out of the total 77 woody species identified 14 species were recorded commonly in all forest land-use systems, among these, 5 species are trees, 7 species are shrubs, and 2 species are woody climbers.

Table 10: Summary of woody species composition and density in different forest LUS

Forest LUS	native woody `species richness and density									
	Seedlings		Saplings		Matured		Total Seedlings and/or saplings		Summary in each forest LUS	
	# of species	density/ha	# of species	density/ha	# of species	density/ha	# of species	density/ha	Total # of species	Total density /ha
Cupressus lusitanica	18	298	22	264	28	692	22	562	32	1254
Eucalyptus globulus	13	178	15	168	19	414	16	346	22	760
Grevillea robusta	21	265	23	243	25	668	25	508	31	1176
Pinus patula	17	258	19	213	24	524	19	471	27	995
Natural forest	48	1285	43	1093	64	1018	49	2378	66	3396

The overall total numbers of woody species, and stems density/ha under different forest land-use systems were observed in the range between 22 to 66, and 760 to 3396, respectively. In the area, the overall woody stems density/ha of forest land-use systems were ranked as natural forest (3396) > *Cupressus lusitanica* (1254) > *Grevillea robusta* (1176) > *Pinus patula* (995) > *Eucalyptus globulus* (760) plantation forest (Table 10).

Table 11: Mean values of native woody species diversity and their densities per quadrat under different forest land-use systems

Forest Land-use systems (LUS)	Seedling		Saplings		Matured woody	
	species richness	Stem density	species richness	Stem density	species richness	Stem density
Cupressus lusitanica	6b	13c	7b	11c	8c	30b
Eucalyptus globulus	3d	7d	4c	7cd	5d	20c
Grevillea robusta	7b	21b	8a	17b	10b	32b
Pinus patula	5bc	11c	5c	9c	6d	23bc
Natural forest	10a	51a	9a	44a	22a	42a
LSD	1.89	3.13	1.38	3.36	1.91	9.92
CV	25.64	28.26	19.21	26.89	14.55	20.84
SIGN	0.0004***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***

Note: Means for land-use systems within a column followed by the same letter are not significantly different from each other at $p < 0.05$.

KEYS: ***** = Significant at P<0.05, ****** = highly significant at P<0.01, ******* = very highly significant at P<0.001, and **ns** = Non-significant (at P> 0.05).

The analysis of variance (ANOVA) for woody species stems density was revealed that significant variations (P<0.001) between *Cupressus lusitanica* and *Pinus patul* at both saplings and matured stages, and between *Cupressus lusitanica* and *Eucalyptus globulus* plantation at seedlings and matured stages. Among exotic tree plantation species the highest species richness and stems density were observed under *Grevillea robusta*, however, the least species richness and stems density were recorded under the *Eucalyptus* *globulus* plantation forest (Table 11). The analysis of variance (ANOVA) for species richness (at all seedlings, saplings, and matured) stages revealed that a significant difference among *Cupressus lusitanica*, *Eucalyptus globulus*, and Natural forest as a function of forest land-use systems ($p<0.0001$).

4.2.6. Species similarity among five forest land-use systems (LUS)

A Jaccard similarity index was used to compare the degree of species similarity among the five forest land-use systems in Yerer forest. The overall species composition similarity indices among five forest land-use systems (LUSs) ranged from 0.26 – 0.49.

Table 12: Jaccard's Coefficients of Similarity (JCS) in species composition among five forest land-use systems (LUSs) at Yerer forest

Forest LUSs	Forest Land-use Systems (LUSs) Categories				
	Natural forest	*C. lusitanica*	*E.globulus*	*G. robusta*	*P. patula*
Natural forest	-	0.37	0.26	0.26	0.32
C. lusitanica	-	-	0.30	0.26	0.46
E.globulus	-	-	-	0.45	0.43
G. robusta	-	-	-	-	0.49
P. patula	-	-	-	-	-

Among different forest land-use systems in the study area, the highest species similarity or homogeneity in forest stands was observed between *G. robusta* and *P. patula* (JCS = 0.49) and followed by the similarity between *C. lusitanica* and *P. patula* (JCS = 0.46), and between *E.globulus* and *P. patula* (JCS = 0.46) plantation forests. However, the lowest species similarity or higher heterogeneity in forest stands were observed between natural forest and *E.globulus* (JCS = 0.26), between natural forest and *G. robusta* (JCS = 0.26), and between *C. lusitanica and G. robusta* (JCS = 0.26) forest land-use systems (Table 12). Among the different forest land-use systems, the species similarity between all exotic tree plantation species and the natural forest was low (JCS = $\leq$ 0.37). This indicates that higher species similarity or homogeneity was observed between exotic tree plantation species forests.

4.2.7. Endemic species in Yerer Forest

Among the native species collected in the study area, 31 species have been recorded as endemic to Ethiopia (Table 13). These endemic species are distributed in 25 genera and 13 families. Asteraceae, Lamiaceae, and Fabaceae were found to be the dominant families of endemic species in the whole forests of the study area represented by 11 species, six species, and 3 species, respectively. Concerning the plant growth habit categories, the endemic species were comprised of 15 species of herbs, 13 species shrubs, 2 species climber, and 1 species tree. Among the five forest land-use systems in the area, the majority of endemic species were recorded in the natural forest than exotic tree plantation species forests.

Based on the information available on the published Floras of Ethiopia among the species collected from the study area, the following species (Table 13) have been recorded to be endemic to Ethiopia.

Table 13: Endemic vegetation species distribution List under different forest LUS in Yerer Forest

No	Species Scientific Name	Family	Growth Habit	Forest land-use systems (LUS)					Species frequency across the forest LUS
				Natural forest	*C. lusitanica*	*E.globulus*	*G.robusta*	*P.patula*	
1	*Acanthopale sp.*	Acanthaceae	S	X	-	-	-	-	1
2	*Aeollanthus abyssinicus*	Lamiaceae	H	X	-	-	X	-	2
3	*Becium grandiflorum*	Lamiaceae	S	X	-	-	-	-	1
4	*Bidens macroptera*	Asteraceae	H		X		X		2
5	*Bidens pachyloma*	Asteraceae	H	X	-	-	-	-	1
6	*Cirsium dender*	Asteraceae	H	X	-	-	-	-	1
7	*Clematis longicauda*	Rununculaceae	C	X	X	X	X	X	5

8	*Crotalaria exaltata*	Fabaceae	S	X	-	-	-	-	1
9	*Cynoglossum coeruleum subsp. Coeruleum*	Boraginaceae	H	-	-	-	X	X	2
10	*Daucus hochstetteri*	Apiaceae	H	X	X			X	3
11	*Echinops ellenbeckii*	Asteraceae	S	X	-	-	-	-	1
12	*Echinops longisetus*	Asteraceae	S	X	-	-	X		2
13	*Gomphocarpus purpurascens*	Asclepiadaceae	S	-	-	-	-	X	1
14	*Inula confertiflora*	Asteraceae	S	X	-	-		X	2
15	*Kalanchoe densiflora*	Crassulaceae	H	X	X	-	-	-	2
16	*Kalanchoe petitiana*	Crassulaceae	H	X	X	X	X	X	5
17	*Leucas abyssinica*	Lamiaceae	S	X	-	-	-	-	1
18	*Lippia adoensis*	Verbenaceae	S	X	X	X	X	X	5
19	*Maytenus arbutifolia.*	Celastraceae	S	X	X	X	X	-	4
20	*Millettia ferruginea*	Fabaceae	T	X	-	-	-	-	1
21	*Pimpinella heywoodii*	Apiaceae	H	X	X	X	X	X	5

22	*Plectocephalus varians*	Asteraceae	H	X		X	X	X	4
23	*Plectranthus garckeanus*	Lamiaceae	H	X	-	-	-	X	2
24	*Senecio fresenii*	Asteraceae	S	X	-	-	-	-	1
25	*Senecio myriocephalus*	Asteraceae	S	-	-	-	-	X	1
26	*Senecio ochrocarpus*	Asteraceae	H	X	X	-	X	-	3
27	*Solanecio gigas*	Asteraceae	S	X	-	-	-	-	1
28	*Thymus schimperi*	Lamiaceae	H	X	X	X	X	X	5
29	*Thymus serrulatus*	Lamiaceae	H	X	X	-	X	X	5
30	*Trifolium decorum*	Fabaceae	H	X	X	X	X	X	5
31	*Verbascum valerianifolium*	Scrophulariaceae	H	X	X	-	-	-	2
	Number of species per forest LUS			27	13	8	14	14	

N.B. Growth Habit: T-tree, S- shrub, C- climber, and H- herbs

4.3. Effect of land-use systems on the soil seed bank species composition, and seed density

4.3.1. Seed bank species composition, and seed density distribution pattern horizontal across land-use systems (LUSs)

A total of 2275 seeds were germinated from the soils sampled of eight land-use systems (natural forest, *Eucalyptus globulus*, *Cuppressus lustanica*, *Grevillea robusta*, *Pinus patula*, grassland, grazing land, and cropland) that varied between the minimum 195 and maximum 390 seedlings per land-use system. The highest numbers of germinated seedlings were observed in natural forest (390), followed by grassland (347), grazing land (320), and cropland (315). However, the least numbers of germinated seedlings from sampled soils were observed in *C. lusitanica* plantation forest (195), followed by *E. globulus (212*), and *G. robusta* (241) seedlings. From the total emerged seedlings, a total of 98 species were identified in seed banks belonging to 42 families and 84 genera from the eight different land-use systems in the area. The largest families were Asteraceae (with 15 genera and 18 species) followed by Poaceae (with 12 genera and 15 species), Fabaceae (with 7 genera and 7 species), Lamiaceae (with 4 genera and 4 species), Apiaceae, Commelinaceae, and Cyperaceae (3 species for each) (Appendix 4).

Table 14: Total seed bank species composition recorded under different land-use systems and their growth habit

Plant growth habit	Land-use Systems Categories							
	Natural forest	*C. lusitanica*	*E.globulus*	*G. robusta*	*P. patula*	Grassland	Grazing land	Cropland
Tree	4	1	1	0	0	2	0	0
Shrub	16	8	6	7	4	8	2	0
Climber	2	1	0	1	1	2	0	0
Herb	31	19	19	22	25	24	21	33
Grass	4	4	3	7	5	8	7	3
Total seed bank composition	57	33	29	37	35	44	30	36

In the study area, the recorded plant species composition includes 62 non-woody (62.27%) and 36 woody (36.73%). The natural forest land-use system (LUS) has the highest species composition or richness among eight land-use systems in the study area.

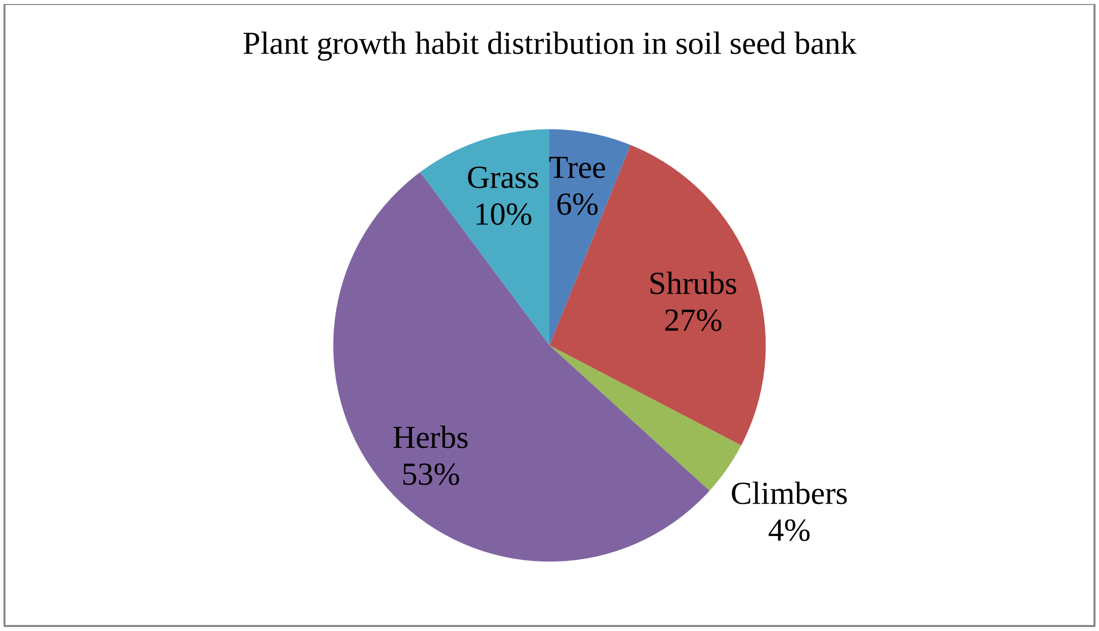

Figure 16: Plant growth habit distribution in the seed bank of Yerer forest and surrounding area

Among the plant growth habits of species in the study area, herbaceous species were dominant (more than 50%) of composition and seed densities/m^2 than the other growth habits of species. However, tree species was contributing 6 % of species composition that observed only in three land-use systems (Natural forest, *C. lusitanica*, and *E. globulus plantation*). The maximum number of species compositions was recorded in natural forest (57) and followed by grassland (44), *G. robusta* (37), and cropland (36). The least number of species compositions was observed in *E.globulus* (29), and followed by grazing land (30) species ((See Table 14, and Figures 16 & 17).

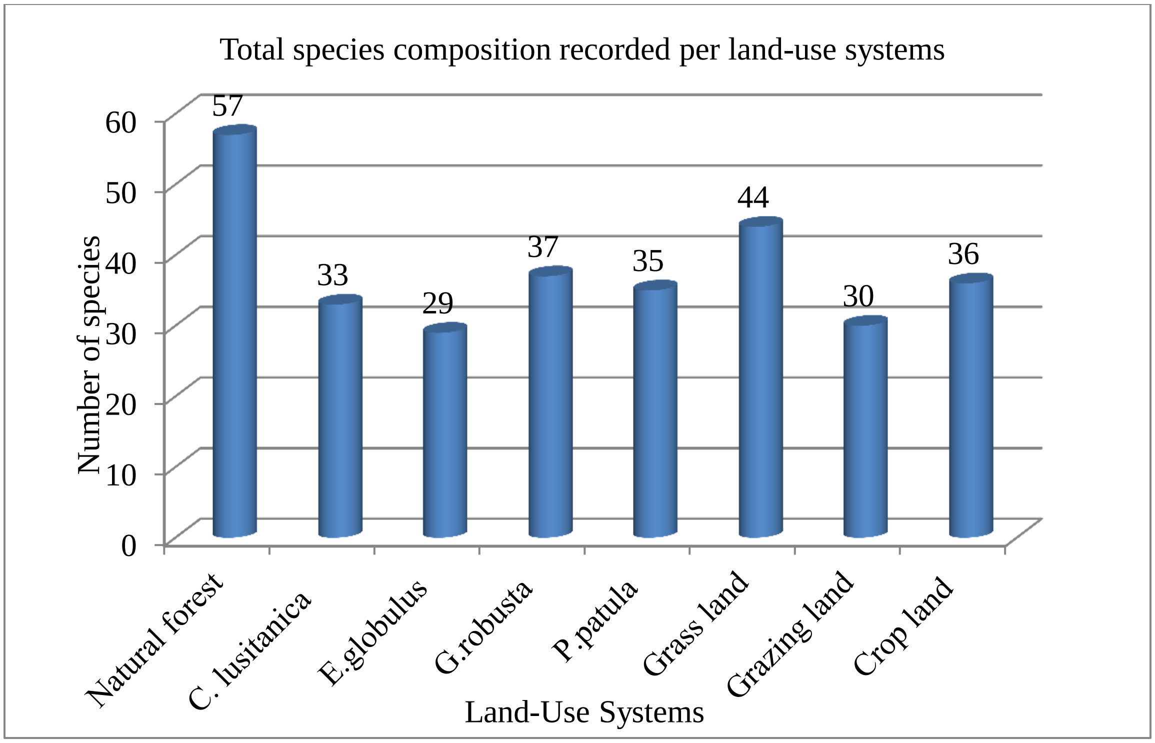

Figure 17: The overall plant species composition under different land-use systems

In the study area, the overall mean value of seed bank species composition, and seed density under different land-use systems were varied between 29 and 57 species composition, and between 1625 and 3250 seed density/ m^2, respectively. Accordingly, the maximum number of species compositions and seed density per m^2 was recorded in a natural forest, while the least number of species compositions and seed density per m^2 were observed in the *E.globulus* plantation forest (Table 14 & 15). The seed bank species composition (species richness) and seed density per m^2 were showed significant differences in numerical values among all land-use systems (LUSs).

Table 15: Mean values of seed bank composition/soil sample and seed density/m2 under different land-use systems

Land-use systems (LUS)	Mean no. of species/soil sample	Mean Seed density m^{-2}	No. of species/ soil sample		Seed density m^{-2}	
			Maximum	Minimum	Maximum	Minimum
Natural forest	13a	3250a	20	11	3667	2767
C. lusitanica	8cd	1767e	16	7	2000	1667
E.globulus	7d	1625e	13	6	1933	1367
G.robusta	10bc	2165d	16	8	2533	1800
P.patula	9c	2008dc	15	8	2433	1367
Grass land	11b	2792b	18	10	3500	2467
Grazing land	9c	2525bc	14	8	2900	2100
Crop land	10bc	2667bc	15	7	3167	2333
LSD	1.12	353.48	-	-	-	-
CV	17.00	13.01	-	-	-	-
SIGN	0.0001	0.0001	-	-	-	-

Note: Means for land-use systems within a column followed by the same letter are not significantly different from each other at $p < 0.05$. However, mean values of different letters within a column indicate significant differences by, a > b > c > d > e.

The analysis of variance (ANOVA) for plant species composition in soil seed bank indicated that there was very highly significant difference horizontally as a function of land-use systems (p<0001) among the natural forest, grassland, *G.robusta*, *C. lusitanica*, and *E.globulus* plantation, but non-significant variation among cropland, *P.patula*, and grazing land. The distributions of seed bank species composition in the study land-use systems were observed as natural forest > grassland > *G. robusta* = cropland > *P. patula* = grazing land > *C. lusitanica* > *E.globulus* plantation forest, which corresponds *to* the numerical values of 13, 11, 10.00, 10, 9, 9, 8, and 7, respectively (Table 15 and Figure 18).

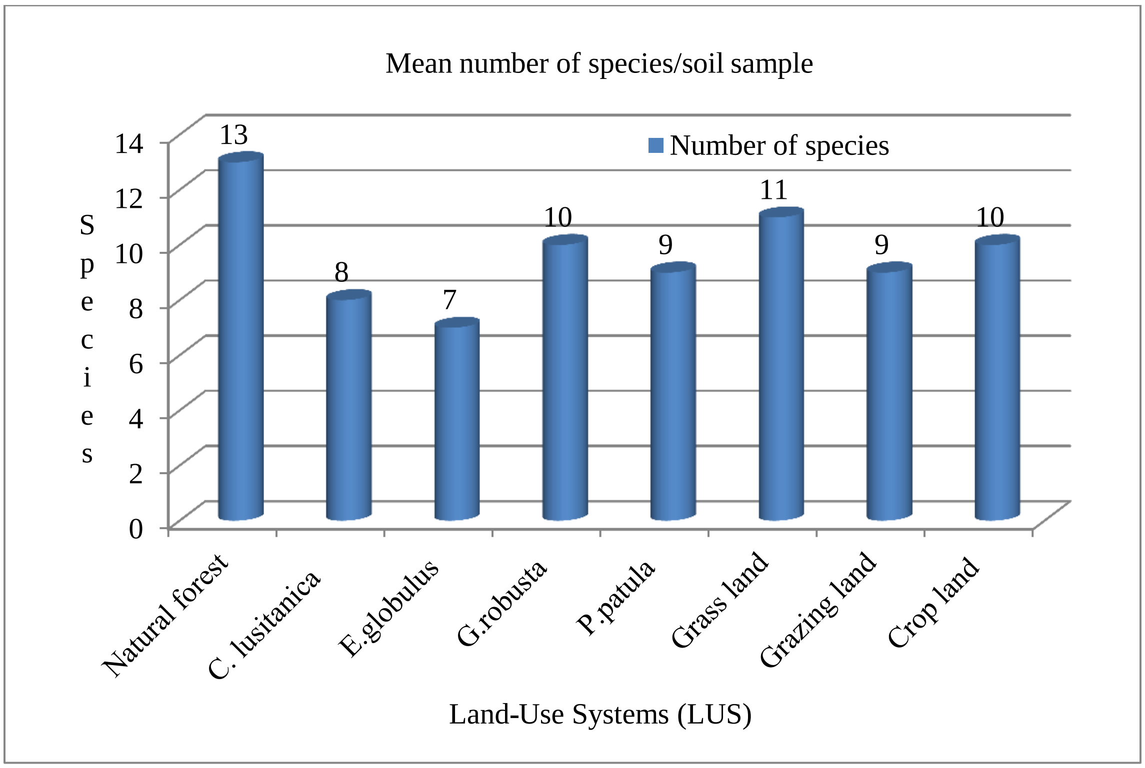

Figure 18: The mean value of plant species composition under land-use systems per soil sample

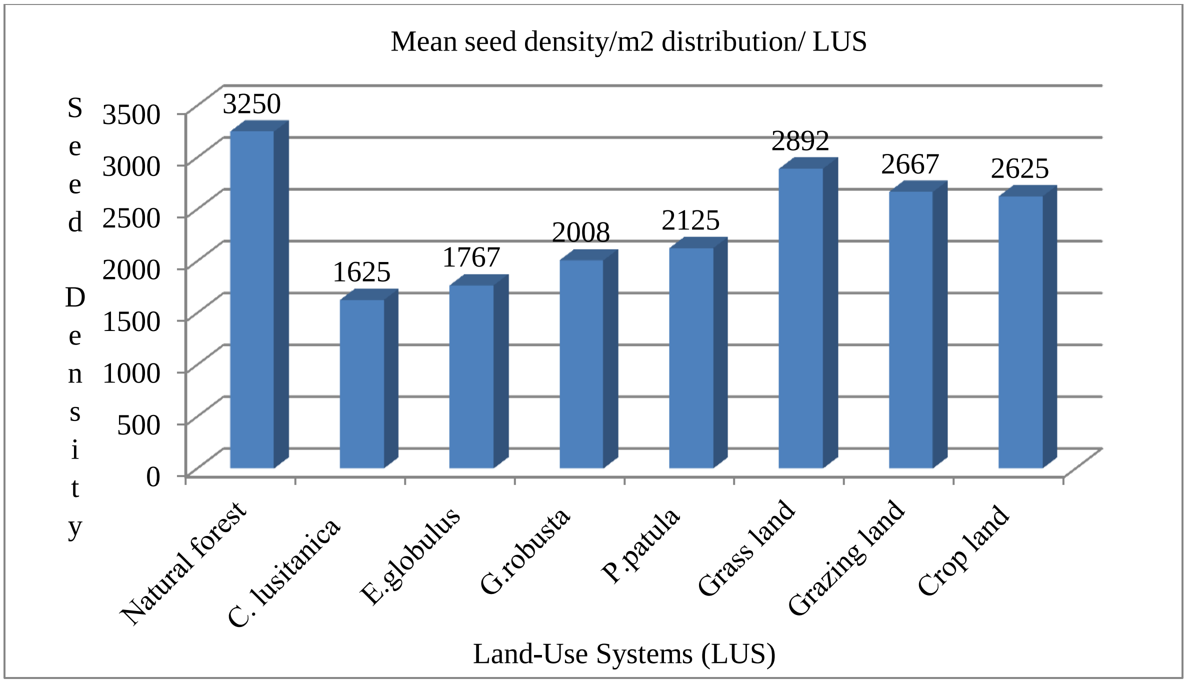

Figure 19: The mean value of seed density/m^2 under different land-use systems

The mean value of seed density per m^2 showed that there was a statistically significant difference as a function of land-use systems ($p<0.0001$) among the natural forest, grassland, *G.robusta,* and *C. lusitanica* plantation forests, but non-significant variation between grazing land and cropland, *P. patula* and *G.robusta,* and *E.globulus* and *C. lusitanica* plantation forests. The distributions of seed density in the study land-use systems were observed: natural forest > grassland > cropland > grazing land > *G. robusta* > *P. patula* > *C. lusitanica* > *E. globulus* plantation forests, which corresponding to numerical values of 3250, 2792, 2667, 2525, 2165, 2008, 1767, and 1625, respectively (Table 15 and Figure 19). The seed density of the soil seed bank was significantly higher in the natural forest (3250 seeds/m^2) and grassland (2792seeds/m^2) than the other land-use systems.

4.3.2. Seed bank species composition and density distribution pattern vertical in soil depth layers

The analysis of variance for species composition and seed bank density/m^2 of the soil seed bank revealed a significant difference vertically as a function of soil depth layers ($p<0.0001$) in all land-use systems. The overall vertical distribution of species composition and seed densities in the soil showed a similar trend gradually decreasing with increasing soil depth in all land-use systems. The highest seed densities occurred in the upper five centimeters of soil depth.

Table 16: Mean values of the number of species and seed density/m2 in soil seed bank across soil depth layers

Soil Depth layers	Mean number of Species/ soil sample	Seed Density/m^2
litters	6d	145d
0 - 5 cm	17a	986a
5 - 10 cm	12b	621b
10 - 15cm	9c	483c
LSD	0.80	89.90
CV	17.00	28.83
SIGN.	0.0001	0.0001

The maximum seed density was recorded in the second soil sampling layer (0-5cm) for all selected land-use systems. However, the least seed density was observed in the lower soil sampling layer (10-15cm) in all land-use systems (Table 16 and Figure 20). The frequency of the number of species composed and seed density/m^2 in all land-use systems were often lower in the deeper soil layers. A small number of seeds found the litter layer as compared to the other three soil depth layers.

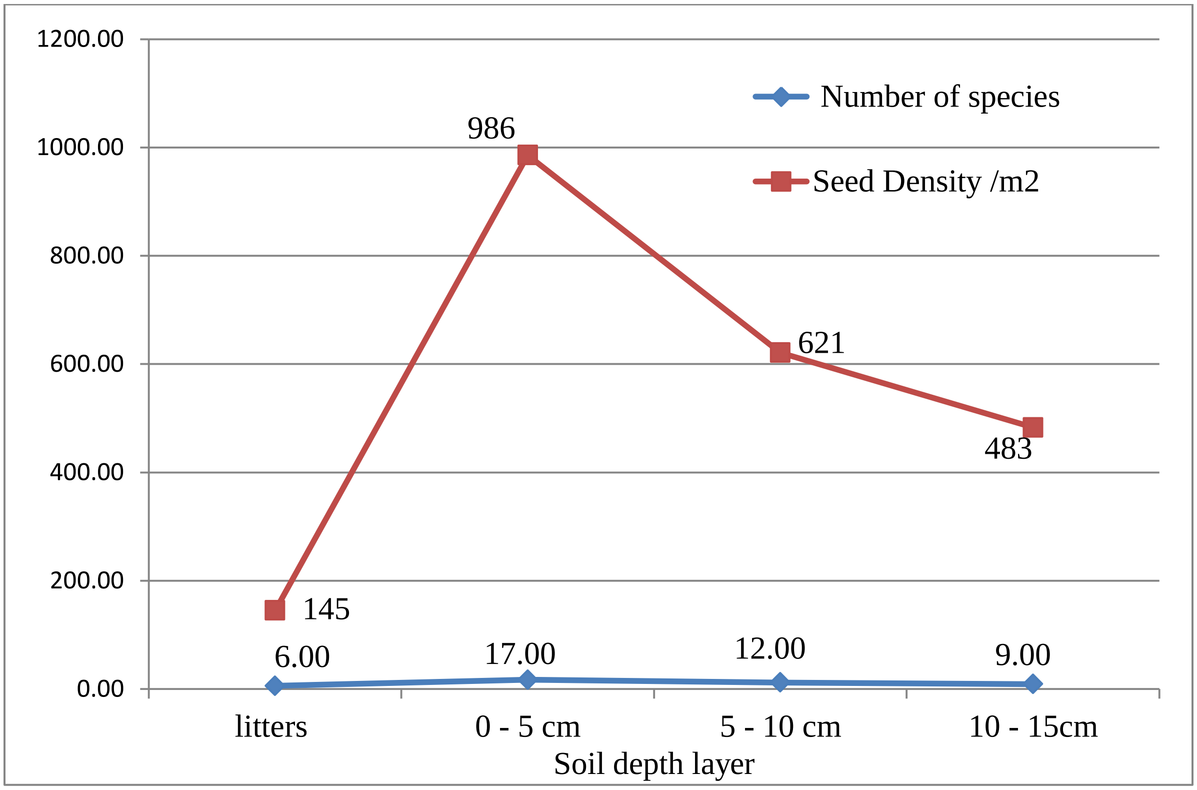

Figure 20: Mean number of species /soil sample and seed density/m2 trend across soil depth layers

4.3.3. Seed bank species composition similarity among land-use systems (LUS)

The similarity in species composition of the soil seed bank between the eight land-use systems ranged from JCS values of 0.25 to 0.64. The first and second highest similarities in species composition were recorded between *G. robusta and* Grassland (0.64), and between *G. robusta and P. patula* (0.53), respectively. While the least species composition a similarity was observed between *P. patula* and cropland (0.25), and between natural forest and cropland (0.26) (Table 17).

Table 17: Jaccard's Coefficients of Similarity in species composition in the soil seed banks between land-use systems

Land-use Systems	Land-use Systems (LUSs) Categories							
	Natural forest	*C. lusitanica*	*E.globulus*	*G. robusta*	*P. patula*	Grass Land	Grazing land	cropland
Natural forest	-	0.38	0.35	0.41	0.28	0.42	0.32	0.26
C. lusitanica	-	-	0.43	0.42	0.45	0.49	0.33	0.33
E.globulus	-	-	-	0.49	0.42	0.42	0.36	0.33
G. robusta	-	-	-	-	0.53	0.64	0.36	0.33
P. patula	-	-	-	-	-	0.52	0.32	0.25
Grass Land	-	-	-	-	-	-	0.52	0.32
Grazing land	-	-	-	-	-	-	-	0.33
Cropland	-	-	-	-	-	-	-	-

Common species composition distribution in seed banks

Of the total identified 98 plant species from the eight different land-use systems, 11 plant species were found in all land-use systems (See Appendix 4). The common distributed plant species in all land-use systems are *Commelina benghalensis*, *Commelina diffusa*, *Cotula abyssinica, Trifolium decorum, Galinsoga parviflora, Guizotia scabra, Medicago polymorpha, Oplismenus hirtellus, Pennisetum thunbergi, Bidens pilosa,* and *Cyperus bulbosus* (See Table 18 below). But the seed densities of these species varied among LUSs. The common distributed plant species were dominated by herbaceous species (90.91%) and followed only by grass species (9.09%).

Table 18: The common plant species recorded in all LUSs of soil seed banks

No.	Plant Species Name				G. habit
	Species Scientific name	Family name	Vernicular name		
			Afan Oromo	Amharic	
1	*Bidens pilosa*	Asteraceae	Maxxaannee Kelloo	Yeseytan Merfie	H
2	*Commelina benghalensis*	Commelinaceae	Gogoora Farda	Yebegi-lati, Yewuha Enqur,	H
3	*Commelina diffusa*	Commelinaceae	Margaa Gurra/Baalaa babaal'aa	-	H
4	*Cotula abyssinica*	Asteraceae	Aramaa Dimbiillalee fakkatuu	-	H
5	*Cyperus bulbosus*	Cyperaceae	Qunnii	Engicha	H
6	*Galinsoga parviflora*	Asteraceae	Abbaa Xaabboo	Yeshewa Arem	H

7	*Guizotia scabra*	Asteraceae	Haadaa	Mech, Gmie,	H
8	*Medicago polymorpha*	Fabaceae	Soggidaa Farda/ Ashaboo	Kurinchit; Kurenchet	H
9	*Oplismenus hirtellus*	Poaceae	Gurra hantuutaa / Kasi	-	H
10	*Pennisetum thunbergi*	Poaceae	Migira Saree	Ye Wusha Sindedo	G
11	*Trifolium decorum*	Fabaceae	Siddissa Horii	Mageti	H

Plant growth Habit refers: H= herbs; G = Grass

4.4. Effect of different land-use systems on soil Physico-chemical properties

4.4.1. Effect of land-use systems on selected soil physical properties

4.4.1.1. Soil texture

The analysis of variance for sand content of the soil revealed significant differences horizontally as a function of land-use systems ($P<0.0001$), and vertical gradient as a function of soil depths ($P<0.01$). The maximum and minimum mean values of large size soil particles (sand) were observed in the plantation of exotic tree species forests of *Cupressus lusitanica (43.80%)***,** and *Pinus patula (28.00%)*, respectively. The result showed that there were non-significant differences on sand among the natural forests, *Eucalyptus globulus*, *Cupressus lusitanica, Grevillea robusta* plantation forest, grassland, and grazing land-use systems.

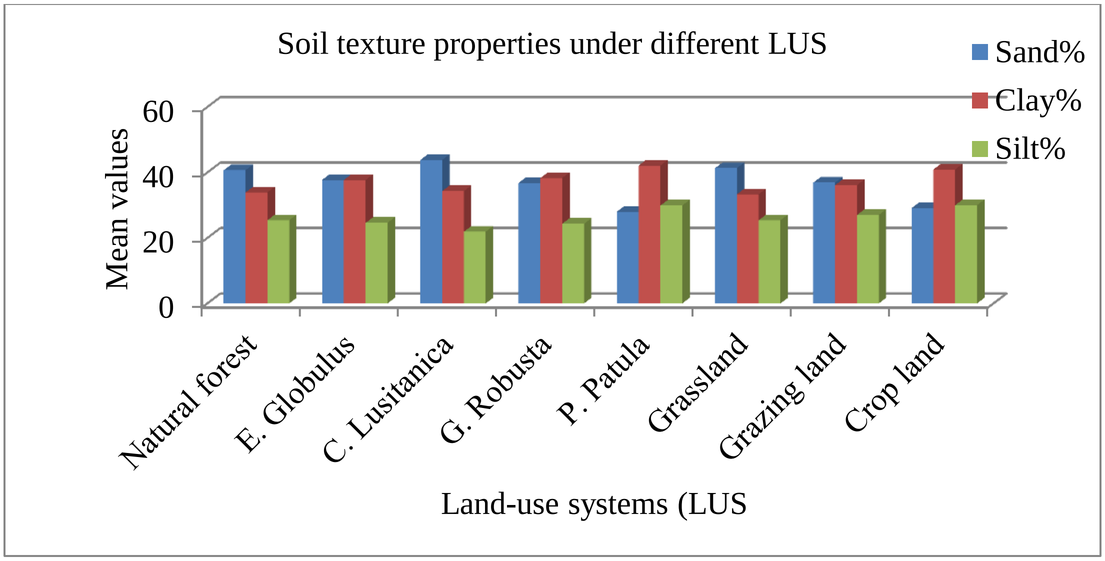

Figure 21: The mean values of soil texture (sand%, clay%, silt %) class distribution under different land-use systems (LUS)

There was a significant difference (P<0.05) in soil clay contents among land-use systems and between soil depth (P<0.0001). The highest average clay content was recorded under *Pinus patula* (42.10%) and the lowest in the grassland (33.30%). Among forest LUS, the maximum and minimum mean values of small-sized soil particles (clay) were observed in the plantation exotic tree species forest of *Pinus patula (42.10%)* and natural forest (33.9%), respectively.

