EFFECTS OF *Eucalyptus globulus* PLANTATION ON SOIL ORGANIC CARBON STOCK AND FARMERS' PERCEPTION TOWARDS ECOSYSTEM SERVICES IN BASONA WERENA DISTRICT, CENTRAL HIGHLANDS OF ETHIOPIA

MSc. Thesis

Ademe Tizazu

June 2019

Debre Berhan, Ethiopia

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A Thesis Submitted to the Department of Plant Science
College of Agriculture and Natural Resource Sciences, School of Graduate Studies, Debre Berhan University

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Soil Science

Ademe Tizazu

Major Advisor: Asmare Melese (Ph.D.)
Co-Advisor: Fikrey Tesfay (Ph.D. Candidate)

June 2019

Debre Berhan, Ethiopia

SCHOOL OF GRADUATE STUDIES
COLLEGE OF AGRICULTURE AND NATURAL RESOURCE SCIENCES

DEBRE BERHAN UNIVERSITY

APPROVAL SHEET - I

This is to certify that the thesis entitled: **Effects of *E. globulus* Plantation on Soil Organic Carbon Stock and Farmers' Perception towards Ecosystem Services in Basona Werena District, Central Highlands of Ethiopia** submitted in partial fulfillment of the requirements for the degree of Masters of Science with specialization in **Soil Science** of the Graduate Program of the Department of **Plant Science**, College of Agriculture and Natural Resource Sciences, Debre Berhan University and is a record of original research carried out by **Ademe Tizazu, 177/2010,** under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged. Therefore, I recommend that it be accepted as fulfilling the thesis requirements.

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Name of Major Advisor	Signature	Date
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Name of Co-Advisor	Signature	Date

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APPROVAL SHEET - II

We, the undersigned members of the board of the examiners of the final open defense by Ademe Tizazu have read and evaluated his thesis entitled. **Effects of *E. globulus* Plantation on Soil Organic Carbon Stock and Farmers' Perception towards Ecosystem Services in Basona Werena District, Central Highlands of Ethiopia** and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of **Master of Science in Soil Science**.

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Name of Internal Examiner	Signature	Date
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Name of External Examiner	Signature	Date

Final approval and acceptance of the thesis are contingent upon the submission of the final copy of the thesis to the Council of Graduate Studies (CGS) through the department graduate committee (DGC) of the candidate's major department.

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DEDICATION

This paper is dedicated to my beloved and esteemed families.

STATEMENT OF THE AUTHOR

I, Ademe Tizazu hereby declare that this thesis is my genuine work and that all sources of materials used for this thesis have been profoundly acknowledged. The thesis has been submitted in partial fulfillment of the requirements for Master of Science (MSc) at Debre Berhan University and it is deposited at the University library to be made available for users under the rule of the library. I intensely declare that this thesis is not submitted to any other institution anywhere for the award of any other academic degree, diploma or certificate.

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Date of Submission: **23/07/2019 GC.**

BIOGRAPHICAL SKETCH

The author, Mr. Ademe Tizazu, was born on February 23, 1994, in Gishe district, North Shewa Zone of Amhara National Regional State, Ethiopia. He attended his primary education at Agnameda Primary School. He attended his secondary and preparatory education at Rabel Secondary High School and Preparatory School, respectively. After he successfully passed the Ethiopian Higher Education Entrance Qualification Exam, he joined Debre Berhan University in 2014 GC and graduated with a BSc degree in Natural Resource Management in June 2017. Following his graduation, in the same year, he has joined the School of Graduate Studies of Debre Berhan University to pursue his MSc degree in Soil Science.

ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
BD	Bulk Density
C:N	Carbon to Nitrogen Ratio
CEC	Cation Exchange Capacity
$cmol_{(+)}/kg$	Centimol Charge per Kilogram
CSA	Central Statistical Agency
CV	Coefficient of Variation
DAP	Diammonium Phosphate
DMRT	Duncan's Multiple Range Test
FAO	Food and Agricultural Organization
FRL	Forest Reference Level
GLM	General Linear Model
GHGs	Greenhouse Gases
IPCC	Inter-Governmental Panel on Climate Change
Mg	Mega Gram
masl	Meter above sea level
mbsl	Meter below sea level
OM	Organic Matter
ODW	Oven Dry Weight
REDD+	Reduction of Emission from Deforestation and Degradation
SOC	Soil Organic Carbon
SOCS	Soil Organic Carbon Stock
SOM	Soil Organic Matter
SAS	Statistical Analysis System
SPSS	Statistical Package for Social Science
TN	Total Nitrogen
TNS	Total Nitrogen Stock

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Effects of *Eucalyptus globulus* Plantation on Soil Organic Carbon Stock and Farmers' Perception towards Ecosystem Services in Basona Werena District, Central Highlands of Ethiopia

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ABSTRACT

Fast growing E. globulus tree is widely practiced and has become part of the farming system, particularly in the central highlands of Ethiopia. This study was designed to determine the effects of E. globulus plantation on soil organic carbon (SOC) stock and to examine farmers' perception towards ecosystem services in Basona Werena District, Central Highlands of Ethiopia. Soil samples were taken from land with E. globulus plantation and cultivated land at two depths (0-20 cm and 20-40 cm) from three slope positions (upper, middle and lower) with three replications. A total of 94 persons responded to the questionnaire survey. Both closed and open-ended questions were used and households were interviewed house-to-house. The values of soil parameters were subjected to a three-way analysis of variance (ANOVA) following the general linear model (GLM) procedure using SAS 9.4. Descriptive statistics and multiple linear regressions were used to analyze the surveyed data. The result revealed that SOC stock was highly significantly (P < 0.001) higher in the E. globulus plantation (28.5 Mg/ha) than cultivated land (21.0 Mg/ha). The mean values of OM ranged from 1.43 to 2.12%. However, the mean values of total N ranged from 0.09 to 0.13%. The mean bulk density of the soils ranged from 1.23 and 1.31 g cm-3. The pH ranged from 5.28 to 5.58. The results of the social survey showed that, despite the negative effects of E. globulus plantation such as competition with cropland (74.5%), reducing soil fertility (66%), it had a tremendous role for the local farmers including source of income (100%), fuelwood (100%) and construction material (96.8%). The multiple linear regression model revealed that several socioeconomic and cognitive variables significantly affected the local farmers' of the dependent variables, i.e. perception towards the conversion of cultivated land to Eucalyptus plantation, (16% variance), feeling on having E. globulus plantation (23% variance) and fears of the expansion Eucalyptus (12% variance explained). Generally, planting Eucalyptus on degraded land had multiple roles in providing households need as well as SOC stock in line with protecting erodible soil. Therefore, to be more benefited from Eucalyptus plantation as SOC stock, regulating the environment and meeting livelihoods consumption, improved management of Eucalyptus plantation should be promoted and should be studied further.

Keywords*: Eucalyptus, Land use, Slope position, Soil fertility, Total nitrogen stocks,*

1. INTRODUCTION

Soil is the largest terrestrial organic carbon pool and has historically known as both as a source and sink for atmospheric CO_2. It plays a major role in the global carbon (C) cycle. Soil organic carbon is an important soil constituent influencing soil and water quality, farming practices and ultimately food production (Kucuker *et al.*, 2014). Carbon storage is broader as it is defined as the increase in soil organic carbon (SOC) stock over time in the soils of a given land unit (Chenu *et al.*, 2018). Soil organic carbon stock is a C pool in mineral and organic soils to a specified depth chosen by the country and applied consistently through the time series (FAO, 2010). Reliable SOC stock measurements of major ecosystems are essential for predicting the influence of advancing climate change (Dessie Assefa *et al.*, 2017).

Globally, forests store more than 650 billion Mg of carbon, of this 45% is stored in forest soils (FAO, 2010). Forest soils are one of the chief C sinks on earth because of the large areas involved at the regional and global scale and their higher soil organic matter (SOM) content (Lal, 2005). As forest soil contains approximately two-thirds of the carbon stored in forest ecosystems (Conard and Ivanova, 1997), soil carbon dynamics can have significant effects on ecosystem C balance. Tropical forests act as the largest carbon sinks in the world (Local and Lushoto, 2014).

Land use changes have caused emission of approximately 20% greenhouse gases (GHGs) globally that leads to shrinkage of carbon storage in the potential areas. Soil carbon pools change rapidly in response to land use change (Datta *et al.*, 2015). Soil organic carbon stocks and fluxes in forest ecosystems are influenced by natural and human disturbances. Deforestation is estimated to account for approximately 17% of human-induced carbon emissions (IPCC, 2013).

E. globulus has been planted in the central highlands of Ethiopia since 1895 (Dessie Assefa *et al.*, 2017). Eucalyptus tree plantation is expanding at the expense of agricultural lands in the country (Girmay Gebregiworgis and Singh, 2012; De *et al.*, 2014; Muluneh Minta *et al.*, 2018). The total areas of plantations in Ethiopia, in the last hundred years, have not reached more than 2000 km^2. This is approximately at the rate of 20 $km^2 yr^{-1}$ of planting, which is only about 1% of the estimated 1500 km^2-2000 km^2 the annual rate of deforestation in the country.

Eucalyptus tree plantation covers more than 90% of the total planted forest area in Ethiopia (Mulugeta Lemenih and Habtemariam Kassa, 2014).

Increasing economic benefits from the Eucalyptus tree is driving farmers to such land cover changes (Girmay Gebregiworgis and Singh, 2012). Biological attributes such as fast growth, even on degraded landscapes, coppicing ability and non-palatability to cattle that attract farmers to convert their cultivated land to Eucalyptus plantations (Dessie Assefa *et al.,* 2017). Moreover, Eucalyptus plantation can grow with sustainable high yield without fertilizer input. Due to its versatile use and substantial economic benefit, Eucalyptus has become an important primary species that have improved livelihood (Mesfin Abebe and Wubalem Tadesse, 2006). Despite that farmers perceive Eucalyptus trees are exhausting productive land and dry up of springs, local farmers insist on planting Eucalyptus because of its high cash income (Tilashwork Chanie *et al.,* 2013).

In Basona Werena district central highland of Ethiopia, considerable cultivated land has been converted to Eucalyptus plantation by farmers to diversify their income (Girmay Gebregiworgis and Singh, 2012). In the district, it seems to dominate crop production and this has made it one of the highly valued tree species in the Basona Werena district and as well in the country. As a result, it has become part of the farming system in certain areas especially in the highlands of Ethiopia (Selamyihun Kidanu *et al.,* 2005).

Better understanding of how Eucalyptus plantation affects soil fertility, water availability and other ecosystem services aspects will contribute to forest development strategy in general and to the design and implementation of Eucalyptus plantation programs in particular to the country. Particularly, understanding the distribution of SOC will provide valuable information for formulating improved management practices for newly established forest plantations that will also help to rehabilitate soil as well as sequester atmospheric CO_2 with co-benefits of livelihood security of the resource-poor farmers (Datta *et al.,* 2015).

Where there is low tree coverage to protect the soil, Eucalyptus has acted as a biological conservation measure. A study has indicated that Eucalyptus plantations are efficient in stocking carbon in the soil in the long term (Ravina, 2012). However, few studies have examined carbon storage in Eucalyptus plantations in the highlands of Ethiopia (Bekele

Lemma *et al.,* 2006; Beyene Belay *et al.,* 2018; Yirdaw Meride, 2018). Investigating the effect of Eucalyptus plantation forests on SOC stock in comparison with adjacent land use systems can give additional information on the debate of Eucalyptus impacts on ecosystem services. It can be used as additional crucial data for the successful implementation of the National Reduction of Emission from Deforestation and Degradation (REDD+) strategy and introduction of carbon credited for climate change mitigation of Ethiopia (Matthews *et al.*, 2014.).

Previous studies in the central highlands of Ethiopia on Eucalyptus plantation focused on assessing temporal changes in biomass production (Zewdie Mulugeta, 2008), opportunities and constraints to sustainable intensification of crop-livestock trees mixed systems (Kuria *et al.,* 2014), management of trees in farmed landscapes (Hussien Adal and Zemede Asfaw, 2015), local peoples' knowledge on the adverse impacts and their attitudes towards growing Eucalyptus woodlot (Solomon Ayele and Solomon Mulu, 2017). All these studies indicated that Eucalyptus is a tree of choice for wood production by farmers in central Ethiopian highlands. However, the contribution of this plantation in SOC stock has got little attention.

Although there are many claims about its negative effect on ecology and water availability, perception of farmers on the impacts of this plantation on ecosystem services are not studied. Therefore**,** the **general objective** of this study was to quantify the effect of *E. globulus* plantation on SOC stock and examining the perceptions of farmers towards the effect of converting croplands to *E. globulus* plantation on ecosystem services, such as soil fertility, water availability and climate regulation in Basona Werena district.

The **specific objectives** of the study were to determine the effects of *E. globulus* plantation and adjacent land use systems on soil organic carbon stock and carbon-related soil properties and to examine the perception of farmers towards the impacts of *E. globulus* plantations on soil fertility, water availability, economic benefit, and microclimate regulation.

2. LITERATURE REVIEW

2.1. Deforestation and Rehabilitation in Ethiopia

The total area of woodland in the world is estimated to be at least 1.1 billion hectares equivalent to 9% of the total land area. The ten countries with the largest area of woodland are Australia, China, Canada, the Russian Federation, Argentina, Sudan, Ethiopia, Brazil, Botswana and Afghanistan (FAO, 2010).

Tropical deforestation is responsible for approximately 20% of world greenhouse gas emissions. Deforestation, mainly in tropical areas contributed up to one-third of total anthropogenic carbon dioxide emissions. There are several reasons for the occurrence of deforestation: trees or derived charcoal can be sold as a commodity and used by humans, while cleared land is used as pasture, plantations of commodities and human settlement (Tsegaye Tadesse, 2007). The main causes of deforestation are agricultural expansion; increasing demand for construction material, industrial use, fuelwood and charcoal; lack of forest protection and conservation policy; absence of strong forest administration system capable of arresting the rapidly increasing rate of deforestation; minimum effort to ensure the participation of communities in forest protection and conservation and the sharing of benefits and failure to clearly demarcate and enforce the boundaries of natural forest reserves (Tigabu Dinkayoh, 2016).

Ethiopia is an agrarian country with a great topographic range from 110 meters below sea level (mbsl) at Dalol depression to 4,620 meters above sea level (masl) at Mount Ras Dashen. Because of its topographic variation and location in the tropics, Ethiopia has diverse climate conditions and ecosystems. As a result, the country is well endowed with natural resources. However, deforestation has gone for the last five decades. Forests which were above 40% of the country's landmass at the beginning of the 20th century are reduced to 2.36% in 2000 (Tigabu Dinkayoh, 2016). Deforestation is ongoing and is shaping the climate of Ethiopia. Deforestation contributes to global climate change and is often cited as one of the major causes of the enhanced greenhouse effect (Adam, 2008).

To minimize the deforestation problem, many efforts have been and are being made by the government and non-governmental organizations. Establishment of protected and forest priority areas, as well as protecting the sacred forest sites and introducing new energy efficient stoves are attempts taken to protect forests in the country. Rehabilitation of forests through afforestation, reforestation and area enclosures with participatory forest management practices are another conservation effort that the government is implementing (Tigabu Dinkayoh, 2016). The practice of rehabilitating degraded lands through establishing area closure has been traditionally exercised for centuries around church boundaries in Ethiopia by restricting the use of forests around churches.

