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Financial analysis of potential *Pinus patula* plantations in Antioquia, Colombia

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Análisis financiero de potenciales plantaciones de *Pinus patula* en Antioquia, Colombia

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ABSTRACT

Keywords:
Land expectation value
Rate of return
Stumpage price
Timberland investments

The establishment of commercial forest plantations requires the selection of sites where reasonable profitability can be attained. A financial analysis was made for the identification of the most suitable areas for the establishment of new *Pinus patula* plantations in the central region of Antioquia, Colombia. The analysis was performed assuming basic silvicultural treatments at the establishment but no management during the entire rotation period. Volume yield data at the stand level was obtained from a previously fitted model that uses biophysical variables and stand density as predictors. The estimated stand volume, a detailed cash flow, and a derived stumpage price were combined to perform a financial analysis. The Land Expectation Value (LEV) and Internal Rate of Return (IRR) at the optimal rotation age, along with their spatial variation, were calculated in this study. Results suggest that the estimated volume and the current stumpage price are not sufficient to guarantee reasonable profitability for new timberland investments. While the LEV was negative, the IRR was in the range 4.1±1.5%, which is less than the discount rate of 6.8% used in the financial analysis. However, a positive LEV and an IRR at 8% would be achieved if forest productivity increases by 20% because of silvicultural practices or costs reduction in a similar proportion (obtaining IRRs up to 8.4%). Moreover, if the government provide subsidies, the IRR would increase up to 10.3% (without requiring an increase in productivity or a decrease in costs) on sites with high growth potential (mean annual increment greater than 16 m^3 ha^{-1} $year^{-1}$), and close to the mills (less than 45 km radii).

RESUMEN

Palabras clave:
Valor económico del suelo
Tasa de retorno
Precio en pie
Inversiones forestales

El establecimiento de plantaciones forestales comerciales requiere seleccionar sitios que garanticen una rentabilidad razonable para inversiones forestales. Se realizó un análisis financiero con el fin de identificar las áreas con mejor aptitud para el establecimiento de nuevas plantaciones de *Pinus patula* en la zona central de Antioquia, Colombia. El análisis se realizó asumiendo tratamientos silviculturales básicos en el establecimiento, pero ningún manejo durante el período de rotación. Información de rendimiento forestal en volumen a nivel de rodal se obtuvo de un modelo previamente ajustado, el cual depende de variables biofísicas y de la densidad de rodal. El volumen estimado a nivel de rodal, un flujo de caja detallado, y el precio de la madera en pie, se usaron en el análisis financiero. Se calcularon como criterios de bondad de inversión el Valor Económico del Suelo (VES) y la Tasa Interna de Retorno (TIR) a la edad óptima de rotación, así como su variación espacial. Los resultados sugieren que el volumen estimado de madera y los actuales precios no son lo suficientemente altos para garantizar una rentabilidad razonable para el establecimiento de nuevas plantaciones. Mientras el VES estimado fue negativo, la TIR encontrada se ubicó en el rango 4,1±1,5%, la cual es menor a la tasa de descuento de 6,8% usada en el análisis financiero. No obstante, valores positivos de VES pueden alcanzarse si se realizaran tratamientos silviculturales que conlleven a un aumento de la productividad forestal de 20%, o a una reducción de costos de la misma magnitud, alcanzando una TIR de hasta 8,4%. En un escenario de subsidios a la reforestación proporcionados por el gobierno, la TIR podría incrementar hasta 10,3%, sin requerir aumentos en la productividad o disminución de los costos, en sitios con alto potencial de crecimiento (incremento medio anual mayor a 16 m^3 ha^{-1} $año^{-1}$), y localizados a un radio de 45 km de los centros de transformación.

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Forest plantations are seen as an attractive investment option compared to alternative investments such as agriculture and livestock. Moreover, increasing global demand for wood (FAO, 2018) encourages timber production from forest plantations. Tropical countries can meet this demand (e.g., Colombia) where high rates of forest growth are possible as a result of more favorable environmental conditions, such as high and constant radiation, and well-distributed rainfall (Cubbage *et al*., 2007). More than seven million hectares (ha) have been identified with high potential for the establishment of new industrial forest plantations in Colombia (UPRA, 2015). However, 360,000 ha have only been established (PROFOR, 2017).

