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Eucalyptus Succession on Croplands in the Highlands of Northwestern Ethiopia: Economic Impact Analysis Using Farm Household Model

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Abstract: The northwestern highlands of Ethiopia are characterized by severe land degradation and apparently low agricultural productivity. This situation is continuously threatening the livelihoods of smallholder farmers who mainly sustain their living from the cultivation of annual crops. In recent years, however, smallholder farmers have started converting their croplands to plantations of *Eucalyptus*, a non-native tree species to Africa, for its rewarding economic contributions. In this study, we aggregated data from 388 smallholder *Eucalyptus* growers located in three agroecology zones (onwards called farm typologies). We measured the economic impact of *Eucalyptus* succession on croplands using a farm household model which is provided in the GAMS (General Algebraic Modeling System) platform. The results of the model varied between farm typologies and showed that households' gross margins increased with a corresponding increase in the conversion of croplands. Results also showed that gross margins from plantations of *Eucalyptus* were higher than that of cultivation of food crops. Furthermore, evaluation of farm portfolios indicated a higher benefit-cost ratio (BCR) for the plantation of *Eucalyptus*. We concluded that the conversion of croplands in the study area is an incentive-driven process in a dynamic farming system, which strongly demands bringing policy-emanated livelihood alternatives. With this arena, the expansion of *Eucalyptus* is recommended for lands of terrain features, high marginality and low suitability for the cultivation of food crops and setting aside fertile arable lands. We generalized that an increase in *Eucalyptus* plantation pays off given the implementation of proper land resource management and the apparent impacts of *Eucalyptus* on biodiversity and cultural landscape is managed with sustainability perspectives. However, it demands collaborative policy efforts that can especially meet socioeconomic, environmental and public interests.

Keywords: *Eucalyptus*; farm portfolio; farm household model; GAMS; succession; trade-off



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1. Introduction

Land use changes driven by human activities and natural factors have resulted in the global loss of native biodiversity and the alteration of ecological processes and services across different ecosystems [1]. Dramatic land use changes and intensive utilization of the natural resource base have taken place in Ethiopia. These changes were driven by rapid population growth, an increase in land degradation and a decline in productivity that in turn, inspired the need for investing in plantations of fast-growing trees such as *Eucalyptus* [2–4]. The expansion of monoculture forest plantations of exotic species like *Eucalyptus* has been incentivized and taken as part of a development strategy by different countries. Chile, for instance, has tended to focus on plantations of exotic Monterey pine (*Pinus radiata*) and *Eucalyptus* as one of its priority development agendas [5].

Land use change dynamics in the study area indicates that cultivable lands are being converted to *Eucalyptus* plantations. Before this change, croplands were succeeding in areas where natural forests existed decades before. Nevertheless, due to the elimination of natural forest stands, declining crop productivity and the rising demand for wood products, croplands are now in turn, succeeded by *Eucalyptus* plantations [6–8]. The global market for *Eucalyptus* wood products and the interest in wide-scale planting for the production of biofuels are among the main factors behind the expansion of *Eucalyptus* as woodlots [9].

Wood is a limited bio-based resource that serves as a source of raw materials for wood industries, power and heat. Economic growth and demographic change are causing an increase in the global wood demand [10]. A study by Lamers [11] showed that between 2000 and 2010, there was a more than tenfold increase in the European Union's demand for wood products. Forest products are, however, limited resources, which are exposed to a continuously growing global demand which requires a sustainable approach for balancing the increasing wood demand through the planting of short rotation plantation trees [12]. There are also other strategies designed to cope with the rising wood demand including intermediate or long-term rotation plantations that are designed for producing sawn wood and non-industrial production plantations intended for fuel and other domestic applications [13].

Eucalyptus is one of the most economically important short rotation plantations grown in various countries as a favored tree in the production of biomass energy and fiber [14]. *Eucalyptus* was introduced to African countries including Ethiopia from Australia in the second half of the 19th century to meet the emerging demands for forest products for use in construction and as fuel [4,15]. The absence of indigenous alternative tree species with comparable economic contributions like that of *Eucalyptus* remained the prominent reason for the expansion of *Eucalyptus* in Ethiopia. Native forest stands such as *Juniperus procera*, *Podocarpus falcatus*, *Olea europaea* and other natural forests including *Cordia africana*, *Acacia dicurens* and *Cupressus* species have slow growth, limited regeneration capacity and low yield compared to *Eucalyptus* [16]. *Eucalyptus* species grow quickly and have a high yield potential in short rotations. Consequently, they are widely planted by smallholder growers for their wide range of economic and social benefits [8,17,18]. The positive attributes of short rotation plantation trees, such as the ability to quickly coppice after harvest, fast-growing tendency, minimum care requirement and ability to grow in a wide range of ecological zones and land types, are the main pushing factors for their expansion [19].

Owing to these positive attributes, recently smallholder farmers have engaged in the conversion of croplands to *Eucalyptus* stands in Ethiopia. Short rotation coppice plantations can provide woody biomass within the first four years of the plantation's life cycle and every three or four years thereafter for up to seven rotations [20]. Studies by Kong et al. [21] and Allen et al. [20] presented the ecological roles and other benefits of urban forests and short rotation trees including offsetting greenhouse gas emissions, improving groundwater and soil quality and expanding some forms of wildlife habitat and revitalizing rural economies. *Eucalyptus* has economic and environmental benefits stemming from its capability of supplying fiber on a reduced land base [22]. Schiberna et al. [23] studied the potential yield and return characteristics of poplar short rotation coppice plantations in a range of sites in Hungary and stated their advantages in supplying bioenergy and other possible bio-products.

Aside from the economic and social benefits, there are scientific debates with regard to the expansion of *Eucalyptus* and its negative ecological impacts. *Eucalyptus* can drain water resources, aggravate soil erosion, suppress undergrowth, deplete soil nutrients and induce allelopathic effects [24]. Studies [25–27] reported the negative ecological impacts of the tree especially the allelopathic effects around the root zone and its shading effect under the tree canopy. A study by Forstmaier et al. [28] stated that large-scale plantations of *Eucalyptus* have a negative ecological impact and bring invasive behavior to the environment. The introduction of *Eucalyptus*, as an alien species to a new area, has serious invasion risks

to biodiversity and the ecosystem. A study by Lopez [29] indicated change in the native Californian ecosystem processes as a result of invasion by *Eucalyptus globulus* which reduced biological diversity as native plants and wildlife habitats are displaced. A similar conclusion was reported by Teketay [30] who reported low herbaceous species richness in *Eucalyptus* plantations than in native forests.

