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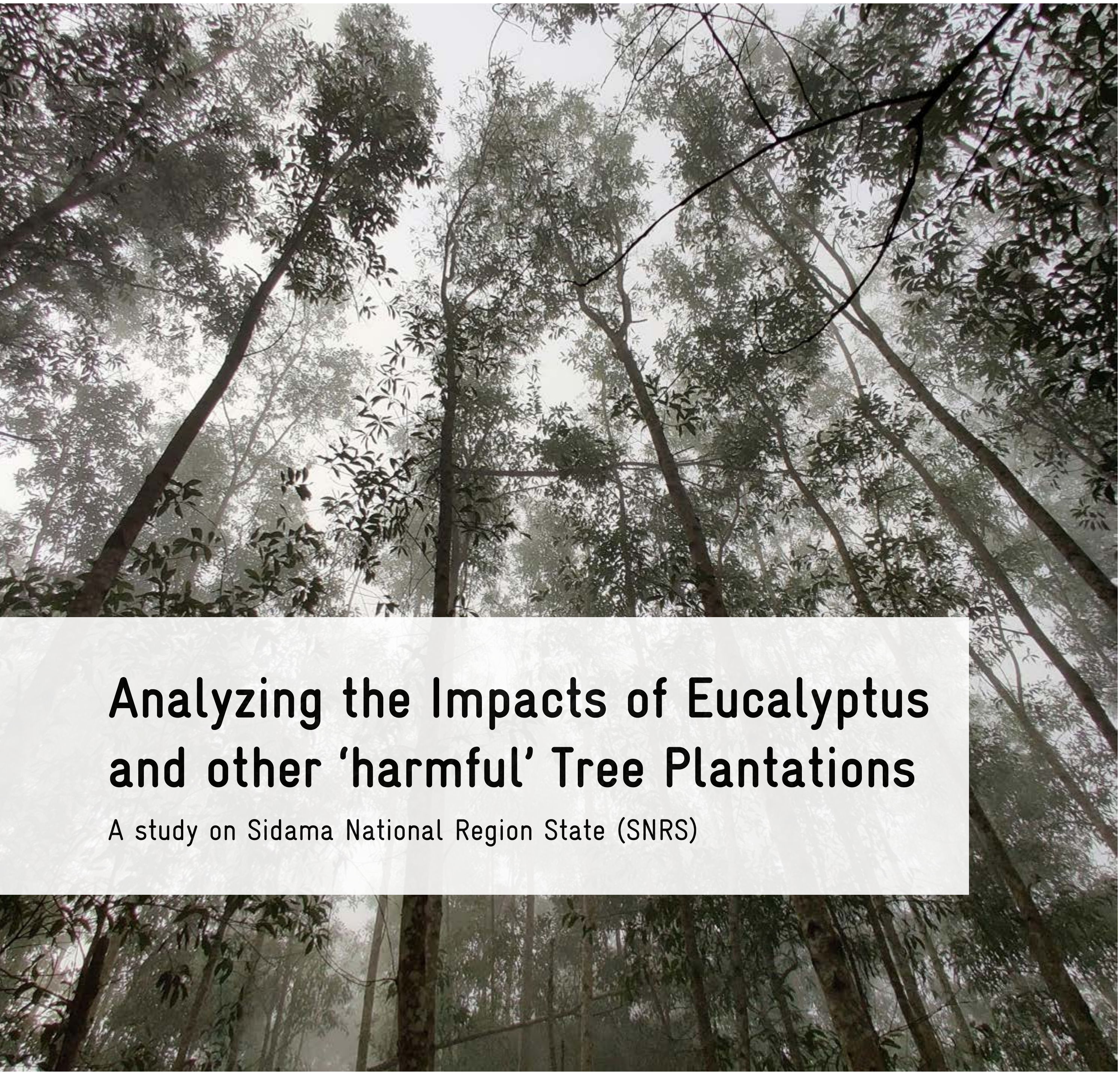

# Analyzing the Impacts of Eucalyptus and other 'harmful' Tree Plantations

A study on Sidama National Region State (SNRS)

Knowledge Series No. 7

**Land Governance II Project**
From fragmentation to future: empowering communities, transforming agriculture & improving governance

# Acknowledgements

This work would have been impossible to prepare without the help of a number of staff from GIZ, Land Governance (LaGo) project, to whom I am very much grateful. I would particularly like to extend my heartfelt thanks and appreciation to Dr. Daniel Behailu for facilitating and creating a link with different stakeholders and following up on the activities. I am also grateful to Dr. Samuel Bekele, Dean of Wondo Genet College of Forestry and Natural Resources, for the generous contribution of a vehicle for fieldwork.

This work would have been impossible without the help of a number of people to whom I am very much grateful. First, I would particularly like to extend my heartfelt thanks and appreciation to Mr. Habtamu Hoyeso for his assistance in facilitating and creating a link with the coordinators at four districts. I recognize the contribution of district-level coordinators Mr. Desalegn Markos, Mr. Mesfin Keya, Mr. Degefu Bakomel, and Mr. Melaku Daniel for coordinating and linking with development agents. I also acknowledge development agents Mr. Dabaro Dansamo, Mr. Ashim Kasim, Mr. Tugasso Felika, and Mr. Zinaye Melku for selecting kebeles, identification of respondents, and data collection at respective kebeles.

Further contributions came from respondent households, key informants, Focus Group Discussion, and experts. I take this opportunity to thank them all for taking time and giving valuable information. I would like to express my appreciation to Desalegn Usira for serving as a driver and for interpreting Sidamu Afo during Key informant interviews and Focus Group Discussions. I also wish to express my appreciation to my daughter Solome and my son Nardos for data processing.

Zebene Asfaw, Author

## Impressum

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**In partnership with and with special thanks to**
FDRE Ministry of Agriculture (MoA)
Land Administration and Use Lead Executive Office
Mr. Tigistu Gebremeske, Lead Executive Officer

**Published by**
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Land Governance II Project, Addis Ababa, Ethiopia

**As of**
January 2024

**Suggested citation**
Asfaw, Z (2024). Analyzing the Impacts of Eucalyptus and other 'harmful' Tree Plantations. A study on Sidama National Region State (SNRS). (Knowledge Series 7). GIZ Ethiopia.

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# Acronyms

| | |
|---|---|
| AFP | Agroforestry practice |
| ANOVA | Analysis of variance |
| CEC | Cation exchange capacity |
| FAO | Food and Agricultural Organization |
| FGD | Focus group discussion |
| MoA | Ministry of Agriculture |
| MSc | Master of Science |
| NGO | Non-Governmental Organization |
| PhD | Doctor of Philosophy |
| SNRS | Sidama National Regional State |
| SPSS | Statistical Package for the Social Sciences |

# Abbreviations

| | |
|---|---|
| Ca | Calcium |
| E | Evenness |
| EC | Eucalyptus camaldulensis |
| H' | Shannon-Wiener diversity index |
| K | Potassium |
| m.a.s.l | Meter above sea level |
| meq per 100g | Mill equivalents per 100 grams of soil |
| Mg | Magnesium |
| N | Nitrogen |
| Na | Sodium |
| OC | Organic carbon |
| OM | Organic matter |
| P | Phosphorus |
| pH | a logarithmic scale that measures how acidic or basic a substance is |

# Executive Summary

The objective of this project is to assess and evaluate the impacts of eucalyptus tree plantation and other tree species on agricultural production, water resources, soil nutrients, natural forests, springs, water reservoirs, and wetland areas, as well as biodiversity in terms of food production and livelihood sustainability for participants. The analysis of eucalyptus impacts, along with other ‚harmful' tree species, was conducted to provide tangible recommendations on where, why, and how to grow and manage this species with respect to biophysical and socioeconomic aspects. The findings are intended to serve as input for the land administration and use regulation of SNRS.

To achieve this objective, both primary and secondary qualitative data were gathered, utilizing interviews with key informants (20 participants) and FGDs (28 participants). Quantitative data were collected via questionnaires from 240 household respondents and 12 experts. Analyses of both the quantitative and qualitative data yielded the following results.

From the field study, a significant proportion of respondents (N=240; 76.3%) strongly agreed that eucalyptus planting reduces water yield, despite controversy in the literature. Key informants (N=20) expressed serious concerns that some farmers plant both blue gum and red gum as close as 2 m to springs and streams, leading to a reduction in water quantity. All key informants, FGD participants, experts, and approximately 85% of household respondents strongly agreed that eucalyptus reduces biodiversity. The replacement of natural forest by monoculture eucalyptus eliminates all its ecosystem services, including biodiversity. Literature shows that eucalyptus expansion reduces pressure on natural forests.

About 79% of the respondents perceived that eucalyptus has an adverse effect on soil fertility. All experts, FGD participants, and key informants shared this opinion, indicating that eucalyptus dries the soils. On the other hand, a large proportion of household respondents (84%) perceive that eucalyptus planting has a positive contribution to soil erosion control.

A very large proportion of household respondents (93.3%) perceived that eucalyptus expansion leads to a reduction in crop productivity and a decline in food production. Key informants and FGD participants noted that this effect is particularly severe on Enset crop production. According to participants, of all land uses converted to eucalyptus plantation, grazing land is the top-ranking. As a result, about 80.4% of respondents perceived that eucalyptus planting reduced livestock products. All key informants, FGD participants, and experts discussed similar experiences. This result indicates that the top-ranking motivating factor for converting different land uses to eucalyptus is because of the negative influence of adjacent farm woodlots.

The majority of respondents (40%) use 0.5m x 0.5m spacing, while 27% use 0.25m x 0.25m spacing, and 16% use 2m x 0.75m spacing. Technically, this is unacceptable due to extremely high stem density, which can lead to significant ecological consequences. At every harvest, almost all respondents (N=240; 99%) practice complete removal of stems, bark, leaves, branches/twigs of eucalyptus woodlots, and boundary plantations. Both key informants and FGD participants shared similar experiences regarding complete removal. Such complete

removal of all tree biomass at a very 4-7-year coppice rotation harvest can have adverse effects on soils. This indicates that nutrient removal in harvested biomass could deplete soil nutrient stocks and limit future productivity if not offset by fertilizer application, raising concerns for the long-term sustainability of the plantations.

Based on existing experience and literature empirical evidence, recommendations are presented to reduce the above-mentioned adverse effects of eucalyptus and to strengthen the regulatory power of the land administration institutions. Eucalyptus should not be planted at less than: (a) 30 m distance from stream or water sources edge, (b) 15 m distance from the edge of an Enset field, (c) 8 m distance from the edge of a grazing field, (d) 10 m distance from the edge of a cereal crop field, (e) 10 m distance from the edge of neighboring compacted woodlots. Special silvicultural management considerations requiring intervention include: planting eucalyptus at least at 1.5 m x 1.5 m; limiting the number of stems per stump to not more than three; limiting the number of coppice rotations not to exceed 6 times; limiting only to stem removal at each harvesting time; ecologically planting eucalyptus at sites receiving more than 400 mm of rain.

Cupressus lusitanica, Khaya edulis, Gravellia robusta, Avocado, and Mango are mentioned as harmful plants. However, there was great controversy on the adverse effect of those species. If proper management is applied, their adverse effect can be reduced. The FGD participants completely disagree with the idea that Avocado and Mango are harmful.

# 1. Introduction / Background

## 1.1 Background

Eucalyptus plantation expansion is attributed to its adverse effects on water quantity and quality, natural forests, biodiversity, soil fertility, forage, and crop productivity. Numerous studies conducted in Ethiopia have demonstrated a reduction in crop growth and yield when agricultural crops are grown in close proximity to eucalyptus trees. Eucalypts are reported to cause crop loss by outcompeting crops for water and soil nutrients and producing allelochemicals. In the Sidama National Regional State (SNRS), various eucalyptus species are planted in diverse locations, including front yards, homesteads, farm boundaries, woodlots, roadsides, communal lands in rural areas, urban and peri-urban areas, compounds of institutions and schools, and around churches. Despite the acknowledged benefits of eucalyptus for sustaining the livelihoods of local communities, different organizations and farming communities claim adverse effects on biophysical resources.

In response to these concerns, Sidama region enacted a land administration and use proclamation (27/2023), with articles 27(1) and 33(15) prohibiting the planting of eucalyptus and other harmful tree species in specific areas due to their water and soil nutrient competing nature and the production of allelochemicals.

However, there is a lack of comprehensive studies guiding decision-makers on where, why, and how to grow and manage eucalyptus, along with its social, ecological, and biophysical implications. Additionally, most studies focusing on the economic benefits of eucalyptus plantations may overlook the rural community's livelihood sustainability and the economic implications for the majority.

The Land Governance project supports the Ministry of Agriculture (MoA) and regional Land Administration institutions in strengthening the regulatory power of land administration institutions. The SNRS recently endorsed the land administration and use proclamation no. 27/2023 and is working on developing a regulation for its implementation, requiring studies to interpret and implement the proclamation meaningfully.

On September 7, 2023, an agreement was signed between the expert (Zebene Asfaw) and Giz to work on a project entitled „Analyzing the Impacts of Eucalyptus and other ‚Harmful' Tree Plantations in the Sidama National Region State (SNRS)." This inception report provides a description of activities accomplished during this phase, including a literature review, annotated outline and roadmap, methodologies, and a detailed work plan.

## 1.2 Objectives of the Study

The objective of this project is to assess and evaluate the impacts of eucalyptus tree plantation and other tree species affecting agricultural production, water resources, soil nutrients, natural forests, springs, water reservoirs, wetland areas, and biodiversity in terms of food production and livelihood sustainability. The findings will serve as input for the land administration and use regulation of SNRS.

# 2. Tools and Methods

## 2.1. The Study Sites

For this survey, study data were collected from communities residing in four districts, purposely chosen due to the extensive presence of eucalyptus. *Eucalyptus globulus* dominates the highlands, while *Eucalyptus camaldulensis* is extensively distributed in the midland and lowland areas of the SNRS. The selected districts include Melga district from the highland (Dega) agroecology (elevation: 2300 to 3100 m.a.s.l), Dale and Shebedino districts from the midland (Weyna Dega) agroecology (elevation: 1500 to 2300 m.a.s.l), and Derara district from the lowland (Kola) agroecology (elevation: 1300 to 1500 m.a.s.l). Similarly, specific kebeles were purposely selected: Abe Jiru kebele from Melga district, Chunie kebele from Dale district, Dilla Aferra kebele from Shebedino district, and Adame Derara kebele from Derara district.

## 2.2. Data Sources

### 2.2.1. Review of Previous Work

A literature review aimed to enhance understanding of eucalyptus impacts, focusing mainly on biophysical and briefly on socioeconomic factors. Information gathered identified paramount points for regulation and guideline development and informed planning for sustainable eucalyptus development in Sidama National Regional State (SNRS). The literature covered eucalyptus effects on biodiversity conservation, water sources, springs, water reservoirs, wetland areas, natural forests, soil and biodiversity, crop production, grazing lands, food production, and livelihood sustainability. Additionally, on-site species matching, planting niche within farms, stocking, coppice management, harvesting, and nutrient depletion were reviewed. The purpose was to:

- Review existing literature, draw lessons, and identify information gaps.
- Assess major eucalyptus management approaches and their effects on biodiversity, water sources, soil fertility, agricultural productivity, and natural forests.
- Analyze the potential of eucalyptus plantation for sustaining rural community livelihoods and urban construction and industries.
- Evaluate conventional and current silvicultural management practices of eucalyptus plantation in different agroecologies and their impacts on natural resource basis and productivity.
- Design appropriate species-site-matching within a given agroecology (planting distance from water sources, crop fields, boundary, and road sides, etc.).
- Analyze farmers' perceptions of the positive and negative impacts of eucalyptus in different areas.

- Propose potential laws, regulations, directives, and guidelines for sustainable eucalyptus management in the Sidama Regional State.

For this review, about 67 papers were consulted, including 70% published articles in journals, 12 PhD dissertations, 10% MSc theses, and 8% different reports (Annex 2.1).

### 2.2.3. Consulting Farming Community

Eucalyptus tree planting has expanded across agricultural landscapes in the Sidama Regional State without extension input, indicating that farmers possess rich knowledge and skills contributing to further understanding of eucalyptus impacts, management, challenges, and opportunities in the region. The survey aimed to:

- Assess farmers‘ local knowledge and skills available to manage eucalyptus for livelihood improvement.
- Evaluate the local community‘s perception of both positive and negative ecological and socioeconomic impacts.
- Assess the major purposes of eucalyptus planting and align them with future development strategies.
- Develop in-depth understanding through interviews with farmers managing trees at or near water points, along stream sides, having shared eucalyptus boundaries, managing trees as boundaries for Enset and coffee, and managing trees as boundaries for maize crops and barley.
- Assess the types of other harmful plants and their effects on the environment and socioeconomic conditions.
- Propose potential laws, regulations, directives, and guidelines for sustainable eucalyptus management in the Sidama Regional State.

### 2.2.3. Consulting Experts

Local experts, including foresters, agronomists, and livestock specialists at different levels, were consulted to understand the extent of eucalyptus expansion, contributing factors, its ecological and socioeconomic impacts, farmers‘ perception and attitude, challenges, and opportunities at the district and regional levels. This study was designed to:

- Assess the perception of experts on the adverse impacts and benefits of eucalyptus to the community in the Sidama Regional State.
- Evaluate the support provided by different government organizations and NGOs, including challenges and opportunities.
- Assess the technical knowledge available to properly manage eucalyptus to reduce adverse impacts.
- Assess the types of other harmful plants and their effects on the environment and socioeconomic conditions.
- Propose potential laws, regulations, directives, and guidelines for sustainable eucalyptus management in the Sidama Regional State.

## 2.3. Data Collection Methods

Both qualitative and quantitative methods were employed. For the qualitative aspect, key informant interviews (20 participants, 5 at each Kebele) and Focus Group Discussions (28 participants) were conducted. For the quantitative survey, 12 experts and 240 households (all farmers) from three agroecologies in four districts were interviewed, with 60 households selected for in-depth interviews.

## 2.4. Methods of Data Analysis

The data collected for evaluation, both quantitative and qualitative, were analyzed using appropriate statistical techniques. Qualitative data obtained through interviews, key informants, FGDs, and document reviews were coded and categorized into pertinent themes. The analysis involved examining expressions of respondents and determining emerging similarities and differences among participants' responses for each category. The results were then presented using descriptions that reflected a mix of different responses. Quantitative data collected through questionnaires from household respondents and experts were entered into SPSS software version 25 for analysis. The analysis included descriptive and inferential statistics, such as frequencies, percentages, means, and standard deviations.

# 3. Results and Discussion

Experience in resource management shows that the positive and negative impact is associated with the way human beings apply different management practices. In addition to the guidelines given on impact study, I found some motivating factors and management practices that have aggravated the adverse effects of eucalyptus in the Sidama National Regional State. Therefore, the report combines the field results and experiences from detailed review work. The following are presented as a foundation for developing sound recommendations.

## 3.1. Eucalyptus Impact on Biophysical Factors

### 3.1.1. On Water Sources

In this context, the water sources include springs, water reservoirs, and wetland areas. From field study, a large proportion of the respondents (N=240; 76.3%) very strongly agreed that eucalyptus planting reduces water yield. Key informants (N- 20) noted a serious concern that some farmers plant both blue gum and red gum as close as 2 m to springs and streams, which reduced water quantity. Focus Group Discussion (FGD) participants and experts also reported similar concerns. All participants were asked to suggest an appropriate distance that reduces the effect on water resources, and their responses are shown in Table 1.

The respondents agree with some of the previous findings. On the other hand, most findings revealed that the effect is not as significant. The distances suggested by the participants are close to the experience from other places. For example, in Kenya, eucalyptus planting is not allowed by law within 30 m distances along rivers (Kenya Forest Service, 2009), and 30 m–45 m is reported for any plantation establishment (Brandywine Conservancy, 2023).

*Table 1: Number of respondents and suggested planting distances from the edge of water sources*

| Participants | No. (N) | Suggested distance | Sources |
|---|---|---|---|
| Household | 240 | 10 m to 16 m | Annex 5.1.1; table 9.15 |
| Key informants | 20 | 16 m to 26 m | Annex 5.1.2; fig. 1 |
| Forces group discussion | 28 | 17 m – 20 m | Annex 5.1.3 |
| Experts | 12 | 5m to 16m | Annex 5.1.4; table 13.14 |

### 3.1.2. On Biodiversity

The majority of the respondents (N=240; 85%) strongly agree that eucalyptus expansion reduced biodiversity. In all kebeles, key informants claim biodiversity under woodlot is almost none mainly because of high stem density. A key informant, from Chume Kebele, noted that teff or coffee can grow under red gum when planted in wider spacing. Key informants at Abe Jiru, in the highland, also reported that blue gum is commonly planted at relatively wider spacing in boundaries where highland plant species such as Tericho (*Euphorbia abyssinica*), Welako (*Erythrina abyssinica*), Hocho (*Juniperus procera*), Gravela (*Grevillea robusta*), Tid (*Cupressus lusitanica*), and other shrubs. Out of 12 experts, eight of them stated eucalyptus reduces biodiversity (Annex 5.1.4; table 13.19). The key informants support the view that compacted eucalyptus plantations are commonly blamed for the suppression of undergrowth. On the other hand, some support eucalyptus has the potential to maintain biodiversity and undergrowth when properly managed at the right site (Annex 5.2.4). Eucalyptus has the potential to maintain biodiversity and undergrowth when properly managed at the right site. This benefit could be significant when planting space is more than 3 m X 3 m.

### 3.1.3. On Natural Forests

All participants involved in the study noted that there is no natural forest in our kebeles, and it is difficult to know the effect. From other experience, eucalyptus plantation has both negative and positive benefits. The replacement of natural forest by monoculture eucalyptus eliminates all its ecosystem services. From the positive side, eucalyptus expansion reduces pressure on natural forest where biodiversity and ecosystem services are conserved.

### 3.1.4. Allelopathic Impact

All participants asserted that eucalypts dry out plants when they are grown very closely under shade. They indicated that various parts of eucalyptus leaves are responsible for adversely affecting plants, primarily enset. According to the literature review (Annex 5.2), not all eucalyptus species produce severe allelopathic conditions, and the impact varies depending on soil moisture levels. Allelopathy may influence species selection when erosion control and grazing are significant considerations in plantation management. Under dry conditions, reversing extreme soil desiccation and allelopathic effects following a crop of Eucalyptus may prove challenging unless the soil is cultivated and provided with mulch or a fallow period.

### 3.1.5. On Soil Fertility

About 79% of the respondents strongly agreed that eucalyptus has an adverse effect on soil fertility (Annex 5.1.1; table 9.16). Again, about 43% of the respondents very strongly agreed, while about 41% of them agreed that eucalyptus planting has a positive contribution to soil erosion. In terms of the adverse effect on soil, all key informants were of the same opinion, indicating it dries the soil. Experts (N=12) stated that eucalyptus declines soil fertility range from high (8.3%) to very high (75%) (Annex 5.1.4; Table 13.19).

Some evidence from the literature supports farmers' perception (Annex 5.2.4). Soils in eucalyptus stands had significantly lower organic matter content than natural forest soil and higher than agricultural soils (Liang et al., 2016). In contrast, long-term plantations of eucalyptus have been reported to improve soil fertility (Oballa and Langat, 2002). Investigations related to the effects of eucalyptus woodlots on soil fertility have shown that soil under eucalyptus species is superior to soil fertility under annual cropping systems. The soil organic matter and total nitrogen were significantly higher than soil in nearby cropland.

### 3.1.6. On Crop Yield

A very large proportion of the respondents (93.3%) very strongly agreed that eucalyptus declines crop yield, and its expansion has led to a decline in food production (Annex 5.1.1; table 9.22). According to key informants (Annex 5.1.2; figure 2a) and FGD participants (Annex 5.1.3), the effect is so severe on Enset.

Literature evidence also supports the farmers' views. For example, the wheat yield decrease was in the order of 64%, 59%, and 47.5% at the age of 12 years, 8 years, and 4 years, respectively, at 2-4m distance from the *E. globulus* woodlot (Annex 5.2: figure 9). Yield and yield parameters suppression were ended at a distance of 14 to 20 m away from the tree stand. In Brazil, intercropping of *E. camaldulensis* showed similar productivity when compared to monoculture. However, in the dry season, the productivity of beans in monoculture was higher than intercropping. In the second year, rice productivity was very low for both *E. camaldulensis* intercropped and rice monoculture systems due to the lack of precipitation during the fructification phase. As noted by key informants and reported by Orwa et al., (2009), *E. camaldulensis* is important as a boundary agroforestry species if managed properly.

According to a key informant from Abe Jiru, completely cleared eucalyptus woodlots when replaced by barley and carrot show good performance and becoming superior to woodlot benefit (Annex 5.2). Like the effects of fallow agroforestry practices, maize plants grown on clear-felled eucalypt stands were taller and developed larger leaf areas than those grown on continuously cultivated farms (Desalegn et al. 2014). Dry matter production and grain yield were also significantly higher in maize plants established on clear-felled eucalypt stands. Farmers also responded that the growth and yield of maize grown on the clear-felled eucalypt stands were better than those grown on continuously cultivated farms. The results suggest that contrary to popular belief, agricultural lands afforested with eucalypts can be reused for annual crop production. Yitaferu et al. (2013) showed improved soil chemical properties (pH, CEC, N) and organic matter from farmlands reclaimed from *E. camaldulensis* plantations. The effect of eucalyptus woodlots and boundary on crop yield depends on the crop field distance from the edge of the plantation. Suggested optimal distances of growing barley/maize and enset crops are shown in Table 2 and Table 3, respectively. Land-use change from agricultural use to eucalyptus plantation does not have an adverse impact on total soil nitrogen, phosphorus, and sulfur content at least up to the age of 14.5 years (Zerfu Hailu, 2002; Annex 5.2).