Site selection analysis for establishing new commercial plantations is crucial to guarantee efficient use of land resources. In Colombia, site selection for establishing forest plantations has been carried out mainly through descriptive biophysical analyses, including variables such as temperature, precipitation, and soil depth (UPRA, 2015). Financial analyses of forest plantations have also been developed using the Net Present Value (NPV), Land Expected Value (LEV) and Internal rate of Return (IRR) for plantation species in the Andean Region (*Alnus jorullensis*, *Cordia alliodora*, *Pinus patula*, *Cupressus lusitanica*, *and Eucalyptus grandis*) (Gutiérrez *et al*., 2006), and the Caribbean region (*Tectona grandis*) of Colombia (Restrepo and Orrego, 2015). Notwithstanding, efforts to identify potential areas for new forest plantations have not had a commercial focus that allows for the identification of areas with higher profitability (UPRA, 2018). So far, an analysis combining both financial analysis and biophysical site selection has not yet been undertaken for any species in the country.

A spatially explicit analysis was developed, aiming to narrow the gap between the traditional biophysical site selection and the typical financial analyses commonly developed in Colombia. This analysis included the determination of the potential timber production in these areas and the estimation of the stumpage price. The study was focused on *Pinus patula* in Antioquia (Colombia), a region identified as having high potential for developing productive rural activities under a post-conflict scenario. Although areas with high potential for the establishment of forest plantations have been previously identified in Antioquia, the main objective of this research was to assess how factors such as distance to mills, hauling costs, and stumpage prices will influence the potential profitability of timberland investments. This research gives insights into how these variables might affect both LEV and IRR. Productivity and distance thresholds, which make LEVs and IRRs attractive for *P. patula* in Antioquia, were also identified. It is assumed that the implicit inclusion of socioeconomic variables for site identification may not be enough to select the most profitable areas. The variables previously described will likely change the selected profitable areas since financial factors can have a stronger influence than biophysical factors from an investment perspective.

Results will guide future timberland investments in the region and guarantee efficient use of resources. The methodology applied relies on geographical information systems, international databases (e.g., Worldclim, SoilGrids, SRTM data), and local information obtained from the main forest products companies currently operating in the region. With additional information provided by the forestry sector at the national level, a broader analysis could be further carried out for the entire country considering other relevant forest species, becoming a valuable tool that could contribute to the current national government plans of commercial forest plantations expansion in Colombia. This analysis can be considered as a baseline analysis based on the current timber market conditions in Colombia. An emerging market where informality tends to be a prevailing feature, and there are not institutions responsible for collecting and analyzing relevant information on timber prices, product specifications, establishment and management costs, and trading volumes.

MATERIALS AND METHODS

Study area

A total of 2.2 million ha have been classified as suitable areas for the establishment of commercial forest plantations in Antioquia (UPRA, 2015). Tracts with at least 2,000 ha within this region were selected as the study area in this research. The size of the selected tracts was consistent with the minimum area required to guarantee profitability for a forest project in Colombia (PROFOR, 2017). Moreover, the optimal altitudinal range for *P. patula*, 2,000-2,800 masl (Perry, 1991) was considered, leading to a study area of 115,655 ha distributed across

27 tracts with an average size of 4,283 ha. The current land use of these tracts is mainly agriculture and livestock, with predominant private ownership. The financial analysis was performed for each of the tracts located in the study area. Six different mills located in the study area are responsible for most of the demand for timber (Figure 1).