Due to a decline in land productivity and per capita land holding, rapid loss of forest stands and the subsequent escalating demand for wood products, farmers were forced to look for farm portfolio choices and focus on the planting of *Eucalyptus* as a potential coping strategy in Ethiopia [31]. Thus, *Eucalyptus* is one of the major sources of income for smallholder growers and became the most preferred tree for its intended provision of wood products.

With this in mind, it is important to examine the economic impact of the conversion of croplands to *Eucalyptus* plantations with different trade-off scenarios. There are a number of methods for measuring an economic impact that can be used to measure gains or improvements in economic wellbeing [32–34]. Of these methods, the farm household model is the most preferred one to analyze farm portfolios conveniently [35].

In order to quantify the contribution of *Eucalyptus* succession to household income and to show comparisons of returns from crop-*Eucalyptus* farm portfolios, applying the right models is highly valid. In this study, we estimated the impact of land succeeded with *Eucalyptus* on households' gross margins using farm household model which is provided in the GAMS (General Algebraic Modeling System) platform [36]. The farm household model has been exhaustively applied by many scholars worldwide for measuring economic and policy impacts [37], analyzing technology options and policy incentives [38] and for evaluating farm types and scenarios [39,40]. In order to analyze farm portfolio choices, we conducted an analysis of gross margins and Benefit Cost Ratio (BCR) taking into account the returns from food crop production and *Eucalyptus* plantations. Studies including Tafa et al. [41] used a similar approach to compare conservation and conventional agriculture in South Africa.

Though there are different studies carried out employing the farm household model, studies that explicitly evaluate the crop-plantation farm portfolio choices are absent. The overall objective of this study was to develop a farm optimization model that involves the cultivation of major food crops and plantation of *Eucalyptus*. The study was also intended to analyze the new farm dynamics by creating trade-off scenarios with hypothetical increases of land allocated for *Eucalyptus* and observing how sensitive will households' gross margins be to the respective changes in land allocated for *Eucalyptus*. The outcomes of the study can provide vital information regarding farm households that are able to make choices between farm portfolios. The study also highlights how future studies can address gaps in similar studies.

2. Materials and Methods

2.1. The Study Area

This study was carried out in potential *Eucalyptus* growing regions of Northwestern Ethiopia that geographically extends from 10°21'23.59"–10°37'28.05" N to 37°40'25.95"–37°53'09.02" E. The study area covers the major *Eucalyptus* growing districts including Senan, Gozamin and Machakel which covers about 2350 square kilometers (Figure 1). The area is characterized by plain to terrain features with altitudes ranging from 2500–3900 masl (meters above sea level). The area has become highly degraded, especially during the last two decades, and recently arable lands are being converted to *Eucalyptus* plantations. The area receives a unimodal average annual rainfall of 1350 mm that dominantly showers from May to September with cool humid (Dega) and cool sub-humid (Woinadega) climatic zonation and an average annual temperature of 18 °C [42].

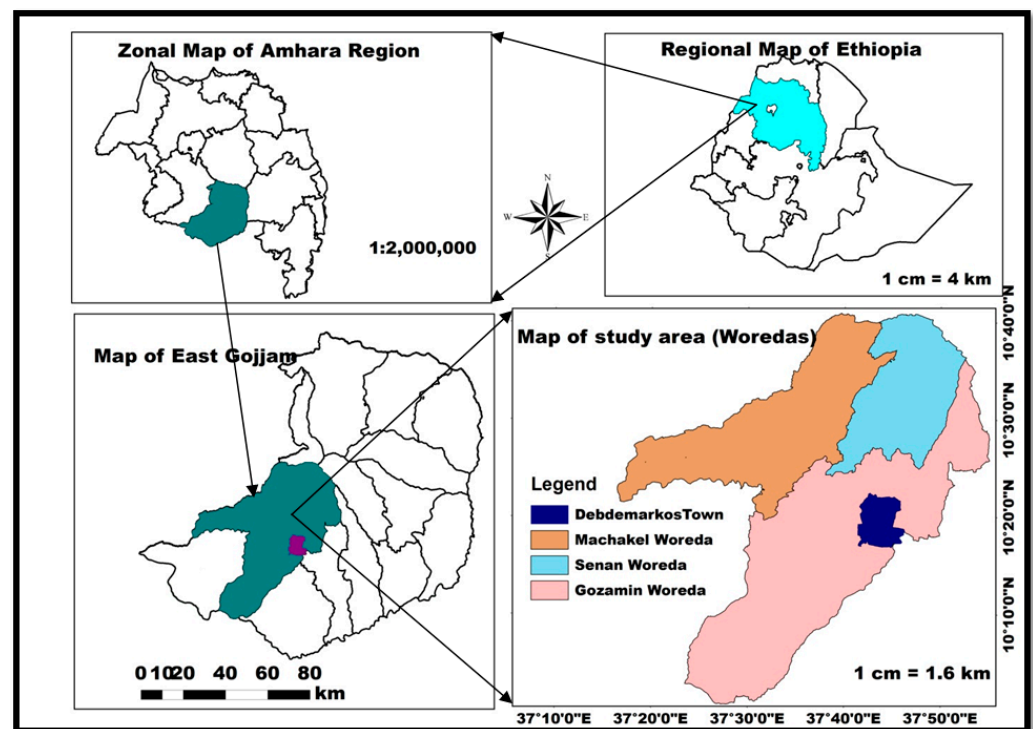


Figure 1. Map of the study area.

A variety of crops including wheat, *teff* (*Eragrostis tef*), maize, potato, barley and faba bean are cultivated in diverse topographic features with slopes ranging from nearly plain to very steep ($>45^\circ$) landscapes. Though intensive cultivation of food crops is the main farming activity in the study area, households are recently converting their croplands to plantations of *Eucalyptus globulus*.

