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Research Paper

Assessment of Farmer's Tree Preferences and Their Seasonal Frost Management Practices in Frost-Affected Highlands of Eastern Ethiopia

Goremsu Getachew[1]*, Daba Bogale[2], Abera Tesfaye[1]

[1]*Ethiopian Forestry Development, Central Ethiopia Research Center, Addis Ababa, 33042, Ethiopia*
[2]*Ethiopian Forestry Development, Dire Dawa Center, Dire Dawa, 1708, Ethiopia*
***Corresponding author e-mail**: goremsugetachew@gmail.com

Abstract
Deforestation, land degradation, and low survival of planted seedlings are serious problems in highland Ethiopia. To address these problems, different land management practices such as afforestation and conservation program have been implemented; however, the success to date limited due to environmental stress and insufficient post-planting care. Therefore, the objective of this study was to investigate farmer's tree needs and their traditional knowledge of seasonal frost management practices in selected frost-affected highlands of Eastern, Ethiopia. A total of 111 households were randomly selected for interviews on farmer's tree species preference, frost management practices, and the causes of seedling mortality in the study area. Furthermore, key informant interviews and focus group discussions were used to collect the data. Descriptive statistics were used to analyze the data. The results confirm that season frost (55.6%) followed by free grazing (22.2%), inappropriate species site match (11.1%), and inappropriate planting time (5.6%) were major causes of seedling mortality in the study area. Organic mulch, plant cover, smoking, watering, and manuring were seasonal frost management practices applied by farmer's to enhance seedlings' survival in the study areas. However, this indigenous knowledge should be encouraged by the government through improved research, and extension services, to enhance seedlings' survival in the study areas as well as to introduce it in different frost-prone highlands of Ethiopia. Moreover, species such as *Eucalyptus globulus' Labill, Cupressus lusitanica Mill., Juniperus procera Hochst. ex Endl., Hagenia abyssinica a (Bruce) J.F.Gmel, and Podocarpus falcatus (Thunb.) Mirb. (syn. P. gracilior Pilg.)*, were suggested as frost-tolerant species in the study area. Therefore, it is recommended that planting these tree species through research and campaign is essential to reduce land degradation in the frost-affected highlands area of the country, particularly in the study area.

Keywords
Eastern Highlands, Frost Hardiness, Indigenous Knowledge, Tree Survival

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1. INTRODUCTION

The Ethiopian highlands are the largest mountain complex in Africa and are rich in a diverse variety of flora and fauna species and nowadays, the percentage of forest cover is less than 4% (Hurni et al., 2010; Meshesha et al., 2014; Nyssen et al., 2015). Rapid deforestation and degradation are severely threatening the forest resources in the highland parts of Ethiopia (Lemenih and Teketay, 2004). Agricultural expansion, population pressure, free grazing, and overexploitation of forests for fuel wood, fodder, and construction materials are the main causes of deforestation and land degradation in highland parts of Ethiopia (Tefera et al., 2014; Tigabu et al., 2014). These deforestation and land degradation had an economic and ecological impact at both local and national levels. For instance, biodiversity loss is accelerated; ecosystem services such as carbon sequestration are also threatened, and reduced capacity of the forest to contribute to products and food security (Taddese, 2001; Gebre et al., 2019).

Drought, invasive species, and climate change are the new threats to forest resources in Ethiopia (Bishaw, 2001). Environmental factor together with deforestation and land degradation has resulted in a shortage of wood products such as fodder, timber, and fruits. Furthermore, environmental stress (frost, low humidity, and drought) together with insufficient post-planting care, poor-quality nursery stock, and limiting site conditions are the main causes of the death of transplanted tree seedlings in Ethiopia (Lemenih and Teketay, 2004; Eshetie et al., 2020). For example, frost is a significant climatic phenomenon that influences the distribution of plant species, particularly in highland areas (Rorato et al., 2018). It hinders tree growth and reduces the productivity of forests in the long run. Frost also causes the formation of ice crystals in the extracellular spaces. As a result of the difference in water potential, water in the cell protoplasm is directed to the extracellular spaces, causing damage because the cell loses water, resulting in dehydration (Rorato et al., 2018). However, assessment of species selection and local management practices of frost are crucial to enhance seedling's survival in frost-affected areas.

