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Economic Analysis of Forest Management for Timber Production and Agricultural Production in Hillside Watershed Areas of Madagascar: A Case Study of the Itasy Region

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Abstract

In hillside watersheds, forests play a crucial role in protecting against soil erosion. Not only does forest vegetation cover serve as a biological measure to prevent soil erosion, it also generates income through sustainable management practices. However, there is a scarcity of research that evaluates and compares the profitability of perennial woody crops with that of other agricultural crops by integrating biological aspects within an economic analytical framework in Central Madagascar. In this study, we address this gap by combining a biological growth model that captures complex forest dynamics with economic management data to utilize the discounted cash flow method. We applied this approach to evaluate and compare the profitability of forest management and agricultural crop production in the hillside watershed areas of Central Madagascar, which have experienced severe human-induced soil erosion. Although our results showed that timber production is a profitable option, other agricultural crops generate much higher profits, indicating that financial subsidies alone may not be enough to shift land use toward perennial woody crops. In addition, growing fruit trees such as oranges and mangoes appears to be a much more financially attractive option for local farmers than annual agricultural crop production.

Keywords: *discounted cash flow*, *soil erosion*, *watershed management*, *perennial crops*, *annual crops*

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Introduction

Historically, agricultural and forest activities have been vied for land resources, resulting in significant changes in forest coverage over time. FAO (2016) reports that over the past 5,000 years, the global forest area has diminished by approximately 1.8 billion ha, primarily driven by the growing need for land for crop cultivation and livestock grazing. While deforestation rates have slowed in temperate and boreal climatic regions during the twentieth century, there has been a notable increase in deforestation within tropical and subtropical regions, particularly in developing countries. This surge in deforestation can be attributed to the expansion of agricultural land (FAO, 2016).

In some African countries, a significant portion of forest land conversion can be attributed to the expansion of small-scale agricultural activities (FAO, 2016). Small-scale farmers in these countries, who are often impoverished, prioritize immediate food production and cash income (Samkelisiwe & Mpandeli, 2020). Their limited resources and concerns about economic survival leave them with little incentive to consider the long-term environmental impact of their actions or wait for delayed economic and environmental benefits (Barbier, 1997). Consequently, the multifaceted benefits of forest vegetation cover, including timber and non-timber forest products, as well as critical ecological functions, such as wildlife habitats, carbon sequestration, and various hydrological services, such as soil erosion control and flood mitigation, are frequently overlooked by local farmers. These intangible services tend to be overshadowed by more tangible forest products.

Agassi et al. (1994) and Inbar et al. (2014) suggested that in hillside watersheds, the role of forests in providing protection against soil erosion is of paramount importance due to several key factors. Firstly, in the absence of vegetation cover, soil becomes vulnerable to the direct impact of raindrops, leading to changes in soil structure and increased soil detachment. Secondly, steeper slopes facilitate water flow with sufficient force to transport larger and heavier soil particles from the surface (Duley & Hays, 1932; Batumalai et al., 2023). Numerous studies have demonstrated that forest cover plays a significant role in reducing soil erosion in hillside watersheds (Zhang et al., 2015). For example, soil loss from “forest land” or “wood land” is much lower than “shrub land” and soil loss from “shrub land” is much lower than “cultivated land” and “bare land” (Aneseyee et al., 2020). Thus, forest vegetation cover serves as a biological measure of soil erosion while also generating income through sustainable management practices.

However, the undervaluation and removal of forest cover in these areas have frequently resulted in the mass movement of solid materials, potentially leading to significant landslides (Pradhan et al., 2012). Even if soil erosion does not reach levels that trigger catastrophic landslides, it can still adversely impact agricultural crop production in the surrounding areas and contribute to the pollution of streams, rivers, and other water bodies.

Hillside watershed areas in Madagascar are not exempt from the detrimental effects of mismanaged land use practices, particularly human-induced severe soil erosion (Figure 1). One prominent cause of deforestation and land degradation in Madagascar is "tavy," which involves slash-and-burn agriculture primarily for rice cultivation, as rice is a staple food in the country (Klein, 2002; Styger et al., 2007). According to the World Bank (2013), slash-and-burn agriculture is responsible for 80–95% of deforestation in Madagascar. The forests surrounding Lake Alaotra, located in the east-central highlands, have suffered from deforestation, resulting in the obstruction of streams and rivers. Historical satellite images revealed that by 2000, Lake Alaotra had decreased to only 20% of its previous size (Bakoariniaina et al., 2006). Similarly, in the Itasy region of the central highlands, in which the Itasy Lake (one of the largest lakes in Madagascar) is located, and which is known as an important rice production area, wetland areas have become polluted due to runoff from adjacent agricultural fields. The Itasy Region in the Central highlands of Madagascar is among the areas that are heavily affected by deforestation and extreme soil erosion, leading the international aid and development agencies to designate those highland areas to have the highest erosion rate in the world (Madagascar et al., 1988; USAID, 1998) with rates of 20,000 to 40,000 t km^{-2} year^{-1} (Randrianarijaona, 1983; Lal, 1988; Grieser, 1994; Ralison et al., 2008). The existence of large and deep gullies, locally named 'lavaka', demonstrates the gravity of soil erosion (Figure 1) and land degradation in the region (Wells, 1991). Those 'lavaka' are commonly viewed both as anthropogenic in origin and as the main contributors to extreme sediment loads in Madagascar rivers (Helfert & Wood, 1986; Mottet, 1988; Gade, 1996). Although the sole theory stating that those extreme soil erosions and sedimentations are of man-made origin is still debatable (Cox et al., 2009), their abundance and negative adverse impacts on adjacent farms, rivers, and lakes are real and heavily affect the lives and livelihoods of farmers (Randrianarijaona, 1983; Aguiar, 1998; Julien & Shah, 2005). DERAD (2005) argued that 38.16% of the Itasy region are highly prone to soil erosion, most specifically in form of 'lavakas'.