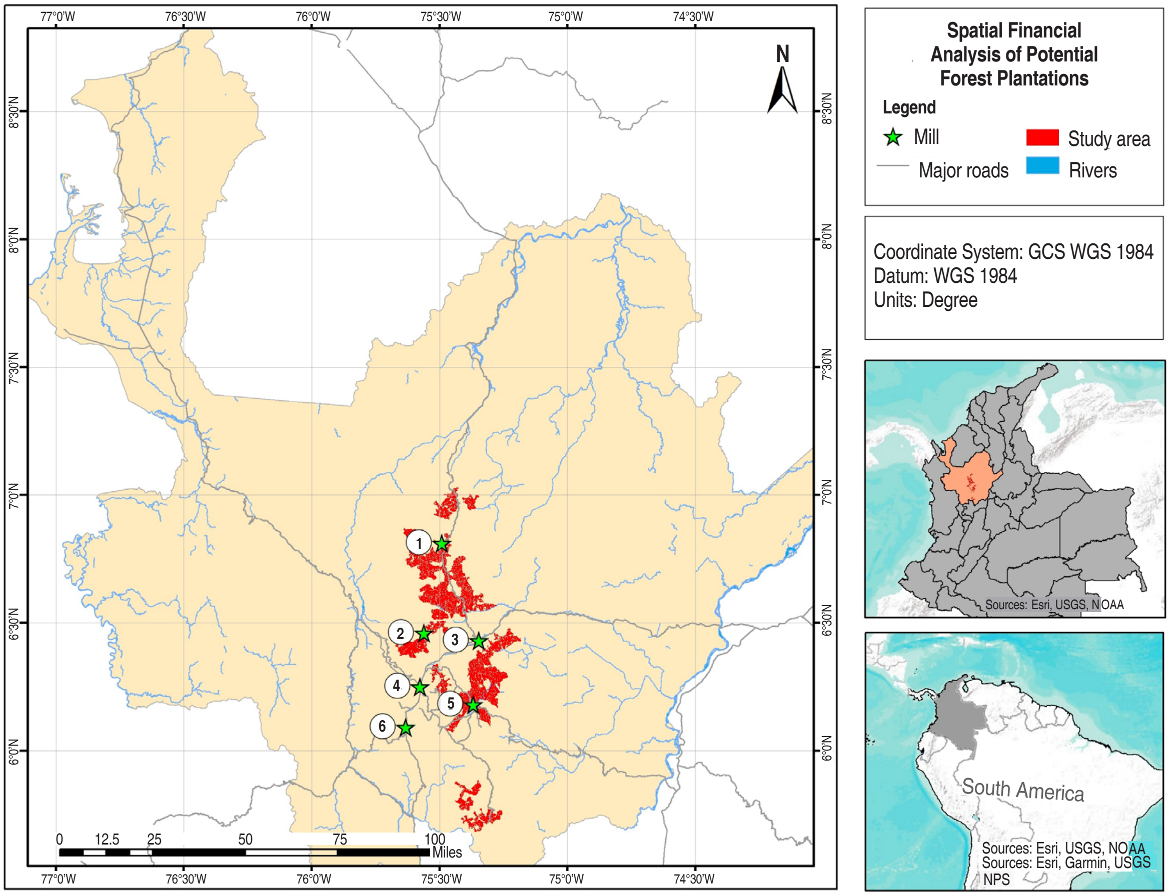

Figure 1. Study area. 1: Cuivá Plains, 2: Northern Plateau, 3: Barbosa, 4: Medellín, 5: Eastern Antioquia, 6: Caldas. Source: own elaboration.

Volume estimation

A yield model fitted by Restrepo *et al.* (2019) was used to estimate forest yield for each tract of land in the study area. In this model, the parameters are expressed as a function of stand density and biophysical variables such as slope, soil pH, mean annual temperature and mean annual precipitation. This stand volume equation is a Bertalanffy-Richards type model that was estimated using 1,119 temporary plots of unthinned, unmanaged, and genetically unimproved *P. patula* plantations in Antioquia, Colombia. Basic silvicultural prescriptions such as fertilization and vegetation control at the establishment were considered. The model can be written as:

$$y = \phi\left[1 - exp(-\beta(Age))\right]^{1/1-\gamma} \tag{1}$$

with:

$$\hat{\phi} = 235.994 - 112.423(pH) + 2.193(S) + 0.176(N) \tag{2}$$

$$\hat{\beta} = -0.123 + 0.545(T_e P_r) \tag{3}$$

$$T_e P_r = \frac{T_e}{P_r} x100 \tag{4}$$

$$\hat{\gamma} = 0.92 \tag{5}$$

Where y is the yield (m^3 ha^{-1}), *Age* is the stand age (years), and ϕ, β, and γ are parameters that denote the asymptote, the intrinsic growth rate, and the shape of the yield curve, respectively. The estimated value for γ does not depend on environmental variables. The parameter ϕ is estimated as a linear function of an intercept, and soil *pH* (a dummy variable that equals one if *pH* is in the range 5.1-6, and zero if *pH* is in the range 4.1-5), slope (*S*, degrees), and stand density (*N*, trees per hectare) (Equation 2). The parameter β was estimated as a linear function of an intercept, and the mean annual temperature (T_e, °C) by the mean annual precipitation (P_r, mm) ratio (T_e P_r) (Brown and Lugo, 1982; Restrepo *et al.*, 2019).

International climate and soil databases available on raster format were the main sources of information for obtaining spatially estimates of ϕ and β. Soil *pH* was obtained from the SoilGrids database, a global compilation of soil profile data layers at 1 km resolution (Hengl *et al.*, 2014). The slope of the terrain was calculated using elevation data from the digital elevation model (DEM) developed by the Shuttle Radar Topography Mission (SRTM), and available at a spatial resolution of 30×30 m (Farr *et al.*, 2008). The mean annual temperature and the annual precipitation were obtained from the Worldclim database, version 2.0, and available at a 1 km resolution (Fick and Hijmans, 2017). Forest yield was estimated using the average value for each biophysical variable and each tract. Merchantable volume was assumed to be 95% of the stand volume, assuming three different products can be obtained from the harvest: roundwood large size, roundwood medium size, and pulpwood.