To address environmental challenges, efforts have been made to launch afforestation and conservation programs; however, success has been limited thus far (Eshetu et al., 2014). The lack of information on the performance of tree species after planting and their responses to environmental conditions has made listing potential species for restoring frost-affected areas a difficult task. Therefore, careful species selection is required to avoid frost-sensitive species, especially for restoration and afforestation programs in frost-affected areas (Rorato et al., 2018). Yet, detailed analyses of the forest resources crises associated with the destruction and practical solutions on how to effectively reverse the course of destruction in the country are generally limited.

Hence, to make plantation and restoration work effective, critical assessments of possible limitations and improving seedling establishment and management techniques in degraded frost-affected highlands would be vitally essential. With this regard, tree species selection for the restoration and management of environmental factors are essential as environmental stress may affect seedling survival in the highland area differently. There have been limited studies concerning farmer's tree preferences and traditional knowledge of seasonal frost management practices in frost-affected degraded highlands of Eastern Ethiopia.

Thus, an investigation of farmer's tree needs and traditional knowledge of seasonal frost management practices was conducted to answer the following questions: (1) How and why do local farmer's manage the frost in the study area? (2) Which tree species were suggested as frost tolerance in the study area? To address these research questions, the following specific objectives were developed. Therefore, the objectives of this study were :(1) to describe e farmer tree species preferences, main niches, and traditional knowledge of seasonal frost management practices in the study area; and (2) to identify frost tolerant tree species in the study area. Thus, the present study provides information about appropriate species selection for frost-affected areas, and environments and resolves land degradation problems through afforestation/reforestation and area ex-closure strategies by improving seedling establishment and management practices in frost-affected highlands. The outcome of this research serves as input for scientific studies, researchers, governmental and non-governmental organizations, policy and decision-makers, and forestry projects in the area and at the national level.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The study was conducted in the Haramaya and Girawa districts of East Hararghe zone, Oromia regional state, Ethiopia. Haramaya district is located around 9° 0'-9° 5' N and 42° 0'-42° 24' E and between 1400 and 2340 m above sea level while Girawa district is found around 8° 42'-9° 24' N and 41° 24'-42° 24' E and between 1215 and 3405 m above sea level. The mean annual rainfall ranges from 769 to 1150 mm in the Haramaya (Marru et al., 2013) and 550 to 1100 mm in the Girawa district (Beyan Ahmed and Geta, 2013). The average mean annual temperature is 18 °C in the Haramaya (Marru et al., 2013) and 20 °C in the Girawa district (Beyan Ahmed and Geta, 2013).

Both Haramaya and Girawa district has three agroecological zones namely highland, midland, and lowland. These agroecological zones vary by altitude and rainfall distribution. The two study kebeles are located in the highland agroecological zone. The physiographic condition of the study areas are plateaus, rugged dissected mountains, deep valleys, gorges, and plains (Beyan Ahmed and Geta, 2013; Marru et al., 2013). Cultivated lands, pasture lands, and forest lands are the land use type found in the study areas (Beyan Ahmed and Geta, 2013; Marru et al., 2013). The dominant soil types in the study areas are nitosol, cambisols, and vertisols (Beyan Ahmed and Geta, 2013; Marru et al., 2013).

The total population is 271,018 in Haramaya and 240,173 in Girawa District (Authority, 2015). Rainfed agriculture with a mixed farming system (crop production and livestock rearing) are the primary livelihood source of the inhabitants in both study areas (Beyan Ahmed and Geta, 2013; Marru et al., 2013). Maize (*Zea mays*), Common bean (*Phaseolus vulgaris*), Pulse (*Haricot bean*), Oilseed, Vegetables, and Fruits are the most dominant crops in both districts (Ahmed et al., 2017). Moreover, Khat (*Catha edulis* Forsk) and Buna (*Coffea arabica* L.) Khat (*Catha edulis*) are the dominant cash crop grown in both districts.