The ANOVA result indicates that there was a significant effect of land-use systems on silt soil particle change ($p < 0.05$), but the non-significant difference between *Eucalyptus globulus* and *Cupressus lusitanica*, *Pinus patula* and cropland, natural forest and grassland, and between vertical soil depths. The maximum and minimum mean values of medium size soil particles (silt) were recorded in the cropland (30.00%), and *Cupressus lusitanica* plantation forest (21.90%), respectively (Table 19, and Figure 21). In soil depth-wise, there was no variation between topsoil and subsoil layers (Table 20).

Table 19: Mean values of selected soil physical properties of different land-use systems (LUS) and the overall effect of LUS

Land-use systems	Sand%	Clay%	Silt%	Textural class	MC %	BD	PD	SP
Natural forest	40.70^{ba}	33.90^{c}	25.40^{ba}	Clay Loam	23.08^{a}	1.17^{d}	1.72^{ef}	0.32^{a}
E. globulus	37.70^{ba}	37.70^{ba}	24.60^{c}	Clay Loam	17.00^{d}	2.18^{a}	2.53^{a}	0.14^{c}
C. lusitanica	43.80^{a}	34.30^{c}	21.90^{c}	Clay Loam	20.92^{bc}	1.31^{cd}	1.90^{ed}	0.31^{ba}
G. robusta	36.80^{b}	38.30^{ba}	24.30^{bc}	Clay Loam	22.74^{a}	1.29^{cd}	1.97^{cd}	0.34^{a}
Pinus patula	28.00^{c}	42.10^{a}	29.90^{a}	Clay	21.28^{ba}	1.19^{d}	1.62^{f}	0.27^{b}
Grassland	41.30^{ba}	33.30^{c}	25.40^{ba}	Clay Loam	20.40^{bc}	1.48^{b}	2.25^{b}	0.34^{a}
Grazing land	36.90^{b}	36.10^{bc}	27.00^{ba}	Clay Loam	19.30^{c}	1.45^{cb}	2.10^{cb}	0.31^{ba}
Crop land	29.10^{c}	40.90^{ba}	30.00^{a}	Clay	16.51^{d}	1.47^{b}	2.18^{b}	0.32^{a}
LSD	6.58	5.60	5.05	-	1.81	0.15	0.20	0.05
CV	20.04	16.92	21.71	-	10.07	11.61	10.83	17.65
Sign.	0.0001***	0.0154 *	0.0277 *	-	0.0001 ***	0.0001 ***	0.0001 ***	0.0001 ***

Note: Means for land-use systems within a column followed by the same letter are not significantly different from each other at $p < 0.05$. However, mean values of different letters within a column are indicate significant differences by , a > ab > b > c > d > e > f

Keys: *, **, ***, and ns = significant at $P < 0.05$, high significant at $P < 0.01$, very high significant at $P < 0.001$, and nonsignificant at $P > 0.05$, respectively.

Table 20: Mean values of selected soil physical properties of soil depths under different land-use systems

Soil Depth	Sand%	Clay %	Silt %	Textural Class	MC	BD	PD	SP
Top Soil layer (0 - 20 cm)	39.10	34.25	26.50	Clay Loam	19.07	1.35	1.88	0.29
Sub-Soil layer (20 - 40 cm)	34.48	39.90	25.63	Clay Loam	21.24	1.54	2.19	0.30
SIGN.	0.0066 **	0.0001***	ns		0.0001 ***	0.0001***	0.0001***	ns

Keys: *, **, ***, and ns = significant at P < 0.05, high significant at P < 0.01, very high significant at P < 0.001, and nonsignificant at P > 0.05, respectively.

4.4.1.2. Soil Moisture Content, Bulk density, Particle Density, and Porosity

Soil Moisture Content

Soil moisture content is the quantity of water contained in a soil material, which can range from 0% (completely dry) to the value of saturation (100%). The analysis of variance of moisture content of the soil revealed significantly influenced by land-use systems (P<0.0001) and vertical soil depths (P<0.0001). The mean soil moisture values under different land-use systems varied between 16.51 (cropland) to 23.08 % (natural forest) in the study area. The moisture contents under natural forest and *Grevillea robusta* plantation were significantly different (at p < 0.05) from *Eucalyptus globulus* plantation, *Cupressus lusitanica* plantation, grassland, and grazing land (Table 19, and Figure22). The variation of mean soil moisture content levels at the topsoil layer (0 – 20 cm) and subsoil (20 – 40 cm) layer under different land-use systems was observed at 19.07% and 21.24%, respectively (Table 20).

Bulk density

Bulk density is one of the important soil parameters that determine the amount of pore space available within the soil because it reflects the porosity of the soil. The analysis of variance for bulk density of the soil revealed very high significantly influenced (P<0.0001) land-use systems among; natural forest, *Eucalyptus globulus*, *Cupressus lusitanica*, grassland, and grazing land; and vertical soil depths (P<0.0001). However, the ANOVA indicates that there was a non-significant difference (P<0.05) between natural forest, *Grevillea robusta*, and *Pinus patula*, and between grassland and cropland land-use systems. The overall mean value of bulk density of the soil under the eight different land-use systems varied between 1.17 to 2.18 gm/cm^3 (Table 19, and Figure 22). The mean values of bulk density of the soil at the topsoil layer (0 – 20 cm) and subsoil (20 – 40 cm) layer under different land-use systems were recorded 1.35 gm/cm^3 and 1.54 gm/cm^3, respectively (Table 20).

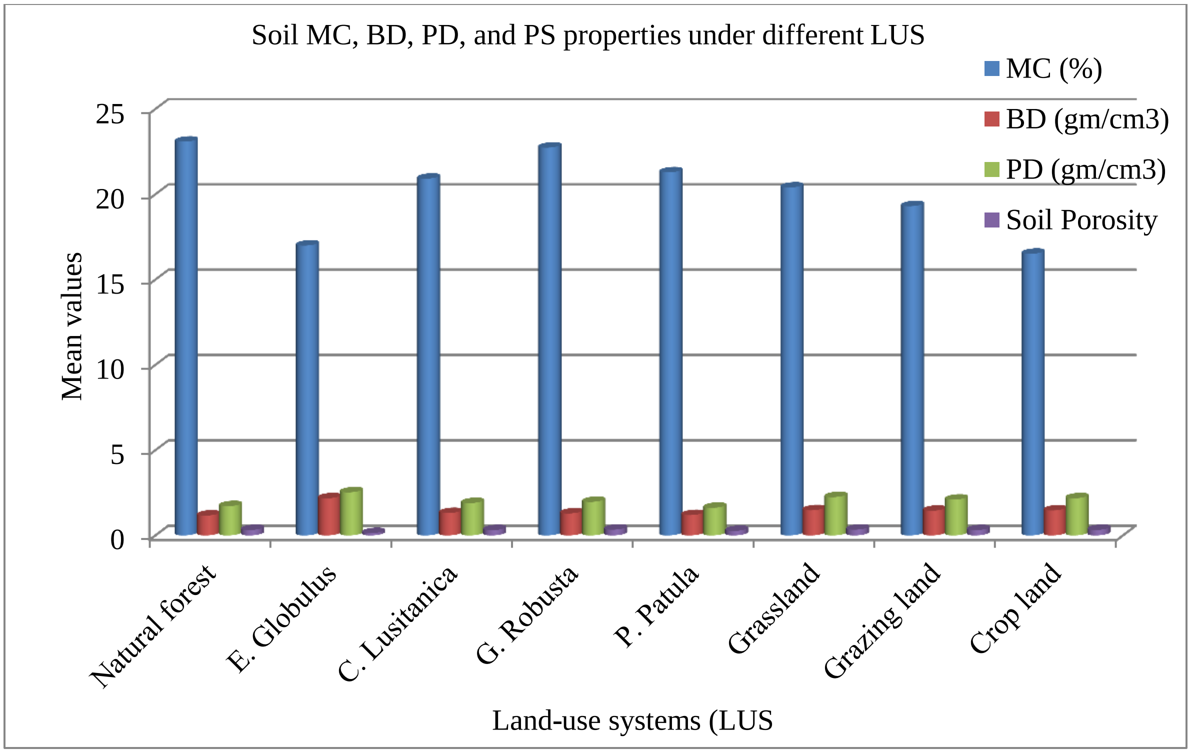

Figure 22: The mean values of soil moisture content (MC), bulk density (BD), particle density (PD), and soil porosity (SP) under different land-use systems (LUS)

Soil Particle Density

Analysis of variance for particle density concentration of the soil indicated that there was a very highly significant difference horizontally as a function of all land-use systems ($p<0001$), except between grassland and cropland. The statistical results also indicated that there was a very highly significant difference vertical between soil depths ($p<0.0001$). In the study area, the overall mean values of soil particle density under different land-use systems were observed between 1.62 to 2.53 gm/ cm^3 (Table 19, and Figure 22). The mean values of the particle density of the soil at the topsoil layer (0 – 20 cm) and subsoil (20 – 40 cm) layer under different land-use systems were showed that 1.88 gm/cm^3 and 2.18 gm/ cm^3, respectively (Table 20).

Soil Porosity

The mean value of porosity of the soil showed that there was a statistically significant difference as a function of many land-use systems ($p<0.0001$), except between natural forest, grassland, and cropland. However, the statistical analysis revealed a non-significant variation between soil depths. The present study result showed that the minimum and maximum mean values of soil porosity or pore space of the Yerer forest and surrounding area were laid between the range of 0.14 and 0.34, respectively (Table 19, and Figure 22). Vertical across the soil depth-wise, the mean values of soil porosity or pore space at the topsoil layer (0 – 20 cm) and subsoil (20 – 40 cm) layer under different land-use systems were revealed that 0.29 and 0.30, respectively (Table 20).

4.4.2. Effect of Land Use Systems on Selected Soil Chemical properties

4.4.2.1. Soil Organic C, Total N, C: N ratio, and Available P

Soil Organic Carbon (%OC)

The analysis of variance for organic carbon concentration of the soil revealed a significant difference horizontally as a function of land-use systems ($p<0001$) except between natural forest and *Grevillea robusta*, and between *Cupressus lusitanica, Pinus patula*, and grazing land. The ANOVA result also indicates, there was a significant variation ($p<0.0001$) between vertical gradients of soil depth. The overall mean value of the organic carbon concentration under the eight different land-use systems varied between 1.47 to 3.49%. Among the land-use systems (LUS) the highest concentration of organic carbon was observed in a natural forest. On the contrary, the lowest concentration of organic carbon was observed in cropland (See Table 21, and Figure 23 below).

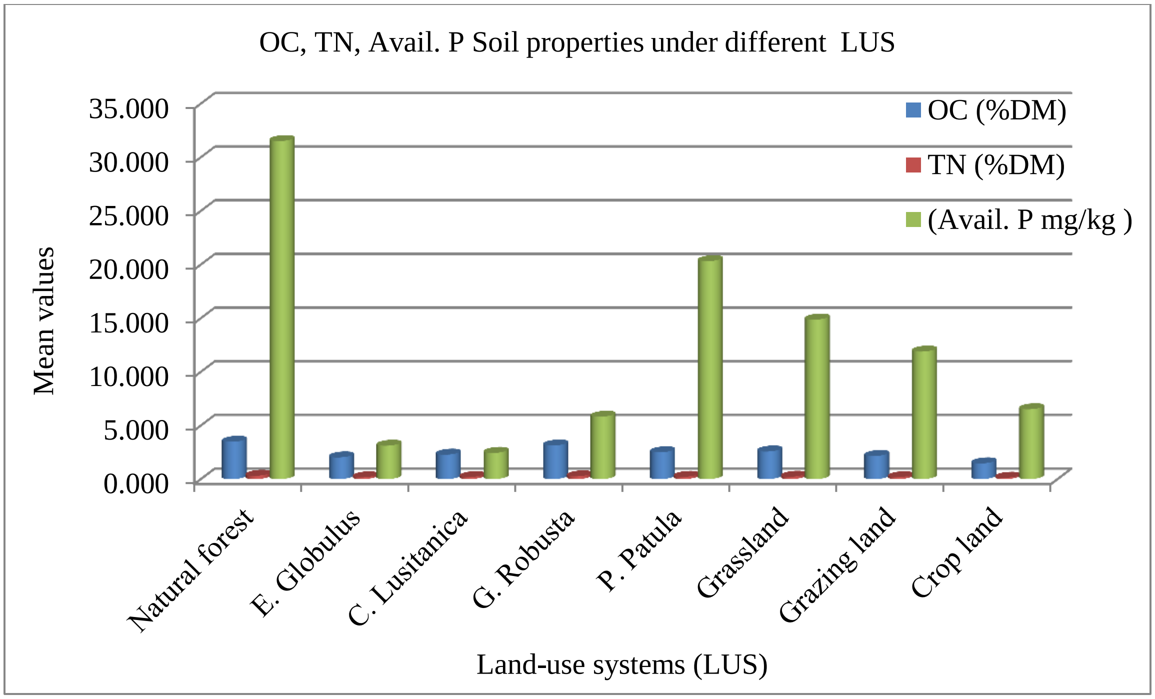

Figure 23: The mean values of soil OC, TN, and avail. P under different land-use systems (LUS)

The overall mean value of organic carbon levels at topsoil (0 – 20 cm) and subsoil (20 – 40 cm) layers were showed 2.89% and 2.02%, respectively (Table 22). The mean values of organic carbon concentration in the natural forest at both topsoil and subsoil layers were higher than that of the rest of the other land-use systems in the study area.

Total nitrogen (%TN)

Statistically, the total nitrogen content of the soil showed that a significant variation as a function of land-use systems ($p<0.0001$), and in vertical gradient between soil depths ($p<0.0001$). The overall mean value of the total nitrogen levels in all different land-use systems varied between 0.13 to 0.22% ranges. Among the land-use systems, the maximum and minimum mean values of total nitrogen percent were recorded in natural forest and cropland in order of 0.31% and 0.13%, respectively (See Table 21, and Figure

23 below). Additionally, in vertical gradient (across soil depth) a higher concentration of total nitrogen was observed at the topsoil layer (0.252%) than the subsoil layer (0.173%) in the study area (Table 22).

Carbon to Nitrogen(C: N) ratio

The C: N ratio shall determine by dividing the value of organic carbon to the total nitrogen corresponding to each soil sampling depths. The overall ANOVA analysis revealed that there was a non-significant ($p<0.05$) influenced by any land-use systems and soil depth variations. The overall mean value of the C: N ratios under eight different land-use systems were found between 11.38 to 12.08 ranges. The C: N ratio values at both topsoil layer (0 – 20 cm) and subsoil (20 – 40 cm) layer under different land-use systems showed 11.37 and 11.96, respectively (Table 21, and Table 22).

Available phosphorus

The analysis of variance for available phosphorus revealed that there were significant differences ($P<0.0001$) between all land-use systems except between *Eucalyptus globulus* and *Cupressus lusitanica*, and between *Grevillea robusta* and cropland. The ANOVA analysis showed also significant variation between vertical gradients of soil depths ($P<0.001$). The overall available phosphorus concentration level under different land-use systems was observed in the range between 2.45 to 31.52 mg/kg of soil. Among the land-use systems (LUS), the maximum and minimum available phosphorus concentration were recorded in natural forest and *Cupressus lusitanica* plantation forest, respectively (See Table 21, and Figure 23).

Table 21: Mean values of selected soil chemical properties of different land-use systems

Land-use systems	OC (%DM)	Total N (%DM)	C:N ratio	Avail. P (mg/kg of soil)	PH-H_2O (1:2.5)	EC (ds/m)	CEC (meq/100gm)	Exch. Na (cmol(+)/kg soil)	Exch. K (cmol(+)/kg soil)	Exch. Ca (cmol(+)/kg soil)	Exch. Mg (cmol(+)/kg soil)	BS (%)
Natural forest	3.49^{a}	0.31^{a}	11.38^{a}	31.52^{a}	6.20^{ba}	1.78^{c}	33.63^{a}	0.39^{b}	3.60^{a}	17.13^{a}	5.37^{a}	77.94^{ba}
Eucalyptus globulus	2.03^{c}	0.17^{dc}	11.87^{a}	3.12^{d}	5.48^{cb}	3.47^{a}	25.78^{cb}	0.60^{a}	1.97^{cb}	11.25^{cb}	3.58^{b}	70.91^{b}
Cupressus lusitanica	2.29^{cb}	0.20^{c}	11.75^{a}	2.45^{d}	5.41^{c}	2.34^{b}	21.26^{dc}	0.27^{ed}	2.46^{b}	11.59^{cb}	2.91^{cb}	80.83^{a}
Grevillea robusta	3.14^{a}	0.26^{b}	12.03^{a}	5.82^{dc}	5.70^{cb}	2.42^{b}	23.24^{c}	0.34^{d}	2.19^{cb}	12.56^{b}	3.51^{b}	79.78^{ba}
Pinus patula	2.50^{cb}	0.22^{cb}	12.08^{a}	20.32^{b}	5.99^{b}	2.35^{b}	29.23^{b}	0.30^{ed}	2.45^{b}	14.93^{ba}	4.75^{ba}	76.35^{ba}
Grassland	2.58^{b}	0.23^{cb}	11.86^{a}	14.88^{cb}	6.49^{a}	1.97^{cb}	28.97^{b}	0.29^{ed}	1.99^{cb}	16.03^{a}	3.42^{b}	73.32^{ba}

Grazing land	2.16^{cb}	0.18^{dc}	11.94^{a}	11.89^{c}	6.00^{ba}	1.88^{cb}	27.46^{b}	0.33^{d}	2.57^{b}	13.36^{b}	3.21^{cb}	74.53^{ba}
Crop land	1.47^{d}	0.13^{d}	11.48^{a}	6.52^{dc}	5.38^{c}	3.07^{a}	18.98^{d}	0.22^{e}	1.20^{d}	9.93^{c}	3.47^{b}	77.80^{ba}
LSD	0.54	0.05	1.42	8.31	0.49	0.56	3.49	0.09	0.65	2.53	0.98	9.92
CV	24.61	26.13	13.48	77.13	9.44	26.50	15.02	24.53	31.78	21.27	28.94	14.53
SIGN	0.0001***	0.0001***	ns	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	ns

Note: Means for land-use systems within a column followed by the same letter are not significantly different from each other at $p < 0.05$. However, mean values of different letters within a column are indicate significant differences by a > b > c > d > e > f

Keys: *, **, ***, and ns = significant at $P < 0.05$, high significant at $P < 0.01$, very high significant at $P < 0.001$, and nonsignificant at $P > 0.05$, respectively.

The overall mean value of available phosphorus accumulation at the topsoil layer was higher than that of in the subsoil layer in the order of 16.17 mg/kg of soil, and 7.96 mg/kg of soil, respectively. In all land-use systems, the available phosphorus concentration distribution at the topsoil layer (0 – 20 cm) was higher than that of in the subsoil (20 – 40 cm) in the study area (Table 22, and Appendix table 7).

Table 22: The overall mean values of selected soil chemical properties across soil depth layers in Yerer area

Soil Depth	OC (%DM)	Total N (%DM)	C:N ratio	Avail. P (mg/kg of soil)	PH-H_2O (1:2.5)	EC (ds/m)	CEC (meq/ 100gm)	Exch. Na (cmol(+) /kg soil)	Exch. K (cmol(+) /kg soil)	Exch. Ca (cmol(+)/ kg soil)	Exch. Mg (cmol(+)/kg soil)	BS (%)
Top Soil layer (0 - 20 cm)	2.89	0.25	11.64	16.17	5.80	2.22	27.31	0.39	2.76	14.74	4.19	81.75
Sub-Soil layer (20 - 40 cm)	2.02	0.17	11.96	7.96	5.86	2.60	24.82	0.29	1.85	11.96	3.36	71.12
Sign.	0.0001***	0.0001***	ns	0.0002***	ns	0.0115*	0.0059**	0.0001***	0.0001***	0.0001***	0.0012**	0.0001***

Keys: *, **, ***, and ns = significant at $P < 0.05$, high significant at $P < 0.01$, very high significant at $P < 0.001$, and nonsignificant at $P > 0.05$, respectively.

4.4.2.2. Soil pH, EC (ds/m), and CEC

Soil pH / Soil reaction

Soil reaction or soil pH is one of the soil chemical properties that used to measure the acidity or alkalinity of the soil. The analysis of variance for soil pH revealed that a significant difference as a function of land-use systems ($p<0.0001$) except between *Eucalyptus globulus* and *Cupressus lusitanica.* There was a non-significant variation between vertical gradients of soil depth at ($p<0.05$). The overall mean value of pH in the soil under the different land-use systems was observed in the range between 5.38 to 6.49. Among the different land-use systems in the study area, the maximum and minimum soil pH values were recorded in grassland, and cropland, respectively (Table 21, and Figure 24). The overall mean value of soil pH under all land-use systems at the topsoil layer and subsoil layer was observed 5.80 and 5.86, respectively. In all land-use systems, the level of soil pH trend between topsoil (0 – 20 cm) and subsoil (20 – 40 cm) layers was varied under different land-use systems (Table 22, and Appendix table 7).

Soil electrical conductivity (EC)

Soil electrical conductivity (EC) is a measure of the quantity of salts in soil (salinity of soil). The statistical analysis for soil electrical conductivity revealed a significant variation among land-use systems ($P<0.0001$) except between *Eucalyptus globulus* and cropland, between *Grevillea robusta* and *Pinus patula*, and between grassland and grazing land. The ANOVA result showed also a significant difference between soil depths ($P<0.01$). The overall mean values of soil electrical conductivity (EC) distribution under different land-use systems varied between 1.78 to 3.47 ds/m. Among all land-use systems, the maximum and minimum mean values in soil electrical conductivity (EC) were observed in *Eucalyptus globulus* plantation forest, and natural forest, respectively (Table 21, and Figure 24). The overall mean value of soil electrical conductivity (EC) under land-use systems, at the top layer (2.22 ds/m) was lower than the subsoil layer (2.60 d/m) in the study area. The distribution of soil electrical conductivity (EC) concentration under the majority of different land-use systems across vertical gradients at topsoil (0-20cm) layer were lower than the sub-soil (20-40cm) layer of depth, except the land-use systems of *Eucalyptus globulus* plantation forest and cropland (Table 22, and Appendix table 7).

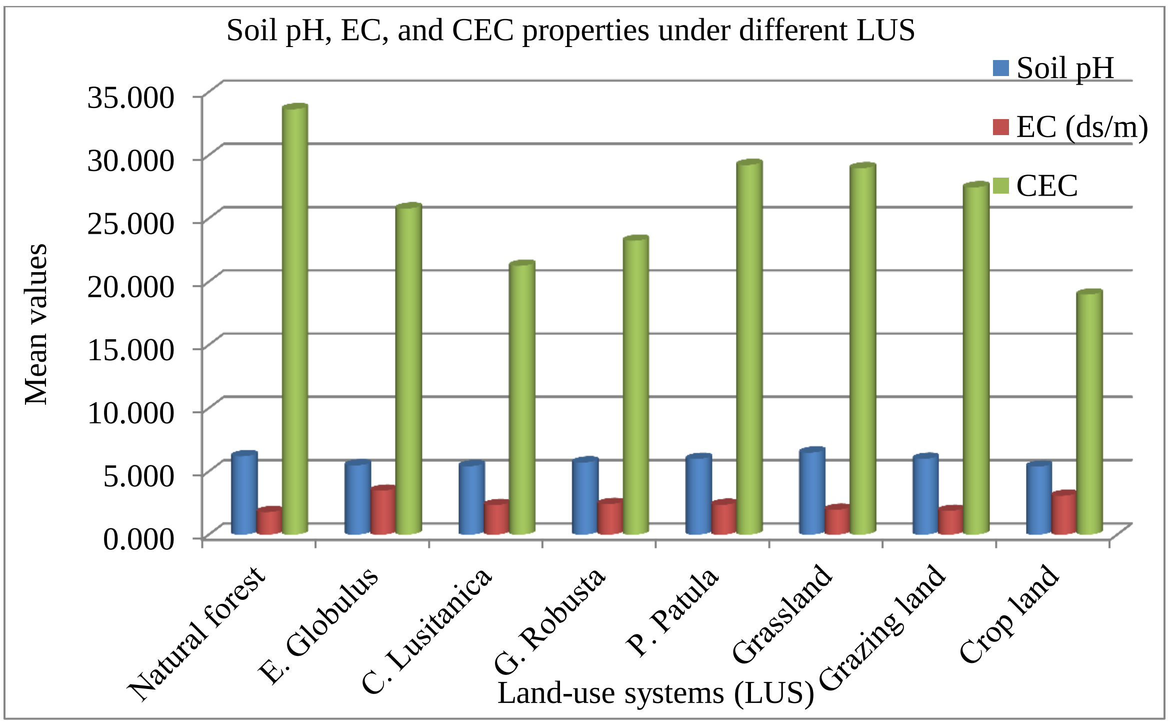

Figure 24: The mean values of soil pH, EC, and CEC under different land-use systems

Cation-Exchange Capacity (CEC)

The analysis of variance (ANOVA) for cation exchange capacity (CEC) was showed a significant variation among land-use systems (P<0.0001) except between *Pinus patula*, grassland, and grazing land. The statistical analysis also indicates a significant difference between soil depths (P<0.01). The overall mean values of the Cation-exchange capacity (CEC) distribution under different land-use systems varied between 18.98 to 33.63 meq/ 100gm soil. Among all land-use systems, the maximum and minimum mean values of soil Cation-exchange capacity (CEC) concentration were observed in a natural forest, and cropland, respectively (Table 21, and Figure 24).

The overall mean value of soil Cation-exchange capacity (CEC) concentration under land-use systems at the topsoil layer (27.31 meq/ 100gm soil) was higher than the subsoil layer (24.82 meq/ 100gm soil) in the study area. The distribution of soil Cation-exchange capacity (CEC) under the majority of different land-use systems across vertical gradients at the topsoil (0-20cm) layer was higher than the subsoil (20-40cm) layer, except the land-use systems of *Eucalyptus globulus* plantation forest (Table 22, and Appendix table 7).

4.4.2.3. Soil Exchangeable bases (Na, K, Ca, Mg), and Percent Base saturation (PBS)

Exchangeable cations (Na, K, Ca, Mg)

The common exchangeable base cations are K+, Ca+2, Mg+2, and Na+ which are held in the soil by organic matter and clay. The present study results indicate that the concentration of exchangeable cations was observed generally in the order of Ca> Mg > K > Na in all different land-use systems. Among all land-use systems, the higher concentration of exchangeable cations of Ca, Mg, and K were observed in the natural forest (Table 21, and Figure 25). The statistical analysis for the exchangeable cation of Na showed a significant variation (P<0.0001) between the majority of land-use systems, except between *Grevillea robusta* and grazing land, and between *Pinus patula* and grassland. The higher concentration of exchangeable cations of Na+ was recorded in the *Eucalyptus globulus* plantation forest.

The analysis of Variance (ANOVA) made for exchangeable cations of K revealed significant differences ($P<0.0001$) between land-use systems of natural forest and cropland, but non-significant differences ($P<0.05$) among land-use systems of *Cupressus lusitanica*, *Eucalyptus globulus*, *Grevillea robusta*, *Pinus patula*, grassland, and grazing land. The distributions of exchangeable cations of K in the study land-use systems were observed: grazing land > *Pinus patula* > *Cupressus lusitanica* > *Grevillea robusta* > grassland > *Eucalyptus globulus* plantation forest > cropland, which numerical values of 2.57, 2.46, 2.45, 2.19, 1.99, 1.97, and 1.20, respectively.

Statistically, the concentration of exchangeable cations of Ca in the soil showed a significant variation ($p<0.0001$) between land-use systems of *Pinus patula* and *c*ropland, but a non-significant variation ($p<0.05$) among land-use systems of natural forest, *Cupressus lusitanica*, *Eucalyptus globulus*, *Grevillea robusta*, grassland, and grazing land. The overall mean values of the distribution of exchangeable Ca in the study area were found in the orders of natural forest > grassland > *Pinus patula* > grazing land > *Grevillea robusta* > *Cupressus lusitanica* > *Eucalyptus globulus* > cropland, with numerical values of 17.13, 16.03, 14.93, 13.36, 12.56, 11.59, 11.25, and 9.93, respectively.

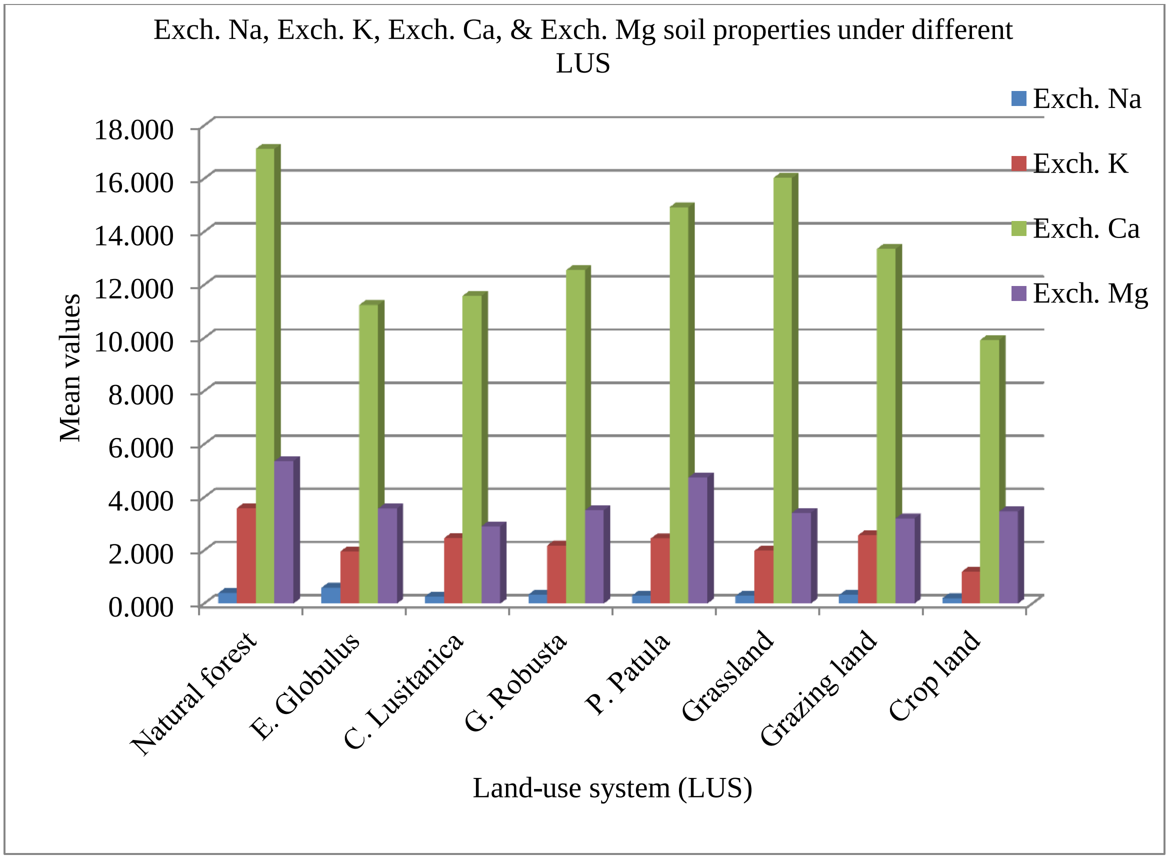

Figure 25: The mean values of soil exchangeable bases (Na, K, Ca, Mg) under different land-use systems (LUS)

The analysis of variance for exchangeable cations of Mg indicates a significant difference ($p<0.0001$) between land-use systems of natural forest and *Pinus patula*, but a non-significant variation ($p<0.05$) among land-use systems of *Cupressus lusitanica*, *Eucalyptus globulus, Grevillea robusta*, grassland, grazing land, and cropland. The statistical analysis showed a significant difference between soil depths for Na ($P< 0.0001$), K ($P<0.0001$), Ca ($P<0.0001$), and Mg ($P<0.001$). The distribution of exchangeable cations of Mg in *Eucalyptus globulus*, *Grevillea robusta*, cropland, grassland, grazing land, and *Cupressus lusitanica* in the order of 3.58, 3.51, 3.47, 3.42, 3.21, and 2.91, respectively.

The analysis of variance (ANOVA) for exchangeable cations of Ca, Mg, K, and Na showed a significant variation between soil depths for Na ($P< 0.0001$), K ($P<0.0001$), Ca ($P<0.0001$), and Mg ($P<0.001$). The higher mean values of exchangeable cations of Ca, Mg, K, and Na were distributed at the topsoil layer (0-20cm) than the subsoil layer (20-40cm) in all land-use systems in the study area (Table 22, and Appendix table 7).

Percent base saturation (PBS)

The analysis of variance (ANOVA) for percent base saturation revealed a non-significant difference ($p< 0.05$) among land-use systems, except between *Eucalyptus globulus* and *Cupressus lusitanica*. However, statistically, the percent base saturation in the soil showed a significant variation ($p<0.0001$) between soil depths. The mean values of Percent base saturation (PBS) in all land-use systems (LUS) were recorded more than 70%. Among all land-use systems (LUS) the minimum and maximum Percent base saturation (PBS) were observed in *Eucalyptus globulus* (70.912%), and *Cupressus lusitanica* (80.83%) plantation forests, respectively (Table 21). The higher mean values of Percent base saturation (PBS) were distributed at the topsoil layer (0-20cm) than the subsoil layer (20-40cm) in all land-use systems in the study area (Table 22, and Appendix table 7).

5. DISCUSSION

5.1. Floristic composition, diversity, and structure of woody species

5.1.1. Floristic Composition of Yerer Mountain natural forest

A total of 93 woody species belonging to 73 genera and 46 families were identified from the Yerer natural forest. This result indicated that the number of woody species composition is higher than in other Dry Afromontane forests of Aba Asrat Monastery Forest (81 species) (Gojjam Bayeh et. ai., 2013), Biteyu Forest (76 species) (Mekonnen Biru et.al., 2003), Wof-Washa forest (51 species) (Demel Teketay and Tamrat Bekele, 1995), and Gole Natural Forest (63 species) (Hailemariam Mesfin, Temam Tamiru 2018) of similar forest types in the country. However, the woody species composition of Yerer natural forest (93 species) is less than similar Dry Afromontane forests, for example Gedo forest (145 species) (Birhanu Kebede et.al., 2010), and Menagesha-Suba forest (113 species) (Dinkissa Beche, and Sebsebe Demissew 2011). These variations of species composition among similar forest types could happen with related to the altitudinal range variation because altitude plays a vital role in plant distribution and richness, environmental factors (like soil properties, climate), land-use history, and anthropogenic factors (human disturbance level). Comparison of the woody floristic composition of Yerer natural forest with other similar dry evergreen Montane forests in Ethiopia showed that the number of woody species composition is more or less similar with Boda forest with 95 species (Fikadu Erenso et. al., 2014), and Yegof natural forest with 95 species (Sultan Mohammed and Berhanu Abraha, 2013).