*Table 2: suggested planting distance from odge of crops (maize, barley, wheat, teff)*

| Participants | No. (N) | Suggested distance | Sources |
|---|---|---|---|
| Household | 240 | 8 m to 14m | Annex 5.1.1. table 9.16 |
| Key informants | 20 | 8m to 11 m | Annex 5.1.2; figure 2b |
| Forces group discussion | 28 | 8 m to 13m | Annex 5.1.3 |
| Experts | 12 | 4 m to 22m | Annex 5.1.4; table 13.14 |
| Study on wheat | | 14m to 20m | Seyoum et al., 2021; Annex 5.2, table 14.7 |
| Study on wheat and teff | | 12 m to 16m | Selamyihun Kidanu. 2004; Annex 5.2, figure 9 |

*Table 3: suggested planting distance from odge of enset crops*

| Participants | No. (N) | Suggested distance | Sources |
|---|---|---|---|
| Household | 240 | 10m to 16m | Annex 5.1.1. table 9.16 |
| Key informants | 20 | 20 to 25 m | Annex 5.1.2; figure 2b |
| Forces group discussion | 28 | 30m to 40m | Annex 5.1.3; |
| Experts | 12 | 6 m to 16 m | Annex 5.1.4; table 13.14 |

*Table 4: suggested planting distance from odge of neighboring farm woodlot on shared boundary*

| Participants | No. (N) | Suggested distance | Sources |
|---|---|---|---|
| Household | 240 | 17m to 15m | Annex 5.1.1; table 9.16 |
| Key informants | 20 | 12m to 18m | Annex 5.1.2 |
| Forces group discussion | 28 | 17m to 20m | Annex 5.1.3 |
| Experts | 12 | 5 m to 13m | Annex 5.1.4; table 13.6 |

### 3.1.7. On Grazing Fields

Approximately 80.4% of respondents very strongly agreed that eucalyptus planting reduces livestock products. As a solution, respondents suggested that the average eucalyptus planting distance (m) from the edge of shared eucalyptus boundary with nearby grazing field should range from 9m – 11m. All experts noted that the reduction of forage productivity existed because of adjacent farm woodlot and recommend eucalyptus planting should be done not less than 5 m to 13m distance from the edge of the grazing field (Table 5).

*Table 5: suggested planting distance from odge of grazing fields*

| Participants | No. (N) | Suggested distance | Sources |
|---|---|---|---|
| Household | 240 | 9m to 11m | Annex 5.1.1. table 9.16 |
| Key informants | 20 | 8m to 11 m | Annex 5.1.2; figure 2b |
| Forces group discussion | 28 | 30m to 40m | Annex 5.1.3 |
| Experts | 12 | 5 m to 7m | Annex 5.1.4; table 13.12 |

## 3.2. Management Employed and Its Consequences

### 3.2.1. Motivating Factors for Eucalyptus Expansion

**Trends in Eucalyptus Expansion**

Understanding the trend in eucalyptus expansion is of paramount importance to assess the extent of positive and negative contributions. In the study kebeles, two species were reported, namely Eucalyptus globulus (blue gum) in Abe Jiru, Melga district (highland) and *Eucalyptus camaldulensis* (red gum) at Chumie (Dale district) and Dilla Aferra (Shebedino district) in midland, Derara Grobe (Derara district) as marginal lowland. Households involved in this survey have, on average, 35 years of farming experience (Annex 5.1.1; table 9.4). The proportion of households (N=240) who converted different land uses was in the order of: grazing land (33.3%) > maize field (31.3 %) > wetland (17.1%) > Enset fields (13 %) > Waste land (5.4%) (Annex 5.1.1; table 9.5). A large proportion of respondents (64%) converted land with medium fertility and high fertility (23.3%) cropland to woodlot/boundary planting (Annex 5.1.1; table 9.6).

**Effect of Boarding or Adjacent Farm Woodlot**

There are variations among respondents (N=240) in terms of motivating factors for the conversion of different land uses to eucalyptus planting. As indicated above, the top-ranking motivating factor for converting different lands uses to eucalyptus is pressure or the negative influence of adjacent farm woodlots. Both key informants (n=20) and FGD (n=28) participants at Shebedino and Dale woredas noted this as the most serious problem they have in their locality. All experts (12) mentioned this being a serious issue requiring special attention by the concerned body. Currently, due to changing conditions and eucalyptus adverse effects, a very large proportion of respondents (95%) have no plan to convert more land uses to eucalyptus planting (Annex 5.1.1; table 9.9).

### 3.2.2. Silviculture Management

**Stocking**

Variation exists among districts in terms of planting spacing in use. Generally, the majority of respondents (N=240;) (40%) use 0.5m x 0.5m spacing, (27%) use 0.25m x 0.25m spacing, and (16%) use 2 m x 0.75 m spacing (Annex 5.1.1; table 9.13). The main reasons for planting eucalyptus seedlings at such extremely high density are to get higher biomass (by 75% respondents) and lack of knowledge (by 24.2% respondents) (Annex 5.1.1; table 9.14). Key informants noted that on average, 0.5 m x 0.5 m spacing is the commonest spacing in use. Out of 12 experts, 5, 4, and 3 reported 0.5m x 0.5m, 0.25m x 0.25m, and 1m x 0.5m, respectively, as spacing in practice in the study kebele (Annex 5.1.4; table 13.10). This number will be at least doubled after the first cut of eucalyptus species. In the field, one observed more than three stems per stump. Unless special intervention is taken, such management may lead to a huge ecological consequence.

**Coppice Management**

At the study sites, once established, the first cut is commonly employed at an age ranging from 4 to 7 years. The former 4 years is commonly used at Dararo Gorbe while the latter is practiced at Abe Jiru kebele. The respondents noted that the cutting height of the stump ranges from 10 cm-20 cm. The local community conducts the first coppice shoot reduction when eucalypts reach a height ranging from 1.5 m and 3m (Annex 5.1.2; figure 5) and second shoot reduction at a height ranging from 4 m to 6 m (Annex 5.1.2; figure 6). After the planted seedlings establish and mature, the local community applies different harvesting methods. A large proportion of respondents (N=240; 64.2%) employ clear cutting method (Annex 5.1.1; table 9.15). After the first harvest, eucalyptus growers use different criteria for deciding rotation ages while managing woodlots and/or boundary plantations. In the study kebeles, a very large proportion of respondents (N=204; 94%) use income generation as a criterion while only 4.6% use the extent of stand maturity (Annex 5.1.1; table 9.16).

It is a common management practice to replace eucalyptus stand when productivity starts decreasing after certain rotation times. At the study sites, respondents reported an average of six (ranging from 4 to 12 times) coppice cutting rotations (Annex 5.1.1 table 9.20). At every harvest, almost all respondents (N=240; 99%) practice complete removal of stems, bark, leaf, branch/twig of eucalyptus woodlots and boundary plantations (Annex 5.1.1; table 9.19). Both key informants and FGD participants discussed similar experiences with regard to complete removal. Such complete removal of all tree biomass at every 4-7 years can have adverse effects on soils.

**Effect of High Stem Density and Frequency of Harvesting on Nutrient Depletion**

Harvesting effect on nutrient removal indicated variable results. As indicated above, extremely high stem density (0.5m x 0.5m and 0.25m x 0.25m used by 67% respondents, Annex 5.1.1. table 9.13) characterizes woodlot and boundary plantation of eucalyptus in the Sidama agricultural landscapes. The high stem density potentially reduces biodiversity or undergrowth vegetation, productivity, and produces low-quality products. As indicated in Annex 5.2, high density of *E. camaldulensis* trees adversely affects nutrient cycling (Zerfu Hailu, 2002).

Evidences indicate that high stocking of eucalyptus drains more nutrient than low stocking. The potential nutrient loss through all biomass harvest from more than 40000 stems per ha in Sidama at 4 years and/or 7 years harvest cycle can be extremely huge. In addition, an average of six (with a range from 4 to 12 times) coppice cutting rotations (Annex 5.1.1 table 9.20) can exacerbate the adverse effect. Therefore, for high productivity and quality product spacing ranging from 1.5m x 1.5m to 3m x 3m for products ranging from fuelwood to transmission poles respectively. Evidence revealed that the maximum accumulation of N, P, K, and Mg in wood whereas that of Ca was in bark. Because of clear felling ten years old plantations, the total uptake, 43 to 44% of N, 48 to 50% of P, 31 to 35% of K, and 37 to 47% of Mg is removed by wood harvesting alone (Georgem. 1984). From 1121 stems per ha with 233.6 ton above-ground biomass removed during harvest per ha, the proportion of nutrient loss was: 291.3 kg for nitrogen; 72.6 kg for phosphorus; 469.3 kg for potassium; 1,163.3 kg for calcium of *E. globulus* at an age of 14.5 years (Zerfu Hailu. 2002). For *E. camaldulensis* plantations removal of nitrogen with stem wood and branches biomass ranges from 47.8-58% of which the removal of only stemwood is as low as 36.4-45.4%. Generally, this study indicates that eucalyptus foliage and bark contain a large number of nutrients, and the retention of foliage and debarking of logs at the felling site is a good management practice to keep the site fertile. Similar trends are reported from Brazil for ten-year-old eucalyptus plantation (Salvador et al. 2021). Harvesting the whole Eucalyptus tree resulted in the removal of approximately 61% of the nutrients from the site in sandy soil, while in clayey soil 57% of the nutrients were removed. This indicated that nutrient removal in harvested biomass could deplete soil nutrient stocks and limit future productivity if not offset by fertilizer application, raising concerns for the long-term sustainability of the plantations.

## 3.3. Harmful Plants

*Cupressus lusitanica, Khaya edulis, Gravellia robusta, Avocado, and Mango* are mentioned as harmful plants. However, there was great controversy among key informants and FGD participants. The FGD participants completely disagree with the idea that Avocado and Mango are harmful. If proper management is applied, the adverse effects can be reduced.

# 4. Conclusion and Recommendations

## 4.1. Biophysical Impact Related

**Agroclimatic Zone**

- Though dry conditions are not a characteristic of Sidama National Regional State, avoid eucalyptus planting in sites with less than 400 mm of rainfall per year.

**Distance from Water Sources**

- Taking into account the semi-humid climatic condition and land scarcity, no eucalyptus planting shall be allowed within 30 m distance from the edge of the water sources.
- As a streamside buffer within 30 m distance, it is of paramount importance to grow deep-rooted grasses like Desho grass and some multipurpose shrubs. Such streamside buffers of deep-rooted and multipurpose shrubs can counteract hydrologic effects of Eucalyptus plantations.
- Beyond 30 m up to 50 m, eucalyptus planting should be minimized by inter-planting with indigenous tree species or in mosaic plantations between indigenous trees with the latter occupying a greater percentage.
- If the prime objective is to drain water from wetland, eucalyptus planting might be allowed with special considerations and community request.

**Biodiversity**

- Like in any compacted plantation, undergrowth of plants is very much limited in eucalyptus plantations. Boundary planting with wider spacings can sustain more biodiversity, and extension service has to focus on such management.
- There are different native woody plant species that have been degraded for fuelwood, construction, and income from agroforestry land use of Sidama. Cultivation of eucalyptus has already saved the diversity of woody species from further destruction or degradation in traditional agroforestry.
- If the proper management is applied, *Eucalyptus camaldulensis* can be used as an agroforestry component in the midland areas.
- Compacted monoculture eucalyptus plantation should not be established in the watershed areas because it may affect biodiversity. However, it should only be planted on barren lands where it is required to increase the forest cover and carbon sequestration.

### Natural Forests

- There are some limited initiations of eucalyptus planting in the open gaps of patch natural forest and woodlands in Sidama. Eucalyptus should not be planted in natural forests/ woodland; if it is a must, its composition should not exceed five percent.
- In SNRS, eucalyptus has been expanded for construction, fuelwood, and income purpose. Therefore, the contribution of eucalyptus planting in saving destruction and degradation woodlands should not be undermined.

### Allelopathic

- Of the two eucalyptus species distributed in SNRS, blue gum is known to produce allelo-chemicals that affect cereals (barley, maize, grasses, wheat, teff, millet). Growing blue gum on moist soils with wider spaces at a minimum of 8 m x 8 m.

### Soil Fertility

- Unlike farmers' views, most literature indicates that soil under eucalyptus plantation has better concentration of organic matter and total nitrogen than soil on which continuously cultivated monoculture agricultural. However, the adverse effect is related to extremely high-density stocking. Therefore, low-density stand with proper management (woody species, coppice management) shall minimize the adverse effect of eucalyptus plantation.
- The soil nutrient levels under Eucalyptus plantations can be improved by adjusting spacing and mixing eucalyptus species with intercropping of shade-tolerant and other leguminous plants like Acacia and Albizia species.
- Eucalyptus foliage and bark contain many nutrients, and the retention of foliage and debarking of logs at the felling site is a good management practice to keep the site fertile.
- Eucalyptus plantations on steep slopes can provide effective erosion control if careful techniques such as contour planting are used. Eucalyptus plantations established for catchment protection should be developed into uneven ones by selective cutting over a period of years.

### Crop Yield

- The scientific evidence and responses of participants in this study indicate an influencing effect of eucalyptus on adjacent crop productivity. To minimize the adverse effect of eucalyptus optimal distance from the edge each individual crop has to be determined;
- Eucalyptus shall not be planted at less than 10 m distance from the edge crop (barley, maize).
- Eucalyptus shall not be planted at less than 15 m distance from the edge enset. The majority of the participants involved showed less enthusiasm and interest for expanding land areas for eucalyptus. Therefore, eucalyptus should not be planted on the farmlands if its returns are less than the reduction in the crop yield, but if the return from its wood compensates for the reduction in crop yield and gives extra profit then it can be planted on farmlands.

## 4.2 Management Related

**Pressure from Neighboring Farms**

- Eucalyptus boundary planting is the major source of conflicts between and among neighbors in Sidama.
- Pressure from neighboring woodlot and boundaries appears to be one of the profound reasons (the top-ranking reason motivating factor by all respondents) for continuing eucalyptus planting in the SNRS.
- For the neighboring woodlot and boundaries, eucalyptus shall be planted at more than 10 m distance from the adjacent edge crop fields.

**Stocking and Its Effect**

- Woodlot and boundary plantation of eucalyptus in the Sidama agricultural landscapes are characterized by high stem density (between 0.25 m X .025 m to 1 m x 1m in some cases more as indicated by respondents). The high stem density potentially reduces biodiversity or undergrowth vegetation, reduces productivity, and produces low-quality products.
- The potential quantity of nutrients to be lost through harvesting of more than 10000 stems per ha at 4 years and/or 7 years harvest cycle can be extremely huge. Therefore, for high productivity and quality, spacing of 2 mx 2 m for fuelwood, of 2.5 m 2.5 m for construction wood and transmission poles should be adopted.

**Coppice Management**

- The current eucalyptus management practice is developed by farmers' motivation without extension input as a result of time of the first harvest, cutting stump height, the season of cutting, and the rotation period is almost to the standard. However, the number of retained shoots and the number of rotation times up to replacement require appropriate intervention through extension services.

**Harvesting and Nutrient Depletion**

- The best harvesting system for eucalyptus involves the removal of only stemwood. Unlike this fact, this study indicates that complete removal of stems, barks, twigs, and other foliage during each harvest. Loss of nutrients from extremely high stems density per ha is a typical problematic management which could lead to an ecological crisis. Therefore, it is recommended that maintaining foliage and debarking of logs at the felling site is a good management option to keep the site fertile.
- Eucalyptus foliage and bark contain a large number of nutrients, and the retention of foliage and debarking of logs at the felling site is a good management practice to keep the site fertile. However, nutrient removal in whole tree harvested biomass could deplete soil nutrient stocks and limit future productivity if not offset by fertilizer application, raising concerns for the long-term sustainability of the plantations. Therefore, it is recommended that maintaining foliage and debarking of logs at the felling site is a good management option to keep the site fertile. Nutrient removal at high stocking of 10000 stems per ha in Sidama and frequent harvesting at 4 years to 7 years cycle can be very huge.

Nutrient loss can be reduced by using agroforestry approaches. In relatively moist sites, intercropping of *E. camaldulensis* with agricultural crops to increase productivity, income, and biofuel (preferred for high-quality cooking in the countryside) and improve the environment (carbon sequestration, soil fertility, and biodiversity).

**Livelihood Improvement**

- Eucalyptus helps households to become wood self-sufficient and provides considerable cash income. Overall, eucalyptus contributes to poverty reduction and ensuring food security for millions of rural households throughout the SNRS. Unlike the last 15 years, however, income contribution during the last two years is inferior to income crops.

## 4.3 Harmful Plants

*Cupressus lusitanica, Khaya edulis, Gravellia robusta, Avocado,* and *Mango* are mentioned as harmful plants. However, there was great controversy if proper management is applied, their adverse effects can be reduced. The FGD participants completely disagree with the idea that Avocado and Mango are harmful.

# 5. Annexes

## 5.1 Annex 1: Community perspectives and expert responses on eucalyptus impacts

### Methods and procedures

Both qualitative and quantitative methods were considered. For the qualitative aspect, key informant interviews (20 persons) and Focus Group Discussions (28) were conducted. The quantitative survey included interviews with 12 experts and 240 households (farmers) from three agro-ecologies and four districts or kebeles. The interviews were conducted in-person, face-to-face with the participants over a two-week period. The focus was on capturing an accurate picture of eucalyptus expansion trends and drivers, ecological and socioeconomic impacts, local knowledge on its management, and challenges for its future development.

### Findings

**Eucalyptus Expansion**

Understanding the trend in eucalyptus expansion is paramount to assess the extent of positive and negative contributions and plan sustainable development of this resource in the Sidama agricultural landscape. In the study kebeles, two species were reported: Eucalyptus globulus (blue gum) in Abe Jiru, Melga district (highland), and Eucalyptus camaldulensis (red gum) at Chumie (Dale district) and Dilla Aferra (Shebedino district) in midland, Derara Grobe (Derara district) as marginal lowland. Households involved in this survey have, on average, 35 years of farming experience (Annex 5.1.1; table 9.4). The proportion of households (N=240) that converted different land uses was in the order of: grazing land (33.3%) > maize field (31.3%) > wetland (17.1%) > Enset fields (13%) > waste land (5.4%) (Annex 5.1.1; Table 9.5). A large proportion of respondents (64%) converted land with medium fertility and high fertility (23.3%) cropland to woodlot/boundary planting (Annex 5.1.1; table 9.6). There are variations among total respondents (N=240) in terms of motivating factors for the conversion of different land uses to eucalyptus planting. Overall, the average proportion of respondents' responses is in the order of: influence of adjacent farm woodlots (26.2%) > low establishment & management cost (23.3%) > high profitability (17.1%) > demand for wood products (13.3%) > land degradation and decline in crop productivity (12.1%) (Annex 5.1.1; table 9.8). A majority (N=240; 60%) of the respondents strongly agreed that eucalyptus expansion increases wood products in the study area. Additionally, about 42% and 32.4% of respondents strongly agreed and agreed, respectively, that eucalyptus expansion increased higher income (Annex 5.1.1; table 9.22). Currently, however, due to changing conditions and the adverse effects of eucalyptus, a very large proportion of respondents (95%) have no plans to convert more land uses to eucalyptus planting (Annex 5.1.1; table 9.9).

Key informants at the study kebeles shared experiences with the respondent households. In Melga district, at Abe Jiru kebele, key informants noted that blue gum expansion took place around 20 years ago at boundary niches, but recently, conversion of grazing land and barley fields to woodlot fields has increased. Key informants stated that grazing is the major land use converted to woodlot, followed by barley fields. In this respect, both household participants and key informants revealed similar perceptions. According to key informants at Abe Jiru, the motivating factors for the land-use conversion are, in order: income > construction > pressure from adjacent farms with blue gum > fuelwood needs. Key informants from Shebedino, Dale, and Darara districts noted that red gum was introduced before 60 years on some farms of better-off farmers, mainly as a boundary planting. There is a consensus among participants that large-scale conversion of grazing lands and maize fields took place during the last 15 years, and between the last 15 to 3 years, there was a further increase in expansion.

Women Focus Group Discussion was conducted to understand how eucalyptus expansion affects tree tenure at the study sites. At all study kebeles, FGD participants noted that there is no established women's right to plant, manage, utilize, and sell eucalyptus trees (Annex 5.1.3). On the issue of eucalyptus expansion trends, FGD participants discussed similar experiences with the key informants at the four kebeles. FGD participant women have a great deal of knowledge on the management of eucalyptus trees. The FGD participants were able to articulate a broad range of knowledge on eucalyptus management, including site selection, stocking and planting pattern trees, coppice management activities, harvesting methods, etc. Respondents noted that tree selection and seed collection can be from own boundary eucalyptus trees in most cases or by buying seedlings from farmers at the local market or from neighboring farmers. When collected from own trees, men collect seeds, and women help during drying and processing activities. The participants also stated that men are responsible for seedbed preparation and sowing, mulching, and watering. Men conduct weeding at least two times for the planted seedlings. There was a consensus that men decide on eucalyptus harvesting when the tree reaches 5 to 7 years of age and cut at „tako" to half a chigilie or 12-25 cm height from the ground. The FGD participants noted that clear-cutting is the commonest type of harvesting method for a woodlot, while selective cutting is preferred for a boundary. The respondents also noted that harvesting takes place from October to February. Men do the first and second coppice reduction when the shoots reach about 1.5 -2 m and 4-6 m height, respectively.

All experts at Abe Jiru and mentioned noted that wetland is the type of land use converted to woodlot or boundary planting. Two respondents each at Dilla Aferara and Ademe Darara discussed similar experiences (Annex 5.1.4; table 13.4). All experts noted that firewood is the main source of energy in the study kebeles (Annex 5.1.4; table 13.5). All experts stated that an adjacent farm with woodlots is a motivating factor to convert different land uses to woodlot and boundary plantation (Annex 5.1.4; table 13.6).

**Management**

*Planting Materials and Sources*

Regarding the source of eucalyptus planting materials, a large number of respondents (N=240; 79.2%) use their own seed sources, followed by purchasing from private local farmers (13.3%) and purchasing from government nurseries (6.3%) (Annex 5.1.1; table 9.9). Key informants noted that locally produced seed is mainly from boundary-grown eucalyptus. Better-off farmers have privileges to keep trees for longer years to produce more seeds than poor farmers do (Annex 5.1.2). A participant shared the following:

> *In our kebele, Abe Jiru, there are some better-off farmers who produce blue gum seeds for sale for increased income and decreased economic risk by diversifying farm production. In addition, they grow seedlings in their own beds for sale to generate extra income through sale of seedlings."*
> *Ato Ulata Wanjala*

At all kebeles, key informants stated that eucalyptus raising seedlings in the nursery is not common; rather, direct seeding on permanent land is the commonest practice. The seedbed for direct sowing is normally plowed at least two times, and then the owner sets light fire on the soil. The men are responsible for sowing, mulching, and watering. In general, the planting site preparation experience of respondents includes plowing three times (N=240; 42.9%), plowing twice pit (planting hole) digging by (20.4%), and plowing once by (15.4%) (Annex 5.1.1; table 9.11). For the establishment of eucalyptus, respondents employ direct seeding on beds (N=240; 49.6%) and bare-root seedlings (48.8%), indicating their level of independency (Annex 5.1.1; table 9.12). In terms of planting site preparation, the key informants discussed similar experiences like household respondents (Annex 5.1.2).

Regarding planting site preparation at the study sites, 58.3% of the experts (N=12) pit (planting hole) digging followed by plowing once and plowing three times and above (Annex 5.1.4; table 13.7). Nine of the experts noted that bare-root seedlings are the dominant planting material for woodlot establishment (Annex 5.1.4; table 13.8).

*Establishment*

Variation exists among districts in terms of planting spacing in use. Generally, the majority of respondents (N=240) use 0.5m x 0.5m spacing (40%), 0.25m x 0.25m spacing is used by (27%), and 2 m x 0.75 m spacing is used by (29.6%) respondents (Annex 5.1.1; table 9.13). The main reasons for planting eucalyptus seedlings at less than 2m x 2m include getting higher biomass (by 75% respondents) and lack of knowledge (by 24.2% respondents) (Annex 5.1.1; table 9.14). Key informants noted that, on average, 0.4 m x 0.4 m spacing is applied at study kebeles. When asked about the existence of appropriate advisory service on eucalyptus management from any organization, key informants stated no service has been provided yet. Key informants at four kebeles stated that at least two times weeding is required to get good survival and growth of young eucalyptus seedlings. Key informants noted that, on average, 0.5 m x 0.5 m spacing is applied at study kebeles. Experts (N=12) 5, 4, and 3 noted spacing of 0.5m x 0.5m, 0.25m x 0.25m, and 1m x 0.5m, respectively used in the study kebele (Annex 5.1.4; table 13.10). The main reasons for planting eucalyptus seedlings at less than 2m x 2m include getting higher biomass (by 66.7% experts) (Annex 5.1.4; table 13.11)

*Coppice Management*

Once established, the first cut is commonly employed when the tree reaches an age ranging from 4 to 7 years. The former 4 years are commonly used at Dararo Gorbe while the latter is practiced at Abe Jiru kebele. The respondents noted that the cutting height of the stump also ranges from 10 cm – 20 cm. The local community conducts the first coppice shoot reduction when eucalypts reach an age ranging from 1.5 and 3 years (Annex 5.1.2; figure 5) and second shoot reduction at a height ranging from 4 m to 6 m (Annex 5.1.2; figure 6). In the study kebeles, coppice rotation period ranges from 4 to 7 years (Annex 5.1.2; figure 7). After the planted seedlings are established and get matured, the local community applies different harvesting methods. A large proportion of respondents (N=240; 64.2%) employ the clear-cutting method. About 29% of them employ both clear cutting, while 10% employ selective cutting (Annex 5.1.1; table 9.15). After the first harvest, eucalyptus growers use different criteria for deciding rotation ages while managing woodlots and/or boundary plantations. In the study kebeles, a very large proportion of respondents (N=204; 94%) use money generation as a criteria, while only 4.6% use the extent of stand maturity (Annex 5.1.1; table 9.16). Respondents at the study kebeles apply various coppice management activities (Annex 5.1.1; table 9.17). They harvest the first cut at an average of 4 years with a range from 3 to 8 years; they do the first and second coppice shoot reduction at a mean height of 2 m (ranging from 1m to 4 m) and 5 m (ranging from 2 m to 7 m), respectively. In general, they apply a mean interval cutting rotation at an age of 5 years (ranging from 3-7 years). But for specific forest products, they apply an average rotation ages ranging from 3 to 5 years for small poles (Mager), ranging from 5 to 6 years for small pole (Weraj), and ranging from 6 to 9 years for medium poles (Kench) (Annex 5.1.1; table 9.18). It is a common management practice to replace eucalyptus stand when productivity decreases over time. In this respect, the respondents apply an average of six (6) coppice cutting rotations (with a range from (4 to 12 times). According to key informants, clear-cutting is the commonest type of harvesting method at all kebeles, though some farmers practice selective cutting by leaving some stems. Once established, the first cut is commonly done when the tree reaches an age ranging from 4 to 7 years. The respondents noted that the cutting height of the stump also ranges from 10 cm to 20cm, which is similar to respondent households (N=240). The local community conducts the first coppice shoot reduction when eucalypts reach age ranging from 1.5 and 3 m years (Annex 5.1.2; figure 5) and second shoot reduction at a height ranging from 4 m to 6 m (Annex 5.1.2; figure 6). In the study kebeles, coppice rotation period ranges from 4 to 7 years (Annex 5.1.2; figure 7). During every harvest, almost all respondents (N=240; 99%) noted a practice of complete removal of stems, bark, leaf, branch/twig of eucalyptus woodlots and boundary plantations (Annex 5.1.1; table 9.19). In this study, a large proportion of respondents (93.3%) sell eucalyptus materials at the production sites (Annex 5.1.1; table 9.20). Similar to the survey result, key informants stated that at each harvest, farmers in the study kebeles remove bark, branches, and leaves that should have been used to decompose and recycle nutrients from the harvest residues. At Abe Jiru keble, key informants noted that after harvesting of blue gum, stems are taken by the buyer, while all branches and leaves are removed by the family of the seller, mainly by women. On the other hand, at Dilla Aferara and Chumie kebele, key informants stated mixed responses on branches and leaves removal after harvest. Depending on the agreement between the seller and buyer, removal of branches and leaves from the harvested plot can be done either by the owner (farmer) in which women and children are highly responsible or by the buyer. The case is completely different at Derara Gorbe kebele, where the buyer has full right to collect and remove all stems, branches, and leaves. If the owner farmer is interested in having branches and leaves, he has to pay based on the agreement.

