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Eucalyptus woodlot adoption and its determinants in the Mecha District, Northern Ethiopia

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Introduction: The land area under *Eucalyptus* plantations has now significantly increased among Ethiopian smallholder farmers whereby *Eucalyptus* is grown on their farms in the form of a woodlot primarily for income generation. Despite its widespread adoption, studies and systematic documentation on its adoption and economic impact are inadequate to inform evidence-based policy development. The purpose of this study was to investigate the variables influencing the adoption of *Eucalyptus* woodlot in Mecha District, northern Ethiopia.

Methods: A multistage sampling method was used to sample 186 respondent households from three villages namely *Enashenifalen, Addisameba,* and *Rim* in the district. Primary data was gathered through key informants (13), in-depth interviews, focus group discussions (3), and direct observations, which were complemented by data from secondary sources obtained from published and unpublished documents. A double-hurdle econometric model was used to identify factors influencing households' adoption decisions and adoption intensity of *Eucalyptus* woodlot.

Results and discussion: The findings indicate that household adoption decisions are significantly influenced by the number of parcels of land, off-farm work engagement, credit availability, and farmers' perceptions of woodlot production. Family size (negatively), land holding size, number of parcels of land, market access, the adjacent farm, and farmers' perceptions of *Eucalyptus* woodlot production all significantly influenced the adoption intensity of *Eucalyptus* woodlots. Furthermore, the major constraints were a lack of support and training, a lack of land segregation, and limited technologies. Providing support and training, alternative options for farmers, cluster planting, technology adoption, developing and implementing *Eucalyptus* policies, and enforcing rules and regulations are all areas that need to be addressed to improve the livelihood of the community.

KEYWORDS

adoption, determinates, double-hurdle, *Eucalyptus* woodlot, Mecha

1. Introduction

Eucalyptus is the most extensively cultivated and grown forest tree by smallholder farmers in the world (Oballa et al., 2010; Tesfaw et al., 2022; Desta et al., 2023). In Kenya, *Eucalyptus* is expanded primarily for wood fuel demand leading to financial gain for growers (Oballa et al., 2010). Farmers in Ethiopia have grown *Eucalyptus* as a substitute for other livelihood strategies like crop production and livestock production (Mekonnen et al., 2007). For instance, studies from the northern (Kelemu and Tadesse, 2010), southern (Derbe et al., 2018), and central (Kebebew and Ayele, 2010; Zerga and Woldetsadik, 2016) parts of Ethiopia showed the significant contribution of *Eucalyptus* as a source of income for farmers. According to all studies, *Eucalyptus* is the second-most important source of livelihood after crop production for income generation. In Mecha District, *Eucalyptus* woodlots have been planted since the 1970s. Currently, it is expanding at an *ever*-increasing rate, even at the expense of agricultural cropland (Tefera and Kassa, 2017). According to Tefera and Kassa (2017), nearly 77% of the sampled households in Ethiopia's Lake Tana Watershed had planted *Eucalyptus*. The study also indicated the peculiar increment trends of *Eucalyptus* plantations since 2002, due to the exclusion of subsidies and credits for agricultural inputs and the beginning of the issuance of agricultural land use certificates (Tefera and Kassa, 2017).

Although *Eucalyptus* is a beneficial species that farmers have planted at the expense of crops. Factors that determine farmers' participation and the level of their participation in *Eucalyptus* planting are, however, not investigated and documented specifically in Mecha District (Tefera and Kassa, 2017). The identification of factors affecting *Eucalyptus* planting decisions and the level of planting by farmers can be an important input for policy development, decision-makers, farmers, and practitioners. Therefore, this study aimed to examine factors influencing adoption decisions and the level of adoption of *Eucalyptus* woodlots by farmers in Mecha District, Northern Ethiopia. It also investigates smallholder farmers' production constraints in *Eucalyptus* woodlots.

2. Methodology/approach

2.1. Area description

This study was conducted in Mecha District, Northern Ethiopia. Mecha District is one of the 13 Districts of the West Gojjam Administrative Zone and is located 30 km southwest of Bahir Dar and 525 km northwest of Addis Ababa (Alebachew et al., 2015). The District is geographically situated between 11°10′ N and 11°30′ N latitudes and between 37°00′ E and 37°20′ E longitudes (**Figure 1**). According to the District Agricultural Office report (2018), the district has a total population of 301,188 of which 151,480 are men and 149,708 are women, and ranges from 1,500 to 2,500 m.a.s.l. with a mean annual rainfall of 1,560 mm and a mean daily temperature ranging from 16 to 20°C. The topography of the District is predominantly flat (75%), as only about a quarter of its area is characterized by jagged topography, valleys, and mountains (with a total coverage of 156,027 ha) (Tefera and Kassa, 2017).