Among the 46 families of woody species Fabaceae, Lamiaceae, and Asteraceae are the three dominant families together constituted 28 species (30.11%) of the total species richness in Yerer natural forest. These families might be due to well-favorable environmental conditions (soils, water, climate) of the area that could contribute to their dispersal, adaptation, and successfully survive in the area by satisfying their growth ecological requirement. Among the identified woody species, eight families (Acanthaceae, Asclepidaceae, Moraceae, Myrsinaceae, Oleaceae, Rhamnaceae, Rosaceae, and Solanaceae) each consists of three species, six families (Anacardiaceae, Apiaceae, Ebenaceae, Hypericaceae, Ranunculaceae, and Sapindaceae) each consists of two species, and the rest twenty-nine families each consists of one species each. In line with the present study results, Sultan Mohammed and Berhanu Abraha (2013) from Yegof natural forest in North Wello Zone, and Birhanu Kebede et.al. (2010) from Gedo forest in the west Shewa zone were reported as the most diverse families of Fabaceae, Asteraceae, and Lamiaceae.

From the total woody species in the natural forest, about 13 species were endemic to Ethiopia, 79 were indigenous and only 1 was exotic species. The percentage distribution of the growth habit of woody species showed that shrubs occupied the highest woody floristic composition proportion followed by trees and woody climbers in the natural forest. The difference in the distribution of woody growth habits may be due to various factors notably: selective cutting of trees, insufficient ecological growth requirements e.g. soil properties, and dispersal variation among species. The present finding with regarding woody growth habit proportion, the dominance of shrubs and followed by trees, and climbers were reported in similar vegetation types of Boda dry evergreen Montane forest

(Fikadu Erenso et. al., 2014), Gedo dry evergreen Montane Forest (Birhanu et.al., 2010), Yegofa dry evergreen Montane Forest (Sultan Mohammed and Berhanu Abraha, 2013), and Biteyu dry evergreen montane forests (Mekonnen Biru et.al., 2003).

5.1.2. Plant Community types

The hierarchical classification showed that the samples quadrats are close together corresponding to sites that are similar in species composition were categorized under the same community. Based on the cover-abundance values of the identified species, five plant community types were recognized from the natural forest. The results from cluster analysis showed that the categorized community types varied in the number of quadrat size, and species composition potential ranging from 7-56, and 31-68, respectively. The variations could be attributed due to environmental gradients variation that can limit the ecological distributions of plant species, environmental factors such as altitude, aspect, slope, soil contents, and moisture stress that can limit the ecological distributions of plant species from specific area to area in the forest. Similarily, Tamrat Bekele (1993), Birhanu Kebede et al. (2010), and Ermias Lulekal (2014) were reported the variation in species composition among plant communities of a forest.

From the five plant communities identified in the natural forest, community 2 was found between altitudinal range from lower and intermediate ranges with 56 quadrats distribution and, it has relatively higher diversity (3.981) and species richness 68 (80.95%). For the existence of the highest woody species, diversity and richness in the community two were arisen due to the intermediate altitude contribute to the integrated moderated favorable environmental conditions to better heterogeneous plant growth together. This community was found surrounding the river and stream of the forest part in both eastern and western directions. In similar to the present finding, Dinkissa Beche, and Sebsebe Demissew (2011), and Gojjam Bayeh et.al. (2013) were reported that the highest species richness at a lower altitude.

The nature of plant communities largely depends on the ecological characteristics in sites, species diversity, and regeneration status of species (Khumbongmayum *et al*. 2006). Plant community type five was dominated by shrubs species particularly by *Erica arborea* and *Hypericum revolutum*. However, among identified plant communities, community 5 was poor in species richness 31 (36.90%) and species diversity (2.816). This could be due to it found at the highest elevation with a small number of 7 quadrats distributions and located near to the human settlement, and vulnerable to human and domestic animals interference. According to Brown and Lomolino, (1998); and Barry (2008) was noted that altitude plays a paramount role in plant species richness, diversity, and distribution by direct causes of climate, and soil properties are related to altitude and influence species growth. The plant diversity at any site is influenced by species distribution and abundance patterns (Palit and Chanda 2012) and the richness of plant species is controlled by a variety of biotic and abiotic parameters (Huston 1994). Topography, soil, climate, and geographical location of a region influence the vegetation diversity and species richness of the forest ecosystem (Ram et al. 2004).

5.1.3. Woody Plant Species Diversity, Richness, and Evenness

Species diversity

Species diversity in a given forest community is used to interpret the relative variation among the communities. Accordingly, the species diversity in the natural forest was varied between 2.82 and 3.98 among five plant communities. These variations were occurred in the forest due to the influence of environmental factors such as soil properties, micro-climate, elevation, and geographical location of a site. A change in species diversity is often used as an indicator of anthropogenic or natural disturbances in a forest ecosystem (Liu and Brakenhielm, 1996; Kalema, 2010). Among the communities, the highest species diversity was observed in community 2. The possible reason for the high species diversity could be attributed due to the large number of quadrats consisted, and the presence of optimum ecological growth requirement factors such as microclimate, altitude, slope, and adequate nutrient and moisture; because community 2 is found at an intermediate altitude. Species diversity plays a central role in ecology and conservation biology (Magurran, 2004) and is connected to ecosystem dynamics and environmental quality (Kalema, 2010).

According to Kent and Coker (1992) were recommended, Shannon-Weiner index (H') values range between 1.5 and 3.5, (which indicate that: if H' > 3 = good, If H; value is between 3.0 and 2.0 = medium, and if H' < 2.0 = low species diversity). The overall Shannon-Wiener diversity index of woody species in Yerer natural forest was 3.39; indicating that the diversity index is relatively high, which grouped under good species diversity (a better combination of the number of species and their relative abundance) as compared with the recommended diversity index values. This high species diversity may be due to the high elevation difference observed between 2265 - 3103 m.a.s.l. However, the least number of species diversity was recorded in community 5. This could be due to the community found at the margin of the elevation at the peak of the mountain where there are settlements and hence exposed to some anthropogenic activities such as selective cutting of matured trees and shrubs, grazing, and browsing by domestic animals. Because many local people had settled near to the top mountain during the Derge regime in settlement programme as compare to the other plant community types sites. In addition to the human disturbance, the high elevation areas have has a very low temperature, which reduces the diversity of species that can get established in these areas. In a similar finding, Gojjam Bayeh et.al. (2013) reported the lowest species diversity index at a higher elevation of the similar forest type. However, in contrary to the present finding Mekonnen Biru et.al. (2003) at Biteyu dry evergreen montane forest and Birhanu Kebede et al. (2010) at Gedo dry evergreen montane forests were reported the least species diversity index at lower and intimidate elevations, respectively.

Species richness

The present study revealed that the species richness in Yerer natural forest was varying between 31 and 68 species among five plant communities. Accordingly, the present study revealed that the highest woody species richness was observed in community 2, followed by community 4. The possible reasons for the high species richness of community 2 attributed might be due to fewer disturbances (found at the center of the forest) and intermediate altitudinal factor because intermediate altitude could be associated with moderately favorable environmental conditions that permit rapid resource acquisition to favor for different plant species ecological growth requirement satisfy. Besides another reason for the highest value of species richness in community 2 may be due to the wide variation of the altitudinal range of the community. According to Huston (1994), the richness of plant species variation among plant communities within the forest may happen due to a variety of biotic and abiotic parameters influence the species growth.

Similarly, reports from other studies also indicated that species richness and diversity tend to peak at an intermediate altitude and decline at the lower and upper elevations (Desalegn Wana and Zerihun Woldu, 2005).

However, community type 5 exhibited the least species richness. This community lies along the margin of the forest and at the higher elevation of peak Mountain. This is due to the plant community 5 occurs at a vicinity to human settlements subjected to high anthropogenic influences, grazing by livestock. As elevation rises, temperature becomes declines, and precipitation increases which causes the existence of soil organic matters erosion and soil mineral nutrients leaching (Körner, 1998), and these factors eventually affect the dispersal of plant species from place to place by water dispersal agent (Lomolino, 2001), all these combines create unfavorable environmental conditions to different species grow and survive.

Evenness

The present study result showed that the species evenness (equitability) values of Yerer natural forest ranged between 0.82 and 0.94 among plant communities. The possible reason for the variability of evenness values between each community type could be due to the difference in the number of species, cover-abundance values, degree of disturbance, and the slope of the quadrats in the community. Species evenness is simply measured by the relative proportional abundance of a similar species in a plant community. Low species evenness value implies the dominance of the few species in a community, whereas high species evenness represents the even distribution of different species in the area. The variation of species evenness values change between communities in the forest might be due to disturbance in the area (Fosaa, 2004). The highest species evenness value was observed in community 2 and followed by community 3. This could be contributing to the high species evenness by the even distribution of different species in the community. According to Kent and Coker (1992), the species evenness **(**equitability) value ranges between 0 and 1 which represents 0 value (low species evenness), and 1 (high species evenness). Accordingly, the overall Shannon evenness in Yerer's natural forest was 0.860, indicating that the evenness of woody species in the forest is high.

The overall Shannon Evenness Index (E) is relatively high (E = 0.86), as compared to similar dry evergreen Montane forests such as Boda forest reported by Fikadu Erenso et. al. (2014) and Yegof natural forest reported by Sultan Mohammed and Berhanu Abraha, (2013). The least species evenness was observed in community 5 and followed by community 4. The possible reason for the low species evenness value in community 5 is probably could be dominant by few species in the entire sample quadrats of a community due to selective cutting of economic importance species, and the local environmental disturbances which led to unfavorable conditions to woody species growth. Similarly, other workers of Alemayehu Wassie and Demel Teketay, 2006, and Fikadu Erenso et. al. (2014) were reported that low species evenness occurred in a particular vegetation type due to the extreme environmental disturbances, variable conditions for regeneration, and selective exploitation of some species.

5.1.4. Floristic species similarity among plant community types

Generally in Yerer Mountain natural forest, the variations of species composition and diversity were observed among communities. The overall species composition similarity coefficients among the five plant communities were ranged from 36 - 78%. Among the five communities comparison, community two has the highest similarity with community 4 and followed with community 3 in floristic composition. The possible reason for the highest similarity between these communities could be due to the existence of some quadrats adjacent to each other, geographical proximity, the close similarity of altitude and slope ranges (i.e. at lower level community 4 and 3 are found within a community two ranges in both altitude and slope) that reveals the ecological requirement of nutrients availability by those species and the adaptation of plants to that particular environment. Similarly, Desalegn Wana and Zerihun Woldu (2005), and Dereje Denu et.al. (2006) reported, in addition to the altitudinal gradient, other environmental factors such as aspect, slope, and soil Physico-chemical properties have sound effects on patterns of plant species composition among communities. If two communities have similar vegetation species they need similar environmental conditions (Oksanen, 2004).

However, the lowest species similarities were observed between community five and one (36%), and five and three (42%). The possible reasons for the higher species dissimilarities between communities might arise from the different number of sample quadrat sizes (7, 20, 32), altitudinal differences, slope differences, degree of human impact (anthropogenic) action variation, climatic conditions, and species growth ecological requirement variation. If two communities have different vegetation species they require different environmental conditions for proper growth (Oksanen, 2004). For all communities, the Sorenson's similarity coefficient values were below 0.5, indicating the existence of low similarities and higher dissimilarity among the recognized communities which in turn implies that all the community were important in terms of floristic diversity and needs attention from a conservation point of view (Shambel Bantiwalu, 2010; Shambel Alemu 2011, Fikadu Enerso et al., 2014).

5.1.5. Vegetation Structure

DBH classes' distribution

The woody structure of the entire Yerer natural forest was showed that the higher stem densities observed in the lower diameter classes and progressively declining stem densities with increasing diameter classes. The occurrence of the highest number of individuals stems in the lower DBH size classes and a gradual decrease towards the higher classes of DBH in the forest of a particular area is often referred to as an 'inverse J-shape' curve, which indicative of good reproduction and recruitment status of the forest. The possible reason for the highest numbers of woody stems density in the lower DBH class could be attributed due to the dominance of shrubs (59.14%), and woody climbers (13.98%) in a natural forest which indicating a better distribution of woody species in the lower DBH classes. The probable reasons for the prevalence of small-sized individuals at lower Dbh classes might be due to forest developed historically under anthropogenic disturbance with excessive selecting cuttings of large-size individuals as indicated by the lower large-sized individuals. Similar results were reported from similar forest types in Ethiopia by Tamrat Bekele, (1993, 1994), Alemayehu Wassie et al. (2005), Birhanu Kebede et al. (2010), Dinkissa Beche, and Sebsebe Demissew (2011), Sultan Mohammed and Berhanu Abraha, (2013), and Gojjam Bayeh et. al. (2013), from Wof-Washa Forest, Gedo forest, Menagesha-Suba forest, Yegof forest, and Aba Asrat Monastery forests, respectively.

Height classes' distribution

The height class distribution follows a similar trend with that of the DBH-class distribution. The present results revealed that the largest numbers of woody species density, 468 (49.21%) of stems were recorded in the lowest height class of 2 – 5 m, and followed by 5.1 – 10 m height class with 359 (37.75%) stems per hectare. The height distribution patterns of Yerer natural forest were characterized by fewer individuals at mature stage than middle and young age of woody species. The variation of height distribution pattern indicates the general trend of individual woody height dynamics and the recruitment status of the species in the study forest. The overall height class distribution shows an inverted J-shaped like that of Dbh class distribution in the forest. This height distribution pattern indicates that the majority of the species had the highest number of individuals in the lower height class, and a gradual decrease towards the upper size woody height, which in turn shows that the forest woody species has good reproduction, and recruitment potential in continuity manner. The possible reason for the highest numbers of woody stems density in the lower height class might be attributed due to the dominance of shrubs (59.14%) in a forest. The percent distribution pattern of woody species density declined with raising height classes indicates a characteristic of the high rate of regeneration status in the Yerer natural forest, for instance, the study results confirmed that a total of 1354 (39.67%) seedlings/ha > 1108 (32.46%) saplings/ha > 562 (59.14%) shrubs/ha > 389 (40.90%) trees/ha based on the woody plant growth height categories. Similar results were reported from similar forest types in Ethiopia by

Mekonnen Biru et.al. (2003), Abate Ayalew et. al., (2006), Birhanu Kebede et al. (2010), Gojjam Bayeh et. al. (2013), and Hailemariam Mesfin and Temam Tamiru (2018).

The density of Woody Species

The average number of individual woody species (tree, shrub, and woody climber) with DBH > 2 cm in Yerer natural forest was 951 individuals per hectare. The distribution of woody species density in different DBH and height size classes showed an inverted J-shaped or positively skewed shape distribution. This pattern indicates that the majority of the species had the highest number of individuals' density in lower DBH and height size classes which in turn showed that the forest vegetation has good reproduction and recruitment potential. The overall woody stems density structure of the entire Yerer natural forest showed that the numbers of stem densities progressively declining as increasing Dbh and height classes. This tells as the dominance of small-sized individuals and the presence of high regeneration of woody species, and probably the selective cutting of bigger tree species in the forest. Similar results were reported in similar forest types by Birhanu Kebede et al. (2010), Gojjam Bayeh et. al., (2013), and Hailemariam Mesfin, Temam Tamiru (2018) from Gedo forest, Aba Asrat Monastery forest, and Gole natural forest, respectively.

The ratio of woody species density DBH ≥10 cm and ≤20 cm to DBH >20 cm is taken as a measurement of the density size class (Grubb et. al., 1963). Accordingly, the ratio at these densities in Yerer's natural forest was 2.23. This result was indicated that the proportion of lower and medium-sized individual's woody species is larger than the large-sized individuals, which indicates that Yerer's natural forest is the second regeneration stage and dominated by shrubs and climbers than trees. When the present value was compared with some other similar forests in Ethiopia, the ratio of Yerer natural forest (2.23) was found to be higher than that of Gedo forest (1.79), Yegof forest (1.95), Wof-Washa forest (1.5), and Denkoro forest (1.90) were reported by Birhanu Kebede et al. (2010), Sultan Mohammed and Berhanu Abraha, (2013), Tamrat Bekele (1993), and Abate Ayalew et al., (2006), respectively. The higher value of the ratio of woody with DBH $\geq$10 cm and $\leq$20 cm to DBH >20 cm indicating a higher predominance of small-sized individuals in Yerer natural forest than the compared similar forests.

Basal area (BA) of woody species

The total basal area of all woody species in Yerer natural forest was 46.82 $m^2 \cdot ha^{-1}$ which calculated from DBH of individual woody species. Among the identified individual woody species in the study area, the seven (7) top of species *Juniperus procera, Olea europaea* subsp. *cuspidata, Maytenus arbutifolia, Myrsine africana, Rhus retinorrhoea, Carissa spinarum,* and *Dodonaea angustifolia* contributing about 62.77% of the total basal area. Based on the DBH class categories the highest basal area of woody species of 11.24m^2/ha (24.01%) was observed in the second DBH class of 10.1-20 cm than the first DBH class of 2-10cm which contribute 6.00 m^2/ha (12.82%), but the highest density of woody species was observed in the first DBH class. This may be due to the basal area of individual woody species is dependent on the size of individual DBH rather than the density of stems, because the basal area is calculated from DBH data. Therefore, the woody species belonging to higher DBH classes contribute higher to the total basal area than woody species with a low DBH classes. In similar to this finding Dereje Denu et. al. (2006), and Birhanu Kebede et.al. (2010) were noted that woody species with the highest basal area do not necessarily have the highest density, but depend on the DBH size difference between the species. Species with the largest contribution in dominance value via higher basal area could be considered as the most important species in the particular study forest. In the study area, the basal area analysis across individual species showed that there was high dominance with very few woody species among the identified species.

The basal area of Yerer natural forest (46.82 $m^2 \cdot ha^{-1}$) was higher than the basal area of similar forest types of Gedo forest (35.45 $m^2 \cdot ha^{-1}$), Menagesha-Suba forest (36.1 $m^2 \cdot ha^{-1}$), and Denkoro forest (45 $m^2 \cdot ha^{-1}$), but less than the basal area of Boda forest (114.64m2/ha), Wof-Washa forest (101.8 $m^2 \cdot ha^{-1}$), and Gole natural forest (49.2 $m^2 \cdot ha^{-1}$), which reported by Birhanu Kebede et al. (2010), Dinkissa Beche, and Sebsebe Demissew (2011), Abate Ayalew et. al. (2006), Fikadu Erenso et. al. (2014), and Hailemariam Mesfin, Temam Tamiru (2018), respectively. General, the results of basal areas of different similar forest types showed different values from place to place in a country. These basal area variations among different forest types might be occurred due to Dbh size difference between species, and dominant woody species density variations. Because forest consists of higher Dbh class sizes and many large sizes of woody species density could be contributing to higher basal area produce, and vice versa. The present finding of the basal area provides information about the relative significance of the species than simply counts the stems sizes.

Important Value Index (IVI)

The Important Value Index (IVI) of a species is an important parameter that is used to express the relative ecological significance of the species in the forest ecosystem (Lamprecht 1989). The Importance Value Index (IVI) of the woody species was calculated from the data of relative frequency (RF), relative density (RD), and relative dominance (RDo). The Importance Value Index (IVI) of individual 93 woody species in the study area result showed that variation values from the lowest to highest. This variation of IVI values could be due to the different ecological importance, resources demand availability (soil nutrients) surrounding species, and disturbance factors for the preference of each species in the natural forest. The analyzed IVI value of Yerer natural forest was revealed that the forest is dominated by the top ten (10) few woody plant species. Accordingly, the top ten (10) most leading dominant and ecologically sound woody species in Yerer natural forest in their IVI values descending order are *Juniperus procera*, *Myrsine africana, Carissa spinarum, Olea europaea* subsp. *Cuspdata, Maytenus arbutifolia, Osyris quadripartita, Rhus retinorrhoea, Rhus vulgaris,* and *Rosa Abyssinia.* The probable reasons for the leading dominant and ecologically sound woody species could be attributed due to the most successful species in regeneration, pathogen resistance, less preference by browsing animals, more attraction of pollinators, and less attraction of seed predators that facilitate seed dispersal within the existing environmental conditions. Simon Shibru and Girma Balcha (2004) stated that species with the greatest importance value are the leading dominant of specified vegetation.

In the study area, among the 10 leading dominant and ecologically sound woody species, the highest IVI value of *Juniperus procera 45.36 (15.12%)* was due to the result of its high relative frequency, relative density, and relative dominance. Because the Importance Value Index combines data from three parameters of relative frequency (RF), relative density (RD), and relative dominance (RDO). In keeping with Mueller-Dombois and Ellenberg (1974), the relative ecological significance and/or dominance of a tree species in a forest ecosystem could best be identified from IVI analysis. Hence, in this investigation, the IVI results also approved that *Juniperus procera*, *Myrsine africana*, and *Carissa spinarum* were the most important species which contributed more than 6% of IVI each in the study area. In this study, the IVI result confirmed that these three species (*Juniperus procera*, *Myrsine africana*, and *Carissa spinarum*) are the most significant/dominant species in Yerer natural forest. However, *Podocarpus falcatus* (0.19), *Paullinia pinnata* (0.23), and *Dregea schimperi* (0.25) were the least dominant species in a natural forest, because they had the least relative dominance, relative density, and relative frequency, which indicate these woody species are vulnerable and need direct conservation measure to save them. This means general, the importance value index of woody species in Yerer natural forest ranged from 0.19 to 45.36, which indicates the variation of the ecological importance of different woody species in a forest ecosystem.

5.1.6. Regeneration status of woody plants

The overall study result showed that the majority (> 50%) of the existing species were belonging to more seedlings than saplings and saplings than mature woody species (priority 4). The ratio of seedlings to saplings was 1.22, the ratio of seedlings to mature individuals of woody species was 1.42, and the ratio of sapling to mature individuals was 1.17 in the forest. These revealed that the distribution of seedlings density is greater than a sapling, and saplings density is greater than mature woody density (i.e. density of seedlings > saplings > mature woody), which indicates the woody species had successful healthy regeneration profiles within the study area of forest. These results indicated the presence of a higher number of seedlings and saplings than the matured parent woody species reflected a good regeneration status performance. This could be due to the availability of the woody species seeds continuously laid to the ground from the mature parent species, the presence of excessive seeds in the seed bank, the viability of germination seeds, less shade effect due to open canopy in the forest, the favorable environmental conditions and good sufficient ecological growth requirements which facilitate seeds germination and support for survival and growth of seedlings and saplings of the woody species. Similar results were reported by Kadavul and Parthasarathy (1999), and Webb and Sah (2003). As compare the present study result with similar forest types, the density of seedlings and saplings of Yerer natural forest was greater than the density of seedlings and saplings of Gedo dry evergreen Montane forest (Birhanu Kebede et. al., 2010), and Aba Asrat Monastery dry evergreen Montane forest (Gojjam Bayeh et. ai., 2013). However, the density of the regeneration status of the present study result was less than the density of seedlings and saplings reported by Sultan Mohammed and Berhanu Abraha, (2013) from Yegof dry evergreen montane forest in North Wello Zone.

Even though the regeneration status of woody species in the forest is good, it has been observed that few woody species are regenerating poorly (priority 2) and not regenerating at all (priority 1). The “poor” regenerating class of woody species includes *Salix mucronata*, *Pterolobium stellatum*, *Croton macrostachyus*, *Podocarpus falcatus*, *Millettia ferruginea, Rumex nervosus, Solanum marginatum,* and *Cussonia arborea*. The distribution pattern of poor regeneration statuses of woody species was showed the species found only either at the sapling or seedling stage. These could be due to the absence of woody species seeds in seed banks due to eating before they germinate by living organisms or death of seedlings with unsuitable resources, soil erosion, shade effect, or the presence of pests (pathogens, insects) which attack seeds and/or seedlings. Besides these the unfavorable environmental conditions of soil moisture stress, temperature, and levels of light availability factors also may alter the germination and/or survival of seedlings in the forest stand. The present finding was agreed with Mwavu, and Witkowski, (2009), Pokhriyal et al. (2010) findings.

Moreover, individuals of woody species at the young stage are more susceptible to any kind of environmental stress and anthropogenic disturbance. The "none" regenerating class of woody species are *Grewia ferruginea, Vernonia amygdalina, Solanecio gigas, Embelia schimperi, Phoenix reclinata, Bersama abyssinica, Ekebergia capensis,* and *Cordia africana.* Those woody species with no regenerate or recruitment in the forest indicate that the future survival of these species would be at risk as there were no individuals that replace the mature individuals. For instance, the hampered regeneration for species in "priority 1" could be the results of either most trees are not producing seeds due to age or there could have been losses due to predators after reproduction. The present finding was agreed with Mwavu, and Witkowski, (2009), Pokhriyal et al. (2010), and Iqbal et al. (2012) findings report. Competition between species can be the cause of the hampered regeneration status of the species. According to Feyera Senbeta et al. (2015), the Bell form pattern woody species regeneration status shows that poor reproduction and regeneration can associate with strong competition from the encompassing trees.

The regeneration or recruitment potential of woody species is one of the major elements that are useful to suggest the individual woody species conservation status. Providing a generalized suggestion for deficient seedlings and saplings (priority class 1 and 2) is difficult since several reasons could account for no and/or poor regeneration status of some woody species in the natural forest. The present finding of poor regeneration of woody species might indicate that the future fate of this forest could be with declined species richness and abundance. Moreover, the complete absence of regeneration species' might show that the future forest of the study area might lose these species from its floristic list unless proper actions are taken like paying attention to the conservation of coppices of these species. Natural regeneration is a central component for tropical forest ecosystem dynamics (Getachew Tesfaye et al. 2010) and is crucial for the management and conservation of biological diversity (Rahman et al. 2011).

5.2. Effects of plantations of exotic tree species on understory native vegetation species composition, and density changes

5.2.1. Effect of exotic tree plantations on native vegetation composition, and density

The native vegetation species richness in five different forest land-use systems (LUS) ranged from 71 to 181 species. The extent and type of land use directly affect local and global biodiversity. In the study area among the five forest land-use systems, the highest native species richness was found in the natural forest. This showed that the potential of natural forest to a more favorable habitat for understory native vegetation species richness and diversity harbor than exotic tree plantation forests. The possible reasons for the highest native species richness in the natural forest than plantation exotic tree species might be due to facilitate the regeneration of understory native species by improving soil Physico-chemical properties to facilitate regeneration, growth, and survival, by the role of dispersal mode, and the origin of seeds (seed bank or seed rain) internal from native parent plant species than exotic tree plantation forests with ranged from open to moderately closed canopies in the natural forest which give a chance for both light and shade demanding vegetation species growth, and survival. These suggestions have supported by the findings of better soil Physico-chemical properties, and high seed banks species composition and density observed in Yerer natural forest than a plantation of exotic tree species under similar climatic conditions in the area. The present finding agreed with the findings of Eshetu Yirdaw (2001), Shiferaw Alem and Tadesse Woldemariam 2009), and Kitessa Hundera (2010), who observe the higher native species composition in natural forest land than plantation forests.

Among the four exotic tree plantation forests, the highest number of species were recorded in *Grevillea robusta* and followed by the *Cupressus lusitanica* plantation forest. The composition of understory native vegetation species under different plantation exotic tree species was influenced by overstory exotic tree species. The exotic tree species can “facilitate” or “inhibit” the understory native vegetation diversity through habitat modification. Hence, *Grevillea robusta* species could enhance the understory native vegetation regeneration and growth through better soil Physico-chemical properties, and micro-climate modification. Similarly, Eshetu Yirdaw (2001) was observed that a higher number of native vegetation species under the *Grevillea robusta* plantation forest than *Cupressus lusitanica* and *Pinus patula* plantation forests. However, among the five forest land-use systems (LUS), the lowest species richness was observed in *Eucalyptus globulus* and followed by the *Pinus patula* plantation forest. The lowest native species richness in *Eucalyptus globulus* and *Pinus patula* plantation forest land-use systems (LUS) might be happened due to the fast-growing species are more competing nutrients and water, by negatively changing soil properties, by creating site conditions unsuitable for native vegetation to re-establish, and by allelopathic effects via released allelochemicals into the soil through leaf litter and water runoff from these exotic tree species that lead to inhibit native vegetation establishment, sustainable growth, and survival. In line with the present finding, Kitessa Hundera (2010) was observed the lowest native species composition and density under *Eucalyptus camaldulensis*; and *Eucalyptus saligna* plantation forests than natural forest; *Pinus patula*; and *Cuppressus lucitanica* plantation forests in Belete forest. However, in contrast to the present finding, Feyera Senbeta, and Demel Teketay, (2001) were observed the highest number of native species composition under the *Eucalyptus globulus* plantation forest than natural forest and other exotic tree plantation forests in central Ethiopia.

In the study area, the maximum and minimum mean values of the number of native species richness and species density/ quadrat distributions were observed in natural forest and *Eucalyptus globulus,* respectively. The possible reasons for the highest number of native species richness and species density in the natural forest than plantation exotic tree species might be due to internal good environmental conditions (good soil properties, micro-climate, soil water content), more access of seeds sources internal from different species of parent plants, and low human disturbance of the forest. The present finding result agreed with Eshetu Yirdaw (2001), Kitessa Hundera (2010) reported in Belete Forest.

However, the reason for the lowest number of native species richness and species density observation under the *Eucalyptus globulus* plantation forest was probably due to poor soil properties in the forest, and allelopathic effect contributed to inhibiting the understory native vegetation established and growth. Eshetu Yirdaw and Olavi (2003) reported that the lower number of native species richness and species density under the *Eucalyptus globulus* plantation forest than the adjacent natural forest in the central highland of Ethiopia. In contrast to the present finding, Feyera Senbeta and Demel Teketay, (2001) observed the highest number of native species composition and species density under the *Eucalyptus globulus* plantation forest than natural forest and other plantation forests in central Ethiopia. Among the plantation exotic tree species forests, the maximum number of native species richness and species density/quadrat were observed under *Grevillea robusta* and followed by *Cupressus lusitanica* plantation forest. This might be occurred due to better soil Physico-chemical properties, well favorable micro-climate conditions, and free allelopathic effects.

5.2.2. Effect of the different plantation of exotic tree species on native vegetation species diversity, richness, evenness, and woody species regeneration and density

Determining species richness is important to measure the importance of an area for biological diversity conservation and management. Across forest land-use systems the native woody species richness laid between 71 and 181 species. The result of species diversity indexes (*H′*) and evenness of forest stands revealed that generally, natural forest stand was more species richness (181), diverse (4.91), and more abundance (0.95) than all plantation exotic tree species in the study area. The possible reasons for the highest species richness and diversity index of natural forest attributed might be due to fewer disturbances than exotic tree plantation forest, moderate favorable environmental condition factors that permit rapid resource acquisition to favor for most native vegetation regeneration and growth, but the reason for high species evenness was due to the even distribution of different species in the natural forest. Currently, due to low anthropogenic disturbances and the conducive micro-environmental conditions (soils, moisture) in the natural forest increase germination and growth rates of native vegetation. In similar to this result Shiferaw Alem and Tadesse Woldemariam (2009) were observed the highest diversity of species (2.74) in the natural forest than the plantation forest (2.19).

The present findings have illustrated those better soil properties and moisture conditions in the natural forests than plantations of exotic species in the area. The native natural forest is a superior habitat to native vegetation species; often supports higher species richness and abundance of native species than plantations of exotic tree species. On another hand, plantations of exotic tree species generally have lower species diversity, richness, and abundance due to fewer specialists introduced species colonized spaces and more compete for nutrients and water to natural regenerate of understory native vegetation. Other workers were also reported that the diversity of native flora found in tree plantations is generally lower than in primary natural forests (Felton et.al, 2010).

On the other hand, the *Eucalyptus globulus* plantation forest had the least species richness (71), the diversity index (3.61), and evenness (0.83) than the other plantation forests and adjacent natural forest. This may be attributed to different factors of *Eucalyptus globulus* plantation forest hampered the native vegetation species through negatively affecting soil properties and soil water holding capacity, created unfavorable micro-climate conditions, and allelopathic effects. Particularly, the higher bulk density might probably create unfavorable soil conditions through limiting regeneration, root growth, and air circulation, which in turn have negative implications for plant growth. In contrast to these results, Feyera Senbeta and Demel Teketay, (2001) were observed the highest species richness, diversity, and evenness/abundance under the *Eucalyptus globulus* plantation forest than natural forest and other plantation forests in central Ethiopia.

Entire the five forest LUS a total of 77 woody species were recorded under four exotic tree plantation forest stands and adjacent natural forest. The naturally regenerated native woody species composition was varied between 22 to 66 species among forest LUS. Out of the total woody species recorded in the study area 24 woody species were recorded only in natural forest. The different populations of naturally regenerated native woody species density/ha were ranged from 760 to 3396 in different forest land-use systems. The present finding result indicated that the highest naturally regenerated native woody species composition and density were recorded in the natural forest than that of all exotic tree plantation forests in Yerer area. This could be attributed due to the mechanisms that encourage the understory native woody regeneration through less shading effect due to less canopy cover with ranged from open to moderately closed canopies in a natural forest, enhancing soil nutrients, better internal micro-climate modification, access of seeds sources from nearby parent species canopies, and available seeds dispersal by dispersal agents that create favorable conditions to increase the chance for seed germination, seedlings establishment, and sustainable growth of regenerated woody species. The other workers were observed that the higher naturally regenerated native woody species composition and density in the natural forest than *Cupressus lusitanica*, *Pinus patula* plantation forest, (Feyera Senbeta and Demel Teketay 2001, Kitessa Hundera 2010***),*** plantation forests ***(***Shiferaw Alem and Tadesse Woldemariam 2009)**,** *Eucalyptus globulus* plantation forest (Getachew Kassa, 2018).

However, the lowest naturally regenerated native woody species composition and density were observed in the *Eucalyptus globulus* plantation forest. On the other hand, the *Eucalyptus globulus* plantation forest was overall less natural regenerated woody species composition and density than natural forest and other exotic tree plantation forests (*Cupressus lusitanica, Grevillea robusta,* and *Pinus patula*). This may be due to the factors of nutrient competition (fast-growing tree species are more competitive for nutrients than native woody species), by negative effects on soil physico-chemical properties led to hinder regeneration of native species, lack of viable seed sources from the canopy species as well as limited seed dispersal into the *Eucalyptus globulus* plantation forest due to unattractive seed dispersal agents, and allelopathic effects caused by tannins produced by the plants via the allelochemicals are deposited into the soil through leaf litter and water runoff from the trees led to inhibit seedlings establishment and sustainable growth. In line with the present finding, Kitessa Hundera (2010), and Getachew Kassa (2018) were reported the lower native woody species composition and density under *Eucalyptus* plantation forests than the adjacent natural forests in different sites of Ethiopia.

Among the four exotic tree species plantation forests, the higher species composition and density of naturally regenerated native woody species were observed in the *Grevillea robusta* plantation forest. The different types of exotic tree plantation species were varied in their ability to facilitate understory native woody species regeneration status and their densities This probable due to various factors of internal favorable micro-climate condition modifications, better-stabilizing soil properties and soil water holding capacity, and more attracting seed dispersal agents that make seedlings establishment and sustainable growth of understory native woody species in the Yerer area. Feyera Senbeta and Demel Teketay, (2001), and Kitessa Hundera (2010) were observed a different number of native woody species composition and density under different exotic tree species plantation forests.

The ratio of seedlings and saplings to the mature woody plants in the natural forests was 1.26 and 1.07, respectively. These results indicated the presence of a higher number of seedlings and saplings than the mature woody species and these reflected a successful healthy regeneration status performance. This could be attributed due to better viable seed sources from the internal woody canopy species as well as available seed dispersal into the natural forest due to attractive seed dispersal agents, and internal favorable environmental conditions that facilitate the establishment of seedlings, and growth than exotic tree plantation forests. In line with the present finding, Ahmed Endris et. al. (2017)

was observed the higher density of seedlings than saplings, and saplings than the mature woody species density in natural forest.