During our semi-informal interviews with local residents in December 2015 and September 2019, they expressed concerns about the current rate of soil erosion, sedimentation, and extinction of freshwater fish species in this area. Land conversion poses a significant threat to the sustainable use of fishery resources and has become a growing concern for communities in the Itasy region

Figure 1 Soil erosion in hillside watershed areas.

(Konoshima et al., 2021). Given these circumstances, there is an urgent need to develop appropriate land-use plans that consider the potential impact of land conversion on soil erosion.

Barbier (1997) argued that the primary cause of land degradation, including soil erosion, in developing countries is an economic issue rather than a technical problem related to soil science or plant breeding. According to Barbier (1997), profitability and the time required for investments are particularly crucial factors in encouraging local farmers in developing countries to choose appropriate land uses for soil conservation.

In hillside watershed areas, local farmers may consider adopting perennial woody plants if they prove to be financially more profitable than other agricultural crops such as rice, tomatoes, cassava, and beans. However, despite the fact that, in general, soil loss from “forest land” or “wood land” is much lower than that from “shrub land”, “cultivated land” or “bare land” (Aneseyee et al., 2020), the majority of farmers investigated in this study opt for land uses that involve annual agriculture or horticulture crops, reflecting their need for short-term and immediate cash flow or their lack of land ownership, which restricts their ability to plant perennial crops.

While various studies have attempted to compare the costs and benefits of different physical barriers and structures, such as soil bunds and stone bunds, as soil conservation measures in Africa (Tesfaye et al., 2016), research evaluating and comparing the profitability of perennial woody crops as a more effective biological measure of soil erosion compared to other agricultural crops in the context of soil conservation and land use management is scarce. Moreover, few studies have provided a comparable assessment of the amount and timing of cash flows associated with crop production in the hillside watershed areas of Madagascar. One of the reasons for the lack of research in this area is the difficulty in developing a biological growth model that captures the complex dynamics of forests, which is necessary to accurately assess cash flow from the management activities of perennial woody crops. In this study, we combined a tree height growth model, a height-diameter model, and a forest stand density model to develop an integrated model that is simple yet captures the relevant features of forest dynamics, including growth, resource competition, and mortality. Then, based on this biological growth model with economic management data, we applied the discounted cash flow method to assess and compare the profitability of forest management for timber production and agricultural crop production.

It is important to note that 'forest management' in this paper indicates the 'action' of managing the forest (especially at the farmers' level). It includes the planning and activities from land preparation, seedling production, transplantation to forest thinning operations, as well as wood harvesting (in this paper, we have not included the production of non-timber forest products (NTFP) within the term 'forest management'. In addition, the term forest management indicates the land conservation and management functions of forest plantations. Agricultural production encompasses a variety of crops, ranging from rice and vegetables that can be sown and harvested within one year to fruit tree cultivation, where the fruits of woody plants are grown for consumption. Therefore, in this study, the term 'agricultural production' refers to annual crop farming, including rice, beans, tomatoes, peanuts, and cassava cropping, as well as perennial fruit production, such as mangoes and oranges.

Methods

To conduct an economic-financial analysis of timber production, we first estimated the harvestable timber volume for the major pine species in the study region. This estimation was based on data obtained from interviews with local farmers, as well as published documents and reports. We collected data on key attributes of forest stands, namely tree height, diameter at breast height (dbh), and stand density. Individual tree volume was calculated using equations for estimating tree volume based on height and dbh. Production projections for agricultural crops were derived from interviews with local farmers. Product prices and management costs were identified through interviews with local farmers. Subsequently, we performed an economic-financial analysis using the discounted cash flow method. For the economic-financial analysis of annual agricultural crop production, the yield for annual agricultural crop production was estimated based on surveys conducted with local farmers. As for the case of perennial agricultural crop production, we estimated the crop yield patterns over the production cycle by combining information from our interviews and literature reviews.

While forest products, such as timber, are perennial in nature, most agricultural crops are annual. To facilitate a meaningful comparison between products with different productive life cycles, we computed the annual gross margin (AGM). The AGM allows us to convert positive and negative cash flows into average annual values (Ericsson et al., 2006; Winans et al., 2015; Testa et al., 2018). To standardize crop yields, management costs, and revenues for comparison purposes, we expressed them on a per-hectare basis.

Study site and data collection Our study site, the Itasy region, is located between latitudes S19°1'18" to S19°5'55" and longitudes E46°44'1" to E46°49'46", covering an area of approximately 3,500 ha (Figure 2). Instead of selecting a predetermined number of farms for investigation, we specifically targeted farms with diverse land cover, including forest plantations and various agricultural crops such as beans, peanuts, and rice fields adjacent to the lake. These farms receive sediments discharged from the upstream areas, primarily originating from the slopes. We approached the farmers who owned or utilized these lands and conducted unstructured semi-informal interviews based on a cross-sectional data collection in December 2015 (main data collection period), and an additional local market survey in September 2019 to update the price of products only.