2.2 Sampling Techniques

In the present study, a multi-stage sampling procedure was used to conduct a household survey. First, preliminary information was collected at the district level through discussions with agricultural experts and local elders who know about degraded lands and frost-prone areas. The discussions were focused on degraded areas, frost occurrence, and frost-prone areas. Then, a reconnaissance survey was conducted to characterize degraded areas and frost-prone highlands. Secondly, two districts (Haramaya and Girawa districts) where seasonal frost is a major threat were selected purposively. Thirdly, two kebeles (Tinike from Haramaya and Birbrsa from Girawa district) were selected purposively with frost-prone areas. The reasons for having the two selected kebeles were due to the presence of degraded areas, frost occurrence, and frost-prone areas. Moreover, the reason to have two

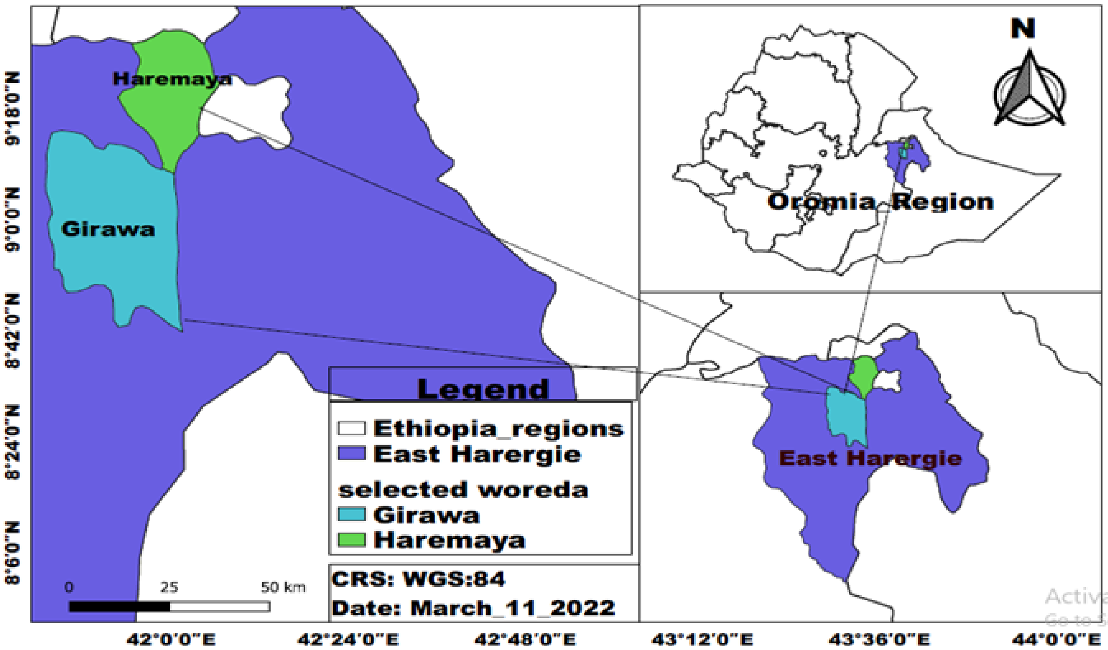

Figure 1. Map of the Study Area

kebeles samples was for replication purposes. The lists of households living in the kebeles were obtained from kebele offices and crossed checked with key informants for their inclusiveness. We identified a total of 1840 households (640 from Tinike kebele and 1200 from Birbrsa kebele). Finally, a total of 111 households, 39 from Tinike and 72 Birbrsa kebeles, were randomly selected for interview. The proportional sample size formula, which was adapted from the (Kothari, 2004) method, was used to determine the needed number of household respondents from the two kebeles.

$$n = \frac{Z^2 pqN}{e^2(N-1) + Z^2 pq}$$

Where:
p = Probability of success = 0.5 and q = 1-p (1-0.5) = 0.5
N = Total number of households in selected kebeles (1840)
Z = Confidence level at 95% which is 1.96 from Z-table
e= the margin of error considered as 9% for this study which is 0.09

$$n = \frac{1.96^2(0.5)(0.5)(1840)}{0.09^2(1839) + 1.96^2(0.5)(0.5)} = 111$$

The number of households for each kebele was calculated as shown below:

$$n = \frac{n * N_1}{N}$$

Where,
n = Sample size in respective kebele,
N_1 = Total number of the households included in the study (111),
N = Total number of households in both kebeles (1840).

$$n(\text{Tinike kebele}) = \frac{640 * 111}{1840} = 39$$

$$n(\text{Birbrsa kebele}) = \frac{1200 * 111}{1840} = 72$$

2.3 Method of Data Collection

To achieve the study objectives both quantitative and qualitative data were used. In this study, both primary and secondary data sources were used. The secondary data were collected from published and unpublished documents to get an overview of the study sites and frost. The primary data were gathered through household surveys, key informant interviews, and focus group discussions.

