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The role of trees for sustainable management of less-favored lands: the case of eucalyptus in Ethiopia

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Abstract

In northern Ethiopia, eucalyptus is the most commonly observed tree species in community and household woodlots. In an environment suffering from biomass and water shortages, erosion and land degradation, fast growing and resilient eucalyptus perform better than most indigenous tree species. Smallholders show a clear preference for eucalyptus poles, which are useful for farm implements and constructing dwellings and fences. In addition, the sale of eucalyptus poles and products has the potential to raise farm incomes, reduce poverty, increase food security and diversify smallholder-farming systems in less-favored areas of Tigray. Despite the potential for eucalyptus to improve rural livelihoods, in 1997 the regional government of Tigray imposed a ban on eucalyptus tree planting on farmlands. The ban was precipitated by concerns about the potential negative environmental externalities associated with eucalyptus, and the desire to reserve farmland for crop production. However, the regional government promotes the planting of eucalyptus in community woodlots, and has recently begun to allow private planting of eucalyptus on community wasteland and steep hillsides. In this paper, we review the ecological debate surrounding the planting of eucalyptus trees. In addition, the economic factors that influence smallholders to invest in tree production are considered. Ex ante benefit–cost analysis based on community and village level survey data from Tigray illustrates that planting eucalyptus yields high rates of return, well above 20% in most circumstances. The effect of variable harvest rates, and the potential costs of decreased crop production when eucalyptus trees are planted on or near farmlands are considered relative to our base case scenario. Based upon the review of the ecological and economic impacts of eucalyptus, we conclude that a policy option favoring the allocation of wastelands for private tree planting offers the greatest opportunity for rural smallholders.

Keywords: Afforestation; Ethiopia; Eucalyptus; Less-favored lands; Policy options; Rate of return

1. Introduction

Rapid population growth, biomass shortages, and land degradation are contributing to low agricultural productivity and extreme poverty in the Ethiopian highlands. Northern Ethiopia has very limited tree cover to provide biomass for fuel or fodder, soil nutrient and water retention, protection against soil erosion, or construction materials for smallholders. Establishing woodlots is one of the best available natural resource management tech-

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nologies for dealing with these shortages. National and local forest policy can substantially influence resource use and the sustainability of agricultural systems. Thus, careful consideration should be afforded to policy issues such as what types of trees are promoted for planting in the region, and under what organizational structures tree planting provides positive economic returns and environmental services to smallholders.

Eucalyptus is by far the most common tree species in northern Ethiopia. Although communities and households have exhibited a strong preference for eucalyptus, regional governments in Ethiopia have sought to discourage eucalyptus planting through a ban on the planting of eucalyptus trees on farmlands (Hagos et al., 1999).[1] Restricting the planting of this fast growing species in resource poor regions may reduce access to woody biomass, forest resources, and opportunities for smallholder income diversification. However, eucalyptus are purported to impose significant environmental costs due to their ability to outcompete crops and other vegetation for water and nutrients. Trade-offs between potential socioeconomic benefits and the environmental risks associated with planting these trees therefore need to be carefully evaluated.

In this paper we explore the controversial issue of eucalyptus tree planting in northern Ethiopia. A review of the current social forestry and ecology literature provides evidence both in support of and against the planting of eucalyptus in Ethiopia. The factors affecting whether or not tree-planting investments will be economically attractive to communities and smallholders are also important to consider. Factors such as the opportunity cost of inputs, smallholder discount rates and the effectiveness of local organizations affect land use decisions. Using socioeconomic data from Tigray we estimate ex ante economic returns to communities and smallholders for planting eucalyptus. We consider three scenarios; a base case, economic returns over variable harvest periods, and the impact of crop losses due to potential negative externalities on rate of return estimates. We then consider policy options to increase the returns and reduce the environmental risks of eucalyptus woodlots in northern Ethiopia.

2. The ecological debate surrounding eucalyptus

There is substantial debate in the ecology literature regarding the ecological effects of eucalyptus. Several of the key arguments in the debate are reviewed in this section.

2.1. Provision of biomass and maintenance of existing forest cover

In Ethiopia, if soil degradation is to be slowed, the provision of woody biomass as an alternative to burning dung and crop residue is a critical issue requiring a short-term solution. In Tigray, dung and crop residue account for as much as 81% of total household energy consumption, leaving little organic matter for the fertilization of crops causing soil degradation and accelerated erosion (Bekele-Tesemma, 1997). Further, approximately 95% of total demand for wood and woody biomass in rural Ethiopia is for fuelwood, leaving little woody material for construction and other purposes (EFAP, 1993).