Nowadays, establishing area closure is one of the most widespread and successful forms of rehabilitating degraded lands in Ethiopia. It involves protecting areas mainly through social fencing from any form of cultivation, cutting trees and shrubs, or grazing by livestock (Mulugeta Lemenih and Habtemariam Kassa, 2014). Afromontane areas have likely been a result of area closure activities (forest restoration) in central and northern highlands and growing of Eucalyptus woodlots by smallholder farmers.

2.2. Eucalyptus Plantation in Ethiopia

Eucalyptus is designated *'Bahirzaf'* which in Amharic means the tree from beyond the sea and is reflective of its overseas origin. Accordingly, the *'red' Eucalyptus*, *E. camaldulenis* and the *'white' Eucalyptus*, *E. globulus*, were designated as *'Qey Bahirzaf'* and *'Nech Bahirzaf'*, respectively (Woody Biomass Inventory and Strategic Planning Project, 2002; Selamyihun Kidanu *et al.,* 2005).

Eucalyptus was introduced to East Africa between the late 19th and early 20th century. In 1895, Emperor Menelik II introduced Eucalyptus plantations in Ethiopia in response to a critical wood shortage. Ethiopia's natural forest, consisting of broad-leaved trees often mixed with conifer species, were being depleted faster than they could be planted. At the same time, the demand for wood was increasing as the population of the capital grew. Recently, the coverage of Eucalyptus plantations reached more than 506,000 ha of land in Ethiopia (FAO, 2009).

Some 15 Eucalyptus species were introduced to Ethiopia in the 1890s with the aim of addressing deforestation and meeting the growing demand for wood in the country. *E. globulus* was the main species planted along the homestead boundary (Kuria *et al.,* 2014). However, some were ill-adapted and died after a certain developmental stage. But a few have thrived (Demel Teketay, 2000; Woody Biomass Inventory and Strategic Planning Project, 2002).

Traditional agro-forestry practices in Ethiopia involve tree planting in various spatial patterns to meet the demand for fuelwood and construction. In recent years, single rows of Eucalyptus species planted along field borders have become a dominant feature of the central highlands of Ethiopia (Zerga Belay, 2015). This places Ethiopia among the ten major Eucalyptus growing countries in the world. Therefore, Eucalyptus is here to stay regardless of views to the contrary that flatly contradict the real objective on the ground. The viable option to resolve ecological and agricultural related issues is the implementation of sound land management (Mesfin Abebe and Wubalem Tadesse, 2006).

2.3. Effects of Eucalyptus Plantation on Soil Organic Carbon Stocks

The Earth's climate has always gone through periods of change. Over the past few decades, however, the implications of increasing fluctuations in weather patterns have led to the recognition of the need for international action. The manmade greenhouse effect is caused by the addition of Greenhouse Gases (GHGs), especially CO_2, which are emitted when fossil fuels, such as petroleum, coal and natural gas, are burned (Melese Worku and Habtamu Agonafir, 2017).

Soil organic carbon (SOC) is an important component in soil that contributes to soil fertility, crop production and soil sustainability (Datta *et al.,* 2015). Forests are stores of carbon and can be either sinks or sources depending upon environmental circumstances. Tree-plant can act as go under the outside from side to side the course of action of trees enlargement and resulting organic carbon appropriation. Thus, better than ever, the quantity of foliage can potentially un-hurried the accretion of impressive carbon (Brown, 2007).

Trees and other green plants remove carbon in the form of carbon dioxide from the atmosphere during the process of photosynthesis and release O_2 back into the atmosphere during normal respiration (Maddox, 2006). Only when trees grow actively forests can remove carbon over an annual or longer time frame. In order for forests to take up carbon, the wood must be harvested and turned into long-lived products and trees must be re-planted. Mature forests alternate between being net sinks and net sources of carbon dioxide (Brown, 2007). According to FAO's Global Forest Resources Assessment (2010), forests are globally storing more than 650 billion Mg of carbon in the soil. Forests are important for the decreasing of CO_2 emissions through the capacity of carbon sequestration in the plant biomass and the soil.

For the era of a productive season, CO_2 from the atmosphere is taken up by vegetation and stored as plant biomass. On the other hand, at what time forest are empty or tainted, their stored carbon is on the rampage into the mood as CO_2. Using the SOC storage of current remnant forests and assuming a 40% forest cover, the SOC stock of the Amhara region before 50 years was about 58 Mg/ha C. Forest cover of the Amhara region is currently estimated to be about 9.5% giving a SOC stock of 12 Mg/ha C. Study in North-central parts of Ethiopia shows that SOC stock of the Eucalyptus plantation was higher than cropland (Dessie Assefa *et al.,* 2017). Another study also showed that SOC pool under Eucalyptus species was maximum (49 Mg/ha) and SOC pool under Eucalyptus species was higher as compared to all other species. It was observed that Eucalyptus species have the maximum mitigation potential while all other plantations (*Shorea robusta, Cedrus deodara, Quercus leucotrichophora, Pinus roxburghii, Picea smithiana, Pinus wallichiana, Pyrus malus, Psidium guava, Mangifera indica and Citrus spp)* do not differ much (Gupta and Sharma, 2012). In contrast, after replacing native vegetation by Eucalyptus plantations, mean SOC changes were -1.5 and 0.3 Mg/ha for the 0-20 cm and 0-40 cm depths, respectively (Fialho and Zinn, 2015).

2.4. Perception of Farmers on the Impacts of Eucalyptus Plantation on Ecosystem Services

Currently, there is a lack of understanding of farmers' perception of ecosystem services and how this is related to their management (Mancini *et al.,* 2018). Trees and shrubs are disappearing fast in anthropogenic landscapes of many countries; this is the case in Ethiopia.

In order to promote conservation on-farm, there is a need to involve farmers. Farmers' involvement in tree/shrub management requires a clear understanding of the households' needs that trees can satisfy, of the priority species to satisfy these needs, as well as of tree management practices and challenges that hinder tree planting, protection, and sustained use. Study by Hachoofwe (2008) showed that smallholder farmers value tree products for household welfare, including needs of accessing food (edible fruits), generating income and accessing construction wood and other non-timber products, in addition to their obvious ecological and spiritual roles.

For a species to be incorporated into farmlands, it should be one that sheds its leaves before the onset of rain and is easily decomposed to increase soil fertility. Evergreen species are kept around the residence, grazing land, and farm boundary to provide shade, fodder and other functions. Multiple-use species and species with major uses are preferred by households. Trees like Eucalyptus are grown around homes and farm boundaries. Shade for people and livestock is one important criterion for setting species preference (Hussien Adal and Zemede Asfaw, 2015).

Solomon Ayele and Solomon Mulu (2017) showed that about 92% of the respondents noted that growing Eucalyptus had positive impacts on the socioeconomic situation of the community considering that it contributes to economic benefits through the sale of wood products, such as poles, construction materials, and fuelwood. However, only 8% of the respondents noted that the negative impacts of Eucalyptus were attributed to the decline in crop and forage production due to its allelopathic effect and the reduction in groundwater availability.

Eucalyptus is fast-growing and preferred species in plantations; it is widely grown in the tropics and subtropics and thus are great commercial importance. At present, Eucalyptus is grown on more than 20 million ha of plantations around the word (Booth, 2013**)**. Recently, Eucalyptus has spread to urban and peri-urban centers, woodlots, homesteads, communal lands, schools, churches and monasteries (Alemayehu Wassie *et al.*, 2005).

Forest plays an indispensable role in the upkeep of an environment that facilitates sustainable development. Ethiopia meets 96% of its energy needs with biomass such as charcoal, wood, dung and plant residues from farming and forestry. The effects of Eucalyptus tree plantation in ecology particularly in competition, undergrowth suppression, soil nutrient, and water depletion, shadow and litterfall effect, and presence of birds and wild animals are well understood by farmers. However, land diminition they faced due to population pressure and valuable income earned from the sale of Eucalyptus overshadowed their opportunity to plant the tree in the ideal site (Zerga Belay, 2015).

2.5. Eucalyptus and Crop Production

The effects of decreased crop production when Eucalyptus trees are planted on or near farmlands due to their ability to out-compete crops and other vegetation for water and nutrients are considerable. The major implication of allelopathic effects in smallholder farming systems is the reduction in crop output when trees are planted adjacent to crops (Jagger and Pender, 2003). Such allelochemicals can be present in soils, leaves, stems, roots, flowers, and seeds. They are released into the environment by several mechanisms, such as leaching from the above-ground parts, root exudation, volatilization, and residue decomposition. They can affect the germination and growth of crops through interference in cell division, energy metabolism, and nutrient uptake. In this regard, Eucalyptus has toxic allelochemicals that consist of phenolic acids, tannins, and flavonoids (Mesfin Abebe and Wubalem Tadesse, 2006).

Logging residues from short rotation *E. globulus* tree crops contain significant stores of plant nutrients, especially where plantation productivity levels are high and large amounts of residues are produced during harvesting (O'Connell *et al.*, 2004). However, the benefits derived in terms of slowing erosion and retaining soil moisture over the entire plot of land may compensate for the losses in crop production experienced. Even where the per hectare value of Eucalyptus production exceeds the per hectare value of crop production, the costs of reclaiming land for crop production after tree planting may be significant. However, a study by Selamyihun Kidanu *et al.* (2004) indicated that adjacent wheat yields were substantially reduced because of the combined effects of water, light and nutrient competition with Eucalyptus plantation. They conclude that the benefit accrued from the tree component adequately compensated for this reduction in wheat yield and generated additional income.

2.6. Eucalyptus and Soil Fertility

Over the past few years, a single row of *E. globulus* trees planted along the borders of cropland has come to dominate central highland agroforestry practices (Selamyihun Kidanu *et al.,* 2004). Although evidence is scanty, there is a perception that this practice adversely affects crop productivity. According to social survey study of Solomon Ayele and Solomon Mulu (2017) decline in soil fertility was among the adverse ecological impacts of Eucalyptus.

With the extension of Eucalyptus root deep into the soil, given its high degree of adaptability, it extracts nutrients outside the realm of the crops feeding zone (Zerga Belay, 2015). However, Eucalyptus species were found to have a beneficial effect on soil structure and on treeless sites, they improved soil fertility through the decayed litter. If the litter is left on the site uncollected, it would have been incorporated into the soil system to slow down runoff and improve infiltration and a substantial amount of nutrients may pass to the soil system, thereby improving soil fertility (Haileab Zegeye, 2015). As reported in various studies Eucalyptus can help to control soil erosion and improve soil fertility (Demel Teketay, 2000; Selamyihun Kidanu *et al.,* 2004; Haileab Zegeye, 2015).

2.7. Eucalyptus-Hydrology Interaction

The effects of Eucalyptus tree plantation in ecology particularly in competition, undergrowth suppression, soil nutrient, and water depletion, shadow and litterfall effect are well understood by farmers (Zerga Belay, 2015). Eucalyptus can survive and grow in a wide range of rainfall conditions. Eucalyptus is commonly grown in relatively low rainfall sites; water-use is probably frequently capped to match the available rainfall supply (Dye, 2013).

Exotic species that have helped in the rehabilitation of degraded landscape and assisted to maintain the ecological integrity of landscapes should be considered an integral part of the conservation of water resources. Eucalyptus appears to use less water per unit weight of biomass produced than other kinds of trees and many agricultural crops, but their potentially high biomass production under low rainfall conditions may reduce stream flow more than slower growing kinds of trees. Water consumption by Eucalyptus can be reduced by planting trees farther apart or by thinning existing plantation. Farmers reported that Eucalyptus trees dry up streams and swampy areas particularly in dry seasons (Zerga Belay, 2015).

High water requirements and characteristics such as deep root systems give Eucalyptus a comparative advantage over other plants with respect to water usage (Jagger and Pender, 2006). The hydrological impacts of Eucalyptus are often manifested in terms of its canopy interception, runoff regulation, water uptake, and soil moisture depletion. This is particularly serious when Eucalyptus trees are planted in regions prone to drought conditions as the trees may cause drying of soil and water sources. Farmers in the highlands of Ethiopia believe that Eucalyptus plantations around water sources significantly affect the flow rate of springs (FAO, 2009).

2.8. Eucalyptus and Micro-Climate

Ethiopia recognizes the importance of the forestry sector for its economic, social and ecological benefits which make a significant contribution to the country's long-term development goals and towards meeting international commitments. Forestry is among the four pillars of the climate resilient green economy strategy which aims to reduce national emissions by 50% in 2030 (Hussien Adal and Zemede Asfaw, 2015). Forests ameliorate the local climate, lowering temperatures and increasing humidity. A windbreak moderates the microclimate for up to twenty or more times its height to leeward.

However, the extent of these effects depends on the amount of leaf surface carried by the trees in relation to the surface area of the ground covered. In the shaded area, average air temperatures are lower, extremes of air and surface soil temperatures are reduced and there is a higher surface air humidity compared to areas with no trees. Generally, the greater the leaf area and the more horizontal the leaves are, the greater the shading effect and the higher the evapotranspiration rate. Eucalyptus cast less shade, on average than other broadleaved trees, but there are big differences in the amount of shade cast by different Eucalyptus species because they have different leaf sizes and orientations. The influences which are the result of shading can be manipulated based on the need through increasing or reducing the initial planting space. Therefore, there is no sufficient reason to distinguish Eucalyptus from other genera with similar crown architecture regarding micro-climate at the local level (FAO, 2009).

2.9. Eucalyptus as Windbreak

A windbreak is used to reduce the wind's force or velocity to make life more livable for humans, plants, and animals in areas where wind speed is very high without protection. Eucalyptus species can be planted as windbreaks or shelterbelts to reduce the force of the wind (Haileab Zegeye, 2015). In dry areas prone to wind erosion; they reduce soil erosion and limits dust storms. In cold areas, it can help reduce the impact of the cold and can help to protect against freezes by cutting back on wind-chill. Furthermore, windbreaks reduce wind damage to crops so that potential yields are maintained.

A windbreak moderates the microclimate for up to twenty times its height to the leeward side. A windbreak is most effective if, rather than acting as a wall which causes turbulence downwind, it filters the wind (FAO, 1992). Eucalyptus has an extensive lateral root system which makes it wind-firm so that it can be fit as a windbreak (FAO, 2009; Shackleton and Shackleton, 2018). These tree species offer a range of socioeconomic benefits (food, cash income, medicine, fodder, bee forage, fuelwood, timber, shades, bird watching towers, live fences, control of runoff, protection of soil through reducing wind speed, improvement of soil fertility and maintain a healthy ecological state) as well as providing proximate and ultimate ecosystem services (Hussien Adal and Zemede Asfaw, 2015).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location of the study area

The study was conducted in Gudoberet kebele, Basona Werena district, North Shewa Zone, of the Amhara National Regional State (Fig. 1). Basona Werena district is situated at about 130 km to the northeast of Addis Ababa, on the way to Dessie. The district is geographically located at a latitude of $9^{0}30'00''$N and longitude of $39^{0}30'00''$E.

