Heliyon 10 (2024) e37174

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Farmers' traditional knowledge on seasonal frost management and their tree preferences in frost affected highlands of Amhara region, Ethiopia

Yeshifana Alemneh Mengesha[a,*], Hailie Shiferaw Wolle[a], Demelash Alem Ayana[a], Alayu Haile Belayneh[a], Sewale Wondimneh Yewogu[a], Sintayehu Eshetu Gebremedhin[a], Amsalu Endalamaw Worku[a], Anteneh Yenesew Desta[a], Abera Tesfaye Yesufe[b]

[a] *Ethiopian Forestry Development, Bahir Dar Center, Bahir Dar, Ethiopia, P.O. Box 2128*
[b] *Ethiopian Forestry Development, Central Ethiopia Center, Addis Ababa, Ethiopia, P.O.Box 30708*

A R T I C L E I N F O

Keywords:
Frost management
Plantation forest
Tree species preference
Frost affected area

A B S T R A C T

Extreme environmental conditions, such as high temperature, frost, low humidity and desiccating winds, are the main causes for the failure of plantation forests in Ethiopia. Frost damage contributes to the low seedling survival and plantation success in frost affected highlands of Amhara region Ethiopia. Research outputs on farmers' traditional knowledge on frost management and technologies that curb frost related problems are limited in the country. This study was conducted to document the farmers' traditional knowledge on frost management and their tree preference in frost affected highlands of Amhara region. Sinan, Guna-begemder and Meket districts were selected purposively in 2020. One representative sample Kebele was selected in each district with a total of 204 households selected with systematic random sampling technique for interview. In addition to interview focus group discussion was also conducted. Both descriptive and inferential statistics data analysis method were employed. In this study, frost was found to be an important limiting factor for plantation development in the study area. Frost occurs, mainly, from September to January. The local community applies traditional frost management techniques. The seasonality of frost occurrence and type of traditional frost management practices varied among the studied Kebeles. *Eucalyptus globulus*, *Oldeania alpina*, *Rhamnus prinoides* and *Chamaecytisus palmensis* were preferred trees species due to their frost resistant performance. The effectiveness of identified traditional frost management techniques needs to be investigated before they can be promoting and disseminating. Farmers should also be trained in proper techniques to protect planted seedlings from frost damage. Adjusting the timing of planting may also help to mitigate the effect of frost damage.

1. Introduction

Ethiopia has a diverse biophysical environment, and its land formations fall broadly into highlands and lowlands. A high incidence

* Corresponding author.
E-mail address: alemnehyeshifana@gmail.com (Y.A. Mengesha).

https://doi.org/10.1016/j.heliyon.2024.e37174
Received 14 December 2023; Received in revised form 28 August 2024; Accepted 28 August 2024
Available online 30 August 2024
2405-8440/

of deforestation and degradation of vegetation is a severe problem in the highlands of Ethiopia. High population growth, agricultural land expansion and high dependence on biomass energy are the major direct drivers of deforestation and forest degradation in the highland areas of the country [1,2].

The needs of the local community for various tree species are also not available in the country.

Furthermore, extreme environmental conditions, such as high temperature, frost, low humidity and desiccating winds, are the main causes for the failure of plantations forests and natural regeneration in the country [3]. The ability to withstand environmental stresses becomes the limiting factor for tree growing, seedling survival and tree species distribution [4].

Frost is the ice crystals that can coat plants, the ground and other inanimate objects if the temperature is cold enough [5,6]. Frost damage on woody plants is a recurring environmental factor in the alpine Zone [7,8]. Low temperature is a key weather factor that limits the growth of trees and shrubs and seedling survival. It can also be detrimental to tree growth and may cause mortality [9]. Frost damage ranges from minor external damage to branches and buds total to tree mortality [9] by freezing through which most tissues can be suddenly destroyed during a period of plant growth [6,9]. Frost also impacts both external and internal structure and processes of trees.

It is challenging to control frost damage on tree seedlings. But it could be minimized the susceptibility of soils to frost action using different techniques, such as chemicals, to reduce frost heaving on soils. Mulches, shade and soil coating can also use to alter the radiation balance of the soil surface. Moreover planting methods of seedlings, sowing methods, types of container for seedling growth, and the type of tree species used for planting can reduce frost damages on tree seedling [9,10].

Frost damage is one of the major factors for the low survival of seedlings and low plantation success in frost-affected highlands in the Amhara region. Limited research outputs on farmers' traditional knowledge of frost management and technologies useful for curbing frost damage lack in the country. Therefore, this study was aimed to assess and document farmers' tree needs and their traditional frost management techniques in frost-affected highlands of the region.

2. Materials and methods

2.1. Description of the study area

The study was conducted in Sinan, Guna-begemidir and Meket districts in the Amhara National Regional State, Ethiopia (Fig. 1). Sinan district is in South-western part of Amhara Region; about 327 km North-west of Addis Ababa and 292 km South-west of Bahir

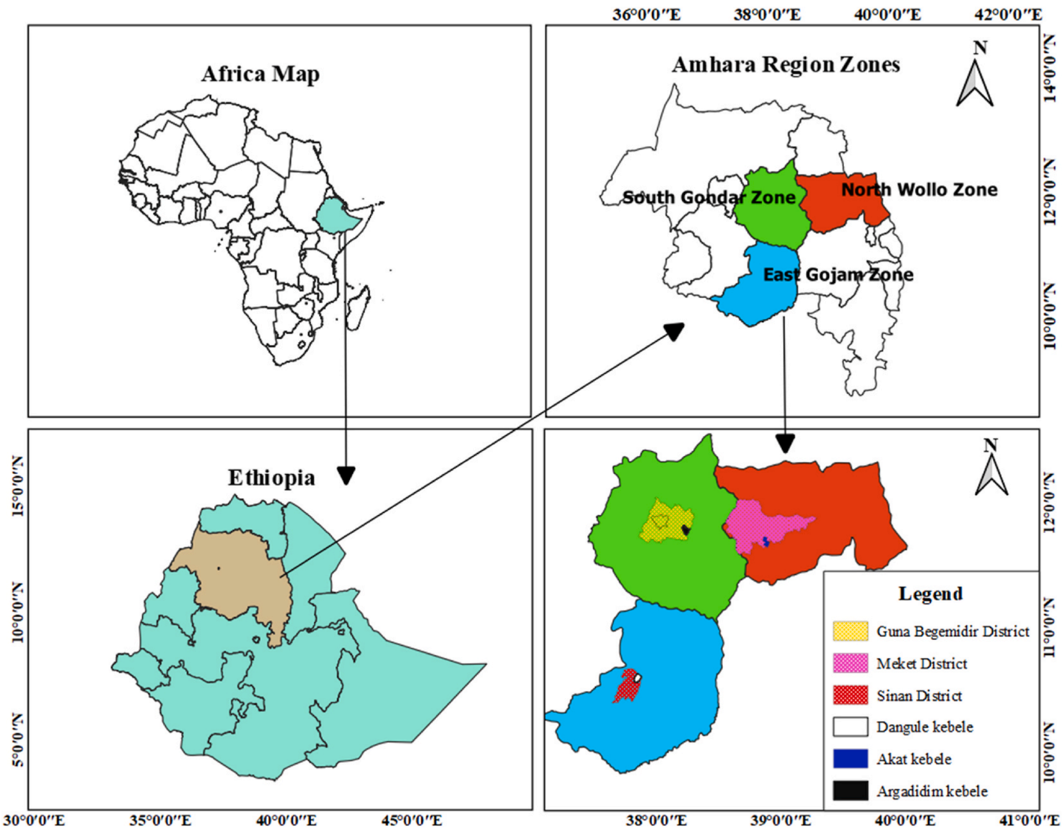

Fig. 1. Map of the study area (source: author 2024).