2.2. Sampling and Data

In order to draw the required sample from the study population, we followed a multi-step sampling procedure. Considering the East Gojjam zone on the basis of its *Eucalyptus* growing potential, we considered three districts namely, Senan, Gozamin and Machakel.

As farm activities and production potentials vary across agroecologies, we created three farm types each constituting four villages for obtaining more or less uniform farm households. The farm types created were Farm typology I (semi-plain midlands), Farm typology II (sloping midlands) and Farm typology III (lands with terrain features) (Table 1). In order to see the trade-offs of *Eucalyptus* plantation versus cultivation of food crops, we also considered the fertility status of lands (fertile versus marginal).

Since farm households in the three farm typologies differ in making farm choices, we made a record of data to the three farm types including endowments such as land holdings, fixed assets, crops cultivated, household characteristics, family labor, farm inputs such as seed and fertilizer and the yield obtained during the 2019/2020 calendar. On the basis of willingness, we chose a representative farm household from each farm type for running the farm household model.

At each farm typology, we drew respective samples following Yamane's [43] sample size formula. A total of 406 questionnaires were dispatched for data collection but 18 were improperly filled and rejected and finally, 388 samples (with a 95.6% response rate) were used for analysis. In addition to the formal questionnaire, three consecutive focus group discussions (each group having members ranging from 8 to 12 persons) were carried out.

Table 1. Classifications of farm typologies and samples taken.

Farm Typology	Dominant Farming System	Soils	Elevation	Actual Number of Farm Households Fulfilling the Selection Criteria	Sample Taken
I. Semi-plain lands	Intensive wheat, <i>teff</i> and maize-based farming with plantation of <i>Eucalyptus</i>	Alisols, Leptosols, and Nitosols	2500–2900	2977	156
II. Sloping lands	Wheat, barley, potato, beans-based farming together with <i>Eucalyptus</i> plantation	Mixture of Leptisols and Nitosols	2900–3400	3593	104
III. Lands with terrain features	Abundant plantation of <i>Eucalyptus</i> with wheat, barley, avena and potato-based farming	Marginal lands with shallow soils of luvisols and leptosols exist dominantly	3400–3800	3004	128
Total				9574	388

Data sets required for the three models were solely generated from a household survey of the above sample households and rely on one another as they are about household statistics, possession and farm activities of similar households. For the farm household model, the average values of data were used for each farm typology. Similarly, data used for undertaking the cost-benefit analysis were the average values of costs incurred and benefits obtained following the cultivation of food crops and plantation of *Eucalyptus*.

2.3. Specification of the Farm Household Model

A farm household model was formulated in order to reproduce the behavior of farm households [44,45] that have to select a set of farm choices under resource constraints with respect to available production factors and technical opportunities.

The farm household model depends on production decisions that contribute to income through farm profits [46,47]. The primary motivation for constructing household models is to analyze the impact of resource use, production and consumption decisions on farm household welfare [48,49]. We employed a farm household model to estimate households' gross margins assuming a discretionary income assuming that farm households want to maximize their expected utility [50,51].

This model is proposed for capturing the behavior of farm households that have to select a set of farm portfolios (crop/*Eucalyptus* and off-farm activities) under existing constraints [38]. The proposed optimization model incorporates essential characteristics of each representative household [52]. A linear programming model for making decisions in farm planning is stated by Rehman [53].

$$\text{Max} Z = c'x - \phi\delta \quad (1)$$

Subject to $Ax \leq b$ and $X \geq 0$

where,

Z = Gross margin (ETB/ha)

c = Vector of gross farm income per unit of activity

x = Vector of activities

ϕ = Risk aversion coefficient ($\phi > 0$)

δ = Standard deviation of total gross margin

A = Matrix of technical coefficients

b = Vector of resource availabilities

The first objective of the farm household model is the maximization of gross margin. With this objective, it is assumed that farmers can reach their highest possible welfare (from the sale of farm activities). A record was made for household incomes (gross margin from farm products and off-farm activities) and expenses such as farm inputs and wages paid for hired labor.

The specified equation for maximization of the gross farm income is:

$$c'x = \sum [(Y_c * P_c) + (Y_E * P_E)] - \sum [(S_c * P_s) + (F_c * P_F) + (E_s * P_{Es})] - \sum [(L^{Hired} * W) + (L^{Off} * W)] \quad (2)$$

where,

Y_c = Yield of crop c (kg/ha)
 P_c = Selling price of crop c (ETB/kg)
 Y_E = Yield of Eucalyptus (m^3)
 P_E = Price of Eucalyptus (ETB/ m^3)
 S_c = Seed used for crop c (kg)
 P_s = Price of seed (ETB/kg)
 F_c = Fertilizer used for crop c (kg)
 P_F = Price of fertilizer (ETB/ha)
 E_s = Number of Eucalyptus seedlings
 P_{Es} = Price of Eucalyptus seedlings (ETB/ha)
 L^{Hired} = Number of hired labor (man labor hours)
 W = Wage rate per hour for man labor (ETB/h)

Then, using the variance/covariance matrix of gross margins for production of crops and *Eucalyptus*, the standard deviation for total gross margin is specified as:

$$\delta = \sqrt{[\text{var}(L_c) + \text{var}(L_E) + 2\text{cov}(L_c, L_E)]} \quad (3)$$

where

$\text{var}L_c$ = variance of gross margin from crops
 L_c = Land allocated for crops
 $\text{var}L_E$ = Variance of gross margin from *Eucalyptus*
 L_E = Land allocated for *Eucalyptus*
 $\text{cov}(L_c, L_E)$ = covariance of gross margins from crop and *Eucalyptus*

The equation for summation productions from cultivation of crops and plantation of *Eucalyptus* per input per farm typology is:

$$\sum (I_c + I_E) \geq 0 \quad (4)$$

where, I_c and I_E are income from crops and *Eucalyptus* respectively. Labor involved in different farm/off-farm activities can be expressed using the labor balance equation as:

$$\sum L_{c,E,L} + L^{Off} \leq L^{Farm} + L^{Hired} \quad (5)$$

where $L_{c,E,L}$ are labor involved in cultivation of crops, *Eucalyptus* plantation and livestock rearing, L^{Off} is labor went out in search of off-farm works, L^{Farm} is labor involved in farm activities and L^{Hired} is hired labor.