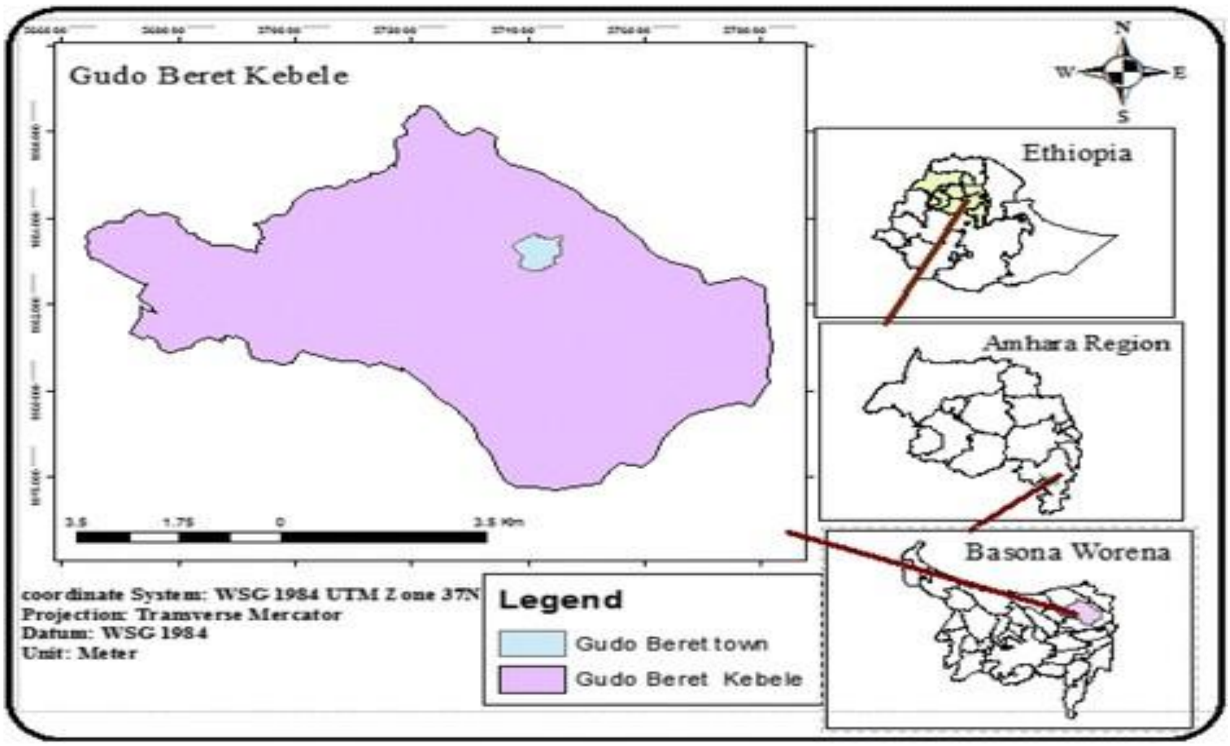

Figure 1. Study area map Source: Solomon Ayele and Solomon Mulu (2017)

3.1.2. Climate and topography

Basona Werena is characterized by a moderate to cool sub-moist mid-highland climate. Dominantly the district is characterized by moist highland (moist *Dega*) climate. This climate is suitable for human and animal habitation and for highland crop cultivation (Kuria *et al.*, 2014). The average annual temperature is 19.7 ^{0}C, with ranges between 5 ^{0}C and 23 ^{0}C (Ermias Seyoum, 2007). The average annual rainfall is about 1100 mm, with bimodal distribution which is about 70% falling during the long rainy season, which is the main cropping season.

Basona Werena district has two rainy seasons. The short rain (*belg*) that falls between February and April and the long rain (*kiremt)* that falls between June and September. Soil erosion is one of the major challenges to the farming system in the district particularly the bottomlands area is prone to flooding (Kuria *et al.*, 2014). Frost is common particularly between October and December when temperatures fall below average (Aklilu Amsalu, 2006). Basona Werena lies at relatively high altitude which ranges 1300 - 3650 meter above sea level (masl); in a zone forming part of the central plateau of Ethiopia. The area is situated on the edge of the western escarpment of the Rift Valley, which forms part of the headstream of the Blue Nile basin. The physiography is mixed with steep-sided hills, plateaus, gullies and river gorges (Aklilu Amsalu, 2006).

3.1.3. Soil and geology

Tertiary rocks (the trap series) chiefly basaltic materials of volcanic origin predominate the Ethiopian highlands (Billi, 2015). The soils of the Basona Werena have been developed from the Tarmaber Megezez formation transitional and alkaline basalts (Tefera *et al.*, 1996). The highland escarpments are characterized by Precambrian Crystalline rocks, while the deep river valleys have sandstone and limestone which are Mesozoic in origin. The soils for the study area are predominantly Vertisols (locally *'Tikurafer'*) and Lithosols (stony and shallow) (Seifu Kebede, 1999). The study area is located in landscapes of impeded drainage, such as seasonally inundated depressions, alluvial/colluvial plains, and others.

3.1.4. Population and livelihood

According to the Federal Democratic Republic of Ethiopia central statistical agency (CSA) population projection for all regions at the district level, the district has a total population of 140,336, of whom 71,739 are men and 68,947 women; 2122 or 1.51% are urban inhabitants. The district has a population density of 193.8 people per km^2 (CSA, 2013). The land is a particularly scarce resource due to high population pressure and land degradation. Agricultural production is primarily intended to meet requirements for subsistence and it is largely sustained with local inputs such as animal manure and own labor (Aklilu Amsalu, 2006).

3.1.5. Land use and land cover

Basona Werena covers an area of 120,799 ha. The land use system of Basona Werena district is dominated and characterized by the mixed farming system. It does not show a distinct spatial pattern. Food crops mainly wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), bean (*Vicia faba*) and field pea (*Pisum sativum*) are grown on the relatively more fertile lands. Trees, nearly all Eucalyptus, are planted on marginal lands, along eroded slope and around houses (Kuria *et al.*, 2014). Homesteads are surrounded by groves of Eucalyptus. Eucalyptus tree plantation was introduced into the area in the early 20^{th} century. Recently, converting private farm/crop lands to Eucalyptus plantation is becoming common practice in the district.

As a result of past afforestation programs, a large area is covered with tree plantation in the district. Nearly all Eucalyptus plantations are planted mostly on hilly patches, parts of farmlands that are not suitable for growing food crops and around homesteads. Of the total area of the district, 15% (18,627.2 ha) is covered with forest and dominated by *E. globulus* and Gudoberet kebele share a total area of 5540 ha with 25.6% (1418 ha) of forest land. *E. globulus* covers 710.52 ha (50%) of Gudoberet forest (Basona Werena District Agricultural Office, 2018).

3.2. Site Selection

For the purpose of this study, Gudoberet Kebele was selected purposively based on its dominance of practice on *E. globulus.* Gudoberet Kebele had patches of government forest mainly comprising *E. globulus, E. camaldulenis, and Cupressus lusitanica*. Among those, *E. globulus* take the largest coverage. There is no natural forest within Gudoberet kebele. Majority of the state-owned plantations in the district are used as an input wood material to the wood product processing factory in Debre Berhan, neighboring towns to Gudoberet Kebele. The privately-owned Eucalyptus plantation is mainly used as a source of income by selling the wood log for the purpose of construction and leaves for the purpose of fuelwood. Eucalyptus leaves are also used as a main source of firewood together with animal dung.

3.3. Soil Sampling

Two land use types namely land with *E. globulus* plantation and its adjacent cultivated land was purposively selected for the purpose of this study. Each land use was stratified into three slope position such as upper slope (shoulder), middle slope (back slope) and lower slope (foot slope) (FAO, 2006). Soil samples were taken from land with *E. globulus* plantation and cultivated lands at two depths (0-20 cm and 20-40 cm) with three slope position (upper, middle and lower) and three replications (2 land uses * 2 soil depths * 3 slope positions * 3 replications), respectively. A total of 36 soil samples were taken for the purpose of this study.

Soil samples were collected using '*Zigzag'* sampling system from five sampling points from each plot. The collected samples were aggregated and pooled into a single composite sample to represent the sample plot from each sampling depth. Soil samples were put into plastic bags, labeled and taken to a soil laboratory for analysis.

Additional undisturbed soil samples were collected using soil core sampler for the determination of bulk density. The soil samples were air-dried at room temperature, grinded and passed through different mesh size based on the requirements for physical and chemical analysis. Laboratory analysis was undertaken at Debre Berhan Agricultural Research Center.

3.4. Soil Laboratory Analysis

Soil bulk density was determined by core sample method (Black and Hertge, 1986). After soil bulk density is determined, a soil core sample was sieved to analyze rock fragment. The stones with a diameter > 20 mm and gravel with a diameter > 2 mm retained on the sieve was weighed and used as percent volume of rock fragments to correct the mass and the volume of the total soil sample during SOC stock determination.

Soil samples which passed through 2 mm sieve size were used to analyze pH, texture, and cation exchange capacity (CEC). Additionally, soil sample that passed through a sieve size of 0.5 mm was used to determine total nitrogen and soil organic carbon. Soil texture was determined by the Bouyoucos hydrometer method (Gee and Bauder, 1986). Soil pH was measured in an aqueous soil extract in distilled water (1:2.5 soil: water) using a pH meter (glass-calomel combination electrode).

Soil organic carbon was determined, using Nelson and Sommers (1996) method in which the carbon was oxidized under standard conditions with potassium dichromate ($K_2Cr_2O_7$) in sulfuric acid solution. SOM was calculated by multiplying SOC by 1.724 following the assumptions that OM is composed of 58% SOC.

The total nitrogen content in soils was determined using the Kjeldahl digestion, distillation and titration method by oxidizing the organic matter in concentrated sulfuric acid solution (0.1N H_2SO_4) as described by Black (1965). Then after, C:N was calculated by dividing organic carbon to total nitrogen. Cation exchange capacity (CEC) was estimated using a titrimetric method by distillation of ammonia that displaced by sodium (Chapman, 1965*)*.

3.5. Soil Organic Carbon and Total Nitrogen Stocks Determination

Soil organic carbon stock and total nitrogen stock for *E. globulus* plantation and cultivated land were calculated based on SOC and TN concentrations, depth of soil, rock fragment percentage and soil bulk density, at both depths (0-20 cm and 20-40 cm). The SOC stock pool was calculated using the formula described by Brown *et al.* (2005):

$$\mathrm{SOCS} = \mathrm{SOC} * \mathrm{D} * (1 - \mathrm{frag}) * \mathrm{BD}$$

$$\mathrm{TNS} = \mathrm{TN} * \mathrm{D} * (1 - \mathrm{frag}) * \mathrm{BD}$$

Where, SOCS = Soil Organic Carbon Stock (Mg/ha), TNS = Total Nitrogen Stock (Mg/ha), SOC = Soil Organic Carbon (%), TN = Total Nitrogen (%), D = Depth of the sampled Soil layer (cm), Frag = Stones with a diameter > 2 mm and BD = Bulk Density (g/cm^3).

3.6. Household Sampling

Quantitative and qualitative data collection methods were used to collect relevant data. Semi-structured questionnaires were used as data collection tool to gather primary data on farmers perception from targeted respondents. The checklist was prepared in advance consisting of different questions in the English language and translated into the Amharic language. A semi-structured questionnaire was set by administering the various socioeconomic (e.g., sex, age, level of education, landholding size) and cognitive (e.g., knowledge, understanding, and experience) variables (Kelboro and Stellmatcher, 2015) that would likely affect local peoples' perception on the impacts of *E. globulus* plantation on ecosystem services in Gudoberet Kebele. The total sample size of the household was determined using the following formula (Israel 1992):

$$n = 1 + \frac{N}{1 + N(e)^2}$$

Where, e = confidence level, N = total households in Gudoberet Kebele, n = sample size. Accordingly, among 1429 households, of which 1093 male headed and the remains of 336 are female-headed, 94 households were purposely selected for interview. Gender proportion was considered in the sampling of households by including 70 male headed and 24 female-headed households. The enumerators were implementing the questionnaire survey via direct house-to-house visits. Random sampling was used in order to avoid biases of data collection.

3.7. Data Analysis

Soil properties were subjected to a three-way analysis of variance (ANOVA) following the general linear model (GLM) procedure. Duncan's Multiple Range Test (DMRT) was used for mean separation if the analysis of variance showed a statistically significant difference ($P < 0.05$). All statistical analyses were performed using SAS 9.4 statistical software (SAS Institute Inc. 2012). Moreover, Pearson correlation analysis was carried out to determine the relationship between analyzed soil physical and chemical properties. Data from household respondents to describe socioeconomic characteristics and their attitudes regarding *E. globulus* plantation was subject to descriptive statistics i.e., frequency distribution and percentage, was analyzed using Microsoft Excel 2016 and inferential statistics were performed using SPSS 20. The qualitative data collected from interviews and direct observations were literally narrated.

Independent variables were derived from the following questions: sex, age, family size, level of education, landholding size, source of fuelwood, preference for *E. globulus* species and the difference in crop production near *E. globulus* plantation.

The dependent variables were derived from the following questions: local people's perception of the effects of *E. globulus* and local peoples' attitudes towards growing *E. globulus*. Multiple linear regression model was employed to identify factors that influenced the farmers' perceptions.

4. RESULTS AND DISCUSSION

4.1. Effects of *Eucalyptus globulus* Plantation on Soil Organic Carbon and Soil Organic Carbon Stock

4.1.1. Effects of *Eucalyptus globulus* plantation on soil organic carbon and soil organic matter

The result of the analysis of variance (ANOVA) showed that the soil organic carbon (SOC) and soil organic matter (SOM) contents were highly significantly ($P < 0.001$) affected by the main effects of land use types and slope positions, and they were also significantly ($P < 0.05$) affected by the main effects of soil depth (Tables 1 and 3). Considering the interaction effects, only the two-way interaction of land use with slope position showed significant ($P < 0.05$) variation on SOC and SOM contents (Table 3). The higher (1.18%) SOC content was recorded under the *E. globulus* plantation while the lower (0.84%) SOC content was recorded from cultivated land (Table 1).

Regarding the interaction effects, the highest (2.75%) value of SOM content was found under Eucalyptus plantation at lower slope position and the lowest (1.29%) value of SOM was recorded from the cultivated land at the upper slope position (Table 3). The trend of the increased SOC and SOM content under Eucalyptus soil was observed as compared to cultivated land. Obviously, the conversion of the forest into cultivated land has led to a reduction in SOM contents. Intensive cultivation and removing of vegetation cover also reduce the recycling of organic carbon in the soil. A relatively lower level of disturbance in soils under Eucalyptus plantation has apparently led to an increase in organic matter content as compared to those cultivated soils.

Land use change from forest to cropland use has decreased microbial population and decomposition activity, also decreased the nutrient content of soils, and increased the rates of erosion and loss of SOM.

Considering the main effects of slope positions, the higher value (2.17%) of SOM content was recorded on the lower slope position and the lowest value (1.53%) of SOM was found on the upper slope position (Table 1). This might be due to the severity of continuous water erosion in the undulated topography of the study area. When moving down from the upper land position to the lower one, soil organic matter dramatically increased. This may be due to undulating topography of the study area and continuous experience of erosion from the upper position and deposition on the lower slope position.

In line with this result, a study in North-West India showed that soil organic carbon pools change rapidly in response to land use change from plantation to agricultural land (Datta *et al.*, 2015). Similarly, study had indicated that Eucalyptus plantations are efficient in stocking carbon in the soil in the long term (Ravina, 2012). Maddox (2006) also confirmed that trees and other green plants remove carbon in the form of CO_2 from the atmosphere during the process of photosynthesis and release O_2 back into the atmosphere during normal respiration.

When soil depth increases, SOM content decreases under both land uses. As it can be observed in the results of Ravina (2012), the amount of carbon in percent was higher in the top layer and decreases with depth. The reason behind these may be crop residues, as well as leaves and debris from Eucalyptus, stand become decomposed by activities of soil microorganisms. Even though soil microorganisms have a wide range of adaptation, large number of beneficial soil microorganisms are present on the top 20 cm soil depth. A similar study also confirmed that soil organic C storage was higher at the surface layer of the soil and decreased with increasing soil depth (Du *et al.*, 2015).