2.2. Sampling method, procedure, and sample size estimation

To choose sample household heads, a multistage sampling method was used. Multistage sampling is a method in which sampling is done in stages with smaller units being defined and selected at each stage within the units selected at the prior stage (Shimizu, 1998), aimed to select samples that are concentrated in a few geographical regions (Hamed, 2016). The method has been used by Asfaw et al. (2022) to select sample households among Date Producers in Afar Region, Ethiopia, Abebaw and Dea (2016) to determine factors affecting *Eucalyptus* woodlot planting in the Meket district. Similarly, Wu et al. (2023) adopted a multistage sampling procedure for estimating the forest volume. Thus, in this study, first, among the Districts in the Amhara region, Mecha District was purposefully chosen for its potential and extensive *Eucalyptus* plantations. As the District agriculture and rural development experts indicated, all the villages in the District are potential areas for *Eucalyptus* production and marketing. In the second stage, by considering farmers' tree planting experience, production potentiality, and current expansion rate on productive and irrigation areas, out of the total 39 villages, three villages, namely *Enashenifalen, Addisameba,* and *Rim* were purposefully selected. Then, 186 sample respondents were selected using a random sampling technique from the three selected villages and allocated proportionally to the population size of the selected villages. The list of households was acquired from the village agricultural office.

As a reliable estimate of the population variance is often unavailable, selecting a sample size using proportional estimates of variability is frequently favored (Cochran, 1977). The method has been applied in many research studies. For example, Abebaw and Dea (2016) used it to determine the sample size of farmers' decision-making for planting *Eucalyptus* trees in Meket District, North Wollow, Ethiopia, and Zeenatul et al. (2022) used it in their study of integrated environment-smart agricultural practices. Similarly, Tamirat (2022) used the Cochran (1977) sample size determination method to investigate factors in chemical fertilizer adoption decisions and their impact on food security in southern Ethiopia. Thus, for this study, a statistical formula developed by Cochran (1977) was used to determine the sample size at a 95% confidence level with a degree of variability of 0.5 and a level of precision of 7% (0.07) and distributed proportionally (**Supplementary Appendix Table 1**).

$$n = \frac{N^*z^{2*}p^*q}{e^2\,(N-1) + z^{2*}p^*q} = \frac{3,727^*1.96^{2*}0.5^*0.5}{0.07^2\,(3,727-1) + 1.96^{2*}0.5^*0.5} = 186.25 \approx 186$$

Where: n = sample size of household heads; P = 0.5, the maximum level of variability taken when previous population variability is unknown; q = 1-0.5, i.e., 0.5; e is the precision level (i.e., 0.07); and N = total population size of the selected villages (3,727), obtained from the administrative office of the selected villages.

2.3. Data collection methods and sources

For this study, a cross-sectional mix of primary and secondary data was used. Various tools were used to gather the primary data. This includes in-depth interviews, key informant interviews, direct field observation, and focused group discussions. Both quantitative and qualitative data were collected. Semi-structured questionnaires (open and closed-ended) were used to conduct an in-depth