*Role of Women in Eucalyptus Management*

The FGD participants noted that women do not have the right to select, plant, manage, and utilize eucalyptus. However, women have a great deal of knowledge on the management of blue gum and red gum trees. The FGD participants were able to articulate a broad range of knowledge on eucalyptus management, including site selection, stocking and planting pattern trees, coppice management activities, harvesting methods, etc. Respondents also noted that tree selection and seed collection can be from own boundary eucalyptus trees in most cases or by buying seedlings from farmers at the local market or neighboring farmers. When collecting from own trees, men collect seed and women help during drying and processing activities. The participants also stated men are responsible for seedbed preparation and sowing, mulching, and watering.

## Impact on the Environment

*Water Resources*

In this study, a large proportion of the respondents (N=240; 76.3%) very strongly agreed that water eucalyptus planting reduces water yield, while about 17.1% of them agreed (Annex 5.1.1; table 9.22). Respondent households suggested that the average eucalyptus planting distance (m) from the edge of water ranges 10 m to 16m (Annex 5.1.1; table 9.16). With respect to the impact on water, key informants at Abe Jiru noted serious concern that some farmers plant blue gum as close as 2 m to springs and streams, which reduced water quantity. Key informants at Darara Grobe mentioned that we do not have a river in our Kebele, but experience at one water spring show that red gum reduces the available amount of water. A participant stated that the effect could be easily noticed on a wetland commonly used as a communal grazing land. A similar experience was discussed by key informants at Dilla Aferara and Chumie kebeles. Key informants proposed that planting distance eucalyptus from water sources should be at least at 26 m, 21 m, 16 m, and 19 m at Abe Jiru. Dilla Aferara, Chumie, and Darara Grobe, respectively. (Annex 5.1.2; fig. 1) Similar to the key informants‘ view, the FGD participants noted that farmers plant eucalyptus very close to water streams. In addition, participants noted that maintenance of current practices is problematic and makes the community rethink eucalyptus expansion. The FGD participants stated that both blue gum and red gum strongly affect water availability. There was consensus among FGD participants that proper eucalyptus planting distance could be 17 – 20 meters from water sources and stream. Experts (N=12) stated that eucalyptus lowers water sources very high (8.3%) to very high (83.4%) (Annex 5.1.4 table 13.19). According to experts‘ suggestions, the average eucalyptus planting distance (m) from the edge of water ranges from 5m to 16m (Annex 5.1.4; table 13.14)

*Soil Fertility and Erosion*

About 49% of the respondents very strongly agreed while about 30% of them agreed that eucalyptus has an adverse effect on soil fertility (Annex 5.1.1; table 9.16). Again, about 43% of the respondents very strongly agreed while about 41% of them agreed that eucalyptus planting has a positive contribution to soil erosion. In terms of the adverse effect on soil, all key informants were of the same opinion, indicating it dries the soil. Experts (N=12) stated that eucalyptus declines soil fertility range from high (8.3%) to very high (75%) (Annex 5.1.4; table 13.19).

*Biodiversity*

A majority of the respondents (58.8%) agree, and (N=240; 27.1%) of them very strongly agree that eucalyptus expansion reduces biodiversity. There was some degree of variation across the study Kebeles when it came to the adverse effect of eucalyptus on biodiversity. In all kebeles, key informants stated that it is very difficult to find different plants and animals in eucalyptus woodlot plots due to high stem density that may reduce biodiversity or undergrowth vegetation. Depending on the situation, plants may grow under eucalyptus when planted in wider spacing. A key informant at Abe Jiru shared the following:

> *„In our kebele there is strong wind problem. Farmers grow blue gum in boundaries by mixing with other plants to protect wind. On boundaries blue gum is commonly planted at relatively wider spacing. Between eucalyptus trees highland plant species such as Tericho (Euphorbia abyssinica), Welako (Erythrina abyssinica), Hocho (Juniperus procera), Gravela (Grevillea robusta), Tid (Cupressus lusitanica) and other shrubs.“*
>
> *Ato Kachara Birega*

Experts (N=12) stated that eucalyptus reduces biodiversity (41.7%) to very high (25%) (Annex 5.1.3; table 13.19).

### Crop Productivity

A significant majority of respondents (93.3%) strongly agreed that eucalyptus negatively affects crop yield, leading to a decline in food production (Annex 5.1.1; table 9.16). According to respondents, the average planting distance of eucalyptus from the edge of maize/barley fields and enset should range from 8m to 14m and 10m to 15m, respectively (Annex 5.1.1; table 9.15).

Key informants from the four kebeles share a similar perception regarding the adverse effects of eucalyptus on crops, resulting in the avoidance of intercropping. A key informant in Derara noted that farmers can grow crops like coffee and even teff. In all kebeles, key informants emphasized the severe impact on Enset, suggesting that eucalyptus must be planted far away, ranging from 20m to 25m from Enset fields (Annex 5.1.2; figure 2a). Overall, participants suggested that the optimal distance to minimize the adverse effects on maize and barley could range from 8m to 10.6m (Annex 5.1.2; figure 2b).

In the study kebeles, FGD participants mentioned that farmers usually plant crops very close to the edge of eucalyptus woodlots or boundary-planted eucalyptus. There is consensus among participants that eucalyptus competes with crops and reduces productivity, with implications for food security (Annex 5.1.3). The participants suggested proper distances of about 8-12m, 30-40m, and 5-7m from barley, Enset, and grazing land, respectively.

Experts (N=12) stated that competition with other crops ranges from high (8.3%) to very high (91.7%) (Annex 5.1.4; table 13.19). According to expert suggestions, the average eucalyptus planting distance (m) from shared eucalyptus boundaries ranges from 4m to 13m, from the edge of Enset fields ranges from 6m to 16m, and from the edge of maize barley ranges from 3m to 22m (Annex 5.1.4; table 13.14).

### Impacts on Grazing Land

Additionally, about 80.4% of respondents strongly agreed that eucalyptus planting reduces livestock products. As a solution, respondents suggested that the average eucalyptus planting distance (m) from the edge of shared eucalyptus boundaries with nearby grazing fields should range from 9m to 10m (Annex 5.1.1, table 9.16).

In terms of the effect on grazing land, key informants at Abe Jiru expressed concern that blue gum occupies more than 60 percent of grazing land, leading to a decrease in animal products over time. Key informants at Dilla Aferara, Chumie, and Darara Grobe shared similar experiences. To minimize the impact on grass fields, key informants suggested suitable planting distances ranging from 8m to 11m (Annex 5.1.2; figure 3).

All experts noted that forage productivity has been decreasing due to eucalyptus woodlot expansion (Annex 5.1.4; table 13.12). They suggested planting distances ranging from 5m to 7m.

## Contributions of Eucalyptus

Participants shared a common understanding of both income generation and fuelwood benefits of eucalyptus. Participants noted that fuelwood collection from standing trees and after each harvest is the responsibility of women. Women also collect eucalyptus foliage (leaves, very small branches at the end), and bark during harvest. There is a consensus that eucalyptus trees supply a large share of overall fuelwood output from their farmlands, and participants feel self-sufficient. However, a participant indicated that this is not the case for poor farmers who may not have an adequate amount of eucalyptus trees. These farmers generally respond to fuelwood shortages by purchasing more supplies or increasing the time spent on fuelwood collection. Some households also resort to burning straw and other less favored fuels. Measures to economize fuelwood use are also adopted, for example, using foods that take less time or fuel to cook, such as chukame, a food made up of enset staple food in Sidama Regional State.

## The Future of Eucalyptus Development

One of the major reasons for the expansion of eucalyptus in the study kebeles includes its benefit in income generation. Key informants stated that income from eucalyptus is currently less attractive when compared to income from barley, maize, and vegetables. The prices of maize crops, vegetables, and coffee have increased, becoming a better alternative to red gum in midland districts. In all kebeles, the high increase in crop prices has also increased farmers' income, motivating them to replace eucalyptus woodlots with crop fields. Some respondents shared the consequences of such development.

A participant at Abe Jiru suggested that eucalyptus is essential for the protection of landslides, and it should be managed for such specific cases. It is also important to control water erosion when planted on degraded lands and for gully rehabilitation. The focus group participants shared similar experiences; for example, FGD participants noted a general trend of converting eucalyptus woodlots to cropland increased during the last three years. Most participants support the idea of replacing eucalyptus woodlots with other land uses. But a participant at Abe Jiru suggested that the complete replacement of eucalyptus woodlot and boundary plantation can lead to a problem:

> *„We need to keep some eucalyptus in boundaries for our children so that they construct houses and use as firewood like what we have been doing. I do not support complete elimination this trees from our kebele since there is no other tree that currently replace eucalyptus for house construction and fuel wood. In addition, we already noticed that eucalyptus protect landslide on slope site."*
> *W/ro Aster Bunara*

When it comes to midland districts, Dilla Aferara and Chume, the FGD participants noted that red gum expansion is being reduced mainly due to price increases in the grain market

It was mentioned that the price of maize crops, vegetables, and coffee has increased, becoming a better alternative to red gum. At Derara Gorbe, FGD participants noted that the increasing price of crops such as maize and different beans demotivated the community to convert red gum woodlots to other land uses.

## Other Harmful Trees

In this study, „harmful trees/shrubs" refer to any plant that has adverse effects when planted as a component of traditional agroforestry and in other land uses in your kebele. The effects considered include adverse effects on soil, water, competition with other crops, and affecting the traditional food system of Sidama. The following are reported during both qualitative and quantitative interviews.

*Table 6: plants reported as harmful by overall respondents*

| Species Name | Frequency | Percentage % |
|---|---|---|
| *Cupressus lusitanica* | 53 | 22.1 |
| *Khata edulis* | 23 | 9.6 |
| *Avocado* | 111 | 46.3 |
| *Grevillea robusta* | 30 | 12.5 |
| *Mango* | 4 | 1.7 |

*Table 7: plants reported as harmful by key informants*

| No. | District / Kebele | Suggested Species |
|---|---|---|
| 1 | Abe Jiru | *Cupressus lusitanica (Yeferenj Tid)* |
| 2 | Dilla Aferra | *Avocado, Yeferenj Tid, Grevillea* |
| 3 | Chumie | *Avocado, Mango and Grevillea* |
| 4 | Derara Gorbie | *Avocado, Mango and Grevillea* |

*Table 8: plants reported as harmful by FGDs*

| No. | District / Kebele | Suggested Species |
|---|---|---|
| 1 | Abe Jiru | *Cupressus lusitanica (Yeferenj Tid)* |
| 2 | Dilla Aferra | *Yeferenj Tid, Grevillea* |
| 3 | Chumie | *Yeferenj Tid and Grevillea* |
| 4 | Derara Gorbie | *Grevillea* |

Note: only two experts mention *Khat* as harmful plant.

### 5.1.1 Household survey report

#### Household socio-economic characteristics

*Table 9.1: Proportion of respondents (%) in terms of sex*

| Kebele | Male | Female |
|---|---|---|
| Abe Jiru | 93.3 | 6.7 |
| Dilla Aferara | 100.0 | 0.0 |
| Chumie | 90.0 | 10.0 |
| Derara Gorbe | 100.0 | 0.0 |
| Overall | 95.8 | 4.2 |

*Table 9.2: Proportion of respondents (%) in terms of marital status*

| Kebele | Single | Married | Windowed |
|---|---|---|---|
| Abe Jiru (n=60) | 6.7 | 93.3 | 0.0 |
| Dilla Aferara (n=60) | 6.7 | 93.3 | 0.0 |
| Chumie (n=60) | 0.0 | 95.0 | 5.0 |
| Derara Gorbe (n=60) | 0.0 | 100.0 | 0.0 |
| Overall (N=240) | 3.3 | 95.4 | 1.3 |

*Table 9.3: number of respondents in percent in terms of education*

| Kebele | Illiterate | Read/ write | Lower Primary (1-4) | Higher Primary (5-8) | High school (9-12) | Degree |
|---|---|---|---|---|---|---|
| Abe Jiru (n=60) | 46.7 | 16.7 | 8.3 | 20.0 | 3.3 | 5.0 |
| Dilla Aferara (n=60) | 35.0 | 1.7 | 31.7 | 8.3 | 21.7 | 1.7 |
| Chumie (n=60) | 8.3 | 0.0 | 20.0 | 46.7 | 23.3 | 1.7 |
| Derara Gorbe (n=60) | 18.3 | 10.0 | 43.3 | 26.7 | 0.0 | 1.7 |
| Overall (N=240) | 27.1 | 7.1 | 25.8 | 25.4 | 12.1 | 2.5 |

*Table 9.4: Mean of years in farming experience with standard deviation*

| Kebele | Mean | Std. Deviation |
|---|---|---|
| Abe Jiru (n=60) | 39.70 | 9.417 |
| Dilla Aferara (n=60) | 31.37 | 5.162 |
| Chumie (n=60) | 34.18 | 10.940 |
| Derara Gorbe (n=60) | 34.85 | 7.586 |
| Overall (N=240) | 35.03 | 9.014 |

Overall higher proportion of (33.3%) respondents converted their grazing lands woodlot or boundary planting followed by cropland (Table 5). At kebele level there is some variations. For example, Dilla Aferara and Chumie large proportion households converted maize feilds to red gum woodlot.

*Table 9.5: Number of respondents mentioning the land use type converted to woodlot or boundary planting*

| Kebele | Maize field | Enset fields | Grazing land | Wet land | Waste land |
|---|---|---|---|---|---|
| Abe Jiru (n=60) | 11.7 | 3.3 | 80.0 | 1.7 | 3.3 |
| Dilla Aferara (n=60) | 35.0 | 33.3 | 26.7 | 5.0 | 0.0 |
| Chumie (n=60) | 61.7 | 11.7 | 21.7 | 5.0 | 0.0 |
| Derara Gorbe (n=60) | 16.7 | 3.3 | 5.0 | 56.7 | 18.3 |
| Overall (N=240) | 31.3 | 12.9 | 33.3 | 17.1 | 5.4 |

Overall, large proportion of respondents (64 %) converted medium Fertility cropland to woodlot or boundary planting. About 52 % and 38 % of respondents at Dilla Aferara and Chumie, respectively, converted their high fertility cropland to woodlot or boundary planting.

*Table 9.6: Number respondents mentioning the extent of cropland soil fertility converted to woodlot or boundary planting.*

| Kebele | Low Fertility | Medium Fertility | High Fertility |
|---|---|---|---|
| Abe Jiru (n=60) | 13.3 | 86.7 | 0.0 |
| Dilla Aferara (n=60) | 10.0 | 38.3 | 51.7 |
| Chumie (n=60) | 8.3 | 55.0 | 36.7 |
| Derara Gorbe (n=60) | 20.0 | 75.0 | 5.0 |
| Overall (N=240) | 12.9 | 63.7 | 23.3 |

*Table 9.7: Number of respondents (%) and energy utilization in the study kebele*

| Source of Energy | Number of respondents (%) and energy utilization | | | | |
|---|---|---|---|---|---|
| | 1st | 2nd | 3rd | 4th | 5th |
| Firewood | 98.3 | 1.7 | 0.0 | 0.0 | 0.0 |
| Crop Residue | 1.3 | 94.1 | 4.2 | 0.4 | 0.0 |
| Charcoal | 0.0 | 7.2 | 24.8 | 67.3 | 0.7 |

*Table 9.8: Number of respondents (5) and motivating factors to converted different land sues to woodlot and boundary plantation*

| Item description | Abe Jiru | Dilla Aferara | Chumie | Ademe Darara |
|---|---|---|---|---|
| Influent adjacent farm woodlots | 43.3 | 23.3 | 20.0 | 18.3 |
| Demand for wood products | 40.0 | 11.7 | 1.7 | 0.0 |
| High price of wood products | 13.3 | 11.7 | 1.7 | 1.7 |
| High profitability | 1.7 | 23.3 | 33.3 | 10.0 |
| Low establishment & management cost | 0.0 | 16.7 | 20.0 | 56.7 |
| Land degradation and decline in crop productivity | 1.7 | 11.7 | 21.7 | 13.3 |
| Special attributes of the tree species | 0.0 | 1.7 | 1.7 | 0.0 |

*Table 9.9: Number of respondents (%) mentioning source of planting materials of eucalyptus species*

| Kebele | Own Nursery | Purchase from gov't Nursery | Purchase from private Nursery | Free of charge from gov't/ community nurseries |
|---|---|---|---|---|
| Abe Jiru (n=60) | 91.7 | 0.0 | 3.3 | 5.0 |
| Dilla Aferara (n=60) | 100.0 | 0.0 | 0.0 | 0.0 |
| Chumie (n=60) | 60.0 | 3.3 | 36.7 | 0.0 |
| Derara Gorbe (n=60) | 65.0 | 21.7 | 13.3 | 0.0 |
| Overall (N=240) | 79.2 | 6.3 | 13.3 | 1.3 |

Overall. Very large proportion of respondents (95 %) have no plan to assign more land to eucalyptus planting.

*Table 9.10: Number respondents (%) and their future plan to assign more land for eucalyptus planting*

| Kebele | Yes | No |
|---|---|---|
| Abe Jiru (n=60) | 0.0 | 100.0 |
| Dilla Aferara (n=60) | 6.7 | 93.3 |
| Chumie (n=60) | 0.0 | 100.0 |
| Derara Gorbe (n=60) | 13.3 | 86.7 |
| Overall (N=240) | 5.0 | 95.0 |

*Table 9.11: Number respondents (%) mentioning types of site preparation at the study sites*

| Kebele | Ploughing once | Ploughing twice | Ploughing three times | Pit (planting hole) digging |
|---|---|---|---|---|
| Abe Jiru (n=60) | 50.0 | 15.0 | 0.0 | 35.0 |
| Dilla Aferara (n=60) | 6.7 | 18.3 | 73.3 | 1.7 |
| Chumie (n=60) | 0.0 | 15.0 | 83.3 | 1.7 |
| Derara Gorbe (n=60) | 5.0 | 36.7 | 15.0 | 43.3 |
| Overall (N=240) | 15.4 | 21.3 | 42.9 | 20.4 |

*Table 9.12: Number respondents (%) mentioning seed sources material for woodlot establishment*

| Kebele | Bare root seedlings | Potted seedlings | Direct seedling | Both potted and bare rooted seedling |
|---|---|---|---|---|
| Abe Jiru (n=60) | 98.3 | 0.0 | 1.7 | 0.0 |
| Dilla Aferara (n=60) | 93.3 | 0.0 | 3.3 | 3.3 |
| Chumie (n=60) | 100.0 | 0.0 | 0.0 | 0.0 |
| Derara Gorbe (n=60) | 96.7 | 3.3 | 0.0 | 0.0 |
| Overall (N=240) | 48.8 | 0.8 | 49.6 | 0.8 |

*Table 9.13: Number respondents (%) mentioning the current spacing between trees in use for woodlots*

| Kebele | 2m x 0.75m | 1m x 1m | 1m x 0.5m | 0.5m x 0.5m | 0.25m x 0.25m |
|---|---|---|---|---|---|
| Abe Jiru (n=60) | 43.3 | 5.0 | 38.3 | 10.0 | 3.3 |
| Dilla Aferara (n=60) | 0.0 | 1.7 | 0.0 | 44.8 | 53.4 |
| Chumie (n=60) | 23.3 | 0.0 | 20.0 | 53.3 | 3.3 |
| Derara Gorbe (n=60) | 0.0 | 0.0 | 0.0 | 51.7 | 48.3 |
| Overall (N=240) | 16.8 | 1.7 | 14.7 | 39.9 | 26.9 |

*Table 9.14: Number respondents (%) mentioning the main reasons for planting seedlings at less than 2m x 2m at study kebeles*

| Kebele | Lack of knowledge | Poor seedling survival | No demonstration | To get higher biomass |
|---|---|---|---|---|
| Abe Jiru (n=60) | 3.3 | 0.0 | 1.7 | 95.0 |
| Dilla Aferara (n=60) | 26.7 | 1.7 | 0.0 | 71.7 |
| Chumie (n=60) | 51.7 | 0.0 | 0.0 | 48.3 |
| Derara Gorbe (n=60) | 15.0 | 0.0 | 0.0 | 85.0 |
| Overall (N=240) | 24.2 | 0.4 | 0.4 | 75.0 |

*Table 9.15: Average eucalyptus planting distance (m) from the edge of water and land use types as proposed by respondents at study kebeles*

| Description of most influenced water and land use type | Proposed planting distance (m) by respondents in study Kebeles | | | |
|---|---|---|---|---|
| | Abe Jiru | Dilla Aferara | Chumie | Darara Gorbe |
| From Water point | 16 | 12 | 10 | 15 |
| From Shared Eucalyptus boundary nearby grazing field | 11 | 10 | 9 | 10 |
| From Enset edge of field | 15 | 12 | 10 | 12 |
| From maize/barley edge of field | 12 | 14 | 8 | 12 |

*Table 9.16: Number respondents (%) and their perception on effect of eucalyptus at study site*

| Items description | Strongly Agree | Agree | Unsure | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| Decline in food Production | 93.3 | 5.0 | 0.0 | 1.7 | 0.0 |
| Decline in livestock product | 80.4 | 17.5 | 0.4 | 1.7 | 0.0 |
| Increase in wood product | 49.6 | 39.6 | 4.6 | 6.2 | 0.0 |
| High Job Opportunity | 9.2 | 25.4 | 15.8 | 47.9 | 1.7 |
| Higher income | 31.7 | 32.5 | 7.1 | 27.1 | 1.7 |
| Soil fertility improved | 12.1 | 19.2 | 5.0 | 25.0 | 38.8 |
| Erosion control | 20.0 | 43.8 | 8.8 | 26.2 | 1.2 |
| Low biodiversity | 7.1 | 58.8 | 25.8 | 7.9 | 0.4 |
| Reduce water yield | 71.2 | 17.1 | 10.4 | 0.8 | 0.4 |

*Table 9.17: Number respondents (%) mentioning criteria in use for deciding rotation age of eucalyptus woodlots*

| Kebele | Need for money | Maturity of stand | Market Demand |
|---|---|---|---|
| Abe Jiru (n=60) | 96.7 | 0.0 | 3.3 |
| Dilla Aferara (n=60) | 91.7 | 5.0 | 3.3 |
| Chumie (n=60) | 100.0 | 0.0 | 0.0 |
| Derara Gorbe (n=60) | 86.7 | 13.3 | 0.0 |
| Overall (N=240) | 93.8 | 4.6 | 1.7 |

*Table 9.18: Number respondents (%) mentioning harvesting methods in use for eucalyptus woodlots*

| Kebele | Clear Cutting | Selective Cutting | Both clear cutting and selective cutting |
|---|---|---|---|
| Abe Jiru (n=60) | 100.0 | 0.0 | 0.0 |
| Dilla Aferara (n=60) | 40.0 | 3.3 | 56.7 |
| Chumie (n=60) | 88.3 | 0.0 | 11.7 |
| Derara Gorbe (n=60) | 28.3 | 36.7 | 35.0 |
| Overall (N=240) | 64.2 | 10.0 | 25.8 |

*Table 9.19: Average values of various coppice management activities in use for eucalyptus woodlots in study kebele*

| Coppice management activities | Unit | Mean | Minimum | Maximum |
|---|---|---|---|---|
| Time of first cut | year | 4 | 1 | 8 |
| First Reduction criteria-Height | meter | 2 | 1 | 5 |
| Second Reduction criteria-Height | meter | 5 | 2 | 7 |
| Interval of cutting rotation age | year | 5 | 3 | 7 |
| Replacement after coppice rotation | number | 6 | 4 | 12 |

*Table 9:20 Average coppice rotation age (year) in use for various eucalyptus products in study kebele*

| Forest product | Abe Jiru | Dilla Aferara | Chumie | Darara Gorbe |
|---|---|---|---|---|
| small pole (mager) | 4 | 4 | 4 | 5 |
| small pole (werag) | 5 | 6 | 5 | 6 |
| Medium pole (Kench) | 9 | 7 | 6 | 6 |

*Table 9.21: Number respondents (%) mentioning complete removal of stems, bark, leaf, branch/twig during harvesting of eucalyptus woodlots.*

| Kebele | Yes % | No % |
|---|---|---|
| Abe Jiru (n=60) | 96.7 | 3.3 |
| Dilla Aferara (n=60) | 98.3 | 1.7 |
| Chumie (n=60) | 100.0 | 0.0 |
| Derara Gorbe (n=60) | 100.0 | 0.0 |
| Overall (N=240) | 98.8 | 1.2 |

*Table 9.22: Number respondents (%) mentioning selling place of harvested eucalyptus product in study kebeke*

| Kebele | On production site | At village market |
|---|---|---|
| Abe Jiru (n=60) | 95.0 | 5.0 |
| Dilla Aferara (n=60) | 100.0 | 0.0 |
| Chumie (n=60) | 100.0 | 0.0 |
| Derara Gorbe (n=60) | 98.3 | 1.7 |
| Overall (N=240) | 98.3 | 1.7 |

*Table 9.23: Number respondents (%) mentioning availability of sufficient labor for eucalyptus at study kebeles*

| Kebele | Yes | No |
|---|---|---|
| Abe Jiru (n=60) | 98.3 | 1.7 |
| Dilla Aferara (n=60) | 96.7 | 3.3 |
| Chumie (n=60) | 100.0 | 0.0 |
| Derara Gorbe (n=60) | 96.7 | 3.3 |
| Overall (N=240) | 74.6 | 25.4 |

### 5.1.2 Key informant report

A complete list of the 20 interview participants is included as Attachment 1.