However, the ratio of seedlings and saplings to the mature woody plants in all plantation exotic tree species was less than one (<1). These results indicated the presence of a lower number of seedlings and saplings than the mature woody species. This could be due to human intervention, shade effect, soil compaction, lack of viable seed sources from the canopy species as well as limited seed dispersal into these exotic tree plantation forests due to unattractive seed dispersal agents, and the presence of pests that attack seeds, seedlings and/or saplings. Seedlings and saplings abundance analysis confirmed that the regeneration potential of native woody species under the exotic tree plantation forests may be a problem unless proper management strategies are soon carried out. Getachew Kassa (2018) was observed the density of seedlings (699) > saplings (344) < matured woody (404) in plantation forest in Qimbaba Forest, North West Ethiopia.

5.2.3. Native floristic composition similarity comparison among five forest land-use systems (LUS)

The common numbers of species shared by any two forest land-use systems (LUSs) were ranged between 36 to 72 species. Among the identified vegetation species (211 species), about 32 species (15.17%) were commonly observed in all five forest land-use systems. The common plant species found in all five forest land-use systems include *Andropogon abyssinicus, Bidens pilosa, Clematis longicauda, Clerodendrum myricoides, Commelina diffusa, Crepis rueppellii, Crotalaria laburnifolia, Cynoglossum amplifolium, Cyperus rigidifolius, Dodonea angustifolia, Geranium ocellatum, Gnaphalium rubriflorum, Gnaphalium tweediae, Jasminum grandiflorum, Juniperus procera, Kalanchoe petitiana,* *Laggera tomentosa, Lippia adoensis, Myrsine africana, Olinia rochetiana, Osyris quadripartite, Panicum atrosanguineum, Pennisetum sphacelatum, Pimpinella heywoodii*, *Rosa abyssincia*, *Satureja abyssinica, Satureja punctate, Sida schimperiana, Sonchus asper, Thymus schimperi, Trifolium decorum*, and *Verbascum sinaiticum.* These 32 native species grown commonly in all five forest land-use systems indicate that they have a resistance potential to adapt under different micro-environmental variations in different land-use systems, and probable they have a potential of nutrient and water competition to plantations of exotic tree species and others native species in the study area. However, 66 species (36.49%) were observed only in one forest LUS. These native species probably required a specific micro-environmental condition (soils, water, and micro-climate) under the specific land-use systems to germinate, survive, and grow. Generally, these results were indicated that it is very clear that the five forest land-use systems (LUSs) at Yerer represent different native vegetation species composition and diversity. Similarly, different workers were reported different native plant species under different forest land-use systems (Mulugeta Lemenih et. al., 2004, Feyera Senbeta et. al. 2002, Kitessa Hundera 2010).

According to the Jaccard similarity index the overall species similarities/ homogeneity among five different forest land-use systems in the study area revealed that less than 50%, this indicated that relatively high heterogeneity of forest land-use systems leads to the creation of vegetation diversity or variety in the area. Generally, the similarity/ homogeneity between *G. robusta* and *P. patula* forest LUSs is the highest (JCS = 0.49) than the rest four forest LUSs. General, 60 vegetation species are commonly found in both *G. robusta* and *P. patula* forest LUSs, among these, the 21 species distribution were observed in more than three quadrats frequency in both forest LUSs are *Ageratum conyzoides, Andropogon abyssinicus, Commelina diffusa, Crotalaria laburnifolia, Croton macrostachyus, Geranium ocellatum, Gnaphalium tweediae, Helichrysum schimperi, Jasminum grandiflorum, Juniperus procera, Laggera tomentosa, Lippia adoensis, Olinia rochetiana, Pennisetum sphacelatum, Pimpinella heywoodii, Plantago lanceolata, Plectocephalus varians, Rosa abyssincia, Satureja abyssinica, Sida schimperiana,* and *Verbascum sinaiticum.* Similarily, Tesfaye Bekele, and Wendawek Abebe (2018) observed the higher similarity index between plantations of exotic tree species.

On the other hand, among exotic tree plantation species forest lands, the maximum Jaccard's similarity index value is exhibited between *G. robusta* and *P. patula* plantation forests. This attributed due to geographical proximity, the close similarity of altitude and slope ranges, uniform climatic conditions, close similar edaphic conditions, plant growth ecological requirements of resources available to similar native vegetation species in the two plantation forests to adaptation that particular environment. Inline with the present finding, Tesfaye Bekele and Wendawek Abebe (2018) reported the high similarity coefficients of 0.743 (74.3%) between *Eucalyptus camaldulensis* and *Cupressus lusitanica* plantation forests. In contrast to the present finding, Feyera Senbeta (1998); and Feyera Senbeta and Demel Teketay (2001) were reported the lower species similarity among different exotic tree plantation forests in different sites of Ethiopia. The vegetation species (21 species) which are found only in *P. patula* plantation forest but not found in *G. robusta* plantation forest: *Anthemis tigreensis, Argyrolobium fischeri, Carissa spinarum, Centella asiatica, Cyperus papyrus, Daucus hochstetteri, Fimbristylis complanata, Gomphocarpus purpurascens, Indigofera arrecta, Jasminum abyssinicum,* *Maesa lanceolata, Monopsis stellarioides, Plectranthus garckeanus, Prunus Africana, Rhamnus prinoides, Salvia nilotica, Senecio myriocephalus, Solanum glganteum, Vernonia auriculifera,* and *Zehneria scabra.*

In the comparison of species similarity of exotic tree plantation species with the natural forest stand, *C. lusitanica* plantation forest (JCS=0.37), and *P. patula* plantation forest (JCS=0.32) stands showed higher similarity. The vegetation species (12 species) found in *C. lusitanica* plantation forest, but not occurred in the natural forest are *Adiantum capillus-veneris, Ageratum conyzoides, Bidens macroptera, Bidens prestinaria, Centella asiatica, Cymbopogon caesius, Galinsoga parviflora, Inula confertiflora, Launaea cornuta, Satureja imbricate, Solanum indicum,* and *Verbena officinalis.* However, plant species found in the *P. patula* plantation forest include *Ageratum conyzoides, Centella asiatica, Cymbopogon caesius, Cynoglossum coeruleum, Cyperus papyrus, Galinsoga parviflora, Gomphocarpus purpurascens, Laggera crispate, Leucas martinicensis,* and *Plantago lanceolata.* Similarly, Kitessa Hundera (2010) was observed higher species similarity between natural forest and *C. lusitanica* plantation forest (JCS=0.80), and between natural forest and *P. patula* plantation forest (JCS=0.80). Feyera Senbeta and Demel Teketay (2001) were observed the higher species similarity between natural forest and C. lusitanica (JCS = 0.46), and between natural forest and P. radiate (JCS = 0.46) plantation forests in Central Ethiopia.

The least species similarity/ homogeneity was observed between natural forest and *E.globulus* (JCS = 0.26), between natural forest and *G. robusta* (JCS = 0.26), and between *C. lusitanica* and *G. robusta* (JCS = 0.26) forest land-use systems. This may be happened due to the overstory woody species influence variation on understory native plant species, internal micro-climatic modification conditions variation, soil properties variation, species growth ecological requirement variation, and degree of human impact (anthropogenic) action variation. Similarly, Feyera Senbeta and Demel Teketay (2001) were observed the lower species similarity between natural forest and *E.globulus* (JCS = 0.39) in central Ethiopia.

The plant species found in *the E. globulus* plantation forest but not found in the natural forests are *Commelina benghalensis*, *Cymbopogon caesius*, *Galinsoga parviflora, Launaea cornuta, Oreoschimperella verrucosa*, and *Plantago lanceolata.* The plants' species found in *G. robusta* plantation forest but not found in the natural forest are *Achyranthes aspera, Ageratum conyzoides, Bidens macroptera, Bidens prestinaria, Cymbopogon caesius, Cynoglossum coeruleum, Echinops longisetus, Euclea racemosa, Galinsoga parviflora, Inula confertiflora, Launaea cornuta, Leucas martinicensis, Plantago lanceolata, Polygala abyssinica, Solanum incanum, Solanum marginatum,* and *Verbena officinalis.* However, plants species found in *C. lusitanica* plantation forest but not found in *G. robusta* plantation forest include *Adiantum capillus-veneris, Anthemis tigreensis, Centella asiatica, Cheilanthes coriacea, Daucus hochstetteri, Dovyalis abyssinica, Eragrostis papposa, Erica arborea, Fimbristylis complanata, Galium spurium, Hyparrhenia rufa, Hypericum quartinianum, Hypericum revolutum, Kalanchoe densiflora, Maesa lanceolata, Olea europaea L.* subsp. *Cuspidate, Parochaetus communis, Periploca linearifolia, Prunus Africana, Rumex nervosus, Salvia nilotica* Juss, *Solanum indicum, Trifolium quartinianum,* and *Verbascum valerianifolium.* Shiferaw Alem and Tadesse Woldemariam (2009) were observed the high similarity of woody species composition between the natural forest and the plantation forest.

However, Feyera Senbeta and Demel Teketay (2001) were reported the higher species similarity between *C. lusitanica* and *P. radiata* plantation forests (JCS = 0.73) in Central Ethiopia.

5.2.4. Endemic species in Yerer Forest

The present study result indicated that the identified endemic species to Ethiopia were contributed about 12.81% of the total species in the area. This indicated that Yerer forests are the place where one can find a range of different endemic plant species composition in the area. According to Friis and Sebsebe Demissew, (2001) the proportion of endemic plant species in the montane forests of Ethiopia is high when it ranging between 11-15% of the total number of species of the area. This showed that Yerer forests comprised high endemicity (12.81%). Therefore, the existing/ appearance of high native species diversity and the presence of high endemic species in the forests could initiate better conservation and management process in the Yerer forests. Horizontal across the forest land-use systems (FLUS), the majority of endemic species (27 species) were observed in a natural forest and followed by *G. robusta* and *P. patula* plantation forests with every 14 species, however, the least endemic species were recorded in *E.globulus* plantation forest with 8 species. Among the total endemic species, 10 species were found only in natural forests. The number of endemic plant species recorded in Yerer forest was higher than the number of endemic species reported by Birhanu Kebede et. al. (2010) from Gedo Forest (25 species), Dinkissa Beche and Sebsebe Demissew (2011) from Menagesha Suba State Forest (9 woody species), and Hailemariam Mesfin and Temam Tamiru (2018) from Gole Natural Forest (17 species).

5.3. Effect of land-use systems on the soil seed bank composition, and seed density

5.3.1. Seed bank species composition, and seed density distribution pattern horizontal across land-use systems (LUSs)

The soil seed bank plays an important role to understand the underground vegetation species composition and density potential to initiate re-vegetation (restoration) of the specific site. In the study area, under the same environmental conditions the different land-use systems (LUS) were responded to the different results of species composition, and seed density in soil seed banks. This implies that the land-use system (LUS) practices were highly significantly influenced the quantity of species composition, seed density, and distribution in soil seed banks. In total, the present study identified 98 species composition belonging to 42 families in the soil seed bank from all eight land-use systems. The common 11 species in seed bank which occurred in all land-use systems include *Ageratum conyzoides, Commelina benghalensis, Commelina diffusa, Cotula abyssinica, Fimbristylis complanata, Galinsoga parviflora, Guizotia scabra, Medicago polymorpha, Oplismenus hirtellus, Pennisetum thunbergi, Plantago palmate,* and *Trifolium decorum*. Of the total recorded species in the seed bank, non-woody species were dominated with the highest proportion (62.27%) whereas the contribution of woody species was low proportion (36.73%). The present findings results agreed with the workers' report of Feyera Senbeta, and Demel Teketay (2001); Mulugeta Lemenih and Demel Teketay (2006), Belay Assefa et al. (2014).

On other hand, the non-woody species significantly dominated the soil seed bank species composition over woody species in all LUSs. Probable the possible reasons for the very low proportion or absence of woody species seeds than herbaceous seeds in the soil under different land-use systems are directly associated with the relative shorter survival of seeds of some woody species in the soil, the absence of mature parent woody species in the aboveground vegetation in the LUS, some woody species seeds lie on the ground surface and remain exposed to the predation and harsh climatic conditions that enhance some seeds decomposition or dead, and, the persistent nature of seeds of some woody species enables their seeds to accumulate in the soil without germinating for a long period. Similar results were also reported by other researchers of Demel Teketay and Granstrom, (1997), Kebrom Tekle and Tesfaye Bekele (2000); Feyera Senbeta, and Demel Teketay (2001); Belay Assefa et al. (2014).

In Yerer forest and surrounding area under different land-use systems, the present results showed that the number of species composition and seed density/m^2 in seed banks was varied between 29 and 57, and 1625 and 3250, respectively. The probable reason for the variation of species composition, and seed density/m^2 among different land-use systems might be happened due to the variation of input and output of seeds in the soil, long and current land-use history, previous and current existing vegetation history, land management practices, and the access and availability of seeds dispersal from a nearby and faraway distance. This implies that the number of species composition and seed densities of the soil seed bank (SSB) were varied considerably in spatial and temporal dimensions horizontally across land-use systems. This agrees with the finding reported by Belay Assefa et. al. (2014). In similar manner, Mulugeta Lemenih and Demel Teketay

(2006) were noted that different pressure of disturbance among different land-use systems causes of variations in soil seed bank density and species composition.

The soil seed bank species composition and seed density/m^2 (number of germinated seeds m^{-2}) were significantly different among the different land-use systems. Among the eight land-use systems (LUS), the highest species composition and seed density/m^2 were recorded in the natural forest land-use system with numerical values of 57, and 3250, respectively. In the seed bank, 12 species found only in a natural forest, but not found in other land-use systems are *Ageratum conyzoides*, *Clematis simensis, Dodonaea angustifolia, Erica arborea, Heteromorpha arborescens, Hypericum revolutum, Juniperus procera, Olea europaea* subsp. c*uspidata, Phytolacca dodecandra, Pittosporum viridiflorum, Rhus vulgaris,* and *Vernonia amygdalina.* The possible reason for the highest species composition and density/m^2 in natural forest land-use system could be attributed probably due to low disturbance of natural forest by human and domestic animals because of its under control from external intervention, the availability of seeds input in the soils from nearby parent plants, the accessibility of different seeds dispersal by different wild animals and birds, due to low seeds outputs or losses from the forest by predators and erosion, and good environmental favorable conditions to restore seedbanks with their viability for a short and long period without damaging or decomposition. The present findings agreed with others workers of Feyera Senbeta and Demel Teketay (2002), Mulugeta Lemenih and Demel Teketay (2006), Belay Assefa et al. (2014).

Similarly, Shen et al., (2007) were noted that favorable microclimatic conditions and phenological events can be considered as possible reasons for higher species richness and seed density m^2 in soil seeds bank. Because after seeds are assimilated into soil seed banks (SSB), they are exposed to different internal and external environmental conditions, which entirely determine their fates. The abundance of species composition and seed density in the seed bank were varied according to the proximity of the parent plants that serve as sources of seeds. Some the seed banks are lived in the soils for a long period (i.e. $\geq$ one year) is known as persistence or state of dormancy (Walck et al. 2005). Solomon Tefera (2011) noted that most of the seeds in the soil seed bank come from the nearby parent plants, while the other seeds are contributed by plant communities a long distance away from the parent plants in dispersal form.

From the identified species in the study area, the herbaceous species composition and density were dominantly found in cropland than other land-use systems. The seed bank species (8) of *Avena sativa, Datura stramonium, Hygrophila auriculata, Lactuca inermis, Lolium temulentum, Malva verticillata, Rumex abyssinicus,* and *Triticum aestivum* are found only in cropland but not occurred in other land-use systems. The possible reason for the higher seed bank species composition and density of herbaceous in cropland is directly associated with herbaceous species have a better chance of natural recovery than woody species by producing a large number of seeds in a short period and possessing means of long-distance dispersal by wind, water and animals, the accumulation of persistent seeds in the soil from the previously existed vegetation, introduced of another weed seeds with crop seeds, and the seed rain from the crop. Similarly, Feyera Senbeta and Demel Teketay (2002) were noted that the restoration of vegetation in permanent arable land might be attributed by the persistent seeds in the soil and the seed rain. Similarly, a lower density of woody species than that of herbaceous (non-woody) species in the soil seed bank has been reported by many workers (Mulugeta Lemenih and Demel Teketay, 2006, Belay Assefa et al. 2014). Generally, the major differences in species composition of the SSB among different land-use systems (LUSs) were due to the dominance number of herbaceous species recovered (Mulugeta Lemenih and Demel Teketay 2006).

However, among all land-use systems, any woody species was not observed in cropland use. On the other hand, the woody species were recorded from all land-use systems of seed banks except the cropland. The possible reasons for the absence of woody species in cropland might be attributed due to lack of viable seeds of woody species inputs to the soil by dispersal and seeds rain, the previously existed woody species seeds outputs (losses) from the soil by different factors, and even probably the newly dispersed woody seeds in the farm may continuously be removed during site preparation and successive weeding in the past long period for crop management. Additionally, the external environmental factors like high temperature and direct solar radiation on the bare soils of cropland for a long period in the past may induce rapid loss of woody seed viability and subsequently disappeared woody species composition in the soil seed bank (SSB) of the farm fields. Shen et al., (2007) indicated that the species composition and seed density in soil seed banks could be influenced not only by the rate of seed input, but also due to seed output (loss of seeds) from the soils due to predation, and germination. Similarly, Demel Tektay and Granstrom, (1995) and Demel Tektay (1998) were observed the dominated of herbaceous weed species, including grasses and sedges more than woody species in the soil seed bank (SSB) of a farm field.

In the study land-use systems (LUS), the lowest species composition and seed density/m^2 were observed in *E.globulus* and *C. lusitanica* plantation forest land-use systems with numerical values of 29, and 1625, and 33 and 1767, respectively. The alternative possible reasons for the lowest species composition and seed density/m^2 in *E.globulus* and *C. lusitanica* plantation forests could be associated with the relative shorter survival of vegetation species seeds in the soil, the lower proportion of mature parent plant species in the aboveground vegetation in the LUSs, low external seeds inputs by dispersal due to unattractive dispersal agents by exotic tree plantation, and these exotic tree plantation forests may be imposed or influenced on the viability of seeds in the soils under them by induced unfavorable environmental conditions. Similarly, Matthew et al., (2004); and Ferreira et al., (2006) were reported that the presence of exotic woody species in soil seed bank flora may relatively become a source of invasion and risk for future regeneration.

Exotic tree plantation forest land-use systems were overall less species composition in seed bank than natural forest and grassland. The seed bank species (12) of *Asparagus africanus*, *Barleria parviflora, Coelachyrum poiflorum, Crotalaria spinosa, Cupressus lusitanica, Cynoglossum coeruleum, Eucalyptus globulus, Hypericum quartinianum, Lippia adoensis, Maytenus arbutifolia, Ocimum lamiifolium,* and *Pennisetum riparium* are recorded only in plantations of exotic tree species but not observed in other land-use systems. The overall seed density and the number of emergency seedlings responses in soil seed banks under all four exotic tree plantation forests were lower than the rest four land-use systems (natural forest, grassland, grazing land, and cropland). This could be attributed due to the variation of seed inputs and outputs in the soil seed bank, temporal seed dispersal distribution, magnitude, and intensity of disturbances by human and domestic animals interferences. Perera, (2005) pointed out the variation of seed rain and seed deterioration under different standing vegetation stands were contribute to the difference in species composition and seed density in soil seed banks.

The overall soil seed bank (SSB) species composition in grazing land was lower than the other land-use systems except for the *E.globulus* plantation forest. In grazing land, domestic animals are the major cause of disturbance due to grazing but vary based on the intensity of grazing. Herault and Hiernaux (2004) have indicated that grazing not only reduces the species composition but also greatly affects the density of seeds. In the study area, *Parthenium hysterophorus* (Asteraceae) species were recorded only in grazing land seed banks. This could be attributed due to the dispersal of *Parthenium hysterophorus* species from long distance to the present study site by animal feces because this invasive herbaceous weed species was commonly grazed by herbivores animals due to their free movement from place to place. Cosyns et al. (2005) noted that herbivore animals significantly play the dispersal of some plant species from one place to another place by feeding plant seeds and passing through their faeces.

5.3.2. Seed bank species composition and seed density distribution pattern along soil depth

The total seed bank species composition and seed density of the Yerer forest and surrounding area decreased as the soil depth increase. This means, the seed bank species composition and seed density decrease with increasing soil depths downward (0-5 cm > 5-10 cm > 10-15 cm) in all land-use systems. The factors contribute to the decline of seed bank species compositions and density with soil depths increase due to the regular seeds rain in the upper surface soil by different seeds dispersal agents for accumulation in the upper soil layer, some matured small-sized and low mass seeds have required more time to become deeply buried in lower soil depth due to its floating on the upper surface, and the slow movement of seeds vertically down in soil profiles by secondary dispersal agents and seeds percolate by water. Similar results were also observed by other workers (Feyera Senbeta and Demel Teketay, 2001; Belay Assefa et al. 2014, Degafi Sileshi and Berhanu Abraha, 2014, Tinsae Assefa and Berehanu Abraha 2014). Mulugeta Lemenih & Demel Teketay, (2006) were observed that a declining trend of species composition richness in seed banks with increasing soil depth under different land-use in Ethiopia.

Additional the variations of the movement and distribution of seeds vertical in the soil profile are based mainly on seed morphology (like mass & shape) that can facilitate penetration of the soil surface, vertical soil structure and particle size distribution, physical animal disturbances (e.g. trampling), and seed size (i.e bigger seeds with more weight would sometimes have better chances to go deeper into the soil). These implications are supported by the findings of soil bulk density increases from the upper to bottom soil depths, which hinder the vertical movement of seeds to deeper soil layers with penetration and percolation processes. The vertical distribution of species composition richness and seed density/ abundance in the soil seed bank was affected by the factors of soil depth layer (Feyera Senbeta and Demel Teketay, 2002; Benvenuti, 2007) and variation of seeds quantity inputs or outputs in each soil layer **(**Thompson et al., 1997). Among the four soil layers, the recovery of seeds from the litter layer was lower than the three soil depth layers (0-5 cm, 5-10 cm, and 10-15 cm) in all land-use systems. This could be attributed due to the loss of seeds by herbivore animals from litters, the stayed of seeds on the upper surface of the soil for a long period may expose these seeds to predators and predation, and the loss of seeds from the surface by wind and water erosion is leading to reduced accumulation of seeds in the litter's layer. The present finding was agreed with the findings reported by other workers (Mulugeta Lemenih and Demel Teketay, 2006, Belay Assefa et al. 2014).

However, the variation of species composition and seed density in cropland were showed that statistical non-significant variation, but to some extent numerical difference as a function of soil depth layers. Agricultural activity is a major factor that affects the vertical distribution of seeds in the soil seed bank. This could be attributed due to the mixing of seed banks between soil layers during cultivation with traditional tillage implements. Besides this, due to low soil bulk density and easily air and water movement in the soil of cropland could contribute to the transportation of some herbaceous seeds from the upper soil layer to the bottom soil depth by water leaching and by some secondary seeds predators. The presence of secondary seed dispersal agents or below-ground organisms in the soils, and seeds percolating with water contribute to the variation of seed bank composition and density at different soil depth layers (Jennifer et al., 2011). Demel Teketay and Granstrom (1995) indicated that the presence of high disturbance favors the incorporation of seeds of herbaceous species into the deeper soil layers. The trampling effect by large animals and increased human activity are the major causes for the incorporation of seeds into the deeper soil layers (Mekuria Argaw et al.1999). Joanne (2006) was noted that land-use and management practices can affect all of the characteristics of seed banks of species composition, seed distribution in the soil, and seed fate dynamics, particularly in crop systems depending on agricultural production practices and timing.

5.3.3. Seed bank species composition similarity among land-use systems (LUS)

A Jaccard similarity index was used to compare the degree of vegetation species similarity among eight land-use systems in the study area. Among the identified vegetation species (98 species), about 11 species (11.23%) were commonly observed in all eight land-use systems, however, 36 species (36.73%) were observed only in one land-use system (LUS). Accordingly, a Jaccard similarity indices result showed that a very clear different species composition in seed banks among different land-use systems (LUS). The overall species composition similarity indices in soil seed banks among all eight land-use systems (LUSs) were ranged from 0.25 – 0.64 or 25 – 64%. In the study area, the highest (> 50%) similarity or homogeneity of species composition in soil seed banks were observed between *G. robusta and* grassland (JCS = 0.64), *G. robusta* and *P. patula (*JCS = *0.53), P. patula and* grassland (JCS = 0.52), and grassland and grazing land (JCS = 0.52). This implies that these land-use systems are shared commonly more than 49 (50%) plant species. The possible reasons for the highest vegetation species composition similarity or homogeneity in seed bank among some different land-use systems could be happened due to the existence of similar species seeds in the soils from the previous aboveground vegetation species similarity, the opportunity of similar species seeds inputs by dispersal mechanism with dispersal agents, and the similar soil environmental conditions that favor similar seeds store in soils for a short and long period. In contrast to the present finding Feyera Senbeta and Demel Teketay, (2002) were observed that the lower species similarity among different exotic tree plantation forests in Ethiopia at Menagesha-Suba forest and Munessa-Shashemene forest.

However, the lowest species similarity or higher heterogeneity of species composition were observed between *P. patula* and cropland (JCS = 0.25), and between natural forest and cropland (JCS = 0.26). The different vegetation species composition between land-use systems could be occurred due to the disturbance intensity variation, seed inputs variation from different parent plants by dispersal mechanism, the accessibility of seed inputs variation from the current standing aboveground vegetation species, and the variation of soil environmental conditions that favor or impose seeds stored in soils for a short and long period. The present finding disagreed with Mulugeta Lemenih and Demel Teketay, (2006) who reported that the higher species similarity (JCS = $\geq$ 32) between natural forest and different aged cultivation land of tropical dry Afromontane forests in Ethiopia. The seed bank species composition (17) of *Ajuga integrifolia, Andropogon abyssinicus, Anthemis tigreensis, Argyrolobium fischeri, Asparagus africanus, Barleria parviflora, Centella asiatica, Coelachyrum poiflorum, Crotalaria spinosa, Cynodon nlemfuensis, Helichrysum splendidum, Laggera tomentosa, Myrsine Africana, Pterolobium stellatum, Rosa abyssincia, Trifolium rueppellianum,* and *Zehneria scabra* are found in *P. patula* plantation forest but not found in cropland land-use system.

5.4. Effect of Different Land Use Systems on Soil Physico-chemical Properties

5.4.1. Effect of land-use systems (LUS) on soil physical properties

5.4.1.1. Soil texture

The soil textural fractions of sand, silt, and clay significantly varied with land-use systems. The particle size distribution data showed that the maximum sand content was observed in the *Cupressus lusitanica* plantation forest (43.80%) followed by natural forest (40.70 %), and *Eucalyptus globulus* plantation forest (37.70%) land-use systems. The higher sand proportion in *Cupressus lusitanica* plantation forest than the other land-use systems (LUS) was attributed due to the lower of soil organic matters (SOM) contents, vegetation type, and density cover, and factors of the soil-forming process; accordingly, a slow weathering rock usually forms sandy, coarse soils. Similar studies results have been reported by Michelsen et.al. (1993) as the higher proportions of sands distribution under *Cupressus lusitanica* plantation (4%), and natural forest (4%), at 0-40cm soil depth in the highland of Ethiopia. Similar results were reported by Mulugeta Lemenih et. al. (2004).

Among the land-use systems (LUS) the contents of the minimum sand were recorded in the *Pinus patula* plantation forest (28.00%), and cropland (29.10%). The variation in the amount of sand proportion among land-use systems might be due to the influence of different land-use systems on the weathering processes of soil formation by transporting of the particles by wind or water and accumulation of particles under vegetation. In contrast to the current results, Woldeamlak Bewket and Stroosnijder (2003), and Kiakojouri and Taghavi (2014) reported the highest sand proportion in farmland/cropland than pasture land as they suggested this may be due to the decreasing of the soil organic matters (SOM) and soil aggregate sustainability during the changes, amount of erosion increases and consequently during the erosion clay and silt are separated and move to the downstream area.

The distribution of sand particles amount or proportions among the three land-use systems of natural forest, grassland, and *Eucalyptus globulus* plantation forest were non-significance differences. The relatively uniform sand distribution proportion in different land-use systems might be due to the relatively similar soil organic matters (SOM) contents, and similar climatic conditions that influence the soil-forming process. As the function of the soil depth factor, the highest mean value of sand proportion was observed at the topsoil layer (39.10%) than the subsoil layer (34.48%). Across the soil depths, the result intended to confirm that the highest sand content distributions were recorded in the top-soil (0-20 cm) layer in all land-use systems (LUS) except in *Cupressus lusitanica* plantation forest. The reason for the higher sand content at the top-soil than the sub-soil layer may attribute to clay translocation from the top layer to the sub-layer, create the opportunity for the dominance of sand particles at the top surface, because, there was a higher of clay particle at sub-surface in the area. This result is in agreement with the findings of Mulugeta Lemenih et.al. (2004), but contract to Michelsen et.al. (1993) reported.

In the study area among land-use systems, the highest clay particle size distribution was recorded in the *Pinus patula* plantation forest (42.10%) and followed by cropland (40.90%), *Grevillea robusta* (38.30%), and *Eucalyptus globulus* (37.70%) plantation forests. The lowest mean value of clay content concentration was observed in grassland

(33.30%). The variation of the relative percentage of clay particles among land-use systems (LUS), indicating the heterogeneity of soil-forming processes and dissimilarity of parent materials, for instance, easily weathered rock and minerals are to form clay-rich soils. Vegetation type and density may be among processes influencing the number of particles constituting soil texture (Bakhshipour et al., 2012). Across the vertical gradients (soil depths), the highest clay content distribution was observed in the subsoil (20-40 cm) layer in all land-use systems (LUS), this means as soil depth increases, the clay content level also increases. The reasons for the higher clay fraction in the subsoil surface than the top surface might be due to clay translocation from the top layer to the sublayer. This result is in agreement with the findings of Mulugeta Lemenih et.al. (2004), and Kizilkaya and Dengiz (2010), who observe the higher clay particle proportions at the subsoil layer in different land-use systems. Bakhshipour et al. (2012) were suggested that leaching and surface runoff processes as factors influencing the reduction of clay particles in addition to vegetation type and density. In contrast to the present finding, Kalhoro et.al. (2017) were observed a higher clay particle proportion at the topsoil layer than the subsoil layer in grassland, abandoned apple orchard, and maize croplands.

As a function of the land-use systems factor, the maximum mean values of silt contents were recorded in cropland (30.00%), and *Pinus patula* plantation forest (29.90%), whereas, the minimum mean values of silt content was observed in *Cupressus lusitanica* plantation forest (21.90%). The variation of silt soil particles across land-use systems (LUS) might be happened due to the process of pedogenesis or soil formation, and vegetation type and density cover. Particularly, in cropland, the continuous human activities of tillage practice and animal trampling might be contributing to the formation of silt particle size contents in the soils by crushing the large soil particles. While in *Pinus patula* plantation forest due to a species produce high litters fall biomass on the ground its might be decomposed via the action of micro-organisms and form soil silt particles. This suggestion was supported by the highest average litters' depth (4.20 cm) accumulation recorded in *Pinus patula* plantation forest during the study. Similar findings were observed by Tsehaye Gebrelibanos and Mohammed Assen 2013 that silts content was higher in cropland than other land-use types of Ethiopia. Cropland is contributing to increases in the weathering process of soil by moisture and temperature changes which led to silts formation (Fantaw Yimer et al. 2007). In contrast to the present finding, Michelsen et. al., (1993) were observed the highest proportions of silts distribution under natural forest (73%) and followed by *Cupressus lusitanica* plantation forest (63%), and *Eucalyptus globulus* plantation forest (60%) at 0-40cm soil depth in the highland of Ethiopia. Awdenegest Moges et al. (2013) were suggested that the soil particles proportions vary vertically in-depth or horizontally as land-use systems due to the process of pedogenesis or soil formation factor.

As the function of the vertical gradient of soil depth factor, the mean values of silt content concentration distribution were observed more closely similar values at both topsoil and subsoil layers. The silt content concentration distribution trend across soil depths was increased from top to subsoil layer in a natural forest, *Eucalyptus globulus*, *Grevillea robusta*, and *Pinus patula* plantation forests, whereas, silt content concentration level decreased from top to subsoil layers in *Cupressus lusitanica* plantation forest, grassland, grazing land, and cropland. The variation of silt soil particles vertically in depth might be occurred due to vegetation type and density cover related to above and belowground biomass accumulation, leaching, and surface runoff that might influence the occurrence of differences between silt particles due to their small size. The partial findings agree with similar studies reported by Kizilkaya and Dengiz (2010) who observe the increment of silt particle proportions with increasing soil depth from top to subsoil layer. Generally, the results show that the soil texture in the study area, the majority of land-use systems soil textural classes were grouped under clay loam except for the land-use systems of *Pinus patula* plantation forest and cropland which grouped under clay textural class.

5.4.1.2. Soil Moisture Content, Bulk density, Particle Density, and Porosity

Soil Moisture Content

The determination of soil moisture content is the basic soil parameter required giving information about the soil wetness, and the quantity of water holding capacity. Because the availability of soil moisture to plants is a function of water input and moisture retention potential. The soil moisture distribution was ranged in all land-use systems from 16.51 to 23.08% with an order of natural forest > *G. robusta* > *P. patula* > *C. lusitanica* > grassland > grazing land > *E. globulus* > cropland. In the assessments of soil moisture content levels under different land-use systems, the obtained results showed that maximum mean values of moisture contents were recorded in natural forest (23.08%), and *Grevillea robusta* plantation forest (22.74%) without significant differences between them as compared to the other land systems(LUS). This may be attributed by different factors of the higher accumulation of organic matters with litters' deposition which contributes to maintenance /improvement of soil structure, porosity, water infiltration, water holding capacity, reducing soil erosion, and reduced evaporation rate, thereby, these contribute to increasing soil water retention capacity. Similar observations were reported by (Gol 2009), who observed higher moisture under natural forest, and Rahman, et.al. (2012) observed higher moisture under Sal plantation and Garjan plantation sites. The medium mean values of moisture contents were observed under *Pinus patula* (21.28%), *Cupressus lusitanica* (20.91%) plantation forest, and grassland (20.40%). Similarly, Soil texture may greatly influence the water-holding capacity of the soils through improving water infiltration, permeability, and porosity of soils. Therefore, the study area soil textural class clay loam particles have many small pore spaces that make water move slower that led to the highest water holding capacity. This argument is supported by positive correlation that existed soil moisture with organic carbon (r= 0.320), clay (r= 0.028), silts (r= 0.158) and other soil properties (Appendix Table 5).