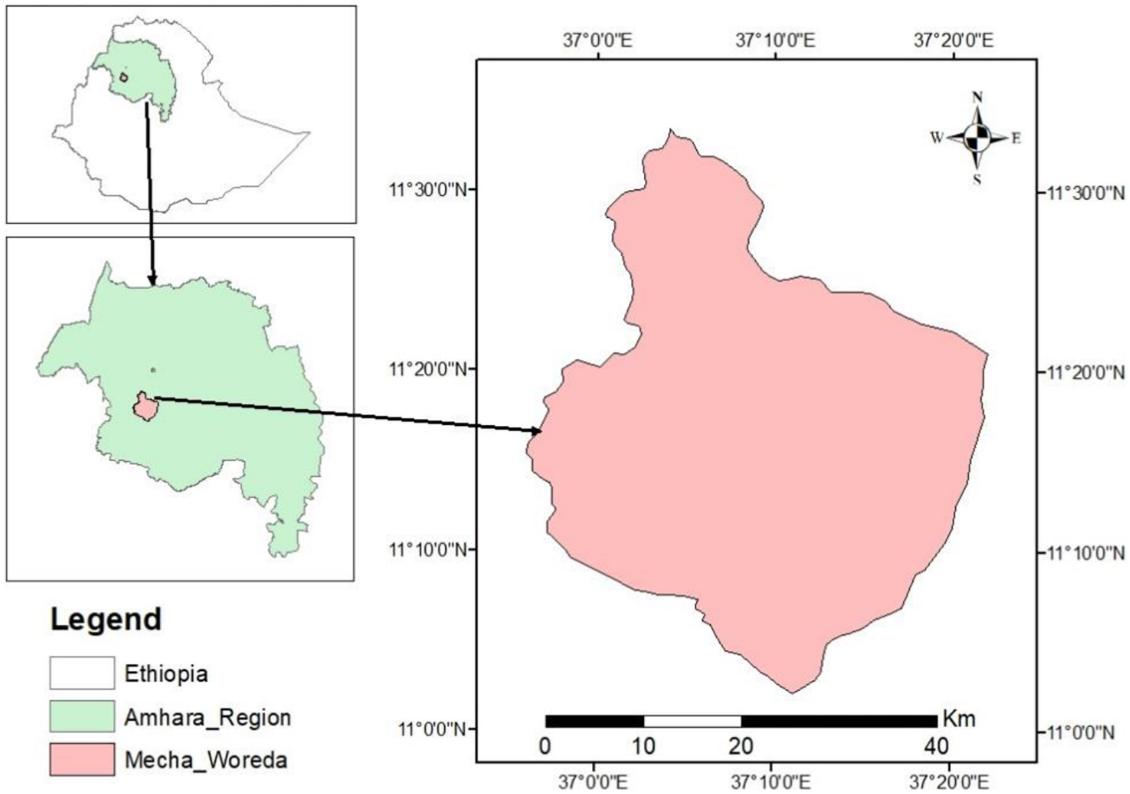

FIGURE 1
Map of the study area (source own survey).

interview. The household surveys were carried out to collect quantitative data that was used to investigate the factors influencing farmers' adoption and intensity of adoption of *Eucalyptus* woodlots by farmers. A key informant (KI) who had a broad knowledge of the farming practices of *Eucalyptus* plantations in the area was given priority for selection. A total of 13 KI interviews were conducted with nine village agricultural experts (three from each village) and one District expert, and three farmers who have long-standing know-how in farming, production, and marketing of *Eucalyptus* were contacted. Three focus group discussions, one at each village level, with a group of 12 farmers using men's, women's, and youth groups, were conducted. The discussion was focused on the status of *Eucalyptus* woodlot management, reasons for the expansion of *Eucalyptus* woodlots by converting cropland, and opportunities and challenges for *Eucalyptus* production and management.

Secondary data were collected from literature and the work of other researchers. Mecha District Agricultural Office (MDAO), Amhara Region Environment, Forest and Wildlife Protection and Development Authority (AREFWPDA) were contacted to gather information about *Eucalyptus* planting experiences and their determinates in the district.

2.4. Analytical framework

In this study, an econometric model was used to identify the factors that affect the adoption decision and adoption intensity of *Eucalyptu*s woodlots by farmers. Different methods can be employed to analyze factors influencing the adoption and adoption intensity of *Eucalyptus* woodlots. One approach to analyzing the issue is to use the well-known Tobit model. The standard Tobit model, originally formulated by James Tobin in 1958, was the first model to attempt a censored dependent variable. However, the Tobit model has a number of potential shortcomings due to the restrictive assumptions it makes. First, it assumes that both the decision to participate in an activity and the level of participation are determined by the same variables with the same sign (Wooldridge, 2002), which means both the value of continuous observations on the dependent variable and the discrete variables were determined by the same stochastic process. Hence, according to the Tobit model, the decision to participate in *Eucalyptus* woodlot adoption and the intensity of the adoption are jointly determined and influenced by the same parameters. Such an assumption may not be appropriate in this study because the factors that affect whether or not a household adopts *Eucalyptus* woodlot may be significantly different from the factors that affect the adoption intensity of *Eucalyptus* woodlot. Secondly, the Tobit model assumes that all the zero observations are, in fact, standard corner solutions (Garcia, 2013) and those households that do not adopt are a result of their economic circumstances. This means, the zero values on the dependent variable, intensity of woodlot adoption in this case, are attributable to economic factors alone. However, the Tobit model currently has been generalized by the use of the double-hurdle model that the possibility of zeros is due to non-participation decision, which arises from factors such as economic, institutional and demographic characteristics (Martínez-Espiñeira, 2006). A test for the double-hurdle model against the Tobit model was made by estimating three regression models (Tobit, truncated and probit regression models) separately the result indicated the rejection of the Tobit model (**Supplementary Appendix Table 5**).