Land required for different farm activities is constrained by the available land of farm households per farm typology:

$$\sum (X_c + X_E) \leq A_{C,E} \quad (6)$$

where X_c and X_E are lands allocated for crops and *Eucalyptus*, respectively, and $A_{C,E}$ is the total available land owned by a household. The hypothesized constraints for the model

were land (both fertile and marginal), labor, fertilizer and seed, and the model activities were the purchase of farm inputs (seeds, fertilizers and *Eucalyptus* seedlings), hiring of labor and selling harvested crop of *Eucalyptus* wood.

2.4. Evaluation of Farm Portfolios

In addition to optimization of gross margins, we also used Benefit Cost Ratio (BCR) as an indicator of farm performance as proposed by studies including Wainaina et al. [54–56]. Such indicators have been used by different projects to evaluate activities that can be useful in public and governmental decision-making [57]. The BCR is calculated as:

$$BCR = \frac{\sum_{i=0}^n \frac{B^i}{(1+r)^i}}{\sum_{i=0}^n \frac{C_i}{(1+r)^i}} \quad (7)$$

where B = net benefits, C = Cost and r = discount rate and i = investment period.

A farm portfolio (farm choice between plantations of *Eucalyptus* versus cultivation of wheat) with a BCR above 1 provides a net economic gain and can be considered economically feasible.

2.5. Farm Typologies and Their Characteristics

In order to measure farm incomes of households, we constructed typologies of different farm households within the main *Eucalyptus* growing areas. We classified the areas into three farm typologies based on the existing agroecology and land suitability for the production of food crops and plantation of *Eucalyptus*.

Farm typology I (semi-plain lands) is demarked at altitude ranges between 2500–2900 masl which are dominated by alisols, leptosols, and nitosols that are suited for the cultivation of wheat, *teff* and maize together with plantation of *Eucalyptus*. Agroecologies within the altitude range between 2900–3400 masl are categorized as Farm typology II (sloping lands) where the dominant soil types are a mixture of leptisols and nitosols that mainly allow the cultivation of wheat, barley, potato, beans and *Eucalyptus* plantation. Farm typology III (lands with terrain features) that lie within the altitude ranges from 3400–3800 masl is characterized by shallow soils of luvisols and leptosols where there is abundant planting of *Eucalyptus* with wheat, barley, avena and potato-based farming.

In all of the farm types, households engage in the planting of *Eucalyptus* and cultivation of the major types of crops together with livestock rearing. The result showed that households are characterized by more or less similar socioeconomic setups and farming systems across farm types. In all farm typologies, the cultivation of crops is accompanied by the planting of *Eucalyptus* as a potential short rotation species.

3. Results

3.1. Technical Findings

Table 2 below presents the optimal level of land allocated for the planting of *Eucalyptus* and different food crops (wheat, potato, barley, *teff*, maize and faba bean) for the 2020 cropping season across the different farm typologies. Wheat is the major crop intensively grown in all farm typologies. In Farm typology I, households allocated the highest portion of their plots to wheat followed by the production of *teff* and the planting of *Eucalyptus*. In Farm typology II, land allocated for potatoes was highest next to wheat. In Farm typology III, households allocated the highest proportion of their plots to planting *Eucalyptus*, next to wheat. This is because Farm typology III is characterized by relatively rugged topographic features with less fertile and shallow soils which are unsuitable for the cultivation of food crops. However, *Eucalyptus* potentially thrives in such marginal plots as it does not demand intensive care and high levels of soil fertility.

Table 2. Farm households' land allocation plan for the 2020 cropping season.

Optimal Land Size (ha)	Farm Typology		
	Typology I	Typology II	Typology III
<i>Eucalyptus</i>	0.41	0.43	0.51
Wheat	0.65	0.86	0.52
Potato	0.38	0.60	0.23
Barley	0.20	0.29	0.26
Teff	0.41	0.34	0.19
Maize	0.25	0.24	0.21
Faba bean	0.20	0.27	0.23
Average	0.357	0.433	0.307

Results of the farm household model show the shadow prices and slack values of utilized resources. Table 3 depicts the optimal level of available resources together with the respective shadow prices and slack values of the farm household model results. The shadow price indicates the rate of improvement in the optimal objective function value that shows the possibility of increasing the value of gross margin by a unit increase of the limiting resource given all other factors held constant. Accordingly, the land had positive shadow prices in all farm typologies as land scarcity is apparent and decreasing per capita with landholding in general. Conversely, the shadow prices of labor were zero in all farm typologies. We found that labor supply was in excess, particularly during the production season. Seed and fertilizer had positive shadow prices in Farm typologies I and II. The result indicated that there was a surplus of labor, seed and fertilizer resources for the fertile land scenario. The result indicated that there were 65 idle labor in Farm typology I, 82 in Farm typology II and 72 in Farm typology III.

Table 3. Optimal level of resource use, shadow prices and slack values.

Resources	Farm Typology I			Farm Typology II			Farm Typology III		
	Optimal Value	Slack Value	Shadow Price (ETB)	Optimal Value	Slack Value	Shadow Price (ETB)	Optimal Value	Slack Value	Shadow Price (ETB)
Land (ha)	0.357	0	836	0.433	0	1352	0.307	0	918
Labor	222	65	0	410	82	0	316	72	0
Seed (kg/ha)	89.7	0	0.12	0.24	0	231	101	52.4	0
Seedling/ha	4800	245	0	4800	211	0	5315	0	1268
Fertilizer (kg/ha)	101.57	0	42	111.6	0	92	86	14	0

Shadow prices of *Eucalyptus* seedlings are positive only in Farm typology III. This was because seedling nurseries and other seedling supply sources are not sufficiently available in this farm typology and thus seedling is a binding constraint.