Dar. Its location extends between 10° 25′ 13″ to 10° 40′ 30″ North latitude and 37° 40′ 00″ to 37° 50′ 20″ East longitude which is generated using quantum GIS of version 3.8. The altitude ranges from 2300 to 4100 m.a.s.l with annual rainfall of 900–1445 mm and the annual temperature of 0–15 °C.

The areal agroecological proportion is 23 % sub-tropical, 75 % temperate and 2 % cool temperate. The land use constitutes 58.8 % cultivated land, 18.3 % grazing land, 0.5 % forest land, 3.2 % settlement, 5.9 % wet land, and 13.3 % other land uses [11,12]. The farming system of the district is characterized by mixed farming (crop production and livestock rearing). Crops contribute a larger share of the farmers' income. Wheat, barley and potato are major agricultural crops in the district [13].

Guna-begemidir district is found in south Gondar Zone of the Amhara Regional State, about 690 km North of Addis Ababa and 30 km from Debre-tabor town. It extends between 11°42′0″ to 12°5′0″ North latitude and 38°6′30″ to 38°27′0″ East longitude. The district has a total area of 51373.2 ha with altitude range of 1200–4220 m.a.s.l. [14]. The average annual rainfall of the district is 1250 mm with temperature of 9–25 °C [15]. The agro-ecology of the district 46 % sub-tropical, 32 % temperate and 5 % cool temperate. The main livelihood for the local community is subsistence agriculture which includes crop production (barley, wheat, bean, teff, potato, pea and common vetch), as well as livestock rearing (sheep, cattle, donkey and horse). Farmers in the district are largely engaged in planting *Eucalyptus globulus Labill* and managing woodlots [14,15].

Meket district is found in North Wollo Zone of Amhara National Regional State and located about 600 km north of Addis Ababa. It extends between 11°35′50″ to 12°20′30″ North latitude and 38°32′35″ to 39°16′40″ East longitude. The agro-climatic zone of the district includes sub-tropical, temperate, and cool temperate [16]. The average annual rainfall of the district ranges from 600 to 1000 mm. The topography is characterized by rugged (65 %), plain (28 %), mountainous (4 %) and gorge/valley (3 %). The land use of the district includes cultivated land (43,584ha), grazing land (15,152), perennial woody vegetation's (54,000), settlement (39,528ha), degraded land (11,592ha) and others (23,184ha). The main livelihood for the local people in the district is agriculture, mainly, crop production and animal rearing [17].

2.2. Data collection methods

2.2.1. Sampling techniques

First reconnaissance survey conducted, and discussion was held with Zonal and district officers to get information about frost occurrence and accompanied damage on seedling establishment and its effect on the success of plantation in the region. Multistage sampling technique was employed to select study areas. In the first stage, three districts (Sinan, Guna-Begemder, and Meket) were selected purposefully based on the intensity of frost occurrence and accompanied damage on planted seedlings and plantations. In the second stage, one *Kebele* from each district was selected. In the third stage, 204 samples were selected randomly from every 20th person on a list of the population in a systematic manner.

The selected *Kebeles* for the study were Argadidim, Dangule and Akat, respectively, from Guna begemidir, Sinan and Meket districts.

To determine the number of households (HHs) for interview in each *Kebele*, the total number of HHs was obtained from district offices and *Kebeles*. In each *Kebele*, 5 % of the total HHs was selected. A systematic random sampling technique was employed to select Households to administer the questionnaire and to conduct FGD. Finally, a total of 204 HHs (71 from Argadidim, 69 from Akat and 64 from Dangule *Kebele*) were selected to collect data using questionnaire (Table 1).

2.2.2. Household survey

Using a semi structured questionnaire, information on the socioeconomic characteristics of the HHs, farmers' tree species and preferences, main obstacles of planting trees and traditional knowledge of seasonal frost management techniques which are used to increase seedling hardiness and prevent early seedling mortality was gathered. The survey data was conducted in 2020.

2.2.3. Focus group discussion

People with more traditional expertise of managing seasonal frost damage to seedlings and other plants were chosen for the FGD. In every Kebele, two independent FGDs were held, one with male farmers and the other with female farmers. As suggested by Refs. [18,19], 6 to 10 members per a group were used to form a focus group. Participants in the focus group were invited to speak freely and the facilitator led the conversations.

Table 1
Sampled households.

No	*Kebele*	Total number of HHs	Number of samples HHs		
			Male	Female	Total
1	Argadidim	1420	57	14	71
2	Akat	1380	61	8	69
3	Dangule	1280	64	0	64
	Total		182	22	204

Source: District Agricultural Bureau (2020).

2.3. Data analysis

The HHs interview data were analyzed by a statistical package for social science (SPSS version 26). Focus group discussion data were categorized and narrated. The relationship between response variables and HH socio-economic characteristics, such as age, educational status and landholding size, was also assessed. The ANOVA function of the *stats* package in R version 4.1.2 [20] was used for analysis of variance and Chi-square tests. Tukey HSD was used to determine significant differences between means ($P \leq 0.05$). The study area map is generated using quantum GIS version 3.8 software.

3. Result and discussion

3.1. Household characteristics

In Argadidim, 38 % of the HHs were illiterate, compared to 35 % in Akat and 31 % in Dangule *Kebeles*. The percentage of people classified as informally educated in Argadidim, Akat, and Dangule *Kebeles* was around 36.6 %, 24.6 %, and 21.9 %, respectively. In Argadidim, Akat, and Dangule *Kebeles*, the percentage of HHs who attended secondary schools was 4.2 %, 4.3 %, and 4.7 %, respectively, while the remaining 21.1 %, 34.8 %, and 42.2 % were educated to grade 1–8. At Argadidim, Akat, and Dangule *Kebeles*, the average family size per HH was 7.0, 6.0, and 6.0, respectively (Table 2). About 0.7 ha is the average landholding size of the study HHs (Table 2) which is below the average land holding size of Amhara region having 1.09 ha.

3.2. Tree growing and frost knowledge

Planting and managing variety of tree species has been a household practice, mostly for fuelwood and construction purposes. About 87.7 %, 92.8 % and 93.8 % of the HHs, in Argadidim, Akat and Dangule *Kebeles*, respectively, have been involved in growing trees and they have better understanding about the characteristics of quality seedling. Moreover, HHs in the focus group discussion mentioned a good stem, a fibrous root system, healthy foliage and well-developed buds as seedling quality characteristics. About 40.8 %, 26.1 % and 51.6 % of HHS in Argadidim, Akat and Dangule *Kebeles*, respectively, had graded seedlings before planting (Table 3).