Although grasses and shrubs contribute to biomass, trees are generally acknowledged to most efficiently convert soil nutrients and water into biomass. Even in severely stressed regions, fast growing tree species such as *Eucalyptus globulus*, *E. camaldulensis* and *E. saligna* produce high volumes of biomass within a short time frame. For example, *E. globulus* produces a harvestable tree crop in some regions of Ethiopia within 5–6 years after planting, although the rotation age that maximizes wood production is approximately 18 years (Pohjonen and Pukkala, 1990). Estimates of mean annual increment (MAI)[2], in Ethiopian eucalyptus woodlots range from approximately 10 m^3/ha per annum on poor sites (Newcombe, 1989; Pohjonen and Pukkala, 1990), to 57 m^3/ha per annum on more productive sites (Stiles et al., 1991). Estimates for other commonly observed coniferous plantation species range from 4.2 m^3/ha per

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[1] Concerns about food security and the ecological impacts of eucalyptus precipitated this ban.

[2] Mean annual increment (MAI) is the estimated volume per hectare (m^3/ha) divided by the age of the stand of trees.

annum on low potential sites, to 9.6 m^3/ha per annum on high potential sites, whereas the MAI of natural woodland is approximately 1.2 m^3/ha per annum (EFAP, 1993).

Tree planting with eucalyptus can also facilitate the preservation of existing forest and woodland. In addition to providing an alternative source of forest products, there is evidence to suggest that indigenous species such as *Juniperus procera* and *Podocarpus gracilior* may regenerate under some species of eucalyptus. For example, if there are indigenous seed trees in the vicinity — and if grazing is prohibited, indigenous species have regenerated under *E. globulus*. Once demand for biomass is met and pressure to cut indigenous woodland reduced, a partial restoration of indigenous forests could occur (Pohjonen and Pukkala, 1990).

2.2. Effects on soils: nutrient depletion and topsoil retention

Up to half of the arable land in the Ethiopian highlands is estimated to be moderately to severely eroded, and as a result of gully formation and loss of topsoil, previously cultivable lands are being (or have been) turned to wasteland (FAO, 1986; REST, 1995). Estimates of soil erosion in the Ethiopian highlands indicate that 2 million hectares of land have been severely degraded, and that, if management practices are not changed, as much as an additional 7.6 million hectares will deteriorate to the same status by 2010 (FAO, 1998). Annual economic losses attributable to soil erosion in Ethiopia are estimated to be EB 10–12 million per annum (calculated to 1994 prices) (Sutcliffe, 1993; Böjo and Cassells, 1995), reducing farm incomes as much as 5–30% by 2010 (Kappel, 1996, as cited in FAO, 1998).[3]

Evidence from the literature suggests that there is potential for eucalyptus to reduce topsoil runoff and slow erosion. For example, Grewal et al. (1992) found that eucalyptus may reduce the rate at which wastelands are being formed. Their study in northern India, in a region topographically and climatically similar to northern Ethiopia, examined rain fed valleys and degraded forests on hillsides focusing on silvopastoral systems (i.e. *E. tereticornis* on sand loam soils with Bhabbar grass for pulp and grazing as lower canopy). Findings indicate that most rainfall was conserved by the system, and that there was negligible water runoff and soil loss. Relative to bare land the silvopastoral system was superior and resulted in greater water retention and reductions in topsoil losses. Pohjonen and Pukkala (1990) argue that the presence of eucalyptus is positive when compared with barren sites in the Ethiopian highlands.

Depletion of soil nutrients is one of the most commonly cited criticisms associated with eucalyptus trees. In contrast to commonly used agroforestry species such as leucaena and acacia, eucalyptus are non-leguminous — they do not fix nitrogen, an essential element for soil health and sustainability. To assess the effect of eucalyptus on cropping systems, several studies have compared tree and agricultural crop interactions (Verinumbe, 1987; Sanginga and Swift, 1992; Michelsen et al., 1993). Michelsen et al. (1993) found that indigenous woodland in Ethiopia provided much higher nitrogen and phosphorus content in above ground herbaceous plants, indicating that nutrient cycling in sites dominated by exotic tree species is more constrained. Bioassay results indicated that the factor limiting growth in agricultural crops such as *Eragtrostis tef* was likely the low availability of phosphorus, calcium and potassium in eucalyptus soils.

2.3. Allelopathy

Allelopathy is the provision of chemicals from leaves or litter that inhibit the germination or growth of other plant species (FAO, 1985).[4] The major implication of allelopathic effects in smallholder farming systems is the reduction in crop output when trees are planted adjacent to crops. The long-term ecological consequences of allelo-

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[3] EB = Ethiopian Birr. Approximately EB 6 = US$1 in April 1994 (Böjo and Cassells, 1995).