3.2. Succession of Croplands by *Eucalyptus*

Information obtained during focus group discussion revealed that a number of socio-economic and environmental factors have contributed to the rapid expansion of *Eucalyptus* in the study area. According to growers' information, native tree species that are of equivalent socio-economic importance as *Eucalyptus* are absent in the study area. There is also a growing market demand for *Eucalyptus* wood products as *Eucalyptus* is becoming the main wood resource for construction, fuel and raw materials for small-and medium-scale wood industries. In addition, *Eucalyptus* has fast-growing potential in a wide range of soil types with little management. Analyzing the costs of production and the returns, farmers who have additional off-farm income sources prefer conversion of their croplands to *Eucalyptus* plantations. Respondents confirmed that crop yields in the adjoining plots are significantly

decreased due to the negative effects of the tree such as shading and competition for nutrients and water. All these facts contributed to the conversion of croplands to plantations of *Eucalyptus* and the trickle-down effect continues year to year. Figure 2 below shows *Eucalyptus* planted on croplands bordering a *teff* field. In this figure, the *teff* and lupin plots are more likely to be planted with *Eucalyptus* in a year or two.



Figure 2. *Eucalyptus* plantation established bordering *teff* (left) and lupin (right) lands.

In the study area, there is a wide-scale degraded land that is unsuitable for the cultivation of food crops. Such aggravated land degradations are mainly attributed to the long-term intensive farming and overgrazing practiced in the area. Increasing levels of soil acidity, especially in areas with steep slopes and terrain features, are another major factor in the decline of land productivity. In such areas, farmers cultivate species such as *avena* (*Avena fatua*), lupin (*Lupinus albus*) and *Eucalyptus*. These species can perform best in such marginal lands. Lupin is mainly sown for its land reclaiming potential for the next season's crop (Figure 3).



Figure 3. Lupin (*Lupinus albus*) and avena (*Avena fatua*) (sown for land reclaiming purpose) and *Eucalyptus* planted on marginal land.

Discussion with key informants indicated that *Eucalyptus* supports the livelihoods of smallholder growers through the provision of various types of services including construction, energy sources, making of plowing tools and making of rope from its bark. Because of its multipurpose uses, growers tend to convert their cultivable lands to the planting of *Eucalyptus* at a year-to-year increasing rate.

Once produced, *Eucalyptus* wood products are supplied to the market in different forms including roofing wood, poles, walling wood, logs, rods and fuel wood with prices that vary on the basis of type and season. Prices are usually set depending on the size/dimensions (such as with roofing wood) or volume of the product (such as with stacked wood). Of all wood types, roofing wood is the most expensive one costing about ETB 162. The product usually has a length of about 12 m and a base diameter of about 21.2 cm. Wood products are transacted through various channels by different market actors such as construction wood retailers, wood processing enterprises, fuel wood retailers and individual house builders. These actors integrate and transact *Eucalyptus* wood to form the value chain. However, due to a lack of sectoral integration and policy focus, the *Eucalyptus* wood sector value chain is found to be undeveloped.

3.3. Economic Results of the Farm Household Model

3.3.1. Impact of Land Succeeded by *Eucalyptus* on Households' Gross Margins

Farm households are not able to separate their resource use and production decisions as they experience direct trade-offs and will continue to produce up to the level where the shadow value of producing one more unit of product is equal to the opportunity cost of producing the product. When farm households make a decision on production, labor allocation and consumption, they will have decisions that are dependent upon each other.

In order to see the impact of land succeeded with *Eucalyptus* on households' gross margins and to realize whether involvement in intensive plantation of *Eucalyptus* can affect the level and distribution of farm households' gross margin, we ran a farm household model by integrating major food crops (wheat and barley, which are commonly grown in the three farm typologies) and *Eucalyptus*, that are subjected to resource constraints (land, labor, seed and fertilizer). For a better representation and estimation of farm outputs, we considered production both at fertile and marginal lands and integrated the respective prices of farm resources such as labor (16.99 ETB/hour for summer labor and 16.95 ETB/hour for the season from September to December). The prices of wheat and barley were 26.01 ETB and 27.39 ETB, respectively. The price of *Eucalyptus* was 1787.08 ETB/ton. Using these resources, the farm household model gave optimal gross margins for each farm typology (Figure 4).

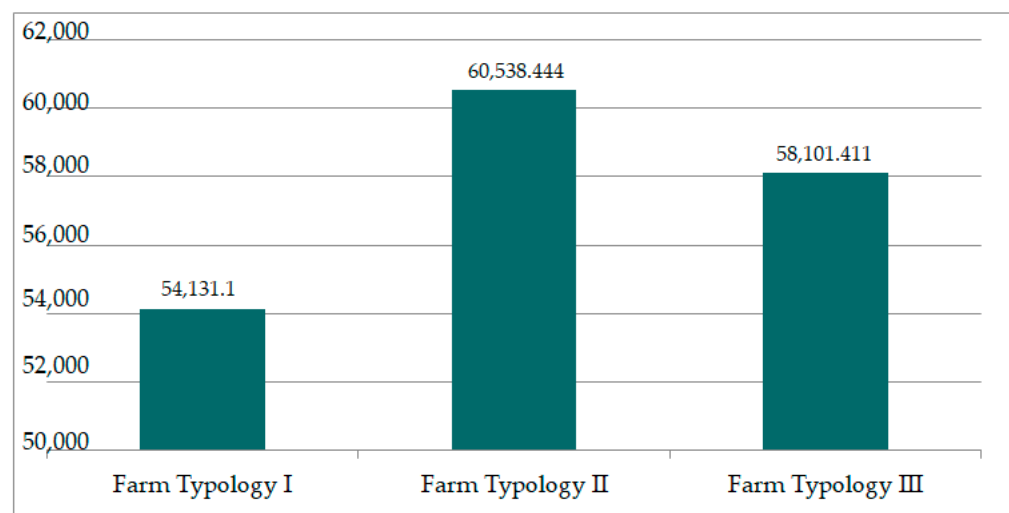


Figure 4. Farm households' gross margin by farm typology (ETB).

Results show that gross margins varied across farm typologies. The farm household model output showed that the optimal gross margins for Farm typologies I, II and III were 54,131.10 ETB, 60,538.44 ETB and 58,101.41 ETB respectively (Figure 4). We observed that gross margin was relatively lower in Farm typology I and highest in Farm typology II. This was mainly attributed to variations in farm activities in the three farm typologies.