Cragg's (1971) double-hurdle model, relaxes the restrictive assumption of the Tobit model by specifying determinants of adoption and the level of intensity of adoption into two separate steps used to determine the adoption decision and level of adoption of *Eucalyptus* woodlots. The pattern suggests that in every decision-making process, farmers face two obstacles: deciding whether to adopt and determining the level of adoption (Asfaw et al., 2010, Kiyingi et al., 2016). The model has been widely used in the literature on decision-making behavior across different research fields, such as consumer purchasing behavior (Asfaw et al., 2022), consumption analysis (Wei et al., 2023) and agricultural and forest technology adoption (Mal et al., 2012; Kiyingi et al., 2016; Jara-Rojas et al., 2020; Gebru et al., 2021). The essential premise of this study is that a farmer makes two decisions: whether to allocate land to establish a *Eucalyptus* woodlot and the intensity of the area assigned for a *Eucalyptus* woodlot. In the first hurdle, a probit model was employed to determine the probability that the households adopt *Eucalyptus* woodlot. In the second hurdle, a truncated regression model was used to determine the intensity of the adoption. The general form of Cragg's double-hurdle model employed in this study is as follows:

$$D_i^* = \alpha Z_i + \mu_i \left(\text{Adoption Decision Equation : first hurdle}\right);$$
$$Di = 1, \text{ if } D_i^* > 0; D_i = 0, \text{ otherwise}$$

Where, D_i* is the latent variable describing the farmer's decision of whether or not to adopt a *Eucalyptus* woodlot and takes the value of 1 if the farmer adopted and 0 otherwise. D_i is the observed variable that represents the farmer's adoption decision; Z_i' is a vector of explanatory variables influencing the farmer's initial adoption decision; α is a vector of parameters to be estimated; and μ_i is the error term.

$$Y_i^* = \beta X_i + \varepsilon_i \left(\text{Intensity of adoption equation : second hurdle}\right);$$
$$Y_i = 1, \text{ if } Y_i^* > 0; \quad Y_i = 0, \text{ otherwise}$$

Where Y_i* is the latent variable describing its decision on the proportion of land to allocate to the *Eucalyptus* woodlot. Y_i is the area allocated for the *Eucalyptus* woodlot in hectares, suggesting the intensity of the adoption. X_i is the vector of explanatory variables influencing how much the farmer adopts *Eucalyptus* woodlot; β is a vector of parameters to be estimated; and ε_i is the error term.

If both decisions made by the individual farmers are independent, the error term is assumed to be independently and normally distributed as:

$$\mu_i \sim N\ (0,\ 1) \text{ and } \varepsilon_i \sim N\ (0, \delta^2)$$

The log-likelihood function, which is the sum of the log-likelihood from a Probit and a truncated regression (Cragg, 1971), is estimated using the maximum likelihood estimation (MLE) technique following Cragg (1971).

Variance-inflating factor (VIF) was used to detect multicollinearity problems among continuous and discrete variables (Gujarati, 2004) and a VIF value of more than 10 indicates a high correlation while less than 10 indicates a weak association among explanatory variables. Contingent coefficient (C.C) techniques were used to detect multicollinearity problems among discrete variables and a value of 0.75 or more indicates stronger associations while a value less than 0.75 indicates weak associations among explanatory variables.

Additionally, a hypothesis test for the double-hurdle model against the Tobit model was made by estimating three regression models (Tobit, truncated and Probit regression models) separately and then conducting a likelihood ratio test that compares the Tobit with the sum of the log-likelihood functions of the Probit and truncated regression models. The LR statistic was computed using the formula developed by Greene (2003) as $\Gamma = -2$ [ln LT − (ln LP + ln LT R)] $\sim \chi^2$k.

Where LT = likelihood for the Tobit model; LP = likelihood for the Probit model; LTR = likelihood for the truncated regression model and k is the number of independent variables in the equations. The test hypothesis is written as H_0: $\lambda = \frac{\beta}{\sigma}$ and H_1: $\lambda \neq \frac{\beta}{\sigma}$; the null hypothesis (H0) that the Tobit model is the best-fit model will be rejected on a pre-specified significance level if $\Gamma > \chi^2$ k.