Forest stand growth and forest management Although forestry (Figure 3) appears to be a potential source of income for local people (especially when combined with farming activities), it is not widely applied in study sites. This is the case despite the awareness of local people regarding the necessity of planting trees and other vegetative covers to protect the soil from erosion and to reduce sedimentation. In

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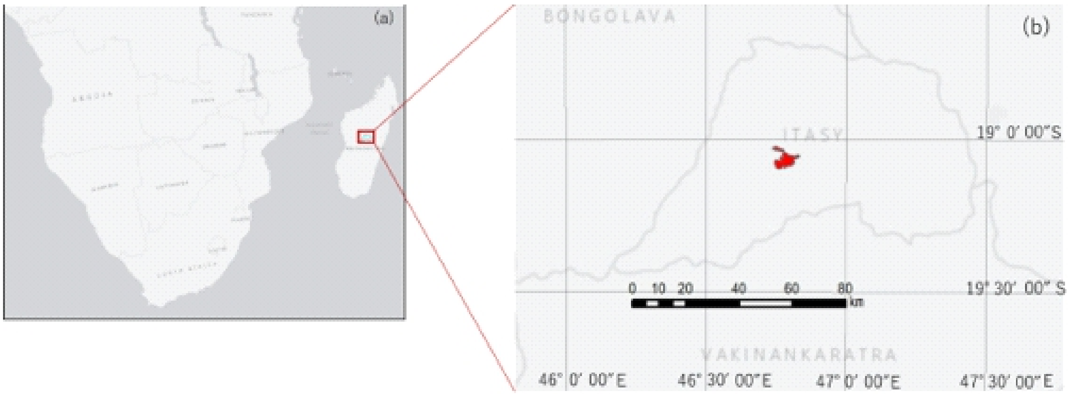

Figure 2 Location of the study area.

Figure 3 Forestry in hillside watershed areas.

some cases, planting trees may also serve as a way to appropriate government-owned land to target crop farming in the future.

One of the major tree species in this region is *Pinus kesiya*. Combining information collected during our semi-informal interviews with local farmers (December, 2015) and literature reviews (Andriamialison & Rambeloarisoa, 1998; Rakotoson, 2014; Nyunaï, 2008), the following conventional management regime was obtained for industrially managed *P. kesiya* stands in this region. The average planting density was 1,300 trees ha^{-1}. The final harvest occurred at 25–30 years.

Forest thinning operations were conducted two or three times, with the first thinning in year 6–10 and the second thinning in year 12–16. The first thinning removed 450–800 trees ha^{-1}, whereas the second thinning removed 150–300 trees ha^{-1}. If the third thinning were conducted, then it would be at year around 20 and thinned to around 150–200 trees ha^{-1}.

In this study, we assumed three thinning operations over the 30-year management plan. The first thinning was assumed to remove 450 trees ha^{-1} at age 6. The second thinning was assumed to remove 180 trees ha^{-1} at age 12. The third thinning was assumed to remove 90 trees ha^{-1} at age 21, which thinned the stand to 185 trees ha^{-1}.

Tree height and dbh are two important forest stand attributes for estimating the growth of individual tree volume (Hoyer, 1985). Tree height growth was projected based on limited published data available for the study area using the Schumacher growth function, as shown in Equation *[1]*.

$$\mathrm{H} = \alpha \exp\left({}^{-\beta}/_{\mathrm{A}^{\gamma}}\right) \qquad [1]$$

note: *H* represents tree height, *A* represents tree tree age. The parameters *α*, *β*, and *γ* were used to estimate growth. For this study, the parameter values for the study area were as follows: $\alpha = 44.769$, $\beta = -16.879$, and $\gamma = 1.158$. The growth in tree height is illustrated in Figure 4.

The growth of diameter at breast height (dbh) was projected based on a height-diameter model developed for *P. kesiya* stands in Zambia (Ng'andwe et al., 2019). We obtained a numerical approximation solution (Equation *[2]*) based on the following height-diameter curve for dbh.

$$H = 1.3 + 34.37(1 - \exp(-0.004 \cdot dbh^{1.918}) \qquad [2]$$

Individual tree volume (V) was calculated based on tree height and dbh using the equation developed by Pham (2010). Their model is defined as shown in Equation *[3]*.

$$V = 0.00006439(dbh^2 \cdot H)^{0.942} \qquad [3]$$

Furthermore, forest stand density (number of trees per hectare) was predicted based on a mortality model developed for *P. kesiya* plantations in Zambia (Saramäki, 1992). Their model is defined as shown in Equation *[4]*.

$$\mathrm{Mortality}_t = -4.06370 \cdot 10^{-6} \cdot N_p \cdot T - 8.36393 \cdot 10^{-3} \cdot T_{diff}$$
$$+1.181063 \cdot 10^{-7} \cdot {N_p}^2 + 0.01188 \cdot T - 1.14037 \cdot 10^{-4} \cdot N_p \qquad [4]$$

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note: Mortality$_t$ represents mortality rate at t, N_p represents planting density, T_{diff} represents time from latest thinning (years), T represents age of the forest stand.

The tree density at time is computed using N_p (1-Mortality$_t$). The model showed a linear decrease in tree density as stand age increased.

For comparison purposes, we also evaluated a "traditional" management plan, which is less intensive and does not generate any intermediate income until the final harvest year of 30 years (Rakotoson, 2014). Although data on forest growth under the "traditional" management approach is limited, the available information suggests that the average tree height and dbh under this approach could be 15% and 12% lower, respectively, compared to those under "industrial" management. Consequently, we developed a growth and yield table for the "traditional" management by adjusting the tree height and dbh growth based on the "industrial" management approach described above.