4.1.2. Effects of *Eucalyptus globulus* plantation on soil organic carbon stock

Soil organic carbon stock was significantly ($p \leq 0.05$) affected only by the main effects of land use types and slope positions and the interaction of land use by slope position (Tables 1 and 3). Regarding the main effects of land use the highest mean value (28.5 Mg/ha) of SOC stock was recorded under Eucalyptus plantation while the lowest mean value (21.0 Mg/ha) of SOC stock was recorded under cultivated land (Table 1). Considering the interaction of land use types by slope position, the highest (34.87 Mg/ha) and the lowest (18.64 Mg/ha) SOC stock values were observed on Eucalyptus plantation at lower slope position and from cultivated land at the upper slope position, respectively (Table 3). This suggested that Eucalyptus soil was higher in SOC as compared to cultivated land in the study site, which gives some implication on the ability of Eucalyptus in carbon sequestration. But, it is important to remind that the measured amounts of SOC have a limit in the soil depth, for a full comparison additional soil depth should have been considered.

In the study area, the lowest carbon stock in agricultural land suggested that rain-fed agriculture, after crop harvesting complete removal of the crop residues and specific soil tillage management practices may result in the reduction of low carbon stock in the agricultural field. The lowest SOC stock size in cultivated land also might be due to low total organic carbon and loss of SOM through crop cultivation, harvesting, and erosion. As per the rating of SOM by Charman and Roper (2007), the mean values of SOM of the study area under Eucalyptus plantation and cultivated land were rated as high and moderate, respectively.

Generally, the results of this study revealed that land use change has a significant effect on SOC stock. FAOs' Global Forest Resources Assessment (2010) confirmed that the forests are globally store more than 650 billion Mg of carbon, 44% in the biomass, 11% in dead wood and litter and 45% in the soil. A study by Nega Emiru and Heluf Gebrekidan (2013) showed that the highest SOM contents were observed in the surface soils of forest land while least figures were from subsurface layers of the cultivated soils. The decomposition rate of the above ground litter under different land uses at the surface as well as subsoil and their relationships with soil properties, particularly BD and soil texture must be considered in identifying strategies for long-term C storage in soil. Improved understanding of the distribution of SOC fractions across land use will provide valuable information for formulating improved management practices for newly established plantations to rehabilitate degraded soil as well as sequester atmospheric CO_2 with co-benefit of livelihood security of the resource-poor farmers (Datta *et al.*, 2015).

The lowest carbon stock size in agricultural land might be due to low total organic carbon and loss of soil structure. This suggested that forest soil was the richest in SOC as compared to cropland in the study site. This result is in agreement with Dessie Assefa *et al.* (2017) who found under Eucalyptus, a significantly higher soil C percentage was shown compared to the cropland. Additionally, they also found that the average SOC stock per land use type can be ranked as Eucalyptus plantation (15.7 Mg/ha) and cropland (6.8 Mg/ha). Moreover, the lowest carbon stock size in the agricultural land could result from the lowest total organic carbon and loss of soil structure. Study by Ravina (2012) indicated that the Eucalyptus reforestation plays a vital role in carbon sequestration in soils with time. Furthermore, a study in North-Central parts of Ethiopia shows that SOC stock of the Eucalyptus plantation was higher than cropland (Dessie Assefa *et al.*, 2017). According to Jandl *et al.* (2007), soil carbon pool is affected by soil properties, forest management practices, and litter input and root turnover.

4.2. Total Nitrogen and Total Nitrogen Stock

According to the results of the analysis of variance (ANOVA), there was no significant difference in the total nitrogen content (TN) in the three-way interaction effect. But, the soil TN was significantly ($P \leq 0.001$) affected by the main effect of land use type, slope position and soil depth and TNS was significantly ($P < 0.001$) affected by the interaction effect of land uses and depth (Tables 1 and 4). Te result of ANOVA was supported by Nega Emiru and Heluf Gebrekidan (2013) who suggested that total nitrogen contents of soils demonstrated significant variation between land uses ($P \leq 0.01$), and soil layers ($P \leq 0.01$). This variation paralleled that of change in SOM. Total nitrogen stock followed a similar trend with that of SOC stock. The higher TN content (0.13%) was recorded under *E. globulus* plantation, while soil sampled from cultivated land resulted in relatively lower TN content (0.09%) compared to *E. globulus* plantation (Table 1). The relatively higher TN in the Eucalyptus plantation than the cultivated land could be due to litterfall of Eucalyptus which can contribute to TNS. It is in line with Mulugeta Tufa *et al.* (2019) who found that the average value of TN in the plantation was higher than cultivated land in the Kuyu district of Ethiopia. Even if cultivated land received nitrogen through fertilizer application, the applied nitrogen might be susceptible to lose due to intensive cropping, harvesting, volatilization, and leaching.

The result of the analysis of variance showed that the mean TN content was relatively higher (0.11%) on the lower slope position than on the upper slope position (0.09%) (Table 1). This was supported by the study of Sisay Assefa *et al.* (2016) who indicated that the mean value of TN was higher on the lower slope position than on the upper slope position. Similarly, TNS has followed the same trend with TN increment moving down the slope. Severe erosion in the study area might contribute to the movement of applied chemical fertilizer from the upper slope position to the lower one. Since the topography is undulated, erosion susceptibility leads to soil (contain nutrients) loss from the upper slope position. As studied by Efrem Haile (2008) slope influences 26.25% of erosion susceptibility in Basona Werena district. The TN content in both the Eucalyptus plantation and cultivated land is rated low (Hazelton and Murphy, 2007).

According to the result of ANOVA the higher mean value (3.33 Mg/ha) of TNS was recorded from Eucalyptus plantation at top soil than lower depth of soil under cultivated land (2.23 Mg/ha) (Table 2). Total nitrogen stock (TNS) decreased with increase in soil depth. This could be due to the presence of organic matter which might be associated with high soil nitrogen supply in the topsoil. Even if Eucalyptus cannot fix N through its root, leaf litter and debris from the plantation contribute organic matter, which might contribute as a source of N in the soil (Ravina, 2012).

Table 1: The main effect of land use, slope position, and depth on SOC, SOM, TN, SOCS, TNS, and C:N

	SOC (%)	SOM (%)	TN (%)	SOCS (Mg/ha)	TNS (Mg/ha)	C:N
			Land use			
Cultivated land	0.84[b]	1.43[b]	0.09[b]	21.0[b]	2.45[b]	9.05[a]
E. globulus	1.18[a]	2.12[a]	0.13[a]	28.5[a]	3.15[a]	9.25[a]
P-value	***	***	***	***	***	ns
			Slope Position			
Upper	0.90[b]	1.53[b]	0.09[b]	22.0[b]	2.37[b]	9.34[a]
Middle	0.96[b]	1.63[a]	0.11[b]	23.1[b]	2.70[b]	8.97[a]
Lower	1.17[a]	2.17 [a]	0.13[a]	29.1[a]	3.33[a]	9.13[a]
P-values	***	***	***	***	***	ns
			Depth (cm)			
0-20	1.06[a]	1.89[a]	0.12[a]	25.3[a]	3.00[a]	8.69[a]
20-40	0.96[b]	1.66[b]	0.10[b]	24.1[a]	2.60[b]	9.60[a]
P-value	*	*	***	ns	*	ns
CV (%)	12.6	18.3	14.6	13.2	18.2	15.9

The main effect means within columns followed by the different letter(s) are significantly different from each other at P ≤ 0.05; ns = not significant; * = significant at P ≤ 0.05; ** = significant at P ≤ 0.01; *** = significant at P ≤ 0.001; SOC = Soil organic carbon; SOM = Soil organic matter; TN = Total nitrogen; SOCS = Soil organic carbon stock; TNS = Total nitrogen stock; C:N = Carbon to nitrogen ratio; CV = Coefficient of variation

Table 2: Interaction effect of land uses and depth on TNS

Land use	**Depth (cm)**	TNS (Mg/ha)
E. globulus	0-20	3.33[a]
	20-40	2.96[ab]
Cultivated land	0-20	2.67[bc]
	20-40	2.23[c]
P-value		***
CV (%)		18.2

Interaction means within columns followed by the different letter(s) are significantly different from each other at P ≤ 0.05; *** = significant at P ≤ 0.001; TNS = Total nitrogen stock; CV=Coefficient of variation.

Table 3: Interaction effect of land uses and slope position on SOC, SOM, TN, SOCS, TNS, and C:N

Land use	**Slope position**	SOC (%)	SOM (%)	TN (%)	SOCS (Mg/ha)	TNS (Mg/ha)	C:N
E. globulus	Upper	1.03^{bc}	1.77^{b}	0.11^{bc}	25.41^{b}	2.64^{bc}	9.67^{a}
	Middle	1.08^{b}	1.84^{b}	0.13^{b}	25.12^{bc}	2.93^{b}	8.82^{a}
	Lower	1.43^{a}	2.75^{a}	0.16^{a}	34.87^{a}	3.89^{a}	9.25^{a}
Cultivated land	Upper	0.77^{d}	1.29^{c}	0.09^{c}	18.64^{d}	2.11^{c}	9.01^{a}
	Middle	0.84^{d}	1.42^{bc}	0.10^{c}	21.05^{cd}	2.47^{bc}	9.12^{a}
	Lower	0.91^{cd}	1.58^{bc}	0.11^{bc}	23.29^{bc}	2.77^{bc}	9.02^{a}
P-value		*	**	ns	*	ns	ns
CV (%)		12.6	18.3	14.6	13.2	18.2	15.9

Interaction effect means within columns followed by the different letter(s) are significantly different from each other at $P \leq 0.05$; ns = not significant; * = significant at $P \leq 0.05$; ** = significant at $P \leq 0.01$; *** = significant at $P \leq 0.001$; SOC = Soil organic carbon; SOM = Soil organic matter; TN = Total nitrogen; SOCS = Soil organic carbon stock; TNS = Total nitrogen stock; C:N = Carbon to nitrogen ratio; CV = Coefficient of variation

4.3. Effects of *Eucalyptus globulus* Plantation on Soil Texture, Bulk Density, pH and Cation Exchange Capacity

4.3.1. Soil texture

The statistical analysis of this study indicated that sand and clay particles were significantly ($P < 0.001$) affected only by the main effect of slope position (Table 4). The higher sand percentage (33.6%) was recorded from lower slope position than lower sand percentage (25.9%) from upper slope position pH (Table 4). In contrast, the result was in contradict with study by Sisay Assefa *et al.* (2016) who found that the highest mean value of sand fractions was recorded on the upper slope positions while the lowest value was recorded on the lower slope positions. This difference might be the result of topographic variation between different study areas. However, sand, silt, and clay did not show any significant variation between land use and soil depth as well as their interaction ($P > 0.05$). The textural class of the soil the under investigation was clay loam based on the soil textural triangle. Regarding the effects of slope position the highest (33.58%) and lowest (25.92%) sand particle of the soil was obtained at lower and upper slope position, respectively (Table 4). The high sand content in the lower slope position could be due to the continuous soil erosion from the upper slope position. Because the sand particle is more susceptible to erosion, it becomes washed away from the upper slope position and deposited to the lower slope position.

4.3.1. Soil bulk density

The soil bulk density value was significantly ($P \leq 0.01$) affected only by the main effect of land use (Table 4). The mean value of BD was lower (1.23 g/cm^3) under *E. globulus* plantation while it was higher (1.31g/cm^3) in cultivated land (Table 4). The relatively lower bulk density in the *E. globulus* plantation could be due to the presence of high OM input in the form of litterfall i.e. leaf and branches form in the Eucalyptus tree. Less animal trampling of the soil under Eucalyptus plantation may also contribute to the low soil bulk density under *E. globulus* plantation. Higher bulk density in cultivated land could be attributed to intensive cultivation which might be result in the loss of organic matter.

The significantly higher soil bulk density of this study was in agreement with Mulugeta Tufa *et al.* (2019) who found the highest bulk density under cultivated land compared to the adjacent forest land. The higher amount of Eucalyptus tree root biomass with considerable soil depth could decrease soil compaction (Ravina, 2012). Farmers also keep their animals on their farmland, especially during offseason. As a result, compaction may contribute to a low amount of organic matter by suffering soil biota on the cultivated land. Continuous cropping followed by residue harvesting may also contributed to a low amount of organic matter and increasing the bulk density of the soil on the cultivated land (Wondimagegn Amanuel *et al*., 2018). According to the rating of bulk density by Hazelton and Murphy (2007) bulk density under Eucalyptus plantation was rated as low (1.23 g/cm^3) and it was rated as moderate on cultivated land (1.30 g/cm^3).

4.3.3. Soil pH

The analysis of variance indicated that the pH of the soil was significantly ($P < 0.01$) affected only by the main effect of land use type and soil depth (Table 4). But, two way and three-way interactions did not show a significant variation on soil pH. Compared to cultivated land pH value (5.28), soil from *E. globulus* resulted in higher (5.58) pH (Table 4). This might be due to the removal of basic cations by leaching, soil erosion and loss of organic matter in the cultivated land. The relatively lower pH on cropland also may be attributed to the intensive application of acid-forming fertilizers such as urea. In addition to continuous cultivation with inorganic fertilizer application, removal of crop residue also contributed to the acidity of the soil in cultivated land. However, the pH of the soil under Eucalyptus plantation had an acidic character which might be due to allelochemical effects of its root. This finding was in agreement with the study by Nega Emiru and Heluf Gebrekidan (2013) who found that soil pH was found to be significantly affected by land use ($P \leq 0.01$) and soil depth ($P \leq 0.01$). Similarly, Zhang and Fu (2009) found that soil acidification caused by some phenolic compounds excreted by Eucalyptus roots.

The result of this study showed that the soil pH increases as soil depth increases. This may be due to the leaching of basic cation down the soil profile. In harmony with this result, another study showed that soil pH increased with depth increment (Datta *et al.*, 2015). Moreover, Habtamu Admasu (2015) also found that the highest pH was observed in the subsurface layer of grazing land and lowest on the surface layer of cultivated land.

The variation in pH within the depth of the soil also might be the result of the loss of base-forming cations down the soil profile, even beyond sampling depths, through leaching. This, in turn, enhances the activity of Al^{3+} and H^{+} in the soil solutions, which reduces soil pH and thereby increases soil acidity (Nega Emiru and Heluf Gebrekidan, 2013). According to Tekalign Tadese (1991) rating of pH, the soil under Eucalyptus plantation was moderately acidic while cultivated land was strongly acidic.

4.3.4. Cation exchange capacity of the soil

The analysis of variance results revealed that the CEC of the soils was not significantly ($P > 0.05$) affected by the land use types, slope position, and soil depth as well as their interaction. Soil CEC was almost similar in the *E. globulus* plantation (20.98 $cmol_{(+)}$/kg) and cultivated land (20.02 $cmol_{(+)}$/kg) (Table 4). Even though there was no statistical variation of soil CEC under different land uses, soil depth, and slope positions there was a mean value variation. Higher CEC average value (26.60 $cmol_{(+)}$/kg) was recorded under a lower slope position while the lower mean value of CEC (16.84 $cmol_{(+)}$/kg) was on the upper slope positions (Table 4). The increasing trends of CEC moving down the slope position may be related to the severity of soil erosion by water in the study area. Obviously, on sloping land, soil can be washed easily down from the upper slope position and deposited in the lower slope position.