Grounded on the existing knowledge from literature review including Ewnetu (2008), Duguma and Hager (2010), Gebreegziabher et al. (2010), Rafael (2011), Jenbere et al. (2012), Anik and Salam (2015), Abebaw and Dea (2016), Kiyingi et al. (2016), Zerga and Woldetsadik (2016), Gizachew (2017), Sete (2017), and Derbe et al. (2018) the possible explanatory variables hypothesized to affect adoption and level of adoption of *Eucalyptus* woodlot were specified (**Supplementary Appendix Table 2**).

2.5. Data analysis and presentation

Descriptive statistics such as mean, maximum, minimum, standard deviation, and frequency distribution were employed to get a clear picture of the socio-economic, institutional, and demographic characteristics of sample households. A chi-square test and an independent sample t-test were used to test the significance of variables associated with the adoption and intensity of *Eucalyptus* woodlots adoption and to identify variables that vary significantly between adopters and non-adopters of *Eucalyptus* woodlots. MS Excel, the Statistical Package for Social Sciences (SPSS) version 19.0, and Stata version 12.0 software were used for entering and analyzing the data.

3. Results

3.1. Characteristics of *Eucalyptus* woodlot adopters and non-adopters respondents

As indicated by Derbe et al. (2018), a *Eucalyptus* woodlot is a parcel of land devoted to *Eucalyptus* plantations and has a size of 0.1 hectares, or what is conventionally called a "block," which is 40 m by 25 m and above. In the study area, almost all smallholder farmers own *Eucalyptus* trees. However, for the interest of this study, farmers who had *a Eucalyptus* woodlot size of 0.1 ha were considered as *Eucalyptus* woodlot adopters. Therefore, of the total 186 sample respondents interviewed, 157 (84.41%) were found to be adopters of *Eucalyptus* woodlot while 29 (15.59%) were non-adopters. Adopters of *Eucalyptus* have allocated the high coverage of their land 65.38% (0.84 ha with a standard deviation of 0.24 ha on average) to *Eucalyptus* woodlot.

The sample respondent's ages ranged from 25 to 77 with an average age of 45.04 years. The minimum and maximum years of schooling for adopters were 0 and 10 years, while the non-adopters have a minimum of 0 and a maximum of 6 years of schooling. Concerning family size, woodlot adopters were found to be 5.64 per family while non-adopters were found to be 4.36 per family on average (**Supplementary Appendix Table 6**). Among the total respondents, 80.60% of them are male-headed while 19.40% of them are female-headed households. Out of 157 *Eucalyptus* adopter participant households, 17.80% are female-headed and the remaining 82.20% are male-headed. The mean land holding for *Eucalyptus* woodlot adopters was 1.30 ha with maximum and minimum of 4.0 and 0.25 ha, respectively. The corresponding figure for the non-adopter households was 0.62 ha with maximum and minimum of 1.75 and 0.10 ha, respectively. Thus, the non-adopters had a limited land area. It indicates that farmers with large farm sizes are more likely to participate in the adoption and intensity of adoption of *Eucalyptus* woodlot than those farmers who have smaller farm sizes.

Adopters were found to own more livestock than their counterparts. It was observed that adopters of *Eucalyptus* woodlot had livestock holding 4.88 Tropical Livestock Units (TLU) on average, while non-adopters had 3.72 TLU. It indicates as farmers own large livestock units, the chance of participating in *Eucalyptus* woodlot adoption become increases. It is because livestock ownership provides the draught power (oxen) for the establishment of *Eucalyptus* woodlots. In the study area, *Eucalyptus* is commonly planted after plowing the land with oxen for crop production. Moreover, as farmers own large livestock populations, the availability of financial income in the household from the sale of livestock, especially bulls for meat, small ruminants, and chickens, increases, which in turn leads to investment decisions in *Eucalyptus* woodlot production. Of the total 186 sample households, only 9.14% (9.55% of adopters and 6.90% of non-adopters) of the sample respondents had got training related to *Eucalyptus* planting by the village representatives, the other (90.86%) of the respondents did not have access to training (**Supplementary Appendix Table 7**). It shows farmers are planting *Eucalyptus* simply because of its economic impacts without or with less government support. On average, *Eucalyptus* woodlot adopters earn 18,349.36 Ethiopian Birr (ETB), while non-adopters had 12,253.45 ETB annually from crop and livestock production. Of all respondents, who had market access 66.24% were *Eucalyptus* woodlot adopters and the other 17.24% were non-adopters. The result indicates that *Eucalyptus* woodlot adopters had better market access than non-adopters did. It means that farmers with market access are more likely to adopt and intensify their adoption of *Eucalyptus* woodlots than farmers without market access.