[4] For example, terpenoids, which are isometric hydrocarbons common to tree species that produce essential oils, resins or balsam, have been identified as allelopathic agents in *E. globulus* and *E. camaldulensis*, two of the commonly observed tree species in Ethiopia (Lisanework and Michelsen, 1993).

pathic tree species on soils are not known. However, it has been hypothesized that long-term exposure to allelochemicals may cause soil erosion by reducing vegetative cover.

Scientifically rigorous studies examining the allelopathic effects of eucalyptus and their spatial extent are few, and offer conflicting evidence regarding the impact of eucalyptus on crops (see Malik and Sharma, 1990; May and Ash, 1990; Sanginga and Swift, 1992). Lisanework and Michelsen (1993) provide evidence of allelopathic effects in Ethiopia by testing the effect of *Cupressus lusitanica, E. globulus, E. camaldulensis* and *E. salinga* on seed germination, radicle and seedling growth of four crops: chickpea, maize, pea, and teff. Bioassay results indicate that all of the tested tree species significantly reduced germination in chickpea and teff, and growth in teff; and that the observed allelopathic effects were most significant under *E. camaldulensis* and *E. salinga*. The results of this particular study indicate the importance of considering interactions between tree species and agricultural crops.

2.4. Hydrological impacts

Competition with crops and other vegetation for water, and water table depletion are common arguments against planting eucalyptus. The general hypothesis is that high water requirements and characteristics such as deep root systems provide eucalyptus with a comparative advantage over other plants with respect to water usage. This may be particularly serious when eucalyptus trees are planted in drought-prone regions.

Three studies in similar agro-climatic regions to northern Ethiopia illustrate the potential hydrological impacts of eucalyptus (Malik and Sharma, 1990; Saxena, 1991; Calder et al., 1993). Findings indicate that in the vicinity trees are planted, eucalyptus out-compete crops for water, causing significant decreases in crop output. For example, Malik and Sharma (1990) found that grain yields of mustard and wheat decrease linearly with increasing moisture extraction, and that *E. tereticornis* extracted five times more water from the 0–150 cm profile than mustard. From a distance of 10 m away from the trees, a 47% reduction in mustard yield and 34% reduction in wheat yield was observed.

Saxena (1991) provides further support for intensive water use by eucalyptus in northwest India where farmers plant trees on farm bunds. Qualitative data indicate that farmers with trees close to water channels did not experience significant reductions in crop output, but farmers that were not close to water channels observed reductions in crop output after the first 2 years that persisted until the trees were harvested. Crop losses were higher during winter months than during the summer monsoon, further indicating excessive water use by eucalyptus. Other qualitative accounts (FAO, 1985) suggest that eucalyptus trees have the capacity to affect domestic water supplies or irrigation reservoirs. However, there is little empirical evidence to support this.

However, the ability to tap deep water sources that crops cannot may be critical to smallholders, for whom eucalyptus may provide much needed income when food crops are destroyed by drought. When drought occurs, eucalyptus trees have a higher probability of surviving ecological disturbances than other tree species (Rocheleau et al., 1988) due to their ability to tap deep-water sources with their roots.[5] Also, due to the purported high volume of water use by eucalyptus, they are effective at drying up waterlogged sites.

Eucalyptus trees planted as windbreaks or shelterbelts may help to conserve topsoil moisture by retaining surface ground water for water recharge, reducing erosion, regulating flow, enhancing infiltration, reducing transpiration, improving water drainage systems and providing shelter from blown sand, drying winds, high temperatures and intense rainfall (FAO, 1985; Anderson, 1987; Stiles et al., 1991; Huchu and Sithole, 1993). Further, tree root systems contribute to soil strength by providing additional soil cohesion and reducing or halting mass wastage of slopes (Böjo and Cassells, 1995).

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[5] Bacon et al. (1993), suggest that the roots of some eucalyptus are known to extend as far down as 10–25 m below ground surface, or three to four times the height of the tree.

2.5. Resistance to destructive pests, climate variability and other risks

Insects, pathogens and livestock, as well as climate variability, fire and other risks can have significant impacts on the survival of herbaceous and woody plant species. The resistance of a tree species to such elements significantly influences the rate of seedling survival and therefore the risk associated with investing scarce resources in planting a particular species. A variety of pests are known to have a significant impact on eucalyptus. In Ethiopia, all species of eucalyptus are susceptible to invasion by locusts, but other pests, common throughout east and southern Africa (including the eucalyptus snout beetle or weevil) have not been observed in Ethiopia (Pohjonen and Pukkala, 1990). Termites are also a threat to eucalyptus in sub-Saharan Africa. However, certain species (for example, *E. camaldulensis*) are resistant to attack (Atkinson et al., 1992). Fungus is the major pathogen threat to eucalyptus. Generally the effects of fungi are less significant at higher elevations, such as most of the highland region of Ethiopia. Eucalyptus also has the ability to survive fire damage. When fire destroys the aerial parts of the tree, anatomical organs in root collars cause dormant buds to sprout due to reserve foods in the protective organs (FAO, 1979; Lacey, 1974).