Table 4: The main effect of land use, slope position, and depth on soil texture, bulk density, pH, and CEC

	Clay (%)	Silt (%)	Sand (%)	Textural class	BD (g/cm^3)	pH	CEC ($cmol_{(+)}/kg$)
Land Use							
Cultivated land	30.4^a	39.9^a	29.7^a	Clay loam	1.31^a	5.28^b	20.02^a
E. globulus	32.1^a	37.4^a	30.5^a	Clay loam	1.23^b	5.58^a	20.98^a
P-value	ns	ns	ns		**	***	ns
Slope Position							
Upper	34.7^a	39.4^a	25.9^c	Clay loam	1.24^a	5.44^a	16.84^a
Middle	35.3^a	36.9^a	30.8^b	Clay loam	1.25 ^{a}	5.43^a	18.06^a
Lower	26.8^b	39.4^a	33.6^a	Loam	1.28^a	5.44^a	26.60^a
P value	***	ns	***		ns	ns	ns
Depth (cm)							
0-20	32.4^a	38.3^a	29.3^a	Clay loam	1.25^a	5.31^b	18.15^a
20-40	30.1^a	39.1 ^{a}	30.9^a	Clay loam	1.26^a	5.55^a	22.85^a
P-value	ns	ns	ns		ns	**	ns
CV (%)	12.6	10.5	10.2		5.31	4.18	54.29

Main effect means within columns followed by the different letter(s) are significantly different from each other at P ≤ 0.05; ns = not significant; * = significant at P ≤ 0.05; ** = significant at P ≤ 0.01; *** = significant at P ≤ 0.001; BD = Bulk density; CEC = Cation exchange capacity; CV = Coefficient of variation.

4.4. Correlation of Soil Parameters

Soil organic carbon was highly significantly ($P \leq 0.001$) and strongly positively correlated (r=0.98 and r = 0.66) with SOM and TN, respectively (Table 5). It was also significantly ($P \leq 0.01$) and positively correlated (r = 0.38) with pH, respectively (Table 5).

Soil organic matter was also significantly ($P < 0.05$) and negatively correlated (r = -0.33) with bulk density (Table 5). The negative correlation between SOM and bulk density might be due to the soil which has free air movement and it contains more microorganisms, while the abundance of soil microorganisms decreases as the soil compaction increases. Microorganisms which are necessary for the decomposition of plant and animal residues need available O_2 to fulfill their function. As the bulk density of the soil increase, free space within the soil occupied by solid soil particles and exchange of O_2 and CO_2 becomes in question. Generally, the correlation indicates that the presence of relatively higher SOM content lowers soil bulk density.

From the correlation matrix, soil organic matter was highly significantly ($P \leq 0.001$) and positively correlated ($r = 0.66$) with TN (Table 5). The direct relationships between SOM and TN might be attributed to the source of nitrogen, which is SOM. Low input of plant residues in such cereal-based farming systems has contributed to the depletion of SOM thereby decreases soil N in cultivated lands. This was supported by a study conducted by Mulugeta Tufa *et al.* (2019) who revealed that SOM was significantly ($P < 0.001$) and positively correlated ($r = 0.95$) with the soil TN. Similarly, organic carbon was highly significantly ($P \leq 0.001$) and strongly positively correlated ($r = 0.86$) with total N (Habtamu Admasu, 2015). Moreover, another study in the Northern Highlands of Ethiopia revealed that SOC is significantly correlated with N (Fassil Kebede and Yamoah, 2009).

Total nitrogen was highly significantly ($P \leq 0.001$) and positively correlated ($r = 0.97$, $r = 0.72$ and $r = 0.51$) with TNS, SOC stock and sand particles, respectively (Table 5). The total N content in soils of the forest land could be associated with the SOM contents of the soils (Mulugeta Tufa *et al.,* 2019). TN was also significantly ($P \leq 0.01$) and positively correlated ($r = 0.43$) with CEC and significantly ($P < 0.05$) and positively correlated ($r = 0.32$) with pH (Table 5). While TN was highly significantly ($P < 0.001$) and negatively correlated ($r = -0.55$) with C:N (Table 5).

Sand was highly significantly ($P \leq 0.001$) and positively correlated ($r = 0.54$) with TNS. It was also significantly ($P < 0.01$) and positively correlated ($r = 0.40$ and $r = 0.50$) with pH and SOC stock (Table 5). But sand particles was significantly ($P \leq 0.01$) and negatively correlated ($r = -0.45$) with clay (Table 5). While silt was significantly ($P < 0.01$) and negatively correlated ($r = -0.46$ and $r = -0.45$) with TN and TNS, respectively (Table 5).

Soil pH was highly significantly ($P \leq 0.001$) and positively correlated ($r = 0.32$) with TNS. It was also significantly ($P < 0.01$) and positively correlated ($r = 0.44$) with SOC stock (Table 5). Moreover pH was also significantly ($P < 0.05$) and positively correlated ($r = 0.38$ and $r =$

0.21) with SOM and CEC, respectively (Table 5). The positive correlation between SOM and pH indicated that as the content of organic matter becomes high, it increases pH values and soil acidity decreases. This is because organic matter contains basic cation in different amounts. Since CEC is a major controlling agent of soil pH, they had positive relationships on the correlation matrix (Table 5). But pH was significantly ($P < 0.01$) and negatively correlated ($r = -0.53$) with silt particles (Table 5).

The CEC was highly significantly ($P < 0.001$) and positively correlated ($r = 0.51$) with TNS. It was significantly ($P < 0.01$) and negatively correlated ($r = -0.42$) with C:N (Table 5). And also C:N was significantly ($P < 0.05$) and negatively correlated ($r = -0.28$) with bulk density (Table 5). This result was similar to the finding of Mulugeta Tufa *et al.* (2019) who confirmed that the soil C:N was negatively correlated with the soil bulk density at $r = -0.28$.

Table 5: Pearson correlations for soil properties

	BD	CEC	Sand	Clay	Silt	pH	TN	SOC	SOM	C:N	SOCS	TNS
BD	1.00											
CEC	0.38*	1.00										
Sand	-0.18	-0.44**	1.00									
Clay	0.11	0.10	-0.45**	1.00								
Silt	-0.03	-0.26	-0.34*	-0.68***	1.00							
pH	0.07	0.21	0.40**	0.19	-0.53***	1.00						
TN	0.05	0.43**	0.51***	0.05	-0.46**	0.32*	1.00					
SOC	-0.23	0.07	0.42**	-0.16	-0.18	0.40**	0.67***	1.00				
SOM	-0.33*	0.10	0.41**	-0.16	-0.17	0.38*	0.66***	0.98***	1.00			
C:N	-0.28	-0.42**	-0.12	-0.30	0.41**	0.05	-0.55***	0.23	0.23	1.00		
SOCS	0.05	0.20	0.50**	-0.20	-0.20	0.44**	0.72***	0.96***	0.94***	0.14	1.00	
TNS	0.29	0.51***	0.54***	0.01	-0.45**	0.32*	0.97***	0.58***	0.57***	-0.59***	0.69***	1.00

*=Significant at P≤ 0.05; ** = Significant at P≤ 0.01; *** = Significant at P≤ 0.001; BD = Bulk density; CEC = Cation exchange capacity; TN = Total nitrogen; SOC = Soil organic carbon; SOM = Soil organic matter; C:N = Carbon to nitrogen ratio; SOCS = Soil organic carbon stock; TNS = Total nitrogen stock

4.5. Perception of Farmers on the Impacts of *Eucalyptus globulus* Plantation on Ecosystem Services

The descriptive statistics analysis showed that over 86.2% of the respondents live in a rural area and only few 13.8% are resident in Gudoberet town (Table 6). Majority of the respondents (about 74.5%) were males and the average age of the respondents was about 44.5±13.42 years (Table 6). Regarding the level of education, about 73.4% were literate and 43.6% of them can read and write (Table 6). The respondents had an average landholding size of 1.7 ha per individual and own an average of 0.55 ha of Eucalyptus plantation.

Table 6: Demographic characteristics of the respondents (n=94)

Variable	Descriptive Results		Proportion (%)
Locality	Rural area (81households)		86.2
	Gudoberet Town (13 households)		13.8
Total sample size (n)	94 households		
Sex	Male (70)		74.5
	Female (24)		25.5
Age	Mean = 44.5 years; SD = 13.42		
Level of education	Illiterate		26.6
	Reading and writing		43.6
	1-4 (Grade)		7.4
	5-8 (Grade)		9.6
	9-10 (Grade)		4.3
	>10 (Grade)		8.5
Occupation	Crop cultivation		52.2
	Mixed farming (Crop and livestock)		47.8
Landholding size (ha)	Mean = 1.7 ha; SD = 1.70		
Size of land occupied by *E. globulus* plantation (ha)	Mean = 0.55 ha; SD = 0.52		
Source of Fuelwood	Collection in the compound of the existing forest	Yes	100
		No	0
	Using cow dung	Yes	68.1
		No	31.9
	Using electrification	Yes	18.1
		No	81.9
	Purchasing from market	Yes	23.4
		No	76.6

However, majority of the respondents (about 47.8%) are engaged in mixed farming (crop cultivation and livestock rearing). All respondents (100%) collect their fuelwood from the collection in the compound of the private as well as state plantation forest. More than half of the respondents (68.1%) use cow dung as a source of fuel. Only 18.1% of the respondents use electricity as their source of fuel in addition to other sources of fuel. Similarly, about 23.4% of the respondents confirmed that they purchase fuelwood from the market (Table 6).

Nearly half of the respondents (48.9%) noted that they had a positive attitude regarding the conversion of cultivated land to Eucalyptus plantation (Table 7). In contrast, 51.1% of the households suggested that they had a negative perception of the conversion of cultivated land to Eucalyptus plantation (Table 7). Similar study also showed the negative effects of Eucalyptus plantation such as inhibition of indigenous species; competition for moisture and nutrients; phytotoxicity; and hostility to wildlife (Mesfin Abebe and Wubalem Tadesse, 2006). The negative attitudes of the local people towards Eucalyptus woodlot may be connected with its adverse effects on the various properties of the soil (e.g., chemical and biological) and a high potential for water and nutrient competition (Zerga Belay, 2015; Solomon Ayele and Solomon Mulu, 2017).

Relatively, the lower proportion (41.5%) of the respondents responded that they sell *E. globulus* leaves as a source of income in Gudoberet Kebele. The household survey showed that only 29.8% of the respondents traditionally burn the leaves of *E. globulus* to improve the fertility of the soil (Table 7).

Table 7: Perception of farmers towards the impacts of *E. globulus* plantation on ecosystem services

Perception Statement			**Proportion (%)**
Effect of the conversion of cultivated land to *E. globulus* plantation	Good		48.9
	Bad		51.1
Sell the leaves of *E. globulus*	Yes		41.5
	No		58.5
Traditionally burn the leaves of *E. globulus* to improve the fertility of the soil	Yes		29.8
	No		70.2
Major reasons to grow Eucalyptus trees	Source of fuelwood	Yes	100
		No	0
	Source of income	Yes	100
		No	0
	Construction materials	Yes	97
		No	3
	Farm implement	Yes	79.8
		No	20.2
Feeling on Eucalyptus trees	Good		92.6
	Bad		7.4
There is a problem related to growing *E. globulus* trees	Yes		57.5
	No		42.5
The major problems faced to the respondents due to the growing of *E. globulus*	Competition with cropland	Yes	74.5
		No	25.5
	Reduces spring flow	Yes	48.9
		No	51.1
	Reduces soil water availability	Yes	51.1
		No	48.9
	Reduces soil fertility	Yes	81.9
		No	18.1
	Resource use conflict arising from border effect	Yes	27.7
		No	72.3
	Shading impact on crops	Yes	56.4
		No	43.6
Households' Fears resulted from the expansion of Eucalyptus trees in the near future	Yes		72.3
	No		27.7

Table 7: Continued

Perception Statement			**Proportion (%)**
Reasons for developing fears resulting from the expansion of Eucalyptus trees in the near future	Competition with cropland	Yes	75.5
		No	24.5
	Reduction of soil fertility	Yes	66
		No	34
	Reduction of spring flow	Yes	48.9
		No	51.1
	Reduction of soil water availability	Yes	52.1
		No	47.9
	Long rotation period to generate economic income	Yes	33
		No	67

All of the respondents confirmed that they have got economic benefits and fuelwood through the practice of *E. globulus* tree. When the respondents were asked about the positive impacts of Eucalyptus, what first came into their mind, they responded that it was the economic benefit that they have got from Eucalyptus plantation, for example, livelihood improvement and diversification to meet household wood demand and generating cash income through the sale of Eucalyptus wood products, such as poles, construction materials, and fuelwood. This is the reason why most of the respondents noted that Eucalyptus had positive impacts from the economic point of view. Among the most prominent perceived benefits to the local people due to growing Eucalyptus in descending order includes source of income (100%), fuelwood (100%), construction material (96.8%), lowering micro-temperature (94.7%), serves as windbreak (83%), soil and water conservation (78.7%) and source of employment opportunity (67%) (Fig. 2). Only a few of the respondents (26%) gave information regarding the role of Eucalyptus as a source of medicine preparation as well as to treat influenza traditionally (Fig. 2). In Ethiopia, if soil degradation is to be slowed, the provision of woody biomass as an alternative to burning dung and crop residue is a critical issue requiring a short-term solution (Jagger and Pender, 2003)

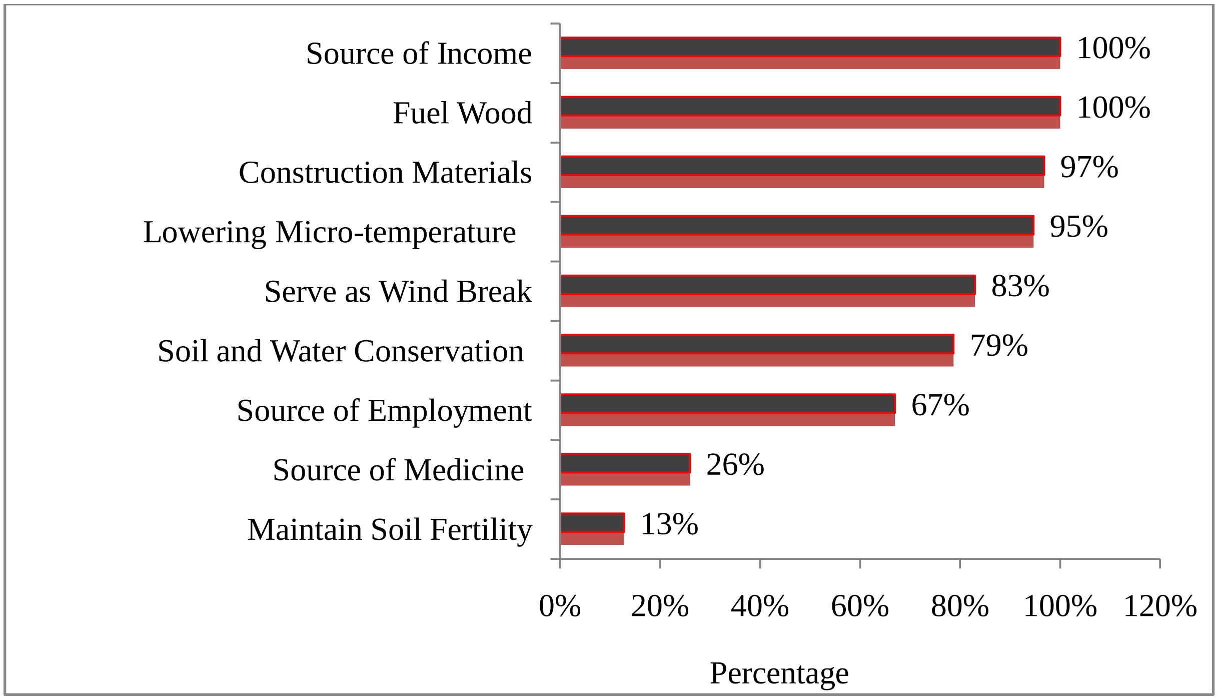

Figure 2. Purpose of Eucalyptus tree plantation

Local people are dependent on Eucalyptus tree plantation directly or indirectly. Additionally, the respondents indicated that Eucalyptus serves as a source of employment opportunity as a daily worker for cutting down tree and load to trucks during the selling of state-owned Eucalyptus stand. The social survey showed that over 52.1% of the respondents get their income from cultivated land. In contrast, only about 23.4% of the respondents confirmed that they have got their income highly from Eucalyptus plantation. Of the respondents, 24.5% responded that they have got their income almost equally from both cultivated land and Eucalyptus plantation (Fig. 3).