Farmers' perception of the relative advantage of *Eucalyptus* woodlot production is one of the factors that can facilitate or undermine their participation in *Eucalyptus* woodlot adoption. Farmers were asked to respond as to how they perceived the importance of *Eucalyptus* woodlot production. From the total respondents, about 77.70% of *Eucalyptus* woodlot adopters and 31.00% of non-adopters were perceived positively on *Eucalyptus* woodlot production. It means farmers who had a positive perception of *Eucalyptus* woodlot production adopted and allocated more land for *Eucalyptus* woodlot production than those who had a negative perception.

The chi-square test result indicates that farmers' perception towards *Eucalyptus* woodlot production ($\chi^2 = 25.603$, df = 1, $p = 0.000$), off-farm work engagement ($\chi^2 = 4.737$, df = 1, $p = 0.012$), adjacent farm ($\chi^2 = 29.799$, df = 1, $p = 0000$) and market access ($\chi^2 = 24.227$, df = 1, $p = 0.000$) were showed a variation between adopter and non-adopters. For the t-test, family size ($t = 2.928$, df = 190, $p = 0.003$), land holding size ($t = 4.891$, df = 190, $p = 0.000$), number of parcels of land ($t = 5.57$, df = 190, $p = 0.000$), livestock holding ($t = 2.742$, df = 190, $p = 0.006$) and income of the household head ($t = 3.822$, df = 190, $p = 0.000$) were compared and showed variation between the adopter and non-adopter groups.

3.2. Determinants of adoption and adoption intensity of *Eucalyptus* woodlot

Before running regression analysis, both the continuous and discrete explanatory variables were checked for the existence of multicollinearity using the Variance Inflating Factor (VIF) and the Contingency Coefficient (CC) methods, respectively. Thus, the VIF values displayed in **Supplementary Appendix Table 3** show that all the continuous explanatory variables had no serious multicollinearity problem, as the VIF is less than 10. Likewise, the values of the contingency coefficient are less than the rule of thumb of 0.75, (**Supplementary Appendix Table 4**), implying a weak degree of association among the variables considered. The likelihood ratio test that compares the Tobit with the sum of the log-likelihood functions of Probit and Truncated regression indicated the rejection of the Tobit model and acceptance of the Double-hurdle model. The calculated statistical value of the likelihood ratio was 50, which was greater than the tabulated or critical value of χ^2 (15) = 32 at a 1% level of significance, which shows the existence of two separate decision-making stages during the adoption process (**Supplementary Appendix Table 5**). This proves the farmers' independent decision-making possibilities regarding the adoption and intensity of adoption of *Eucalyptus* woodlot. Similarly, Heckman's two-step model was regressed and the independence between the participation and intensity decision was tested and the corresponding Wald test of independence suggests the independence assumption cannot be rejected (*p*-value = 0.2), as Mills ratio is insignificant, which strengthens the use of double hurdle-approach. In other words, the sample-selection bias is not an issue in this study.

The likelihood ratio of the chi-square result revealed that the overall fitness of the model was found to be significant at a 1% probability level, indicating the partial effects of each explanatory variable on the response of the dependent variable and similar to the intensity of adoption. Out of the fifteen explanatory variables, four variables from the probit model and six variables from the truncated model were found to be significantly determining adoption and intensity (area of *Eucalyptus* planted in hectare) of adoption of *Eucalyptus* woodlot at 5% and 1% level of significance, respectively **Supplementary Appendix Tables 8, 9**).

The number of parcels of land was found to positively and significantly influence the probability of adoption and intensity of adoption of *Eucalyptus* woodlot at less than 5 and 1% level of significance, respectively. It indicates that if the other factors are kept constant, a unit increase in the number of plots of land increases the probability of adoption and intensity of adoption of *Eucalyptus* woodlot by 8.80, and 10.60%, respectively. Similarly, the positive perception of farmers towards *Eucalyptus* woodlot production increased the adoption and its level by 14.03 and 7.74%, (1 and 5% of significance level), respectively.

Off-farm work engagement and credit availability were found to positively and significantly influence the probability of adoption of *Eucalyptus* woodlot at a 5% level of significance. The marginal effect estimate indicates that if the other factors are kept constant, participation in off-farm work increases the adoption of *Eucalyptus* woodlot by 10.23% and a 1% increase in credit availability for households increases the adoption of *Eucalyptus* woodlot by 8.8%. While land holding size, adjacent farms (the farm of another framer which is adjacent or close to the owner of *Eucalyptus* woodlot) and access to market had a positive and significant influence on farmers' decision to allocate land for *Eucalyptus* woodlot at less than 1% significant level, which increases the land allocated for *Eucalyptus* woodlot by 47.27%. Likewise, keeping all other variables constant, the intensity of adopting *Eucalyptus* woodlot was increased by 18.72 and 19.78% for the households who have more land near to *Eucalyptus* woodlot and have access to market, respectively. While, a one-person increase in the family size decreases the land allocated for *Eucalyptus* woodlot by 3.34% at a 1% significance level, *ceteris paribus*.