Stumpage price

The stumpage price can be estimated as the timber price at the mill minus hauling and harvesting costs, using the residual price methodology (Giudice *et al.*, 2012). The equation proposed by Stone (1998), in which the stumpage value is a decreasing linear function of the distance, was adapted in this study to estimate the stumpage price for each tract. All the values were calculated in US dollars (USD) using an exchange rate of 2,854 Colombian pesos (COP) per USD.

Three main timber classes (*k*) were considered: roundwood large size, roundwood medium size, and pulpwood. A blended stumpage price was calculated, corresponding to the average timber price of each product weighted by the proportion of that product in a typical harvest (Table 1).

Table 1. Product class specifications and pricing.

	Specifications	Average proportion per harvest (%)	Average delivered price (USD t^{-1})
Roundwood large size	Diameter >16 cm in the smallest section	58	78.32
Roundwood medium size	Diameter between 11-15 cm in the smallest section, length >6 m	19	72.68
Pulpwood	Diameter >5 cm	23	42.92

The blended stumpage price for each tract in the study area was calculated as follows:

$$\pi_{B_i} = p_B - c - hd_i - f_r \qquad (6)$$

Where π_{B_i} is the blended stumpage price (USD t^{-1}) for the tract *i*, p_B is the blended delivered price (69 USD t^{-1}), c is the harvesting cost at 21 USD t^{-1}, h is the hauling cost at 0.18 USD t^{-1} km^{-1}, d_i is the distance from the tract's nearest existing road to the nearest mill (km), and f_r is the forest road construction cost (diluted to two rotations), obtained as an average cost per ton of wood at 2.2 USD t^{-1}. Harvesting and hauling costs correspond to average harvesting costs (including loading) for the region and include skyline cables and animal-powered logging. The information required for estimating the stumpage price was largely obtained from interviews with professional employees of the main forest products companies located in the study region.

Stumpage price was estimated using the ArcGIS software 10.3. Cost distance analysis was used to determine the transportation cost on existing roads (d_i). This analysis allowed for the identification of the least-cost path for timber transportation, optimizing the use of the existing roads, and minimizing the number of new roads to be constructed.

Financial Analysis

Two financial criteria, the LEV and the IRR, were used to evaluate the potential investments in the area of study. LEV can be defined as the NPV of the cash flow of a timberland investment by assuming infinite rotations, with no changes in economic conditions (Samuelson, 1976; Chang, 1984). The discrete version of LEV was used in this study (Clutter *et al.*, 1983).

$$LEV = \frac{\sum_{j=0}^{t} CF_j (1+i)^{t-j}}{(1+i)^t - 1} \quad (7)$$

Where LEV is the Land Expectation Value (USD ha^{-1}), CF_j is the cash flow after tax (incomes minus costs) at year j (USD ha^{-1}) with a maximum financial horizon time of 20 years, i is the discount rate at 6.8% (Mendell and Sydor, 2006), and t is the rotation age (years). The financial horizon was defined to cover all the expected optimal rotations based on previous research on *P. patula*, suggesting a financial optimal rotation age between 12 and 14 years (Restrepo *et al.*, 2012).

For each tract, an iteration process was implemented to evaluate different rotations (t from 1 to 20) to choose the t that maximizes the LEV, thereby identifying the optimal rotation age (T). The R software version 3.4.4 was used for this analysis (R Core Team, 2018). Likewise, the IRR at T for each tract was estimated with the FinCal package in R (Yanhui, 2016).

Costs in Equation 7 were consolidated as the average establishment and management costs for a typical *P. patula* stand in Antioquia. The cash flow used was consolidated after analyzing and compiling the average costs provided by the main forest products companies. All pre-planting and establishment activities, as well as the technical assistance and insurance, were included. Thinning and pruning were not included. A summary of the costs for the first five years is presented in Table 2. The detailed costs are presented in Appendix 1.

Table 2. Costs of establishment and management for *P.patula* in Antioquia. Source: own elaboration.

Year	Cost (USD ha^{-1} year^{-1})	Activities
0	1,304	Land preparation, vegetation clearing, fertilizer application, planting, phytosanitary control, forest road maintenance, replanting, fire protection.
1	447	Competing vegetation control, fertilization, phytosanitary control, forest road maintenance.
2	415	Competing vegetation control, phytosanitary control, forest road maintenance.
3	194	Competing vegetation control, phytosanitary control, forest road maintenance.
4	62	Phytosanitary control, forest road maintenance.
5	58	Phytosanitary control, forest road maintenance.