Households believe that seedlings with good stems and health, can resist seasonal frost and perform well in frost occurrence periods. In line with our finding, planted seedling survival is a function of seedling quality [21]. Furthermore, according to other author, there is a favorable association between the height of seedlings at establishing and the increase in survival likelihood [22].

Responses from HHs revealed that the occurrence of seasonal frost is one of the major challenges for seedling survival and plantation success in the study *Kebeles*. Traditional frost control methods are used by the locals in the study *Kebeles* to lessen the harm that seasonal frost does to agricultural crops and planted seedlings. Table 3 shows that conventional frost management strategies are used by about 42.3 %, 46.4 %, and 18.8 % of HHs in Argadidim, Akat, and Dangule *Kebeles*, respectively [6]. also stated that these different management techniques could be used to reduce risks of frost damage in tree seedling survival and growth.

3.3. Sources of seedlings, planting niche and characteristics of tree species required by the community

3.3.1. Households' source of seedlings

The HHs in the studied *Kebeles* obtained tree seedlings from different sources such as government nurseries, NGOs, other private nurseries, and their own nurseries. Except for Akat, where the government nursery is the second-largest supplier of tree seedlings in the *Kebele*, the majority of HHs in each research region acquired their tree seedlings from their own nurseries, followed by those from

Table 2
Demographic characteristics of the sample HHs.

Variable	*Kebele*		
	Argadidim	Akat	Dangule
Sex (%)			
Male	80.3	88.4	100.0
Female	19.7	11.6	0.0
Average family size	7.0	6.0	6.0
Average landholding (ha)	0.6	0.7	0.6
Educational status (%)			
Illiterate	38.0	35.0	31.0
Read and write	36.6	24.6	21.9
Grade1-8	21.1	34.8	42.2
Grade 9-10	4.2	4.3	4.7
Social status (%)			
Kebele Administration	4.2		4.7
Kebele Admin executive	15.5	18.8	6.3
Religion leader	11.3	18.8	1.6
Ordinary resident	69.0	62.3	87.4

Source: field survey result (2020).

Table 3
Percentage of HHs about tree planting experiences and traditional protection methods for frost damage on tree seedlings in the studied *Kebeles*.

	Percent of HH response in the study site					
	Argadidim		Akat		Dangule	
	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)	No (%)
Do you grow trees?	87.7	18.3	92.8	7.2	93.8	6.3
Do you grade seedlings before planting?	40.8	59.2	26.1	73.9	51.6	48.4
Do you practice traditional frost management?	42.3	57.7	46.4	53.6	18.75	81.3

Source: field survey result (2020).

commercial nurseries (Fig. 2). Contrary to the findings of the present study, it was said that government-run tree nurseries are the nation's primary source of seedlings, followed by privately owned production and other sources [23].

Several governmental entities, including higher education institutions, research institutes, farmers training centers, and regional bureaus of agriculture with offices at the zonal and district levels, are among the public sectors that play a role in the seed and seedling system. NGOs are engaged in the manufacture and planting of tree seedlings and have also provided help to the public sector [24].

3.3.2. Tree planting niches

The study revealed that, for planting a tree local community uses different places, such as home gardens, scattered trees on farmlands, boundary planting and other land areas. In line with our findings, other studies reported that the local community in Ethiopia plant tree seedlings as homestead, boundary planting, as scattered trees on farmlands and as woodlots [23]. Trees are planted around homesteads, farm boundaries, along roads and footpaths, inside and along gully sides, and in some cases, larger blocks of trees are grown in formerly cultivated or grazing fields [25].

In Dangule *Kebele*, home gardens are the most popular niche for planting seedlings as they are close to homes and therefore easier to protect and maintain. About 70.3 % of HHs in Dangule *Kebele*, 34.8 % in Akat and 46.5 % in Argadidim *Kebele* preferred the home garden niche for planting trees (Fig. 3). Niche preference is related to tree care and protection as there are challenges associated with open grazing and potential conflicts associated with border planting [,23]. Besides home garden planting, border planting is the most preferred planting niche in the study area. About 53.6 %, 34.4 % and 23.9 % of HHs from Akat, Dangule and Argadidim *Kebeles* preferred border planting (Fig. 3). In line with our finding [25,26], noted farm boundaries as the dominant and favorite tree planting niches by the local communities. Likewise [27,28], also support that most of the farmers plant trees and shrubs along the boundary of their farms to protect their crops from wind and used for a source of different wood products. Scattered trees on farmland was the least recommended planting niche in this survey. Scattered trees are planted on farmlands by only around 7.0 %, 5.8 %, and 9.4 % of the HHs in Argadidim, Akat, and Dangule *Kebeles*, respectively.

3.3.3. Characteristics of preferred tree species

The study revealed that fast-growing nature, ease of establishment, multipurpose nature, drought resistance and frost resistance were used as criteria for selecting tree seedlings for planting. However, the proportion of HHs who responded to each criterion varied among the studied *Kebeles* (Fig. 4). In Argadidim and Akat *Kebeles*, the percentage of HHs who used frost resistant nature of seedlings as seedling selection criteria for planting is low. This could be attributed to lack of awareness about the impact of frost on seedling survival or due to lack of alternative tree species for planting. Except Dangule *Kebele* the selection of frost tolerant species is less and use

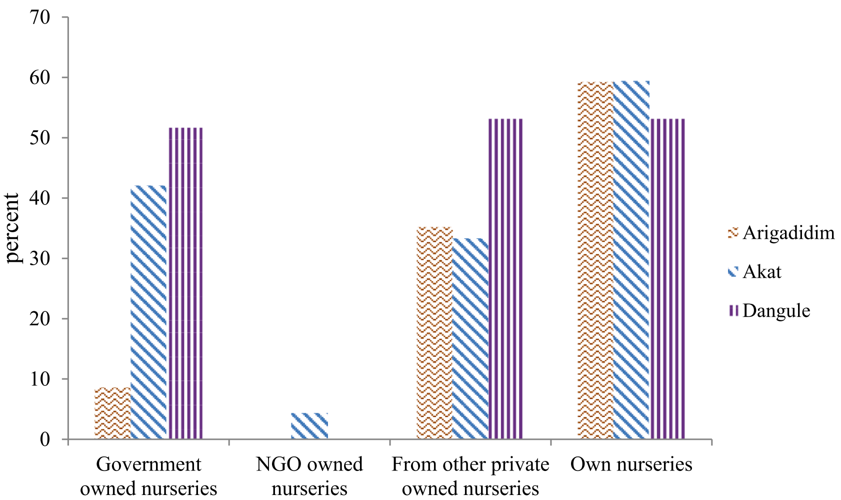

Fig. 2. Tree seedling sources of HHs in each studied *Kebeles*. Source: field survey result (2020).