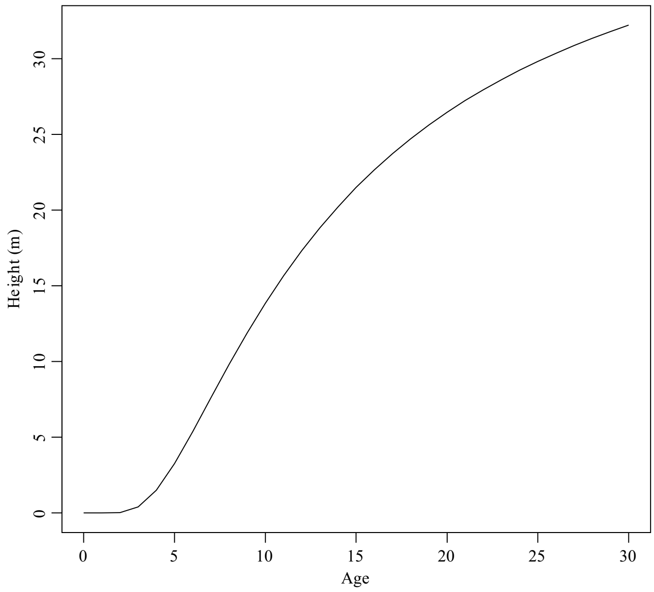

Figure 4 Tree height growth curve.

Management cost and prices *Pines trees* Traditional management costs include seedling purchase, seedling transport from the nursery, labor costs for site preparation (including manual cleaning, digging holes, and planting seedlings), labor costs for manual pruning, and firebreak preparation. These costs were incurred during the planting stage. Weeding is conducted in the first year, so labor costs are associated with it as well. Finally, labor costs for the final harvest occurred in the 30th year. In Madagascar, farmers who practice traditional management often sell felled trees at landings, with buyers assuming transportation costs. According to Rakotoson (2014), the assumed price of felled trees in the final harvest year is MGA5,000 tree^{-1} (Malagasy Ariary) (MGA1 = USD0.000221 as of January 2023).

Industrial farms typically employ more intensive management practices that generate income before the final harvest. In addition to the costs mentioned above, fertilizer was applied twice during planting. Moreover, pruning was conducted in the 5th year, and three thinning operations occurred in the 6th, 12th, and 21st years. Thus, labor costs are associated with these operations. For the purpose of comparison, we assumed that the "industrial manager" sells felled trees at landings, with the buyer covering transportation costs. Based on Rakotoson's study (2014), the assumed prices for felled trees in the 2nd thinning, 3rd thinning, and final harvest years are MGA15,700 m^{-3}, MGA21,206 m^{-3}, and MGA43,300 m^{-3}, respectively. Trees harvested during the 1st thinning are assumed to be sold as firewood at MGA21,222 truck^{-1} (which can carry approximately10–12 m^3 of firewood). We assume a discount rate of 5% based on Madagascar's central bank discount rate (IMF, 2021). Table 1 summarizes the costs associated with the schedule of the operations.

Annual agricultural crops This study considered 6 common agricultural crops in the region, namely rice (irrigated), beans, tomatoes, peanuts, and cassava, for the economic analysis. Based on our semi-informal interviews with local farmers, two types of rice were grown in this region. "Early season" rice is planted in October and harvested in May, while "normal season" rice is typically planted in July and harvested in December. The production per hectare of

Table 1 Annual cost of growing trees for traditional and industrial timber management

Item	Unit	Cost/Unit	Quantity	Year of operation
Seedling purchase	seedling	20	3,000	0
Seedling transport	round trip	4,000	3	0
Digging holes	hole	80	1,500	0
Land preparation + planting	day	2,000	12	0
Gasoline	litter	2,860	20	0
Renting (tractor)	hour	4,000	0.6	0
Fire break preparation	day	1,600	150	0
Manual pruning	day	1,600	10	0
Fertilisation 1st*	kg	300	0.85	0
Fertilisation 2nd*	kg	300	10	0
Fertilization labor	day	2,000	6	0
Weeding	day	1,600	14	1
Pruning*	day	1,500	4	5
Thinning labor*	day	1,600	8	6, 12, 21
Final harvest	day	2,000	12	30

* items required additionally for industrial timber management

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"normal season" rice is 30% higher than that of "early season" rice.

According to the same interviews, we assumed the production of "early season" rice to be 17,500 kg ha^{-1} and "normal season" rice to be 22,500 kg ha^{-1}, both with a sale price of MGA1,200 kg^{-1}. The production of beans was assumed to be 1,350 kg ha^{-1} with a sale price of MGA800 kg^{-1}, tomatoes were assumed to yield 3,000 kg ha^{-1} with a sale price of MGA175 kg^{-1}, peanuts were assumed to yield 500 kg ha^{-1} with a sale price of MGA1,500 kg^{-1}, and cassava was assumed to yield 3,500 kg ha^{-1} with a sale price of MGA150 kg^{-1}. The production costs of these crops are summarized in Table 2.

The perennial agricultural crops Orange and mango are perennial fruits commonly cultivated in this area. The production cycles for these fruits in the region typically span approximately 50 years. Based on our semi-informal interviews with local farmers, both oranges and mangoes could be harvested 45 years after planting. At maturity, orange trees can yield up to a maximum of 20 tons ha^{-1}, whereas mango trees can yield up to 8 tons ha^{-1}. Because yield data were limited in this area, we estimated the crop yield patterns for oranges and mangoes over the production cycle by combining information from our interviews and literature reviews (Testa et al., 2018). Figure 5 illustrates the assumed quadratic functions depicting the yield patterns for oranges and mangoes after the 4th year.

Local farmers were assumed to sell orange and mango fruits directly from their farms at a selling price of MGA1,000 kg^{-1}. For orange production (Equation [5]), the initial costs for land preparation, planting, and fertilization amount to MGA75,000 ha^{-1}. Additionally, pest and disease control management costs of MGA120,000 ha^{-1} are incurred twice per year after plantation. Pruning is necessary in the 3rd year, incurring a cost of MGA400,000 ha^{-1}. Mango fruit harvesting costs were estimated at MGA60,000 ha^{-1} (Equation *[6]*). For mango production, the initial costs for land preparation, planting, and fertilization amount to MGA95,000 ha^{-1}. Pest and disease control management costs of MGA80,000 ha^{-1} are required annually after plantation. Mango fruit harvesting costs are estimated at MGA 60,000 ha^{-1}. The costs associated with these productions are summarized in Table 3.

$$Orange = -0.0162 \cdot OTA^2 + 0.8136 \cdot OTA + 11.066 \quad [5]$$

note: Orange represents yield (ton) of orange per ha, *OTA* represents the age of orange trees.

$$Mango = -0.0089 \cdot MTA^2 + 0.548 \cdot MTA + 0.4705 \quad [6]$$

note: Mango represents yield (ton) of mango per ha, *MTA* represents the age of mango trees.