Costs and incomes were varied to conduct a sensibility analysis. Factors from 0.7 to 1.3 were applied to both costs and incomes, and the LEV and IRR variations, *ceteris paribus*, were assessed. The 95% prediction interval of the volume estimates is within +/-30% of the mean yield curve (Restrepo *et al.*, 2019). Besides, although the volatility in the timber market in Colombia has not been assessed, other authors have found volatility of ~23% for more mature markets (Restrepo *et al*., 2020). Therefore, variations between +/-30% seemed reasonable for this analysis. Another scenario evaluated was the tax exemption for newly registered forest plantations approved by the Colombian government (Congreso de la República de Colombia, 2016). This tax corresponds to 33%, and that level of exemption may have a substantial effect on the profitability of the investment. All new plantations registered with the environmental authority can apply for this exemption.

Scenarios considering simultaneous changes in costs and incomes were evaluated. A total of 169 scenarios were used to evaluate how sensitive the LEV and IRR were to simultaneous changes in costs and incomes. Factors in the range 0.70-1.30 and increments of 0.05 were applied to costs and incomes, with all possible combinations defining the scenarios.

RESULTS AND DISCUSSION

Estimated potential yields at rotation age were in the range of 183-257 m^3 ha^{-1} (Figure 2), values that correspond to mean annual increments (MAIs) in the range of 9-18 m^3 ha^{-1} $year^{-1}$. The estimated MAI was low compared to other studies (26-30 m^3 ha^{-1} $year^{-1}$) (López *et al*., 2010; Restrepo *et al*., 2012). The model used reflects the potential yield for unmanaged stands, which can explain the lower estimated MAIs. Nevertheless, the model provides a conservative estimate of volume yield compared to that obtained from plantations in Colombia with some genetic improvement and silvicultural treatments such as thinning. This model leads to a conservative financial analysis that can be considered as a reasonable lower bound for any financial decision.

Derived stumpage price varied according to the distance to the mills (Figure 3). Stumpage prices in the tracts located around the Northern Plateau mill were in the range 42-45 USD t^{-1}, whereas for the tracts located around the Cuivá Plains were in the range 35-45 USD t^{-1}. An average stumpage price of 40.4±4.9 USD t^{-1} was estimated for all the tracts in the study area, varying from 29 to 45 USD t^{-1}. This result

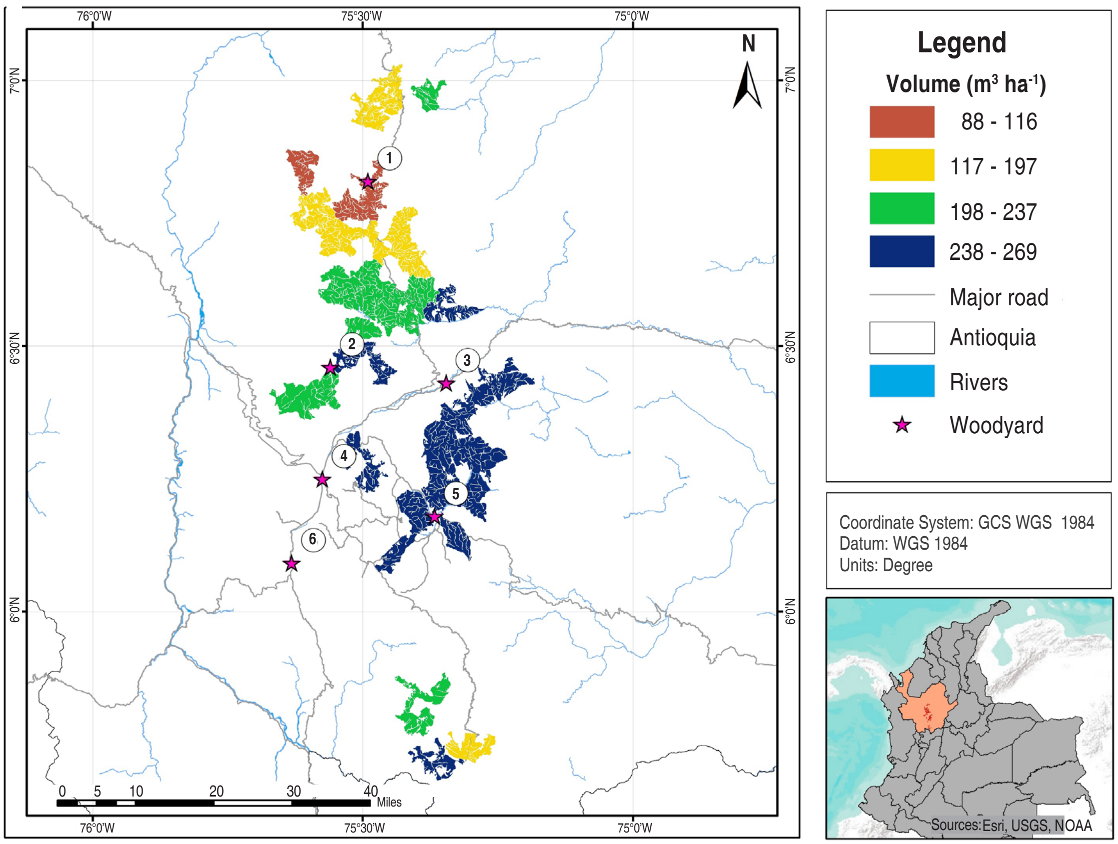

Figure 2. Estimated yield at age 15 years.