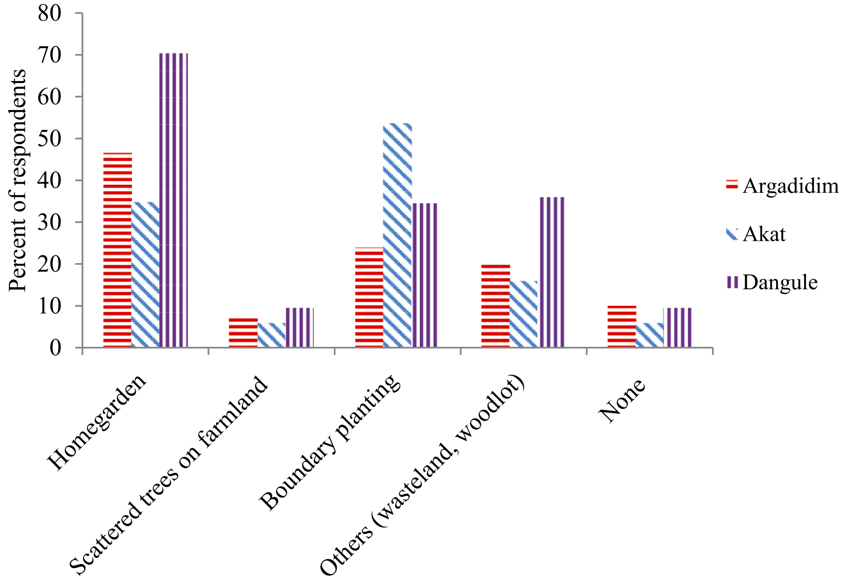

Fig. 3. Seedling planting niche in each study *Kebele*. Source: field survey result (2020).

mostly fast-growing tree species which even though it needs physical intervention and further investigation may be due to the fast-growing tree can be grown faster and escapes the frost season. In addition to the fast-growing species HHs are dominantly select multipurpose tree since the multipurpose trees have also short term benefits thy give attention to them and even, they protect from frost.

Similarly, other studies such as [29] reported that HHs use fast growth nature, compatibility, multipurpose nature, and drought resistance as criteria to integrate seedlings on their farmland [30]. also argued that farmers have varying needs and preferences for planting different tree species. Moreover, most often farmers prefer species whose silvicultural characteristics are well known, mostly native species [,30].

3.4. Major challenges of tree planting in frost affected highlands of the study area

The HHs in this study mentioned the causes of seedling mortality were frost damage, rodents, drought, inappropriate species site matching, free grazing, inappropriate planting time and inappropriate planting material. In line with the current study [21], stated that seedling survival is a function of seedling quality, species-site matching, proper planting at the right time, seasonal precipitation patterns, and watering in dry seasons.

In Argadidm, Akat, and Dangule *Kebeles*, frost was identified as the main cause of seedling mortality by approximately 91.5 %, 100.0 %, and 81.3 % of households, respectively (Fig. 5). Conversely, factors such as drought, inappropriate species site match, free

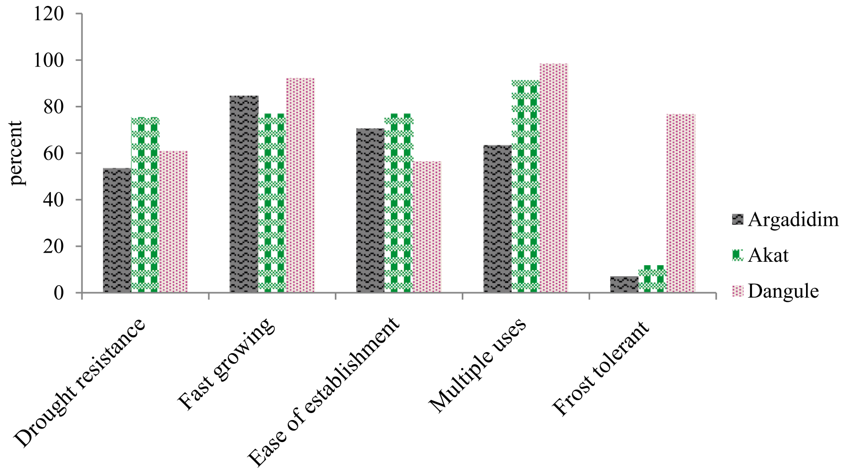

Fig. 4. Tree selection criteria in the study *Kebeles*. Source: field survey result (2020).

grazing, inappropriate planting time, and inappropriate planting materials were considered less significant contributors to seedling mortality in these *Kebeles*. It is worth noting that drought is a prevalent issue in the alpine Zones of Ethiopia, particularly during the dry season [31,32].

3.5. Frost susceptible degree under different occurrence season, age and niche

3.5.1. Season of frost occurrence

Tree growers in the study area have good knowledge on the seasons when frost occurs. They mentioned that frost occurs from mid-September to the end of January. Other studies indicated that nocturnal frost in the highlands of Ethiopia is regular in September/October and December/January [32]. Most of the time, frost occurs during the autumn season, starting from the months of October to December and sometimes it extends up to January [33]. Similar to, other findings more than 50 % of HHs indicated that seasonal frost starts from the end of September to the beginning October (Table 4); and the frost that occurs from September to October is less severe than that occurs during December to January.

Other studies stated that, radiative frost which occurs in September to October is less severe as it occurs after the long rains when the relative humidity and dew point temperature are relatively high. While, convective frost that occurs typically in December to January; when the air is dry in northern Ethiopia, the temperatures do not reach the low dew point and the effect of frost on plants is sever [32]. [9] also explained that frost events are most common during the spring and fall seasons in the temperate regions throughout the world.

3.5.2. The impact of frost along the growth stage of plants

This study showed that the impact of seasonal frost on plants varies depending on the stage of growth. Frost affects planted seedlings within the first six months after planting, accordingly around 68.0 %, 56.0 %, and 41.0 % of HHs in Akat, Dangule, and Argadidim *Kebeles*, respectively (Fig. 6). This might be the result of the seedlings having fewer and smaller leaves as well as immature stems, which made them less resilient to freezing temperatures during frost events. According to Ref. [34], a plant's resistance to frost is extremely poor in its early development stage. There are reports that seedlings are particularly vulnerable to frost damage on their main leaves. As seedlings age, the extent of frost damage reduces, according to the HHs' reactions in every *Kebele* under study (Fig. 6). Seedlings in this research are damaged by frost up to three years after planting. According to other research, frost that falls in the first year following planting has an impact on tree stability and development [10].

3.5.3. Frost vulnerable planting niche

Studies indicated that successful tree species establishment is achieved when the proposed planting niche matches with climate and edaphic requirements of a species [35]. To mitigate the effects of frost on seedlings, it is crucial to have knowledge about planting niches that experience cold. This may be achieved by either avoiding planting seedlings in these niches or by managing the frost appropriately. We discovered in our present study that HHs are cognizant of the planting niches in their area that are susceptible to frost.

Similarly, it is reported that plantations in degraded hillsides and agricultural lands are more susceptible to frost damage than plantations in heavy shade areas [10].

The response from the HHs also indciated that less frost damage occurs around homesteads since plantation in these areas are close and receive better management such as mulching, manuring, fencing, and other management practices (Fig. 7). [35] also reported that homestead plantation is a preferred niche for seedling plantation and management because it is more accessible and easily managed by women and the youth.