#### Eucalyptus Expansion Trends

In Melga district, in Abe Jiru kebele, key informants identified Eucalyptus globulus or blue gum as the only single species. The period of blue gum introduction is a recent phenomenon. Some 20 years back, blue gum planting was restricted to boundary niches, but recently, the conversion of grazing land and barley fields to woodlot fields increased across the kebele. Key informants stated that grazing is the major land use covered by woodlots, followed by barley fields. The motivating factors for the land use conversion, in order of importance, are income, construction, pressure from adjacent farms with blue gum, and fuelwood needs.

*Eucalyptus camaldulensis* or red gum is the only eucalyptus managed in Shebedina, Dale, and Darara districts. Key informants from those districts noted that red gum was introduced before 60 years on some farms of better-off farmers mainly as boundary planting. There is consensus among participants that large-scale conversion of grazing lands and maize fields took place during the last 15 years. Between the last 15 to 3 years, there was a further increase in expansion. Unfortunately, planting of red gum has decreased during the last two years. Participants identified the need for wood products for fuelwood, construction, and income generation as major drivers to expand red gum across the districts. In addition, pressure from adjacent eucalyptus woodlots belonging to neighbors is also a motivating factor for eucalyptus. Key informants from Chimie, Dilla Afarara, and Darara Gorbe noted that this factor is the most motivating one, particularly for farmers neighboring better-off and private investors living in urban centers.

## Effects of Eucalyptus on Environment and Mitigating Means

### Water Sources

With respect to the impact on water, key informants at Abe Jiru noted serious concern. Currently, some farmers plant blue gum as close as 2 m to springs and streams, reducing water quantity. Key informants at Darara Grobe mentioned that they do not have a river in their Kebele, but experience at one water spring shows that red gum reduces the available amount of water. A participant stated that the effect could be easily noticed on wetland commonly used as a communal grazing land. A similar experience was discussed by key informants at Dilla Aferara and Chumie kebeles. When asked what is a potential distance to plant eucalyptus to reduce effects, the figure 1-3 provides some general statistics extracted from the interviews. So, in terms of water aspects, participants share their proposal as shown (Fig. 1).

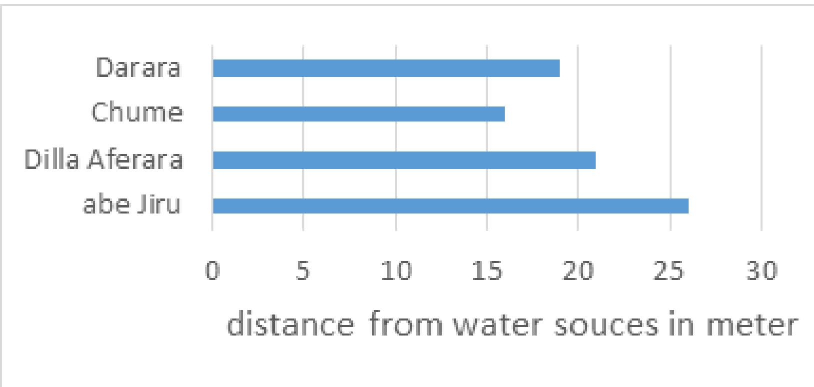



*Figure 1: Average distance of eucalyptus plantings to water sources as suggested by participants*

### Soil Fertility

In terms of adverse effects on soil, all participants were of the same opinion, indicating it dries the soil. Many key informants noted the adverse effect of red gum, but some interviewees shared the following.

### Crop Productivity

Key informants from the four kebeles have a similar perception of the adverse effect of eucalyptus on crops, and as a result, they never use it in intercropping. A key informant at Deraro noted that farmers can grow crops like coffee and even teff.

*From Abe Jiru*

*One of the farmer in our kebele converted his 0.25 ha blue gum woodlot to carrot and barley. He harvest about 200 quintals of carrot last season. This season he planted barley on the replaced plot, and it has a good growth performance. If we generalize that blue gum dry soil, we could be wrong.*

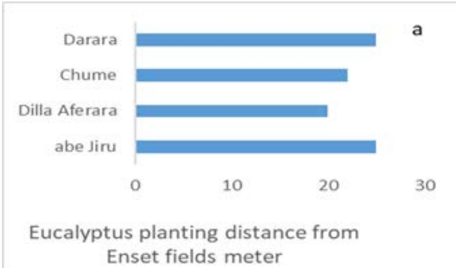
*Ato Gissara Ginbo*

*From Derara*

*After more than 10 years under woodlot plot was converted to maize crop last year. The growth performance of mixed maize and haricot bean is very promising. In my view, we should further see the consequences. He also noted that some farmers intercrop coffee and teff.*

*Ato Mengistu Kachara*

In all kebeles, key informants stated that the effect is so severe on Enset, and eucalyptus must be planted far away (ranging 20 to 25 m) from Enset fields (figure 2a). Overall, participants suggested the possible distance to minimize the adverse effect on maize and barley could range from 8 to 10.6 m (figure 2b). For shared boundaries, the distance should not be less than 12 to 18 m from the edge of crops.



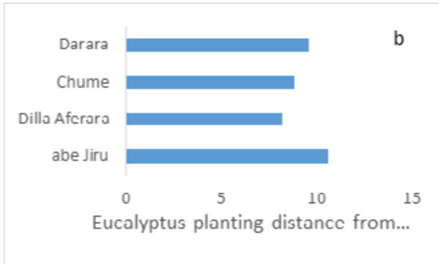




*Figure 2: Summary of key informant's suggestions on potential eucalyptus planting distances from Enset and maize/ barley fields*

### Biodiversity

There was some degree of variation across the study Kebeles when it came to the adverse effect of eucalyptus on biodiversity. In all kebeles, key informants stated that it is very difficult to find different plants and animals in eucalyptus woodlot plots as a result of high stem density that may reduce biodiversity or undergrowth vegetation. Depending on the situation, plants may grow under eucalyptus when planted in wider spacing. A key informant at Abe Jiru shared as follows:

> *„In our kebele there is strong wind problem. Farmer grow blue gum in boundaries by mixing with other plants to protect against wind. On boundaries blue gum is commonly planted at relatively wider spacing in between tree highland species Tericho (Euphorbia abyssinica), Welako (Erythrina abyssinica), Hocho (Juniperus procera), Gravela (Grevillea robusta), Tid (Cupressus lusitanica) and other shrubs.“*
>
> *Ato Kachara Birega*

### Grazing Land

In terms of the effect on grazing land, key informants at Abe Jiru noted special worry that blue gum took more than 60 percent of grazing, and animal product has decreased from time to time. Key informants at Dilla Aferara, Chumie, and Darara Grobe discussed similar experiences. In order to minimize the effect on grass fields, the key informants suggested suitable planting distances ranging from 8 m to 11m (Figure 3).

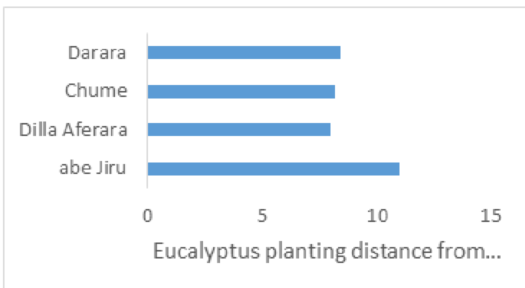



*Figure 3: suggested planting distance from grazing land.*

## What Are the Existing Eucalyptus Management Practices and Constraints?

**Planting Materials and Source**

Key informants at Abe Jiru stated that some 15 years back, they used to purchase eucalyptus seeds from Kofele district, but nowadays, less time has spent searching for seed sources and less money is spent on seed purchases. The key noted that they locally produced seed from mainly boundary-grown eucalyptus. In their kebele, tree seed collection, handling, processing, and sowing on beds are tasks for men. Better-off farmers have privileges to keep trees to produce more seeds than poor do. A participant shared as follows.

> *„In our kebele, there are some better-off farmers who produce blue gum seeds for sale for increased income and decreased economic risk by diversifying farm production. In addition, they grow seedlings in their own beds for sale to generate extra income through sale of seedlings."*
> *Ato Ulata Wanjala*

Key informants at Dilla Aferara and Chume noted that the main red gum seed sources are from their plantation. Since most of the farmers sell the red gum tree standing when it is without seed, the amount of seed produced in their kebele has reduced during the last five years. However, source seed is still from their kebele either from their plantations or through purchasing seeds or seedlings.

At Derara Grobe, key informants noted the majority of community members produce their seeds and seedlings, except some women-headed households and poor farmers. Unlike at Abe Jiru kebele, farmers selectively leave several trees to serve as mother trees during woodlot harvesting.

In all kebeles, key informants stated that eucalyptus is not raised in nurseries; rather, direct seeding on permanent land is the commonest practice. The seedbed for direct sowing is ploughed at least two times, and then the owner sets light fire on the soil. Men are responsible for sowing, mulching, and watering. Once the seedlings grow, mulch is removed step by step gradually. Matured seedlings are planted as summarized in Figure 4 in any planting niches even as close as 2m away from barley, maize water sources, and grazing fields. Key informants noted that on average, a 1.4 m x 0.4 m spacing is applied in study kebeles. When asked about the existence of appropriate advisory service on eucalyptus planting spacing from any organization, key informants stated no service has been provided yet.

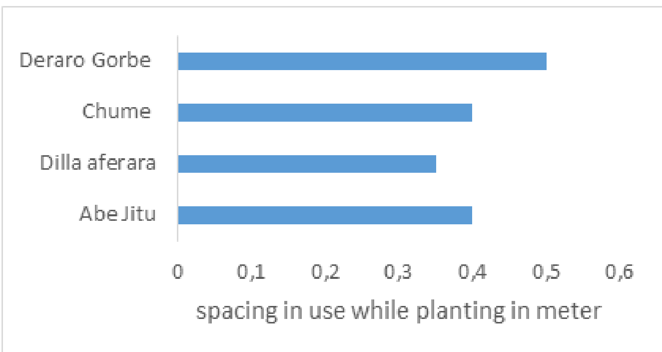



*Figure 4: summary statistics from key informant interviews on initial spacing (in meter) of eucalyptus*

Key informants at four kebeles stated that at least two times weeding is required to get good survival and growth of young eucalyptus seedlings. Once established, the first cut commonly done when the tree reaches an age ranging from 4 to 7 years. The former 4 years are commonly used in Dararo Gorbe, while the latter is practiced at Abe Jiru kebele. The respondents noted that the cutting height of the stump also ranges from 10 cm – 20 cm. The local community conducts the first coppice shoot reduction when eucalypts reach an age ranging from 1.5 and 3 m years (Figure 5) and second shoot reduction at a height ranging from 4 m to 6 m (Figure 6). In the study kebeles, coppice rotation period ranges from 4 to 7 years (figure 7).

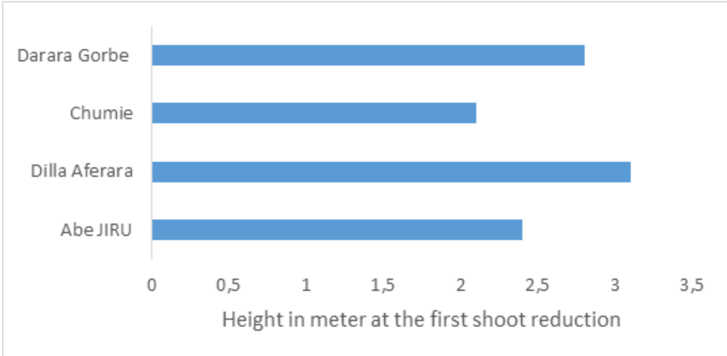



*Figure 5: Height (m) growth criteria for the determination of the first coppice shoot reduction*

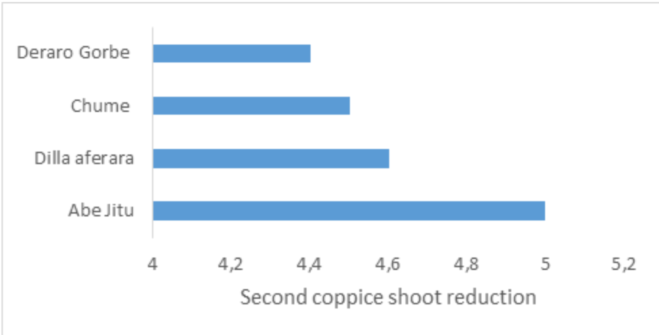



*Figure 6: Height (m) growth criteria for the determination of the second coppice shoot reduction*

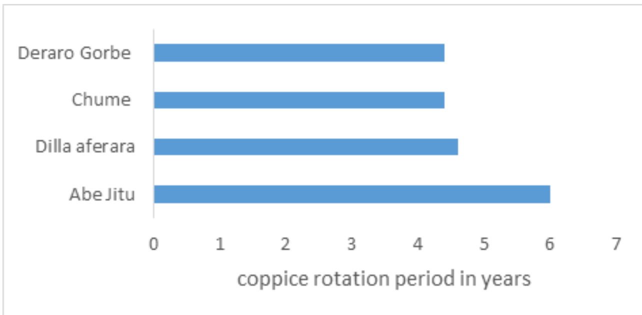



*Figure 7: Eucalyptus coppice rotation (year) at study kebeles*

Clear cutting is the commonest type of harvesting method at all kebeles, though some farmers practice selective cutting by leaving some stems. During each harvest, farmers at the study kebeles remove bark, branches, and leaves that should have been used to decompose and recycle nutrients from the harvest residues. At Abe Jiru kebele, key informants noted that after harvesting of red gum, stems are taken by the buyer, while all branches and leaves are removed by the family of the seller mainly by women. On the other hand, at Dilla Aferara and Chumie kebele, key informants stated mixed responses on branches and leaves removal after harvest. Depending on the agreement between the seller and buyer, removal of branches and leaves from harvested plots can be done either by the owner (farmer) in which women children are highly responsible or by the buyer. The case is completely different at Derara Gorbe kebele that the buyer has full right to collect and remove all stems, branches, and leaves. If the owner farmer is interested in having branches and leaves, he has to pay based on the agreement.

## What Opportunities Are Available for Eucalyptus Expansion in the Future?

One of the major reasons for the expansion of eucalyptus in the study kebeles includes its benefit in income generation. Respondents stated that income from eucalyptus is currently less attractive when compared to income from barley, maize, and vegetables. The prices of maize crops, vegetables, and coffee have increased and become a better alternative to red gum. The high increase in crop prices also increased the income of farmers, which motivated them to replace the eucalyptus woodlots fields with crop fields. Some respondents share the consequences of such development.

> *„Currently replacement of eucalyptus by crop production may not be promising unless all neighbor famers also replaced the woodlot annual crop. In our kebele, non-farming persons person leaving in towns own most of woodlots. Unless woodlot adjacent to crop fields also removed, completion from trees could be a serious problem.“*
>
> *Ato Wantu Waishe from Dilla Aferra and Ato Ayele Abebe fro Chumie*

A participant at Abe Jiru suggested that eucalyptus is so important for the protection of landslides that we have to manage it as a particular case. It is also important to control water erosion when planted on degraded lands and for gully rehabilitation. Participants noted a general trend during the last two years showing that converting eucalyptus woodlots to cropland is increasing. Most participants support the idea that eucalyptus woodlot is replaced by other land uses.

## What Are the Harmful Trees and/or Shrubs in Your Kebele? What Are Their Effects?

To have a common understanding, the description of harmful plants was introduced as „harmful plants refer to any plant that has an adverse effect when planted as a component of traditional agroforestry and planted in other land uses in your kebele.“ The key informants identified important harmful trees as follows:

*Table 10: harmful species identified by key informants:*

| No. | District / Kebele | Suggested harmful Species |
|---|---|---|
| 1 | Abe Jiru | *Cupressus lusitanica (Yeferenj Tid)* |
| 2 | Dilla Aferra | *Avocado, Yeferenj Tid, Grevilla* |
| 3 | Chumie | *Avocado, Mango* |
| 4 | Derara Gorbie | *Avocado, Mango, Grevillea* |

*Table 11: List of Key Informants and their Age*

| No. | Abe Jiru | Dilla Aferra | Chumie | Derara Gorbie |
|---|---|---|---|---|
| 1 | Aruga Birega (62) | Assefa Hakamo (57) | Abebe Mulugeta (62) | Darimo Dangiso (60) |
| 2 | Buta Bushura (65) | Gachamo Farie (67) | Awel Badishie (68) | Erane Tumicha (63) |
| 3 | Gissara Gimbo (70) | Sanbata Lentamo (64)<br>Ayele Abebe (65) | Lidamo Rakiso (66) | |
| 4 | Kachara Birega (60) | Solomon Filipos (55) | Mohamed Tariku (66) | Mengistu Kachara (59) |
| 5 | Ulata Wanjala (66) | Wantu Waishe (60) | Shokara Balako (57) | Samuel Emara (64) |

### 5.1.3 Focus Group Discussions

#### A) Who owns the land? How does land tenure affect eucalyptus expansion?

*Melga district at Abe Jiru kebele*

Among the Melga focus group participants, when asked about land and tree tenure, each group responded with, "There is no established women's right to plant, manage, utilize, and sell eucalyptus trees." The farming community living in our kebele has the right to use the land.

> *„A participant noted that land tenure is a prerequisite for tree planting. No one is interested to plant eucalyptus without having land though it growth anywhere except on stone and in a house."*
> *W/ro Shure Shona*

*Shebedino district at Dilla Aferara kebele*

Regarding land and tree tenure, FGD participants at Dilla Aferara kebele discussed a similar experience with the participants at Abe Jiru. Participants stated that some poor farmers contract out their land for eucalyptus planting to persons living in towns for a single or two harvests. In doing so, these farmers are involved in off-farm activities in towns.

*Dale district at Chumie kebele*

On the issue of land and tree tenure, FGD participants at Chumie kebele discussed a similar experience with the participants at Abe Jiru and Dilla Aferara kebele.

*Darara district at Derara Gorbe*

On the issue of land and tree tenure, FGD participants discussed a similar experience with the participants at Abe Jiru, Dilla Aferara kebele, and Chumie kebele.

#### B) Who has access to plant, manage, and utilize eucalyptus trees at different niches?

*Melga district at Abe Jiru kebele*

Participants are knowledgeable about the commonest eucalyptus planting niches in their Kebele, including boundaries, wetlands used for grazing, and woodlots. At all niches, women do not have the right to select, plant, manage, harvest, and sell eucalyptus. However, women can collect dead branches and leaves from standing trees. Additionally, participants mentioned that they have full right to collect and use branches and leaves after each harvest of eucalyptus.

*Shebedino district at Dilla Aferara kebele*

The participants identified the eucalyptus as "Barzafie," which is Eucalyptus camaldulensis, hereafter called red gum. Unlike blue gum at Abe Jiru kebele, red gum is dominantly managed as a woodlot plantation at Dilla Aferara. When asked why such expansion is unique to your Kebele, the FGD participants noted that the existence of a better price and market for red gum contributed most. As noted by a participant, this is not promising.

> *„In the last two years, the income a person earns from the maize sale is better than what one can get from sale of red gum at every four-year harvesting cycle."*
> *W/ro Sara Samuael*

*„Getting access dead branches and leaves depends on the type of agreement made between the seller and the buyer. If seller (farmer) decide to keep branches, twigs and leaves for house consumption, some price reduction may be required. In some cases, cost of collection and transport might discourage the buyer, in such case the buyer leave all at harvested plot."*
*W/ro Duwene Kayemo*

Next to woodlots, FGD participants stated that the other major niches in their kebele include boundary planting and front yard planting. Similar to FGD participants at Abe Jiru, FGD participants at Dilla Aferara stated that women in our kebele do not have the right to select, plant, manage, harvest, and sell eucalyptus. However, women can collect dead branches and leaves from standing trees and after every harvest. A participant indicated this is not always the case.

Contrary to the right to eucalyptus, FGD participants stated that women in our kebele have the right to plant avocado and papaya inside the garden and front yards. In addition, women have the right to harvest, utilize, and sell those fruits.

*Dale district at Chumie kebele*

On the issue of tree tenure, FGD participants discussed a similar experience with the participants at Abe Jiru and Dilla Aferara kebele. A participant noted that planting red gum by women could lead to conflict.

*„I planted one red gum in our front yard and employed the necessary care up to the harvesting stage. At four years of age I harvested it and used for fuel wood. Again, I managed the shoot grown from the stump up the third year the time when the tree reached maturity. At this time, I was told by my husband not to cut it. This led to a conflict between us."*

Similar to the discussion and experience of FGD at Dilla Aferara, the FGD participants at Chumie kebele stated that women in their kebele have no right to plant avocado and papaya inside and front yards. They also mentioned that in times of severe firewood shortage, men can cut some trees and make them available. In addition, women have the right to harvest, utilize, and sell the fruits.

*Darara district at Derara Gorbe*

In Derara district, red gum is the dominant eucalyptus species. Again, similar to FGD participants' views at Dilla Aferara and Chumie kebele, FGD participants at Derara Gorbe stated that women have no right to plant, manage, utilize, and sell eucalyptus trees. On the other hand, they can plant avocado, mango, and Psidium guajava (Zeituna) but not red gum. In addition, there is consensus among FGD participants that men sell the whole standing red gum with branches and leaves, and women do not get access to branches and leaves that are supposed to be used for fuel.

### C) Which tree species types do you prefer and why?

*Melga district at Abe Jiru kebele*

The participants stated that they prefer tree species that provide aromatic and firewood that we have the right to manage and utilize at home. The participants mentioned that Cupressus lusitanica (Yeferej tid) and Olea africana (Ejersa) trees planted in the front yard are preferred, with proper pruning of the former. From the former tree, we commonly get branches for firewood, while we use the splits of the latter species for smoking milk jars. A participant stated that the Korch tree is also an important tree for firewood, which women can use when needed.

*Shebedino district at Dilla Aferara kebele*

Participants of the FGD noted that avocado, papaya, and Ejersa are the preferred species by women. The participants stated that those trees provide food and income to be used for buying the needed items.

*Dale district at Chumie kebele*

On the tree preference issue, FGD participants discussed a similar experience with the participants at Dilla Aferara kebele. The participants stated that those trees provide food and income to be used for buying the needed items.

*Darara district at Derara Gorbe*

Participants of the FGD noted that avocado, mango, Zeituna, and Ejersa are the major species preferred by women. The participants stated that those trees provide food and income for buying the needed items. In addition, Ejersa is used for an aromatic purpose.

### D) What role do women play, and what knowledge exists for managing eucalyptus?

*Melga district at Abe Jiru kebele*

The FGD participants identified eucalyptus species in the area as Nich Barzaf (Eucalyptus globulus) or blue gum. As indicated above, women participants do not have the right to select, plant, manage, and utilize eucalyptus. But women have a great deal of knowledge on the management of blue gum trees. The FGD participants were able to articulate a broad range of knowledge on eucalyptus management, including selection, stocking and planting pattern trees, coppice management activities, harvesting methods, etc. Respondents noted that tree selection and seed collection can be from one's boundary eucalyptus tree in most cases or by buying seedlings from farmers at the local market in neighboring farms. When collected from own trees, men collect seeds, and women help during drying and processing activities. The participants also stated men are responsible for seedbed preparation and sowing, mulching, and watering. Once the seedlings reach plantable size, which is about 30-50cm height, men plant them at different niches using irregular spacing ranging from "tako" (about 12 cm) to half a chigilie (25 cm). They mentioned that chigilie is nearly equivalent to 50 cm. Men conduct weeding at least two times for the planted seedlings. There was consensus that men decide eucalyptus harvesting when the tree reaches 5 to 7 years of age and cut at "tako" to half a chigilie or 12-25 cm height from the ground. The FGD participants noted that clear-cutting is the commonest type of harvesting method for a woodlot while selective cutting is preferred for boundary blue gum. The respondents also noted that harvesting took place from October to February. Men do the first and second coppice reduction when the shoots reach about 1.5 -2 m and 4-6 m height, respectively.