2.6. Discussion

Many of the studies we have cited in this section address ecological impacts in isolation. However, both the positive and negative effects of eucalyptus on any given site are likely to be many and interrelated, making the question of the net effect of the tree crop on the site in question very complex. Consider the case where a shelterbelt of *E. camaldulensis* is planted adjacent to a barley plot in the Ethiopian highlands, decreasing crop output in the vicinity of the trees. However, the benefits derived in terms of slowing erosion and retaining soil moisture over the entire plot of land may compensate for the losses in crop production experienced within the zone affected by the trees.

Whether or not planting eucalyptus is an ecologically favorable land use will also be highly dependent upon the environmental conditions that smallholders face. In regions where rainfall is sufficient to sustain trees, soil conditions are conducive to tree growth and perhaps less appropriate for food crops, and households have sufficient access to inputs such as water (especially during establishment) and seedlings, tree planting may be an environmentally sustainable land use alternative. We stress the site-specific nature of these alternatives, noting that in all likelihood there will be a high degree of variability even within Tigray.

3. Estimating economic returns

Households determine their land use portfolios based upon potential benefits and costs given their environmental and economic resource endowments, and taking into consideration the time frame in which outputs will be profitable.

3.1. Parameters and hypotheses employed in benefit-cost estimates

We consider several economic parameters and how they may influence potential economic returns to tree planting in estimating ex ante benefit–cost estimates. We formulate the following hypotheses about conditions for higher net economic returns:

- Tree planting investments in land abundant areas (i.e. those with low population densities) and lands with low or no potential/opportunity cost will yield high economic returns.
- Regions with low wage rates will be most attractive for tree planting investments, but high wage rates may also favor tree planting when compared with other more labor intense activities.
- Tree planting in regions remote from markets will yield lower returns. Good access to input markets (for example, seedlings), implies lower prices and transportation costs for inputs. Access to output markets implies lower transportation costs as well as sufficiently elastic demand.
- High rates of return will result when discount rates (which dictate the time frame in which investments are profitable) are low, and access to credit markets is good.

- Institutional factors are important for high returns on investment. For community woodlots, strong collective action is essential and control over the rights of access to benefits very important.

3.2. Data

To formulate benefit–cost estimates we rely on data collected during a survey of 50 *tabias* (communities) — the lowest administrative unit in Tigray, usually comprised of four to five villages — administered in the highlands of Tigray during the 1998–1999 cropping season.[6] *Tabias* were selected based on a random sample, stratified by proximity to market town and the presence of an irrigation project. Within each *tabia* two villages were randomly selected. A questionnaire was administered with representatives of the community's households at both the *tabia* and *kushet* levels (Gebremedhin et al., 2000).

For the purpose of this analysis we distinguish between woodlots on community land that are managed by communities, and woodlots on community owned land that are privately managed by smallholders.[7] Private woodlots have been established on community-administered lands in recent years, particularly on hillsides and wastelands that have limited alternative uses. Of the fifty *tabias* in our sample, 46 have community woodlots. On average there are about nine woodlots per *tabia. Tabia* councils manage approximately one-third of the woodlots, and all members of the *tabia* generally have the right to use the woodlot. All other community woodlots are managed at the village level by village councils and are used only by the members of that village. Twenty-five percent of *tabias* in the survey have privately managed woodlots on community land.

3.3. Assumptions and values used to estimate internal rates of return

We estimate internal rates of return (IRR) for both community woodlots and privately managed woodlots established on community land. We estimate a base case scenario, and then consider the influence of variable harvesting periods and potential crop losses related to negative externalities. Due to limited data, benefit-cost estimates are based on simple parameters and sensitivity analysis is used to reflect the key variables we hypothesize to influence returns to investment for tree planting.[8] We emphasize that this is an ex ante analysis of benefits and costs.

On the cost side we include the annual opportunity cost of land, the value of labor, and the value of seedlings. We assume that the opportunity cost of land is zero for wasteland (i.e. those lands with no alternative use), or 841 birr, the estimated gross value of cropland per hectare for all other alternative land uses. We note that this is an over estimate of opportunity cost for farmlands, since it is based on gross, rather than net returns to cropland, and even more of an overestimate for less productive lands.