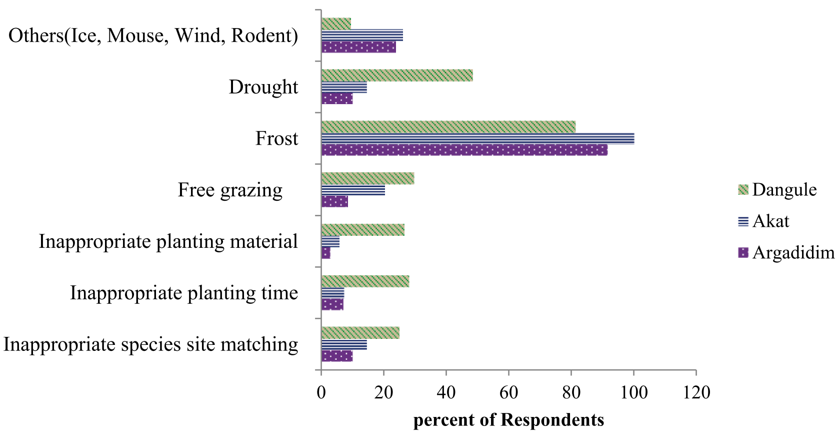

Fig. 5. Factors of seedling mortality in the three studied *Kebeles*. Source: field survey result (2020).

Table 4
Percentage of response on the season of frost occurrence in the three-frost affected *Kebeles*.

Months	Starts			Ends		
	Argadidim	Akat	Dangule	Argadidim	Akat	Dangule
September	12.67	21.74	53.12			
October	61.97	75.36	37.5	61.97	76.81	40.62
November	18.31	7.25	18.75	18.31	5.79	17.19
December	4.22	62.32	23.43	36.62	62.32	26.56
End of January				23.94	18.84	23.43

Source: field survey result (2020).

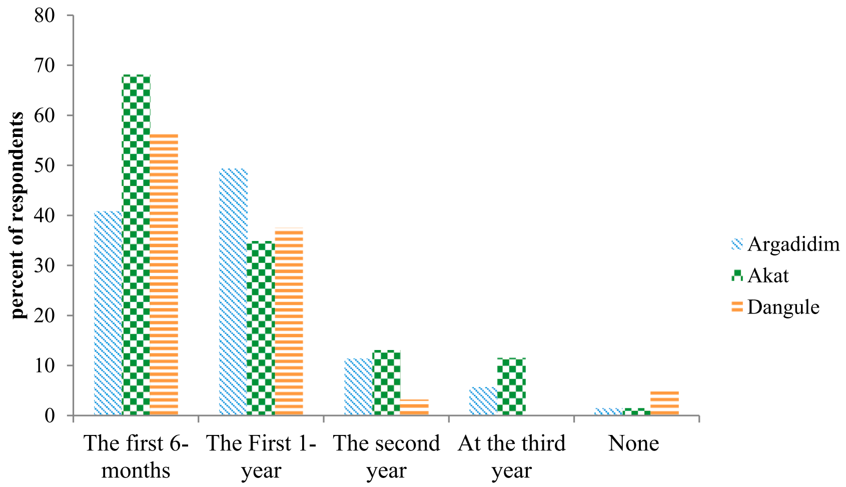

Fig. 6. The growth age of seedlings affected by frost in the studied *Kebeles*. Source: field survey result (2020).

3.6. Traditional frost management techniques

More than half of the HHs in each of the studied *Kebeles* did not apply any frost management practice on tree seedlings during times of frost. About 59.2 % of HHs at Argadidim, 58.0 % at Akat, and 78.1 % at Dangule *Kebeles* did not use any of the seasonal frost management techniques on planted tree seedlings. Those who practice use stone or wood fence, mulch, and plant cover to protect planted seedlings from frost (Fig. 8).

Other studies also show that different traditional frost management practices, such as top-dressing ground with straw, manure,

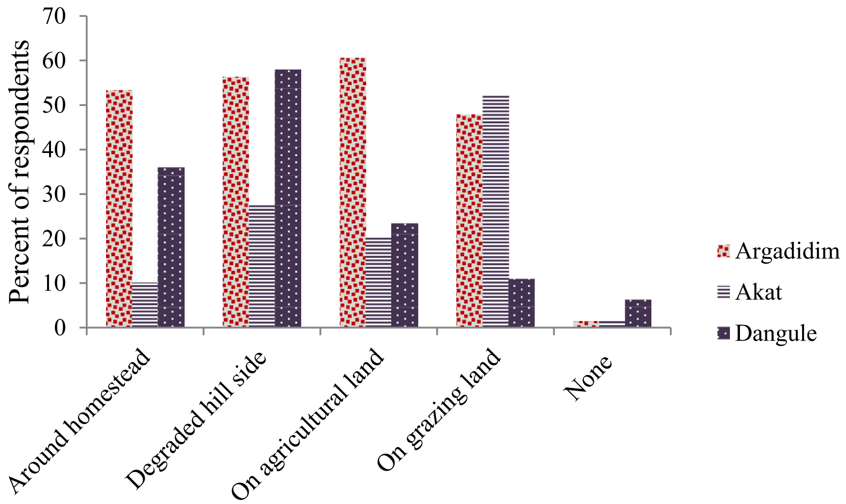

Fig. 7. Percentage of response from HHs on degree of susceptibility of seedling planting niches to frost in the studied *Kebeles*. Source: field survey result (2020).

forest litter, or wooden laths, can be used to reduce frost damage on plants [6,10,35]. [6] reported that plant cover is one of the frost management techniques since it enables the plant rows to be warmer than the clear sky and increase downward long-wave radiation at night, in addition to reducing conventional heat losses to the air.

3.7. Traditional frost management strategies in the studied Kebeles

The response from the HHs revealed that different traditional frost management techniques, such as manuring, watering and chemical fertilizer application, are used to reduce the effect of frost damage on tree seedlings planted in the studied *Kebeles*. Manuring of planted seedlings was mentioned as a successful frost management technique in the study *Kebeles*. More than 45.0 % of the HHs in each *Kebele* used manuring as a frost management technique on planted tree seedlings.

Some of the HHs also uses watering and fertilizer applications to reduce frost damage on planted seedlings. However, a considerable number of HHs in each studied *Kebeles* did not use any of the frost management techniques (Fig. 9). The HHs mentioned that fertilizer application helps seedlings grow fast and resist frost damage.

A study by Ref. [6] suggested that when soils are dry, there are more air spaces which inhibit heat transfer and storage. Therefore, in the dry season, watering or irrigation of dry soil is one method of frost management; when the soil is wet well in advance of the frost event, the sun can warm the soil. Irrigation/watering at the beginning of the frost season increases soil moisture content and improves heat and energy absorption. In addition, healthy trees are less susceptible to frost damage, hence, application of fertilization and manure improves plant health and growth. Thus, all traditional frost management strategies reduce the impact of frost on planted seedlings.