Closed and open questionnaires were developed and semi-structured and face-to-face interviews were conducted to collect qualitative and quantitative data from respondents. The household questionnaires were prepared in English and translated into Afan Oromo, the study area language. Enumerators who were experts and knowledgeable about the area were involved in data collection. Before interviewing household respondents, the objectives of the study were explained to enumerators, and they were trained in data collection and interview methods.

For qualitative data, both key informant interviews and focus group discussions were conducted. In this study, key informants are defined as persons who are knowledgeable about frost, frost occurrences, and frost management practices and who have lived for a long time in the respective kebele. The selection of key informants was done by using the snowball sampling method (Bernard, 2017). Twelve key informants (six per kebele) were interviewed for the entire study. The purpose of selecting key informants was to identify the local name of tree species and to cross-check the number of households living in the kebeles. The following points were addressed during key informant interviews: farmer's tree species preferences, frost management practices, and major causes of seedling mortality in the study areas.

In the focus group discussion, model farmer's, youths, and women households were selected from each kebele. The focus group discussions were conducted separately with men and women and with different wealth ranks. The purposes of the discussions were to verify farmer tree needs and traditional frost management practices. The information generated here was used to validate the information obtained from household respondents.

2.4 Data Analysis and Presentation

The data were analyzed by using both quantitative and qualitative methods. Before data analysis, data encoding and data management were conducted. Then, the quantitative data were analyzed by using descriptive statistics (frequency, percentage, and means) with the SPSS version 25 Package Software program. On the other hand, qualitative data interpretation was done through the description and narration in words.

3. RESULTS AND DISCUSSION

3.1 Households and Socio-Economic Characteristics

In this study, the socio-economic features of the sampled households were assessed and presented (Table 1). About 79.3% of the respondents were men. Marital status also showed that the majority of sampled respondents were married (91.3%), and the remaining were divorced. The average age of the sample households was 39.5 years. The majority (39.5%) of them had ages between 30 and 45 years old. Concerning, educational status, the majority of sample respondents (57.6%) were illiterate (Table 1). The mean land holding size of the sampled households at the study sites were 0.58 ha and it was a major fixed asset for farmer's in the study area. Farmer's in the study area pursued farming in which livestock production was a component. Cattle, Goats, Donkeys, Mules, and Poultry were important species of livestock kept by farmer's in the study area. The average total livestock holding of the sampled respondents was 5.8 tropical livestock units. Farming was the primary occupation for all of the households, which represents about 92.4% and 7.4% of the households were involved in other income such as petty trading, charcoal selling, and labor work.

3.2 The Source of Seedlings, Planting Niches, and Species Preference for Planting

About 66% of respondents stated that they got seedlings from government nurseries, 21% of them produced seedlings in their nurseries by broadcasting seed on prepared plantation sites, while 12% and 1% of the respondents get seedlings from other private nurseries and NGO-owned nurseries, respectively (Figure 2). This was supported by the finding of Dedefo et al. (2017) who reported that government nurseries followed by individual groups, non-governmental organizations, and projects provide seedlings for farmer's, afforestation, and community tree planting programs. Moreover, farmer's can also participate in the production of tree seedlings individually or collectively to access markets for their consumption (Gregorio et al., 2015; Dedefo et al., 2017).