Labor inputs are valued by multiplying average number of labor days invested in the first 3 years of production (251, 81 and 4 labor days per hectare in years 1, 2 and 3, respectively, for *tabia* managed woodlots, and 127, 83 and 96 labor days in years 1, 2 and 3, respectively, for both *kushet* and privately managed woodlots), by average wage rates in the region.[9] We employ two wage rates, 4 birr/person day and 8 birr/person day in our sensitivity analysis. We rely on *kushet*-managed community woodlots to provide estimates of labor inputs for privately managed woodlots. This is likely an underestimate of labor inputs for private woodlot labor investments. We assume that any labor inputs beyond year 3 will be negligible, as the trees should be established by the fourth year.

The only input we consider is the value of seedlings (1 cent birr/seedling), as other material inputs such as pesticides, fertilizer and fencing materials are not commonly used, particularly in community woodlots. The number of seedlings per hectare are estimated using median planting density values derived from our survey data (3287,

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[6] Highlands are defined as those areas above 1500 m.a.s.l.

[7] The community survey did not investigate private tree planning on private lands. This was examined in a household level survey conducted in 2000.

[8] See Jagger and Pender (2000) for a detailed description and for summary tables of parameter assumptions and sensitivity analysis values.

[9] At the time of surveying EB 8 = US $1.

4717 and 3024 trees per hectare for *tabia, kushet*, and private woodlots, respectively).[10]

Because there are institutional barriers to obtaining the right to harvest both timber and non-timber forest products, we estimate potential rather than actual benefits.[11] Ex ante benefits are estimated by multiplying the total number of trees planted in the woodlot (adjusted for coppicing capacity), by a range of pole prices (17, 30 and 41 birr/pole)[12], and taking into account average survival rates in the region for eucalyptus (47%, 58% and 71% for *tabia, kushet*, and private woodlots, respectively). We also assume that grass is harvested from woodlots during the first 3 years of production at the rate of 22 headloads per hectare per year for *tabia* woodlots and 161 headloads per hectare per year for both *kushet* and private woodlots, using estimates of average grass production per hectare from *kushet* level community woodlots as a proxy for grass produced in private woodlots. Grass is valued at 6.5 birr/headload. We note that other benefits associated with eucalyptus woodlots have been excluded from our analysis (for example, fuelwood, honey, etc.) due to lack of data and the difficulties associated with estimating the value of non-market forest products.

Finally, we assume that the first harvest of the total standing stock of trees will take place in year 10 of production, with subsequent harvests of coppice crops taking place in years 20 and 30. These assumptions are based upon data presented in Poschen-Eiche (1987), and reflect harvesting patterns observed in the Hararghe highland region of Ethiopia. Although it is likely that smallholders will want to harvest some portion of their crop as early as year 5 or 6 of production (if allowed by the Bureau of Agriculture), in the absence of data to validate this hypothesis we follow the above conservative assumptions regarding harvesting patterns and returns.

3.3.1. Base case scenario

To determine which variables influence returns to tree planting we first estimate internal rates of return for a base case. Estimates are based upon the summary statistics for *tabia* and *kushet* community woodlots and privately managed stands of eucalyptus that were discussed in the previous section. Unless otherwise specified the same assumptions and sensitivity analysis parameters apply to estimates for both community and privately managed woodlots.

3.3.2. Impact of different harvest periods

The base case analysis assumes rates of tree growth that allow for the harvest of the total tree stock in year 10 of production, followed by subsequent harvests of coppice crops in production years 20 and 30. These harvest ages are assumed to represent an average case for the Ethiopian highlands region. We hypothesize, however, that factors such as altitude and land potential will have a significant impact on rates of tree growth (MAI/hectare). Based upon anecdotal evidence from Tigray we assume that communities and smallholders planting eucalyptus trees at lower elevations or on high potential lands may be able to harvest stocks as early as year 5 in the production cycle, with subsequent harvests at years 10 and 15. Conversely, tree-planting investments made at very high elevations and/or on very low potential lands may not allow for the first harvest until as late as year 15 of production, with subsequent harvests of coppice crops taking place in years 30 and 45.

3.3.3. Impact of crop losses due to nutrient and water uptake by eucalyptus

As we have already noted, eucalyptus trees may reduce crop yields on plots adjacent to woodlots or rows of trees. The allelopathic effects of euca-

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[10] We employ median planting density values in our analysis as outliers in the data were causing very high estimates of mean planting density, particularly for *tabia*-managed woodlots and privately managed woodlots.

[11] We also make the basic assumptions that smallholders are relatively tenure secure (i.e. willing to invest in tree planting and other medium- to long-term investments in land), and that the government of Tigray does not prohibit community or private tree planting.