*Shebedino district at Dilla Aferara kebele*

Respondents noted that tree selection and seed collection can be from one's boundary eucalyptus tree in most cases or by buying seedlings from farmers at the local market in neighboring farms. When collected from own trees, men collect seeds, and women help during drying and processing activities. The participants also stated men are responsible for seedbed preparation and sowing, mulching, and watering. Once the seedlings reach plantable size, which is about 30-50cm height, men plant them at different niches using irregular spacing at half a chigilie (20-25 cm). Men conduct weeding at least two times for the planted seedlings. There was consensus that men decide eucalyptus harvesting when the tree reaches 5 to 7 years of age and cut at "tako" cm height from the ground. The FGD participants also noted that clear-cutting is the commonest type of harvesting method for a woodlot while selective cutting is preferred for boundary blue gum. The respondents also noted that harvesting took place from October to February. Men do the first and second coppice reduction when the shoots reach about 1.5 -2 m and 4-6 m height, respectively.

*Dale district at Chumie kebele*

Participants at Chumie kebele have nearly similar knowledge regarding red gum. Once the seedlings reach plantable size, which is about 30-50cm height, men plant them at different niches using irregular spacing ranging from "tako" (about 12 cm) to half a chigilie (25 cm). They mentioned that chigilie is nearly equivalent to 50 cm. Men conduct weeding at least two times for the planted seedlings. There was consensus that men decide eucalyptus harvesting when the tree reaches 5 to 7 years of age and cut at "tako" to half a chigilie or 12-25 cm height from the ground. The FGD participants noted that clear-cutting is the commonest type of harvesting method for a woodlot while selective cutting is preferred for boundary blue gum. The respondents also noted that harvesting took place from October to February. Men do the first and second coppice reduction when the shoots reach about 1.5 -2 m and 4-6 m height, respectively. In terms of the rotation cycle, the participant noted that we have little knowledge.

*Darara district at Derara Gorbe*

Similar to discussed issues in the three previous FGDs, the FGD participants noted that the optimal planting size of red gum seedling ranges from 30-50cm height. They also noted that men are responsible for planting seedlings at different niches using irregular spacing of a chigilie. In addition, men are responsible for weeding at least two times after planting the seedlings. There was consensus that men decide the first eucalyptus harvesting when the tree reaches 5 years of age at "tako" 10 -12 cm height from the ground. The FGD participants noted that clear-cutting is the commonest type of harvesting method for a woodlot while selective cutting is preferred for boundary blue gum. The respondents also noted that harvesting took place from October to February. Men do the first and second coppice reduction when the shoots reach about 1.5 -2 m and 4-6 m height, respectively. In addition, they mention that the rotation cycle is normally about every 4-5 years for about 6-8 cycles.

### E) Contribution of eucalyptus to wood fuel requirements

*Melga district at Abe Jiru kebele*

The participants have a shared understanding of both income generation and fuelwood benefits of eucalyptus. The participants noted that fuelwood collection from standing trees and after each harvest is the women's responsibility. Women also collect eucalyptus foliage (leaves, very small branches at the end) and bark during harvest. There is consensus that eucalyptus trees supply a large share of overall fuelwood output from their farmlands, and the participants feel self-sufficient. However, a participant indicated that this is not the case for poor farmers who may not have an adequate amount of eucalyptus trees. These farmers generally respond to fuelwood shortages by purchasing more of their supplies or increasing the time spent on fuelwood collection. Some households also move down to burning straw and other less favored fuels. Measures to economize fuelwood use are also adopted, for example, using foods that take less time or fuel to cook, such as chukame, a food made up of enset, a staple food in the

Sidama Regional State.

*Shebedino district at Dilla Aferara kebele*

The FGD participants mentioned that the main source of energy is red gum wood. Women have the right to collect dead branches from standing trees and to cut dead trees for home consumption. In our kebele, the majority of households also use crop residue for fire.

*Dale district at Chumie kebele*

Similar issues like in the case of Aferara kebele were discussed among FGD participants.

*Darara district at Derara Gorbe*

The FGD participants mentioned that the main source of energy is red gum wood. Women have the right to collect dead branches from standing trees and to cut dead trees for home consumption. In our kebele, the majority of households also use crop residue for fire.

### F) What are your concerns regarding the influence of eucalyptus on the environment?

*Melga district at Abe Jiru kebele*

When asked about the current distance of planting eucalyptus from water courses, crops, and grass fields, the FGD participants stated blue gum is planted as close as about 2m. There is consensus among the participants that eucalyptus competes with crops and reduces productivity, which has implications for our food security. In addition, participants noted that the maintenance of current practices is problematic and makes the community rethink eucalyptus expansion. The FGD participants stated that blue gum strongly affects water availability; it does not allow plants with paramount importance for both ecological and economic roles when planted so close or under its canopy. There was consensus among FGD participants that the proper eucalyptus planting distance could be 17 – 20 meters from water sources and streams. The same 17 – 20 meters distance was recommended for planting by neighbors bordering farms. The participants also stated that the proper distance could be about 8-12 m, 30 - 40m, and 5-7 m from barley, enset, and grazing land, respectively.

*Shebedino district at Dilla Aferara kebele*

The FGD participants stated that red gum planting took place very close to water sources and streams. Participants noted that red gum significantly reduces crop yield and productivity. There was consensus among FGD participants that the appropriate proper planting distance of red gum from water sources, enset, and maize edge could be 20 meters, 40 m, and 10 m, respectively.

*Dale district at Chumie kebele*

When asked about the current distance of planting eucalyptus from water courses, crops, and grass fields, the participants stated red gum is planted as close as about 2m. There is consensus among the participants that eucalyptus competes with crops and reduces productivity, which has implications for food security. In addition, maintenance of current practices is problematic and makes the community rethink eucalyptus expansion. The FGD participants stated that blue gum strongly affects water availability; it does not allow plants with paramount importance for both ecological and economic roles when planted so close or under its canopy. There was consensus among FGD participants that the proper eucalyptus planting distance could be 20 meters from water sources and streams. The participants also stated that the proper distance could be about 12 m, 40m, and 10 m from barley, enset, and grazing land, respectively.

*Darara district at Derara Gorbe*

The FGD participants stated that red gum planting took place very close to water sources and streams. Participants noted that red gum significantly reduces crop yield and productivity. There was consensus among FGD participants that the appropriate proper planting distance of red gum from water source, enset, and maize edge could be 10 meters, 40 m, and 15 m, respectively.

### G) In your opinion, what opportunities are available for eucalyptus expansion in future?

*Melga district at Abe Jiru kebele*

Participants noted a general trend during the last two years showing that converting eucalyptus woodlots to cropland is increasing. Most participants support the idea that eucalyptus woodlot replacement by other land uses. A participant noted that sustainable production of wood products might be affected, but still, we need to have eucalyptus for fuelwood and construction.

> *„We need to keep some eucalyptus in boundaries for our children so that they construct houses and use as firewood like the one we have been doing. I do not support complete elimination this trees from our kebele since there is no other tree that currently replace eucalyptus for house construction and fuel wood. In addition, we already noticed that eucalyptus protect landslide on slope site."*
> *W/ro Aster Bunara*

*Shebedino district at Dilla Aferara kebele*

The FGD participants noted that red gum expansion is being reduced mainly due to the price increase of the grain market. It was mentioned that the price of maize crops, vegetables, and coffee has increased and become a better alternative to red gum. There is a general trend of the last two years in converting eucalyptus woodlots to cropland.

*Dale district at Chumie kebele*

The FGD participants noted that red gum expansion is being reduced mainly due to the price increase of the grain market. It was mentioned that the price of maize crops, vegetables, and coffee has increased and become a better alternative to red gum. There is a general trend of the last two years in converting eucalyptus woodlots to cropland.

*Darara district at Derara Gorbe*

Participants described the future expansion of red gum could be limited in the future. Participants noted that the increasing price of crops such as maize and vegetables is providing better alternatives to red gum. There is a general trend of the last two years in converting eucalyptus woodlots to cropland.

### H) In your opinion, what are the harmful trees and/or shrubs in your kebele?

*Melga at Abe Jiru kebele*

To establish a common understanding, the description of harmful plants was introduced as "harmful plants refer to any plant that has adverse effects when planted as a component of traditional agroforestry and in other land uses in your kebele." The FGD participants identified

Cupressus lusitanica (Yeferenj Tid) as an important harmful tree. The effects could be very severe when pruning is not done in a regular way.

*Shebedino district at Dilla Aferara kebele*

In terms of definition and description, similar issues were discussed as in the FGD at Abe Jiru. The FGD participants noted that Yeferenj Tid and Grevillea robusta.

*Dale district at Chumie kebele*

In terms of definition and description, similar issues were discussed as in the FGD at Abe Jiru. Yeferenj Tid, Bisanna, and Grevillea robusta.

*Darara district at Derara Gorbe*

In terms of definition and description, similar issues were discussed as in the FGD at Abe Jiru. Yeferenj Tid and Grevillea robusta.

*Table 12: List of FGD participants*

| No. | Melga<br>Abe Jiru | Shebdino<br>Dilla Aferara | Dale<br>Chumie | Darara<br>Derara Gorbe |
|---|---|---|---|---|
| 1 | Alemitu Fanalk | Asnakech Maja | Agegnehu Abebe | Abebech Belayneh |
| 2 | Aster Bunar | Bekelech Dawit | Debritu Girma | Bereket Wasuhun |
| 3 | Endatu Wasie | Birtunan Neka | Etenesh Shibiru | Hana Erana |
| 4 | Shure Shona | Duwene Kayemo | Mindaye Beshir | Hirut Kafo |
| 5 | | Elfe Sharew | Ramatie Mohamed | Jirame Anza |
| 6 | | Sara Samuael | Rawda Esmael | Kemisie Shalamo |
| 7 | | | Rukiya Temesgen | Nadewe Arba |
| 8 | | | Sofiya Siraj | Shigute Babule |
| 9 | | | | Tadelech Kebede |
| 10 | | | | Yeshi Worku |

### 5.1.4 Response of experts at district level

*Table 13.1: number of respondents in percent in terms of education*

| Kebele | 1st degree | Msc | Total |
|---|---|---|---|
| Abe Jiru (n=3) | 33.3 | 66.7 | 100.0 |
| Dilla Aferara (n=3) | 100.0 | 0.0 | 100.0 |
| Chumie (n=3) | 100.0 | 0.0 | 100.0 |
| Derara Gorbe (n=3) | 100.0 | 0.0 | 100.0 |
| Overall (N=12) | 83.3 | 16.7 | 100.0 |

*Table 13.2: Mean of years in eoreda experience with standard deviation*

| Kebele | Mean | Count | Std. Deviation |
|---|---|---|---|
| Abe Jiru (n=3) | 12 | 3 | 4 |
| Dilla Aferara(n=3) | 11 | 3 | 5 |
| Chumie (n=3) | 15 | 3 | 6 |
| Ademe Darara (n=3) | 13 | 3 | 5 |

*Table 13.3: Type of Eucalyptus prevalent in percentage*

| Kebele | E globulus *(Nech bahirzaf)* | E. camldulensis *(keyi bahirzaf)* |
|---|---|---|
| Abe Jiru (n=3) | 100 | 0 |
| Dilla Aferara(n=3) | 0 | 100 |
| Chumie (n=3) | 0 | 100 |
| Ademe Darara (n=3) | 0 | 100 |
| Overall (N=12) | 25 | 75 |

All experts at Abe Jiru mentioned that wet land is the type of land usually converted to woodlot or boundary planting which aligns with the statements of two respondents each at Dilla Aferara and Ademe Darara (Table 13.4). Two the experts stated that graze land is converted woodlot or boundary planting.

*Table 13.4. Number of respondents mentioning the land use type converted to woodlot or boundary planting*

| Kebele | Crop land | Grazing land | Wet land | Degraded land | Waste land | Other specific |
|---|---|---|---|---|---|---|
| Abe Jiru (n=3) | 0 | 0 | 100 | 0 | 0 | 0 |
| Dilla Aferara(n=3) | 0 | 33.30 | 66.70 | 0 | 0 | 0 |
| Chumie (n=3) | 0 | 66.70 | 0 | 33.30 | 0 | 0 |
| Ademe Darara (n=3) | 0 | 33.30 | 66.70 | 0 | 0 | 0 |

*Table 13.5. Number of respondents (%) and energy utilization in the study kebele*

| **Source of Energy** | **Number of respondents (%) and energy utilization** | | | |
|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | **4th** |
| Firewood | 100.0 | 0.0 | 0.0 | 0.0 |
| Crop Residue | 0.0 | 83.3 | 16.7 | 0.0 |
| Charcoal | 0.0 | 8.3 | 58.3 | 33.3 |
| Cow Dung | 0.0 | 8.3 | 25.0 | 66.7 |

All household respondents adjacent farm with woodlots is a motivating factors to converted different land sues to woodlot and boundary plantation (*see table above*).

*Table 13.6. Number of respondents (5) and motivating factors to convert land to woodlot and boundary plantation*

| **Item description** | **Abe Jiru** | **Dilla Aferara** | **Chumie** | **Ademe Darara** |
|---|---|---|---|---|
| Influence of adjacent farm woodlots | 100.0 | 100.0 | 100.0 | 100.0 |
| Demand for wood products | 66.7 | 0.0 | 0.0 | 0.0 |
| High price of wood products | 0.0 | 0.0 | 66.7 | 66.7 |
| High profitability | 33.3 | 0.0 | 0.0 | 33.3 |
| Low establishment & management cost | 0.0 | 0.0 | 0.0 | 0.0 |
| Land degradation and decline in crop productivity | 0.0 | 0.0 | 33.3 | 0.0 |
| Special attributes of the tree species | 0.0 | 0.0 | 0.0 | 0.0 |

With regard to planting site preparation at the study sites, 58.3 % of the experts pit (planting whole) digging followed by ploughing once and ploughing three times and above (table 13.7)

*Table 13.7. Number respondents (%) mentioning types of site preparation at the study sites*

| **Kebele** | **Ploughing once** | **Ploughing twice** | **Ploughing three times and above** | **Pit digging (planting hole)** | **Total** |
|---|---|---|---|---|---|
| Abe Jiru (n=3) | 0 | 33.30 | 0 | 66.70 | 100 |
| Dilla Aferara(n=3) | 66.70 | 0 | 33.30 | 0 | 100 |
| Chumie (n=3) | 0 | 0 | 33.30 | 66.70 | 100 |
| Ademe Darara (n=3) | 0 | 0 | 0 | 100 | 100 |
| Overall (N=12) | 16.70 | 8.30 | 16.70 | 58.30 | 100 |

Nine of the experts noted that bare root seedlings are the dominant planting material for woodlot establishment (table 13.8)

*Table 13.8. Number respondents (%) mentioning seedling sources material for woodlot establishment*

| Kebele | Bare root seedlings | Direct Seedling | Both potted and bare rooted seedling | Total |
|---|---|---|---|---|
| Abe Jiru (n=3) | 100 | 0 | 0 | 100 |
| Dilla Aferara(n=3) | 66.70 | 0 | 33.30 | 100 |
| Chumie (n=3) | 100 | 0 | 0 | 100 |
| Ademe Darara (n=3) | 33.30 | 33.30 | 33.30 | 100 |
| Overall (N=12) | 75 | 8.30 | 16.70 | 100 |

*Table 13.9. Number of respondents (%) mentioning source of planting materials of eucalyptus species*

| Kebele | Own Nursery | Purchase from gov't Nursery | Purchase from private Nursery | Total |
|---|---|---|---|---|
| Abe Jiru (n=3) | 0 | 0 | 100 | 100 |
| Dilla Aferara(n=3) | 0 | 33.30 | 66.70 | 100 |
| Chumie (n=3) | 100 | 0 | 0 | 100 |
| Ademe Darara (n=3) | 66.70 | 0 | 33.30 | 100 |
| Overall (N=12) | 41.70 | 8.30 | 50 | 100 |

Experts (n=12) noted the current space in use be 41.7%, 33.3% 16.7% and 0.5m x 0.5m, 0.25m x 0.25m and 1m x 0.5m (Annex 5.1.4; table 13.10)

*Table 13.10. Number respondents (%) mentioning the current spacing between trees in use for woodlots*

| Kebele | 1m x 1m | 1m x 0.5m | 0.5m x 0.5m | 0.25m x 0.25m |
|---|---|---|---|---|
| Abe Jiru (n=3) | 33.30 | 0 | 33.30 | 0 |
| Dilla Aferara(n=3) | 0 | 33.30 | 66.70 | 0 |
| Chumie (n=3) | 0 | 0 | 33.30 | 66.70 |
| Ademe Darara (n=3) | 0 | 33.30 | 33.30 | 33.30 |
| Overall (N=12) | 8.3 | 16.7 | 41.7 | 33.3 |

*Table 13.11. Number respondents (%) mentioning the main reasons for planting seedlings at less than 2m x 2m at study kebeles*

| Kebele | Lack of knowledge | Poor seedling survival | No demonstration | To get higher biomass | Total |
|---|---|---|---|---|---|
| Abe Jiru (n=3) | 0 | 0 | 33.30 | 66.70 | 100 |
| Dilla Aferara(n=3) | 0 | 33.30 | 0 | 66.70 | 100 |
| Chumie (n=3) | 33.30 | 0 | 0 | 66.70 | 100 |
| Ademe Darara (n=3) | 33.30 | 0 | 0 | 66.70 | 100 |
| Overall (N=12) | 16.70 | 8.30 | 8.30 | 66.70 | 100 |

*Table 13.12. Number respondents (%) mentioning decline of forage productivity as a result of adjacent woodlot expansion*

| **Kebele** | **Yes** |
|---|---|
| Abe Jiru (n=3) | 100 |
| Dilla Aferara(n=3) | 100 |
| Chumie (n=3) | 100 |
| Ademe Darara (n=3) | 100 |
| Overall (N=12) | 100 |

According to the experts, mean distance of eucalyptus from crop and other resources rages from 3m to 22m.

*Table 13.13. Mean distance of eucalyptus from crop and other resources*

| **Kebele Abe Jiru** | **Dilla** | **Aferara** | **Chumie** | **Ademe Darara** |
|---|---|---|---|---|
| Abe Jiru (n=3) | 5 | 16 | 13 | 8 |
| Dilla Aferara(n=3) | 4 | 7 | 13 | 10 |
| Chumie (n=3) | 6 | 16 | 13 | 13 |
| Ademe Darara (n=3) | 3 | 22 | 13 | 15 |

According to experts suggestions average eucalyptus planting distance (m) from the edge of water ranges from 5m to 16m (Annex 5.1.4; table 13.14)

According to experts suggestions average eucalyptus planting distance (m) from the share eucalyptus boundary ranges from 4m to 13m, from the edge of enset field ranges from 6m to 16m and from the edge of maize barley ranges from 3m to 22m (Annex 5.1.4; table 13.14).

*Table 13.14. Average eucalyptus planting distance (m) from the edge of water and land use types as proposed by respondents at study kebeles*

| **Kebele** | **Abe Jiru** | **Dilla Aferara** | **Chumie** | **Ademe Darara** |
|---|---|---|---|---|
| From Water point | 5 | 16 | 13 | 8 |
| Share Euclaptus boundary | 5 | 7 | 13 | 10 |
| Enset or Coffee | 6 | 16 | 13 | 13 |
| Maize crop | 3 | 22 | 13 | 15 |

*Table 13.15. Number respondents (%) mentioning harvesting methods in use for eucalyptus woodlots*

| Kebele | Clear cutting | Selective cutting | Both clear cutting and selective | Other specify | Total |
|---|---|---|---|---|---|
| Abe Jiru (n=3) | 0 | 0 | 66.70 | 33.30 | 100 |
| Dilla Aferara(n=3) | 66.70 | 33.30 | 0 | 0 | 100 |
| Chumie (n=3) | 0 | 0 | 100 | 0 | 100 |
| Ademe Darara (n=3) | 33.30 | 0 | 66.70 | 0 | 100 |
| Overall (N=12) | 25 | 8.30 | 58.30 | 8.30 | 100 |

According to experts average coppice rotation age (year) in use for various eucalyptus products in study kebele ranges from 3–5 years for small pole (Mager), 5-8 years for small pole (werag) and from 7-11 years for Medium pole (Kench) (table 13.16)

*Table 13.16. Average coppice rotation age (year) in use for various eucalyptus products in study kebele*

| Kebele | Abe Jiru | Dilla Aferara | Chumie | Ademe Darara | Overall |
|---|---|---|---|---|---|
| Small pole (mager) | 4 | 3 | 4 | 5 | 4 |
| Small pole (werag) | 5 | 5 | 5 | 8 | 6 |
| Medium pole (Kench) | 7 | 9 | 7 | 11 | 9 |

Large proportion of experts (N-12; 66.7%) farmer practice complete removal of stems, bark, leaf, branch/twig during harvesting of eucalyptus woodlots at the study site

*Table 13.17. Number respondents (%) mentioning complete removal of stems, bark, leaf, branch/twig during harvesting of eucalyptus woodlots.*

| Kebele | Yes | No |
|---|---|---|
| Abe Jiru (n=3) | 66.70 | 33.30 |
| Dilla Aferara (n=3) | 66.70 | 33.30 |
| Chumie (n=3) | 0 | 100 |
| Ademe Darara (n=3) | 0 | 100 |
| Overall (N=12) | 33.30 | 66.70 |

Assorting to the experts veiw, average values of various coppice management activities in use for eucalyptus woodlots include time of first cut ranges 4-6 year, first coppice reduction ranges 2-4m height, second coppice reduction ranges 6-7 m height, interval of cutting rotation age ranges 4-6 years and replacement after coppice rotation number of times ranges in 5-8 times (table 13.18)

*Table 13.18. Average values of various coppice management activities in use for eucalyptus woodlots in study kebele*

| Kebele | Abe Jiru | Dilla Aferara | Chumie | Ademe Darara | Overall |
|---|---|---|---|---|---|
| time of first cut | 6 | 5 | 4 | 6 | 5 |
| first reduction criteria height | 4 | 3 | 2 | 2 | 3 |
| Second reduction criteria height | 7 | 6 | 6 | 7 | 6 |
| interval of cutting rotation age | 5 | 5 | 4 | 6 | 5 |
| Replacement after coppice | 6 | 6 | 5 | 8 | 6 |

Experts (N=12) stated that competition with other crop range from high (8.3%) to very high (91.7%); soil Fertility decline from high (8.3%) to very high (75%); Lower water sources very high (83.3%) to very high (83.4%); Biodiversity (41.7%) to very high (25%) table 19.

*Table 13.19. Number respondents (%) and their perception on effect of eucalyptus at study site*

| | Very Low | Low | Medium | High | Very High |
|---|---|---|---|---|---|
| Competition with other crop | 0 | 0 | 0 | 8.30 | 91.70 |
| Soil Fertility decline | 16.70 | 0 | 0 | 8.30 | 75 |
| Lower water sources | 0 | 0 | 8.30 | 8.30 | 83.30 |
| Invasive | 16.70 | 16.70 | 41.70 | 25 | 0 |
| Biodiversity | 8.30 | 8.30 | 16.70 | 41.70 | 25 |
| traditional sustainable food | 8.30 | 16.70 | 0 | 33.30 | 41.70 |
| Grazing land | 0 | 0 | 0 | 66.70 | 33.30 |
| Not preferred as a feed | 50 | 0 | 16.70 | 0 | 33.30 |
| Sidama Culture | 8.30 | 16.70 | 58.30 | 8.30 | 8.30 |

*Table 13.20. Average coppice rotation age (year) in use for various eucalyptus products in study kebele*

| Kebele | Abe Jiru | Dilla Aferara | Chumie | Ademe Darara | Overall |
|---|---|---|---|---|---|
| Small pole (mager) | 11 | 12 | 11 | 11 | 11 |
| Small pole (werag) | 16 | 13 | 16 | 15 | 15 |
| Medium pole (Kench) | 20 | 15 | 20 | 17 | 18 |

*Table 13.21. Number respondents (%) and their perception on effect of eucalyptus at study site*

| | Strongly Agree | Agree | Unsure | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| Decline in food Production | 50.0 | 41.7 | 0.0 | 8.3 | 0.0 |
| Decline in livestock product | 33.3 | 41.7 | 16.7 | 8.3 | 0.0 |
| Increase in wood product | 33.3 | 25.0 | 41.7 | 0.0 | 0.0 |
| High Job Opportunity | 0.0 | 8.3 | 25.0 | 58.3 | 8.3 |
| Higher income | 25.0 | 8.3 | 58.3 | 8.3 | 0.0 |
| Soil fertility improved | 8.3 | 16.7 | 0.0 | 50.0 | 25.0 |
| Erosion control | 25.0 | 41.7 | 16.7 | 16.7 | 0.0 |
| Low biodiversity | 16.7 | 33.3 | 25.0 | 25.0 | 0.0 |
| Reduce water yield | 50.0 | 33.3 | 0.0 | 16.7 | 0.0 |

*Table 13.22: list of experts involved in the study*

| No | Name | Kebele |
|---|---|---|
| 1 | Kaleb Birhanu | Derara Gorbe |
| 2 | Habtamu Tariku | Derara Gorbe |
| 3 | Teshome Kayamo | Derara Gorbe |
| 4 | Mesfin Daye | Chumie |
| 5 | Tadesse Teshkitie | Chumie |
| 6 | Dabaro Dansamo | Chumie |
| 7 | Degefu Debeko | Dilla Aferara |
| 8 | Yacob Wonago | Dilla Aferara |
| 9 | Mulugeta Muntasha | Dilla Aferara |
| 10 | Adano Sinad | Abe Jiru |
| 11 | Beyenech G/sadik | Abe Jiru |
| 12 | Ayele Belachewu | Abe Jiru |

## 5.2 Annex 2: Literature review on impact of eucalyptus and its management

### 5.2.1 Abstract

The abundance of studies and reviews on eucalyptus distribution and its environmental impacts in the tropics has increased significantly in recent decades. The introduction of Eucalyptus species to Ethiopia for various purposes has spanned over a century. Currently, species like *E. globulus* and E. camaldulensis exhibit high adaptability and wide distribution, even on degraded lands. The socio-economic contribution of Eucalyptus as a short rotation, high-yielding cash crop is noteworthy, making it the primary species for many Ethiopian farmers and wood lot growers. This review aims to enhance understanding of the ecological and socioeconomic impacts of eucalyptus, particularly in Sidama Regional State. Approximately 67 sources were consulted, with 70% being published journal articles, 12% PhD theses, 10% MSc theses, and 8% various reports. In Ethiopia, well-managed eucalyptus contributes to wood self-sufficiency and provides significant cash income, contributing to poverty reduction and food security for rural households. Proper management is crucial to prevent environmental harm, and with good practices, eucalyptus can offer ecological benefits such as reduced runoff, erosion control, biomass provision, and biodiversity conservation. The controversy around eucalyptus water consumption is discussed, emphasizing the importance of location-specific considerations. Eucalyptus is also considered as an agroforestry component in moist areas, promoting increased productivity, income, biofuel production, and environmental improvement.