The minimum moisture contents were recorded in cropland (16.51%), and *Eucalyptus globulus* plantation forest (16.99%) without significant differences between them. This probable due to lower accumulation of organic matters with litters' felled which contributes to low-quality soil structure formation, less water infiltration, and low water holding capacity. Particularly, the lower soil moisture contents recorded in cropland may be due to high evaporation rate because cropland is open land area and low organic matter cover it is simply directly exposed to heat. This implication is supported by the positive correlation between moisture contents and organic carbon (r = 0.320) which indicates that the soil organic carbon content level is directly related to organic matters; because organic carbon is derived from the decomposed organic matter. For the lower of soil moisture contents observation under *Eucalyptus globulus* plantation forest as compared to the other land-use systems, the reasons may be due to the fast-growing of *E. globulus* species consumed more water in the soils, high evaporation rate due to open canopy, and low surface covers by litters, and low water infiltration and permeability due to soil compaction because of high soil bulk density registered under it. Regarding the relationship, soil moisture content was negatively correlated with bulk density (r= -0.354) under the *Eucalyptus globulus* plantation forest. This suggestion is supported by the present findings of lower canopy cover (61%) estimation, and lower average litter depth (1.3 cm) recorded under the *E. globulus* plantation forest than other forest land-use systems in the area. Kakaire et al. (2015) noted that a higher soil bulk density means that less quantity of water content within the soil at field capacity level. Similarly, Aweto and Moleele (2005) indicated the sparse or absence of undergrowth vegetation cover and open canopy of *Eucalyptus* trees in plantations can lead to a higher rate of soil water evaporation than the dense undergrowth vegetation cover and closed canopy in the native forest could be led to lower soil temperature, reduce evaporation, and enhance soil water infiltration. Gol (2009) was also reported that the lowest available water content found in an agricultural cornfield.

In contrast to the present finding, Tellen, and Yerima, (2018) reported the higher moisture content under *Eucalyptus* plantation forest (5.86%) than Virgin savanna land (4.01%), park afforestation land (3.49%), farming land (3.99%), and grazing land (3,90%) in North West region of Cameroon. As the function of the vertical gradient of soil depth factor, the highest mean value of moisture content was observed at the sub-soil layer (21.24%) than at the topsoil layer (19.07%). The moisture content levels distribution trend across soil depths was increased gradually from topsoil to subsoil layer in all land-use systems in the Yerer area. This may be due to the subsoil (20-40cm) layers were less exposed to soil water evaporation during dry season than the topsoil (0-20cm) layers, high water infiltration, and permeability to subsoil layers in all land-use systems. In a similar way, Rahman, et.al. (2012) were observed higher moisture at subsoil layers than topsoil.

Bulk density

The bulk density values varied in response to land-use systems. In the study area, the mean values of bulk density were ranged from 1.7 to 2.180 g/cm^3 under different land-use systems. The present study indicated that the lower mean values of bulk density of the soil were recorded in a natural forest, *Pinus patula*, and *Grevillea robusta* plantation forests in the order of 1.167 g/cm^3, 1.193 g/cm^3, and 1.292 g/cm^3, respectively without significant difference among them. The reason may be due to the difference in soil organic matters (OM) content among land-use systems. The lower bulk density is attributed to the higher organic matter accumulation under the canopy which leads to an increase of the soil looseness, porous or well aggregated, and, thereby, resulting in lower bulk density. This argument is by the negative correlation that exists between bulk density and soil organic carbon (r = -0.403). In line with the present finding, Michelsen et.al. (1993 and 1996) reported the lower bulk density under natural forest as compared to plantation exotic tree species (*Cupressus lusitanica*, *Eucalyptus globulus,* and *Pinus patula)* forests, at 0-40cm soil depth in central high land Ethiopia. Similarly, lower bulk density values under natural forest than the other land-use systems were reported by Mostafa et.al. (2008), Gol (2009), Kaur and Toor (2012), Mulugeta Sebhatleab (2014), Maqbool et.al. (2017), Tellen, and Yerima (2018). Similar results have been reported by

Mulugeta Lemenih et al. (2004) that the lowest bulk density was observed under natural forest than the other four land-use systems in Ethiopia. These results are in disagreement with the findings of Rosell and Galantini (1997), Batjes and Dijkshoon (1999), and Feller et al. (2001) whose reported higher soil bulk densities under natural forests than cultivated areas.

On the other hand, the highest mean value of bulk density of the soil was recorded in the *Eucalyptus globulus* plantation forest (2.18 g/cm^3). This probable due to the soil compaction encountered as a result of lower organic matter accumulation and large sand proportions. This argument is by the positive correlation that exists between bulk density and sand (r = 0.2153). The higher bulk density might probably create unfavorable soil conditions through limiting root growth and air circulation, which in turn have negative implications for plant growth. Similarly, Michelsen et. al. (1993) were observed high bulk density under the *Eucalyptus globulus* plantation forest at 0-40cm soil depth in central high land Ethiopia. The present finding indicated that the mean values of bulk density under *Cupressus lusitanica*, *Eucalyptus globulus*, and *Pinus patula* plantation forests were statistically significant differences. In contrast to the present finding, Michelsen et.al. (1996) were observed numerical equal mean values of bulk density (1.2 gm/cm^3) under *Cupressus lusitanica*, *Eucalyptus globulus*, and *Pinus patula* plantation forests without significant difference.

Across the vertical gradient of soil depth, the lowest mean value of bulk density (1.35 g/cm^3) of the soil was observed at the topsoil layer than the subsoil layer (1.54 gm/cm^3). The bulk density levels distribution trend across soil depths was increased gradually from topsoil to subsoil layer in all land-use systems. This is due to the higher accumulation of organic matter effect at the topsoil layer than the subsoil layer, and the effect of tillage to cropland that results in penetration resistance and increased soil aeration and porosity, which leads to lower bulk density. Inline to the present finding, Michelsen et. al. (1993 and 1996) were reported the lowest mean value of bulk density at topsoil layer than subsoil layer, and consistently increased from topsoil to subsoil layers under different forest land-use systems such as natural forest, *Juniperus procera*, *Cupressus lusitanica*, *Pinus patula*, *Eucalyptus globulus*, *Eucalyptus grandis*, and *Eucalyptus saligna* plantation forests in the central highland of Ethiopia. Similarly, different researchers have been observed the increase of bulk density with soil depth increase under different land-use types (Franzluebbers, 2005, Aumtong et al 2009, and Kaur and Toor, 2012).

Soil Particle Density

Soil particle density is the weight of given soil particles or separates per unit volume of soil particles or separates (soil solid phase) which expressed in gm/cm^3 or g/cc (McCarty et.al. 2016). As the function of land-use systems the overall proportional distribution of particle density was observed in the order of *E. globulus* > grassland > cropland > grazing land > *G. robusta* > *C. lusitanica* > natural forest = *P. patula* plantation forest. The inconsistency in particle density means values in the study area may be due to the inherent differences among the land-use patterns. The lower mean values of the particle density of the soil were recorded in natural forest ($1.620 g/cm^3$), and *Pinus patula* plantation forest ($1.620 g/cm^3$). This may be attributed due to the effect of the high accumulation of organic matters by litters' deposition in soil contributes to the maintenance of soil structure, and porosity, lead to decrease particle density. This explanation is supported by the negative correlation between particle density with organic carbon (r = - 0.4742), and porosity (r = - 0.1785). Similarly, the lowest soil particle density was reported under forest land than other land-use systems by Maqbool et.al. (2017). Similar results were found by Woldeamlak Bewket and Stroosnijder (2003) that the lower soil particle density was observed in forest land than other land-use systems. Watt et al. (2005) found a significant impact of vegetation on soil particle density in the sustainability of plantation forests in New Zealand.

On the other hand, the highest mean value of particle density of the soil was recorded in the *Eucalyptus globulus* plantation forest (2.53 g/cm^3). This probably due to the effect of low organic matters addition from woody litters and herbaceous residuals, low CEC, and low pH (acidity) levels under the *Eucalyptus globulus* plantation forest. Additional for the higher soil particle density may be attributed due to the higher amount of heavy minerals like iron compounds if present in the soil also contributes to increasing the particle density under *Eucalyptus globulus* plantation forest than other land-use systems. Maqbool et.al. (2017) has been observed the highest soil particle density under wasteland and unirrigated agriculture than other land-use systems. In the vertical gradient of soil depth, the lowest mean value of particle density of the soil was registered at the topsoil layer (1.88 g/cm^3) than the subsoil layer (2.19 g/cm^3). The particle density levels distribution trend across soil depths was increased gradually from top to subsoil layer in all land-use systems. This is due to the higher accumulation of organic matter effect at the topsoil layer than the subsoil layer, which leads to lower particle density. Similarly, Rahman, et.al. (2012) were observed that the increase of soil particle density levels with increasing soil depth under Sal plantation, Garjan plantation, and deforested site land-use patterns in north-eastern Bangladesh.

Soil Porosity

Porosity is a measure of the total amount of pore spaces or open space between particles (clay, silt, and sand) in the soil that make up the structure of the soil to facilitate the movement of air and water through it**,** which express in volume (between 0 and 1) or percent (between 0 and 100) (Carter and Ball 1993). Many important soil processes take place in soil pores; therefore, porosity affects the supply of root-zone air, moisture, and nutrients available for plant uptake. Without significant difference, the higher mean values of porosity of the soil were recorded in *Grevillea robusta* plantation forest, grassland, cropland, and natural forest, in the order of 0.34, 0.34, 0.32, and 0.32, respectively. This may be attributed due to the higher organic matter deposition, which contributes to binds large soil particles into aggregates to made many smaller pore spaces or open spaces and greater pore interconnectivity between larger particles in the soil lead to increase soil porosity and water holding capacity of the soil. This argument is supported by the positive correlation between porosity and organic carbon (r = 0.107). Similar results were also reported by Mohammed Assen et. al. (2005) and Wakene Negassa (2001) for soils of Chercher highlands and the Bako area of Ethiopia, as they suggested that the higher values of total porosity corresponded to the greater amount of organic matter held and lesser bulk density. The reason for the higher amount of porosity under the *Grevillea robusta* plantation forest, grassland, cropland, and natural forest land-use systems, may be due to the effect of soil texture on porosity by measuring the dimensions, number, and interconnection of pores.

A fine soil or smaller size particles have high porosity than coarse soil or bigger size particles (sand) because smaller size particles (clay) lead to made smaller caliber/capacity porosity, greater surface area, and greater pore interconnectivity than bigger size particles, thereby raise the amount of porosity in soil. This explanation is supported by the total amount of porosity that was positively correlated with the clay contents (r = 0.0178). Besides this a pore space or open space in soil made from particles that leave gaps between them, probably due to the movement of plant roots within the soil structure, amount of soil micro-organisms sorting the soil structure, expanding gases trapped within these spaces by groundwater; and/or the dissolution of the soil parent material could contribute for the higher of porosity. Similarly, Salwinder and Bijay, (2003) were reported relatively similar mean values of porosity (0.41 – 0.45) under four different land-use systems.

Among the land-use systems, the lower mean values of soil porosity were registered under the *Eucalyptus globulus (*0.14), and *Pinus patula* (0.27) plantation forests. This may be occurred due to the lower organic matter addition or the removal of organic matter litters from the site by collecting from the ground firewood purpose may contribute to making less binds of large soil particles into aggregates, and lesser pore interconnectivity between larger particles in the soil lead to decline soil porosity. Additionally, surface crusting and compaction lead to inhibit water entry into the soil and increase surface runoff and erosion, which possibly decrease porosity under *Eucalyptus* *globulus* and *Pinus patula* plantation forests. The higher bulk density may also reduce the porosity of the soil that hinders the movements of water and minerals in the soil (Mulugeta Sebhatleab 2014). Similar studies reported that bulk density values were inversely related to soil porosity as high bulk density resulted in lower total soil porosity (Igwe, 2005).

Across the vertical gradient of soil depth, the lower mean value of porosity (0.29) of the soil was observed at the topsoil layer than at the sub-soil layer (0.30), but the variation was insignificant. The soil porosity levels distribution trends across soil depths were increased gradually from top to subsoil layer in the majority of land-use systems, except in natural forest, *Eucalyptus globulus*, and *Grevillea robusta* plantation forests. This might be attributable due to the higher organic matter accumulation at the topsoil layer than the subsoil layer may contribute to making more binds of large soil particles into aggregates, and greater pore interconnectivity between larger particles in the soil leads to higher soil porosity at the subsoil layer than topsoil layer. Additional the reason may be due to the high compaction of subsoil layers than the topsoil layer because higher bulk density values were observed at subsoil layers. These findings support earlier work by Amusan et al, (2006), who reported inverse relationships between bulk density and porosity of soils under different cropping systems. Similar results have been reported by Vanden et al. (1999) which observed a reduction of total pore volume and a total number of pores in the top 0 to 0.25 m of soil depth in non-cropland for 11 years, as they stated that due to increasing in root penetration and biological activity.

5.4.2. Effect of Land Use Systems on Selected Soil Chemical Properties

5.4.2.1. Soil Organic C, Total N, C: N ratio, and Available P

Soil Organic Carbon (%OC)

Among the different land-use systems, the organic carbon concentration levels were observed in the order of natural forest > *G. robusta* > grassland > *P. patula* > *C. lusitanica* >grazing land > *E. globulus* > cropland. The overall maximum mean value of the organic carbon concentration was observed beneath the natural forest (3.49 % DM), and *Grevillea robusta* plantation forest (3.14% DM). The organic carbon concentration levels under natural forest and *Grevillea robusta* plantation were significantly different from the rest six land-use systems. This is probably due to the higher accumulation of soil organic matters (SOM) by litters from different heterogeneous plant species with a high rate of biomass production, and better carbon nutrient mineralize to the soils through decomposition. Organic carbon (OC) enters the soil through the decomposition of plant and animal residues, root exudates, dead microorganisms, and soil biota which indicates the organic matter content of the soil. Similar results have been reported by Michelsen et. al. (1996), Mulugeta Lemenih et.al. (2004), Bekele Lemma et.al. (2006) that the higher soil organic carbon concentrations observed in the natural forest than different exotic tree plantation forests in different regions of Ethiopia. Similar studies reported that higher soil organic carbon concentrations were observed under *P. patula* than *Eucalyptus* plantations (Zhang et.al. 2015).

Among the land-use systems in the study area, the minimum value of organic carbon concentration was observed in cropland (1.47% DM) followed by *Eucalyptus globulus* plantation (2.03 % DM). The difference could be attributed to the addition of lower organic matter to the soil via litter inputs and losses of organic matter through the harvesting of crops biomass from sites. Besides these, the continuous cultivation of land is aggravated by organic matter oxidation lead to losing carbon from the soil in CO_2 form. Organic carbon contents were highly affected by soil texture and slightly by land-use systems. This argument is supported by the soil organic carbon that negatively correlated with the soil texture of clay (r = - 0.340), and silt (r = - 0.106). The results were in agreement with the findings of Wakene Negassa (2001), Dhaliwal and Singh, (2003), Mulugeta Lemenih et. al. (2004), Lalisa Duguma. et.al. (2010), Mulugeta Sebhatleab (2014), Wasihun Mengiste et.al. (2015) and Tellen, and Yerima, (2018) reported less organic carbon in croplands and *Eucalyptus* plantation than others land-use systems.

Considering the vertical gradient of soil depth, the higher mean value of organic carbon concentration was recorded in the upper part of the soil layer at 0-20 cm depth (2.89% DM) than in the lower of soil part at 20-40 cm depth (2.02% DM). The organic carbon concentration levels distribution trend across soil depths decreased gradually from top to subsoil layers in all land-use systems. This may be due to the higher organic matter inputs to the topsoil layer by litters, crop residues, and animal dung than to the subsoil layer. This is in agreement with previous studies (Michelsen et. al., 1996, Mulugeta Lemenih et. al., 2004, Sugihara, 2014).

Total nitrogen (%TN)

The total nitrogen analysis measures nitrogen in all organic and inorganic forms and it does not indicate the available nitrogen to plant (Marx and Hart 1999). The total nitrogen concentration levels distribution trend horizontal as a function of land-use systems were registered in the order of natural forest > *G. robusta* > grassland > *P. patula* > *C. lusitanica* >grazing land > *E. globulus* > cropland. The highest mean value of total nitrogen content was observed in natural forest (0.31% DM) and followed by the *Grevillea robusta* plantation (0.26% DM), with significant statistical differences between them. These might be attributed to the long–term accumulation of above and below-ground organic matter inputs from litterfall, root turnover mineralization by actions of soil microbes, and N fixation by symbiotic in leguminous plant species diversity in natural forest and other soil microorganisms. This argument is supported by the significant strong positive correlation (r = 0.947) between the total nitrogen and organic carbon. Similar studies were also reported as the higher total nitrogen content was observed in the natural forest than other land-use systems in different areas (Michelsen et. al., 1996, Mulugeta Lemenih et. al. 2004, Bekele Lemma et. al., 2006, Mulugeta Sebhatleab, 2014, Tellen, and Yerima, 2018).

On the contrary, the lowest mean value of total nitrogen content was observed in cropland (0.13% DM) followed by *Eucalyptus globulus* plantation (0.17% DM), without significant differences statistically between them. The reasons for the lower total nitrogen content may be attributed to the loss of nitrogen either to the atmosphere by evaporation or leached down by the water. Because there is no real store of available nitrates in the soil as nitrates are released from organic matter breakdown unless they are used by plants. Similar studies reported that lower total nitrogen concentrations were observed under cropland, and *Eucalyptus* plantation forest than the other land-use systems in different regions of Ethiopia (Michelsen et. al., 1996, Mulugeta Lemenih et. al. 2004, Lalisa Duguma et. al. 2010).

The vertical gradient of soil depth higher means the value of total nitrogen concentration was observed at the topsoil layer (0.25% DM) than the subsoil layer (0.17% DM) with a significant difference. The total nitrogen concentration levels distribution trend across soil depths decreased gradually from top to subsoil layer in all land-use systems. This may be due to the higher organic matter inputs from litters, crop residues, commercial fertilizers, and animal waste materials to the topsoil than the subsoil layer. The higher total nitrogen on topsoil than subsoil was also reported by (Michelsen et. al., 1993, Abebe Yadesa, 1997; Tadesse Hailu et. al., 2000; Mulugeta Lemenih et. al., 2004, Yadesa Bato et.al., 2010, Kaur and Toor, 2012).

Carbon to Nitrogen (C: N) ratio

The C: N ratio or index of N mineralization provides the availability of nitrogen and rate of decomposition (Sae-lee et al., 1992, Bengtsson et al., 2003; Springob and Kirchmann, 2003). The two main primary nutrient resource parameters for plant growth are Carbon and Nitrogen as a function of carbon providing the energy and nitrogen providing the tissue building in an optimum range of ratios to enable appropriate growth. The overall mean value of the C: N ratio in all land-use systems were not statistically significant differences. The C: N ratio was significantly narrowed from 11.38 in the natural forest to 12.08 in the *Pinus patula* plantation soils. The lowest value of the C: N ratio was observed in the natural forest. This may be attributed to the increasing nitrogen nutrient inputs with a high rate of nitrogen fixation by different leguminous plant species diversity with a relatively higher protein and nutrient contents in the natural forest that leads to the lower C: N ratio, due to their fast decomposition rate and release of nitrogen to the soil. This implication is supported by the present findings of the dominant of Fabaceae family with fourteen species (15.05 %) to the total species, and better distribution in space and density in a natural forest that contributes to the nitrogen fixation and released nitrogen nutrients to soils via decomposition. Faster decomposition of leaf litter enhances the transfer of fresh carbon to mineral soil (Polglase et al., 2000). Similarly, different workers have reported that, the lower C: N ratio under different native plant species (Abebe Yadesa, 1997; Tadesse Hailu et. al., 2000, and Yadesa Bato, et.al., 2010).

The highest value of the C: N ratio (12.08) was observed in the *Pinus patula* plantation. This may be attributed due to lower nitrogen and higher organic carbon contents in the litters of organic matters which results in a higher C: N ratio, and slow decomposition rate. The optimum C: N ratio (less than 20:1) ensures that the soil has a suitable energy reserve as well as tissue building material to enable the plants to thrive. Plant residue with a low C/N ratio (high nitrogen content) decompose more quickly than plant residue with a high C/N ratio (high carbon content) and do not increase soil organic matter accumulation levels as quickly, because of the immediate supply of mineralized N for crop growth by fast decomposition processes (Janssen BH 1996, Bengtsson et al., 2003; Springob and Kirchmann, 2003).

The higher mean value of the C: N ratio was observed at the subsoil layer (11.96) than at the topsoil layer (11.64). The C: N ratio levels distribution trend across soil depths was increased gradually from topsoil to subsoil layer in all land-use systems except

Eucalyptus globulus plantation forest. This probably, due to the highly decomposed organic matter releases higher N- levels on the topsoil than the subsoil layers, thereby, the lowering C: N ratio has occurred at the topsoil layer. Similar to this finding, Abebe Yadesa (1997) and Tadesse Hailu et. al. (2000) also found a lower C/N ratio at the topsoil than in the subsoil layers under different native woody plant species diversity on farmland.

Available phosphorus

In the study area, the concentration of available phosphorus levels was found in the following order: natural forest > *P. patula* > grassland > grazing land > cropland > *G. robusta* > *E. globulus* > *C. lusitanica* land-use systems. The available phosphorus concentration mean values ranged between 2.45 and 31.52 mg/kg of soil. The overall available phosphorus concentration in natural forest (31.52 mg/kg of soil) was found to be higher than other land-use systems. The higher concentration of available phosphorus in the soil may be due to the higher accumulation of organic matter. Because the main natural source of phosphate in many soils is from the breakdown of organic matter or decomposition via the action of micro-organism then release available phosphorus to the soil. This result is in agreement with the findings of Nsabimana, et. al. (2008) who document the higher concentration of available phosphorus in the natural forest than other land-use systems.

Additionally, the higher available phosphorus in the natural forests was probably due to a combination of low nutrient demand by natural forest trees when compared with plantation of different exotic trees species; better phosphorus nutrient release or mineralization to the soils by different heterogeneous plant species via organic matters decomposition. This argument is supported by the simple linear correlation relationships between available phosphorus and organic carbon was positively correlated (r = 0.547). Similarly, other workers have also reported a high concentration of available phosphorus in the natural forest than other land-use systems (Michelsen et. al., 1996, Mulugeta Sebhatleab, 2014). On the contrary, in the previous studies Mulugeta Lemenih et. al. (2004) were reported that the higher mean value of available phosphorus concentration under mechanized farming (11.3), and *Cupressus lusitanica* (7.9) than natural forest (6.2) land-use systems, Michelsen et al., (1993) observed the higher available phosphorus concentration under *P. patula* plantation forest (17.6) than natural forest (6.9), Kaur and Toor (2012) were reported higher available phosphorus concentration under cropland (21.44), and agroforestry (15.86) than forest land (13.45) at 0-15 cm soil depth, and Mostafa et.al., (2008) recorded the higher available phosphorus under pasture land (47.10) than forest land (43.10) at 0-20 cm soil depth.

The medium mean values of available phosphorus concentration were registered in *Pinus patula* plantation, grassland, and grazing land in the order of 20.32, 14.88, and 11.89 mg/kg of soil, respectively. This effect is due to the variability of medium accumulation of soil organic matters (SOM) by adding litters, roots, and animal dung's to soils via medium mineralization process. Mohammed Assen et al., (2005) were reported that the variability of available P level is related to land use, altitude, slope position, and other characteristics of soils, such as clay and calcium carbonate content. The lower mean values of available phosphorus concentration were recorded in *Cupressus lusitanica*

(2.45), and *Eucalyptus globulus* (3.12) plantation forests. This may be attributed due to the fast-growing tree plantation species were associated with a more intense uptake of nutrients from the soil than slow-growing forest species. Additionally, the lower available phosphorus concentration under *C. lusitanica* and *E. globulus* plantation may be due to the loss of organic matters by rotational harvesting and took away from the site. Michelsen et al. (1993); and Lisanework Nigatu and Michelsen (1994) were noted that phosphorus (P) concentration limiting plant growth and leaf litter decomposition under *C. lusitanica* and *E. globulus* plantations in Ethiopian.

Concerning the soil depth factor, the higher mean value of available phosphorus concentration was observed at the topsoil layer (16.17) than at the subsoil layer (7.96). Across the vertical gradient of soil depth, the distribution of available phosphorus concentration levels decreased gradually from top to subsoil layer in all land-use systems. This may be due to the effect of the higher organic matter inputs at the topsoil layer which leads to an increase in the levels of soil available phosphors. Similar results have been reported by Michelsen et.al. (1993, 1996), and Mulugeta Lemenih et.al. (2004).

5.4.2.2. Soil pH, EC (ds/m), and CEC

Soil pH /Soil reaction

Soil reaction or soil pH is one of the soil chemical properties that used to measure the acidity or alkalinity of a soil which ranges from 0 to 14 pH readings. The present results showed that soil pH significantly varied with land-use systems. The overall mean value of soil pH level distribution in different land-use systems was observed in the order of grassland > natural forest > grazing land > *P. patula* > *G. robusta* > *E. globulus* > *C.*

lusitanica > cropland. The pH changes depending on the magnitude of the external and internal inputs of soil exchangeable basic cations. The results revealed that numerically soil pH ranges from 5.38 in the cropland to 6.49 in the grassland. Among the land-use systems, the maximum mean value of pH (6.49) observed in grassland, followed by natural forest (6.20) without significant difference between them. This might be attributable to the higher litter deposition from the aboveground and below ground (roots) which gone under decomposition by the action of micro-organisms and subsequent mineralize to releases basic cations to the soil in both land-use systems. This agrees with the simple positive correlation relationships between soil pH with soil organic carbon ($r = 0.432$), cation exchange capacity (CEC) ($r = 0.649$), exchangeable cations of Ca ($r = 0.592$), Mg ($r = 0.26062$), K ($r = 0.3253$), and negative correlation with Na ($r = -0.101$) in the soils. Similar studies results were reported by Michelsen et al. (1993), Michelsen et. al., (1996), and Nsabimana et al., (2008), for soils of higher pH levels under natural forest than other land-use systems. Similarly, the higher soil pH under grassland than other land-use systems was reported by Kaur and Toor (2012).

The lower mean values of soil pH were recorded in cropland, *Cupressus lusitanica*, and *Eucalyptus globulus* plantations in the orders of 5.38, 5.41, and 5.48, respectively, without significant statistical differences between them. The main reasons for the lowest value of soil pH in the cropland are probably due to poorly managed cultivation; use of chemical fertilizers including urea and DAP, intensive use of herbicides such as roundup which contain high amounts of cations that helps to neutralize the negative charges i.e. a higher concentration of H^+ (lower pH) will neutralize the negative charge in soils, and soil erosion. Besides these, the leaching of more soluble soil minerals and basic cations may have caused the slight acidity of the soils in the area. Balesdent et al, (2000) and Tejada and Gonzalez (2008) have found that cultivation on farmlands led to the soil acidity increase. Other researchers have also observed a lower soil pH in cultivated farmland than other land-use systems (Nega Emiru and Heluf Gebrekidan, 2013, Tellen, and Yerima, 2018).

Similarly, the decrease in soil pH under the *Cupressus lusitanica* and *Eucalyptus globulus* plantations could be due to lower accumulation of soil organic matters (SOM) by adding few litters to soils from mono exotic tree plantation species, low basic cations release to soils, and prolonged uptakes of basic cations from soils by fast-growing plantation tree species roots. Additional reasons may be fast-growing exotic plantations are acidify the soil in nature by accumulating excess basic cations in the forest biomass, increasing production of organic acids from decomposing litter, and increasing cation leaching. The fast-growing exotic tree species that require high water for biomass production may increase solute concentrations and the mineralization of organic sulfur in the soil which leads to decrease soil pH. Similar studies were also reported that a decline in soil pH under the fast-growing exotic trees plantation forests (Jobbágy and Jackson, 2003; Mishra et al., 2003, Sanchez et al., 2003, Nsabimana et al., 2008, Tegenu Ashagire et. al., 2008, Tellen, and Yerima, 2018).

The study indicated that the overall mean value of pH at the topsoil layer (5.80) was lower than that of the subsoil layer (5.86) without significant differences between them. Among the LUS the soil pH levels distribution trend across soil depths decreased gradually from topsoil to subsoil layer in a natural forest, *Grevillea robusta* plantation, and grassland. The higher value of soil pH at the topsoil than subsoil layers could be due to the higher accumulation of organic matters at surface soil and passed under decomposition via micro-organism action then mineralized and released basic cations to a soil that lead to raised pH at topsoil layer. Similar results were reported by Michelsen et al. (1993), Michelsen et al. (1996), and Mulugeta Lemenih et al. (2004) in which case the higher value of soil pH observed at topsoil layer than subsoil layer under natural forests in different sites.

On another hand, among LUS the pH levels distribution trend in soil increased gradually from topsoil to subsoil layers in *Eucalyptus globulus*, *Cupressus lusitanica*, and *Pinus patula* plantations, grazing land, and cropland of land-use systems. The result of the higher value of soil pH at subsoil than topsoil layers probably is due to the leaching of more soluble soil minerals and basic cations from topsoil to subsoil layers. Similarily, Michelsen et al. (1996) and Mulugeta Zewdie and Olsson (2008) reported the increment of pH values from topsoil to subsoil layers in *Eucalyptus globulus* and, *Pinus patula* plantation forest land-use systems in the Ethiopian Highlands. In contrast to the present finding, other workers have reported the decline of soil pH values from topsoil to subsoil layers under *Cupressus lusitanica* plantation forest in different Ethiopian sites (Michelsen et al. 1993, Michelsen et al. 1996, and Mulugeta Lemenih et al. 2004).

Soil electrical conductivity (EC)

Soil electrical conductivity (EC) is a measure of the number of salts in soil or salinity of the soil. In the present finding, the mean values of electrical conductivity (EC) of soil were found numerical between 1.78 and 3.47 deciSiemen per meter (dS/m) ranges.

According to the current finding the mean value of electrical conductivity (EC) of soil levels across land-use systems was found in the order of *E. globulus,*> cropland > *G. robusta* > *P. patula* > *C. lusitanica* > grassland > grazing land > natural forest. The maximum mean value of electrical conductivity (EC) was observed in the *Eucalyptus globulus* plantation (3.47) and followed by cropland (3.07) without significant differences between them. The higher value of EC under *Eucalyptus globulus* plantation may be attributed due to the soil compaction that related with high bulk density, lower soil moisture content that related to soluble salts accumulate in the upper soils rather than leached down, high evaporation rate due to open canopy and low infiltration rate, salts originate from the disintegration (weathering) of minerals and rocks, soils with an accumulation of exchangeable sodium are often characterized by poor tilth and low permeability making high EC. These reasons are supported with the positive correlation between the electrical conductivity (EC) and exchangeable sodium, Na ($r = 0.202$), bulk density ($r = 0.433$), and negative correlated with moisture content ($r = - 0.265$), porosity ($r = - 0.264$), and organic carbon ($r = - 0.466$). This result is in agreement with the findings of Michelsen et al. (1996). On the contrary, Michelsen et al. (1993) were observed a higher electrical conductivity (EC) level in natural forest (0.404 dS/m) than the *Eucalyptus globulus* plantation (0.29 dS/m) in the Ethiopian highland. However, for the high level of EC in cropland probably due to tillage intensity and land management practice, cropping system and nature, salt accumulation from commercial fertilizers, chemical contamination (from herbicide, insecticide, and fungicide use by farmers), erosion, runoff, animal manures (usually high tunnels), and compost were contributed to raising EC. Similar studies findings were reported by Gol, (2009), Kaur and Toor, (2012).

The minimum mean value of electrical conductivity was observed in the natural forest (1.783) than the other land-use systems. The lower level of EC under natural forest is probably attributed due to the higher accumulation of organic matters (litter deposition) that decomposed and release higher exchangeable cations (K, Ca, Mg) to the soils, which lead to reducing the salinity level in the soils. The variation in high litterfall addition or organic matter accumulation was decomposed and released exchangeable cations to the soil which leads to lower values of electric conductivity under the natural forest. This explanation is supported by the negative correlation between electrical conductivity and exchangeable cations K($r = -0.400$), Ca($r = -0.532$), Mg($r = -0.173$), and organic carbon ($r = -0.466$). This finding is in agreement with a similar study report by Michelsen et al. (1996), and Gol (2009) who had reported that a lower mean value of electrical conductivity under natural forest than other land-use systems.

The lowest value of electrical conductivity (EC) was observed at the topsoil layer (2.22) than the subsoil layer (2.60). Across the soil depth factor, the mean values of electrical conductivity (EC) were increased from topsoil to subsoil layer in all land-use systems, except the *Eucalyptus globulus* plantation. The lower mean values of EC at topsoil is probably due to the addition and accumulation of organic matters at the topsoil surface than the subsoil surface that liberates exchangeable cations, thereby, reducing soil EC. Generally, the EC values increased with increasing soil depth, which is possibly due to the high mobility of salts of various ions towards the subsoil layer that leads to raising soil EC. In contrast to the present finding, Michelsen et al. (1996) reported the decrease of soil EC level from topsoil to subsoil layer in *Cupressus lusitanica, Eucalyptus saligna*, *Pinus patula*, *Juniperus procera,* and natural forest land-use systems in the highland of Ethiopia.

Cation-Exchange Capacity (CEC)

Cation Exchange Capacity (CEC) is a measure of the degree or capacity of the soil to hold and exchange cation nutrients (e.g., Ca, Mg, Na, K). The present study showed that the mean values of CEC were found between 18.98 and 33.63 meq/100gm of soil ranges. The overall mean value of soil CEC level distribution in different land-use systems was recorded in the order of natural forest > *P. patula* > grassland > grazing land > *E. globulus* > *G. robusta* > *C. lusitanica* > cropland. Among the land-use systems the highest concentration of cation exchange capacity (CEC) was registered in natural forest (33.63). This is probably influenced by the high amount of clays contents, organic matter accumulation, and high soil pH in the natural forest that lead to higher CEC. This means the CEC of soils is affected mainly by the amount and type of clay and the amount and degree of decomposition of the organic matter. In general, the higher soil organic matter (SOM) and clay content are resulting in the higher the CEC. This reason is supported by a significant positive correlation between the soils CEC and OC ($r = 0.644$), clay ($r = 0.184$), and pH ($r = 0.649$). The CEC is positively correlated with pH; therefore, acid soils have a lower potential of CEC. The present results agree with the findings of Michelsen et al. (1996), Dhaliwal and Singh (2003), Mulugeta Lemenih et al. (2004), Nsabimana et al. (2008), and Habtamu Kassahun et.al. (2018) were observed the highest cation exchange capacity (CEC) values in the natural forest than others of land-use systems in different areas. Cation Exchange Capacity (CEC) is one of the very significant soil property components that influencing soil structure, stability, soil pH, nutrient availability, and other soil properties improvement (Hazleton and Murphy 2007).

The cation exchange capacity (CEC) concentration was distributed more/leas uniformly in *Pinus patula* plantation, grassland, and grazing land of land-use systems in order of 29.23, 28.97, and 27.46, respectively without significant differences among them. The lowest concentration value of cation exchange capacity (CEC) was observed in cropland (18.98), followed by the *Cupressus lusitanica* (21.26), *Grevillea robusta* (23.24), and *Eucalyptus globulus* (25.78) plantations. The variations may be attributed due to the low additions of organic matters or litter deposition in the cropland which results from low libration of exchange cation nutrients (Ca, Mg, Na, K) to soil by decomposition. Similar to the present findings, Mulugeta Lemenih et al. (2004) reported the lower values of CEC in mechanized farming (MF). In contrary to the current result, Kaur and Toor (2012), and Mulugeta Sebhatleab (2014) was declared the higher value of cation exchange capacity (CEC) concentration in cropland than the others of land-use systems.

Across the vertical gradient of soil depth, the overall mean value of the highest cation exchange capacity (CEC) concentration was registered at the topsoil layer (27.31) than the subsoil layer (24.82). The study showed that the distributions of cation exchange capacity (CEC) concentrations were decreased from topsoil to subsoil layers in all land-use systems except the *Eucalyptus globulus* plantation. This may be attributed to the higher amount of organic matter accumulation at topsoil than the subsoil layer, thereby, released of exchange cation nutrients (Ca, Mg, Na, K) to soil. In a similar way, other workers (Michelsen et al., 1993, Mulugeta Lemenih et al., 2004, Mulugeta Zewdie and Olsson 2008) observed the higher mean values of cation exchange capacity (CEC) concentrations at topsoil layer than subsoil layer under different land-use systems.