[12] Pole prices were estimated using community level survey data for the region. Analysis of aggregate data of eucalyptus poles prices in *Woreda* towns and within villages (*tabias*) indicates that the average price per pole in the region is approximately 30 birr. The lowest average pole prices were observed in *Woreda* towns in the more remote western zone of Tigray, and the highest average prices were observed in the population dense central zone.

lyptus and competition for water and soil nutrients when planted adjacent to food crops may lead to losses in crop production that reduce household food security and income. Although a complete portfolio analysis of the various land use activities smallholders undertake is necessary to fully understand the effect of tree related crop losses on smallholder livelihoods, we incorporate crop losses to neighbors into the tree production rate of return estimates to provide a rough estimate of the impact of potential losses on the social rate of return.

We consider a situation where a smallholder plants eucalyptus trees on a one-hectare square plot. Four neighboring smallholders surround the woodlot, each farming cereal crops on a one-hectare plot on each side of the eucalyptus plot. If we assume that 100% of crop yield will be lost within 10 m of the trees, each of the four neighboring smallholders will loose 11% of their gross crop production. The total loss to all four smallholders is equivalent to 370 Ethiopian birr (conservatively assuming a gross land value of 841 birr/ha). We estimate a social rate of return for private eucalyptus woodlots by adding 370 birr to our base case opportunity cost of land estimates for woodlots planted on sites with an initially positive opportunity cost.

4. Results

4.1. Base case internal rate of return estimates

Internal rate of return (IRR) estimates for the base case scenario are summarized in Table 1. Community and privately managed stands of eucalyptus appear to be generally highly profitable in Tigray. However, it is likely, based upon observations of local informal interest rates and estimated discount rates for smallholders in Tigray, that these rates of return may not be high enough to make tree-planting investments attractive to many households.[13]

Predicted IRR estimates for village-managed community woodlots and privately managed woodlots are higher than those for *tabia*-managed community woodlots. These differences are largely attributable to lower survival rates and the lesser amount of grass collected in *tabia* woodlots. This finding suggests that more localized or private management of woodlots yields higher returns on investment. Given that our estimates are based on an assumption of three separate harvests of the total standing tree stock, it is interesting to consider how rates of return might change if access to benefits (i.e. poles) were limited by woodlot governing bodies as is often the case with community woodlots. If pole production is reduced to half of the total stock in each consecutive harvest period, IRR estimates drop from 64% to 47% for *kushet* woodlots.[14] For very poor households with high discount rates, lack of assurance of full benefits in return for investing in woodlots may be enough to deter investment. Finally we note that land values have a greater effect on rate of return estimates than pole prices and wage rates, implying that the opportunity cost of land is an important consideration when planting eucalyptus trees. This has implications when considering the issue of planting trees on farmlands vs. wastelands.

4.2. Impact of different harvest periods

Table 2 summarizes rate of return estimates for short, average (base case) and long rotation cycles, with varying land values, wages, pole prices and other factors for *tabia* woodlots (assuming no grass harvested). The results in Table 2 illustrate the strong influence of harvesting periods on returns to investment for tree planting. *Tabia*-managed woodlots are clearly highly profitable when the first harvest can be undertaken in year 5 of production, and every five years to year 15. However, rate of return estimates for less frequently harvested woodlots (for example, woodlots planted on high altitude sites) indicate that tree

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[13] Holden et al. (1998) estimated the average discount rate in one of the most productive grain producing regions of Ethiopia to be 53%, with the discount rate being inversely related to household wealth. Households with no oxen had an average discount rate of 79%, whereas the average discount rate was estimated to be 28% for households with more than two oxen.

[14] These estimates are based upon the following criteria, low wage rates (4 birr/day), mid-range pole prices (30 birr/pole), positive opportunity cost of land (841 birr/ha), and grass collection allowed in the first three years of woodlot production.

Table 1
Internal rate of return estimates for base case scenario

	Community-managed *tabia* woodlots		Community-managed *kushet* woodlots		Privately-managed woodlots on community land	
	No grass harvest	Grass harvest	No grass harvest	Grass harvest	No grass harvest	Grass harvest
Land value = 0						
Wage rate = 4						
Pole price = 17	41%		55%		51%	
Pole price = 30	50%	N/A	65%	N/A	61%	N/A
Pole price = 41	55%		72%		67%	
Wage rate = 8						
Pole price = 17	32%		44%		40%	
Pole price = 30	39%	N/A	53%	N/A	49%	N/A
Pole price = 41	44%		59%		54%	
Land Value = 841						
Wage rate = 4						
Pole price = 17	22%	23%	31%	50%	27%	44%
Pole price = 30	31%	32%	41%	64%	37%	58%
Pole price = 41	36%	37%	47%	72%	43%	66%
Wage rate = 8						
Pole price = 17	19%	20%	28%	39%	25%	34%
Pole price = 30	27%	28%	38%	51%	33%	45%
Pole price = 41	32%	33%	43%	57%	39%	52%