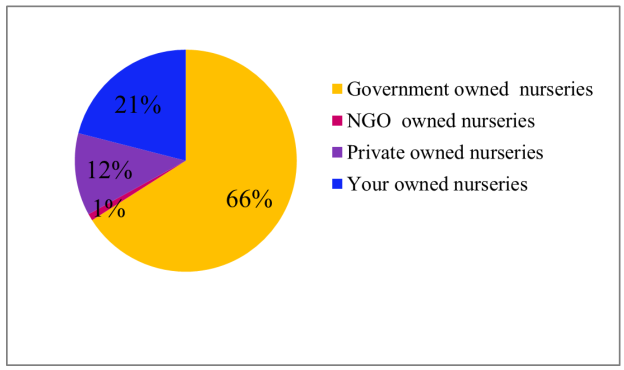

Figure 2. The Main Source of Seedlings for Planting in the Study Area

In this study, households retained tree species in different land use types for multiple products and services. Therefore, in the present study, the most preferred niches for planting tree species were boundary planting followed by homegarden and scattered trees in crop filed (Table 2). Farmer's tree planting was limited to boundary and homegarden could be to prevent disturbance from animals and for better management of the tree species. Boundary planting and homegarden were preferred because browsing and fire were easier to control, and manure and refuse could be applied more easily than in a distant field. Women, in particular, stated that they prefer planting trees close to their homes so that they do not have to leave their homes for long periods in search of fuel wood medicine and animal fodder. Furthermore, planting close to home reduces the risk of others secretly collecting fruits from their trees. Planting along borders is also done to mark the boundaries and deter stray animals. The majority of tree species are retained in boundary planting and homegarden to meet the immediate needs of the household, such as food, medicines, income, handcrafting materials, and ecological needs. This conforms to the results reported by Fikir et al. (2018), that farmer's only planted trees in their backyards and boundary

Table 1. Socio-Economic Characteristics of the Sampled Household Heads (N=111) Interviewed in the Study Area

Variables	Categories	Number (%) of respondents	Mean
Sex	Male	88(79.3)	
	Female	23 (20.7)	
Marital status	Married	101(91.3)	
	Divorced	10(8.7)	
Age (Years)			39.5
Educational status	Illiterate	64 (57.6)	
	Literate	47 (42.4)	
Size of land holding (ha)			0.58
Family size			5.7
Total livestock in TLU			5.8

planting due to the homeowner feeling a strong sense of ownership and trees directly managed by household members. Moreover, such a tendency to maintain multipurpose species limited to the homestead and boundary planting may be for the sake of easing management practices, to protect the farm from theft, and livestock grazing (Negash, 2007; Fikir et al., 2018). In addition, farmer's maintained scattered tree species on their crop fields for their wood products and soil fertility improvement.

Furthermore, the respondent stated that they match planting niches with planting objectives. For instance, a species that will grow in farmlands loses its leaves before it starts to rain and easily decomposes to improve the fertility of the soil.

Table 2. The Main Niche Where the Farmer's Grow Tree Species in the Study Area

Planting niches	Percent
Home garden	20.9%
Scattered trees in the crop field	17.9%
Boundary planting	61.9%

From the total respondents, about 73% of the respondents mentioned that they planted tree species and managed for a different purpose in their farmland while the remaining 27% of the respondents did not plant tree species on their farms. The major reasons farmer's did not grow the tree on their farms are due to the shortage of land (52%) and lack of planting materials especially fruit trees (48%). Likewise, previous studies have reported various constraints that could affect the integration of tree species in farmland including land shortage, lack of seedlings for planting, poor survival of seedlings, and lack of sufficient material (Dedefo et al., 2017; Fikir et al., 2018).

According to the respondent, *Eucalyptus globulus* (94%), *Cupressus lustinica* (52%), *Olea africana* Mill. (36%), *Juniperus procera* (23.8%), *Cordia africana* Lam. (21%), and *Podocarpus falactus* (19%) were tree species planted on their farms for different products and services. *Eucalyptus globulus* is exotic species that was retained in farmlands for its pole for construction, timber, source of cash, and fuelwood, as it is fuelwood demand is high in the highland area. Moreover, the species are highly preferred by farmer's in the study area due to their easy adaptability, propagation, and management regimes of *Eucalyptus globulus*. A previous study elsewhere reported that *Eucalyptus globulus* was the most performed tree species in the highland of Ethiopia (Mekonnen et al., 2006; Tesfaye et al., 2015; Fikir et al., 2018). Furthermore, *Eucalyptus globulus* species support the livelihood of local peoples through the sale of stands, fuelwood, and building materials (Kebede, 2022).