### 5.2.2 Introduction

Australia, the native place of Eucalyptus, is home to around 800 species (ABARES, 2019). Eucalyptus is a highly successful tree, adapting to various habitats with evolutionary features such as tolerance to moisture stress, low soil fertility, fire damage, and insect damage. The choice of Eucalyptus species for plantations should consider factors like wood production, ecological sustainability, marketability, and local community utility. Plantation establishment can take various forms, including small woodlots, groups, belts, lines, and single trees in both rural and urban areas. In Ethiopia, about 55 Eucalyptus species are known, with five to ten widely planted, mainly for fuelwood and construction material.

### 5.2.3 Approach Employed

This paper is based on extensive literature review, with over 80% comprising original research papers. The author's teaching and research experiences in Sidama National Regional State, along with field observations, contribute to the presented information on why, where, and how Eucalyptus is grown in Ethiopia.

### 5.2.4 Eucalyptus Impacts

**Biodiversity**

Native eucalypt forests support diverse wildlife adapted to them in ways non-Australian fauna have not. Plantation stands generally have lower animal species diversity than natural forests. Eucalyptus plantations in Ethiopia show both positive and negative interactions with other plants. Reports indicate good natural regeneration of native species in certain Eucalyptus plantations, with varying effects on ground cover diversity. The density and diversity of woody plant species in Eucalyptus plantations compared favorably with adjacent natural forests.

*Table 14.1. List of species in the ground cover of the four sites, including seedlings of shrubs and trees less than 0.5 m tall, and the percentage coverage of the species (Michelsen et al. 1993)*

| Forest type | No. of plant spps | Performance |
|---|---|---|
| Cupressus soil | 21 | most plants poorly developed and/or sterile |
| Eucalyptus soil | 57 | most plants normally developed |
| Juniperus soil | 31 | most plants normally developed |
| Natural forest soil | 35 | most plants normally developed |

*BN: Natural Juniperus-Olea-Podocarpus forest site*

Table 14.2. Comparison woody plant species regeneration and mean density in ha under *E. globulus* plantations and adjacent forests at Munessa-Shashemene Forest

| Forest type | Age (years) | Species richness | Density in ha |
|---|---|---|---|
| *E. globulus* | 17 | 27 | 7730 |
| C. lusitanica | 18 | 18 | 5770 |
| C. lusitanica | 24 | 11 | 1630 |
| Pinus radiata | 24 | 15 | 3130 |
| P. patula | 24 | 17 | 3940 |
| Natural forest | | 27 | 11680 |

*Source: Senbeta and Teketay (2001)*

In Entoto Mountain, *E. globulus* plantation stands with lower density harbor more regenerated plant species than those with higher density (Fekadu Debushe et al., 2010). The low-density *E. globulus* stands (C, Table 3) exhibited the highest mean values of Shannon species diversity (3.129) and species richness (61), followed by C2 with 2.872 species diversity and species richness (58), while the high-density stands (C3) exhibited the lowest mean values of Shannon species diversity (2.653), species richness (45). In total, 41 naturally regenerated woody species were recorded in the Entoto *E. globulus* plantation. The trend indicates a decrease in the density of naturally regenerated woody species with an increase in the density of *E. globulus*. The less dense stands of Eucalyptus globulus plantations harbor more naturally regenerated woody species than the denser stands of Eucalyptus globulus plantation, or vice versa. All the afore-mentioned evidence shows that in high rainfall areas, *E. globulus* plantations play a role in fostering the regeneration of native plant species.

Table 3. Shannon-Wiener diversity index (H'), species richness and species evenness, under the three categories of *E. globulus* plantation in Entoto

| Stem density /ha category | Shannon index (H) | Species richness (S) | Evenness (E) | Density in ha of regenerated woody plants |
|---|---|---|---|---|
| C1 = < 64 | 3.129 | 61 | 0.761 | 1291 |
| C2 = 64 to 83 | 2.872 | 58 | 0.701 | 1259 |
| C3 = > 83 | 2.653 | 45 | 0.697 | 1066 |

*Source: (Fekadu Debushe et al. 2010)*

**Water sources, springs, water reservoirs, and wetland areas**

In dry climates or areas with small water reserves, eucalyptus plantations may reduce the amount of stream water and groundwater available to local farmers and families, especially in the dry season. However, the water use of Eucalyptus is a controversial issue, and the impacts of other fast-growing trees on water resources are almost similar. Some eucalyptus tree species lower the groundwater table due to their high rate of evapotranspiration, exacerbating desertification (FAO, 2009). The water uptake rate by the Eucalyptus plantation is expected to be high at a young age due to its fast growth habit. At the peak of the dry season, eucalyptus transpires 4-5 times more than Podocarpus and Cupressus trees of similar size (Fetene and Beck, 2004). Eucalyptus has three times the fine root biomass in the surface soil compared to other mixed plantations, indicating that planting herbaceous crops in association and adjacent to eucalyptus may lead to water competition stress on crops (Gindaba, 2003). In heavily waterlogged areas and floodplains, Eucalyptus trees have commonly been planted to drain water, which could otherwise harbor mosquitoes (FAO, 2009). Comparing water use in plantations of eucalypts, indigenous forest, and annual agricultural crops (Calder, 1994) reported: (1) in the dry zone, the water use of a young eucalyptus plantation was no greater than that of indigenous dry deciduous forest; (2) the annual water use of eucalyptus and indigenous forest was equal to annual rainfall; (3) the annual water use of either indigenous or plantation forests was higher than that of agricultural crops.

According to Davidson (1989), Eucalyptus species need, on average, 785 liters of water to produce a kg of dry biomass, as opposed to agricultural crops that consume 1000 to over 3000 liters of water to produce a kg of dry biomass. When precipitation was close to the mean annual precipitation of 1350 mm, there was enough water to supply the demands of Eucalyptus grandis (Almeida et al., 2006). Afforestation with eucalyptus species negatively affects soil water storage and the flow to small streams and rivers, due to their high rates of evapotranspiration, and such negative effects would be worse in a context of climate warming and aridization (Liu et al., 2017; Ouyang et al., 2018). Water consumption by eucalypts can be reduced by planting trees farther apart or by thinning existing plantations (Davidson, 1989). He also reported that eucalypts consumed less water per unit of biomass produced than other species in India and China.

About soil erosion by water under trees, there is no evidence to single out eucalypts for special criticism. The erodibility (physical characteristics) of soils is more important than crop management, and crop management is more important than the type of tree crop. The erosive energy of rain under tree crowns depends much on the surface area of individual leaves; large leaves produce larger size droplets, which have a greater impact energy on the ground. The erosive energy of rain under the crowns would be least for narrow-leaved eucalypts (e.g., E. camaldulensis ) occupying the mid-range, and the broad-leaved eucalypts (e.g., *E. globulus*) at the top of the range for eucalypts (Davidson, 1989).

### Natural forests soil impacts

The status of soil conditions under eucalyptus plantations and other perennial-based land uses has been investigated by different researchers. For example, Michelsen et al., (1993) reported a low content of organic matter and N under eucalyptus compared to the other three forest types (Table 4). The soils of the Cupressus and Eucalyptus plantations generally had the lowest nutrient content. Calcium and K were low in the Eucalyptus soil, followed by the Cupressus soil. In another study, Amsalu and Hailu, (2019) reported that the concentrations of total nitrogen and total organic matter under the eucalyptus plantation were significantly lower than in natural forest. The natural vegetation of Etoto Mountain is an Afro-montane forest, and agricultural land (Figure 1). Potassium cations under the eucalyptus plantation were significantly lower than natural forest soils.

*Table 14.4. Selected soil properties in Menagesha suba forests and adjacent eucalyptus forest*

| Forest type | Depth (cm) | OM (%) | N (%) | P (PPM) | Exchangeable cations (meq per 100g) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Na | K | Ca | Mg |
| Cupressus soil | 0-40 | 6.13 | 0.268 | 2.6 | 0.669 | 1.04 | 19.26 | 4.97 |
| | 50-100 | 1.02 | 0.059 | 0.8 | 0.644 | 1.03 | 10.91 | 4.5 |
| Eucalyptus soil | 0-40 | 5.70 | 0.274 | 4.2. | 0.644 | 0.800 | 14.83 | 5.20 |
| | 50-100 | 0.8 | 0.052 | 2.3 | 0.666 | 0.90 | 5.87 | 4.85 |
| Juniperus soil | 0-40 | 6.76 | 0.337 | 17.6 | 0.627 | 1.53 | 26.05 | 5.53 |
| | 50-100 | 1.68 | 0.112 | 6.8 | 0.596 | 1.52 | 15.93 | 5.04 |
| Natural forest soil | 0-40 | 6.94 | 0.339 | 6.9 | 0.604 | 1.57 | 25.82 | 6.20 |
| | 50-100 | 0.82 | 0.053 | 4.8 | 0.773 | 1.00 | 12.62 | 5.2 |

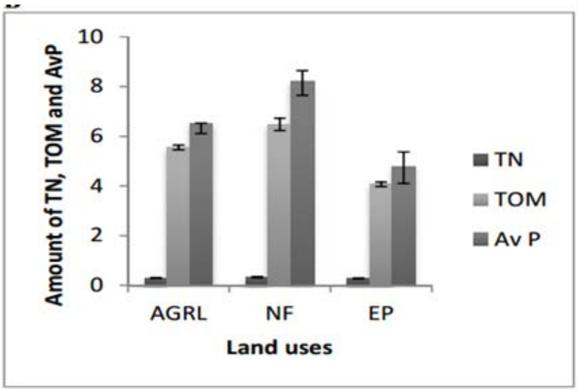



*Figure 8. Selected soil properties in Etoto Mountain is an Afro-montane forest and adjacent eucalyptus forest (Amsalu and Hailu, 2019).*

Liang et al. (2016) evaluated soil status under interior church forests, at the edge, eucalyptus, and agricultural plots. Organic matter content differed significantly between the interior, edge, eucalyptus, and agriculture plots of the 20 study sites (Table 5). The mean organic matter contents of the interior (16.5%) and edge (15.4%) plots were not significantly different. However, both the mean organic matter contents of the interior and edge plots were significantly different from the mean organic matter content of the eucalyptus (7.71%) and agriculture plots (4.83%). Their report also indicates that soils in eucalyptus stands had significantly higher organic matter content than agricultural soils. Additional analysis among only the church forest sites where eucalyptus plots were known to have previously been farmland (n = 7) yielded a significant difference between the mean organic matter content across the eucalyptus plots (8.70%) and the agriculture plots. There was a significant difference found in the mean pH levels of the interior, edge, eucalyptus, and agriculture plots. The mean nitrogen levels were not statistically different between the interior plots (34.4 mg/kg) and edge plots (35.0 mg/kg), nor between the eucalyptus plots (14.9 mg/kg) and agriculture plots (8.55 mg/kg). There was a statistically significant difference between the phosphorus levels of the interior, edge, eucalyptus, and agriculture plots of the sampled church forests ($p < 0.05$). Unlike total nitrogen and organic matter, the eucalyptus plots did not have a mean phosphorus level (34.7 mg/kg) that was statistically different from either of the indigenous plots (interior and edge) (Table 5). The mean phosphorus content of the agriculture plots (18.9 mg/kg), however, was significantly lower than the interior plots (48.7 mg/kg, $p < 0.01$), as well as the edge plots (47.3 mg/kg, $p < 0.05$).

*Table 14.5 Average concentration of pH, organic matter, nitrogen, and phosphorus under four land uses (Liang et al., 2016)*

| Land use | pH | Organic matter (%) | N (mg/kg) | P (mg/kg) |
|---|---|---|---|---|
| Interior church forest | 6.50 | 16.5 | 34.4 | 48.7 |
| At the edge | 6.39 | 15.4 | 35.0 | 47.3 |
| Eucalyptus | 5.95 | 7.71 | 14.9 | 34.7 |
| Agricultural plots | 5.92 | 4.83 | 8.55 | 18.9 |

Research in Kenya has indicated that areas under Eucalyptus have high levels of micronutrients compared to those under old tea crops (Oballa and Langat, 2002). Long-term plantations of Eucalyptus have been reported to improve soil fertility within a relatively short period, ranging from 8 to 10 years (Couto and Betters, 1995; Sunder, 1995; Laclau et al., 2003). Comparative studies of soils under Eucalyptus and adjacent grasslands have shown no significant differences if the trees are older than 10 years (Couto and Betters, 1995).

## Eucalyptus Impact on Agricultural Production: Food Production and Livelihood Sustainability

### *Soil Nutrients and Crop Yield*

Reduction in crop yield attributed to Eucalyptus could be related to allelopathy impacts and soil fertility depletion. Allelopathy is highly selective, and studies in the literature often lack experimental precision, proper controls, and sufficient replication (Davidson, 1989). Some studies do not replicate natural conditions, and evidence for strong allelopathic effects is often based on laboratory studies with artificial extracts, which may not reflect field conditions. Allelopathy may influence species choice when erosion control and grazing are essential functions of the plantation. Practices such as wider tree spacing, mixed planting, and deliberate understory planting may help alleviate allelopathic effects. Soil cultivation, fertilization, and irrigation can also mitigate allelopathic effects in appropriate situations (Davidson, 1989).

Regarding competition with crops for moisture and nutrients, as well as other competitive effects, including allelopathy, general guidelines can be outlined. In areas with annual rainfall less than 400 mm, food crops should not be grown in proximity to eucalypts due to high risks of adverse competition and allelopathy, especially in nutrient-poor and coarse-textured soils, and when trees are grown in blocks rather than scattered. Under dry conditions, reversing extreme desiccation and allelopathic conditions following a Eucalyptus crop may be challenging unless the soil is cultivated and given a mulch or fallow period. In areas with annual rainfall between 400 and 1200 mm, eucalypts can be grown in mixtures with food crops and other trees, but careful assessment of available water is necessary, adjusting planting density to achieve a balanced water use between trees and crops, leaving enough surplus for humans and livestock. If annual rainfall exceeds 1200 mm, no special precautions are required. The choice of the 400 mm and 1200 mm annual rainfall change points is based on literature indicating that under 400 mm annual rainfall, evapotranspiration is approximately equal to rainfall in well-stocked eucalypt forests about 5 years old for the majority of eucalypt species, which have some control over their rate of transpiration. Between 400 and 1200 mm annual rainfall, there is a surplus of up to about 200 mm of rain, sufficient to support the growth of other vegetation in addition to the trees, especially with reduced tree stocking rates below 1000 trees/ha (Davidson, 1989). Above 1200 mm, the surplus of water over average evapotranspiration increases rapidly.

In Ethiopia, a study on the potential allelopathic effect of Cupressus lusitanica, Eucalyptus globulus, E. camaldulensis , and E. saligna on seed germination and growth of Cicer arietinum (chickpea), Zea mays (maize), Pisum sativum (pea), and Eragrostis tef (teff) (Lisanework and Michelsen, 1993) found that aqueous leaf extracts concentrations of 1% or 2.5% significantly reduced the shoot and root dry weight of crops. Chickpea and teff were the most susceptible among the four crops, with teff being most affected in terms of growth. The overall data suggested an increasing allelopathic potential of the leaf extracts of the four tree species, arranged as C. lusitanica, *E. globulus*, *E. saligna, and E. camaldulensis* .

Depletion of soil nutrients is a commonly cited criticism associated with eucalyptus trees. Several studies assessing the effect of eucalyptus on cropping systems have compared tree and agricultural crop interactions (Michelsen et al., 1993; Selamyihun Kidanu, 2004; Seyoum et al., 2021). Michelsen et al. (1993) found that indigenous woodland in Ethiopia provided much higher nitrogen and phosphorus content in above-ground herbaceous plants. Bioassay results indicated that the factor limiting growth in agricultural crops such as Eragrostis tef was likely the low availability of phosphorus, calcium, and potassium in eucalyptus soils. According to Seyoum et al. (2021), lower mean soil pH values were recorded at the center of the woodlot compared to soils away from the woodlot. Soil organic matter and total nitrogen were significantly higher at the center of the woodlot than away from the nearby cropland, showing a reducing trend with increasing distance from the center of the woodlot towards the crop field in all directions. Selamyihun Kidanu (2004) reported that the highest wheat yield decrease was 64%, 59%, and 47.5% at 2-4m distance from the *E. globulus* woodlot at 12 years, 8 years, and 4 years, respectively. The yield reduction was 5.5% at 8-12 m distance at 4 years of age and still highest (33.5%) at 12 years of age. Seyoum et al. (2021) evaluated the effect of Eucalyptus globulus woodlot plantation on selected soil physico-chemical properties and wheat yield. The yield of wheat at 15 and 40 m distance was significantly higher than at the two closest distances (Table 14.7). At the closest distance, there was a decline of nearly 43% and 29% in wheat grain and biomass, respectively, compared to 40 m distance.

When compared with a range of crops, eucalypts can achieve high biomass production with low nutrient uptake, ranging from one-half to one-tenth that of most agricultural and estate tree crops (Davidson, 1989). This implies that most eucalyptus species can be successful on poor soils without fertilizer. However, sufficient fertilizer or mulch should be applied to more than compensate for nutrient loss in the harvest, following the practice in agriculture. An excess of added nutrients is usually required over removals due to the inefficiencies of nutrient uptake by plants and losses through leaching in some soil types, similar to agriculture.

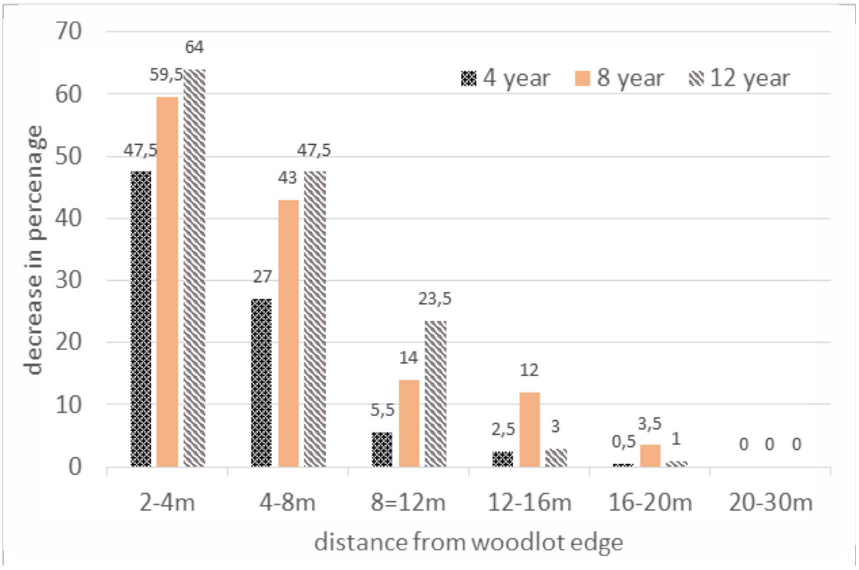



*Figure 9. Wheat yield reduction in percent as a function of distance at different age E, globulus woodlot around Ginchi. Extracted from (Selamyihun Kidanu. 2004)*

*Table 14.7. Mean yield and biomass of wheat as a function of distance from Eucalyptus Globules woodlot boundary Wogera District. (Seyoum et al., 2021)*

| Distances (m) | Yield of wheat | Biomass/straw |
|---|---|---|
| 5 | 335.71a | 437.57a |
| 10 | 370.24a | 472.50b |
| 15 | 411.27b | 503.53c |
| 40 | 478.91c | 564.75d |

According to Alebachew et al. (2015), maize grain yield and biomass reduction were around 6.6 and 15-fold difference from the tree stand to 20 m (control) sampling points, respectively; whereas, for finger millet, the grain yield difference was around 2.9 fold from the tree stand. Yield and yield parameters suppression ended at a distance of 14 to 20 m away from the tree stand. Therefore, poor performances of adjacent crops, particularly the most important parameter, grain yield, were due to competition for growth resources between Eucalypts and adjacent food crops. When planted on farms, eucalypts should be restricted to sites where neighboring crop productivity will not be adversely influenced.

Land-use change from agricultural use to Eucalyptus plantation does not have an adverse impact on total soil nitrogen, phosphorus, and sulfur content, at least up to the age of 14.5 years (Zerfu Hailu, 2002), but there is a presence of improvement in total soil N due to land-use changes from cropland to *E. camaldulensis* plantations in the highlands of Ethiopia. A similar report indicated that Soil potassium content in Vertic Luvisols under *E. globulus* plantations and in Humic Alisols under *E. camaldulensis* plantations was lower than the content in the agricultural lands. An adverse effect was found on exchangeable calcium content due to land-use changes from agricultural use to Eucalyptus plantation in Vertic Luvisols and Humic Alisols. However, the adverse effect of *E. camaldulensis* plantation in Humic Alisols seems to be because of the density of trees planted and the continuous effect of litterfall raking from the plantation site. Yitaferu et al. (2013) showed improved soil chemical properties (pH, CEC, N) and organic matter from farmlands reclaimed from E. camaldulensis plantations. Bekele Lemma et al. (2006) and Shiferaw Alem et al. (2010) found increased soil nutrients and organic carbon in plantations of Eucalyptus grandis.

*Agroforestry/polyculture*

Eucalyptus has proven to serve as a nurse tree for Juniperus, Podocarpus, and Olea species, as indicated from scientific trials under certain conditions. According to the World Agroforestry Center, the database and experience from Gedeo and Sidama indicate that Eucalyptus can also be useful as an agroforestry crop, although there are still few experiences in Ethiopia. This implies that it can maintain the biodiversity of some shade-tolerant species, microbial diversity (Asfaw Zebene, 2003), and fauna. As shown by Orwa et al. (2009) and plates 2, 3, and 4, some eucalyptus like *E. camldulensis* are important as boundary agroforestry species if managed properly.

In Brazil, intercropping of *E. camaldulensis* showed similar productivity when compared to monoculture. But in the dry season, the productivity of beans in monoculture was higher than intercropping. In the second year, rice productivity was very low for both *E. camaldulensis* intercropped and rice monoculture systems due to the lack of precipitation during the fructification phase. The equivalence area index (EAI) confirmed the advantages of the intercropping system over the monoculture system for *E. camaldulensis* and beans and rice, at least in the first 2 years. Like the effects of fallow agroforestry practices, maize plants grown on clear-felled eucalypt stands were taller and developed larger leaf areas than those grown on continuously cultivated farms (Desalegn et al. 2014). Dry matter production and grain yield were also significantly higher in maize plants established on clear-felled eucalypt stands. Farmers also responded that the growth and yield of maize grown on the clear-felled eucalypt stands were better than those grown on continuously cultivated farms. The results suggest that, contrary to popular belief, agricultural lands afforested with eucalypts can be reused for annual crop production.

In Ethiopia, some eucalyptus species are used as a shade tree in wetland agroforestry systems Plate 3. Shiferaw Alem and Tadesse Woldemariam, (2010) reported that the number of coffee seedlings in the E. grandis plantation was 3,350 seedlings/ha while in the natural forest, it was 7,000 seedlings/ha. The quality of the coffee product is arguably the most important aspect of any production system and must be included in any discussion of shade management practices. When E. grandis is used as a shade tree, it has a similar effect on the cup quality of coffee to the natural forest. (Shiferaw Alem Tadesse Woldemariam, 2010).

*Livelihood improvement*

Eucalyptus is contributing to supply efficiently the growing population demands. Besides its main use as fuel wood, it is a common construction material alternative to metals as well as a raw material for making/producing farm implements. In addition, it is utilized for essential oils distillation and honey production as well as for medicinal purposes. It is a major raw material source for the pulp and board industries; as an efficient resources provider, it releases human pressure on native vegetation and local biodiversity; Eucalyptus plantations have a high economic value for the rural population and industries. They have become a source of emergency cash for poor households, a source of raw material for industries when planted as a backyard crop. The sale of eucalypt products is generating high income, increasing food security, and diversifying smallholder farming systems (Zenebe et al. 2007). Eucalyptus helps households become wood self-sufficient and provides considerable cash income. Overall Eucalyptus contributes to poverty reduction and ensuring food security for millions of rural households throughout the highlands of Ethiopia. Rural landscapes, particularly those close to human settlements and main roads, throughout the highlands of Ethiopia appear greener than the outfields because of eucalypt farm forests. A number of factors motivate farmers to plant eucalypt trees although the factors vary from site to site based on ecological and socio-economic circumstances. The most common factors for planting eucalypt are two: wood scarcity both for construction and fuel wood and thus the need to satisfy household subsistence demand, and to generate cash income. In some communities, eucalypt trees are regarded as an insurance resource or life savior since they are cut and readily converted to cash during critical needs (Mesele 2002). In Gurage area, planting eucalypt is a privilege and obligation of all households not only for meeting household wood requirements and generate cash revenues but to preserve social pride and reputation (Negussie 2004). Eucalypt woodlots also give considerable reputation and social value to the owner, and these reputations depend very much on the size of the woodlots. Farmers grow eucalypt for income generation. In areas, such as northern, central, and southern highlands of Ethiopia where natural forests have been impoverished eucalypt farming is contributing up to 25 % of household cash income (e.g. Tesfay 1996; Minda 2004). For poor households of some areas income up to 72% is reported to be contributed from eucalypt sale (Zenebe et al. 2007). The lucrative cash income generating from eucalypt is driving the conversion of farmlands in many areas (Mesele 2002). In general, the above findings indicate that eucalypt has the potential to raise farm incomes, reduce poverty, increase food security, and diversify smallholder-farming systems.