Scenarios Based on our semi-informal interviews with local farmers, we identified 9 scenarios for our financial analysis. In this region, beans and tomatoes are planted sequentially within a year. For our analysis, we designated the scenario of producing both beans and tomatoes as Scenario 3 (S3), rather than assuming the production of only beans or tomatoes individually. Additionally, as "early season" rice is often planted after producing beans in the same plot, we have designated the scenario of producing "early season" rice and beans as Scenario 7 (S7). The remaining scenarios involved a single production of either timber or a specific crop.

The following are the nine scenarios considered in the analysis based on actual options adopted by local farmers: Scenario 1 (S1): timber (traditional), Scenario 2 (S2): timber (industrial), Scenario 3 (S3): beans and tomatoes, Scenario 4 (S4): peanuts only, Scenario 5 (S5): cassava only, Scenario 6 (S6): irrigated normal season rice, Scenario 7 (S7): irrigated early season rice and beans (one time), Scenario 8 (S8): mango, and Scenario 9 (S9): orange. These scenarios encompass various production combinations for our financial analysis.

Financial analysis First, we calculated the net present value (NPV) for timber production and perennial agricultural crops. NPV is a measure that combines all cash flows (revenue and cost) by discounting them at a given rate. It is commonly used to assess project profitability. If the NPV is positive NPV indicates that the value of the revenue exceeds the cost, making the project profitable. The NPV was calculated using the following equation (Equation *[7]*).

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+i)^t} \quad [7]$$

note: B_t represents the revenues at *t*, C_t represents the cost at *t*, *T* corresponds to the duration of management, *i* is the discount rate.

For each crop, we computed the annual gross margin, which converted all discounted cash flows (revenue and cost) into an average annual value. This approach, known as the equivalent annuity method, is often used to evaluate and compare the profitability of investments of different lengths of time (Ericsson et al., 2006; Winans et al., 2015; Testa et al., 2018). The annual gross margin can be calculated using Equation *[8]*.

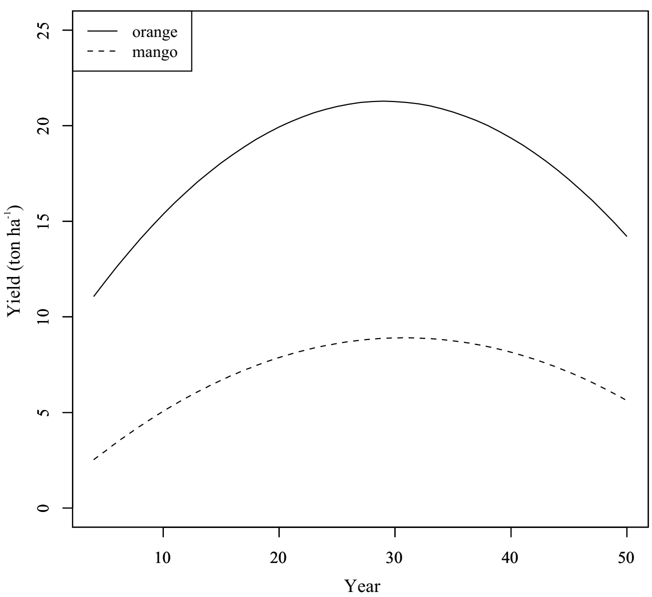

Figure 5 Yield patterns of orange and mango.

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Table 2 Management cost of annual agricultural crops

Item	Unit type	Irregated rice			Beans			Tomatoes			Peanuts			Casava		
		Unit cost (Ar)	Quantity ha^{-1}	Cost ha^{-1}	Unit cost (Ar)	Quantity ha^{-1}	Cost ha^{-1}	Unit cost (Ar)	Quantity ha^{-1}	Cost ha^{-1}	Unit cost (Ar)	Quantity ha^{-1}	Cost ha^{-1}	Unit cost (Ar)	Quantity ha^{-1}	Cost ha^{-1}
Land preparation																
Tillage	WD (work day)	3,000	100	300,000	3,000	40	120,000	3,000	20	60,000	3,000	20	60,000	3,000	40	120,000
	Zebu rental	7,000	10	70,000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Levelling	WD	3,000	50	150,000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Fertilization	Frequency	n/a	n/a	n/a	2,000	10	20,000	2,000	10	20,000	2,000	10	20,000	3,000	10	30,000
Seeds/seedlings	Kg	2,500	35	87,500	500	100	50,000	n/a	n/a	n/a	1,500	50	75,000	1,000	10	10,000
Plantation/transplantation	WD	3,000	80	240,000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a			
Weed management	WD	3,000	80	240,000	n/a	n/a	n/a	3,000	20	60,000	3,000	20	60,000	2,000	20	40,000
Pests and disease control	Frequency	n/a	n/a	n/a	1,000	10	10,000	1,500	20	30,000	8,000	10	80,000	8,000	10	80,000
Harvest	WD	3,000	20	60,000	3,000	20	60,000	3,000	20	60,000	3,000	20	60,000	3,000	20	60,000
Other Costs		n/a	n/a	n/a	n/a	n/a	n/a		0			0		3,000	20	60,000
			Total	1,147,500		Total	260,000		Total	230,000		Total	355,000		Total	400,000