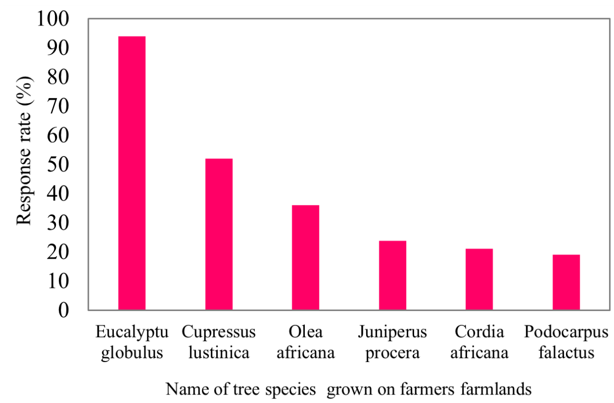

Figure 3. Most Preferred Tree Species for Planting on Farmer's Fields in the Study Area

3.3 Farmer's Species Selection Criteria and Preferences of Tree Products/ Services

In the study area, farming households have long relied on tree species for different products and services. About 50.5%

of the respondent's plant tree species for the production of fuel wood and 24.9% of the respondents' plant trees for the production of poles for construction (Table 3). They also retained tree species for diverse purposes such as fruit, fodder production, soil fertility improvement, erosion control, shade, and medicinal value. The majority of farmer's, used tree species for fuelwood may be due to the fuelwood shortage is a critical problem in highland areas. Farmer's normally retained tree species in farmland for multiple useful and valuable purposes to optimize the capture and use of environmental resources (Negash, 2007). This is dependent on the tangible that they render to the household such as food, cash income, medicine, fodder, bee forage, shades, live fences, improve soil fertility through mulching, animal feed as fodder, shade reduction over integrated crops, fuelwood, timber and construction wood (Mohammed and Asfaw, 2015; Mamo and Asfaw, 2017). The other reasons farmer's integrate tree species in farmlands are also to regulate leaching and improve crop yield, productivity, and sustainability of the land (Negash, 2007).

Table 3. Tree Services and Products Most Preferred by Respondents in the Study Area

Tree products/service	Percent
Fuelwood	50.5%
Fodder	6.8%
Soil fertility and erosion control	3.5%
Fruits	8%
Medicine	1.3%
Shade	5%
Pole for construction	24.9%

According to the survey result, fast-growing (64.2%,) followed by multiple uses (23.9%), drought resistance (7.5%), and ease of establishment (11%) were the major criteria for selection of tree species to plant in their farmlands (Table 4). Fast growing was the most preferred attribute of tree species in the study area. Similarly, fast-growing and high biomass-producing tree species were preferred in highland areas (Mekonnen et al., 2006). This finding was also supported by Negash et al. (2012) reported that farmer's prefer species that give multiple products and services. Furthermore, fast-growing tree species are being increasingly integrated with traditional land-use types, mainly for poles for construction and timber. Furthermore, farmer's employ some characteristics, including fast growth, utility, compatibility, multipurpose use value, and drought resistance to incorporate tree species on farms (Mohammed and Asfaw, 2015).

3.4 Causes of Seedlings Mortality

About 97% of the respondents had information on tree-planting activities and seedling survival in the study area.

Table 4. Attributes of Trees Most Valued by Respondents in the Study Area

Attributes	Percent	Rank
Drought resistance	7.5%	3rd
Fast growing	64.2%	1st
Ease of establishment	4.5%	4th
Multiple uses	23.9%	2nd

The respondents noted that the major causes of seedling mortality were frost (55.6%), free grazing (22.2%), inappropriate species site match (11.11%), inappropriate planting time (5.6%), inappropriate planting material (3.3%), and drought (2.2%) (Figure 4). Previous studies elsewhere supported that insufficient management care, species site match, and limited site condition contributed to the death of transplanted trees before they can make a meaningful economic and environmental contribution to the communities (Eshetie et al., 2020). On other hand, many factors influence the survival of seedlings and their importance varies according to the species and agroecological condition (Reubens et al., 2009). For instance, insufficient soil moisture during the early growth stage is one of the most important causes of high seedling mortality; hence watering during this period can improve seedling survival (Jegora et al., 2019) and animal grazing and termite were the two major biotic factors for survival of transplanted tree species (Eshetie et al., 2020). Furthermore, weeds can pose a threat to the planted seedlings, especially in the first year, due to competition for water, nutrients, and light and weeding can have a positive effect on seedling survival (Eshetie et al., 2020).