### 5.2.5 Management

While improper management such as planting in wrong sites and improper tending may make eucalypt environmentally detrimental, they also have many potential ecological benefits, direct and indirect, including reduced run-off and erosion, biomass provision, reducing pressure on natural forests and substituting cow dung and crop residue in fuel wood use. Planting of Eucalyptus species might fail because they have frequently been of the wrong species, site, or management. The blame then falls on Eucalyptus rather than on the real culprit, which is bad forestry practice (Poore and Fries 1985). Actually, the poor management should be blamed rather than Eucalyptus. All things are always changing; and our way of thinking should change with the rapidly changing conditions of our world. Most species of Eucalyptus do not have to be replanted after felling because they can be regenerated by coppicing.

The second crop matures more quickly than the original one because it has well-developed roots left by the first crop. Coppicing is needed since water use efficiency decreases with increasing age. Coppicing also helps to obtain more boles/stems from a single crop, but this should be followed by thinning the new shoots and remaining about 2-3 sprouts for the next rotation. However, eventually replanting must take place.

The choice of Eucalyptus species for plantations should be based on many criteria such as maximum wood production, ecological sustainability, marketability of the planted species (commercial production of timber), and usefulness of the species to the local communities. All these criteria involve not only a choice of species planted but also a choice of plantation management methods from initial planting to the final cutting of the trees. The establishment of Eucalyptus plantations could take different forms, e.g. a huge number of small woodlots, groups, belts, lines, and single trees scattered throughout the rural as well as urban areas. Eucalyptus species can be planted in homesteads, farm boundaries, woodlots, roadsides, communal lands in rural areas, urban and peri-urban areas, compounds of institutions and schools, around churches and monasteries, etc. In some areas Eucalyptus species will be very useful; in other areas, Eucalyptus species will not be appropriate. As with other forestry and land use decisions, careful analysis of the needs of the local communities and potential productivity of the sites is the key to success. Whatever the tactics adopted, better quality planting material, species-site matching, establishment and aftercare, in short better silviculture and management, are required (Davidson 1989).

In Ethiopia, farmers seem to know better when it comes to planting Eucalyptus. They plant dense stands and periodically coppice only part of the stand at a time so that there is a multi-layered canopy, and they allow grass to grow. However, most of the State-owned Eucalyptus plantation stands are harvested on a clear-felling scheme, particularly on steep slopes that expose the site to soil erosion. On the other hand, the State-owned Eucalyptus plantation stands have been established at wider spacing, particularly on gentle slope sites. Wider spacing has an advantage to let the penetration of sun rays to the forest floor, which is one of the many prerequisites for undergrowth development. The presence of ground vegetation cover minimizes surface runoff.

A number of research results have shown that appropriate silvicultural techniques and management methods can help to improve the environmental and socioeconomic benefits rendered by Eucalyptus species. For instance, the study made by Schönau (1984) showed that proper site selection, site preparation, establishment, fertilizing at the time of planting, weeding, pruning, thinning, regeneration, and standard management methods increased the productivity of E. grandis. On the other hand, economically optimal coppice rotations are not frequently employed in Eucalyptus plantations management (Diaz-Balteiro and Rodriguez 2006). They considered E. urophylla plantations in Brazil and *E. globulus* plantations in Spain in order to evaluate the optimal rotations including carbon sequestration. Different clear-cut ages were established in each country, 5–9 years in Brazil and 13–18 years in Spain. The results revealed different rotations and the optimal number of coppice rotations for each site index and case considered (wood or carbon). Moreover, to repeat the seedling rotation in the following coppice rotations usually is a bad option. In the Ethiopian highlands, *E. globulus* produces a harvestable tree within 4-5 years although farmers on Vertisols prefer a longer rotation period (8-12 years) to maximize wood production (Selamyihun Kidanu 2004).

**Site species matching**

Suitable sites for planting depend on the type of species. The following are considered as suitable sites for planting eucalyptus:

1. areas degraded through soil erosion and loss of soil fertility (Demel Teketay, 2000)
2. as shelter belts and windbreaks on large-scale farms (Davidson 1989)
3. waterlogged areas for purposes of draining the area
4. farmlands as plantations or woodlots
5. on areas with saline soils

Most studies show that planting of eucalyptus on farm and along road reserves should be done at least six to eight meters from the boundary. In view of this requirement, planting of Eucalyptus in land sizes of less than 0.1ha as woodlot might require further understanding. Planting, near buildings is not recommended as branches/stems of some species break off easily.

Unsuitable sites for eucalypts planting include:

1. Wetlands and marshy areas (Demel Teketay, 2000);
2. Like other planted forest (Brandywine conservancy. 2023), eucalyptus should be planted not less than 30 to 45 m from water streams/rivers, lakes, swamps, and other standing water as indicated above eucalyptus takes shallow groundwater but does not affect deep groundwater that has more than 8 m depth. Since it has a spreading root system and tap root is not deeper than 9 m it does not affect the deep water table. The eucalyptus's annual water consumption is about 1000 mm and if the rainfall is more than 1000 mm it will not affect the water table. If the precipitation is less than 1000 mm, it will tap groundwater where the water table is shallow.
3. Avoid planting in sites with less than 400mm of rainfall (Davidson, 1989). Because the compact eucalyptus plantations do have allelopathic effects in areas with less than 400 mm annual precipitation. However, linear and mixed plantations have a little allelopathic effect on ground vegetation;
4. In farms next to water sources, planting should be minimized by inter-planting with indigenous tree species or in mosaic plantations between indigenous trees with the latter occupying a greater percentage or strip planting of eucalyptus with natural vegetation.
5. Avoid planting at irrigated farmlands. However, planting is possible where an irrigation site assigned only for eucalyptus management.
6. Compact and pure plantations do affect biodiversity (Forestrypedia. 2023.). Therefore, the eucalyptus should not be planted in natural forests, and if planted its composition should not exceed five per cent.
7. Eucalyptus should not be planted on the farmlands if its returns are less than the reduction in the crop yield but if the return from its wood compensates the reduction in crop yield and gives extra profit then it can be planted on farmlands. It is true that eucalyptus has oil in its leaves and too much litter found under compact plantations can create forest fires;
8. Eucalyptus should only be planted in barren lands where it is required to increase the forest cover. However, it should not be planted in the watershed areas because it may affect biodiversity.

**Planting niche with the farms**

Eucalyptus camaldulensis should be planted as a mixture with other tree species when rainfall is more than 1000 mm per year.

**Stocking**

When growing Eucalypts for timber or large poles, the plant stocking (spacing) should not be as dense as for fuelwood and small poles. Depending on site conditions the recommended planting spacing of eucalyptus in Ethiopia ranges from: 2.5 m x 2.5 to 3 m x 3m for Transmission poles and timber; 2 m x 2 m to 2.5 m x 2.5 m for construction poles; 2 m x 2 m for fuel wood (Asfaw Z 1994)

**Coppice management**

Eucalypts and some other species have the ability to regrow from cut stumps (referred to as ratooning with some agricultural crops). The regrowth from the stump is called coppice. Coppicing is the practice of selecting certain stems and the removal of others from this regrowth. Coppicing allows the grower to have a second crop without replanting – provided the first was established well and there are enough stumps that have regrown. Plantations that have been severely stressed will not coppice well and should be replanted after harvest. The cut stump which is also called stool death is the commonest problem in coppice management. If less than 75% of stumps produce healthy coppice, replanting should generally be undertaken. Coppice reduction should be carried out in a two-stage operation. The first reduction should be carried out when the dominant shoot height is 3 to 4m. At this stage 2 to 3 stems should be retained per stool. The second reduction should be carried out when the dominant shoot height is 7 to 8 m. At this stage reduction to 2 or 3 stems (only if there are 2 or 3 strong stems) should be left along the edge of a stand (along roads and fire breaks). These stools receive more light and water than those inside the plantation and can thus support more stems.

**Harvesting and nutrient depletion**

The harvesting age (rotation age) will vary depending on the management objective of the species (Table 14.8). The following facilitations are important while harvesting:

1. the first harvest should be done when the root system is firmly attached to the soil system;
2. harvesting should be done using saws and not axes and pangas because they damage the tree stump and affect its ability to coppice;
3. the stump should be cut in a slanting way to ensure that water does not accumulate on the stump;
4. harvesting should be done during the rainy season;
5. the stumps should not be less than 10cm and more 25 cm height;
6. care should be taken not to damage the bark of the stump;
7. the stump should not be left covered with slash as this will obstruct coppice shoots.

*Table 14.8 Eucalyptus, harvesting age and rotations under various management objectives (Kenya Forest Service. 2009).*

| Management objective | Harvesting age (years) | Rotations |
|---|---|---|
| Fuel wood | 4 and above | 4 |
| Timber | 15-20 | 2 |
| Transmission poles | 8–15 | 2 -3 |
| Construction poles | 3-4 | 5 |
| Charcoal | | 4 |

The impact of harvesting on nutrient removal showed variable results. At 10 years of age, wood (under bark) production was 93,187 kg/ha for 992 trees/ha, 98,683 kg/ha for 1,023 trees/ha, and 82,804 kg/ha for 1,133 trees/ha, constituting 69% to 74% of the total above-ground biomass (Georgem, 1984). The maximum accumulation of N, P, K, and Mg occurred in wood, while Ca accumulation was in the bark. Due to clear-felling ten-year-old plantations, 43% to 44% of N, 48% to 50% of P, 31% to 35% of K, and 37% to 47% of Mg were removed by wood harvesting alone (Georgem, 1984).

A study in central-north Shewa indicated an above-ground biomass of 233.6 tons/ha from 1,121 stems/ha of *E. globulus* at the age of 14.5 years (Zerfu Hailu, 2002). Out of this aboveground biomass removed during harvest, the per ha proportion of nutrient loss was 291.3 kg for nitrogen, 72.6 kg for phosphorus, 469.3 kg for potassium, and 1,163.3 kg for calcium. In E. camaldulensis plantations, the estimated potential removal of nitrogen with stem wood and branch biomass ranges from 47.8% to 58%. The removal of only stemwood is as low as 36.4% to 45.4%. Proportionally, potential removal of nitrogen with stem wood and branch biomass harvest in E. camaldulensis plantation is higher than in *E. globulus* plantations. Potential phosphorus removal appears to be 57.2% to 70.8% in *E. globulus* plantations and 40.4% to 51.8% in E. camaldulensis plantations. In general, this study indicated that Eucalyptus foliage and bark contain a large number of nutrients, and the retention of foliage and debarking of logs at the felling site is a good management practice to keep the site fertile.

Similar trends were reported from Brazil for ten-year-old eucalyptus plantation (Salvador et al., 2021). Harvesting the whole Eucalyptus tree resulted in the removal of approximately 61% of the nutrients from the site in sandy soil, while in clayey soil, 57% of the nutrients were removed. With harvesting of only the commercial stemwood, only 22% of the nutrients were removed from the sandy soil, and 21% from the clayey soil, implying that the best harvesting system involves the removal of only stemwood. Nutrient concentrations (N, P, K, and Mg) in different components of Eucalyptus clones were in the order of: foliage > stembark > branches > stemwood (Zhang et al., 2022). While Ca was more concentrated in stembark. Consequently, nutrient removal in harvested biomass could deplete soil nutrient stocks and limit future productivity if not offset by fertilizer application, raising concerns for the long-term sustainability of the plantations. However, the cumulative effects of multiple harvests in established plantations are less well studied.

### 5.2.6 Eucalyptus plantation management Sidama

**Distribution and major eucalyptus species**

Detailed studies by different authors reported that Sidama agricultural landscape is characterized by indigenous agroforestry systems (Asfaw Zebene, 2003; Abebe Tesfaye, 2005; Gonfa et al., 2015. Gebrehiwot., 2017; Mellisse B.T. 2017; Eyob Tadessee. 2022). Farms in the midland Sidama are commonly categorized into different niches, including Front-yard. Homegarden (Gata) and Fisha a block having Enset. Coffee, Maize. khat, Grazing, boundary, and woodlot niches (Asfaw Zebene, 2003; 2021; Gabiso and Abebe. 2017, Asfaw Zebene, 2021; Eyob Tadessee. 2022) Farmers usually plant Eucalyptus species on roadsides, around homesteads, along crop fields, and as demarcation boundaries and woodlots. The expansion took place by replacing communal grazing and crop fields.

Many Eucalyptus species have been introduced to Sidama, particularly at Wondo Genet (33 species) of which Eucalyptus grandis and E. saligna are expanded on farms around Wondo Genet area. In general, Eucalyptus camaldulensis and Eucalyptus globulus are the widely distributed species in Sidama agricultural landscapes. Eucalyptus globulus is suitable for high-altitude areas as it tolerates frost. It performs well in upper Dry, Moist, and Wet, Weyna Dega and Dega agroclimatic zones, ranging 2300–3200 m above sea level. Eucalyptus camaldulensis (hereafter red gum) grows in dry Kola dry lowland, moist lowland, wet lowland, dry midland. It does well in semi-arid regions and tolerates a long dry season as well as some salinity. In Ethiopia, it does well in deep silt or clay soil in Dry and Moist Kolla agroclimatic zones 900 – 2300 m above sea level. According to FAO, it grows under a wide range of climatic conditions from tropical to temperate. Temperature conditions may vary from a minimum of -6°C to a maximum of 54°C with a diurnal range up to 21°C. The annual rainfall is mainly 250 mm – 650 mm but may reach 1,000 mm in limited areas. In the areas below 400 mm, the species relies on irrigation by seasonal flooding, or a high water table. (https://www.fao.org/3/e4209e/E4209E07.htm#:~:text=CLIMATE,E.,up%20to%2021%C2%B0C.August). As indicated in the Agroforestree Database, Eucalyptus camaldulensis is well recognized and dominantly planted as an agroforestry species in the tropic. http://apps.worldagroforestry.org/treedb2/

**Case studies and their implications**

Two case studies focusing on impacts of Eucalyptus camaldulensis management on soil properties and initial spacing of Eucalyptus globulus. As the case studies are based on farmers' strategies for managing farm resources, they can establish a foundation for further understanding and developing guidelines. Additional cases on field observations are included.

#### Case study 1: Agroforestry impact on soil (focus Eucalyptus comaldulensis)

**Introduction**

Indigenous agroforestry is the characteristic farming system in Sidama Regional State. The inclusion of compatible and desirable species of trees/woody perennials in agroforestry practices can result in a marked improvement in soil fertility by: (i) increasing the organic matter content of the soil through the addition of leaf litter and roots as well as other plant parts (Young, 1997; Rao et al., 1998), improving organic matter status, which can, in turn, result in increased activity of microorganisms in the root zone (Young, 1997), (ii) enhancing efficient nutrient cycling within the systems (Rao et al., 1998), and (iii) controlling soil erosion (Young, 1997; Rao et al., 1998). In addition, agroforestry practices, like in Sidama region, are known to host high plant biodiversity or Circa situ conservation (Asfaw Zebene 2003; Abebe et al., 2014; Kewessa et al., 2015; Gabiso et al., 2017; Eyob et al., 2021).

Some adverse effects of trees like Eucalyptus have also been reported, notable among which include: (i) fast-growing species with a high demand for soil resources influencing soil (Michelsen et al., 1993; Asfaw and Agren 2007; Selamyihun Kidanu. 2004; Seyoum et al., 2021, (ii) nutrient loss by whole-tree harvest (Grewal et al. 1992; Harrison et al. 2000; Zerfu Hailu, 2002), particularly for woodlots with frequent harvest, (Michelsen et al., 1993; Selamyihun Kidanu. 2004; Seyoum et al., 2021), (iii) shading changes in spectral quality of light on the growth of other crops beneath the tree canopy or in close proximity (Selamyihun Kidanu. 2004; Seyoum et al., 2021, (iv) chemical/biological effect of some tree species which could lead to acidification, (Basu and Mandi, 1987; Kushalapa, 1987), allelopathy, accumulation of toxic exudates, provision of alternative hosts of pests and pathogens (Malika and Sharma, 1990; Ralhan et al., 1992; Lisanework and Michelsen, 1993; Michelsen et al., 1993), (iv) eucalyptus influence on water (Poore and Fries. 1985; Rao et al., 1998; Fetene and Beck 2004). In general, the magnitude of the influence depends on management systems, notably type, canopy and root characteristics, age, size, and density of the tree species (Rao et al., 1998). Hence, to properly manage farm trees, understanding their biophysical and socio-economical attributes is crucial.

In Sidama, traditional agroforestry systems have been practiced for a long period. Its main agroforestry practices (AFP) include (i) tree-enset-coffee, (ii) tree-enset (iii) Eucalyptus woodlot (iv) scattered/parkland trees on maize and grazing fields and (v) boundary planting. Enset ventricosum (enset) is the staple food crop for about 20 million people (Woldetensaye, 1997). Zea mays (maize) is also a main food crop. On both enset and maize fields, Cordia africana and Millettia ferruginea have been managed in large numbers for various reasons (Asfaw Zebene, 2003). Due to its light canopy and N-fixing ability Millettia is popular in the southern region of Ethiopia. Eucalyptus camaldulensis is cultivated in monoculture as woodlot fields. These traditional agroforestry practices managed, without any extension input, have developed over time.

Traditionally, native trees such as Cordia and Millettia trees are managed through intercropping with different plant components. On the other hand, massive expansion of Eucalyptus camaldulensis (red gum) and are currently, dominantly used in the Sidama agricultural landscapes. This case presents an evaluation of the influence of Eucalyptus camaldulensis on topsoil conditions and compares it to soils from Cordia and Millettia trees grown in the overstorey of enset and coffee plots at three sites.

## Materials and methods

### *Study sites*

The three study sites are located in the Sidama zone of Ethiopia (7°00–7°06‘ N and 38°34'E 38°37'E). The latitude ranges from 1800 to 2250 m a.s.l. The climate is of a semi-humid type with bimodal rainy seasons. Mean annual rainfall varies between

1200–2500 mm, and mean annual temperature ranges from 12–20 °C. This study was conducted at Entaye (Enta) and Haranfama (Hara) in the Awassa district and Murancho Mura (Mura) in the Shebedino district.

*Selection of farms and fields*

Two villages were selected at each of the Enta, Hara, and Mura sites. A purposive sampling procedure was employed within each selected village. The farmers' strategies (in terms of species selection, age, arrangement, and frequency of pruning and harvesting) differed from individual to individual within and between wealth categories. Within a sample farm, two enset fields and woodlot field, containing the farmer's preferred three top-priority tree species (Cordia-enset-coffee, Millettia-enset-coffee, and Eucalyptus camaldulensis (EC) woodlot, were selected. Within the enset field, Cordia-enset-coffee and Millettia-enset-coffee plots were selected. A field is defined as a unit of land with distinct management characteristics for a particular purpose, i.e., enset field, maize, coffee, woodlot.

*Tree sampling*

Informal interviews with the farmers provided baseline information for sample selection, particularly for native trees. Sampling designs for trees were based on the farmer's knowledge about (i) the field: cropping history, intensity of cultivation, traditional and improved practice of soil management and (ii) the tree: objective for choosing the species, age, frequency of pruning and harvesting, and influence of canopy environment (crops and soil). Knowledge about those and related tree management issues was gained during informal interviews with individual farmers and focus group discussions. To select three farmers' priority trees, 110 farmers were involved. The order of the three farmers' priority tree species was: Cordia africana > Millettia ferruginea > EC. Hence, the agroforestry practices selected for this study were (i) Cordia-enset-coffee and Millettia-enset-coffee (ii) woodlot of EC.

*Soil sampling*

Three replicate soil samples were taken under three Cordia and Millettia trees and in EC woodlots, at 0-20 cm depth were bulked to obtain a composite sample. Finally, 1 kg of the sample was taken for soil analyses.

*Statistical analysis*

Two-way ANOVA with the site as factor one and agroforestry practices with three tree species as factor two were employed. Statistical analysis was conducted mainly with STATISTICA (STATSOFT, 1999).

**Results and discussion**

*Tree management strategies*

Traditionally, Millettia (Engidicho) and Cordia (Wadicho) managed most agricultural crops common to the study sites (110 households or farms). Unlike those two species, farmers do not allow red gum in crop fields or enset fields, due to its perceived negative effect on crops and soils. Eucalyptus was originally cultivated along roadsides/boundaries and in front-yards for household consumption (poles for fences, construction and firewood), but an increase in the price of Eucalyptus altered the land-use pattern, which had developed over a number of decades. Currently, some medium and wealthy households and small-scale investors from towns grow Eucalyptus species in separate woodlots/ blocks. On the other hand, due to a lack of space, poor households grow Eucalyptus in front yard boundaries. Woodlots of Eucalyptus are expanding fast as a shortage of fuelwood and construction wood and are becoming more acute in nearby towns and/or as a market becomes available. Eucalyptus trees planted very densely, particularly on farms of poor households, and harvested after 3 years. After the first harvest, the poor households manage Eucalyptus on a 3 to 5 years rotation basis. On farms of wealthier households, the rotation period extends up to 7 years, particularly at sites with less access to the local market (Haranfama).

Wide variations in the density of the three species were noticeable between farms of households with varying wealth status and between the sites (Table 9). The overall stem density per ha at the study site is 1,283 which is lower than values (2,310 stems per ha) reported by Mesele Negash (2002) and the recent value (13,052 stems per ha) reported by Eyob Tadesse (2022), both from Sidama. The stem density per ha of Eucalyptus in other parts of Ethiopia is lower than values reported for Sidama. For example, 693 stems/ha for Bosona Wereda and 993 stems in Sodo Zuria by Zeleke (2008).

*Table 9. Stem $ha^{-1}$ (± std) of Cordia africana, Millettia ferruginea, and Eucalyptus camaldulensis species on farms with different wealth status. L = poor, M = medium and W = wealthy households (Asfaw Zebene and Agren, 2007)*

| **Site** | **Status** | **Stem ha-1 and tree species types** | | | | |
|---|---|---|---|---|---|---|
| | | **Total** | **Milettia** | **Cordia** | **Eucalyptus** | **Others[1)]** |
| Enta | L | 231±315 | 3 (1.3) | 9 (3.9) | 169 (73.2) | 50 (21.6) |
| | M | 716±882 | 6 (0.8) | 14 (2.0) | 670 (93.6) | 26 (3.6) |
| | W | 2063±2087 | 4 (0.2) | 22 (1.1) | 1940 (94.0) | 97 (4.7) |
| Hara | L | 1337±1134 | 40 (3.0) | 49 (3.7) | 548 (41.0) | 700 (52.3) |
| | M | 1656±1659 | 20 (1.2) | 43 (2.6) | 1025 (61.9) | 568 (34.3) |
| | W | 1092±791 | 14 (1.3) | 14 (1.3) | 473 (43.3) | 591(54.1) |
| Mura | L | 2748±758 | 13 (0.5) | 56 (2.0) | 2293 (83.4) | 386 (14.1) |
| | M | 1618±2172 | 4 (0.2) | 16 (1.0) | 1461 (90.3) | 137 (8.5) |
| | W | 3643±2796 | 5 (0.1) | 15 (0.4) | 3449 (94.7) | 174 (4.8) |

*[1)]Others includes 84 tree species not included here*

*Figures in the brackets indicate percentage contribution of individual species to total stems ha-1 per farms of wealth status.*

Information on age structure has important implications for the management of farm trees and resource bases, particularly on soil fertility. The age distribution of stem numbers of the three species studied varied between farms belonging to farmers with different wealth categories (Fig. 3a-c). There was, however, a noticeable difference between species. The proportion of stems less than 15 years was 77%, 46%, and 86% for Millettia, Cordia, and Eucalyptus, respectively. When the strategies of households with varying wealth categories are considered, poor households have higher proportions of stems (Fig. 10a) medium (83%) and wealthy households (87%). On farms of poor households, no Millettia were recorded at 20 years or older (Fig. 10a). Cordia trees represented in all age classes on farms of all wealth statuses. However, wealthier households had a more even distribution of Cordia over age classes (Fig. 10c). In general, this study indicates that poor households manage trees at less than 15-years-old classes than medium (Fig. 10b) and wealthy households (Fig. 10c). According to the farmers' perception, the introduction of Eucalyptus to farms started 20 to 30 years ago (Fig. 10a-c). The management strategy for Millettia for poor age-classes distribution is skewed towards lower age-classes of the three species in age-classes distribution is skewed towards lower age-classes of the species in households has been to keep a high proportion (95%) of stem in less than 20 years-age classes.

Except at Hara, the number of stems ha$^{-1}$ for red gum was higher on farms of wealthier households than on farms of poor and medium households. Since wealthier farmers have more resources, particularly land, they can afford to plant more trees for sale. The wealthier farmers can also prolong the rotation period, as they commonly do for Cordia. On the contrary, poor farmers manage their farm trees on a short rotation basis. For example, at the Hara site, the number of stems ha$^{-1}$ on farms of poor households was higher than on farms of wealthier households. Since poor farmers often are short of money at some point during the season, they cannot afford to wait longer without harvesting their trees.