was consistent with a 23-42 USD t^{-1} range provided by the main forestry companies operating in the region.

In the Andean region, stumpage prices between 20-53 USD t^{-1} and 53-60 USD t^{-1} have been reported for pulp and sawtimber, respectively, with variations depending on location concerning the woodyard, species, dimensions, and specific conditions of local supply and demand (CIIEN, 2011). The stumpage price found in this study can be considered high compared with stumpage prices in other more mature markets like in the southeast United States, where stumpage prices of 11, 17, and 24 USD t^{-1} are reported for pine pulpwood, chip-n-saw, and sawtimber, respectively (TimberMart-South, 2019). Nevertheless, a lower profit margin can be obtained in Colombia due to the substantially higher transportation costs.

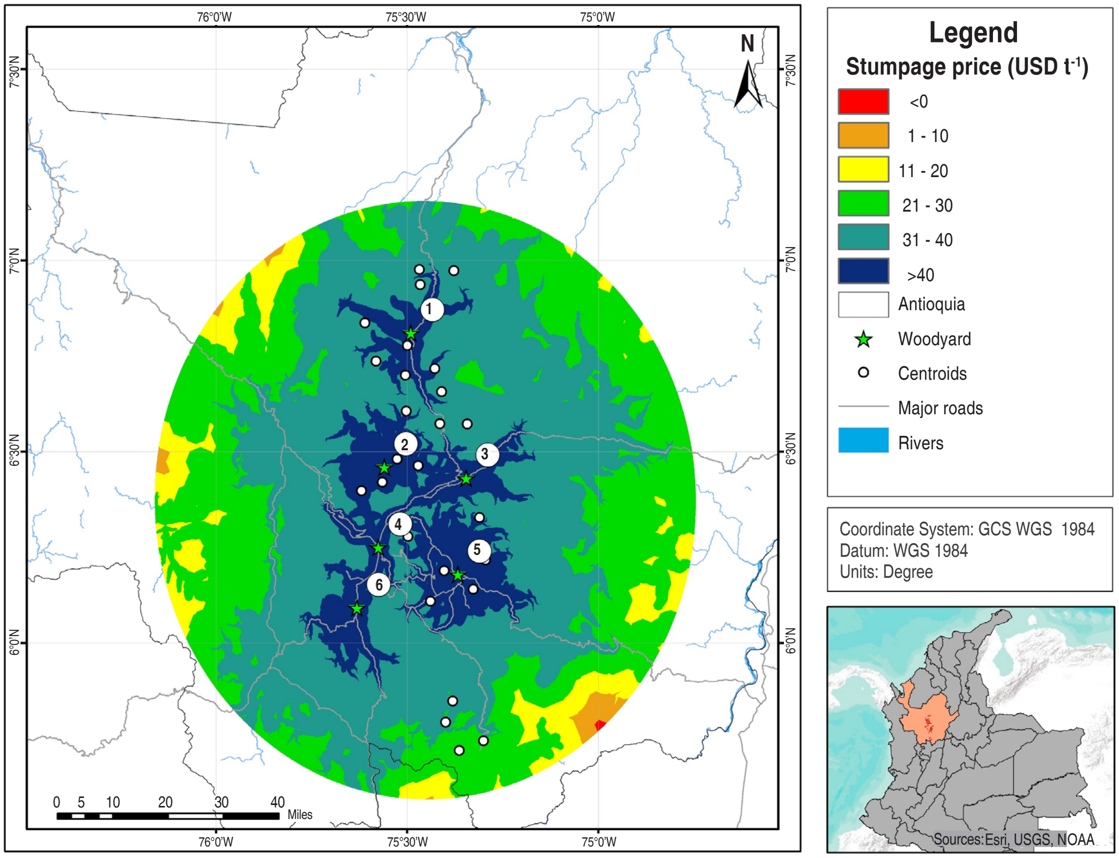

Figure 3. Estimated stumpage price.