Table 3 Management cost of orange and mango

Item	Orange					Mango			
	Unit type	Unit cost (Ar)	Quantity	Total	Year	Unit cost (Ar)	Quantity	Total	Year
Land preparation									
Tillage	WD (work day)	3,000	20	60,000	0	3,000	20	60,000	0
Fertilization	Frequency	2,000	10	20,000	0	2,000	10	20,000	0
Seeds/seedlings	No. of plants	150	500	75,000	0	150	100	15,000	0
Pests and disease control	frequency	12,000	10	120,000	twice per year after plantation	8,000	10	80,000	once per year after plantation
Harvest	WD	3,000	20	60,000	every year after 3rd year	3,000	20	60,000	every year after 3rd year
Pruning	frequency	40,000	10	400,000	3	n/a	n/a	n/a	

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$$\text{Annual gross margin} = \frac{i \cdot NPV}{(1-(1+i)^{-t})} \qquad [8]$$

note: *i* represents the discount rate, *NPV* is the net present value calculated earlier (Equation *[7]*), and *t* is the time duration of the project.

These calculations allowed us to assess the financial performance and profitability of timber production and perennial agricultural crops.

Results

The present value of total costs for traditional and industrial management is MGA570,486 ha^{-1} and MGA599,716 ha^{-1}, respectively. In both cases, over 90% of the total costs were incurred during plantation establishment. As anticipated, industrial management is more expensive than traditional management because of the increased frequency of interventions in the early stages of the plantation. However, because industrial management can generate intermediate income before the final harvest, the net present value from industrial management timber production is MGA1,438,699 ha^{-1}, which is more than double that of traditional management (MGA568,503 ha^{-1}). The annual gross margin (AGM) for traditional and industrial management was MGA36,982 ha^{-1} and MGA93,589 ha^{-1}, respectively (Figure 6). All financial indicators indicate that timber production is a profitable land use in this area, although farmers need time to recoup their substantial initial costs. For traditional management, it takes 30 years to recover these costs, while for industrial management, the initial cost can be partially recovered in 6 years.

Perennial agricultural crops Orange had the highest annual gross margin (AGM) among the surveyed crops, while mango had the second highest AGM (Figure 6). These two perennial crops are financially appealing to local farmers. In particular, orange production generates AGM that is three times higher than that of the second-highest crop, mango, and 100 times higher than timber production. Additionally, compared to timber production, it takes significantly less time to achieve net profit and positive financial returns.

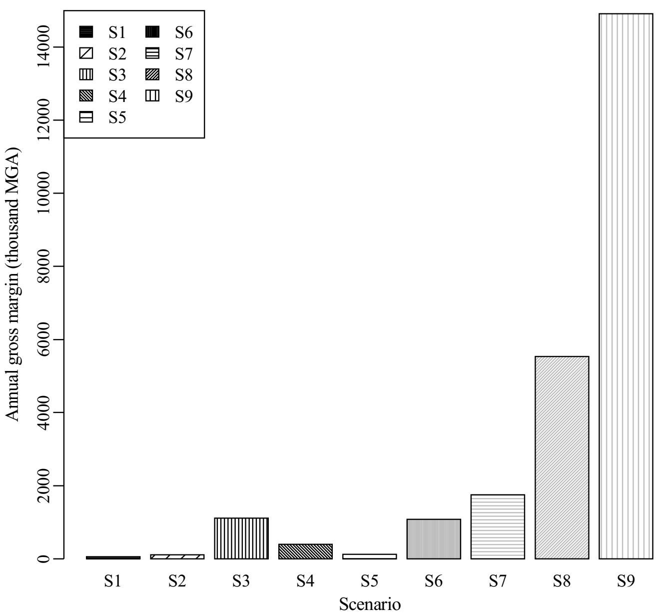

Figure 6 Comparing annual gross margins among scenarios.

Annual agricultural crops Among the annual crop production scenarios, S7 (irrigated early season rice and beans) generated the highest annual gross margin (AGM), followed by S3 (beans and tomatoes) and S6 (irrigated normal season rice). Although all annual crops generate higher AGMs than timber production, the AGM of S7, the highest among the annual crop production scenarios, is only one-fifth that of mango. Figure 6 illustrates that, while timber production yields positive profits, most other agricultural crops are significantly more financially attractive to local farmers.

Sensitivity analysis We conducted a sensitivity analysis to evaluate the robustness of our annual growth margin calculation results, which were based on assumed values of the relevant parameters for our study area. The profitability of timber and agricultural crop production depends not only on physical yields but also on financial inputs, such as management costs and sale prices, both of which are subject to uncertainty. Therefore, to evaluate how 1) site productivity, 2) management costs, 3) sale prices, and 4) discount rates influence the financial performance of timber and agricultural crop production, we conducted a sensitivity analysis by individually varying these parameters. This analysis can also help assess the influence of policy changes on the profitability of different types. For instance, farmers can receive economic subsidies to plant and cultivate trees instead of engaging in agricultural production on erosion-prone farmlands (Brauman et al., 2007). Public funds are often available for establishing forest plantations in various regions, including the U.S. (Kuboyama et al., 2000), European countries (Zorn, 1999; Lawson et al., 2002), and Japan (Zorn, 1999). The availability of such funds can be simulated by reducing the forest establishment costs. Each parameter was varied by 20% and 40% above and below the baseline values, respectively.

Our sensitivity analysis demonstrated that, except for S5 (producing cassava only), local farmers achieved positive profits within the defined ranges for all parameters (Table 4). Specifically, our analysis showed that cassava, which generates the third-lowest AGM, yields negative profits when the price decreases by 40%, productivity decreases by 40%, or cost increases by 40%. However, timber production, which generates the two lowest AGMs, generates positive profits within the defined ranges for all the parameters. Therefore, our case study indicates that while timber production may yield lower profits than annual crops such as cassava, it could be a more stable option for local farmers under varying economic and environmental conditions.