5.4.2.3. Soil Exchangeable bases (Na, K, Ca, Mg), and Base saturation percent

Exchangeable cations (Na, K, Ca, Mg)

According to Rayment and Higginson (1992) reported that exchangeable bases are the alkaline earth metals (mainly Ca, Mg, P, and Na) joined to the clay and organic matters contents of soils and which can be exchanged with every other, and with other positively charged ions in the soil solution. As the function of land-use systems, the concentration of exchangeable cations was generally in the order of Ca > Mg > K > Na in all different land-use systems of soils. These results agree with the principle stated as the energy of the adsorption sequence of: Ca > Mg > K > Na. The highest concentration of exchangeable cations of Ca, Mg, and K, were observed in the natural forest in the order of 17.13, 5.37, and 3.60 cmol (+)/kg soil, respectively. These probably attributed due to the higher accumulation of soil organic matters (SOM) by adding woody plant litters and understory herbaceous plant residues to soils from different heterogeneity plant species with the high rate of biomass production and those undergone decompositions, thereby, liberate cations nutrients of Ca, Mg, and K to the soils. The main exchangeable cations (positively charged ions) in soils are calcium, magnesium, potassium, and, sodium which are held or stick in the soil by organic matter and clay minerals of mostly negatively charged ions to preventing them from leached out by water. These results are in agreement with the findings of Michelsen et. al., (1993), and Tellen, and Yerima (2018). Similarly, Nsabimana et al., (2008) also observed a higher concentration of exchangeable cations of Ca, and Mg under Mixed native species (MNS) forest than other plantations of mono exotic tree species in southern Rwanda.

Additional reasons for the higher concentration of exchangeable cations of Ca, Mg, and K, in the natural forest, may be due to reduced losses of cations nutrients from the soil by leaching out withholding positively charged ions (cations) by electrostatic force, reduced runoff, and soil erosion via upper surface cover approach with litters, and low cations nutrients demand by some species in a natural forest, might contribute to the higher of cations nutrients under natural forest. These explanations are supported by the positive correlation between the organic carbon and exchangeable cations in the soils K ($r = 0.576$), Ca ($r = 0.677$) and Mg ($r = 0.426$). In general, McKenzie et al. (2004) noticed that the clay mineral and organic matter components of soils with large quantities of negative charge ions are more fertile because they retain more cations nutrients (positively charged ions) by saving them from leaching out. A similar observation was reported by Michelsen et. al., (1996) in the highland of Ethiopia.

The highest concentration of Na was observed in the *Eucalyptus globulus* plantation (0.60 cmol (+)/ kg soil) than the other land-use systems. The overall mean values of the distribution of exchangeable Na in the area were found in the orders of *Eucalyptus globulus* > natural forest > *Grevillea robusta* > grazing land > *Pinus patula* > grassland > *Cupressus lusitanica* > cropland. For the highest concentration of the exchangeable Na^+ in *Eucalyptus globulus* plantation might be contributed due to the effects of high soil compaction that result with high bulk density, and lower soil moisture content could be facilitated to the soluble salts accumulate in the upper soils rather than leached down. Similar observations were reported by Michelsen et. al., (1993), Michelsen et. al., (1996), that the higher exchangeable sodium under *Cupressus lusitanica, Eucalyptus globulus, Eucalyptus grandis, and Eucalyptus saligna* plantation in the highland of Ethiopia. Contrary to the present result, Nsabimana, et.al. (2008) were reported that a higher concentration of Na under *Pinus patula* (7.6), *Cupressus lusitanica* (7.5), and *Grevillea robusta* (7.1) plantations without significant difference between them than other plantation species in southern Rwanda.

The lowest concentration of exchangeable cations of Na, K, and Ca, were recorded in cropland in the order of 0.21, 1.20, and 9.93 cmol (+)/kg soil, respectively. This could be due to the low addition of organic matters from external factors and the removal of crop residuals from the cropland by harvesting may be contributing to lower addition of the cations nutrients of Na, K, and Ca to soils. Besides these, the lowest concentration of exchangeable Na, K, and Ca in cropland probably due to continuous intensive tillage and cropping systems facilitate to lower bulk density, lower CEC, higher porosity, and higher infiltration rate in soils could lead simply these cations nutrients of Na, K, and Ca were leached out down to the soil depth by water. In a similar way, Lalisa Duguma et.al. (2010) was observed that the highest concentration of exchangeable Ca in cereal farmland than other land-use systems. However, the minimum mean value of exchangeable Mg was recorded in *Cupressus lusitanica* plantation (2.91 cmol (+)/kg soil). This probably due to the lower addition of organic matters to soils from external factors, and the lower exchangeable Mg content of litters to liberate this cation.

Considering the vertical gradient of soil depth, the overall higher mean value of exchangeable cations of Na, K, Ca, and Mg concentration was observed at the topsoil layer than the subsoil layer with a significant difference. The distribution of exchangeable Na, K, Ca, and Mg concentration decreased vertical from the topsoil (0 – 20 cm) to subsoil (20 – 40 cm) layers in all land-use systems. These probably due to the higher deposition of organic matters that undergoes decomposition and mineralized cations nutrients of Na, K, Ca, and Mg to soils, then CEC plays the roles to retain the released cations at topsoil from the decomposed organic matter rather than translocating them to the subsoil layer. Brady and Weil (2007) noted that Cations, such as K^{+}, Na^{+}, and Ca^{2+}, are adsorbed in soil or organic colloids, making the cations available for plant uptake by preventing cation leaching from the system. Similar studies results have been reported by Michelsen et.al. (1996), Mulugeta Lemenih et al. (2004), Mulugeta Zewdie, and Olsson (2008) as the majority of exchangeable cations nutrient concentrations were declined as soil depth increase, except exchangeable Na in some land-use systems in different areas. Lalisa Duguma et.al., (2010) were also reported that all the exchangeable cations decreased with soil depth increase except exchangeable Ca^{2+} in woodlots, exchangeable K+ in homesteads, and exchangeable Na+ in cereal farms central highland of Ethiopia.

Percent Base saturation (%BS)

Base saturation is the relative percentages of the major cation nutrients found in the cation exchange sites (CEC) in a given soil. Among the land-use systems, the highest mean value of percent base saturation (80.83) was observed in the *Cupressus lusitanica* plantation. This probably due to the amount and nature of clay particles contents and low concentration of CEC, and low pH level in soils could be contributed to the existence of higher percent base saturation (PBS) under *Cupressus lusitanica* plantation forest than other land-use systems. The amount and type of clay minerals are responsible factors for CEC in that both clay and colloidal organic matters (COM). These reasons are supported by a significant negative correlation between the soils PBS and clay (r = - 0.202) between PBS and CEC (r = - 0.300) and between PBS and pH (r = - 0.050). Similarly, Fassil Kebede and Charles (2009) were suggested that clay and colloidal organic matters are negatively charged and can act as anions; as a result, these two materials can absorb and hold positively charged ions (cations). These findings are in agreement with a similar study report by Nsabimana, et.al. (2008), who had reported the higher percent base saturation (93.7%) under *Cupressus lusitanica* plantation among other plantation forests in southern Rwanda.

The lowest mean value of percent base saturation (70.912) was recorded in the *Eucalyptus globulus* plantation. This probably due to the lower addition of organic matters that undergoes decomposition and liberate low cations nutrients of Na, K, Ca, and Mg to soils and higher pH level; that lead to lower percent base saturation under *Eucalyptus globulus* plantation than the other land-use systems. This explanation is supported by the positive correlation between percent base saturation and organic carbon (r = 0.262), and a negative correlation between PBS and pH (r = - 0.050). The variation of the percent base saturation (PBS) means values among different land-use systems may be due to the variation of amount, and nature of organic matters addition, and degree of decomposition to release cation nutrients to soils. Similar observations were reported by Mulugeta Lemenih et al. (2004), Nsabimana, et.al. (2008), and Lalisa Duguma et.al. (2010), as different percent base saturation (%BS) levels under different land-use systems.

Vertically across soil depth, the highest percent base saturation (%BS) levels were observed in the topsoil (81.75) than the subsoil (71.12) layer. The distribution of percent base saturation (% BS) levels was decreased vertical from the topsoil layer to the subsoil layer in all land-use systems. This may be attributed due to the effect of higher organic matter depositions from litters of woody, herbaceous residuals, animal manures, crop residuals on croplands, and lower pH value at the topsoil layer than subsoil layer in land-use systems. The availability of nutrient cations such as Ca, Mg, and K to plants increases at topsoil with increasing BS%. Similar observations were made by Mulugeta Lemenih et al (2004), and Mulugeta Zewdie and Olsson (2008).

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

Yerer Mountain natural forest is one of the remnants protected forests in Ethiopia and recognized by legislation in 1965 in the form of state forest for environmental protection purposes. Over the many years in the past, the natural forest cover shrunk while the extent of the forest monoculture plantations in reforestation and afforestation programs with fast-growing exotic tree species have increased for multiple purposes. The present study identified eight (8) different land-use systems (LUS): natural forest, four exotic tree plantation species (*Eucalyptus globulus, Cupressus lusitanica, Grevillea robusta,* and *Pinus patula*), grassland, grazing land, and cropland. The finding was synthesized and provided the quantitative data and scientifically organized information of the effects of different land-use systems (LUS) on the above and belowground native vegetation species composition, diversity, density, and woody natural regeneration status, and as well as soil properties in the central high land of Ethiopia.

The present study revealed 93 woody plant species (trees, shrubs, and woody climbers) belonging to 73 genera, and 46 families were identified from the Yerer Mountain natural forest within the altitudinal range of 2265 to 3103 m.a.s.l. Among the identified woody species, 26.88% species were trees, 59.14% species were shrubs, and 13.98%) species were woody climber. This indicates that the forest is dominated by shrub and small-sized tree species in the remnant secondary stage of the natural forest, which reflect the dominance of small-sized individuals, due to the presence of high regeneration of woody species found in the lower DBH and height class sizes, and by anthropogenic factors in the selective cutting of bigger tree species in the forest. In Yerer Mountain natural forest, five plant community types were identified as those having varying degrees of species richness, evenness, and diversity due to different factors of anthropogenic, altitude, soil moisture, and soil nutrients variations among communities. The analyses of Sorenson's coefficient of similarity on the species composition among communities were varied between 0.36 and 0.78, due to the variations of the number of sample quadrat sizes, geographical distance, altitude, slope, degree of an anthropogenic factor on some species, and ecological requirement of nutrients availability by different species among plant communities.

The analysis of vegetation structure has shown the overall individuals of woody species DBH and height class distribution were a regular inverted J-shape curve. This means the occurrence of the highest number of individuals stems in the lower DBH and height size classes and a gradual decrease towards the higher classes of DBH and height indicating good reproduction potential of the natural forest. The total basal area of all woody species in Yerer natural forest was 46.82 $m^2 ha^{-1}$. The overall woody species basal area distributions among DBH classes revealed a bell-shaped curve. The analysis of the IVI values of Yerer natural forest revealed that the forest is dominated by few woody plant species of *Juniperus procera*, *Myrsine africana*, *Carissa spinarum*, *Dodonaea angustifolia*, and *Olea europaea* subsp. *Cuspidata* which express the relative ecological significance in the natural forest. The overall assessment of the regeneration status of woody species revealed that the distribution of seedlings density (1354) > saplings density (1108) > matured woody density (951), indicates the woody species had successful healthy regeneration profiles in the natural forest. This implies that the composition, distribution, and density of seedlings and saplings potential indicate the future appearance of native woody species in Yerer natural forest.

In a comparative study among plantations of exotic tree species, a total of 211 aboveground native species belonging to 59 families, and 153 genera represented by 132 herbs, 77 woody species, and 2 ferns were recorded under five forest land-use systems. The overall total native vegetation richness under different forest land-use systems (LUS) ranged from 71 to 181 species. It is also documented; the natural forest is more diverse of native species than plantation forests. Particularly, the current result indicated that the highest native vegetation composition and density were observed in a natural forest, whereas, the lowest species composition and density were observed in *Eucalyptus globulus* plantation. This implies that natural forest has the potential to facilitate understory vegetation regeneration and growth by creating better favorable environmental conditions (moisture, soil properties, and seed banks) that required plants for germinating and growth than exotic tree plantations. On the other hand, the present study results showed that the lower number of native vegetation species diversity, richness, density, and natural regeneration status were recorded under plantations of exotic tree species than the adjacent natural forest.

The findings indicated that different species richness and density of seed banks have shown significant variations between land-use systems (LUSs). The soil seed banks showed a total of 98 plant species that belong to 42 families and 84 genera. A total plant species composition and seed density /m^2 were recorded between 29 to 57, and 1625 to 3250, respectively, under eight land-use systems. General, the historical changes in land-use systems by human intervention have altered the soil seed bank species composition and seed density across the horizontal as a function of land-use systems and vertical as a function of soil depth. The highest species richness and seed density/m^2 were recorded in a natural forest, while the lowest species richness and seed density/m^2 were observed in the *E. globulus* plantation. Among the plantations of exotic tree species, *E. globulus* plantation influence on seed bank species richness and density. The overall vertical distribution of species composition and seeds densities in the soil were similar in all land-use systems with gradually decreasing with increasing soil depth.

In soil Physico-chemical properties study, the results revealed that the highest mean values of MC, OC, TN, Available P, CEC, Exch. Ca, Exch. Mg, and Exch. K were observed under natural forest than others of land-use systems in the area. On the other hand, the lowest mean values of soil BD, PD, and soil EC properties were registered under natural forest than other land-use systems. These indicate that a natural forest land-use system has a more positive effect on soil Physico-chemical properties change as compared to the other land-use systems under similar climatic conditions. The study results showed that the lowest mean values of MC, OC, TN, soil pH, CEC, and exchangeable bases (Na, K, and Ca) were recorded under cropland than other land-use systems. Among the five forest land-use systems the lowest mean values of soil MC, SP, OC, TN, Avail. P and BS% were recorded under the *Eucalyptus globulus* plantation. However, the highest mean values of BD, PD, EC, and Exch. Na was also observed under the *Eucalyptus globulus* plantation than other land-use systems. In general, the majority of soil Physico-chemical properties under the cropland and *Eucalyptus globulus* plantation were poorer than the soils subjected to other land-use systems.

6.2. Recommendation

Based on the study of this thesis that dealt with the different land-use systems in various aspects of floristic composition of native and introduced species, soil seed banks, and soil Physico-chemical properties, the following recommendations are made:

- The species composition of the Yerer forest is very heterogeneous and rich in diversity with 93 woody species in 46 families. The responsible Federal and Regional government's body should provide due attention to conserve and sustainably use the forest. The result of this study will be provided information regarding the priority conservation species required to help with the implementation.
- The assessment of regeneration status based on seedlings and sapling count revealed that a significant proportion of 8 (8.60%) woody species with "poor regeneration" (such as *Salix mucronata*, *Pterolobium stellatum*, *Croton macrostachyus*, *Podocarpus falcatus*, *Millettia ferruginea*, *Rumex nervosus*, *Solanum marginatum*, and *Cussonia arborea)* and 9 (9.68%) woody species were"not regenerating" (*Grewia ferruginea*, *Vernonia amygdalina*, *Solanecio gigas*, *Embelia schimperi*, *Phoenix reclinata*, *Bersama abyssinica*, *Ekebergia capensis*, *Acacia albida*, and *Cordia africana*) at all in Yerer natural forest, which implying that they are under threat. Therefore, a systematic management intervention measure is recommended to develop and implement effective conservation measures to save and sustain these rare woody species in the area.
- The native floristic composition, diversity, density, and natural regeneration status were lower under the plantations of exotic tree species than natural forest, which

indicates that the exotic tree plantations have lower understory native floristic diversity than natural forests. It is recommended that appropriate government bodies (particularly, Oromia Forest and Wildlife Enterprise) should give attention to develop appropriate management intervention measure to restore the natural native vegetation composition, density, and natural regeneration status under the plantations of exotic tree species or keep the exotic tree plantations expansion particularly, *Eucalyptus globulus* in restricted places for a restricted use based on the confine specific land-use objective.

- Different species of exotic tree plantations showed variability in their influence on aboveground and seed bank species richness, diversity, density, and natural regeneration status, and soil Physico-chemical properties under similar climatic conditions. Therefore, the concerned bodies (governmental forest enterprises, private sectors, and individual cultivators) should be select the appropriate multipurpose tree species of fast-growing and friendly with above and belowground native vegetation species, and soil properties for establishing exotic tree plantations with the aim of native vegetation restoration and conservation, and soil properties improvement.

    - ♣ Even though it is not part of this dissertation, but during my study, I have observed, local people in the environs of the Yerer forest commonly use plant species in the forest for the medicine to both human and animal ailments. This requires ethnobotanical studies in the future to explore the indigenous knowledge of local people on the socio-economics importance of plant biodiversity.

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8. APPENDICES

Appendix 1: Woody plant species List in Yerer Mountain Natural Forest

	Species Scientific Name	Family name	Local name		Groth Habit	Spp. coll. Code No.
			Afan Oromo	Amharic		
1	*Acacia abyssinica* Hochst. ex Benth.	Fabaceae	Laafitoo	Girar	T	YB 049
2	*Acacia albida* Del.	Fabaceae	Garibii	Gerbi; Grar	T	YB 036
3	*Acacia seyal* Del.	*Fabaceae*	Waacuu	Girar Wacho	T	YB 073
4	*Acacia sieberiana* DC.	Fabaceae	Laftoo adii	Girari	T	YB 025
5	*Acacia tortilis* (Forssk.) Hayne subsp. *spirocarpa* (Hochs t. ex A.Rich.) Brenan	Fabaceae	Gollollee, Tedecha	Girari, Korera, Koresra, Deweni Grar	T	YB 062
6	*Acanthopale* sp. Puff& Ensermu	Acanthaceae			S	YB 081
7	*Albizia schimperiana* Oliv.	Fabaceae	Sasa, Shimoro	Sesa, Sasa, Shimoro	T	YB 075
8	*Asparagus africanus* Lam.	Asparagaceae	Saaritii	Seriti	S	YB 035
9	*Barleria parviflora* R.Br.ex T. Anders.	Acanthaceae			C	YB 088

10	*Becium grandiflorum* (Lam.) Pic.Serm.	Lamiaceae		Mandusey, Mentesa, Yedega Mentesie,	S	YB 092
11	*Bersama abyssinica* Fresen. *subsp. abyssinica*	Melianthaceae	Lolichissa guracha	Tikuri Azamir	S	YB 026
12	*Buddleja polystachya* Fresen.	Loganiaceae	Adadoo	Anifar, Chocho, Amefar, Anfar, Atquar, Atkuar	T	YB 002
13	*Cajanus cajan* (L.) Millsp.	Fabaceae	Ataraa Simbiiraa	Yergib Ater; Yewef Ater;	S	YB 089
14	*Calpurnia aurea* (Ait.) Benth.	Fabaceae	Ceekaa/Ancabi	Digta, Ginda; Qimba; Tobia	S	YB 053
15	*Capparis sepiaria L.*	Capparidaceae	Arraangama Gurracha	Gmero, Gimero	S	YB 087
16	*Carissa spinarum L.*	Apocynaceae	Agamsa, Hagmasa	Agemi	S	YB 017
17	*Clematis hirsuta* Perr. & Guill.	Ranunculaceae	Hidda adii, Feetii,	Nech Ye Azo Hareg, Qemida	C	YB 056
18	*Clematis longicauda* Steud. ex A. Rich.	Rununculaceae	Hida Fitii	Alaya;Nech Ye Azo Hareg	C	YB 006
19	*Clematis simensis* Fresen.	Ranunculaceae	Hida Fiitii fakkate Habaaboo adii		C	YB 052
20	*Clerodendrum myricoides* (Hochst) Vatke	Lamiaceae	Erbaa/Maraasisaa	Misirichi, Meserech	S	YB 004
21	*Cordia africana* Lam.	Boraginaceae	Waddeessa	Waniza	T	YB 079
22	*Croton macrostachyus* Del.	Euphorbiaceae	Bakanisa	Bissana; Mesana	T	YB 029

23	*Cussonia arborea* A.Rich.	Araliaceae	Muka somboo fakkatuu	Gedetamo; Yeznjero Gomen	T	YB 072
24	*Dodonaea angustifolia* L. f.	Sapindaaceae	Ittacha	Kitikita	S	YB 019
25	*Dombeya torrida* (J.F. Gmel.) P. Bamps	Sterculiaceae	Dannissaa	Wulkfa; Wolkefa	S	YB 057
26	*Dovyalis abyssinica* (A. Rich.) Warb.	Flacourtiaceae	Koshoomii = Akuukkuu, Angago,	Koshim	S	YB 045
27	*Dregea schimperi* (Decne.) Bullock	Asclepiadaceae	Hidda mukaati marraamuu		C	YB 065
28	*Ekebergia capensis* Sparrm	Meliaceae	Somboo	Lol; Sembo; Duduna	T	YB 027
29	*Embelia schimperi* Vatke	Myrsinaceae	Hanquu	Inikoko/Enqoqo, Enkoko	S	YB 046
30	*Erica arborea L.*	Ericaceae	Hasiti	Asita, Adal, Wuchena,	S	YB 007
31	*Euclea divinorum* Hiern	Ebenaceae	Mi'eessaa	Dedeho	S	YB 083
32	*Euclea racemosa* Murr. subsp. *schimperi* (A. DC.) White,	Ebenaceae	Me’essaa	Dedeho	S	YB 031
33	*Ficus cycomorus* L.	Moraceae	Luugoo/Odaa	Bamba, Bambba,	T	YB 044
34	*Ficus sur Forssk.*	Moraceae	Harbuu	Shola	T	YB 024
35	*Grewia ferruginea* Hochst. ex A. Rich.	Tiliaceae	Doqqoonuu/Lanqisa,	Dokima (Alenqoza, Lenkoata), Alunqato	S	YB 047
36	*Hagenia abyssinica* (Bruce) J.F.Gmelin	Rosaceae	Heexoo	Kosso	T	YB 063

37	*Hebenstretia dentata L*	Scrophularlaceae			S	YB 086
38	*Helinus mystacinus* (Ait.) E.Mey. ex Steud.	Rhamnaceae	Hida Diima	Qemida; Kemida (Tya)	C	YB 042
39	*Heteromorpha arborescens* (Spreng.) Cham. & Schltdl.	Apiaceae	Rigaa Qaluu	Ye Jibi merikuzi,	S	YB 021
40	*Hypericum revolutum* Vahl	Hypericaceae	Hindhee	Ameja	S	YB 051
41	*Indigofera arrecta* Hochst. Ex A. Rick.	Fabaceae	Adara karraa	Buk Buk, Bukbuk	S	YB 080
42	*Inula confertiflora* A. Rich.	Asteraceae	Managiftee/Mognoree	Weynageft	S	YB 070
43	*Jasminum abyssinicum* Hochst.ex DC.	Oleaceae	Hidda Ilichiibee	Tembelel, Terark, Tero-hareg, Zohun-kechamo	C	YB 059
44	*Jasminum grandiflorum* L. subsp. *floribundum* (R.Br. ex Fresen.) P.S.Green	Oleaceae	Hida Qammaxee	Tembelel	C	YB 011
45	*Juniperus procera* Hochst. ex Endl.	Cupressaceae	Gatira abesha	Ye abesha Tidi	T	YB 009
46	*Justicia schimperiana* (Hochst. ex Nees) T. Anders.	Acanthaceae	Dhumugaa	Sensel	S	YB 064
47	*Lantana trifolia* L.	Verbenaceae	Kase, Kaseh	Yregna kollo,Yeregna kolo,	S	YB 086
48	*Leonotis ocymifolia* (Burml. f.)	Lamiaceae	Bokkooluu Mata Diimaa	Ras Kimir;	S	YB 061

	Iwarsson					
49	*Leucas abyssinica* (Benth.) Briq.	Lamiaceae	Shimoo Buree	Dereta, Chimida,	S	YB 093
50	*Lippia adoensis* Hochst. ex Walp.	Verbenaceae	Kussayee/Koshonota,	Koserti, kasse	S	YB 020
51	*Maesa lanceolata* Forssk.	Myrsinaceae	Abayii	Qalaya, Kaleya, Akalua,	T	YB 033
52	*Maytenus arbutifolia.* (A.Rich.) Wilczek	Celastraceae	Kombolicha	Atatt; Atat	S	YB 003
53	*Millettia ferruginea* (Hochst.) Bak.	Fabaceae	Sotellu, Dedatu,	Brbra; Birbira	T	YB 060
54	*Myrsine africana L.*	Myrsinaceae	Qacamoo	Qechemo; Kechemo	S	YB 010
55	*Ocimum forskolei* Benth	Lamiaceae	Argaa-dimecha		S	YB 085
56	*Ocimum lamiifolium* Hochst. ex. Benth.	Lamiaceae	Damakase	Dama-kassie	S	YB 028
57	*Ocimum urticifolium* Roth.	Lamiaceae	Dammakasse Adii	Anten beye, Damakesie, Damakase	S	YB 082
58	*Olea europaea L*. subsp. *cuspidata* (Wall. ex G. Don) Cif.	*Oleaceae*	Ejjeersa	Weyira	T	YB 013
59	*Olinia roch*etiana A.Juss.	Oliniaceae	Xifii/ Daalachoo (Nacilloo)	Tifei, Asqamo; Dalecho; Ttfie	S	YB 023
60	*Osyris quadripartita* Decn.	Santalaceae	Watoo	Kereti	S	YB 001
61	*Otostegia integrifolia* Benth.	Lamiaceae	Xuunjiitii	Tunjut; Tinjut; Mararaja	S	YB 034
62	*Otostegia tomentosa* A. Rich. subsp. *ambigiens* (Chiov.) Sebald	Lamiaceae	Muka Xuunjiiti fakatuu/ Ilili-addi	YEFERES-ZENG, Geram tunjut; Nechita;	S	YB 083

				tunjut		
63	*Paullinia pinnata* L.	Sapindaceae	Hidda Gafaarsa		C	YB 055
64	*Pentas schimperiana* (A. Rich.) Vatke subsp. *schimperiana*	Rubiaceae	Daassee	Weynagefet	S	YB 061
65	*Periploca linearifolia* Quart.-Dill. & A.Rich.	Asclepidaceae	Hida Annannoo	Moyder/Domayto;	C	YB 005
66	*Phoenix reclinata* Jacq.	Arecaceae	Meexii	Zenbaba; Zembaba	T	YB 071
67	*Phytolacca dodecandra* L'Hérit.	Phytolaccaceae	Inddoodee, Andode,	Indodi, Endod; Indod	S	YB 069
68	*Pittosporum viridiflorum* Sims.	Pittosporaceae	Sole	Ahot, Anqewalit,	T	YB 012
69	*Plectranthus ornatus* Codd	Lamiaceae	Ossollee fakkata, Ajessa	Gudsemel, Endefdel	s	YB 090
70	*Podocarpus falcatus* (Thunb.) R. B. ex. Mirb.	Podocarpaceae	Birbirsa	Zigiba	T	YB 074
71	*Premna schimperi* Engl.	Lamiaceae	Urgeessaa	Chocho	S	YB 078
72	*Prunus africana* (Hook.f.) Kalkm.	Rosaceae	Hadheessaa (Bouraio)	Tikuri Inichet, Aqoma	T	YB 037
73	*Pterolobium stellatum* (Forssk.) Brenan	Fabaceae	Araangama dimaa	Qonixir/ Kontir, Qentafa; Kentafa	S	YB 016
74	*Rhamnus prinoides* L'Herit.	Rhamnaceae	Geeshoo	Gesho	S	YB 030
75	*Rhamnus staddo* A.Rich.	Rhamnaceae	Qadida	Tedo; Teddo, Tsedo	S	YB 014
76	*Rhus retinorrhoea* Oliv.	Anacardiaceae	Dabalucaa	Talo; Tlem; Sisay	T	YB 015
77	*Rhus vulgaris* Meikle	Anacardiacea	Xaxxeessaa	Kimo, Yeahya Talo	S	YB 008
78	*Rosa abyssincia* Lindley.	Rosaceae	Goraa/Qaqaawee	Kega	S	YB 018

79	*Rubus apetalus* Poir.	Rosaceae	Goraa aribaa	Injori	S	YB 039
80	*Rumex nervosus* Vahl	Polygonaceae	Dhangagoo/ Angaagoo	Imbwacho; Embuacho	S	YB 058
81	*Salix mucronata* L.	Salicaceae	Alaaltuu, Barodo	Ahaya, Wonz admik	T	YB 038
82	*Scolopia theifolia* Gilg.	Flacourtiaceae	Koffallee		T	YB 032
83	*Senecio myriocephalus* Sch. Bip. ex A. Rich.	Asteraceae	Naacciloo	Simbita, ,	S	YB 084
84	*Senna didymobotrya* (Fresen.) Irwin & Bameby	Fabaceae	Shokokissa		S	YB 076
85	*Smilax aspera* L.	Smilacaceae	Hidda Qoree	Ashikla	C	YB 054
86	*Solanecio gigas* (Vatke) C. Jeffrey	Asteraceae	Gommana osolee / Dilu Arbaa	Yeshikoko Gomen; Yeshekoko Gomen;	S	YB 091
87	*Solanum incanum* L.	Solanaceae	Hiddii Loonii/Hiddii		S	YB 067
88	*Solanum marginatum* L.f.	Solanaceae	Hiddi Hoonqoorcaa	Tileku Enbuay	S	YB 066
89	*Sonchus oleraceus* L.	Asteraceae	Caaree Habaaboo kelloo	Yahya Choma;	s	YB 050
90	*Stephania abyssinica* (Dillon & A. Rich) Walp.	Menispermaceae	Hida Kalaalaa, Alala, Hidda hantuuta,	Engochit/Etse Yesus;	C	YB 048
91	*Vernonia amygdalina* Del.	Asteraceae	Ebiicha, Eebicha,	Girawa	S	YB 041
92	*Vernonia auriculifera* Hiern	Asteraceae	Reejii	Gujo/Reji	S	YB 043
93	*Zehneria scabra* (Linn. f.) Sond.	Cucurbitaceae	Hidda Gorrissa/Indiriffaa	Ye Resa harregi,	C	YB 022

Plant growth Habit refers: S= shrubs; T= trees; C= climbers

Appendix 2: Synoptic cover-abundance values for species having a synoptic value greater than 1.0 at least in one community type

Species Name	Communities					Growth habit
	C1	C2	C3	C4	C5	
Juniperus procera	**8.05**	3.86	2.45	5.42	1	T
Myrsine africana	**6.9**	3.14	1.66	4.77	1.71	S
Rosa abyssincia	**6.8**	4.29	4.45	1.92	2.14	S
Osyris quadripartita	**6.5**	0	5.68	5	0	S
Rhus retinorrhoea	**6.1**	1.29	4.68	5.19	1.43	T
Maesa lanceolata	**5.65**	2	0.52	0.23	0	T
Rhus vulgaris	**5.6**	3.57	5.19	3.27	0	S
Pittosporum viridiflorum	**5.2**	1.71	4.97	2.12	0	T
Dodonaea angustifolia	**4.85**	1.86	3.76	4.42	0.71	S
Buddleja polystachya	**4.45**	0	1.82	1.31	0	S
Olinia rochetiana	**3.35**	0.43	3.19	1.08	0	T
Periploca linearifolia	**2.3**	0	0.18	0.23	0	C
Dombeya torrida	**1.2**	0.43	0	0.31	0	S
Clerodendrum myricoides	**1.05**	0	0.82	0.35	0	S
Ficus sur	0	**6.43**	`1	0.27	0.71	T
Pterolobium stellatum	0.3	**5.14**	0.69	0.46	0	S
Bersama abyssinica	0	**4.57**	1.26	1.27	0	S
Vernonia auriculifera	1.65	**4.43**	0	0.19	0	S
Croton macrostachyus	0.7	**4.39**	0.65	0.35	0	T
Clematis longicauda	2.55	**3.86**	1.87	0	0	C
Salix mucronata	0	**3.71**	0	0.69	0	T
Helinus mystacinus	0.85	**3.43**	0.23	1.5	0	C
Phoenix reclinata	0	**3.29**	0	0	0	T

Stephania abyssinica	1.3	**3**	0.35	0	0	C
Vernonia amygdalina	0	**3**	0.05	0.54	0.57	T
Acacia abyssinica	0	**2.71**	0.15	0	0	T
Clematis simensis;	1.7	**2.29**	0.24	0.38	0	C
Dovyalis abyssinica	0.5	**2.29**	0.26	0.58	0	S
Hagenia abyssinica	0	**2.29**	0.16	0.12	0	T
Ficus cycomorus	0	**2.29**	0	0.46	0.43	T
Rubus apetalus	0	**2.14**	0.56	0.35	0.71	S
Grewia ferruginea	0	**2**	0.15	0.38	0.57	S
Acacia sieberiana	0	**1.86**	0.76	0	0	T
Jasminum abyssinicum	0	**1.71**	1.4	0.15	0	C
Embelia schimperi	0	**1.71**	0.03	0.38	0.29	S
Premna schimperi	0	**1.71**	0	0.31	0.71	S
Phytolacca dodecandra	0	**1.71**	0	0.46	1.43	S
Ekebergia capensis	0.35	**1.57**	0.19	0	0	T
Rumex nervosus	0.3	**1.57**	0.03	0.15	2.43	S
Ocimum lamiifolium	0	**1.57**	0.16	0.27	0	S
Calpurnia aurea	0.35	**1.29**	0.06	0.46	0.29	S
Pentas schimperiana subsp. *schimperiana*	0	**1.29**	0.08	0.38	0	S
Justicia schimperiana	0	**1.14**	0.06	0.54	0	S
Clematis hirsuta	0.35	**1**	0.52	0.12	0	C
Smilax aspera	0.25	**1**	0.23	0.15	0	C
Millettia ferruginea	0	**1**	0	0	0	T
Podocarpus falcatus	0	**1**	0	0	0	T
Acacia albida	0	**1**	0.1	0	0.57	T
Cussonia arborea	0	**1**	0	0.27	0.43	T
Carissa spiranum	4.6	1	**7.13**	6.19	0	S

Maytenus arbutifolia	5.8	3.57	**6.29**	5.08	0.71	S
Prunus africana	0.55	2.43	**6.18**	3.15	0.71	T
Heteromorpha arborescens	0.25	0	**5.81**	2.35	0	S
Rhamnus staddo	0.3	0	**2.15**	0	0	S
Otostegia integrifolia	0	0	**1.76**	0.27	0	S
Olea europaea subsp. cuspidata	3.3	2.71	3.56	**7.19**	0	T
Euclea racemosa subsp. *schimperi*	0.65	2.14	1.31	**6.62**	0	S
Jasminum grandiflorum subsp. *floribundum*	1.95	2.14	2.32	**6.35**	0	C
Erica arborea	5.65	0	0.23	0	**8.71**	S
Hypericum revolutum	2	0	0	0.19	**8.57**	S
Inula confertiflora	0	0	0	0.38	**6.57**	S
Hypericum quartinianum	0.35	1	0.13	0	**5.71**	S
Lippia adoensis	2.9	1.14	0.97	0	**5.43**	S
Solanum marginatum	0	0.29	0	0.23	**2.14**	S