Compared to regional markets, it is estimated that for Pinus, the production costs are 40% higher in Colombia than in Brazil (UPRA, 2018a). A high proportion of these costs is attributed to transportation costs, which in Colombia can vary between 12-16 USD t^{-1} (100 km)$^{-1}$ compared to 9 USD t^{-1} (100 km)$^{-1}$, on average, for other countries (UPRA, 2018a). In this study, the average transportation cost was 18 USD t^{-1} (100 km)$^{-1}$. Abrupt topography and a mountainous landscape in the Andean region of Colombia, make the establishment of forest plantations challenging and expensive (Cubbage *et al*., 2010).

Financial analysis

Negative LEVs were found for all the tracts in the study area. This result implies that based on the current costs, timber volumes and timber prices, it is not profitable to establish new forest plantations in the region. An average IRR at 4.1±1.5% was estimated, varying from 1.0 to 6.3%. Although these areas were previously classified as zones with medium/high potential for forest plantations establishment (UPRA, 2015), the stumpage price and distance to the mills had a substantial influence on the LEV, making these areas not suitable from a financial perspective. Similar conclusions were found by CIIEN (2011) for a biomass production feasibility study in Colombia. Although similar competitive stumpage prices were found, it was also concluded that high transportation costs reduced profitability and discouraged tree harvesting.

In the baseline scenario, the IRRs were low compared to the IRR reported by Cubbage *et al.* (2007) and López *et al.* (2010). The observed differences are likely due to the higher MAI and timber prices used in their studies, lower establishment costs, and additional government subsidy. This subsidy was not included in this research since the government has not provided it during the last two years. A summary of the IRRs reported in similar studies and the estimated values in this study are presented in Table 3.

Table 3. Summary of the Internal Rate of Returns (IRRs) reported in this and previous studies.

IRR (%)	Description	Reference
1.0-6.3 (mean 4.1)	MAI: 9-18 $m^3 ha^{-1} year^{-1}$ All tax included	Present study
4.0-10.3 (mean 7.5)	MAI: 9-18 $m^3 ha^{-1} year^{-1}$ Tax exemption included	Present study
7.5-10	*P. patula* plantations in Antioquia, MAI: 20 $m^3 ha^{-1} year^{-1}$, government subsidy included	(López *et al.*, 2010)
10.5-16.9 (mean 14.3)	Pine plantations in South America, MAI: 22-33 $m^3 ha^{-1} year^{-1}$	(Cubbage *et al.*, 2007)
3.9-5.7	*P. patula* plantations in Antioquia, MAI: 7-27 $m^3 ha^{-1} year^{-1}$ All tax included	(Restrepo *et al.*, 2012)
8.3-10.6	*P. patula* plantations in Antioquia, MAI: 7-27 $m^3 ha^{-1} year^{-1}$ Tax exemption included	(Restrepo *et al.*, 2012)
11.2	*P. patula* plantations in Colombia MAI: 19 $m^3 ha^{-1} year^{-1}$ Before taxes rate	(Cubbage *et al.*, 2010)

Sensitivity analysis

The scenarios evaluated showed that positive LEVs in the range of 52–235 USD ha^{-1} would be obtained by either a 10% decrease in costs or a 10% increase in incomes. The results showed that LEV tends to be more sensitive to changes in costs than in incomes. A 10% decrease in the costs would increase the LEV by 53%, whereas a 10% increase in the incomes would increase the LEV by 43%. Moreover, the high variability of the LEV among tracts was also found: LEV increased up to 200% (rising from -217 USD ha^{-1} to 235 USD ha^{-1}) or just 17% (rising from -2,170 USD ha^{-1} to -1,794 USD ha^{-1}). The higher variability was identified in those tracts with a combination of high stumpage price and/or high timber production, whereas smaller changes were identified in tracts with low forest productivity and low stumpage price.

When a 10% decrease in costs or a 10% increase in incomes was simulated, the average IRRs for the tracts with positive revenues were 7.2% and 7.1%, respectively. A 20% cost decrease would increase the IRR to 7.5%, whereas a 20% rise income would increase the IRR to 7.4% for those tracts with positive LEV. The average IRR with a 30% decrease in costs was 8.2%, and with a 30% increase in incomes was 7.9%. Table 4 summarizes the LEVs and IRRs found in all of the evaluated scenarios.

Table 4. Summary of sensitivity analysis[a].