In line with this finding, another study also showed that the adoption of the growing practice of Eucalyptus by the local people might also be attributed to the value of Eucalyptus for poles, construction material, fuelwood and shelterbelt against wind erosion (Solomon Ayele and Solomon Mulu, 2017). Moreover, Zerga Belay (2015) also concluded that the role of the Eucalyptus tree in stabilizing peasant livelihoods' income diversification is immense, which overshadows all the drawbacks of the species through its financial return.

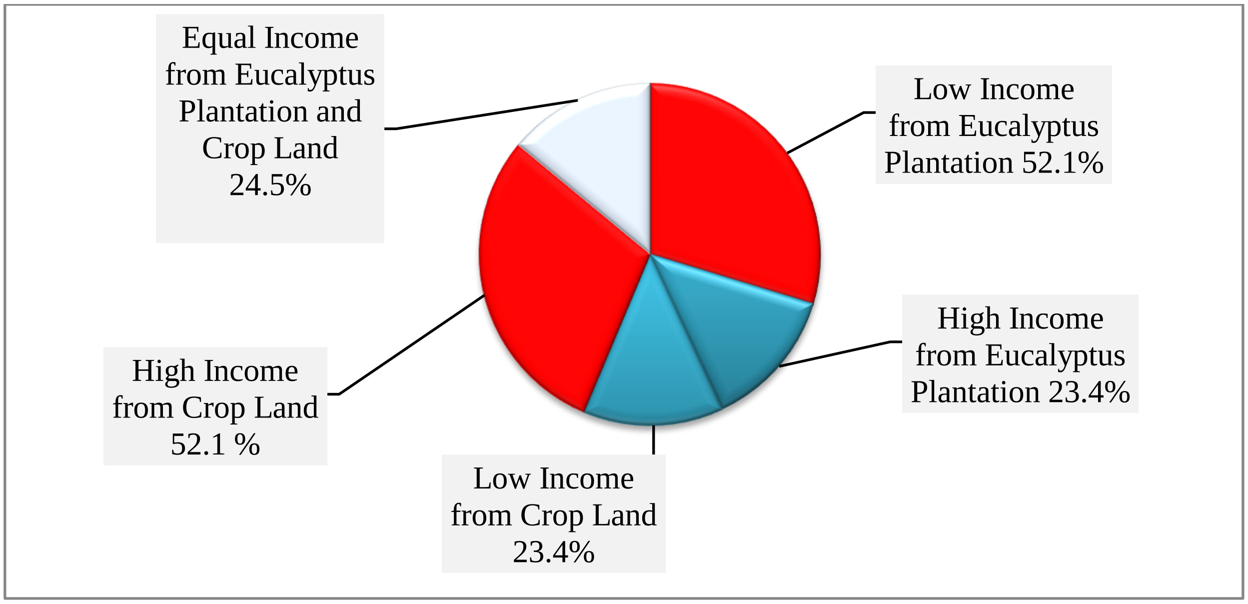

Figure 3. Comparison of income generated from Eucalyptus and cropland

4.5.1. Eucalyptus and soil fertility

A significant percentage (81.9%) of the respondent suggested that Eucalyptus plantation reduces soil fertility (Table 7). The perception of farmers in this study was supported scientifically by Selamyihun Kidanu *et al.* (2004) who studied in the Ginchi watershed in the central highlands of Ethiopia and they found that adjacent wheat yields were substantially reduced because of the combined effects of water, light and nutrient competition with Eucalyptus plantation. Since Eucalyptus is a fast growing tree species, it needs a considerable amount of nutrient and water (Haileab Zegeye, 2015). Therefore, it competes with the adjacent crop to meet its demand as far as its fast growth and development. As a result soil fertility surrounding the Eucalyptus plantation might be unable to give required crop production. With the extension of its deep root into the soil, Eucalyptus tree given its high degree of adaptability, it extracts nutrients outside the realm of crops feeding zone (Zenebe Mekonnen, 2016).

Fast-growing tree species such as *E. globulus* deplete soil nutrient reserves, particularly when grown in short rotations (Selamyihun Kidanu *et al.*, 2004). According to Solomon Ayele and

Solomon Mulu (2017), a study in the central highlands of Ethiopia showed that the decline in soil fertility was among the adverse ecological impacts of Eucalyptus plantation.

In contrast, few respondents (12.8%) confirmed that Eucalyptus can improve soil fertility by burning its leaf on adjacent cropland. This is due to the management aspects and as well as the art of the local farmers which makes soil fertility improvement by exotic species like Eucalyptus. This result is also in agreement with various findings who conclude that Eucalyptus can help to control soil erosion and improve soil fertility (Demel Teketay, 2000; Selamyihun Kidanu *et al.,* 2004; Haileab Zegeye, 2015). Moreover, respondents confirmed that they cut the horizontal root of Eucalyptus trees found nearest to their cropland. This is to reduce competition between cropland adjacent Eucalyptus trees.

Farmers also understand the purpose of Eucalyptus plantation in conserving soil and water on degraded land. But more than half of the respondents (51.1%) confirmed that, if the soil is fertile, it is better to produce crops rather than convert to Eucalyptus plantation. In addition to this, they prefer other tree species supplied by the government rather than Eucalyptus.

4.5.2. Crop yield in the surrounding area of *Eucalyptus globulus* plantation

Respondents noted that the negative effects of the conversion of cultivated land to *E. globulus* plantation resulted in different problems such as competition with cropland (74.5%), shade effect on crops (56.4%) and land use conflict arising from border effect (27.7%) (Table 7). Information from the household survey indicated that if there are different landowners and use their land differently (crop cultivation and Eucalyptus plantation); the result will initiate conflict with each other. Farmers who produce crop cannot cut the roots of adjacent Eucalyptus tree. Additionally, shading impacts also might be accelerated. Respondents explained that there should be some distance between Eucalyptus stand and cropland to reduce the negative impacts of the Eucalyptus tree on crop production. This result is in agreement with a similar study, local farmers responded that the negative impacts of Eucalyptus were attributed to the decline in crop and forage production due to its allelopathic effect and the reduction in groundwater availability (Solomon Ayele and Solomon Mulu, 2017).

Although evidence is scanty, there is a perception that the practice of growing Eucalyptus around farmland adversely affects crop productivity (Selamyihun Kidanu *et al.*, 2004). Their study also suggested that allelopathic is an interaction among plants by means of chemical compounds that exist in natural plant communities. Such allelochemicals can be present in soils, leaves, stems, roots, flowers, and seeds. They are released into the environment by several mechanisms, such as leaching from the above-ground parts, root exudation, volatilization, and residue decomposition. They can affect the germination and growth of crops through interference in cell division, energy metabolism, and nutrient uptake. Eucalyptus has toxic allelochemicals that consist of phenolic acids, tannins, and flavonoids (Mesfin Abebe and Wubalem Tadesse, 2006). The major implication of allelopathic effects in smallholder farming systems is the reduction in crop output when trees are planted adjacent to croplands (Jagger and Pender, 2003). Competition with crops and other vegetation for water and water table depletion are common arguments against planting Eucalyptus.

4.5.3. Eucalyptus-hydrology interaction

Respondents confirmed that the conversion of cultivated land to Eucalyptus plantation resulted in different problems such as reduced soil water availability (51.1%) and reduced spring flow (48.9%) (Table 7). To grow fast in a short period of time, the Eucalyptus tree utilizes more water even from the deepest soil depth through its deep root system. Depletion of water quantity and drying up of water springs adjacent to Eucalyptus plantation is quite common in the study area.

Despite a negative effect on soil water availability, Eucalyptus can play a vital role in managing the swampy area. Thus, for the management of water logging area, Eucalyptus may be the best option. In a study conducted by Zerga Belay (2015) in Gurage land, Ethiopia farmers reported that Eucalyptus trees dry up streams and swampy areas, particularly in dry seasons. Eucalyptus can survive and grow in a wide range of rainfall conditions. Despite Eucalyptus drying up springs, the growers insist on planting Eucalyptus because of its high cash income (Tilashwork Chanie *et al.*, 2013).

Eucalyptus is commonly grown in relatively low rainfall area (Dye, 2013). Another study also showed that reduction in groundwater availability was included under negative impacts of

Eucalyptus (Solomon Ayele and Solomon Mulu, 2017). Water consumption by Eucalyptus can be reduced by planting trees farther apart or by thinning existing plantation.

It seems probable that although the trees supplemented deep subsoil water with water from nearer the soil surface, most of the transpiration by Eucalyptus boundaries concerns water drawn from below the crops' rooting zone (Selamyihun Kidanu *et al.*, 2004).

4.5.4. Eucalyptus plantation and micro-climate

Majority of the respondents (94.7%) explained that Eucalyptus play a vital role in modifying the micro temperature in the study area (Fig. 2). Vegetation including all plants from evergreen forest including Eucalyptus tree to grasses; play a role in both water cycle and Earth's energy balance. Plants are inherently responsible for the regulation of micro-climate. Eucalyptus tree intercept precipitation by their leaves and some of this water, which infiltrates into the soil, is absorbed by its roots.

When water is available in excess, Eucalyptus can transpire large amounts of water as a byproduct of photosynthesis. This causes cooling of the surrounding environment. Like other green plants, Eucalyptus also releases water through their stomata and the surrounding area becomes cool. This tree species, i.e. Eucalyptus, use carbon dioxide during photosynthesis which is being released in the atmosphere. Even during dry season Eucalyptus can adapt water stress and stay as green (Zenebe Mekonnen *et al.,* 2007)

Ethiopia recognizes the importance of the forestry sector for its economic, social and ecological benefits which make a significant contribution to the country's long-term development goals and towards meeting international commitments. Forestry is among the four pillars of the climate resilient green economy strategy which aims to reduce national emissions by 50% in 2030. Forests ameliorate the local climate, lowering temperatures and increasing humidity (Bell, 2006).

4.5.5. Eucalyptus as windbreaks

Majority of the respondents (83%) confirmed that Eucalyptus serves as a windbreak in the study area especially in the hilly areas (Table 6). Windbreaks are used to reduce the wind's force or velocity to make life more livable for humans, plants, and animals in areas where wind speed is very high without protection. In fact, it is better to make windbreaker from the livable and growing plant rather than from dry wood. A windbreak is most effective if, rather than acting as a wall which causes turbulence downwind, it filters the wind (FAO, 1992).

Windbreak moderates the microclimate for up to twenty or more times its height to the leeward direction. In cold areas, it can help reduce the impact of the cold and can help to protect against freezes by cutting back on wind-chill (FAO, 2009). Furthermore, windbreaks reduce wind damage to crops so that potential yields are maintained. Similarly, Haileab Zegeye (2015) reported that Eucalyptus species can be planted as windbreaks or shelterbelts to reduce the force of the wind. Eucalyptus has an extensive lateral root system which makes it wind-firm so that it can fit as a windbreak (Shackleton and Shackleton, 2018).

4.6. Determinants of Respondents' Perceptions on the Impacts of *Eucalyptus Globulus* Plantation on Ecosystem Services

The multiple linear regression model revealed that several socioeconomic and cognitive variables significantly affected the perceptions of local people towards the effect of the conversion of cultivated land to *E. globulus* plantation. As revealed from their coefficients, those who were males (ß = 0.26), more educated (ß = 0.13), whose occupation was mixed farming (ß = 0.25) and have large land holding size (ß = 0.47) significantly had positive perceptions towards the effect of the conversion of cultivated land to *E. globulus* plantation (Table 8). It is common that people who have large land size may be more interested in planting and growing Eucalyptus tree so that their perception towards the conversion of cultivated land to *E. globulus* plantation might increase due to their enough landholdings. It is intuitively logical that people who have large land size may be more interested in plant and grow Eucalyptus woodlot so that their attitudes towards growing Eucalyptus woodlot might increase as far as they have enough landholdings (Solomon Ayele and Solomon Mulu, 2017). In contrast, those who have large size of land occupied by *E. globulus* plantation (ß = -0.23) significantly had negative perceptions towards the effect of the conversion of cultivated land to *E. globulus* plantation (Table 8). Majority of the respondents (72.3%) develop fears regarding the conversion of cultivated land to Eucalyptus plantation due to a shortage of cropland (75.5%) as well as the difficulty of conversion of Eucalyptus plantation to cultivated land within a short period of time (33%) (Table 7). The difficulty of conversion of Eucalyptus plantation to cultivated land is mainly due to the deep-rooted system of the Eucalyptus tree.

Table 8: Multiple linear regression model to predict the perceptions of local farmers towards the effect of the conversion of cultivated land to *E. globulus* plantation

Variable	***ß***	***T***	***P***
Intercept	0.46	1.38	-
Sex (Male = 2; Female = 1)	0.26	2.69**	0.009
Age	-0.01	-0.09	0.927
Educational Status	0.13	3.29**	0.003
Occupation	0.25	2.57**	0.012
Landholding size (ha)	0.47	3.45***	0.001
Size of land occupied by *E. globulus* plantation (ha)	-0.23	-2.74**	0.004

Adjusted R^2 = 0.16; df = 5; F = 3.94; Over all *P* = 0.002. * Represents significant at the 95% confidence level.

The possible reason for the negative correlation of the large size of land occupied by Eucalyptus plantation with the effect of the conversion of cultivated land to Eucalyptus plantation might be attributed to local farmers who have large size of land occupied by Eucalyptus plantation are worried about their cropland availability. In addition, when the local people know much about the difference in crop production near Eucalyptus plantation, their perception to notice the adverse impacts of Eucalyptus tree would likely increase (Solomon Ayele and Solomon Mulu, 2017). As a result, they may likely develop bad insights about the conversion of cultivated land to Eucalyptus plantation in the study site.

As revealed from their coefficients, those who were more educated (ß = 0.20) had significantly positive responses towards traditionally burning the leaves of *E. globulus* to improve the soil fertility (Table 9). Since the soil of the study area is acidic, adding ash might be as reclaiming of acidity of the soil. More educated farmers understand the content of wood ash and the purpose of adding this ash to their farm. Wood ash contains basic cations which increase pH values. In addition, to ameliorating acidity, burning of plant leaves and debris is organic practice and it may contribute essential nutrients to the soil. The addition of organic materials to the soil also improves soil physical properties such as water holding capacity, structure, infiltration, bulk density. It will lead to higher turnover rates of soil organic matter including higher microbial activity and soil respiration. As the structure of the soil improved it will form aggregation and the soil may not be easily eroded.

Table 9: Multiple linear regression model to predict the responses of the local farmers to traditionally burn the leaves of *E. globulus* to improve the soil fertility

Variable	***ß***	***T***	***P***
Intercept	2.02	6.97	-
Sex (Male = 2; Female = 1)	0.05	0.52	0.604
Age	-0.29	-3.14**	0.002
Educational Status	0.20	2.18*	0.032
Occupation	-0.21	-2.27*	0.026
Landholding size (ha)	-0.29	-2.24*	0.028
Size of land occupied by *E. globulus* plantation (ha)	-0.03	-0.26	0.795

Adjusted R^2 = 0.26; df = 5; F = 6.40; Over all *P* < 0.0001. *Repre9sents significant at the 95% confidence level.