3.8. Potential frost-resistant tree species in frost affected area

All the HHs in the study area plant different tree species for various uses and services mainly for fuelwood and construction. A total of 22 plant species were recorded from the entire 204 sample HHs in the study *Kebeles*. The number and types of tree species varied with *Kebeles*. The highest number of tree species was recorded at Akat *Kebele* followed by Argadidim *Kebele*. The lowest number of species was recorded at Dangule *Kebele* (Table 5).

Among the tree species identified in each *Kebeles*, *Eucalyptus globulus* Labill was the dominant preferred tree species due to the growing demands for its wood products. HHs considered *Eucalyptus* as a cash crop. In this regard, 83.09 % of HHs at Arigadidim, 52.17 % at Akat and 96.87 % at Dangule *Kebeles* plant *E. globulus.* A study by Ref. [17] confirmed that *Eucalyptus* trees account for high percentage of the exotic tree species in Meket district because of their ease of management and adaptability, low establishment costs and non-palatability to livestock. *Eucalyptus* is the most preferred tree species by farmers due to its fast growth and resistance to various environmental factors [25].

Among the tree species identified in each *Kebele*, *E. globulus* (83.09 % of the HHs), *Oldeania alpina K. Schum.* (73.23 %), and *Chamaecytisus palmensis* (H.Christ) Hutch. (29.58 %) were the top three best-suited tree species in resisting frost damage in Argadidim *Kebele* (Table 5), whereas, *E.globulus* (96.87 %), *Rhamnus prinoides* L'Herit. (53.12 %), and *C.palmensis* (45.31 %) were the top three best-suited tree species in resisting frost damage in Dangule *Kebele*. The top three tree species that are most frost resistant in Akat *Kebele* were *E. globules* (52.17 %), *Acacia decurrens* (J. C. Wendl.) Willd (23.19 %) and *Malus domestica* Borkh. (17.39 %) [23]. also found that *E. globulus, R.prinoides,* and *C. palmensis* tree species are the major tree seedlings produced in Sinan district.

3.9. Relations among the different parameters

The time when frost happened differed across the locations studied. Yet, the level of education of the households did not greatly affect their traditional methods of dealing with frost, their knowledge on how to predict the survival of seedlings in their area, or how to evaluate seedlings before planting.

The evaluation of seedlings also did not show a strong relation with frost as a reason for the death of seedlings in their area. The level of education significantly influences the types of frost management techniques used (Table 6). Research by Refs. [34,36] indicates that education is a key factor in spreading new technologies in agriculture and can simplify the adoption of advanced technologies.

Tree-growing experience was affected by family size, traditional frost management practices and type of frost management (Table 7). In line with this [26], explained that family size had a great influence on tree planting and growing in the highlands of Ethiopia. Also [37], explained that households with large family sizes are willing to adopt different practices due to the high availability of labor.

Conversely, the implementation of conventional frost management techniques differed across districts. Likewise, the traditional approach to frost management varied based on the level of experience in tree cultivation. Moreover, the social status of households played a role in determining whether farmers graded seedlings prior to planting. Tree cultivation experience was also a factor in farmers' decision to grade seedlings before planting (Table 7).

4. Conclusion and recommendation

Frost has a negative impact on the growth and distribution of tree seedlings in the study area. It occurs mainly between September to January in every year. Although the use of traditional frost management practice (mulch, plant cover and stone/wood fence) and its implementation have been varied among each *Kebeles*, though the local communities have been adopting different traditional frost

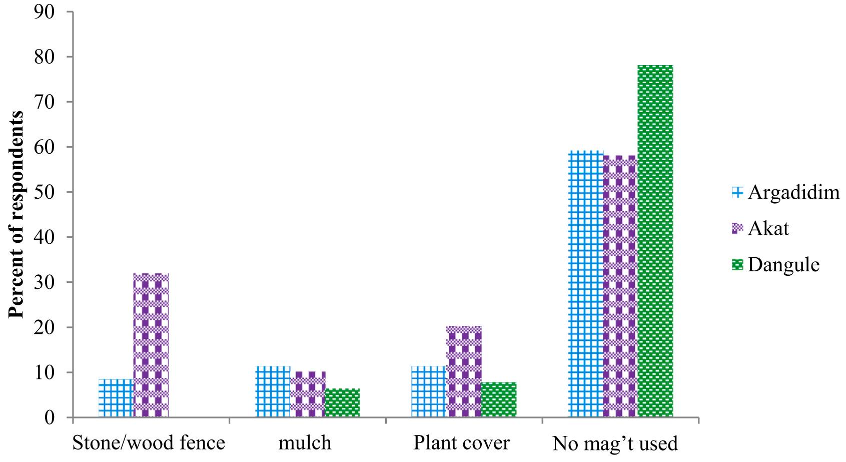

Fig. 8. Percentage of HHs who apply frost management techniques in each studied *Kebele*. "mag't" on x-axis mean management. Source: field survey result (2020).

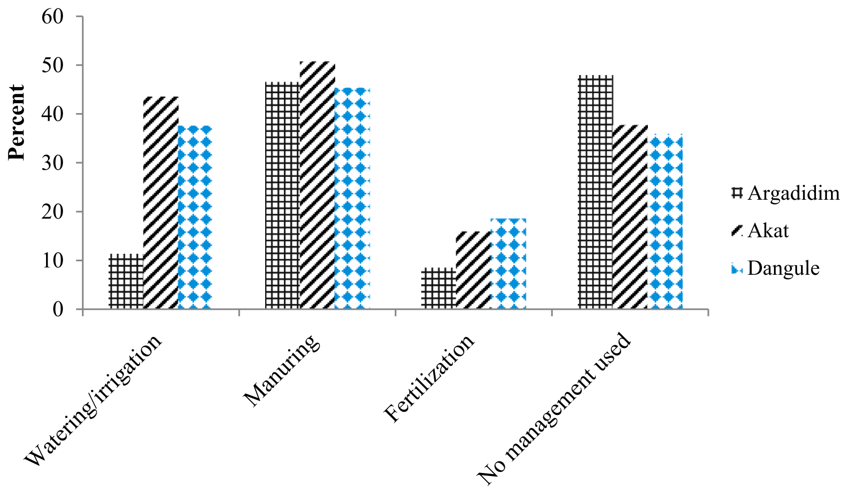

Fig. 9. Frost management techniques on planted seedlings. Source: field survey result (2020).

management techniques in each *Kebele.*

The local community has been planting and managing different tree species for various uses and services mainly for fuelwood and construction purpose. Government nurseries, other private nurseries and their own nurseries are the most important sources of seedlings in the study area. For seedling planting, they have chosen different planting niches such as home gardens, degraded hill sides, grazing land and agricultural lands.

Eucalyptus globulus, Oldeania alpina, Rhamnus prinoides and *Chamaecytisus palmensis* are the top four mentioned as frost resistant tree species in the study area. In addition, frost resistance, provision of multiple uses, easy of establishment and fast-growing tree nature characteristics are the most preferred one. However, inappropriate species site match, inappropriate planting time, inappropriate planting material, free grazing, frost and drought have been identified as a major challenge for tree growth in the study areas.