To generate negative profits from timber production, not only the productivity of the site but also economic parameters must be simultaneously varied (two-way sensitivity analysis). For example, in the case of traditional management, timber production results in negative profits if: 1) the productivity of the site and the price of timber decrease

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simultaneously by 40% and 20%, respectively; 2) the productivity of the site and the price of timber decrease simultaneously by 20% and 40%, respectively; 3) the productivity of the site decreases by 40%, while the management costs increase by 20%; 4) the productivity of the site decreases by 40%, while the discount rate increases by 20%; or 5) the productivity of the site decreases by 20%, while the discount rate increases by 40% (Table 5).

Furthermore, our sensitivity analysis revealed that within the range of cost reductions defined in this analysis (-20% and -40%), it is uncommon for timber production to become a more favorable option than other agricultural products. Therefore, subsidies for forest management activities, such as afforestation, may not be sufficient to incentivize farmers to shift their land use towards forests.

Discussion

Unlike the construction of physical structures for soil erosion control, growing tree cover offers the dual benefits of protecting against soil erosion and providing income-generating opportunities if managed appropriately. In this study, we aimed to provide a comparative analysis of cash flows for crop production in the hillside watershed areas of Central Madagascar. Our goal was to evaluate and compare the profitability of forest management and agricultural crop production, while also determining the time required to obtain revenues from these crop productions using discounted cash flow methods.

Our findings revealed that the industrial timber management option yielded higher profits and was more competitive than the traditional timber management option under current market conditions from the perspective of local farmers. However, overall, perennial agricultural crops and annual crops were found to be financially more advantageous. It should be noted that the net present value calculations for timber management (both traditional and industrial) were based on conventional (typical) management strategies, despite the availability of various options for thinning timing or intensities. Therefore, optimizing management strategy through the use of dynamic programming, for example, is believed to enhance management efficiency and potentially generate higher profits. Such improvements could contribute to the increased feasibility of timber management in this region. Future

Table 4 Sensitivity analysis of all scenarios (in MGA ha^{-1})

	S1	S2	S3	S4	S5	S6	S7	S8	S9
Base	**36,982**	**93,589**	**1,115,000**	**395,000**	**125,000**	**1,552,500**	**1,752,500**	**5,238,941**	**14,331,306**
Price -40%	7,345	40,549	473,000	95,000	-85,000	472,500	480,500	3,085,283	8,478,967
Price -20%	22,163	67,069	794,000	245,000	20,000	1,012,500	1,116,500	4,162,112	11,405,137
Price +20%	51,800	120,110	1,436,000	545,000	230,000	2,092,500	2,388,500	6,315,771	17,257,476
Price +40%	66,619	146,630	1,757,000	695,000	335,000	2,632,500	3,024,500	7,392,600	20,183,645
Cost -40%	51,826	109,194	1,311,000	537,000	285,000	2,011,500	2,323,500	5,297,023	14,451,124
Cost -20%	44,404	101,392	1,213,000	466,000	205,000	1,782,000	2,038,000	5,267,982	14,391,216
Cost +20%	29,560	85,787	1,017,000	324,000	45,000	1,323,000	1,467,000	5,209,901	14,271,400
Cost +40%	22,138	77,985	919,000	253,000	-35,000	1,093,500	1,181,500	5,180,860	14,211,492
Disc -40%	74,122	141,400	n/a	n/a	n/a	n/a	n/a	5,806,348	15,558,226
Disc -20%	54,661	116,382	n/a	n/a	n/a	n/a	n/a	5,523,364	14,952,776
Disc +20%	20,935	72,858	n/a	n/a	n/a	n/a	n/a	4,959,181	13,706,652
Disc +40%	6,365	54,011	n/a	n/a	n/a	n/a	n/a	4,688,704	13,089,148
Prod -40%	7,345	40,549	473,000	95,000	-85,000	472,500	480,500	3,085,283	8,478,969
Prod -20%	22,163	67,069	794,000	245,000	20,000	1,012,500	1,116,500	4,162,112	11,405,138
Prod +20%	51,800	120,110	1,436,000	545,000	230,000	2,092,500	2,388,500	6,315,771	17,257,478
Prod +40%	66,619	146,630	1,757,000	695,000	335,000	2,632,500	3,024,500	7,392,600	20,183,647

Table 5 Two-way sensitivity analysis for timber production [Scenario 1 (S1): timber (traditional)]

		Price					Cost					Discount rate				
		-40%	-20%	Base	20%	40%	-40%	-20%	Base	20%	40%	-40%	-20%	Base	20%	40%
Productivity	-40%	-10,438	-1,546	7,345	16,236	25,127	22,189	14,767	7,345	-77	-7,500	32,734	19,553	7,345	-3,971	-14,480
	-20%	-1,546	10,308	22,163	34,018	45,873	37,008	29,586	22,163	14,741	7,319	53,428	37,107	22,163	8,482	-4,057
	Base	7,345	22,163	36,982	51,800	66,619	51,826	44,404	36,982	29,560	22,138	74,122	54,661	36,982	20,935	6,365
	20%	16,236	34,018	51,800	69,583	87,365	66,645	59,223	51,800	44,378	36,956	94,816	72,216	51,800	33,389	16,788
	40%	25,127	45,873	66,619	87,365	108,111	81,463	74,041	66,619	59,197	51,775	115,510	89,770	66,619	45,842	27,210

studies should explore an optimal timber management strategy using dynamic programming, a widely employed method for determining the optimal timing and intensity of thinning and final harvest activities (Yoshimoto et al., 2016).