Moreover, lack of support (59%), lack of training (34%), lack of segregation of land (22.14) and disease (18%) were the major constraints on tree growers (**Supplementary Appendix Figure A1**). Moreover, policies that encourage *Eucalyptus* planting activities have not existed and rules and regulations on production and marketing of *Eucalyptus* are not functional as evidenced from the key informant interviews and focus group discussions.

4. Discussion

Currently, many of the Ethiopian smallholders have been planting *Eucalyptus* in their productive and fertile lands mainly in a form of woodlots primarily due to its economic significance. In the current study, majority of farmers are adopting *Eucalyptus* in their productive lands and allocated more than half of their lands mainly for income generation. In line with this, Jenbere et al. (2012) stated majority (74.8%) of the farmers practiced the establishment of *Eucalyptus* woodlots by dividing their land into smaller units. Similarly, as Tefera and Kassa (2017) stated close to 77% of the sampled households had planted *Eucalyptus* in the Tana watershed of Ethiopia. Despite this expansion, adoption and intensity of adoption by farmers have been influenced by several socioeconomic, demographic and institutional factors. For instance, in this study, adopter and non-adopter farmers were significantly different in their perception towards *Eucalyptus* woodlot production, land-holding size, number of parcels of land, livestock holding, income, off-farm work engagement, adjacent farm and market access, etc., that in turn determines their decision to adopt and intensity of adoption of *Eucalyptus* woodlot on their limited land.

Farmers who have a positive perception of *Eucalyptus* woodlot production tend to adopt and allocate more land to *Eucalyptus* woodlot than farmers who have negative perceptions. In connection with this result, Derbe et al. (2018) indicated the positive and significant influence of the perception of farmers on *Eucalyptus* woodlot adoption. Similarly, Jenbere et al. (2012) stated that despite the perceived negative ecological impacts of *Eucalyptus* plantings among the respondent farmers, the majority (96%) of the respondents still support the continued expansion of *Eucalyptus* plantations. Correspondingly, households that have a greater number of parcels of land are more likely to adopt *Eucalyptus* and allocate more land to *Eucalyptus* woodlot than their counterparts. The high number of plots indicated high fragmentation of land, which is the main determinant of land productivity (Alemu et al., 2017). In line with this, Ewnetu (2008) indicated the positive and significant effects of the number of plots of land on the farmer's decision to allocate and plant a tree. In addition, as the number of plots increased the likelihood for many of the plots to be located away from the homestead is usually high and thus these plots of land are preferred to be used for tree planting, which requires less supervision and protection at least after the establishment stages (Ewnetu, 2008).

Credit service is an important source of finance for poor farmers to buy inputs for *Eucalyptus* production. In line with this study, Abebaw and Dea (2016) indicated that the availability of loans and credit facilities for farmers had a positive effect on the *Eucalyptus* tree adoption decision. The possible reason for the positive and significant effect of off-farm work in *Eucalyptus* woodlot adoption is that farmers can be able to generate more income from the off-farm work and thus their willingness for taking risks in long-term investment alternatives such as growing *Eucalyptus*. However, according to Ewnetu (2008), off-farm work engagement discourages farmers to plant a tree. Landholding size and intensity of *Eucalyptus* woodlot adoption have a positive and significant relation with land holding size, while it has negatively related to family size. It means farmers with more land are more likely to allocate a larger proportion of their land to *Eucalyptus* woodlot to maximize their gain from the sale of its products. This result is in line with Abebaw and Dea (2016), and Gizachew (2017) that the total number of *Eucalyptus* trees that a farmer planted was positively correlated with the farm size. In contrast, the negative and significant influence of family size on the intensity of *Eucalyptus* woodlot adoption indicated farmers with big families are less likely to allocate more hectares of land to *Eucalyptus* woodlot than those with small family sizes. The reason could be that as family size increases, the requirement for food may also increase and this needs intensive and extensive crop production for the survival of the family members. As a result, resources including family labor, land, money and time have been devoted to crop production instead of planting *Eucalyptus* to feed their large family (Gizachew, 2017; Derbe et al., 2018). Opposing this, according to Abebaw and Dea (2016), household size had a positive and significant effect on farmers' decision in adopting *Eucalyptus* woodlot.