The local community should be trained and encouraged to apply their traditional knowledge and acquired skills to planted seedling in frost affected areas. Moreover, knowledge on timing and duration of frost is important to adjust seedling planting time in the study *Kebeles*. Developing a brief calendar on seasonality of frost occurrence and creating awareness to HHs are important in areas where frost damage on tree seedlings is a major challenge.

The findings of this research can help for policymakers to understand the unique requirements and difficulties associated with planting trees in regions that have experienced frost. Further research to investigate different frost management techniques and species screening for frost affected areas is required.

Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on a

Table 5
List of potentially suited tree species found in three frost affected *Kebeles* based on HHs' ranking.

Scientific name	Local name (Amharic)	Argadidim (n = 71)	Akat (n = 69)	Dangule (n = 64)
Eucalyptus globulus Labill.	*Nech bahir zaf*	83.09	52.17	96.87
Oldeania alpina K. Schum.	*Kerkeha*	73.23	0.00	26.56
Chamaecytisus palmensis (H.Christ) Hutch.	*Meno zaf*	29.58	8.69	45.31
Rhamnus prinoides L'Herit.	*Gesho*	4.22	4.34	53.12
Malus domestica Borkh.	*Apple*	2.81	17.39	17.19
Acacia decurrens (J. C. Wendl.) Willd	*Dekerence Girar*	1.41	23.19	7.81
Hagenia abyssinica (Bruce) J.F. Gmel	*Koso*	8.45	1.45	14.06
Discopodium penninervum Hochst	*Almit*	8.45	1.45	0.00
Juniperus procera Hochst. ex Endl.	*Habesha tid*	1.41	5.79	0.00
Buddleja polystachya Fresen	*Anfar*	0.00	2.89	0.00
Acacia abysinica Hochst. ex Benth.	*Bazira girar*	0.00	1.45	0.00
Schinus molle L	*Kundoberbere*	0.00	1.45	0.00
Casuarina equisetifolia L.	*Shewushewe*	0.00	4.35	0.00
Allophylus abyssinicus Hochst. Radlk.	*Embis*	0.00	1.45	0.00
Olea africana Mill.	*Woyira*	0.00	1.45	1.56
Croton macrostachyus Mill.	*Bisana*	1.41	1.45	0.00
Cupresus lustanica Mill.	*Yeferenji tid*	0.00	2.89	0.00
Rosa abyssinica R.Br. ex Lindl.	*kega*	0.00	0.00	1.56
Dombeya torrida (J.F.Gmel.)	*wulkefa*	0.00	0.00	7.81
Sesbania sesban (L.) Merr.	*sesbania*	0.00	0.00	3.12
Vernonia myriantha Hook. f.	*dengorita*	0.00	0.00	7.81
Erica arborea L.	*Asta*	0.00	0.00	1.56

Note: *"0"* indicates that the tree species is not mentioned in that *Kebele*. Source: field survey result (2020).

Table 6
Relationship among the different parameters.

Variable 1	Variable 2	Chi-squared	df	P-value
Educational status	Traditional frost management	8.43	10	0.587
Educational status	Knowhow on seedling survival	13.63	20	0.849
Educational status	Practice of traditional frost management	8.43	10	0.587
Kebele	Season of frost occurrence	109.38	28	<0.001***
Educational status	Seedling grading	8.27	5	0.1419
Educational status	Type of frost management practiced	142.21,	70	<0.001***
Seedling grading	Seedling mortality because of frost	0.17	1	0.6794

Note: (*) represents p-value is less than 0.05, (***) represents p-value is less than 0.0001.
Source: field survey result (2020).

Table 7
Factors affecting seedling planting and frost management in the study areas.

Factors affecting tree growing experience				
	Estimate	*Std. Error*	*t value*	*Pr(>|t|)*
District	−0.2038575	0.0608889	−3.348	0.000987 ***
Family size	−0.0380682	0.0102202	−3.725	0.000260 ***
Traditional frost mag. practice	0.1073546	0.0439414	2.443	0.015505 *
Type of frost mgt.	0.0131072	0.0056042	2.339	0.020419 *
Factors affecting practice of traditional frost management				
	Estimate	*Std. Error*	*t value*	*Pr (>|t|)*
District	0.244786	0.113603	2.155	0.032481 *
Tree growing experience	0.292678	0.119796	2.443	0.015505 *
Factors affecting seedling grading				
	Estimate	*Std. Error*	*t value*	*Pr (>|t|)*
HH social status	−0.073453	0.032893	−2.233	0.0267*
Tree growing experience	0.227602	0.124438	1.829	0.0690

Note: (*) represents p-value is less than 0.05, (***) represents p-value is less than 0.0001.
Source: field survey result (2020).

reasonable request.

CRediT authorship contribution statement

Yeshifana Alemneh Mengesha: Writing – review & editing, Writing – original draft, Validation, Software, Formal analysis, Data curation. **Hailie Shiferaw Wolle:** Writing – original draft, Validation, Software, Formal analysis, Data curation. **Demelash Alem Ayana:** Writing – original draft, Validation, Software, Formal analysis. **Alayu Haile Belayneh:** Writing – original draft, Validation, Data curation. **Sewale Wondimneh Yewogu:** Writing – original draft, Validation. **Sintayehu Eshetu Gebremedhin:** Writing – original draft, Validation, Data curation. **Amsalu Endalamaw Worku:** Data curation. **Anteneh Yenesew Desta:** Data curation. **Abera Tesfaye Yesufe:** Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Yeshifana Alemneh Mengesha reports was provided by Ethiopian Forestry Development. Yeshifana Alemneh Mengesha reports a relationship with Ethiopian Forestry Development that includes: employment. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] D. Teketay, Deforestation, wood famine, and environmental degradation in Ethiopia's highland ecosystems: urgent need for action, NE Afr. Stud. 8 (1) (2001) 53–76, https://doi.org/10.1353/nas.2005.0020.

[2] H. Hurni, S. Abate, A. Bantider, B. Debele, E. Ludi, B. Porter, B. Yitaferu, G. Zeleke, Analysing degradation and rehabilitation for sustainable land management in the highlands of Ethiopia,", Land Degrad. Dev. 9 (6) (1998) 529–542, https://doi.org/10.1002/(SICI)1099-145X(199811/12)9:6<529::AID-LDR313>3.0.CO;2-O.

[3] M. Lemenih, D. Teketay, Restoration of native forest flora in the degraded highlands of Ethiopia: constraints and opportunities, Feature article, *SINET*: Ethiop, J. Sci. 27 (1) (2004) 75–90.

[4] G. Charrier, N.M. Stpoul, C. Damesin, N. Delpierre, H. Hanneninen, J.M.T. Ruiz, H. Davi, Interaction of drought and frost in tree ecophysiology: rethinking the timing of risks, Ann. For. Sci. 78 (2) (2021), https://doi.org/10.1007/s13595-021-01052-5.

[5] D.W. Inouye, The ecological and evolutionary significance of frost in the context of climate change, Ecol. Lett. 3 (5) (2000) 457–463, https://doi.org/10.1046/j.1461-0248.2000.00165.x.

[6] FAO, Frost protection, Fundamentals , Practice and Economics, vol. 1, 2005.