This finding is in agreement with other study indicated that if the litter is left on the site uncollected, it would have been incorporated into the soil system to slow down runoff and improve infiltration and a substantial amount of nutrients may pass to the soil system, thereby improving soil fertility (Haileab Zegeye, 2015). In contrast, those who were older (ß = -0.29), practice mixed farming (ß = -0.21), had large land holding size (ß = -0.29), significantly had negative responses towards traditionally burn the leaves of *E. globulus* to improve the soil fertility (Table 9).

As revealed from their coefficients, those who were older (ß=0.13) and more educated respondents (ß = 0.19) significantly had a positive feeling about having *E. globulus* plantation (Table 10). This may be due to the long historical role of Eucalyptus plantation as a source of fuelwood in the study area. Typical biological attributes that attract farmers to Eucalyptus include fast growth, coppicing ability, ease of management (such as non-palatability to cattle), established market demand for its wood, its ability to grow well even on degraded landscapes and its better growth performance than most indigenous tree species on degraded lands (Dessie Assefa *et al.,* 2017). Study by Hachoofwe (2008) showed that smallholder farmers value tree products for household welfare, including generating income and accessing construction wood and other non-timber products, in addition to their obvious ecological and spiritual roles.

Table 10: Multiple linear regression model to predict the feeling of the local farmers on having *E. globulus* plantation

Variable	ß	T	P
Intercept	1.66	8.91	-
Sex (Male = 2; Female = 1)	0.01	0.09	0.931
Age	0.13	2.85**	0.003
Educational Status	0.19	3.78**	0.002
Occupation	0.05	0.50	0.617
Landholding size (ha)	0.04	0.34	0.733
Size of land occupied by *E. globulus* plantation (ha)	-0.01	-3.09**	0.002

Adjusted R^2 = 0.23; df = 5; F = 5.63; Over all *P* = 0.001. *Represents significant at the 95% confidence level.

In contrast, those who have large Eucalyptus plantation (ß = -0.01) significantly had a negative feeling of having *E. globulus* plantation (Table 10). This is due to the increase of understanding of the impacts of the Eucalyptus tree around their farm. When there is large land covered with Eucalyptus, undergrowth competition for water, nutrient and sunlight become visible for the owners. The negative effects of Eucalyptus tree plantation in ecology, particularly in competition, undergrowth suppression, soil nutrient, and water depletion, shadow and litterfall effect and presence of birds and wild animals are well understood by farmers (Zerga Belay, 2015). Farmers in the highlands of Ethiopia believe that Eucalyptus plantations around water sources significantly affect the flow rate of springs (FAO, 2009).

Depending on their coefficients, those who were more educated (ß=0.13) significantly had no fears resulted from the expansion *E. globulus* plantation in the area in the near future (Table 11). In contrast, those who have more land occupied by *E. globulus* plantation (ß = -0.10), significantly had a great fear resulted from the expansion of *E. globulus* plantation in the area in the near future (Table 11). The negative correlation of more educated respondents with fears resulted from expansion of *E. globulus* plantation might be attributed to their management strategies of Eucalyptus tree (thinning pollarding, spacing between crop and Eucalyptus) around their farm. During an interview with respondents, farmers who have relatively large land occupied by *E. globulus* plantation suggested that, if the expansion of Eucalyptus is continued, availability of land for crop cultivation will be under question.

Table 11: Multiple linear regression model to predict the households' fears resulted from the expansion *E. globulus* plantation in the area in the near future

Variable	***ß***	***T***	***P***
Intercept	1.92	6.21	-
Sex (Male = 2; Female = 1)	-0.01	-0.12	0.915
Age	-0.14	-1.37	0.176
Educational Status	0.13	3.25**	0.002
Occupation	0.11	1.07	0.290
Landholding size (ha)	-0.23	-1.60	0.114
Size of land occupied by *E. globulus* plantation (ha)	-0.10	-3.73***	0.001

Adjusted R^2 = 0.12; df = 5; F = 3.06; Over all *P* = 0.009. *Represents significant at the 95% confidence level.

Overall, the multiple linear regression model analysis revealed that socioeconomic and cognitive variables had significant effects on the dependent variables, i.e. perceptions of local farmers towards the effect of the conversion of cultivated land to *E. globulus* plantation (16% variance explained), responses of the local farmers to traditionally burn the leaves of *E. globulus* to improve the soil fertility (26% variance explained), feeling of the local farmers on having *E. globulus* plantation (23% variance explained) and households' fears of the local farmers resulted from the expansion *E. globulus* plantation in the area in the near future (12% variance explained) (Tables 8, 9, 10 and 11).

5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1. Summary and Conclusions

In the central highlands of Ethiopia, coverage of Eucalyptus plantation is increasing from time to time. Particularly a considerable cultivated land is being converted to *E. globulus* plantation. This study analyzed the effects *E. globulus* plantation on SOC stock by comparing adjacent cultivated land across three different slope positions (upper, middle and lower) and two soil depths (0-20 cm and 20-40 cm).

Statistical analysis of this study showed that soil bulk density and soil pH value was significantly ($P \leq 0.01$) affected by land use. Soil bulk density was significantly lower (1.23 g/cm^3) under *E. globulus* plantation. The soil pH in the cultivated land was strongly acidic (5.28). This implies that there is existence of soil acidity problems in both land use types of the study area. Intensive application of chemical fertilizer such as urea and Diammonium Phosphate (DAP) and removal of crop residue during harvesting by the farmers also contribute to the acidic characteristics of the soil. Sand and clay particle content were affected by land use type, instead, sand and clay were significantly ($P < 0.001$) affected by slope positions. Overall, both land use types have a clay loam soil texture.

The result of this study indicated that *E. globulus* plantation showed significantly ($P < 0.001$) higher SOC stock (28.5 Mg/ha) than the adjacent cultivated land (21.0 Mg/ha). The relatively higher SOC stock in the *E. globulus* plantation might maximize the value of Eucalyptus in the study area. This gives insight regarding the role of Eucalyptus species in sequestering terrestrial carbon. Despite the debates, this study showed that afforestation with Eucalyptus has the potential to restore SOC. Significantly ($P \leq 0.001$) higher TN content (0.13%) was also recorded under *E. globulus* plantation comparing to adjacent cultivated land (0.09%). However, the TN content in both the Eucalyptus plantation and cultivated land is rated low. Loses due to intensive cropping, harvesting, volatilization, leaching, of nitrogen might be the reason for the low rate of TN in the cultivated land.

In addition to soil analysis, there were different questionnaires to examine the perception of farmers' towards the effects of Eucalyptus plantation on ecosystem services. Respondents showed that conversion of the cultivated land to *E. globulus* plantation resulted in different problems such as competition with cropland (74.5%), shade effect on crops (56.4%), resource use conflict arising from border effect (27.7%), reduces soil water availability (51.1%) and reduces spring flow (48.9%). Majority of the respondents, 94.7% and 83% explained that Eucalyptus play a role in modifying micro temperature and serves as a windbreak, respectively.

The multiple linear regression model result of this study indicated that the perceptions of local farmers conversion of cultivated land to Eucalyptus plantation was positively correlated with land holding size, education status, and farming practices, but it was negatively correlated with owning large size of Eucalyptus plantation. However, the responses of the farmers to traditionally burn the leaves of *E. globulus* to improve the soil fertility positively correlated with educational status, it was negatively correlated with farming practice, landholding size.

Eucalyptus tree species offer a range of socioeconomic benefits (cash income, medicine, fuelwood, timber) as well as providing proximate and ultimate ecosystem services i.e., shades, live fences, control of runoff, protection of soil through reducing wind speed, improvement of soil fertility and maintain a healthy ecological state. Based on result of this study, it is possible to conclude that farmers who have large land size might be interested in growing more Eucalyptus tree by converting their cultivated land. As a result, in the study area, it has become part of the farming system. On the other hand, farmers who have large size of Eucalyptus stand are being worried about the shortage of cultivated land for growing food crops. Therefore, the expansion of Eucalyptus plantation in the study area needs compromising management option to benefit all local farmers by reducing the negative impacts of the species on crop suppressing, water consumption, shading effect.

Generally, Eucalyptus plantation is becoming a dominant cash crop in the region. In line with its role in regulating the environment, Eucalyptus plantation shows better SOC stock than cultivated land. This indicates that Eucalyptus plantations can rapidly accumulate large quantities of biomass carbon. The ecological impacts of tree planting on hillsides and degraded lands are also likely to be positive. There could be negative indirect effects on community woodlots if community members begin to devote less attention to manage those in favor of investing in private woodlots. The viable option to resolve ecological and agricultural related issues is the implementation of appropriate land management. With sound management, correct site-species mix, and genetic improvement, efficient utilization of Eucalyptus plantation can be sustained with little adverse impact on ecology and agriculture.

5.2. Recommendations

- The soil analysis result indicated that the area was moderate to strongly acidic soil (Appendix Table 9). Therefore there should be management option such as reclaiming with lime and use organic fertilizer by the local farmers.

- Even if the Eucalyptus plantation has higher SOC stock than cultivated land, the organic matter content of the soil was categorized under low classes (Appendix Table 9). In order to increase the SOM content, litterfall must not be collected. Researchers must find another alternative biomass fuels and energy-saving technologies.

- There should be focus on awareness creation to farmers to manage the spacing of Eucalyptus and crop better, site selection as well as management strategies to minimize the negative impacts of Eucalyptus trees.

- There should be a supply of improved indigenous tree species that use as timber, fuelwood, animal fodder and simultaneously conserve soil and water.

- Eucalyptus is the major source of fuel in the study area. In addition to Eucalyptus, 68.1% of the respondents use cow dung as a source of fuelwood. However, using animal dung as a source of fuel should be discouraged since it has a significant advantage to fertilize the soil.

- Furthermore, the future researcher should focus on the interaction of Eucalyptus plantation with soil microorganisms and related issues in order to manage Eucalyptus plantation in harmony with crop production as well as to maximize its ecosystem.

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7. APPENDIX

Appendix Table 1: Mean squares of three-way ANOVA for TN, SOC, SOM, C:N, SOCS and TNS

		TN		SOC		SOM		C: N		SOCS		TNS	
Factors	DF	MS	P-value	MS	P-value	MS	P-value	MS	P-value	MS	P-value	MS	P-value
Land use	1	0.003	0.000***	0.23	0.000***	1.41	0.000***	0.41	0.82ns	173.61	0.000***	2.81	0.000***
Slope Position	2	0.009	0.000***	1.04	0.000***	4.22	0.000***	0.35	0.68ns	502.6	0.000***	4.39	0.000***
Depth	1	0.003	0.001***	0.06	0.05*	0.47	0.04*	7.48	0.07ns	12.56	0.28ns	1.5	0.02*
LU*SP	2	0.001	0.09 ns	0.06	0.02*	0.53	0.01**	0.71	0.72 ns	43.3	0.03*	0.40	0.24 ns
LU*SD	1	0.001	0.07 ns	0.006	0.54ns	0.09	0.36 ns	0.74	0.56 ns	2.88	0.61 ns	0.01	0.83 ns
SP*SD	2	0.001	0.93 ns	0.004	0.76 ns	0.03	0.72 ns	1.73	0.45 ns	4.91	0.64 ns	0.03	0.90 ns
LU*SP*SD	2	0.001	0.76 ns	0.003	0.79 ns	0.28	0.78 ns	0.38	0.84 ns	0.58	0.95 ns	0.03	0.87 ns
Error	22	0.001	-	0.02	-	0.11	-	2.11	-	10.67	-	1.56	-

*= Significant at P≤ 0.05; **= Significant at P≤ 0.01; *** = Significant at P≤ 0.001; LU = and use; SP = Slope position; SD = Soil depth; TN = Total nitrogen; SOC = Soil organic carbon; SOM = Soil organic matter; C:N= Carbon to nitrogen ratio; SOCS = Soil organic carbon stock; TNS = Total nitrogen stock MS = Mean square; P = Probability.

Appendix Table 2: Mean squares of three-way ANOVA for BD, CEC, texture, and pH

	DF	BD		CEC		Sand		Clay		Silt		pH	
Factors		MS	P-value	MS	P-value	MS	P-value	MS	P-value	MS	P-value	MS	P-value
Land use	1	0.05	0.0046***	8.37	0.79 ns	5.44	0.45 ns	25	0.21 ns	53.77	0.08 ns	0.82	0.0006***
Slope Position	2	0.003	0.45 ns	33957	0.086 ns	181	0.000***	197.5	0.0002***	27.75	0.20 ns	0.001	0.99 ns
Depth	1	0.009	0.165 ns	198.9	0.21ns	21.77	0.14 ns	49	0.08 ns	5.44	0.57 ns	0.52	0.04*
LU*SP	2	0.008	0.17ns	32.78	0.77 ns	2.86	0.74 ns	3.08	0.82 ns	0.19	0.99 ns	0.071	0.27 ns
LU*SD	1	0.005	0.73 ns	64.32	0.48 ns	0.11	0.91 ns	11.11	0.40 ns	13.44	0.38 ns	0.07	0.24 ns
SP*SD	2	0.001	0.66 ns	3.08	0.98 ns	0.86	0.91ns	9.25	0.55 ns	15.53	0.40 ns	0.03	0.58 ns
LU*SP*SD	2	0.006	0.27 ns	186.3	0.24 ns	6.02	0.53 ns	22.03	0.26 ns	19.53	0.32 ns	0.03	0.61 ns
Error	22	0.005	-	123.88	-	9.48	-	15.5	-	16.4	-	0.05	-

*= Significant at P≤ 0.05; **= Significant at P≤ 0.01; *** = Significant at P≤ 0.001; LU = Land use; SP = Slop position; SD = Soil depth; BD = Bulk density; CEC = Cation exchange capacity; DF= Degree freedom; MS = Mean square; P = Probability.

Appendix Table 3: Interaction effect of slope position and depth on SOC, SOM, TN, SOCS, TNS, and C:N

Depth (cm)	**Slope position**	SOC (%)	SOM (%)	TN (%)	SOCS (Mg/ha)	TNS (Mg/ha)	C:N
0-20	Upper	0.93^{c}	1.61^{bc}	0.11^{bc}	22.19^{b}	2.62^{bc}	8.46^{a}
	Middle	1.00^{bc}	1.71^{bc}	0.12^{bc}	23.36^{b}	2.85^{b}	8.62^{a}
	Lower	1.24^{a}	2.35^{a}	0.14^{a}	30.14^{a}	3.55^{a}	8.99^{a}
20-40	Upper	0.89^{c}	1.46^{c}	0.09^{d}	21.86^{b}	2.13^{c}	10.22^{a}
	Middle	0.92^{c}	1.54^{c}	0.11	22.81^{b}	2.55^{bc}	9.31^{a}
	Lower	1.11^{ab}	1.99^{ab}	0.12^{b}	27.76^{a}	3.11^{ab}	9.28^{a}
P-value		ns	ns	ns	ns	ns	ns
CV (%)		12.6	18.3	14.6	13.2	18.2	15.9

Interaction means within columns followed by the different letter(s) are significantly different from each other at $P \leq 0.05$; ns = not significant; * = significant at $P \leq 0.05$; ** = significant at $P \leq 0.01$; *** = significant at $P \leq 0.001$; SOC = Soil organic carbon; SOM = Soil organic matter; TN = Total nitrogen; SOCS = Soil organic carbon stock; TNS = Total nitrogen stock; C:N = Carbon to nitrogen ratio; CV=Coefficient of variation.