N/A, not applicable.

planting investments may not offer sufficient returns, especially for poor households, particularly when the opportunity cost of land is high. *Tabia*-managed woodlots are profitable on varying land quality sites if we take 10% as an acceptable rate of return. However, if households consider 50% as the minimum acceptable rate of return for tree planting investments (due to high discount rates and risks), then trees planted on low altitude or high potential sites with high mean annual increments will be attractive.

The issue of harvesting period raises an interesting question — the long-term sustainability of investments in eucalyptus. If we consider the shorter rotation age of 5 years and assume three productive harvest periods, eucalyptus woodlots will no longer be productive after only 15 or 20 years of production. The question of what to do with the site after the productive life of the woodlot has ended will have implications for smallholders that have planted trees on farmlands or other areas with positive opportunity costs.[15] For example, if a smallholder produced eucalyptus trees on farmland for 20 years and at the end of that period decided to return that land to cropland, the labor and other costs involved in removing stumps and the opportunity cost of a fallow period for the site may be high. The long-term ecological consequences are ambiguous. Soil and water resources may be depleted from 20 years of intensive tree growing, but the positive effect of 20 years of tree cover and organic matter produced from decomposing tree roots may outweigh nutrient and water depletion.

Given the lack of information regarding the economic and ecological implications of reclaiming farmland for crop production after several years of eucalyptus tree planting, policy makers

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[15] We assume that the long-term benefit of planting trees on wasteland will be positive regardless of whether the site is cleared of stumps and replanted or allowed to lie fallow after years of eucalyptus production.

Table 2
Effect of different harvesting periods on rate of return estimates

	Tabia-managed community woodlots		
	5-year harvest rotation	10-year harvest rotation	15-year harvest rotation
Land value = 0			
Wage rate = 4			
Pole price = 17	119%	41%	25%
Pole price = 30	152%	50%	29%
Pole price = 41	173%	55%	32%
Wage rate = 8			
Pole price = 17	86%	32%	19%
Pole price = 30	113%	39%	24%
Pole price = 41	130%	44%	26%
Land value = 841			
Wage rate = 4			
Pole price = 17	75%	22%	11%
Pole price = 30	104%	31%	16%
Pole price = 41	122%	36%	19%
Wage rate = 8			
Pole price = 17	62%	19%	10%
Pole price = 30	86%	27%	15%
Pole price = 41	102%	32%	17%

should be cautious to promote planting eucalyptus trees on crop land. Even where the per hectare value of eucalyptus production exceeds the per hectare value of crop production, the costs of reclaiming land for crop production after tree planting may be significant. Intensive eucalyptus tree planting on degraded hillsides, wastelands, and other low opportunity cost lands; combined with policies that allow eucalyptus to be planted as windbreaks or live fences around cropland should be considered.

4.3. Impact of crop losses due to nutrient and water uptake by eucalyptus

The estimated impacts of crop losses on social rates of return are presented in Table 3. When compared with base case estimates, the impact of crop losses does not alter the predicted rate of return substantially. These estimates indicate that the external cost of planting eucalyptus trees on nearby crop production is relatively small compared with the benefits. This is due in part to low crop productivity in northern Ethiopia, and to the scarcity of trees in this region. However, we note that the above estimates do not take into account possible downstream effects (evidence of such effects is not available), or the medium to long-term issue of reclaiming land for crop production after several consecutive years of eucalyptus tree growing.

Table 3
Effect of crop losses on rate of return estimates

	Privately-managed woodlots on community land	
	Base case (private rate of return)	Social rate of return accounting for crop losses
Land value = 841		
Wage rate = 4		
Pole price = 17	27%	23%
Pole price = 30	37%	32%
Pole price = 41	43%	37%
Wage rate = 8		
Pole price = 17	25%	21%
Pole price = 30	33%	29%
Pole price = 41	39%	35%

5. Conclusions and policy recommendations

We have reviewed the literature on the ecological impacts of eucalyptus trees and found that they are complex, mixed, and dependent upon local conditions. In moisture-stressed environments such as in most of northern Ethiopia, there are good reasons to be concerned about the negative impacts that eucalyptus trees may have on crop production and water sources (water competition, allelopathic effects, etc.). However, there are also many potential ecological benefits associated with eucalyptus including reduced run-off and erosion, biomass provision, and reducing pressure on natural forests. We conclude that it is not advisable to make decisions about the use of eucalyptus based upon consideration of single impacts, or without considering the reasons why poor households choose to plant these trees, and the economic impacts that these trees may have on their welfare.