[7] G. Neuner, Frost resistance in alpine woody plants, Front. Plant Sci. 5 (DEC) (2014), https://doi.org/10.3389/fpls.2014.00654.

[8] A. Sakai, W. Larcher, Frost Survival of Plants responses and adaptation to freezing stress, Ecol. Stud. 62 (1987).

[9] D.B.K. Pedersen, Frost events, frost damage, and potential frost ring formation in woody species of northern Arizona, Angew. Chem. Int. Ed. 6 (11) (2010) 951–952.

[10] F. Goulet, Frost heaving of forest tree seedlings, N. For. 9 (1995) 67–94.

[11] M. Salele, T.M. Enyew, Prioritizing apple production constraints in Sinan Woreda, Ethiopia: a constraint facing index (CFI) approach,", Int. J. African Asian Stud. (October) (2020) https://doi.org/10.7176/jaas/68-01.

[12] A. Nigatu, M. Wondie, A. Alemu, W. Tadesse, Y. Chanie, Indigenous management practices of highland bamboo (Yushania alpina) in West Amhara, Ethiopia, Cogent Food Agric. 7 (1) (2021), https://doi.org/10.1080/23311932.2021.1926683.

[13] D. Amare, Assessing the effect of land degradation on farmer's livelihood options at Choke Mountain, South Asian Journal of Development Research 2 (2) (2020) 114–129.

[14] T.A. Adamu, A.T. Tsegaye, Burden and associated factors of Scabies outbreak in Guna-begemidir district, south Gondar, Amhara, Ethiopia (2018) 1–17, https://doi.org/10.21203/rs.2.20900/v1, 2020.

[15] S. Mulu, Z. Asfaw, A. Alemu, D. Teketay, Determinants of decision making by smallholder farmers on northwestern Ethiopian highlands,", Land 11 (2022) 1–16.

[16] G. Wollie, L. Zemedu, B. Tegegn, Economic efficiency of smallholder farmers in barley production in Meket district, Ethiopia,", J. Dev. Agric. Econ. 10 (10) (2018) 328–338, https://doi.org/10.5897/jdae2018.0960.

[17] S. Abebaw, T. Betru, Status and trends of Eucalyptus expansion and its environmental implication in Meket district, north Wello zone, Ethiopia,", Ethiop. J. Environ. Stud. Manag. 12 (2) (2019) 181–193.

[18] R.S. Jayasekara, Focus groups in nursing research: methodological perspectives,", Nurs. Outlook 60 (6) (2012) 411–416, https://doi.org/10.1016/j.outlook.2012.02.001.

[19] B. Kc, Land Use and Land Cover Change in Relation to Internal Migration and Human Settlement in the Middle Mountains of Nepal, University of Twente Faculty of Geo-Information and Earth Observation (ITC), 2015.

[20] R.T. Core, "Team. R: a Language and Environment for Statistical Computing, R Foundation for Statistical," Computing, Vienna, Austria, 2021.

[21] A. Derero, R. Coe, C. Muthuri, K.M. Hadgu, F. Sinclair, Farmer-led approaches to increasing tree diversity in fields and farmed landscapes in Ethiopia, Agrofor. Syst. 95 (7) (2021) 1309–1326, https://doi.org/10.1007/s10457-020-00520-7.

[22] H. Bugmann, C. Bigler, Early emergence increases survival of tree seedlings in Central European temperate forests despite severe late frost, Ecol. Evol. 9 (14) (2019) 8238–8252, https://doi.org/10.1002/ece3.5399.

[23] A. Derero, Seed seedling system evaluation in Basona Werana , Enda mehoni , Lemo and Sinana woredas , Ethiopia (2013), https://doi.org/10.13140/RG.2.2.28807.39847.

[24] A. Derero, Evaluation of Tree Seeds and Seedling System in Ethiopia With Evaluation of Tree Seeds and Focus in Wolaita and Arsi (2012), https://doi.org/10.13140/RG.2.2.32162.84163.

[25] W. Bewket, Household level tree planting and its implications for environmental management in the Northwestern highlands of Ethiopia: a case study in the Chemoga watershed, blue nile basin, Land Degrad. Dev. 14 (4) (2003) 377–388, https://doi.org/10.1002/ldr.559.

[26] L.A. Duguma, H. Hager, Woody plants diversity and possession, and their future prospects in small-scale tree and shrub growing in agricultural landscapes in central highlands of Ethiopia, Small-scale For 9 (2) (2010) 153–174, https://doi.org/10.1007/s11842-009-9108-0.

[27] A. Abiyu, D. Teketay, G. Gratzer, M. Shete, Tree planting by smallholder farmers in the upper catchment of Lake Tana Watershed, Northwest Ethiopia, Small-scale For 15 (2) (2015) 199–212, https://doi.org/10.1007/s11842-015-9317-7.

[28] A. Agidie, B. Ayele, A. Wassie, K.M. Hadgu, E. Aynekulu, Agroforestry practices and farmers' perception in Koga watershed, upper blue nile basin, Ethiopia 59 (3) (2013) 14–27.

[29] H. Mohammed, Z. Asfaw, Smallholder farmers' perceptions, attitudes, and management of trees in farmed landscapes in Northeastern Ethiopia, USA USAID P 51 (2015).

[30] Z. Gebreegziabher, A. Mekonnen, M. Kassie, G. Köhlin, Household tree planting in Tigrai, Northern Ethiopia: tree species, Purposes, and Determinants 2473 (432) (2010).

[31] F. Montagnini, S. Mansourian, D. Vallauri, N. Dudley, Forest restoration in landscapes: beyond planting trees, For. Restor. Landscapes Beyond Plant. Trees (2005) 1–437, https://doi.org/10.1007/0-387-29112-1.

[32] M. Fetene, Y. Gebre-Egziabher, E. Beck, Comparison of the frost resistance of barley (hordeum vulgare l.) landraces of upland Ethiopia using electrolyte-leakage and chlorophyll fluorescence," 35 (1) (2012) 41–50.

[33] N.M. Zeleke, effect of frost hazard on major crops grown in Banja woreda, Awi aministrative zone, Amhara national regional state, north west Ethiopia (MSc Thesis), Climate Change and development (2019), http://hdl.handle.net/123456789/9682.

[34] D. Graczyk, M. Szwed, Changes in the occurrence of late spring frost in Poland, Agronomy 10 (11) (2020), https://doi.org/10.3390/agronomy10111835.

[35] Froch F.T., growth performance and nutritive quality of tree lucerne (chamaecytisus palmensis) fodder under different management conditions in the highlands of Ethiopia (2016) msc. thesis.

[36] E.V.G. Groeneveld, L. Rochefort, Nursing plants in peatland restoration: on their potential use to alleviate frost heaving problems, Suo 53 (3–4) (2002) 73–85.

[37] B.M. Gebru, S.W. Wang, S.J. Kim, W.K. Lee, Socio-ecological niche and factors affecting agroforestry practice adoption in different agroecologies of southern Tigray, Ethiopia, Sustain. Times 11 (13) (2019) 1–19, https://doi.org/10.3390/su11133729.