Appendix Table 4: Interaction effect of land uses and depth on SOC, SOM, TN, SOCS, and C:N

Land use	**Depth (cm)**	SOC (%)	SOM (%)	TN (%)	SOCS (Mg/ha)	C:N
E. globulus	0-20	1.23^{a}	2.29^{a}	0.14^{a}	29.3^{a}	8.93^{a}
	20-40	1.13^{a}	1.96^{b}	0.12^{b}	27.6^{a}	9.56^{a}
Cultivated land	0-20	0.87^{b}	1.50^{c}	0.11^{b}	21.3^{b}	8.45^{a}
	20-40	0.81^{b}	1.37^{c}	0.09^{c}	20.7^{b}	9.65^{a}
P-value		ns	ns	ns	ns	ns
CV (%)		12.6	18.3	14.6	13.2	15.9

Interaction means within columns followed by the different letter(s) are significantly different from each other at $P \leq 0.05$; ns = not significant; * = significant at $P \leq 0.05$; ** = significant at $P \leq 0.01$; *** = significant at $P \leq 0.001$; SOC = Soil Organic Carbon; SOM = Soil Organic matter; TN = Total nitrogen; SOCS = Soil Organic Carbon Stock; C:N = carbon to nitrogen ratio; CV=Coefficient of variation.

Appendix Table 5: Interaction effect of land use, slope position, and depth on SOC, SOM, TN, SOCS, TNS, and C:N

Land use	**Depth (cm)**	**Slop position**	SOC (%)	SOM (%)	TN (%)	SOCS (Mg/ha)	TNS (Mg/ha)	C:N
E. globulus	0-20	Upper	1.05^{cd}	1.86^{cd}	0.12^{cd}	25.9^{b}	2.86^{bc}	9.04^{a}
		Middle	1.14^{bc}	1.96^{bc}	0.13^{bc}	25.5^{b}	3.00^{bc}	8.72^{a}
		Lower	1.52^{a}	3.04^{a}	0.17^{a}	36.7^{a}	4.14^{a}	9.04^{a}
	20-40	Upper	1.01^{cd}	1.68^{cd}	0.10^{de}	25.0^{bc}	2.41^{cd}	10.3^{a}
		Middle	1.03^{cd}	1.71^{cd}	0.12^{bcd}	24.8^{bcd}	2.85^{bc}	8.91^{a}
		Lower	1.34^{ab}	2.48^{b}	0.15^{ab}	33.0^{a}	3.63^{ab}	9.04^{a}
Cultivated land	0-20	Upper	0.81^{de}	1.36^{cd}	0.10^{cde}	18.5^{d}	2.37^{cd}	7.88^{a}
		Middle	0.86^{de}	1.49^{cd}	0.12^{cd}	21.3^{bcd}	2.69^{bcd}	8.53^{a}
		Lower	0.95^{cde}	1.66^{cd}	0.12^{bcd}	24.1^{bcd}	2.95^{bc}	8.94^{a}
	20-40	Upper	0.74^{e}	1.23^{d}	0.07^{e}	18.8^{cd}	1.85^{d}	10.1^{a}
		Middle	0.82^{de}	1.36^{cd}	0.08^{de}	20.8^{bcd}	2.25^{cd}	9.72^{a}
		Lower	0.88^{de}	1.51^{cd}	0.10^{e}	22.5^{bcd}	2.58^{cd}	9.10^{a}
P-value			ns	ns	ns	*	ns	ns
CV (%)			12.6	18.3	14.6	13.2	18.2	15.9

Interaction means within columns followed by the different letter(s) are significantly different from each other at $P \leq 0.05$; ns = not significant; * = significant at $P \leq 0.05$; ** = significant at $P \leq 0.01$; *** = significant at $P \leq 0.001$; SOC = Soil organic carbon; SOM = Soil organic matter; TN = Total nitrogen; SOCS = Soil organic carbon stock; TNS = Total nitrogen stock; C:N = carbon to nitrogen ratio; CV=Coefficient of variation.

Appendix Table 6: Interaction effect of soil depth and slope position on texture, BD, PH, and CEC

Depth (cm)	**Land use**	Clay (%)	Silt (%)	Sand (%)	BD (g/cm^3)	pH	CEC ($cmol_{(+)}$/Kg)
0-20	Upper	36.67[a]	38.00 [a]	25.33[d]	1.25 [a]	5.32[ab]	14.98 [a]
	Middle	33.50[ab]	36.33 [a]	30.17[bc]	1.23 [a]	5.26[b]	15.74 [a]
	Lower	27.00[c]	45.5 [a]	32.50[ab]	1.28 [a]	5.63[ab]	23.73 [a]
20-40	Upper	32.67[ab]	40.83 [a]	26.50[cd]	1.3 [a]	5.55[ab]	18.7 [a]
	Middle	31.00[bc]	37.5 [a]	31.50[ab]	1.27 [a]	5.60[a]	20.38 [a]
	Lower	26.50[c]	38.83 [a]	34.67[a]	1.29[a]	5.51[ab]	29.48 [a]
P-value		ns	ns	ns	ns	ns	ns
CV (%)		12.6	10.5	10.2	5.31	4.18	54.29

Interaction means within columns followed by the different letter(s) are significantly different from each other at P ≤ 0.05; ns = not significant; * = significant at P ≤ 0.05; ** = significant at P ≤ 0.01; *** = significant at P ≤ 0.001; BD= Bulk density; CEC = Cation exchange capacity; CV=Coefficient of variation.

Appendix Table 7: Interaction effect of land uses and slope position on texture, BD, PH, and CEC

Land use	**Slope position**	Clay (%)	Silt (%)	Sand (%)	BD (g/cm^3)	pH	CEC ($cmol_{(+)}$/Kg)
E. globulus	Upper	35.17[a]	38.33 [a]	26.50[b]	1.27[ab]	5.58[ab]	18.53[a]
	Middle	33.67[a]	35.67 [a]	30.66[a]	1.19[b]	5.51[ab]	16.66[a]
	Lower	27.33[b]	38.33 [a]	34.33[a]	1.24[ab]	5.67[a]	27.76[a]
Cultivated land	Upper	34.17[a]	45.50 [a]	25.33[b]	1.28[a]	5.29[bc]	15.15[a]
	Middle	30.83[ab]	38.17 [a]	31.00[a]	1.31[a]	5.35[bc]	19.46[a]
	Lower	26.17[b]	41.00[a]	32.83[a]	1.32[a]	5.20[c]	25.44[a]
P-value		ns	ns	ns	ns	ns	ns
CV (%)		12.6	10.5	10.2	5.31	4.18	54.29

Interaction means within columns followed by the different letter(s) are significantly different from each other at P ≤ 0.05; ns = not significant; * = significant at P ≤ 0.05; ** = significant at P ≤ 0.01; *** = significant at P ≤ 0.001; BD= Bulk density; CEC = Cation exchange capacity; CV=Coefficient of variation.

Appendix Table 8: Interaction effect of land use and depth on texture, BD, PH, and CEC

Land use	**Depth (cm)**	BD (g/cm^3)	Silt (%)	Sand (%)	Clay (%)	pH	CEC ($cmol_{(+)}/Kg$)
E. globulus	0-20	1.22^{b}	36.4^{a}	29.8^{a}	33.8^{a}	5.51^{a}	17.3^{a}
	20-40	1.25^{b}	38.4^{a}	31.2^{a}	30.3^{a}	5.67^{a}	24.7^{a}
Cultivated land	0-20	1.29^{ab}	40.1^{a}	28.9^{a}	31.0^{a}	5.11^{b}	19.0^{a}
	20-40	1.33^{a}	39.7^{a}	30.6^{a}	29.8^{a}	5.45^{a}	21.0^{a}
CV (%)		12.6	10.5	10.2	5.31	4.18	54.29
P-value		ns	ns	ns	ns	ns	ns

Interaction means within columns followed by the different letter(s) are significantly different from each other at $P \leq 0.05$; ns = not significant; * = significant at $P \leq 0.05$; ** = significant at $P \leq 0.01$; *** = significant at $P \leq 0.001$; BD= Bulk density; CEC = Cation exchange capacity; CV=Coefficient of variation.

Appendix Table 9: Interaction effect of land use, slope position, and depth on texture, BD, PH, and CEC

Land use	**Depth (cm)**	**Slope position**	Clay (%)	Silt (%)	Sand (%)	BD (g/cm^3)	pH	CEC ($cmol_{(+)}/kg$)
E. globulus	0-20	Upper	38.0^{a}	35.3^{a}	26.7^{cd}	1.28^{ab}	5.53^{abc}	12.9^{a}
		Middle	36.7^{ab}	34.0^{a}	29.3^{bcd}	1.15^{b}	5.41^{abc}	10.9^{a}
		Lower	26.7^{de}	40.0^{a}	33.3^{ab}	1.24^{ab}	5.58^{ab}	28.1^{a}
	20-40	Upper	32.3^{abcde}	41.3^{a}	26.3^{cd}	1.26^{ab}	5.63^{ab}	24.2^{a}
		Middle	30.7^{abcde}	37.3^{a}	32.0^{abc}	1.23^{b}	5.6^{ab}	22.4^{a}
		Lower	28.0^{cde}	36.7^{a}	35.3^{a}	1.25^{ab}	5.75^{a}	27.4^{a}
Cultivated land	0-20	Upper	35.3^{abc}	40.7^{a}	24.0^{d}	1.23^{ab}	5.11^{c}	17.1^{a}
		Middle	30.3^{bcde}	38.7^{a}	31.0^{abc}	1.3^{a}	5.10^{c}	20.6^{a}
		Lower	27.3^{de}	41.0^{a}	31.7^{abc}	1.33^{a}	5.14^{c}	19.4^{a}
	20-40	Upper	33.0^{abcd}	40.3^{a}	26.7^{cd}	1.34^{a}	5.47^{abc}	13.3^{a}
		Middle	31.3^{abcde}	37.7^{a}	31.0^{abc}	1.32^{a}	5.6^{ab}	18.3^{a}
		Lower	25.0^{e}	41.0^{a}	34.0^{ab}	1.32^{a}	5.27^{bc}	31.5^{a}
CV (%)			12.6	10.5	10.2	5.31	4.18	54.3
P-value			ns	ns	ns	ns	ns	ns

Interaction means within columns followed by the different letter(s) are significantly different from each other at $P \leq 0.05$; ns = not significant; * = significant at $P \leq 0.05$; ** = significant at $P \leq 0.01$; *** = significant at $P \leq 0.001$; BD= Bulk density; CEC = Cation exchange capacity; CV=Coefficient of variation.

Appendix Table 10: Rating of various soil parameters

Soil parameters	Very low	Low	Moderate	High	Very high	Sources
SOM (%)	0-0.4	0.4-1	1-1.8	1.8-3	> 3	Charman and Roper, (2007)
SOC (%)	< 0.5	0.5-1.5	1.5-3.0	> 3.0	-	Tekalign Tadesse, (1991)
TN (%)	0-0.1	0.1-0.2	0.2-0.5	0.5-1	> 1	Landon, (1991)
CEC ($cmol_{(+)}$/kg)	0-6	6-12	12-25	25-40	>40	Hazelton and Murphy, (2007)
Soil BD (g/cm^3)	< 1	1-1.3	1.3-1.6	1.6-1.9	> 1.9	

pH	Very strongly acidic	Strongly acidic	Moderately acidic	Slightly acidic	Neutral	Moderately alkaline	Strongly alkaline	Tekalign Tadesse, (1991)
	< 4.5	4.5-5.2	5.3-5.9	6.6-6.6	6.7-7.3	7.4-8.0	> 8.0	

Appendix Table 11: Spearman correlation between the independent variables included in the multiple linear regressions

Variable	Sex	Age	Educational Status	Occupation	Landholding size (ha)	Size of land occupied by *E. globulus* plantation (ha)
Sex	1.00					
Age	-0.09	1.00				
Educational Status	0.14	-0.26	1.00			
Occupation	-0.07	-0.04	0.08	1.00		
Landholding size (ha)	-0.23	0.22	-0.01	-0.17	1.00	
Size of land occupied by *E. globulus* plantation (ha)	-0.10	0.04	0.14	0.01	0.66	1.00

Survey Questionnaire for Households' Interview

The purpose of this interview is to collect information regarding the ecosystem services (soil fertility, fuelwood, water availability and microclimate regulation) of Eucalyptus plantation. To obtain necessary and accurate information, your honest co-operation is highly appreciated in answering the question. The responses that you are giving will be used only for academic purpose.

District…………………………...........

Respondent code………………….

Date: _______________

Kebele: ______________________

Village (Mender): _____________

Name of Interviewer: ______________________

I. Personal Information

1. Sex: ☐ Male ☐ Female
2. Age: `__________
3. Educational status of the household head:

☐ Illiterate ☐ Read and Write ☐ Grade 1-4 ☐ 5-8 ☐ 9-10 ☐ > 10

4. Occupation ☐ Crop cultivation ☐Livestock rearing ☐ Mixed farming

☐ Other (specify) _______________

5. Land holding size _________ (ha)

II. History of Settlement and Land Ownership

1. Do you own any tree plantation? ☐ Yes ☐ No
2. If "*Yes*", list species of the tree species and area covered (ha)

Species name	Area (ha)
_________________________________	____________
_________________________________	____________
_________________________________	____________

3. Do you think conversion cultivate land into Eucalyptus plantation is good?

   ☐ Yes   ☐ No

3.1. If yes, what makes it good? ____________________

4. Do you sell Eucalyptus leaves for source of fuelwood? Yes No

5. Do you think that burning Eucalyptus leaves will have positive effect on the fertility of the soil? Yes ☐ NO ☐

6. What is your main source of fuelwood?

☐ Collection of fuelwood from the compound of the forest

☐ Collection of fuelwood from the existing natural forest

☐ Using cow dung

☐ Using crop residue as a source of fuelwood

☐ Using electrification

☐ Purchasing additional fuelwood from the market

☐ Other (Please specify): ____________________

III. Knowledge, Perception and Attitudes of Respondents About the Effects of *Eucalyptus globulus* Plantation on Ecosystem Services

1. Are you happy with owning Eucalyptus? ☐ Yes ☐ No

1.1. If you say "Yes" for question number, why?

____

____

____

____.

1.1. If you say "No" for question number, why?

____

____

____

1. For what purpose do you use the Eucalyptus tree?

Perceived benefits to the local people due to *E. globulus* plantation in the area	**Yes**	**No**	**Unsure**
Employment opportunities			
Soil and water conservation			
Fuelwood			
Soil fertility			
Construction materials			
Source of medicinal plants			
Other (specify):____.			

1. Is there any challenge related with *E. globulus* plantation?

   ☐Yes, ☐ No

2. If "yes", list the major challenges____________

3. Identify the effect of *E. globulus* on ecosystems?

Components	There is a problem	List the effects
Crop Production	Yes	
	No	
Soil Fertility	Yes	
	No	
Soil Water	Yes	
	No	
Temperature	Yes	
	No	
Soil Erosion	Yes	
	No	
Other	Yes	
	No	

4. Did you ever convert Eucalyptus plantation into cultivated land? ☐ Yes ☐ No
5. What do you think the productivity of the Eucalyptus plantation land to cultivated land for agricultural crop production?

____

6. Which land use type increases your income more?

☐ Cultivated land ☐ Eucalyptus plantation ☐ Other (Specify_______)

7. Households' fear of the expansion of Eucalyptus to farmlands in the near future:

☐ Yes ☐ No

8. If "yes", list the reason to develop fear on the expansion of Eucalyptus plantation?

____

____

Thank you in advance for your time and co-operation!