N.B. C1-community 1, C2-community 2, C3-community 3, C4- community 4, and C5-community 5

Appendix 3: Native species composition distribution across the forest land-use systems (LUS)

	Species Scientific name	Family name	Local name		Groth Habit	Vegetation species observed Density and frequency under different forest LUS										Spp. Coll. No.
						Natural forest		Cupressus lusitanica		Eucalyptus globulus		Grevillea robusta		Pinus patula		
			Afan Oromo	Amharic		Frequency	stem Density	Frequency	stem Density	Frequency	stem Density	Frequency	stem Density	Frequency	stem Density	
1	*Acacia abyssinica* Hochst. ex Benth.	Fabaceae	Laafitoo	Girar	T	3	19	-	-	-	-	-	-	-	-	YB 105
2	*Acacia albida* Del.	Fabaceae	Garibii	Gerbi; Grar	T	3	7	-	-	-	-	-	-	-	-	YB 062
3	*Acacia seyal* Del	*Fabaceae*	Waacuu	Girar Wacho	T	3	6	-	-	-	-	-	-	-	-	YB 161
4	*Acacia sieberiana* DC.	Fabaceae	Laftoo adii	Girari	T	8	47	-	-	-	-	-	-	-	-	YB 106
5	*Acacia tortilis* (Forssk) *Hayne* subsp. *spirocarpa* (Hochs t. ex A.Rich.) Brenan	Fabaceae	Gollollee, Tedecha	Girari,r	T	2	3	-	-	-	-	-	-	-	-	YB 066

6	*Achyranthes aspera* L.	Amaranthaceae	matanne, dargu,		H	-	-	-	-	-	-	2	6	-	-	YB 198
7	*Achyrospermum schimperi* (Hochst. ex Briq.) Perlcins	Lamiaceae	Shimoo		H	1	1	-	-	-	-	-	-	-	-	YB 147
8	*Acmella caulirhiza* Del.	Asteraceae	Gutichaa abbaa	Yemidir Berbere	H	3	7	-	-	1	1	6	23	-	-	YB 071
9	*Adiantum capillus-veneris* L.	Adiantaceae	Ani-Jiraa gubaa'uu		F	-	-	1	3	-	-	-	-	-	-	YB 185
10	*Aeollanthus abyssinicus* Hochst. ex Benth.	Lamiaceae	Uuffuu Jaldeessaa	Yejib Besobil	H	3	4	-	-	-	-	4	29	-	-	YB 160
11	*Agave sisalana* Perro ex Engel	Agavaceae	Qaacaa	Qacha; Kacha	H	1	1	-	-	-	-	1	4	-	-	YB 132
12	*Ageratum conyzoides* L.	Asteraceae	Gunyato	Arema	H	-	-	2	8	-	-	5	11	6	40	YB 211
13	*Ajuga integrifolia* Ham.-Buch.	Lamiaceae	Arma-gussa	Etse Libawit	H	6	26	-	-	-	-	-	-	-	-	YB 025
14	*Alchemilla pedata* A. Rich.	Rosaceae	Xuuxaa		H	2	6	5	35	-	-	2	54	-	-	YB 170
15	*Aloe macrocarpa* Tod.	Aloaceae	Arrigissa	Ret	H	3	6	-	-	7	26	3	10	2	4	YB 026
16	*Andropogon abyssinicus* Fresen.	Poaceae	Balaamii	Yelami Sar,	H	2	9	9	106	6	58	7	125	9	218	YB 032
17	*Anethum foeniculum L.*	Apiaceae	Insiillaallee	Insilaalee	H	2	3	-	-	-	-	-	-	-	-	YB 091
18	*Anthemis tigreensis* J. Gay ex A. Rich.	Asteraceae	Arama Dimbilale		H	2	7	2	12	1	7	-	-	6	25	YB 012

19	*Argyrolobium fischeri* Taub.	*Fabaceae*	Ataraa Hantuutaa		H	4	11	-	-	-	-	-	-	1	3	YB 027
20	*Arundo donax* L.	Poaceae	Shambaaqoo	Shembek o	H	4	26	-	-	-	-	-	-	-	-	YB 146
21	*Asparagus africanus* Lam.	Asparagacea e	Saaritii	Seriti	S	3	6	-	-	-	-	1	3	-	-	YB 145
22	*Becium grandiflorum* (Lam.) Pic.Serm.	Lamiaceae	Muka kuussaayee fakkatuu = Ossollee	Manduse y, Mentesa,	S	2	5	-	-	-	-	1	2	-	-	YB 129
23	*Bersama abyssinica* Fresen.	Melianthacea e	Lolichissa guracha	Tikuri Azamir	S	7	18	-	-	-	-	-	-	-	-	YB 107
24	*Bidens biternata* (Lour.) Merr. & Sherff	Asteraceae	Maxxannee Kelloo	Yemesqe l Abeba	H	3	6	1	3	-	-	3	8	-	-	YB 123
25	*Bidens macroptera* (Sch.-Bip. ex Chiov.) Mesfin	Asteraceae	Kelloo	Yemesqe l Abeba	H	-	-	2	4	-	-	3	11	-	-	YB 187
26	*Bidens pachyloma* (Oliv. & Hiern) Cufod.	Asteraceae	Kelloo/Hadaa	Yemesqe l Abeba;	H	2	6	-	-	-	-	-	-	-	-	YB 098
27	*Bidens pilosa* L.	Asteraceae	Maxxaannee kelloo	Yeseytan Merfie	H	1	2	2	3	2	8	3	9	1	4	YB 118
28	*Bidens prestinaria* (Sch.-Bip.) Cuf.	Asteraceae	Kelloo Booyyee	Yemesqe l Abeba	H	-	-	1	3	-	-	3	7	-	-	YB 183

29	*Bidens rueppellii* (Sch. Bip. ex Walp.) Sherff	Asteraceae	Kello	Adey Abeba,	H	3	7	-	-	1	2	-	-	-	-	YB 097
30	*Buddleja polystachya* Fresen.	Loganiaceae	Adadoo	Anifar/C hocho	S	6	24	-	-	1	3	3	6	6	13	YB 006
31	*Cajanus cajan* (L.) Millsp.	Fabaceae	Ataraa Simbiiraa	Yergib Ater	S	2	7	-	-	1	2	-	-	-	-	YB 028
32	*Calpurnia aurea* (Ait.) Benth.	Fabaceae	Ceekaa/Anca bi	Digta,	S	3	11	-	-	-	-	-	-	-	-	YB 045
33	*Carduus chamaecephalus* (Vatke) Oliv. & Hiern	Asteraceae	Kossooruu Harree	Kosheshi la	H	1	2	-	-	-	-	-	-	-	-	YB 103
34	*Carduus schimperi* Sch. Bip. ex A. Rich, subsp. *schimperi*	Asteraceae	Baalaa Waarrantii		H	6	20	1	2	3	7	-	-	-	-	YB 030
35	*Carissa spinarum* L. (C. edulis)	Appocynace ae	Agamsa	Agemi	S	12	149	6	46	10	39	-	-	10	39	YB 008
36	*Centaurea melitensis L.*	Asteraceae	Maxxaannee Qorree Gammoojjii		H	1	2	-	-	-	-	-	-	-	-	YB 119
37	*Centella asiatica* (L.) Urban	Apiaceae	Xuuxaa		H	-	-	1	4	-	-	-	-	3	9	YB 192
38	*Cheilanthes coriacea*. Decne.	Sinopteridac eae	Ani-Jiraa gubaa'uu		F	2	3	3	9	-	-	-	-	-	-	YB 010
39	*Chloris gayana* Kunth	Poaceae	Coqoorsa		H	3	18	-	-	-	-	-	-	-	-	YB 047

40	*Cirsium dender* Friis	Asteraceae			H	2	21	-	-	-	-	-	-	-	-	YB 074
41	*Clematis longicauda* Steud. ex A. Rich.	Rununculaceae	Hida Fitii	Nech Ye Azo Hareg	C	9	33	3	6	5	12	9	16	1	4	YB 081
42	*Clematis simensis* Fresen.	Ranunculaceae	Hida Fiitii Habaaboo adii		C	3	13	-	-	-	-	-	-	-	-	YB 080
43	*Clerodendrum myricoides* (Hochst) Vatke	Lamiaceae	Erbaa/Maraasisaa	Misirichi, Meserech	S	5	9	1	2	1	1	1	2	1	2	YB 060
44	*Commelina benghalensis* L.	Commelinaceae	*Gorooraa Fardaa*	Yebegi-lati,	H	-	-	-	-	1	4	-	-	-	-	YB 194
45	*Commelina diffusa* Burm.f.	Commelinaceae	Marga Gurraa Babaal'aa		H	2	5	2	15	1	7	6	82	8	122	YB 189
46	*Conium maculatum* L.	Apiaceae	Aramaa Gollollee		H	1	3	-	-	-	-	-	-	-	-	YB 018
47	*Crassocephalum sarcobasis (*DC) S.Moor	Asteraceae	Maxxannee hababoo “Rose”		H	2	6	-	-	1	5	3	11	-	-	YB 121
48	*Crepis rueppellii* Sch.-Bip.	Asteraceae		Yefyel Wotet;	H	2	4	9	52	2	6	1	4	7	42	YB 015
49	*Crotalaria laburnifolia*	Fabaceae	Misira	Ye-ayit	H	7	33	11	90	5	38	12	160	8	71	YB 128

	L.,subsp. *laburolfolia*		hantuuta	missir												
50	*Crotalaria exaltata* Polhill	Fabaceae	Attaraa Hantuutaa		S	2	7	-	-	-	-	-	-	-	-	YB 029
51	*Croton macrostachyus* Del.	*Euphorbiaceae*	Bakkanissa	Bisana	T	2	8	-	-	-	-	4	8	8	17	YB 031
52	*Cucumis ficifolius* A. Rich.	Cucurbitaceae	Hiddii Holootoo	Yemidir Embauy	H	2	5	-	-	-	-	-	-	-	-	YB 088
53	*Cymbopogon caesius* (Hook. & Arn.)	Poaceae	Qacaa		H	-	-	1	6	4	12	4	12	1	5	YB 191
54	*Cymbopogon commutatus* (Steud.) Stapf	Poaceae	Qacaa	Sembeliet	H	4	14	-	-	1	10	3	20	1	2	YB 133
55	*Cynodon dactylon* (L.) Pers.	Poaceae	Coqoorsa		H	2	6	-	-	1	20	4	49	-	-	YB 048
56	*Cynodon nlemfuensis* Vanderysl	Poaceae	Qarxiissaa /Coqorsa gurraacha	Waratii	H	3	12	-	-	3	7	2	13	-	-	YB 137
57	*Cynoglossum amplifolium* Hochst. ex A.DC.,	Boraginaceae	Maxxannee Hucuu qabaatu		H	2	8	7	23	7	42	10	64	1	2	YB 122
58	*Cynoglossum coeruleum* Hochst. ex A.DC.	Boraginaceae	Maxxannee Chati	Chigogit	H	-	-	-	-	-	-	2	7	1	2	YB 202
59	*Cyperus papyrus* L.	Cyperaceae	Alaaduu	Ketama	H	-	-	-	-	-	-	-	-	2	9	YB 205
60	*Cyperus rigidifolius* Stued.	Cyperaceae	Qunnii /		H	2	4	6	38	1	10	2	8	4	25	YB 142

			Gicha													
61	*Dactyloctenium aegyptium* (L.) Willd.	Poaceae	Coqoorsa		H	1	6	-	-	-	-	-	-	-	-	YB 046
62	*Daucus hochstetteri* Braun ex Drude	Apiaceae	Urgoo Fardaa	Yedur Karot	H	3	9	3	15	-	-	-	-	1	2	YB 158
63	*Delphinium dasycaulon* Fres.	Ranunculace ae		Gedel Admiq	H	3	7	-	-	-	-	-	-	-	-	YB 033
64	*Delphinium wellbyi* Hemsl.	Ranunculace ae		Gedel-Amuq	H	2	9	-	-	-	-	3	20	-	-	YB 034
65	*Dodonea angustifolia* L. f.,	Sapindaacea e	Ittacha	Kitikita	S	10	72	5	25	2	3	8	33	1	3	YB 093
66	*Dovyalis abyssinica* (A. Rich.) Warb.	Flacourtiacea e	Koshoomii	Koshim	S	3	14	1	2	-	-	-	-	-	-	YB 101
67	*Echinops ellenbeckii* O. *Hoffm.*	Asteraceae	Qoree-harree		S	3	5	-	-	-	-	-	-	-	-	YB 199
68	*Echinops hispidus* Fresen.	Asteraceae	Kossooruu	Kosheshl a	H	1	1	-	-	-	-	3	12	-	-	YB 102
69	*Echinops longisetus* A. Rich.	Asteraceae	Sokkoruu	Keyilo	S	1	3	-	-	-	-	3	9	-	-	YB 095
70	*Ekebergia capensis* Sparrm	Meliaceae	Somboo		T	4	8	-	-	-	-	-	-	-	-	YB 139
71	*Eleusine floccifolia* (Forssk.) Spreng.	Poaceae	Coqorsa	AKirma	H	4	33	-	-	2	6	2	7	-	-	YB 154

72	*Embelia schimperi* Vatke	Myrsinaceae	Hanquu	Inikoko/ Enqoqo	S	1	3	-	-	-	-	-	-	-	-	YB 049
73	*Eragrostis papposa* (Roem. & Schull.) Sleud.	Poaceae	Xaaffii Qammallee		H	2	7	1	4	-	-	-	-	-	-	YB 075
74	*Eragrostis tenuifolia* (A. Rich.) Steud.	Poaceae	Xaaffii Simbiraa	Mowacca araa	H	6	29	-	-	-	-	4	32	-	-	YB 164
75	*Erica arborea* L.	Ericaceae	Hasiti	Asita,	S	5	26	6	28	-	-	-	-	-	-	YB 116
76	*Euclea divinorum* Hiern.	Ebenaceae	Mi'eessaa	Dedeho	S	5	23	-	-	-	-	-	-	-	-	YB 077
77	*Euclea racemosa* Murr. subsp. *schimperi* (A. DC.) White	Ebenaceae	Me’essaa	Dedeho	S	-	-	-	-	-	-	1	2	-	-	YB 209
78	*Ferula communis* L.	Apiaceae	Insiillaallee	Enslal; Inslal	H	2	6	-	-	-	-	-	-	-	-	YB 203
79	*Festuca abyssinica* Hochst. ex A. Rich.	Poaceae			H	2	6	-	-	-	-	-	-	-	-	YB 092
80	*Ficus cycomorus* L.	*Moraceae*	Luugoo/Odaa		T	2	7	-	-	-	-	-	-	-	-	YB 021
81	*Ficus sur* Forssk.	Moraceae	Harbuu	Shola	T	5	17	-	-	-	-	-	-	-	-	YB 108
82	*Fimbristylis complanata (*Retz.) Link	Cyperaceae	Qunnii		H	2	7	2	5	2	7	-	-	3	13	YB 076
83	*Galinsoga parviflora* Cav.	Asteraceae	Abbaa Xabboo		H	-	-	7	83	9	65	3	11	2	7	YB 141

84	*Galium spurium* L.	Rubiaceae	Maxxaannee Dinchaa		H	2	12	4	84	-	-	-	-	-	-	YB 184
85	*Gastridium phleoides* (Nees & Meyen) C.E. Hubb.	Poaceae	Margaa migiraa saree		H	5	20	-	-	-	-	-	-	-	-	YB 117
86	*Geranium ocellatum* Cambess.	Geraniaceae	Xuuxaa		H	3	13	5	64	10	147	7	63	9	98	YB 113
87	*Girardinia dlverslfolla* (Link) Friis	Urticaceae	Doobbii		H	1	5	-	-	-	-	-	-	-	-	YB 171
88	*Gnaphalium rubriflorum* Hilliard	Asteraceae	Carree Arama		H	2	5	1	2	2	9	3	9	8	38	YB 056
89	*Gnaphalium tweediae* Hilliard	Asteraceae	Carree Arama		H	2	5	3	23	4	14	6	37	5	13	YB 041
90	*Gomphocarpus fruticosus* (L.) Ait. f. Subsp. *flavidus* (N.E. Br.) Goyder	Asclepiadaceae	Qarfassaa	Ti'frigina	S	-	-	-	-	1	5	1	5	5	17	YB 042
91	*Gomphocarpus purpurascens* A. Rich.	Asclepiadaceae	Biqiltuu muka Jirbii	Tifrindo;	S	-	-	-	-	-	-	-	-	3	7	YB 035
92	*Grewia ferruginea* Hochst. ex A. Rich.,	Tiliaceae	Doqqoonuu	Dokima	S	1	2	-	-	-	-	-	-	-	-	YB 206
93	*Guizotia schimperi* Sch. Bip. ex Walp.	Asteraceae	Hadaa	Adey Abeba	H	3	5	3	15	-	-	7	13	3	6	YB 057
94	*Guizotia villosa* Sch. Bip. ex Walp.	Asteraceae	Haadaa	Mecc; Mech	H	3	6	6	28	-	-	6	13	2	10	YB 073

95	*Helichrysum foetidum* (L.) Moench.	Asteraceae	Haancaabii		H	3	8	-	-	-	-	-	-	-	-	YB 072
96	*Helichrysum schimperi* (Sch. Bip. ex A. Rich.) Moeser	Asteraceae	Carree Ibsa		H	3	15	6	23	-	-	12	71	13	42	YB 020
97	*Helichrysum splendidum* (Thunb.) Less.	Asteraceae	Carree kanniissaa	Newode	H	2	5	-	-	-	-	1	1	1	2	YB 043
98	*Helinus mystacinus* (Ait.) E.Mey. ex Steud.	Rhamnaceae	Hida Diima	Qemida;	C	8	30	2	6	-	-	4	11	-	-	YB 044
99	*Heteromorpha trifoliata* (Wendel.) Eckl. & Zeyh.	Apiaceae	Rigaa Qaluu	Ye Jibi merikuz	S	6	23	-	-	-	-	4	20	-	-	YB 079
100	*Hyparrhenia dregeana* (Nees) Stent	Poaceae	Daggala		H	1	4	-	-	-	-	1	4	-	-	YB 144
101	*Hyparrhenia hirta* (L.) Stapf	Poaceae	Dagalla	Sembelie t	H	4	20	-	-	-	-	-	-	-	-	YB 052
102	*Hyparrhenia rufa* (Nees) Stapf	Poaceae	Qacaa		H	1	14	1	6	-	-	-	-	-	-	YB 051
103	*Hypericum quartinianum* A. Rich.	Hypericacea e	Carree kelloo	Yeqola Amja	S	1	2	1	4	8	38	-	-	-	-	YB 134
104	*Hypericum revolutum* Vahl	Hypericacea e	Hindhee	Ameja	S	2	10	4	10	-	-	-	-	-	-	YB 040
105	*Hypoestes forskaolii* (Vahl) R.Br.	Acanthaceae	Darguu	Tiqur-T'eleng	H	2	3	-	-	-	-	1	3	-	-	YB 089

106	*Indigofera arrecta* Hochst. ex A. Rich.	Fabaceae	Adara karraa		S	3	9	-	-	-	-	-	-	2	6	YB 054
107	*Inula confertiflora* A. Rich.	Asteraceae	Managiftee	Weynage ft	S	-	-	2	3	-	-	1	3	-	-	YB 007
108	*Ipomoea tenuirostris* Choisy	Convolvulac eae	Hidda Hantuutaa	Yealt'-Hareg	H	2	5	2	7	-	-	3	25	3	30	YB 188
109	*Isodon schimperi* (Vatke) J.K. Morton	Lamiaceae		Yefiyel Gomen	H	2	5	-	-	-	-	-	-			YB 085
110	*Jasminum abyssinicum* Hochst.ex DC.	Oleaceae	Hidda Ilichiibee	Tenbelel	C	5	16	-	-	-	-	-	-	3	14	YB 180
111	*Jasminum grandiflorum* L. subsp. *floribundum* (R.Br. ex Fresen.) P.S.Green	Oleaceae	Hida Qammaxee	Tembelel	C	4	11	3	12	5	12	7	18	4	9	YB 086
112	*Juniperus procera* Hochst. ex Endl.	Cupressacea e	Gatira abesha	Ye abesha Tidi	T	14	95	2	7	4	14	7	29	11	39	YB 083
113	*Kalanchoe densiflora* Rolfe.	Crassulaceae	Bossoqee	Bicha Indahulla	H	2	8	1	3	-	-	-	-	-	-	YB 063
114	*Kalanchoe petitiana* A.Rich	Crassulaceae	Bossooqqee	Indahulla ,	H	2	8	2	5	2	5	4	6	2	4	YB 039
115	*Lactuca inermis* Forssk.	Asteraceae	Maxxannee Qoree		H	2	6	-	-	1	2	5	16	-	-	YB 038

116	*Laggera alata* (D. Don) Sch. Hip. ex Oliv.	*Asteraceae*	Aramaa balaa babaal'aa ajahuu		H	4	18	-	-	-	-	-	-	-	-	YB 004
117	*Laggera crispata* (Vahl) Hepper & Wood	Asteraceae	Ajaya	Gemie,	H	-	-	-	-	-	-	5	14	3	12	YB 016
118	*Laggera pterodonata* (DC.) Sch.-Bip.	Asteraceae	Sokkooruu muka	Keskesa;	H	3	7	-	-	-	-	1	3	1	5	YB 196
119	*Laggera tomentosa* (Sch. Bip. ex A. Rich.) Oliv. & Hiern	Asteraceae	Kaskasse	Koskoso	H	3	5	2	5	6	13	6	28	9	60	YB 151
120	*Launaea cornuta* (Hochst. ex Oliv. & Hiern) C. Jeffrey	Asteraceae	Kachoo	Yeseytan Gomen	H	-	-	4	11	2	3	1	2	-	-	YB 096
121	*Leonotis ocymifolia* (Burml. f.) Iwarsson	Lamiaceae	Bokkooluu Mata Diimaa	Ras Kimir;	S	4	13	-	-	5	12	-	-	-	-	YB 182
122	*Leucas martinicensis* (Jacq.) R. Br.	Lamiaceae	Bokkoluu mata adii	Ras Kimir	H	-	-	-	-	-	-	5	12	2	2	YB 002
123	*Linum volkensii* Engl.	Linaceae			H	6	39	-	-	7	42	7	42	1	5	YB 197
124	*Lippia adoensis* Hochst. ex Walp.	Verbenaceae	Kussayee	Koserti,	S	8	37	10	33	6	23	5	31	12	44	YB 172
125	*Maesa lanceolata* Forssk.	Myrsinaceae	Abayii	Qalaya/ Kaleya	T	5	22	3	16	-	-	-	-	4	8	YB 104
126	*Maytenus arbutifolia.* (A.	Celastraceae	Kombolicha	Atatt;	T	12	49	9	15	1	3	6	22	-	-	YB 005

	Rich.) Wilczek			Atat												
127	*Medicago polymorpha* L.	Fabaceae	Soogdaa Fardaa	Kurinchit	H	5	30	8	42	6	40	8	27	-	-	YB 100
128	*Milletia ferruginea* (Hochst.) Bak.	Fabaceae	Birbirraa		T	1	1	-	-	-	-	-	-	-	-	YB 155
129	*Monopsis stellarioides* (Presl) Urb.	Lobeliaceae			H	4	7	-	-	-	-	-	-	1	2	YB 037
130	*Myrsine africana* L.	Myrsinaceae	Qacamaa	Qechemo	S	12	135	12	60	9	76	5	43	1	3	YB 173
131	*Ocimum lamiifolium* Hochst. ex. Benth.	Lamiaceae	Damakase	Dama-kassie	S	2	5	-	-	-	-	3	6	-	-	YB 067
132	*Olea europaea L.* subsp. *cuspidata* (Wall. ex G. Don) Cif.	*Oleaceae*	Ejjeersa	Weyira	T	8	36	1	3	1	4	-	-	-	-	YB 135
133	*Olinia rochetiana* A.Juss.	Oliniaceae	Xifii/ Daalachoo	Tifei,; Dalecho	S	6	16	6	16	11	55	7	29	11	50	YB 053
134	*Olyra latifolia* L.	Poaceae	Qassaamii	Kessimi	H	4	32	-	-	-	-	-	-	-	-	YB 059
135	*Oplismenus hirtellus* (L.) P. Beauv.	Poaceae	Gurra hantuutaa		H	5	25	6	39	2	23	5	27	-	-	YB 167
136	*Oreoschimperella verrucosa* (A. Rich.) Rauschert	Apiaceae	Aramaa afeexoo		H	-	-	-	-	5	22	-	-	-	-	YB 138
137	*Orobanche minor* Smith	Orobanchace	Biqiltuu		H	1	3	-	-	-	-	-	-	-	-	YB 109

		ae	qoricha Kormamuu													
138	*Osyris quadripartita* Decn.	Santalaceae	Watoo	Kereti	S	9	48	8	40	2	12	4	41	1	4	YB 193
139	*Otostegia integrifolia* Benth.	Lamiaceae	Xuunjiitii	Tunjut	S	4	34	-	-	-	-	1	4	-	-	YB 036
140	*Panicum atrosanguineum* A.Rich.	Poaceae	Xaaffii Saree		H	2	7	1	10	1	1	2	16	1	18	YB 162
141	*Parochaetus communis* D.Don	Fabaceae	Aramaa Sogida fardaa	Yemdr Koso	H	3	10	2	5	-	-	-	-	-	-	YB 169
142	*Paullinia pinnata* L.	Sapindaceae	Hidda Gafaarsa		C	3	8	-	-	-	-	-	-	-	-	YB 165
143	*Pennisetum riparium* Hochst. ex A.Rich.	Poaceae	Marga maxxanee murii		H	1	2	-	-	-	-	-	-	-	-	YB 022
144	*Pennisetum sphacelatum* (Nees) Th. Dur. & Schinz	Poaceae	Migiraa	Sindedo	H	4	12	4	30	12	81	10	65	10	77	YB 084
145	*Pennisetum thunbergi* Kunth	Poaceae	Migira-Saree	Wusha Sindedo	H	2	9	-	-	-	-	3	13	-	-	YB 110
146	*Pennisetum villosum* Fresen.	Poaceae	Margaa saree		H	1	6	-	-	-	-	3	15	-	-	YB 126
147	*Periploca linearifolia* Quart.-Dill & A.Rich.	Asclepidacea e	Hida Annannoo	Moyder/ Domayto ;	C	2	16	1	2	-	-	-	-	-	-	YB 127

148	*Phoenix reclinata* Jacq.	Arecaceae	Meexii	Zenbaba	T	2	5	-	-	-	-	-	-	-	-	YB 115
149	*Phytolacca dodecandra* L'Hér.	Phytolaccaceae	Handoodee	Indodi, Endod;	S	2	8	-	-	-	-	-	-	-	-	YB 078
150	*Pimpinella heywoodii* Abebe	Apiaceae	Urgoo Fardaa		H	6	16	12	118	11	145	11	117	11	81	YB 125
151	*Pittosporum viridiflorum* Sims.	Pittosporaceae	Sole		T	11	29	5	15	-	-	5	14	-	-	YB 003
152	*Plantago lanceolata* L.	Plantaginaceae	Kottee Harree	Yebeg Lat	H	-	-	-	-	6	24	11	39	8	48	YB 159
153	*Plectocephalus varians* (A. Rich.) C. Jeffrey ex Cufod.	Asteraceae		Etse Yohannes	H	4	13	-	-	4	31	7	30	6	32	YB 153
154	*Plectranthus barbatus* Andr.	Lamiaceae	Aramaa Biyaa Baassaa	Yefyel Doqa	H	3	9	-	-	1	2	-	-	-	-	YB 195
155	*Plectranthus garckeanus* (Vatke) J.K. Morton	Lamiaceae	Ajessa; Gogoro	Dengogule;	H	2	2	-	-	-	-	-	-	3	5	YB 174
156	*Plectranthus ornatus* Codd	Lamiaceae	Ossollee	Gudsemel	H	1	4	-	-	-	-	-	-	-	-	YB 017
157	*Plectranthus punctatus* (L.f.) L`Her.	Lamiaceae			H	2	6	-	-	-	-	-	-	-	-	YB 001
158	*Polygala abyssinica* R.Br. ex Fresen.	Polygalaceae		Etse Lbona	H	-	-	-	-	-	-	2	6	-	-	YB 131

159	*Polygala persicariifolia* DC.	Polygalaceae		Harmela	H	1	12	-	-	-	-	-	-	-	-	YB 175
160	*Polygala steudneri* Chod.	Polygalaceae			H	5	17	-	-	-	-	-	-	-	-	YB 204
161	*Polypogon monspeliensis* (L.) Desf.	Poaceae			H	2	6	-	-	-	-	-	-	-	-	YB 176
162	*Premna schimperi* Engl.	Lamiaceae	Urgeessaa	Chocho	S	1	2	-	-	-	-	-	-	-	-	YB 177
163	*Prunus africana* (Hook.f.) Kalkm.	Rosaceae	Hadheessaa, Buraayuu	Tikuri Inichet	T	4	15	2	3	2	3	-	-	3	5	YB 112
164	*Pterolobium stellatum* (Forssk.) Brenan	Fabaceae	Araangama diimaa	Qonixir	S	1	5	-	-	1	2	-	-	-	-	YB 157
165	*Rhamnus prinoides* L. Herit.	Rhamnaceae	Geeshoo	Gesho	S	1	4	-	-	-	-	-	-	2	3	YB 011
166	*Rhamnus staddo* A.Rich	Rhamnaceae	Qadida	Tedo	S	8	27	-	-	-	-	-	-	-	-	YB 178
167	*Rhus retinorrhoea* Oliv.	Anacardiaceae	Dabalucaa	Tlem;	T	11	30	1	3	-	-	7	26	-	-	YB 064
168	*Rhus vulgaris* Meikle	Anacardiacea	Xaxxeessaa		S	12	41	6	21	-	-	4	37	2	7	YB 136
169	*Rosa abyssincia* Lindley.	Rosaceae	Goraa/Qaqaa wee	Kega	S	10	57	7	19	7	35	9	36	10	28	YB 050
170	*Rubia cordifolia* L.	Rubiaceae	Hidda Inciibiirii	Moncherer	C	6	15	-	-	-	-	3	12	2	4	YB 166
171	*Rubus apetalus* Poir.	Rosaceae	Goraa aribaa	Injori	S	1	3	-	-	-	-	-	-	-	-	YB 068

172	*Rumex nepalensls* Spreng.	Polygonaceae	Tultii,	Tult	H	3	7	-	-	-	-	-	-	-	-	YB 087
173	*Rumex nervosus* Vahl	Polygonaceae	Dhangagoo	Imbwacho	S	1	5	2	5	-	-	-	-	-	-	YB 156
174	*Salix mucronata* Willd.	Salicaceae	Alaaltuu	Wonz admik	T	2	15	-	-	-	-	-	-	-	-	YB 055
175	*Salvia nilotica* Juss ex Jacq.	*Lamiaceae*	Sokookisa, Urgu	Hulegeb	H	5	16	1	3	-	-	-	-	1	3	YB 009
176	*Sanicula elata* Buch -Ham. ex D. Don	Apiaceae			H	5	18	-	-	-	-	-	-	-	-	YB 152
177	*Satureja abyssinica* (Benth.) Briq.	Lamiaceae	Aramaa Xoosseenyii	Etse Maaza	H	1	6	4	22	6	86	9	206	4	46	YB 179
178	*Satureja imbricata* (Forssk.) Briq.	Lamiaceae	Aramaa Xoosseenyii		H	-	-	2	11	-	-	3	60	10	192	YB 023
179	*Satureja punctata* (Benth.) Briq.	Lamiaceae	Aramaa Xoosseenyii		H	1	8	5	37	2	40	4	19	3	23	YB 186
180	*Scabiosa columbaria* L.	Dipsacaceae	Girbbii	Yetija Zago;	H	2	5	-	-	-	-	-	-	-	-	YB 024
181	*Scadoxus multiflorus* (Martyn) Raf.	Amaryllidaceae	Qullubii waraabeessaa	Yejib Ageda	H	4	9	1	6	-	-	6	15	3	13	YB 065
182	*Scolopia theifolia* Gilg.	Flacourtiaceae	Koffallee		T	6	12	-	-	-	-	-	-	-	-	YB 140

183	*Senecio fresenii* Sch. Bip. ex Oliv. & Hiern	Asteraceae	Angaasuu		H	2	4	-	-	-	-	-	-	-	-	YB 099
184	*Senecio myriocephalus* Sch. Bip. ex A. Rich.	Asteraceae	Naacciloo	Simbita	S	-	-	-	-	-	-	-	-	1	1	YB 210
185	*Senecio ochrocarpus* Oliv. & Hiern	Asteraceae	Arama Gurra Harree	; Kebkebo	H	3	4	6	30	-	-	4	10	-	-	YB 014
186	*Setaria pumila* (Poir.) Roem. & Schult.	Poaceae	Maxxanne		H	1	2	-	-	-	-	3	15	2	5	YB 120
187	*Setaria viridis (L.) P. Beauv.*	Poaceae	Margaa Muriyee Fakkatuu		H	5	19	-	-	-	-	-	-	-	-	YB 114
188	*Sida schimperiana* Hochst. Ex Rich.	Malvaceae	Guftee	Chifrig;	S	1	1	3	9	11	75	5	33	10	61	YB 069
189	*Silene macrosolen* A. Rich.	Caryophyllaceae	Waggaartii	Wegert,	H	5	17	-	-	-	-	-	-	-	-	YB 163
190	*Solanum glganteum* Jacq.	Solanaceae	Hiddii	Ti'qur Imbway	S	-	-	-	-	-	-	-	-	2	4	YB 207
191	*Solanum incanum* L.	Solanaceae	Hiddii Loonii		S					3	5	2	8			YB 200
192	*Solanum indicum* L.	Solanaceae	Samaa Saree	Imbway	S	-	-	1	1	-	-	-	-	-	-	YB 208
193	*Solanum marginatum* L.f.	Solanaceae	Hiddii-Hoonqoorcaa	Embuway	S	-	-	-	-	-	-	2	8	1	3	YB 201
194	*Sonchus asper* (L.) Hill	Asteraceae	Kachoo		H	1	3	1	2	5	15	2	8	3	5	YB 094

195	*Sporobolus africanus* (Poir.) Robyns & Tournay	Poaceae	Murrii	Murie	H	4	21	-	-	2	13	5	22	2	10	YB 130
196	*Sporobolus pyramidalis* P.Beauv.	Poaceae	Marga Xaafii Maxxannee		H	2	4	-	-	-	-	-	-	-	-	YB 111
197	*Stephania abyssinica* (Dillon & A. Rich) Walp.	Menisperma ceae	Hida Kalaalaa	Engochit	C	4	9	-	-	1	2	-	-	-	-	YB 082
198	*Tagetes minuta* L.	Asteraceae	Arama Gollolee	Gime;	H	1	15	-	-	-	-	-	-	-	-	YB 013
199	*Thymus schimperi* Ronniger	Lamiaceae	Xoosanyii	Tosign	H	2	9	9	246	2	68	3	28	5	170	YB 168
200	*Thymus serrulatus* Hochst. ex Benth.	Lamiaceae		Tosign; Wawati	H	1	21	10	174	-	-	1	14	4	41	YB 181
201	*Trifolium decorum* Chiov.	Fabaceae	Siddissaa Horii	Mageti	H	4	15	4	24	7	34	1	5	1	2	YB 150
202	*Trifolium quartinianum* A.Rich.	Fabaceae	Siddisa	Yebeg-Lat	H	3	11	2	25	-	-	-	-	-	-	YB 148
203	*Trifolium rueppellianum* Fresen.	Fabaceae	Siddissa/ Kaddo	Mageti	H	2	6	4	18	1	2	5	43	-	-	YB 149
204	*Verbascum sinaiticum* Benth.	Scrophularia ceae	Gurra-Harre,	Yeahya-Jero,	H	2	6	1	1	5	12	9	32	4	12	YB 070
205	*Verbascum valerianifolium* (A. Rich.) Hub.-Mor.	Scrophularia ceae	Aramaa Gurraa Harree		H	3	7	1	3	-	-	-	-	-	-	YB 019