Growers in Farm typology I mainly engage in the cultivation of food crops. In Farm typology II, intensive plantation and production of crops are practiced simultaneously. In Farm typology III, lands are highly degraded for sole cultivation of food crops; they grow *Eucalyptus* well and are still surplus for the plantation of *Eucalyptus*.

The main focus of this study was to see the economic impact of the succession of *Eucalyptus* on household gross margins.

3.3.2. Trade-Off Scenarios

In order to see the trade-offs of conversion of croplands to *Eucalyptus* plantations, we considered the three farm typologies of households where we assumed a hypothetical increase of land allocated for *Eucalyptus* and a proportional decrease in cropland and observed how sensitive households' gross margins were for the respective percentage changes in the land. Three scenarios were created by increasing land allocated for *Eucalyptus* by from 30 to 50%. With these land conversion scenarios, the actual changes in gross margins from the status were 13,937.71 ETB, 8367.80 ETB and 8542.72 ETB in Farm typologies I, II and III, respectively (Table 4).

Table 4. The trade-off scenarios and change in households' gross margins (ETB).

	Typology I	Typology II	Typology III	Average
Model output of gross margin for the status quo (ETB)	54,131.10	60,538.44	58,101.41	57,590.32
Gross margin value when <i>Eucalyptus</i> land is increased by:				
Scenario I (30%)	56,802.60	62,623.94	61,139.62	60,188.72
Scenario II (40%)	64,980.34	65,917.74	63,605.93	64,834.67
Scenario III (50%)	68,068.81	68,906.24	66,644.13	67,873.06
Actual change in gross margin from the status quo (ETB)	13,937.71	8367.80	8542.72	10,282.74

With the available resources, households' gross margins increased for every percentage increase in land allocated for *Eucalyptus*, depicting that the conversion of cultivable plots to *Eucalyptus* plantation is a rational choice to bring about improvement in farm gross margins.

3.4. Farm Portfolio Evaluation

Plantation trees have a longer gestation period as compared to food crops and thus, estimations of their returns at a point in time may not provide reliable estimates as prices are subjected to dynamism over ten years. In order to handle such price dynamics, we estimated gross margins from plantations of *Eucalyptus* and the cultivation of wheat by discounting future benefits using Benefit Cost Ratio (BCR) as an appraisal indicator. Gross margins calculated for the two cases showed that the highest margin value of 42,890.96 ETB was obtained from plantations of *Eucalyptus* (Table 5).

Our main purpose of undertaking these analyses is for quantifying the net financial gains from using a given plot of land for the production of wheat and planting of *Eucalyptus* for ten years at a 12% discount rate, a discount rate which is the current lending interest rate of the Commercial Bank of Ethiopia.

The ten-year projections indicate that both the cultivation of wheat and plantation of *Eucalyptus* are feasible in the existing states. However, the BCR value for *Eucalyptus* indicates a greater worthiness, 2.15 for *Eucalyptus*, while that of wheat is 1.08 (Table 6).

Table 5. Evaluation of *Eucalyptus* versus food crops portfolio choice.

Cost of Production	Wheat (ha)			<i>Eucalyptus</i> (ha)		
	Amount	Price (ETB/Unit)	Cost (ETB)	Amount	Price (ETB/Unit)	Cost (ETB)
Seed(ton)/seedling	0.327	9358.29	3060.16	3200.00	0.50	1600.00
Fertilize(ton)	0.295	14,450.00	4262.19	4.30	75.00	322.50
Herbicide (lt)	1.321	165.00	218.43	—	—	—
Labor (hour)	101.00	16.09	1625.09	244.62	15.00	3669.23
Total cost (A)			9165.87			5591.73
Income	Amount (ton)	Price	Product value	Amount	Price	Product value
Revenue (B)	1.717	28,550.00	49,020.35	27.17	1787.08	48,554.96
Gross margin (B-A)			39,854.48			42,890.96

Note: Fertilizer used for *Eucalyptus* is locally available manure.

Table 6. Cost-benefit analysis for the two farm portfolios.

Wheat											Eucalyptus			
Year	Cash Outflows	Cash Inflows	Net Cash Flows	Discounted Factor (r = 12%) 1/(1 + r) ⁿ	Net Present Value	Discounted Cash Outflows	Discounted Net Cash Inflows	Cash Outflows	Cash Inflows	Net Cash Inflows	Discounted Factor (r = 12%) 1/(1 + r) ⁿ	Net Present Value	Discounted cash Outflows	Discounted Net Cash Inflows
2020	9165.87	39,854.48	30,688.61	1	30,688.61	9165.87	39,854.48	5591.73	42,890.96	37,299.23	1	37,299.23	5591.73	42,890.96
2021	9165.87	39,854.48	30,688.61	0.893	27,400.54	8183.81	35,584.36	5591.73	42,890.96	37,299.23	0.893	33,308.21	4992.62	38,301.63
2022	9165.87	39,854.48	30,688.61	0.797	24,464.77	7306.97	31,771.75	5591.73	42,890.96	37,299.23	0.797	29,727.49	4457.69	34,184.10
2023	9165.87	39,854.48	30,688.61	0.712	21,843.55	6524.08	28,367.63	5591.73	42,890.96	37,299.23	0.712	26,557.05	3980.08	30,538.36
2024	9165.87	39,854.48	30,688.61	0.636	19,503.17	5825.08	25,328.24	5591.73	42,890.96	37,299.23	0.635	23,685.01	3553.64	27,235.76
2025	9165.87	39,854.48	30,688.61	0.567	17,413.54	5200.96	22,614.50	5591.73	42,890.96	37,299.23	0.567	21,148.66	3172.90	24,319.17
2026	9165.87	39,854.48	30,688.61	0.507	15,547.80	4643.71	20,191.52	5591.73	42,890.96	37,299.23	0.507	18,910.71	2832.94	21,745.72
2027	9165.87	39,854.48	30,688.61	0.452	13,881.97	4146.17	18,028.14	5591.73	42,890.96	37,299.23	0.452	16,859.25	2529.41	19,386.71
2028	9165.87	39,854.48	30,688.61	0.404	12,394.61	3701.94	16,096.56	5591.73	42,890.96	37,299.23	0.404	15,068.89	2258.41	17,327.95
2029	9165.87	39,854.48	30,688.61	0.361	11,066.62	3305.30	14,371.92	5591.73	42,890.96	37,299.23	0.361	13,465.02	2016.43	15,483.64
2030	9165.87	39,854.48	30,688.61	0.322	9880.91	2951.16	12,832.08	5591.73	42,890.96	37,299.23	0.322	12,010.35	1800.39	13,810.89
	Total				204,086.09	56,808.88	265,041.18					248,039.9	37,186.24	285,224.89
	BCR				1.08							2.15		