3.5 Seasonal Frost Occurrence and Management Practices

The result indicated that frost was occurring once a year (monomodal). Therefore, the majority of respondents, 84.5% stated that seasonal frost occurs once a year (between September- January). This line with the finding of Charrier et al. (2015) who reported that with the current climate condition, the risk of frost damage is greatest in the autumn or spring. To enhance seedling survival and mitigate frost farmer's applied frost management techniques. Therefore, about 64% of respondents pointed out that they used local frost management practices while 36% of the respondents didn't apply any management practices. The management practices applied for frost protection were organic mulch (39%), plant cover (32%), smoking (23.7%), watering, and manuring (5%). The result is in line with the finding of Amin et al. (2018) reported organic mulch and plant cover were the two important management practices for enhancing the survival of transplanted seedlings.

Respondents stated that there is no prevention method to protect seedlings and crops from frost damage. It is an

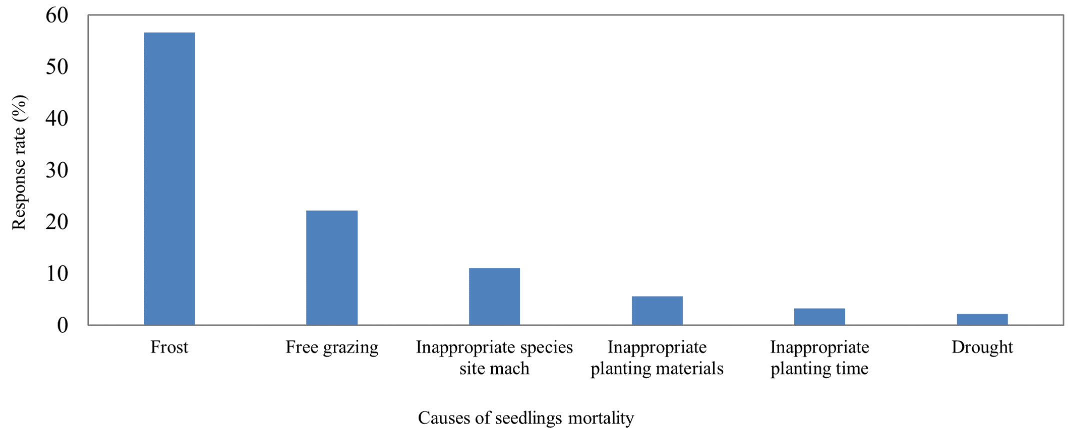

Figure 4. Causes of Seedling Mortality in the Study Areas

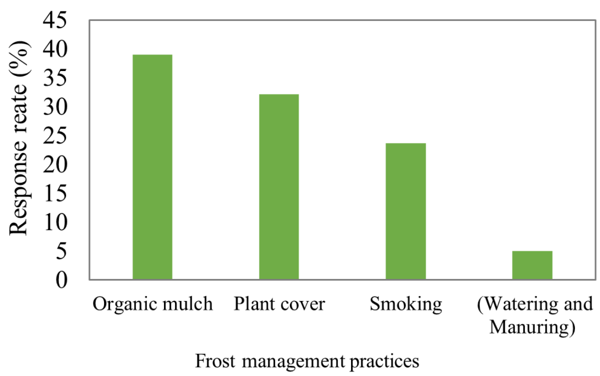

Figure 5. Farmer's Frost Management Practices in the Study Area

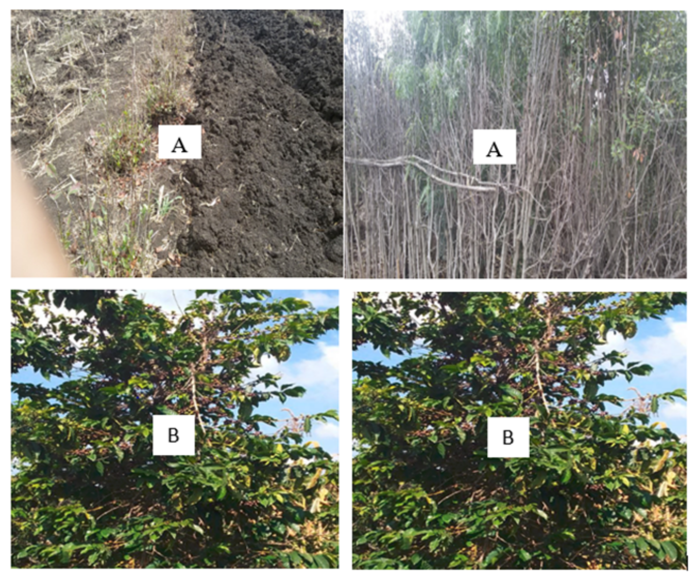

Figure 6. The Pictures Show the Effect of Seasonal Frost on *Catha adulis* (A) and *Coffea arabica* (B) Species in the Study Areas

emergency or natural disaster that partially or completely damages the planted seedlings. Therefore, they apply management practices to enhance the survival of seedlings and crops, but not for the total prevention of frost. Damage from abiotic stresses such as frost may hinder tree growth and affect the productivity of forest products (Figure 6). Therefore, assessing and documenting traditional knowledge of frost risk is critical for forestry and agriculture.

Concerning the stage when seedlings are more prone to frost damage, 54.3% of the respondents reported that seedlings at the first 6 months of their growth stage were prone to frost damage. This was supported by the finding of Eshetie et al. (2020) who reported that the seedlings were dead in the first seven months after planting between July to January and also a similar finding was reported that frost damage often occurs on newly planted seedlings (Man et al., 2009).