206	*Verbena officinalis* L.	Verbenaceae	Maxxannee	Atuch	H	-	-	3	23	-	-	1	3	-	-	YB 190
207	*Vernonia amygdalina* Del.	Asteraceae	Ebiicha	Girawa	T	2	7	-	-	-	-	-	-	-	-	YB 058
208	*Vernonia auriculifera* Hiern	Asteraceae	Reejii	Gujo	S	4	15	3	9	-	-	-	-	1	2	YB 143
209	*Vicia hirsuta* (L.) S. F. Gray	Fabaceae	Gaayoo Hantuutaa		H	2	14	1	5	-	-	3	16	-	-	YB 061
210	*Xanthium spinosum* L.	Asteraceae	Maxxannee	Yeseit Milass,	H	2	6	-	-	-	-	-	-	-	-	YB 124
211	*Zehneria scabra* (Linn. f.) Sond.	Cucurbitaceae	Indiriffaa		C	4	16	-	-	-	-	-	-	1	2	YB 090
	Total species per forest LUS					-	181	-	87	-	71		101		79	

Plant growth Habit refers: S = shrubs; T= trees; C= climbers, H = herbaceous, and F = fern

Appendix 4: Summary Lists of Plant species composition in the soil seed bank of Yerer forests and surrounding area across 8 different LUS

Sr. No.	Species Scientific name	Family name	Local name		Groth Habit	Species Frequency of LUS	Land-use Systems Categories							
			Afan Oromo	Amharic			Natural forest	*C. lusitanica*	*E. globulus*	*G. robusta*	*P. patula*	Grass land	Grazing land	Cropland
1	*Ageratum conyzoides* L.	Asteraceae	Maxxannee		H	1	X	-	-	-	-	-	-	-
2	*Ajuga integrifolia* Ham.-Buch. ex D. Don	Lamiaceae	Harma guussaa	Etse Libawit,	H	3	-	-	-		X	X	X	-
3	*Alchemilla pedata* A. Rich.	Rosaceae	Xuuxaa		H	7	-	X	X	X	X	X	X	X
4	*Amaranthus spinosus* L.	Amaranthaceae	Assangira	Almaa	H	4	-	X	X	X	-	-	-	X
5	*Andropogon abyssinicus* Fresen.	Poaceae	Baalaamii	Yelami Sar,	G	7	X	X	X	X	X	X	X	-
6	*Anthemis tigreensis* J. Gay ex A. Rich.	Asteraceae			H	2	X	-	-	-	X	-	-	-
7	*Argyrolobium fischeri* Taub.	*Fabaceae*	Ataraa Hantuutaa		H	4	-	-	-	X	X	X	X	-
8	*Artemisia afra* Jacq. ex	Asteraceae	Xiroo	Chqugn	H	2	X	-	-	-	-	X	-	-

	Willd.													
9	*Asparagus africanus* Lam.	Asparagaceae	Saaritii	Seriti	S	1	-	-	-	-	X	-	-	-
10	*Avena sativa* L.	Poaceae	Ajjambilaa	Sinari	H	1	-	-	-	-	-	-	-	X
11	*Barleria parviflora* R.Br.ex T. Anders.	Acanthaceae			S	3	-	-	X	X	X	-	-	-
12	, *Bidens pilosa* L.	Asteraceae	Maxxaannee Kelloo	Yeseytan Merfie	H	6	X	-	X	X	X	X	-	X
13	*Bidens prestinaria* (Sch.-Bip.) Cufod.	Asteraceae	Kelloo Booyyee	Yemesqe l Abeba	H	3	X	-	-	-	-	X	-	X
14	*Carduus camaecephalus* (Vatke.) Oliv. & Hiern	Asteraceae	Kossoruu Harree		H	1	-	-	-	-	-	X	-	-
15	*Carissa spinarum L.*	Appocynace ae	agamsa	Agemi	S	4	X	-	X	X	-	X	-	-
16	*Centella asiatica* (L.) Urban	Apiaceae	Xuuxaa	Etse Leul	H	6	X	-	X	X	X	X	X	-
17	*Chenopodium album* L.	Chenopodia ceae		Amedma do	H	4	X	-	X	X	-	-	-	X
18	*Clematis longicauda* Steud. ex A. Rich.	Rununculac eae	Hidda Adii		C	2	-	-	-	X	-	X	-	-
19	*Clematis simensis* Fresen.	Ranunculac eae	Hida Fiitii		C	1	X	-	-	-	-	-	-	-
20	*Clerodendrum myricoides*	Lamiaceae	Erbaa/Maraasisa	Misirichi	S	2	X	X	-	-	-	-	-	-

	(Hochst) Vatke		a	,										
21	*Coelachyrum poiflorum* Chiov.	Poaceae	Marga Hillessa	Yetinchel Sari	G	1	-	-	-	-	X	-	-	-
22	*Commelina benghalensis* L.	Commelinaceae	Gogoora Farda	Yebegi-lati,	H	8	X	X	X	X	X	X	X	X
23	*Commelina diffusa* Burm.f.	Commelinaceae	Margaa Gurra/Baalaa babaal'aa		H	8	X	X	X	X	X	X	X	X
24	*Cotula abyssinica* Sch. Bip. ex A. Rich.	Asteraceae	Aramaa Dimbiillalee		H	8	X	X	X	X	X	X	X	X
25	*Crotalaria laburnifolia* L.	Fabaceae	Misira hantuuta	Ye-ayit missir	H	5	X	-	X	X	-	X	-	X
26	*Crotalaria spinosa* Hochst. ex Benth.	Fabaceae	Ataraa Qamalee /Gufti	Yemidir Girar, ,	H	4	-	X	X	X	X	-	-	-
27	*Cupressus lusitanica* Mill.	Cupressaceae	Gatiraa Faaraanjii		T	1	-	X	-	-	-	-	-	-
28	*Cymbopogon commutatus* (Steud.) Stapf	Poaceae	Qacaa	Sembeliet	G	1	-	-	-	-	-	-	X	-
29	*Cynodon nlemfuensis* Vanderyst	Poaceae	Qarxiissaa	Waratii	G	6	X	X	-	X	X	X	X	-
30	*Cynoglossum amplifolium* Hochst. ex A.DC.,	Boraginaceae	Maxxaannee hucuu		H	4	-	-	-	X	X	X	-	X

31	*Cynoglossum coeruleum* Hochst. ex A.DC.	Boraginaceae	Maxxannee	Chigogot	H	1	-	X	-	-	-	-	-	-
32	*Cyperus fischerianus* A.Rich.	Cyperaceae	Qunnii	Engecha	H	5	X	X	-	-	-	-	-	
33	*Cyperus rigidifolius* Stued.	Cyperaceae	Qunnii/ Gicha	Engicha	H	3	X	X	-	X	-	-	-	-
34	*Datura stramonium* L.	Solanaceae	Manjii	Aste-faris	H	1	-	-	-	-	-	-	-	X
35	*Dodonaea angustifolia* L. f.	Sapindaacea e	Ittachaa	Kitikita	S	1	X	-	-	-	-	-	-	-
36	*Echinops hispidus* Fresen.	Asteraceae	Kossooruu	Kosheshla	H	2	X	-	-	-	-	-	-	X
37	*Eleusine floccifolia* (Forssk.) Spreng.	Poaceae	Choqorsa,Coqorsa	AKirma	G	2	-	-	-	-	-	X	X	-
38	*Eragrostis papposa* (Roem. & Schult.) Steud.	Poaceae	Xaaffii Qammallee		G	4	X	-	-	X		X	X	-
39	*Eragrostis tef* (Zucc.)	Poaceae	Xaaffii	Teff	H	4	X	X	X	-	-	-	-	X
40	*Eragrostis tenuifolia* (A.Rich.) Steud.	Poaceae	Margaa Xaaffii Simbiraa	Mowaccaaraa	G	1	-	-	-	-	-	X	-	-
41	*Erica arborea L.*	Ericaceae	Hasiti	Asita,	S	1	X	-	-	-	-	-	-	-
42	*Eucalyptus globulus* Labill	Myrtaceae	Baargaammoo adii	Nech Bahir Zaf;	T	1	-	-	X	-	-	-	-	-

43	*Euclea racemosa subsp. schimperi* Murr.	Ebenaceae	Me'essaa	Dedeho	S	2	X	-	X	-	-	-	-	-
44	*Fimbristylis complanata (*Retz.) Link	Cyperaceae	Qunnii		H	8	X	X	X	X	X	X	X	X
45	*Galinsoga parviflora* Cav.	Asteraceae	Abbaa Xaabboo	Deha Neqay	H	8	X	X	X	X	X	X	X	X
46	*Guizotia scabra* (Vis.) Chiov.	Asteraceae	Haadaa		H	8	X	X	X	X	X	X	X	X
47	*Helichrysum schimperi* (Sch. Bip. ex A. Rich.) Moeser	Asteraceae	Carree Ibsa /Baalcii		S	1	-	-	-	-	-	X	-	-
48	*Helichrysum splendidum* (Thunb.) Less.	Asteraceae	Carree kannissaa		H	6	X	X	X	X	X	-	X	-
49	*Helinus mystacinus* (Ait.) E.Mey. ex Steud.	Rhamnaceae	Hida Diima		C	3	X	X	-	-	-	X	-	-
50	*Heteromorpha arborescens* (Spreng.) Cham. & Schlecht.	Apiaceae	Rigaa Qaalluu	Yejeb Merkuz	S	1	X	-	-	-	-	-	-	-
51	*Hygrophila auriculata* (Schum.) Heine	Acanthaceae		Yesiet-mlas	H	1	-	-	-	-	-	-	-	X
52	*Hypericum quartinianum* A. Rich.	Hypericacea e	Carree Habaaboo	Yeqola Amja,	S	1	-	-	-	X	-	-	-	-

			kelloo											
53	*Hypericum revolutum* Vahl	Hypericaceae	Hindhee	Ameja	S	1	X	-	-	-	-	-	-	-
54	*Ipomoea tenuirostris* Choisy	Convolvulaceae	Hida Hantuutaa	Yealt'-hareg	H	4	-	-	-	X	X	X	-	X
55	*Juniperus procera* Hochst. ex Endl.	Cupressaceae	Gattiraa abesha	Ye abesha Tidi	T	1	X	-	-	-	-	-	-	-
56	*Kalanchoe petitiana* A. Rich	Crassulaceae	Bossooqee	Indahulla,	H	2	X	X	-	-	-	-	-	-
57	*Lactuca inermis* Forssk.	Asteraceae	Arama Kachoo		H	1	-	-	-	-	-	-	-	X
58	*Laggera tomentosa* (Sch. Bip. ex A. Rich.) Oliv. & Hiern	Asteraceae		Koskoso	H	3	X	-	-	-	X	X	-	-
59	*Lippia adoensis* Hochst. ex Walp.	Verbenaceae	Kuussaayee	Koserti,	S	1	-	-	-	X	-	-	-	-
60	*Lolium temulentum* L.	Poaceae	Macheessaa	Enkrdad	H	1	-	-	-	-	-	-	-	X
61	*Malva verticillata L.*	Malvaceae	Litii		H	1	-	-	-	-	-	-	-	X
62	*Maytenus arbutifolia* (A .Rich.) Wilczek	Celastraceae	Kombolicha	Atatt	S	1	-	X	-	-	-	-	-	-
63	*Medicago polymorpha* L.	Fabaceae	Soggidaa Farda		H	8	X	X	X	X	X	X	X	X
64	*Myrsine africana* L.	Myrsinaceae	Qacaama	Kechem	S	3	-	X	-	-	X	X	-	-

				o										
65	*Ocimum lamiifolium* Hochst. ex Benth.	Lamiaceae	Damakassee	Dama-kesie	S	1	-	-	-	X	-	-	-	-
66	*Olea europaea* subsp.c*uspidata* (Wall. ex G. Don) Cif.	Oleaceae	Ejjeersa	Weyira	T	1	X	-	-	-	-	-	-	-
67	*Olinia rochetiana* A. Juss.	Oliniaceae	Xiifii	Nachilo	S	3	X	X	-	-	-	X	-	-
68	*Oplismenus hirtellus* (L.) P. Beauv.	Poaceae	Gurra hantuutaa		H	8	X	X	X	X	X	X	X	X
69	*Osyris quadripartita* Decn.	Santalaceae	Waattoo	Kereti	S	2	X	X	-	-	-	-	-	-
70	*Otostegia integrifolia* Benth.	Lamiaceae	Xuunjiitii	Tunjut	S	1	-	-	-	-	-	-	X	-
71	*Parthenium hysterophorus* L.	Asteraceae	Faramississaa		H	2	-	-	-	-	-	-	X	X
72	*Pennisetum riparium* Hochst. ex A.Rich.	Poaceae	Margaa Migira / Duffaa		G	1	-	-	-	X	-	-	-	-
73	*Pennisetum sphacelatum* (Nees) Th. Dur. & Schinz	Poaceae	Migira	Sindedo	G	4	X	-	-	X	-	X	X	-
74	*Pennisetum thunbergi* Kunth	Poaceae	Migira Saree	Yewusha Sindedo	G	8	X	X	X	X	X	X	X	X
75	*Phytolacca dodecandra* L'Hérit.	Phytolaccaceae	Handoodee	Indodi	S	1	X	-	-	-	-	-	-	-

76	*Pimpinella heywoodii* Abebe	Apiaceae	Urgoo Fardaa		H	2	-	-	-	-	X	-	-	X
77	*Pittosporum viridiflorum* Sims.	Pittosporaceae	Sollee	Shole,	T	1	X	-	-	-	-	-	-	-
78	*Plantago lanceolata* L.	Plantaginaceae	Qoorxoobii		H	4	X	X	-	-	-	-	X	X
79	*Plantago palmata* Hook.f.	Plantaginaceae	Kottee Harree	Yehaheya Kote	H	8	X	X	X	X	X	X	X	X
80	*Pterolobium stellatum* (Forssk.) Brenan	Fabaceae	Araangama	Qonixir	S	6	X	X	X	X	X	X	-	-
81	*Rhamnus staddo* A.Rich	Rhamnaceae	Qadiida	Tedo	S	3	X	X	X	-	-	-	-	-
82	*Rhus vulgaris* Meikle	Anacardiacea	Xaxxeessaa	Kimo	T	1	X	-	-	-	-	-	-	-
83	*Rosa abyssincia* Lindley.	Rosaceae	Goraa/Qaqaawee	Kega	S	5	X	X	-	X	X	X	-	-
84	*Rumex abyssinicus* Jacq.	Polygonaceae		Meqimeqoo	H	1	-	-	-	-	-	-	-	X
85	*Rumex nepalensls* Spreng.	Polygonaceae	Shultii/ Tulti		H	2	-	-	-	-	-	X	X	-
86	*Rumex nervosus* Vahl	Polygonaceae	Dhaangaagoo	Imbwacho	S	2	X	-	-	-	-	X	-	-

87	*Sisymbrium erysimoides* Desf.	Brassicaceae	Gommaanaa Simbiiraa	Yewef Gomen	H	2	-	-	-	-	X	-	-	X
88	*Solanum incanum* L.	Solanaceae	Hiddii saree		S	2	X	-	-	-	-	X	-	-
89	*Sonchus asper (*L.) Hill	Asteraceae	Kachoo		H	6	X	-	X	X	-	X	X	X
90	*Tradescantia fluminensis* Vell.	Commelinaceae	Margaa Gurraa Babaal'aa		H	3	-	-	-	-	-	X	X	X
91	*Trifolium decorum* Chiov*.*	Fabaceae	Siddissa Horii	Mageti	H	8	X	X	X	X	X	X	X	X
92	*Trifolium rueppellianum* Fresen.	Fabaceae	Siddissa/ Kaddo	Mageti	H	3	-	-	-	X	X	X	-	-
93	*Triticum aestivum* L.	Poaceae	Qamaadii	Sinde	H	1	-	-	-	-	-	-	-	X
94	*Verbascum sinaiticum* Benth.	Scrophulariaceae	Gurraa Harree	Yeahya-jero	H	2	X	-	-	X	-	-	-	-
95	*Vernonia amygdalina* Del.	Asteraceae	Ebichaa	Girawa	S	1	X	-	-	-	-	-	-	-
96	*Vernonia auriculifera* Hiern	Asteraceae	Reejjii		S	4	X	-	X	-	-	-	X	-
97	*Vicia hirsuta* (L.) S. F. Gray	Fabaceae	Gaayoo Hantuutaa		H	2	X	-	-	-	-	-	-	X
98	*Zehneria scabra* (Linn. f.) Sond.	Cucurbitaceae	Indiriffaa		C	1	-	-	-	-	X	-	-	-

Plant growth Habit refers: H= herbaceous; S= shrubs; T= trees; C= climbers, G = Grass

Keys: X = refers species present, and - = refers species absent

Correlation Relationship between soil properties

Appendix 5: The simple linear Pearsons correlation matrix relationships among soil Physico-chemical properties

	Sand	Clay	Silt	MC	BD	PD	SP	OC	TN	C:N ratio	P	pH	EC	CEC	Na	K	Ca	Mg	BS
Sand	1.000	-0.723	-0.605 ***	-0.069 ns	0.215 ns	-0.140 ns	-0.028 ns	0.333 **	0.371* **	-0.249 *	0.094 ns	0.109 ns	-0.138 ns	0.131 ns	0.210 ns	0.266 *	0.221*	0.027*	0.197ns
Clay		1.000	-0.099 ns	0.028 ns	0.158 ns	0.228 **	0.018ns	-0.339 **	-0.382 ***	0.238 *	-0.111 ns	-0.076 ns	0.273 **	-0.184 ns	-0.231 *	-0.214 ns	-0.271 *	-0.202 ns	
Silt			1.000	0.158 ns	-0.044 ns	-0.074 ns	-0.079 ns	-0.106 ns	-0.107 ns	0.080 ns	0.001 ns	-0.093 ns	-0.100 ns	0.014 ns	-0.055 ns	-0.129 ns	-0.017 ns	0.191ns	0.013*
MC				1.000	-0.354 ***	-0.255 *	0.323* *	0.320* *	0.393* **	-0.229*	0.194 ns	0.329 **	-0.264 *	0.298 **	-0.104 ns	0.416 ***	0.386* **	0.275* *	0.221*
BD					1.000	0.856* **	-0.656 ***	-0.403 ***	-0.380 ***	-0.012 ns	-0.365 ***	-0.235 *	0.433 ***	-0.179 ns	0.403 ***	-0.248 *	-0.301 **	-0.310 **	-0.25 *
PD						1.000	-0.179 ns	-0.474 ***	-0.452 ***	0.007 ns	-0.375 ***	-0.165 ns	0.375* **	-0.273 *	0.154 ns	-0.353 ***	-0.343 **	-0.405 ***	-0.29 **
SP							1.000	0.107 ns	0.095 ns	0.030 ns	0.159 ns	0.235 *	-0.265 *	-0.044 ns	-0.497 ***	-0.004 ns	0.081 ns	0.004 ns	0.055ns
OC								1.000	0.947 ***	-0.026 ns	0.547* **	0.432 ***	-0.466 ***	0.644 ***	0.165 ns	0.576 ***	0.677* **	0.426 ***	0.262*

TN	1.000	-0.321	0.559	0.441	-0.478	0.651	0.205	0.699	0.749	0.484	0.388**
		**	***	***	***	***	ns	***	***	***	*
C: N ratio		1.000	-0.098	0.049	0.094	-0.033	-0.179	-0.415	-0.240	-0.134	-0.42
			ns	ns	ns	ns	ns	***	*	ns	***
P			1.000	0.366	-0.398	0.613	0.094	0.439	0.584	0.484	0.168ns
				***	***	***	ns	***	***	***	
pH				1.000	-0.449	0.649	-0.101	0.325	0.592	0.261	-0.05 ns
					***	***	ns	**	***	*	
EC					1.000	-0.478	0.202	-0.400	-0.532	-0.173	-0.15 ns
						***	ns	***	***	ns	
CEC						1.000	0.203	0.533	0.786	0.542	-0.03 ns
							ns	***	***	***	
Na							1.000	0.360	0.199	0.215	0.312**
								***	ns	*	
K								1.000	0.661	0.429	0.545**
									***	***	*
Ca									1.000	0.481	0.511**
										***	*
Mg										1.000	0.266*
BS											1.000

Keys: *, **, ***, and ns = significant at $P < 0.05$, $P < 0.01$, $P < 0.001$, and nonsignificant at $P > 0.05$, respectively. OC = organic carbon; OM = organic matter; TN = total nitrogen; Avail.P = available phosphorus; EC = electrical conductivity, Exch.Na = exchangeable Sodium; Exch.K = exchangeable Potassium; Exch.Ca = exchangeable Calcium; Exch.Mg = exchangeable Magnesium; CEC = Cation exchange capacity; %BS = percent base saturation; MC = moisture content; BD = bulk density, PD = particle density, and SP = pore space.

Appendix 6: The mean, maximum, minimum, and standard deviation value of soil Physico-chemical properties under different land-use systems (LUS)

LUS	Statistical values	Physical Properties							Chemical Properties											
		Sand (%)	Clay (%)	Silt (%)	MC (%)	BD (gm/cm3)	PD (gm/cm3)	Soil Porosity	OC (%DM)	TN	C:N ratio	Avail. P mg/kg	Soil pH	EC (ds/m)	CEC	Exch. Na	Exch. K	Exch. Ca	Exch. Mg	BS (%)
Natural forest	**Mean**	40.7	33.9	25.4	23.084	1.167	1.716	0.3189	3.487	0.313	11.382	31.515	6.200	1.783	33.634	0.394	3.597	17.126	5.369	77.939
	Max	51	43	30	29.38	1.3	2.04	0.402	5.87	0.59	12.78	57.61	7.56	2.59	48.51	0.57	7.29	27.68	8.45	97.89
	Min	31	27	20	18.32	0.97	1.47	0.261	2.27	0.20	8.97	7.57	5.32	1.18	22.02	0.27	0.91	10.08	3.04	49.34
	Sd	5.72	4.98	3.37	3.82	0.11	0.16	0.04	1.13	0.12	1.38	19.38	0.72	0.52	7.27	0.10	1.80	5.58	1.94	15.89
	CV%	14.045	14.680	13.280	16.545	9.491	9.465	13.132	32.322	38.424	12.130	61.510	11.614	29.320	21.627	24.555	49.984	32.582	36.171	20.386
	Range	20.00	16.00	10.00	11.06	0.33	0.57	0.14	3.60	0.40	3.81	50.04	2.24	1.41	26.49	0.30	6.38	17.60	5.41	48.55
Eucalyptus globulus	**Mean**	37.7	37.7	24.6	16.996	2.18	2.531	0.1386	2.029	0.173	11.865	3.119	5.480	3.474	25.780	0.604	1.965	11.245	3.578	70.912
	Max	51	50	30	23.02	2.48	2.84	0.205	3.62	0.29	19.34	15.46	6.94	4.29	34.98	0.81	3.34	13.43	5.53	102.52
	Min	26	29	18	12.7	1.74	2.19	0.104	1.07	0.12	6.37	0.32	4.45	2.01	16.7	0.37	0.60	8.60	0.80	42.7

plantation					6										9					1
	Sd	7.99	7.07	3.75	3.38	0.20	0.22	0.03	0.78	0.05	3.58	4.39	0.76	0.75	5.45	0.16	0.96	1.39	1.24	20.89
	CV%	21.185	18.758	15.234	19.891	9.245	8.733	24.397	38.649	30.526	30.177	140.633	13.816	21.716	21.124	26.145	49.022	12.324	34.662	29.463
	Range	25.00	21.00	12.00	10.26	0.74	0.65	0.10	2.55	0.17	12.97	15.14	2.49	2.28	18.19	0.44	2.74	4.83	4.73	59.81
Cupressus lusitanica plantation	**Mean**	43.8	34.3	21.9	20.916	1.313	1.899	0.3097	2.287	0.197	11.749	2.449	5.414	2.335	21.258	0.270	2.460	11.594	2.912	80.830
	Max	69	48	33	25.03	1.85	2.36	0.404	3.98	0.34	16.15	5.00	6.10	3.77	23.88	0.47	2.92	15.54	5.12	93.35
	Min	27	19	12	17.92	0.91	1.34	0.177	1.35	0.117	8.4311	1.61	4.87	1.58	18.36	0.19	1.51	7.84	1.68	66.503
	Sd	13.79	10.04	6.21	2.47	0.29	0.33	0.07	0.89	0.07	1.99	1.16	0.37	0.64	1.86	0.08	0.50	2.41	1.10	10.50
	CV%	31.485	29.285	28.349	11.804	22.012	17.612	23.846	38.993	37.298	16.966	47.445	6.868	27.446	8.772	28.900	20.133	20.771	37.606	12.988
	Range	42.00	29.00	21.00	7.11	0.94	1.02	0.23	2.63	0.22	7.72	3.39	1.23	2.19	5.52	0.28	1.41	7.70	3.44	26.84
Grevillea robusta plantation	**Mean**	36.8	38.3	24.3	22.735	1.292	1.969	0.3417	3.135	0.261	12.030	5.823	5.704	2.416	23.237	0.344	2.192	12.557	3.513	79.775
	Max	47	51	36	26.63	1.73	2.29	0.4148	3.83	0.316	12.612	17.95	6.41	3.44	29.51	0.53	3.63	17.05	4.78	89.68
	Min	27	22	17	19.81	1.03	1.47	0.2242	2.40	0.19	10.61	0.81	5.13	1.27	20.32	0.17	1.41	9.84	1.76	69.13
	Sd	7.04	8.59	5.87	2.06	0.23	0.31	0.06	0.54	0.05	0.61	4.82	0.34	0.73	2.58	0.11	0.66	2.34	0.88	6.49
	CV%	19.1	22.4	24.1	9.04	17.698	15.99	18.66	17.1	18.1	5.05	82.75	5.99	30.0	11.0	31.4	29.9	18.6	25.0	8.13

		21	28	56	5		0	7	99	85	1	7	5	62	97	05	86	28	41	5
	Range	20.00	29.00	19.00	6.82	0.70	0.82	0.19	1.43	0.13	2.00	17.14	1.28	2.17	9.19	0.36	2.22	7.21	3.02	20.56
Pinus patula plantation	**Mean**	28	42.1	29.9	21.283	1.193	1.62	0.2648	2.504	0.216	12.076	20.319	5.986	2.354	29.227	0.302	2.454	14.931	4.754	76.351
	Max	38	58	39	24.5	1.51	1.94	0.3295	3.26	0.316	14.477	45.68	6.62	3.69	33.17	0.53	3.86	19.18	6.58	91.706
	Min	22	33	20	18.79	1.01	1.37	0.2099	1.08	0.075	10.252	2.58	5.45	1.51	26.34	0.21	1.01	10.4	2.98	55.755
	Sd	5.52	7.36	7.77	1.56	0.16	0.18	0.04	0.77	0.08	1.46	13.60	0.36	0.73	2.20	0.10	0.98	3.43	1.07	13.73
	CV%	19.706	17.471	25.976	7.329	13.654	10.884	13.302	30.57	37.57	12.12	66.92	6.04	30.92	7.52	32.62	40.13	22.98	22.52	17.99
	Range	16.00	25.00	19.00	5.71	0.50	0.57	0.12	2.18	0.24	4.23	43.10	1.17	2.18	6.83	0.32	2.85	8.78	3.60	35.95
Grass land	**Mean**	41.3	33.3	25.4	20.396	1.476	2.249	0.3409	2.579	0.226	11.859	14.875	6.486	1.966	28.967	0.286	1.988	16.028	3.422	73.323
	Max	52.00	39.00	38.00	25.84	1.82	2.88	0.40	3.92	0.365	13.519	36.48	7.81	3.77	38.13	0.37	3.25	25.14	4.67	89.075
	Min	27	27	12	17.2	1.07	1.72	0.2674	1.41	0.10	9.50	0.24	5.69	1.20	22.96	0.18	0.60	10.00	2.60	58.45
	Sd	7.32	4.19	8.10	2.70	0.23	0.38	0.05	0.85	0.09	1.31	11.43	0.77	0.76	5.43	0.06	0.86	6.10	0.65	11.35
	CV%	17.721	12.586	31.887	13.261	15.601	16.828	15.663	32.96	41.03	11.08	76.86	11.85	38.70	18.74	19.66	43.08	38.05	18.86	15.48
	Range	25.00	12.00	26.00	8.64	0.75	1.16	0.13	2.51	0.26	4.02	36.24	2.12	2.57	15.17	0.19	2.65	15.14	2.07	30.63

Grazing land	**Mean**	36.9	36.1	27	19.303	1.45	2.1	0.309	2.159	0.184	11.944	11.892	5.996	1.878	27.455	0.325	2.571	13.356	3.210	74.528
	Max	43	48	32	25.05	1.89	2.49	0.3745	2.74	0.24	14.54	29.95	6.56	2.80	32.05	0.55	4.83	17.43	5.40	107.02
	Min	26	28	18	15.24	1.23	1.73	0.241	1.52	0.11	9.25	0.32	5.42	1.19	23.02	0.15	0.60	10.04	0.72	53.62
	Sd	5.32	7.17	4.85	3.17	0.19	0.24	0.05	0.48	0.05	1.56	7.85	0.34	0.49	3.03	0.12	1.48	2.57	1.28	15.45
	CV%	14.422	19.866	17.976	16.422	13.114	11.558	14.620	22.08	24.51	13.10	66.02	5.60	26.15	11.03	37.44	57.37	19.23	39.96	20.73
	Range	17.00	20.00	14.00	9.81	0.66	0.76	0.13	1.22	0.12	5.29	29.63	1.14	1.61	9.03	0.40	4.23	7.39	4.68	53.40
Cropland	**Mean**	29.1	40.9	30	16.512	1.468	2.18	0.3219	1.472	0.130	11.482	6.516	5.377	3.072	18.983	0.206	1.197	9.931	3.469	77.796
	Max	35	49	33	20.06	1.65	2.92	0.4349	1.84	0.17	14.49	17.55	5.83	4.23	22.08	0.33	2.19	12.92	4.76	92.79
	Min	21	34	25	12.45	1.21	1.83	0.262	1.12	0.092	9.1367	1.93	4.65	2.41	14.73	0.11	0.6	6.51	2.39	72.509
	Sd	4.33	4.61	2.49	2.30	0.14	0.32	0.05	0.24	0.02	1.93	4.55	0.40	0.63	1.94	0.07	0.55	1.97	0.78	7.06
	CV%	14.887	11.261	8.315	13.955	9.590	14.527	15.238	16.526	18.365	16.777	69.801	7.497	20.656	10.209	32.780	46.141	19.856	22.354	9.080
	Range	14	15	8	7.61	0.44	1.09	0.1729	0.72	0.08	5.35	15.62	1.18	1.82	7.35	0.22	1.59	6.41	2.37	20.28

Appendix 7: Mean values of soil Physico-chemical properties of different land-use systems in vertical gradient at two soil depths

		Physical Properties							Chemical Properties											
LUS	Soil Depth(D)	Sand (%)	Clay (%)	Silt (%)	MC (%)	BD (gm/cm3)	PD (gm/cm3)	Soil Porosity	OC (%DM)	TN	C: N ratio	Avail. P mg/kg	Soil pH	EC (ds/m)	CEC	Exch. Na	Exch. K	Exch. Ca	Exch. Mg	BS (%)
Natural forest	D_1	44.2	30.8	25	21.582	1.088	1.632	0.33	4.272	0.3959	10.958	41.02	6.516	1.54	36.59	0.47	4.782	19.9	6.24	85.78
	D2	37.2	37	25.8	24.586	1.246	1.8	0.30	2.702	0.2299	11.805	22.01	5.884	2.026	30.68	0.318	2.412	14.35	4.498	70.10
Eucalyptus globulus	D_1	41.8	34.8	23.4	15.986	2.08	2.424	0.14351	2.404	0.1964	12.661	4.474	5.208	3.944	25.66	0.682	2.192	11.61	4.396	75.975
	D2	33.6	40.6	25.8	18.006	2.28	2.638	0.13375	1.654	0.1504	11.07	1.764	5.752	3.004	25.9	0.526	1.738	10.88	2.76	65.849
Cupressus lusitanica	D_1	40.6	33.4	26	19.798	1.228	1.708	0.28398	2.758	0.2456	11.106	2.848	5.286	1.892	22.27	0.306	2.868	13.36	3.246	89.039
	D2	47	35.2	17.8	22.034	1.398	2.09	0.33542	1.816	0.1485	12.391	2.05	5.542	2.778	20.25	0.234	2.052	9.824	2.578	72.621
Grevillea robusta	D_1	41.6	33.2	24	21.95	1.19	1.868	0.3579	3.522	0.2938	11.993	7.528	5.744	1.926	24.58	0.38	2.4	13.88	3.826	83.347
	D2	32	43.4	24.6	23.52	1.394	2.07	0.32553	2.748	0.2291	12.067	4.118	5.664	2.906	21.9	0.308	1.984	11.23	3.2	76.203
Pinus	D_1	31.6	39.8	28.6	20.368	1.132	1.534	0.26204	2.984	0.265	11.365	29.656	5.93	1.866	30.7	0.364	2.986	17.11	5.274	83.857

patula	D2	24.4	44.4	31.2	22.198	1.254	1.706	0.26746	2.024	0.166	12.788	10.982	6.042	2.842	27.75	0.24	1.922	12.76	4.234	68.845
Grass land	D_1	41.8	30.8	27.4	19.616	1.348	1.974	0.31763	3.026	0.2618	11.754	19.356	6.614	1.576	30.05	0.314	2.426	17.29	3.616	77.126
	D2	40.8	35.8	23.4	21.176	1.604	2.524	0.36413	2.132	0.1898	11.964	10.394	6.358	2.356	27.89	0.258	1.55	14.76	3.228	69.521
Grazing land	D_1	40.2	32.6	27.2	17.782	1.348	1.924	0.29827	2.578	0.217	11.888	15.374	5.8	1.554	28.99	0.374	2.968	14.72	3.054	79.761
	D2	33.6	39.6	26.8	20.824	1.552	2.276	0.31967	1.74	0.1507	12	8.41	6.192	2.202	25.92	0.276	2.174	11.99	3.366	69.294
Agricultural cropland	D_1	31	38.6	30.4	15.446	1.366	1.968	0.30521	1.58	0.1398	11.368	9.114	5.314	3.496	19.67	0.25	1.414	9.998	3.896	79.075
	D2	27.2	43.2	29.6	17.578	1.57	2.392	0.33853	1.364	0.1205	11.596	3.918	5.44	2.648	18.3	0.162	0.98	9.864	3.042	76.517

Keys: D_1 is soil depth 1 which refers to topsoil layer (0-20 cm), and D_2 is soil depth 2 which refers to subsoil layer (20-40 cm)