As market access increased, the intensity of *Eucalyptus* woodlot adoption also increased. It indicates, farmers who have access to the market can get the required input for *Eucalyptus* woodlot production as well as could sell products of *Eucalyptus* at the right time and at a reasonable price. Derbe et al. (2018) found a similar result that farmers who had market access had a high probability of planting *Eucalyptus* than their counterparts. In addition, Bernard (2011) pointed out that the availability of a market for farm forest products increases households' decision to use the land to plant trees. The positive and significant relationship between land allocation and adjacent land indicated that farmers who have land adjacent to the *Eucalyptus* woodlot of their neighbor are more likely to allocate more land for *the Eucalyptus* woodlot. This could be associated with the negative impacts of *Eucalyptus* on other crops. As indicated by Alebachew et al. (2015), crops grown adjacent to *Eucalyptus* stand has poor performance as compared to crops grown without *Eucalyptus* mainly because of the competition for growth resources between *Eucalypts* and adjacent food crops.

5. Conclusion and recommendations

Generally, adopters of *Eucalyptus* woodlot differ from their counterparts in various demographic, socioeconomic, and institutional-related perspectives. About 84.41% of sampled farmers have already adopted *Eucalyptus* woodlot while 15.59% of them are non-adaptors of *the Eucalyptus* woodlot. *Eucalyptus* adopters were allocated on average 0.84 ha (65.38%) of their land to *Eucalyptus* woodlot. A double-hurdle model result shows that the adoption intensity of *Eucalyptus* woodlot follows two independent decisions: the decision to adopt *Eucalyptus* and the decision concerning the intensity of adoption of *Eucalyptus*. The finding of this study revealed that the result confirmed the model assumptions of independent sets of variables that some of the variables under investigation affecting the probability of adoption decisions were not affecting the adoption intensity of *Eucalyptus* woodlot and vice versa. Among the fifteen explanatory variables used:

- Market access was found to be positively and significantly influencing the adoption intensity of *Eucalyptus* woodlot. Thus, providing a well-organized and integrated marketing system with appropriate infrastructure is critical to optimize the contribution of *Eucalyptus* woodlot production.
- Landholding size had a positive association with the adoption intensity of *Eucalyptus* woodlot, however, land is the main constraint in the study area, therefore, developing efficient land use systems, improving the productivity of land and better management practices needs to be critically performed by the national, regional and local level governments.
- Perception of farmers toward *Eucalyptus* woodlot has a positive and significant effect on the adoption and adoption intensity of *Eucalyptus* woodlot. Training needs to be provided on the advantage and disadvantages of *Eucalyptus* to increase farmers' awareness about *Eucalyptus* woodlot production.
- Number of parcels of land positively and significantly influencing adoption and adoption intensity of *Eucalyptus* woodlot. However, the increase in parcels of land is an indication of land fragmentation, as land is fragmented more and more, land productivity becomes reduced, which in turn puts the livelihood of the society in question, as *Eucalyptus* alone may not be a sustainable solution for food security. Thus, there is a need to develop systems that help to minimize land fragmentation such as controlling population growth and increasing the productivity of land
- Adjacent farmland was found to be a positive and significant influence on the intensity of adoption. Appropriate policies need to be developed for *Eucalyptus* planting for example through cluster plating, which also helps to avoid conflict between farmers.
- Developing an appropriate credit system for farmers with a reasonable interest rate should also be seen critically by the local and national government.
- Off-farm work engagement is also an important variable for *Eucalyptus* adoption. Thus, diversification of the livelihood portfolios of farmers is vital to improving their income and the productivity of *Eucalyptus* woodlot.
- Moreover, specific policies for *Eucalyptus* production have not existed and rules and regulations are not enforced, thus developing specific policies and enforcing the existing forest rules and regulations are critical for sustainable utilization and livelihood improvement.
- Provision of services including training on silviculture tree management, processing, marketing as well as technology development to tree growers, arranging credit facilities, road, and transport access, etc., are essential for the development of the sector by the government or NGOs.

Data availability statement

The original contributions presented in this study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

AA designed and performed the experiments, analyzed and interpreted the data, contributed materials, analysis tools, or data, and wrote the manuscript. YM guided the experiment, analyzed the data, and wrote the manuscript. AE wrote and proofread the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/ffgc.2023.1111301/full#supplementary-material

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