The main factors influencing household or community decisions to invest in tree growing are the costs and returns of the investment. Using survey data from Tigray to estimate the costs and benefits of eucalyptus production under different circumstances we found that eucalyptus generally yields a high-expected rate of return, well above 20% in most circumstances. The most important factors influencing the rate of rate of return are the harvesting period and the opportunity cost of land (the latter especially where eucalyptus is planted on cropland). Woodlots that are managed by villages or private individuals are estimated to yield higher rates of return than those managed at a higher administrative level, due to greater management intensity and higher survival rates of trees. The economic impact of eucalyptus planting in farmlands on reducing crop production of neighboring farmers' fields was estimated to be relatively small compared with the benefits received by the investor.

Recall, however, that we estimate potential rather than actual benefits. This assumption pre-supposes that smallholders will have the right to access the benefits of the woodlot including grass, poles, and other timber and non-timber benefits. As noted earlier, there are institutional barriers (both real and perceived) with respect to the right to harvest both timber and non-timber forest products in Tigray that currently preclude their harvest. A significant shift in Ethiopian forest policy where harvesting is prohibited, and increased awareness of stakeholder rights where there is confusion among resource users, is required before local farmers can effectively realize the benefits of these woodlots.

We also caution that the market for eucalyptus poles is not well understood in Tigray. Little information is available regarding how robust, thin, or stable the markets for both timber and non-timber products are in rural Ethiopia. Markets for poles, fuelwood, and to a much lesser extent charcoal, are well developed close to Addis Ababa and other urban areas characterized by high population densities, extensive deforestation, reliable transportation infrastructure, and high prices for substitutes (Newcombe, 1989). Uncertainty about markets in Tigray for poles and other timber and non-timber products associated with eucalyptus woodlots suggests that the character and potential of markets should be further explored before afforestation with eucalyptus is widely promoted, particularly in cases where the primary motivation for tree planting is smallholder income generation.

Based upon our ecological and economic analysis, and the hypothesized need to devolve decision-making power regarding woodlot management into the hands of the resource users we suggest two potential policy options. The first involves more localized woodlot management. As we have already noted, access to benefits is currently limited by local administrations. Allowing *kushets* and *tabias* to decide on their own when to harvest woodlot products, and/or encouraging the management of woodlots at the village level are policies that may allow near-term benefits to be better realized by communities in Tigray. As illustrated in Table 2, the rate of return to woodlots declines as a result of delaying the harvest, which may make woodlots unattractive investments to smallholders with high discount rates.

The second and most promising policy option involves increased allocation of hillsides and degraded lands for private tree planting. The Tigray Bureau of Agriculture is presently studying the impacts of allowing communities to allocate hillsides and degraded lands for private tree planting or other conservation uses on a pilot scale. The economic benefits of expanding private tree planting on hillsides and degraded areas could be very large. There are approximately 0.1 hectares of wasteland per person in the highlands of Tigray. If this area were allocated for private tree planting, eucalyptus trees were planted with the same density as the median found on private woodlots in our survey (approx. 3000 trees per hectare), and survived at the same rate (71%), that would amount to approximately 200 eucalyptus trees surviving per person. If these trees were cut for poles worth 17 EB (the minimum average price found in the region in 1998), every 10 years, the annual average return would be approximately 370 EB per capita in Tigray (almost half of the per capita Gross Domestic Product in Ethiopia in 1998) (IMF, 2000). Clearly, even if a significant fraction of wastelands were used for tree planting, or even if pole prices were to fall below 17 EB, the economic impact of allocating wastelands for private tree planting could still be very large.

The ecological impacts of tree planting on hillsides and degraded lands are also likely to be positive. Increased biomass, greater recycling of organic material to the soil, watershed protection, and reduced erosion on barren hillsides, is likely to occur. There could be negative indirect effects on community woodlots if community members begin to devote less attention to managing those in favor of investing in private woodlots. And there may be negative consequences for water supplies or crop production if private woodlots are established too close to water sources or crops. Thus, some training and monitoring by governmental authorities appears warranted for this option, as for the previous option.

Some of the results of this study are based upon limited information, particularly regarding the management of private woodlots and the pattern of investments in woodlots and returns over time. In addition, we have not included non-monetary costs and benefits in our estimates of rates of return, and as we have seen, the ecological impacts can be quite complex and varied from one location to the next. More research on these issues is warranted.

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