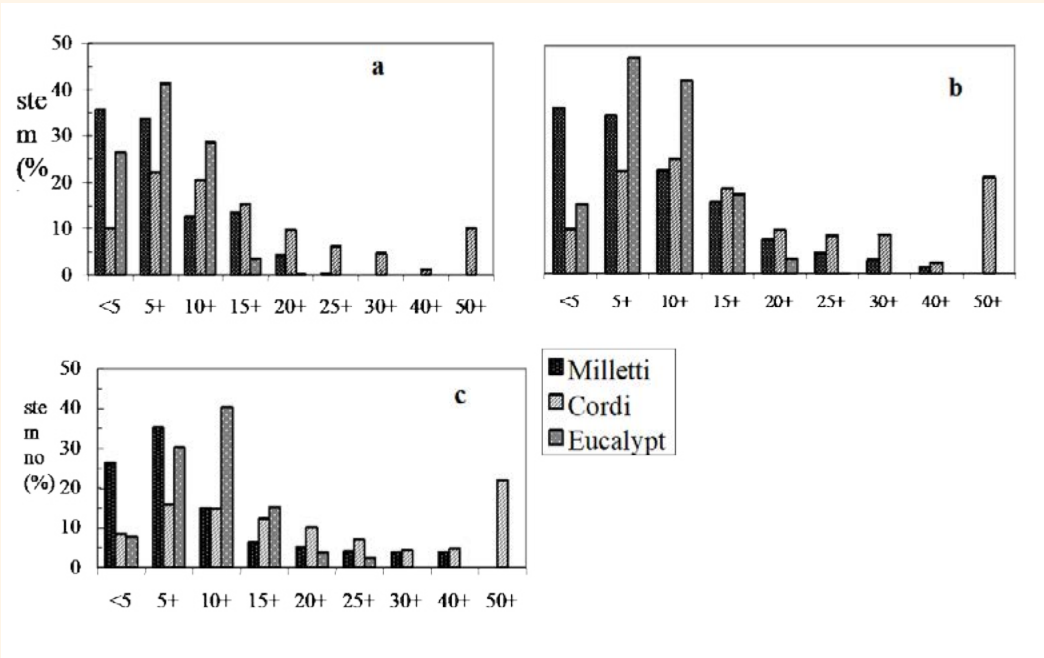



*Fig. 10: Distribution of number of stems per ha over age-classes of Millettia ferruginea Cordia africana and Eucalyptus species in farms of poor (a), medium (b) and wealthy (c) households. (Asfaw Zebene and Agren, 2007)*

*Farmers' perception of soil fertility under tree canopy*

Until 50 years ago, when livestock was the major activity, crop production was confined to areas close to home (Asfaw and Agren, 2007). During those periods, soil fertility was maintained predominantly by animal dung. In addition to animal dung, organic matter input to the soil consisted of leaves from native trees. Currently, insufficient application of organic manure from both animal dung and plants was mentioned as the major cause of declining soil fertility. The decline in soil fertility is generally perceived as a problem, and most farmers made a conscious effort to maintain soil fertility by growing Millettia and Cordia. In contrast to these species, all interviewed farmers agreed that Eucalyptus causes „dry soil" (equivalent to decreased soil fertility). According to the interviewed farmers, Millettia can be grown and managed without a negative effect on crops. Leaves and pods of Millettia were mentioned as important inputs of soil organic matter. The tree sheds leaves and pods from November to December. Cordia is mentioned as another popular upper-storey tree, particularly with enset and coffee crops. Similarly, the most important organic inputs by Cordia are leaves. The Cordia tree sheds leaves from December to February and inflorescence from September to October. Cordia has an extremely high inflorescence production. In addition to input from the trees, chopped parts from enset harvesting and processing, and enset roots add additional inputs to the system. It was mentioned that leaves, pods, and inflorescence of Millettia and Cordia decompose within one season. Enset residues decompose more slowly and might require more than a year to decompose completely.

**Impact on topsoil conditions**

*Total N, organic C, and C:N*

At the Enta site, total N under Millettia and Cordia was significantly ($P < 0.05$) higher than under red gum (Table 10). Total N was lower under red gum than under Cordia and Millettia at Hara, but no significant difference was observed. The organic C content shows a scattered picture without clear trends with respect to species or sites, despite observed significant differences. The same is true for the C:N ratio, and although no significant effects of tree species were observed, the Enta site shows a high C:N ratio.

*pH, available P, and CEC*

Across the sites, pH was in the order: Millettia > Cordia > EC (Tables 14.10). However, the differences were significant ($P < 0.05$) only at the Enta site. One of the most clearly observed effects of tree species is found for available P, which is more than twice as high under Cordia and Millettia as under EC. Also, Enta separates itself from Mura and Hara by having a considerably higher available P.

*Exchangeable bases*

Concentrations of topsoil exchangeable bases under the three species at the three study sites are shown in Table 11. Only at the Enta site did topsoil under Millettia and Cordia have significantly ($P < 0.05$) higher levels of exchangeable Ca and Mg than red gum. Although statistically not different, levels of exchangeable K under red gum were lower than under Millettia and Cordia at the Enta and Hara sites. However, K concentrations under Cordia were significantly higher than under EC at Mura. No significant difference in Na concentrations was detected among the tree species at all sites.

*Table 10. Mean value and standard deviation of topsoil (0-20 cm) pH, total N, organic C, available P, and CEC sampled under agroforestry practice with Millettia ferruginea and Cordia africana grown in enset-coffee plots and from Eucalyptus camaldulensis woodlots at three study sites in Sidama, south Ethiopia. (Asfaw Zebene and Agren, 2007)*

| Site | AFP[1)] | pH | Total N (%) | organic C (%) | C:N | Available P (ppm) | CEC (meq/100g) |
|---|---|---|---|---|---|---|---|
| Enta | ML | 7.16a±0.29 | 0.38a±0.07 | 3.86a±0.68 | 10.4±1.29 | 64.60a±9.20 | 23.30a±2.35 |
| | CO | 6.82ab±0.14 | 0.35a±0.09 | 4.16a±1.09 | 11.9±1.06 | 57.75a±4.05 | 25.87a±4.41 |
| | EC | 6.11b±0.42 | 0.26b±0.06 | 2.63b±0.36 | 10.3±0.94 | 13.72b±2.40 | 14.60b±0.85 |
| Hara | ML | 6.86±0.65 | 0.33±0.05 | 3.36a±0.48 | 8.31±0.54 | 10.66a±2.54 | 26.45±4.21 |
| | CO | 6.75±0.68 | 0.36±0.09 | 3.03b±0.23 | 8.94±1.51 | 11.59a±3.69 | 26.94±3.10 |
| | EC | 6.51±0.62 | 0.29±0.09 | 3.75a±0.97 | 9.47±0.96 | 4.22b±2.37 | 24.63±3.81 |
| Mura | ML | 6.96±0.27 | 0.27±0.02 | 2.21a±0.07 | 8.90±0.42 | 17.79b±5.66 | 23.68±2.15 |
| | CO | 6.92±0.33 | 0.32±0.01 | 3.11b±0.38 | 9.80±0.65 | 33.74a±12.41 | 27.27±3.31 |
| | EC | 6.52±0.39 | 0.27±0.05 | 2.47b±0.61 | 9.10±0.87 | 7.45c±3.17 | 22.85±2.46 |

*[1)] AFP agroforestry practices at where the samples were taken. ML = Millettia-enset-coffee plots in enset field ; CO = Cordia-enset-coffee plots in enset field; EC = woodlot of Eucalyptus camaldulensis species*

*Within column, site means followed by the same letter(s) are not significantly different at $P < 0.5$*

*Table 11. Mean value ±std of topsoil (0-20 cm) exchangeable bases sampled under agroforestry practice (AFP) with Millettia ferruginea (ML) and Cordia africana (CO) grown in enset-coffee plots and from Eucalyptus camaldulensis woodlots at three study sites in Sidama, south Ethiopia. (Asfaw Zebene and Agren, 2007)*

| Site | AFP | Exchangeable base in the soil (meq/100g) | | | |
|---|---|---|---|---|---|
| | | Na | K | Ca | Mg |
| Enta | ML | 0.67±0.38 | 2.48±1.05 | 12.43a±2.24 | 3.28a±0.59 |
| | CO | 0.83±0.4 | 2.51±0.93 | 17.96b±3.81 | 3.58a±0.55 |
| | EC | 0.79±0.48 | 1.37±0.68 | 10.41c±2.66 | 1.92b±0.18 |
| Hara | ML | 0.81±0.12 | 1.75±0.54 | 13.6±3.54 | 2.54±0.62 |
| | CO | 0.60±0.1 | 2.38±1.02 | 13.52±3.16 | 2.86±0.45 |
| | EC | 0.45±0.07 | 1.31±0.47 | 13.19±3.64 | 3.01±0.07 |
| Mura | ML | 1.05±0.42 | 1.79ab±0.75 | 13.17±2.33 | 3.11±0.87 |
| | CO | 0.92±0.15 | 2.56a±1.13 | 16.15±2.13 | 2.55±0.39 |
| | EC | 1.14±0.031 | 1.32b±0.22 | 12.61±2.63 | 3.26±0.46 |

*Within column, site means followed by the same letter(s) are not significantly different at $P < 0.5$ Brief*

**Discussion on soil impacts**

Locally, nutrient concentrations are modified mainly by differences in species characteristics and management practices of other farm resources. The Cordia and Millettia trees grown over enset and coffee crops are basically a multistorey system, which includes other diverse vegetables and herbaceous species in the ground layer. As in the case of above-ground, the underground system also has different layers consisting of roots with diverse roles. The diversity of different layers and networks of roots could enhance or maintain soil fertility (Young, 1997). The mechanism of soil improvement may involve maintenance or an increase in soil organic matter, biological N2 fixation, improved nutrient uptake through mycorrhizal associations, reduced loss of nutrients by preventing erosion and leaching, increased water infiltration and storage, and improved biological activities (Young, 1997; Buresh and Tian, 1998; Rao et al., 1998). Although there were no significant differences between soils sampled under Cordia and Millettia and red gum woodlot in some of the assessed variables, there is an overall tendency for results of the latter to be inferior to the former.

The higher concentration of nutrients under Cordia and Millettia than red gum is likely to be attributed to the low nutrient drain of the former two at harvest. Available reports indicate that there is a considerable nutrient drain through the harvesting of Eucalyptus. Harrison et al. (2000) reported removal (bolewood + bole bark) of *E. camaldulensis* at an age of 41 months could represent 29% of total P, the whole tree 11.0 kg ha-1, and 72% total P entire above-ground harvest. For a fertilized 9 year and 7-month-old E. camaldulensis stand, Fernandez et al. (2000) estimated an exportation of 48% of total P, representing 33 kg ha-1 of P, through the harvest of shoot + litter. At 14.5 years harvest, *E. camaldulensis* foliage and bark contain a large number of nutrients, and the retention of foliage and debarking of logs at the felling site are good management practices to keep the site fertile (Zerfu Hailu, 2002). Michelsen et al. (1993) reported lower soil nutrient status under Eucalyptus plantations than native tree species in central and south Ethiopia.

As age and spacing increase, the individual diameter increases, and the total N and P accumulation increases. For red gum plantations 41 months of age, Harrison et al. (2000) reported that bole harvest removed N 17%, of a total biomass of 204-240 kg N, and for P 29% of a total biomass of 10.4-12.2 kg P ha-1. Grewal et al. (1992) also reported that nutrient removal from the soil in a Eucalyptus plantation, at age 3.5 years, was 373, 17, and 241 kg/ha for N, P, and K, respectively. On the other hand, Kushalapa (1987) reports nutrient return through litter fall of ca. 35 to 50% of the total uptake of various nutrients. Mallik and Pati (1996) also estimated about 8234 kg/ha (76% leaf and 24% non-leaf litter) annual litter fall for E. terticornis (hybrid). The farmers' perception that EC depletes soil nutrients is not supported by Kushalapa (1987), who argues that EC does not exhaust the soil; rather, it improves the structure and nutrient status of the soil like N, P, and K. In the present study, the organic C concentration under EC relative to the other species depended upon the site. Basu and Mandi (1987) indicated that organic carbon content under Eucalyptus, particularly in the surface soil, had increased considerably with age. The pH was lower in the EC woodlot soils, probably as a result of acidic substances in decomposing plant material. Basu and Mandi (1987) also reported that Eucalyptus trees change the soil to acidic, but Kushalapa (1987) claimed that Eucalyptus plantations do not turn the soil acidic. Case study 2. Spacing effects Eucalyptus globulus on growth and soil

## Case study 2: Spacing effects of Eucalyptus globulus on growth and soil

The effect of Eucalyptus globulus spacing on selected soil properties in Arbegona/ Gorche area was conducted by Chane and Belay (2021) and summarized as follows. The study was conducted in Gorche woreda, Sidama region, Ethiopia, during November to December 2019. The study was carried out to evaluate the effect of different spacing on soil physical and chemical properties in 0-25cm topsoil depths of smallholding farmers' *E. globulus* woodlot plantations. A total of 19 soil samples were analyzed. The results show the soil bulk density; significantly differ between; 1m x 0.0.75m and 0.5m x 0.5m as well as between 0.75m x 0.5m and 0.5m x 0.25m spacing regime (Figure 4a) (Chane and Belay, 2021). The soil moisture content significantly different between 1m x 0.75m and 0.5m x 0.25m spacing regime (Figure 4b). Organic carbon percent increased significantly under wider spacing of *E. globulus*, and it decreased with the increase in spacing (Figure 4c). They also reported that cation exchange capacity of the woodlot plantation was found statistically significant between 1m x 0.75m; with 0.5m x 0.5m and 0.5m x 0.25m spacing regimes (Figure 4b). Total nitrogen Figure 4d) and organic carbon percent increased significantly under wider spacing of *E. globulus* woodlot, and it decreased with the increase in spacing.

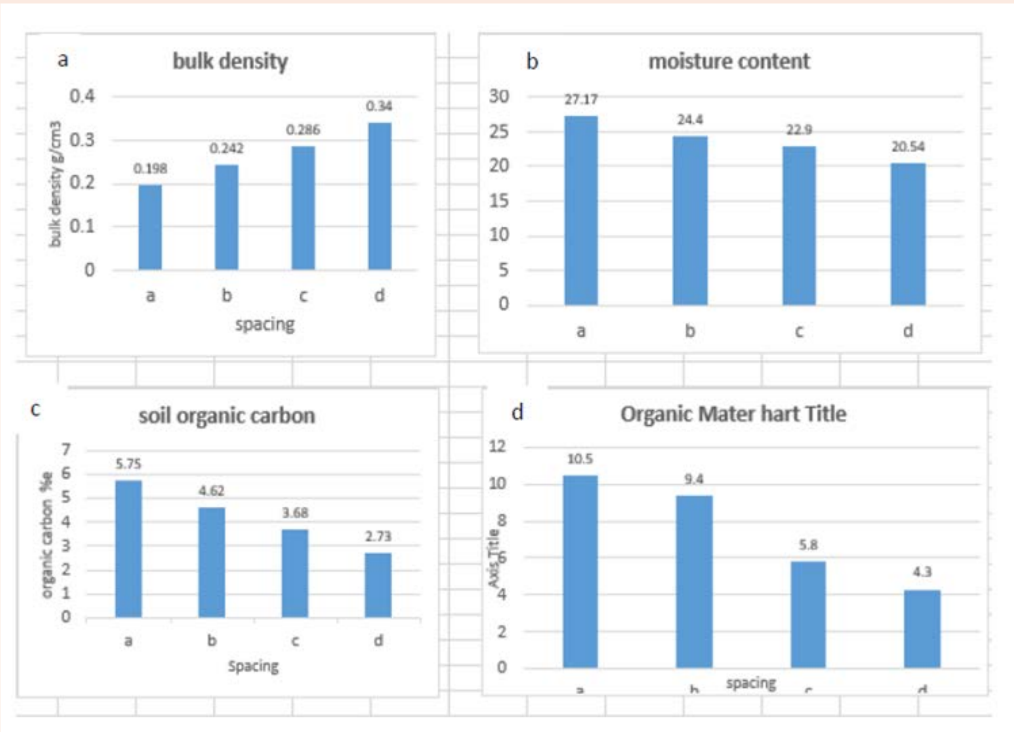



*Figure 4 illustrates the effects of spacing on soil properties, including bulk density (a), moisture content (b), soil organic carbon (c), and organic matter (d) (Chane and Belay, 2021).*

Note:

- a = 1m x 2.75m
- b = 0.75m x 2.5m
- c = 0.5m x 0.5m
- d = 0.5m x 0.25m

### Case Study 3: Observations on the Effect of Eucalyptus on Vegetation (Afrocarpus falcatus, Zigba) and Other Experiences.

Plantation stands of Eucalyptus and other tree species have been found to promote the regeneration of native woody species under their canopy, especially when they are located near seed sources and protected from disturbances caused by humans and animals. This phenomenon enhances biodiversity (Michelsen et al., 1993; Senbeta and Teketay, 2001; Fekadu Debushe, 2010). According to Kidane Woldu (1998), the distribution of height and diameter classes, density, and structure of the Juniperus procera population indicates successful recruitment under the *E. globulus* plantation. It is evident that a dense forest of Juniperus, possibly mixed with other species such as O. europaea and P. falcatus, once covered the hills before it was cleared and replaced by Eucalyptus plantations. The plantations may have created favorable conditions for the regeneration of Juniperus by allowing sufficient light through the canopy and protecting the seedlings and saplings from excessive light and drying winds.

Silvicultural practices are currently shifting towards the utilization of mixed forests. Mixed forests are generally believed to be more biologically diverse and ecologically stable compared to monoculture plantation stands. Therefore, mixed forests are considered a key aspect of sustainable forest management. To investigate the catalytic effect of Eucalyptus saligna plantations, Afrocarpus falcatus seedlings were planted under the second coppice at a spacing of 2m x 2m in Wondo Genet college campus. After 31 years, Afrocarpus falcatus showed promising performance, with 2150 stems per hectare (90% survival), a mean height of 13 meters (ranging from 9m to 15m), and a mean diameter at breast height of 18 cm (ranging from 16cm to 22cm) (Asfaw Zebene, 2023) (Plate 1). In the Sidama region, farmers traditionally grow and manage Afrocarpus falcatus in their front yards and under eucalyptus boundary plantations (Plate 2).

Plate 1

**Regeneration trial at 31 year old *Afrocarpus falcatus* podocarpus.** Planted under second rotation coppice of *Eucalyptus saligna* at Wondo Genet. As shown E saligna totally replaced by Podo

egeneration trial at 31 year old *Afrocarpus falcatus* podocarpus. Planted under secon
coppice of *Eucalyptus saligna* at Wondo Genet. As shown E saligna totally replaced b

Plate 2.

Podo regeneration under ***Eucalyptus camaldulensis*** at Murancho Kutal, in Sidama

**Eucalyptus-Based Agroforestry Practices in Gedeo**

Eucalyptus plantations were established as shade trees for coffee agroforestry with the aim of improving water drainage 35 years ago near Yiga Chefe town in Gedeo. According to the farm owner (Plate 3), coffee yields under this system were lower compared to a shade system based on native trees. However, the tall eucalyptus trees were effective in reducing frost damage in some traditional agroforestry practices.

Plate 3

**Plate 3 Eucalyptus camaldulensis** for coffee shade management around Yirgacheffe, Gedeo

Plate 3 Eucalyptus camaldulensis for coffee shade management around Yirgacheffe, Gedeo

Plate 4 shows a mixed windbreak agroforestry system with Eucalyptus globulus in the upper layer and Cupressus lusitanica in the Gedeb district of Gedeo. It is noteworthy how farmers are managing mixed plantations in an unconventional way. Both species are light-demanding and challenging to manage for silvicultural operations.

*Plate 4: Mixed Tree Species Windbreak Agroforestry Practice in Gedeb District, Gedeo Zone*

### 5.2.7 Concluding Remarks and Recommendations

The research results mentioned above provide valuable evidence, but definitive conclusions regarding the ecological suitability of Eucalyptus cannot be drawn. Many studies have examined ecological impacts in isolation, but the reality is that the positive and negative effects of Eucalyptus on a given site are likely to be numerous and interconnected, making it a complex question to determine the net effect of the tree crop on the site. Based on this review of ecological and socioeconomic impacts of Eucalyptus, several policy options can be considered.

One policy option that shows the potential for significant economic benefits is to increase the allocation of marginal lands, populated areas, homesteads, and private Eucalyptus plantations. This option could substantially increase average household income and wealth. The ecological risks can be controlled through proper management and the development of sound extension services by trained foresters. One of the potential ecological benefits is significant, as this option would be implemented in degraded areas. Implementing this and other options could make Eucalyptus cultivation an important pathway for development. While improper management, such as planting in unsuitable sites and improper tending, can have negative environmental impacts, Eucalyptus also has many potential ecological benefits, both direct and indirect, including reduced run-off and erosion, biomass provision, reduced pressure on natural forests, and substituting cow dung and crop residue in fuelwood use.

Based on the review results, the following conclusions and recommendations are proposed:

Impact on biodiversity: While compacted Eucalyptus plantations are often blamed for suppressing undergrowth, reports suggest that they can maintain biodiversity and undergrowth when properly managed at the right site. For instance, *E. camaldulensis* can be used as an alley-cropping agroforestry species with wider spacing to cultivate crops. Eucalyptus has provided opportunities to reduce pressure on natural forests, which are crucial for biodiversity conservation, watersheds, and environmental benefits.

**Allelopathic impact:** Not all Eucalyptus species create severe allelopathic conditions, and the effects depend on soil moisture levels. Under dry conditions, extreme desiccation of the soil and allelopathic effects may be challenging to reverse after a crop of Eucalyptus unless the soil is cultivated and given a mulch or fallow period. Compact Eucalyptus plantations have an allelopathic effect in areas with less than 400 mm annual precipitation, but linear and mixed plantations have minimal allelopathic effects on ground vegetation.

**Impact on water sources:** Eucalyptus is often blamed for high water consumption and lowering the water table, but this is more of a misconception than reality and requires thorough investigation along scientific lines, considering other variables responsible for water depletion. In areas with limited water reserves, Eucalyptus plantations may reduce the availability of stream water and groundwater for local farmers and families, especially during the dry season. However, the issue of water use by Eucalyptus is controversial. Water consumption by Eucalyptus can be reduced by planting trees farther apart or thinning existing plantations. With proper management, Eucalyptus planting can support the protection and conservation of biodiversity.

**Soil Nutrient Depletion:** Depleting soil nutrients is often cited as a negative impact of Eucalyptus trees. However, recent investigations have shown that soil fertility under Eucalyptus species is actually superior to that under annual cropping systems. Eucalyptus foliage and bark contain many nutrients, and it is a good management practice to retain foliage and debark logs at the felling site in order to maintain soil fertility.

Overall, the ecological impacts of Eucalyptus are complex and context-specific, and careful consideration should be given to site selection, proper management practices, and involvement of trained foresters to maximize the potential benefits and minimize the negative effects.

Species-Site Matching/Niche:

- Eucalyptus should not be planted in wetlands and marshy areas unless the primary objective is to drain water and special permission is obtained from the community.
- Eucalyptus should be planted at a distance of no less than 30 to 45 meters from water streams/rivers, lakes, swamps, and other standing water. The suitability of this rule of thumb should be determined through community consensus in Sidama.
- Avoid planting Eucalyptus in areas with less than 400 mm of rainfall per year, which is not very common in Sidama Regional State.
- In farms located near water sources, planting of Eucalyptus should be minimized by inter-planting with indigenous tree species or establishing mosaic plantations where indigenous trees occupy a greater percentage or strip planting Eucalyptus with natural vegetation.
- Avoid planting Eucalyptus in irrigated farmlands unless the site is specifically designated for Eucalyptus management.
- Eucalyptus should not be planted in natural forests. If it is planted, its composition should not exceed five percent.
- On farmlands, Eucalyptus should only be planted if its wood returns compensate for the reduction in crop yield and provide additional profit.

- Compacted and monoculture Eucalyptus plantations should not be established in watershed areas due to potential impacts on biodiversity. However, Eucalyptus can be planted on barren lands to increase forest cover and carbon sequestration. If Eucalyptus plantations are established on steep slopes, proper erosion control techniques such as contour planting should be used. Eucalyptus plantations developed for catchment protection should be gradually transformed into uneven ones through selective cutting over time.

- Eucalyptus boundary planting has been a major source of conflicts among neighbors in Sidama. In both crop fields and bordering boundaries, Eucalyptus should be planted at a distance of no less than 6 to 8 meters from crop and grazing fields. However, the appropriateness of this rule of thumb for annual crops compared to perennial-based polyculture/agroforestry in Sidama may require further understanding and discussion with the community.

**Stocking and its Effects:** Woodlot and boundary plantations of Eucalyptus in the Sidama agricultural landscapes are characterized by high stem density, with some cases exceeding 1 meter by 1 meter spacing. This high stem density can potentially reduce biodiversity and under-growth vegetation, decrease productivity, and result in low-quality products. Studies indicate that high stocking of Eucalyptus trees drains more nutrients compared to low stocking. The potential nutrient loss from harvesting more than 10,000 stems per hectare in Sidama within a 4-7 year harvest cycle can be significant. Therefore, for higher productivity and quality, spacing of 2 meters by 2 meters for fuelwood, and 2.5 meters by 2.5 meters for construction wood and transmission poles should be adopted.

**Coppice Management:** As the current management practices are driven by farmers' motivation without extension input, further understanding is needed regarding the timing of the first harvest, cutting stump height, the season of cutting, singling practices at different phases, maintaining shoot quality, and determining rotation periods.

**Harvesting and Nutrient Depletion:** Studies on the effects of Eucalyptus harvesting on nutrient removal have shown variable results. The removal of only stemwood is the best harvesting system, as the nutrient removal in the whole tree biomass can deplete soil nutrient stocks and limit future productivity if not offset by fertilizer application. This raises concerns about the long-term sustainability of the plantations. It is recommended to maintain foliage and debark logs at the felling site as a good management option to keep the site fertile. Nutrient removal is particularly significant at high stocking levels of 10,000 stems per hectare in Sidama, especially with frequent harvesting cycles of 4 to 7 years.

**As an Agroforestry Component:** In moist areas, intercropping *Eucalyptus camaldulensis* with agricultural crops can increase productivity, income, and biofuel production (which is preferable for high-quality cooking in rural areas), while also improving the environment through carbon sequestration, soil fertility, and biodiversity. These benefits have already been observed in the agricultural landscapes of Sidama.

**Livelihood Improvement:** Eucalyptus trees help households become self-sufficient in wood and provide substantial cash income. Overall, Eucalyptus contributes to poverty reduction and ensures food security for millions of rural households throughout the highlands of Ethiopia.

**Understanding Community and Expert Views in the Region:** In my opinion, a technically explanatory approach is preferred to gain in-depth understanding through key informant interviews and focus group discussions that are selected in an unbiased way. The information collected should be used to develop a questionnaire for verification purposes during interviews with different social segments.

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# Imprint

**Published by**
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

**Registered offices**
Bonn and Eschborn, Germany

**Land Governance II**
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https://www.giz.de/en/worldwide/336.html

**As of**
February 2024

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**Layout and editing**
Benjamin Kalkum

**Photo credits**
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German Federal Ministry for Economic Cooperation and Development (BMZ)