While our biological growth model was built by incorporating models and data from prior research to the best of our current knowledge, we acknowledge its limitations. These constraints stem from the limited studies and data available in our specific study area. Future studies should also be conducted to accumulate forest inventory data in the study area to refine our growth model.

Sensitivity analysis revealed that the availability of public funds for establishing forest plantations can significantly reduce the upfront cost of forest stand establishment, which represents a substantial portion of the total cost. This reduction in cost can improve the profitability of forest management, as demonstrated in similar cases reported in African countries by Gondo (2012) and in other countries worldwide by Cubbage et al. (2022). However, the sensitivity analysis also indicates that relying solely on public funds to partially cover the establishment cost may not be sufficient to make forest land use more attractive than other agricultural crops.

As mentioned earlier, the stable production of agricultural crops relies, at least partially, on the control of soil erosion and sedimentation, which are ecosystem services provided by upland forest tree growers. In such cases, the implementation of payments for ecosystem services (PES) could serve as an effective mechanism for transferring payments from service users (agricultural crop producers) to service providers (tree growers). This approach has the potential to make forest management more financially appealing by recognizing and compensating for the ecosystem services provided.

In addition, our findings show that perennial agricultural crops such as oranges and mangoes generate the highest average gross margin (AGM) and are financially attractive options for local farmers. Although managing these fruit tree species may not be as effective in preventing soil erosion and controlling sedimentation as managing forests (Troeh et al., 1999; Liu et al., 2023), several studies have demonstrated that orchard management can reduce soil erosion by increasing the litter layer and improving soil conditions (Montanaro et al., 2017; Ayoubi et al., 2022). Ayoubi et al. (2022) indicated that the improvement of soil conditions varies across spatial locations, such as footslope and toeslope, suggesting that growing fruit trees could provide a balanced approach between financial needs and soil erosion control, depending on the slope location.

The discussion of growing fruit trees is often intertwined with forest management for timber production when considering the expansion and/or maintenance of forest areas to provide multifaceted benefits of forest cover, including soil erosion control and flood mitigation. For example, in Vietnam, a reforestation program (Program 327) had the primary objective of growing fruit trees and industrial trees alongside replanting and protecting the remaining natural forest (Hieu, 2004). While solely focusing on timber production may not be financially attractive, incorporating the cultivation of fruit trees, even on a small portion of the land near timber production, can be acceptable for local communities due to the high profits generated from fruit trees. In terms of soil erosion mitigation, this combination of fruit tree cultivation and timber production may be more effective than any other combination involving annual agricultural crop production.

However, studies on the effects of orchard management on soil quality are limited (Ayoubi et al., 2022). Future research in this region should further investigate the effects of fruit orchards on soil quality, soil erosion, and sedimentation. Understanding the effects of growing different fruit tree species on soil quality in various slope locations will facilitate the consideration of spatial allocation for different land use management strategies. This information, combined with the presented financial analysis, can be valuable for developing appropriate land use plans that consider the potential impact of land conversion on soil erosion. Some studies have reported that although fruit orchards can lead to soil quality reduction and increased soil erosion, erosion rates can be reduced through soil-improving cropping systems, such as the no-tillage system (Tsanis et al., 2021).

Since land use changes have been a major cause of soil erosion (Yang et al. 2003), various studies have attempted to evaluate soil erosion with regard to land use changes (Xu et al., 2011; Aneseyee et al., 2020). Recently, land use optimization models have been increasingly applied to explore appropriate land use allocation plans for controlling soil erosion and achieving a better balance between maximizing profits and minimizing soil erosion (Zhang & Huang, 2015; Sokouti & Nikkami, 2017). The land use optimization model enables us to quantify and evaluate trade-offs among various land uses (Nie et al., 2019). This provides valuable insights for developing land use patterns, particularly in cases involving conflicting objectives, such as mitigating soil erosion and maximizing profits from land use. Therefore, future studies should expand upon and build upon our financial assessment, focusing on the development of a land use optimization model tailored to our study area.

Conclusion

Conducting financial analysis and quantifying the financial competitiveness of each land use is crucial for developing land use management plans that consider the mitigation of soil erosion and sedimentation. Despite the aforementioned limitations, our study provides a quantitative evaluation and comparison of the profitability of forest management and agricultural crop production, clarifying the time required to generate revenues from these crop productions using discounted cash flow analysis. Evaluating the profitability of forest management activities conducted over longer decision time horizons requires a detailed assessment of forest dynamics, including tree growth and changes in the number of trees resulting from resource competition over time. However, developing a model that describes such forest dynamics is often a challenging task, particularly when data for constructing a biological growth model are limited, and there is a shortage of talent capable of constructing such models. These factors have hindered us from conducting economic analyses involving forest management in this region of Madagascar. In this study, we developed a simple yet effective model that captures the most relevant dynamic features of forest growth by integrating three models: a tree height growth model, a height-diameter model, and a stand density model. By combining this model with detailed economic data collected through extensive fieldwork and a literature survey, we were able to quantitatively evaluate and compare the profitability of forest management and agricultural crop production, elucidating the time required to generate revenues from these crop productions using discounted cash flow analysis. In addition, the data collected in this study are valuable and significant, as detailed economic data in this region of Madagascar are scarce and seldom published in the literature. Therefore, future studies can leverage the data collected here to enhance the economic analytical framework or expand and improve the existing dataset. We believe that this study provides valuable insights for future research on the profitability of forest management and agricultural crop production, revenue generation for farmers, and assists local and regional planners and forest managers in making informed decisions to strengthen fragile terrestrial environments while establishing sustainable forest and crop management systems that pose fewer risks to existing natural resources, thereby supporting the lives and livelihoods of local farmers.

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