4. Discussion

Land use changes in the study area have undergone a typical conversion from crops to plantations of *Eucalyptus* at an increasing rate. This was mainly driven by an increasing population that supports their livelihoods with subsistence farming, putting pressure on the natural resource base. The current study measured the economic impact of the conversion of croplands to *Eucalyptus* plantations on households' gross margins using a farm household model where we incorporated important characteristics of each representative farmer that are grouped according to type and the agroecology in which they operate. In order to see the economic impact of *Eucalyptus* expansion on households' annual average revenue, we ran the farm household model as employed by [54,58]. We also made comparisons of farm returns from two farm portfolios using BCR.

The increasing demand for wood products, socioeconomic forces and the land use regulation that allows right-of-use to farmers have significantly contributed to this land conversion trajectory. This finding is in line with the studies by Karttunen et al. [59] which examined the impacts of intensive forest management arising from increased demand for wood biomass with major emphasis on intensive forest management on the regional gross domestic product, private consumption and employment. Land use regulation in the study area which permits land rental and right-of-use is among the driving factors for the expansion of *Eucalyptus*. In Ethiopia, the land belongs to the state and the people and it is the major impeding factor of production. However, the government allows use rights to the people to use their plots for different investment options [7,60–62]. Because of this, growers are converting their cultivable lands to *Eucalyptus* plantation stands.

Currently, the *Eucalyptus* wood products have a potential market share and the demand for the products is spectacularly hiking following the growing market opportunities, particularly in the construction sector [22]. The increasing number of small- and medium-scale wood processing enterprises is another opportunity for the development of the wood sector value chain and thereby supports the livelihoods of smallholders. A similar conclusion was drawn by Ullah et al. [63] who studied the economic roles of fuelwood and timber smallholders' livelihoods in Pakistan.

This rapid expansion of *Eucalyptus* has bilateral implications for the study area's socio-economic setup. On one hand, with the existing increase in population and declining productivity of croplands, *Eucalyptus* can be taken as an opportunity that guarantees smallholder growers an alternative income. A study by Simo [64] witnessed the economic contribution of the tree to smallholder growers, especially in areas where the productivity of lands is declining. On the other hand, the alarming expansion rate of *Eucalyptus* over croplands may pose a threat to food crops, diminishing the quantity of production, the types of food crops and biodiversity in the future.

The results revealed that households plant *Eucalyptus* at the expense of croplands for a multitude of reasons, including the growing demand for construction wood and subsequent increase in the price of *Eucalyptus* wood, its ability to thrive best with minimal management, its multiple roles and its ability to provide better profitability from a given parcel of land. This has become a threat to fertile arable lands by diminishing food crops in the study area [8]. Cultivation of food crops and livestock rearing complemented with *Eucalyptus* plantation are the main farming activities in the study area. Apart from the cultivation of food crops such as wheat, *teff*, maize, potato, barley and faba bean, farmers are showing a tendency of converting their plots to plantations of *Eucalyptus*. Labor is the main factor of production and factor source of difference in household endowments. In the study area, farm households mainly use family labor. In peak times (sowing, weeding and harvesting), hired labor and labor sharing arrangements (locally called *debo*) are commonly used.

Aside from all the above, the expansion of *Eucalyptus* has been reported to have a negative impact on ecology and biodiversity. There is significant, supporting evidence regarding the negative impacts of *Eucalyptus* on ecology and biodiversity. The impact of *Eucalyptus* on wood-decaying fungi and saproxylic beetles has been studied by Hopkins et al. [65]. A study by Bonham et al. [66] in Tasmania found that native land snails and millipedes were

less diverse in *Eucalyptus* plantations than in native forests. Studies by Riffell et al. [67] and Teketay [4] found low diversity and abundance of birds and browsing animals in *Eucalyptus* plantations than in native forests. Because of its morphology, mainly, limited availability of large stems, *Eucalyptus* is not convenient for cavity-nesting bird species and thus, it has a moderate capacity to harbor species of fauna, leading to migration and decreased species richness. A similar study by Proenca et al. [68] reported lower plant and animal diversity in *Eucalyptus* plantations relative to native forests. In Brazil, Rocha et al. [69] found fewer species of lizards and selected invertebrates in *Eucalyptus* plantations than in primary Atlantic forests. Generally, *Eucalyptus* in its niches of plantations apparently negatively impacts species richness and consequently causes increased biodiversity erosion.

If the rate of expansion continues at the same pace the entire area will be covered with *Eucalyptus* within a few years. Understanding such land conversions is central to the proper management of land resources, especially in areas where the majority of the people support their livelihood using a base of natural resources. These conclusions are consistent with the study that indicated the importance of knowledge of the land use dynamics for land resource management [70].

We employed the farm household model to examine the behavior of farm households that have to make choices about farm portfolios with respect to available factors of production and resource constraints. In the study area where land resources are limited and per capita land holding is declining, maximizing the economic return per unit area is essential for increasing households' income. The model gave varying values of gross margins for different farm typologies that are in line with the findings of scholars who analyzed different policy impacts and farm alternatives [37–40]. Our results are also in line with Alvarez-Lopez et al. [71] who studied the typology, classification and characterization of farms for agricultural production planning in Northwest Spain. In the farm household model, we assumed that the household budget is endogenous and depends on production decisions that contribute to income through farm profits [40,47].