3.6 Tree Species Suggested as Frost-Tolerant Species

Species respond differently to frost, regardless of the size of the container in which the seedling is produced or the ecological group. The result shows that species such as *Eucalyptus globulus*(45.3%) followed by *Cupressus lusitanica* (23.3%), *Juniperus procera* (18.9%), *Haginia abyssinica* (10%), and *Podocarpus flactus* (2.5%) were suggested as frost-tolerant species in the study area (Figures 5 and 7). A previous study elsewhere reported that *Eucalyptus globulus* and *Cupressus lusitanica* were the most performed tree species in the highland of central Ethiopia (Mekonnen et al., 2006). Therefore, planting these species play an important role in the rehabilitation and restoration of degraded land in highland areas.

Table 5. The Main Stages of the Seedlings Susceptible to Frost (N = 111) in the Study Area

The main stage of planted seedlings susceptible to frost	Frequency	Percent
First six months after planting	60	54.3%
The first year after planting	35	31.5%
First two years after planting	12	10.9%
First three years after planting	4	3.3%

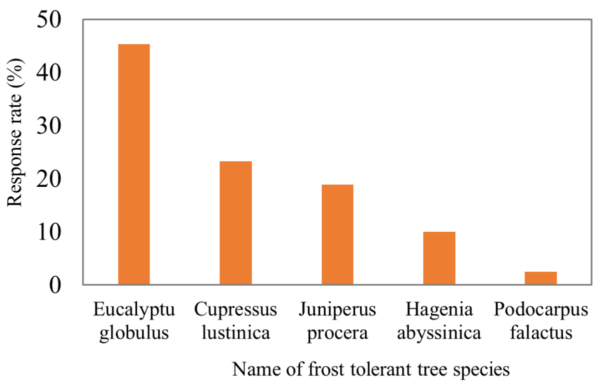

Figure 7. Tree Species Suggested by Respondents as Frost Tolerant in the Study Area

4. CONCLUSIONS

The present study has provided valuable information on the assessment of farmer's tree needs and their traditional knowledge of seasonal frost management in the study area. The result of this study confirms that boundary planting and homegarden were the most preferred planting niches in the study area. Frost is an emergency or natural disaster that partially or completely damages the planted seedling in the study area. Therefore, organic mulch and plant cover were the two most important management practices for enhancing the survival of transplanted seedlings in the study area. However, these management practices should be encouraged by the government through improved research, and extension services, to enhance seedlings' survival and successful establishment of tree species in the study areas. Species *Eucalyptus globulus*, *Cupressus lusitanica*, and *Juniperus procera* were suggested as frost-tolerant species in the study area. Therefore, we recommended that planting these tree species through research and campaign is essential to essential to reduce land degradation in the frost-affected highlands area of the country, particularly in the study area.

5. ACKNOWLEDGEMENT

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