Similar results were reported by Elouadi et al. [58] who examined the socioeconomic impact of climate change on agriculture activities, taking into account the agricultural, socio-economic and hydrology systems in Eastern Morocco and found that climate change tremendously impacted the income and living standards of farmers. In all farm typologies, households are converting their croplands to plantations of *Eucalyptus*. This is in line with the study by Worku et al. [72] who noted that an increase in demand for wood motivated people to have privately planted trees. This suggests that farmers still have the advantage of obtaining additional benefits from the increases in conversion of croplands to *Eucalyptus* leaving other factors constant. Studies [35,37] drew similar conclusions about how farmers make rational choices concerning farm portfolios.

Scenarios created by increasing land allocated for *Eucalyptus* showed corresponding increases in households' gross margin. The result implies that farm returns obtained from increases in land allocated for *Eucalyptus* cannot be compensated for with a proportional level of increase in land allocated for the cultivation of food crops. This further suggests that farmers still have the advantage of obtaining additional benefits from the increases in conversion of croplands to *Eucalyptus* leaving other factors constant. Studies [39,73] drew similar conclusions about how farmers make rational choices concerning farm portfolios.

Gross margins and BCR analysis results gave higher values for the plantation of *Eucalyptus* than for the cultivation of food crops. This implies that *Eucalyptus* contributes better to households' income as compared with food crops cultivated using the same plot of land. This result is consistent with the study which indicated that plantations support local economies and rural livelihoods in many mountainous regions, where poverty and a fragile environment are often interlinked [38]. The result is in line with the findings of Tafa [41] who investigated farm-level cost-benefit analysis for evaluating the economics of conservation agriculture in Kwa-Zulu Natal Province of South Africa.

The likeness of the findings of this study with other previous studies undertaken worldwide has policy implications in that it is possible to make generalizations to other

areas with similar environmental and socioeconomic setups. The results presented in this study, however, differed from another study by Rondhi et al. [74] which measured the economic value of land in rural and peri-urban areas in East Java, Indonesia in the sense of making economic comparisons. To the best of our knowledge, this study is the first of its kind in Ethiopia which maximized households' gross margins from similar farm alternatives using the farm household model. An exception to this study is that we were able to measure the optimal level of households' gross margin for each of the farm types and made farm portfolio evaluations with hypothetical land conversion scenarios. The findings are useful for guiding the proper and sustainable management of future land resources.

5. Conclusions

The succession of croplands in the study area is an incentive-driven process in a dynamic farming system in need of policy attention. In this study, we analyzed the interlinkage between the land converted to *Eucalyptus* plantation and the respective change in the level of gross margin. We measured the economic impact of the conversion of croplands to *Eucalyptus* plantations on households' gross margins in major *Eucalyptus* growing areas of Northwestern Ethiopia using a farm household.

Due to rapid land degradation, a decline in soil fertility and a subsequent decrease in crop productivity, farmers in the study area are shifting their cultivable lands to *Eucalyptus* plantations with a yearly expansion rate irrespective of the fertility status of their plots. In the current study, we characterized farm households in three typologies that showed diversity in endowment and farming system where there is a general increase in conversion of croplands to *Eucalyptus* plantation year to year. The expansion of *Eucalyptus* over croplands has created a two-dimensional ongoing debate. On one hand, the expansion of *Eucalyptus* can be viewed as a major source of income and livelihood supporting strategy for farm households that exercise dynamic income alternatives and coping strategies. On the other hand, the alarmingly increasing population may be threatened by a shortage of food as *Eucalyptus* is expanding at the expense of croplands which will ultimately lead to a decline in food crop production.

In Farm typology I, where lands are relatively plain, fertile and preferred for the cultivation of food crops such as wheat and *teff*, policies must restrict the expansion of *Eucalyptus* over croplands and only marginal lands should be reserved for *Eucalyptus* plantations. In Farm typology II, where lands are relatively sloped with mixed soils of Leptisols and Nitosols, farming systems are mainly based on the cultivation of major crops such as wheat, barley, potato and beans together with *Eucalyptus* plantation. A study by Simane et al. [42] has made a similar characterization of farms across agroecologies. Lands in this farm typology are less fertile and have a high percentage of marginal area coverage compared to those in Farm typology I. For this farm typology, a hand-in-hand increase in *Eucalyptus* expansion with the level of marginal area coverage is recommended as it can give optimal farm income from the crop-plantation farm portfolios.

Farm typology III is characterized by lands with steep slopes, highly erodible terrain features and a high degree of marginality. In this farm type, plots are less productive which lead to the election of plantations as a compensatory option for the farm household in light of ecological considerations, especially with regard to slope stabilization.

In Ethiopia, as a developing country with high demographic and economic transition, the need for land (for cultivation, plantation or housing) is becoming significantly higher [60]. In the same arena, conservation of the cultivable land is vitally important for meeting the mounting food demand of the growing population.

Scenarios created by percentage increases in land allocated for *Eucalyptus* were accompanied by corresponding increases in households' gross margins implying that *Eucalyptus* is the most economically important tree that pays off as compared to the returns from food crops cultivated using the same area of land.

Results reported in this study indicate that there is still a potential of improving households' gross margin with optimal allocation and proper management of land resources for

the two farm portfolios. The ten-year projections of farm portfolios from a hectare of land at a 12% discount rate showed a higher BCR for plantation of *Eucalyptus*. Following these conclusions, we drew the following policy suggestions:

1. *Eucalyptus* plantations can be taken as important resources which can contribute to a number of high-priority policy objectives of the country including contributing raw materials for the industrialization of the forest sector. However, this is only valid if there is proper utilization of land resources.
2. There is a need to design and implement a land use policy for the country which concisely states the proper usage of land considering *Eucalyptus* as a farm portfolio choice beyond the conventional criteria for land use, which is based only on suitability. Efforts should be made to encourage and incentivize farmers to use their land with pre-specified characteristics (focusing plantations on marginal lands and setting aside fertile lands for food crops).
3. There should be evidence-based land choice and prioritization while allocating lands for *Eucalyptus* plantations; ensuring the wellbeing of water reserve areas and fertile croplands and reserving marginal lands for the planting of *Eucalyptus*.
4. To ensure proper usage of land resources in a Pareto-efficient and optimal way, collaborative policy efforts of the Ministry of Environment, Forest and Climate Change and the Ministry of Agriculture are vitally important. Such efforts can help promote the optimal choice of farm portfolios in different farm typologies with a trade-off with a win-win economic and environmental scenario.

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