Scenario (ID)			All the polygons		Tracts with positive LEV	
			LEV (USD ha^{-1})	IRR (%)	LEV (USD ha^{-1})	IRR (%)
Baseline scenario			-1,203±611	4.1±1.5	---	---
Cost decrease	(1)	10%	-784±630	4.9±1.6	176±77	7.2±0.2
	(2)	20%	-364±650	5.8±1.7	323±237	7.5±0.6
	(3)	30%	60±670	6.8±1.8	570±352	8.2±0.9
Income increase	(4)	10%	-904±691	4.8±1.6	148±85	7.1±0.2
	(5)	20%	-605±772	5.5±1.7	300±238	7.4±0.5
	(6)	30%	-304±853	6.1±1.7	598±310	7.9±0.6
Tax exemption	(7)		454±1,009	7.5±1.8	1,037±637	8.6±1.1

[a]The interval presented corresponds to one standard deviation.

Under the income tax exemption scenario, the LEV was positive for most of the tracts. For these tracts, the average LEV was 1,037 USD ha^{-1} (Figure 4). In this scenario, IRRs increased up to 10.3%. An average increase in 3.4% of the IRR was obtained in this study beacuse of the income tax exemption. Other studies carried out in South America indicated that government subsidies boost timber investments, increasing the rate of return by 2-3% (Cubbage *et al.*, 2007; Bussoni and Cabris, 2010). Well-designed carbon sequestration payment schemes may generate a similar effect.

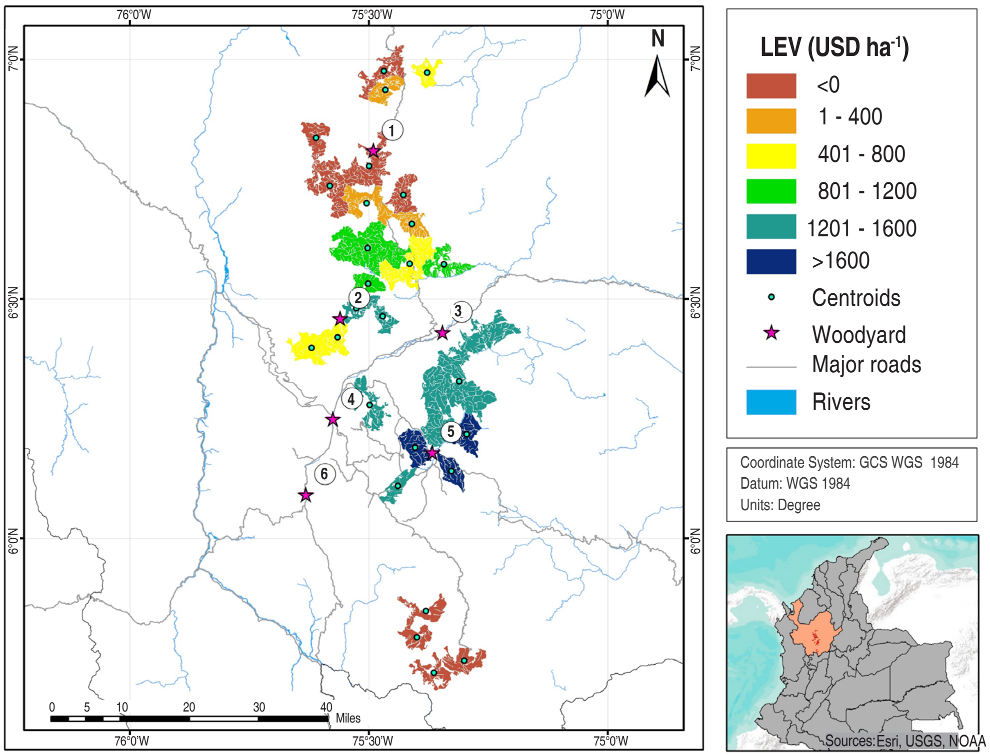

Figure 4. Spatial distribution of the LEV with tax exemption.

Cubbage *et al.* (2007) reported higher average IRRs for pine plantations in South America (10.5-16.9%), a value higher than that reported by López *et al.* (2010) and the value found in this study. Nonetheless, these authors recognize the use of MAIs higher than those reported in the literature, which may lead to higher IRRs. In the present study, similar IRRs (~13%) were obtained after the inclusion of both the tax income exemption and a 25% cost reduction. Restrepo *et al.* (2012) evaluated the profitability of *P. patula* plantations in Antioquia and reported an IRR consistent with the results of this study in the range of 3.9-5.7%. Table 5 shows the average LEV obtained per woodyard with the income tax exemption compared to the baseline scenario. The higher financial returns were obtained for the tracts spatially linked to the woodyard in Eastern Antioquia, a region exhibiting the highest forest productivity. Tracts in the Northern Plateau had the second-highest financial returns, as a result of higher stumpage prices.

Table 5. Average Land Expectation Value (LEV) and Internal Rate of Return (IRR) for each mill.

Mill[a]	Yield[b] (m^3 ha^{-1})	Stumpage price (USD t^{-1})	Baseline scenario		Tax exemption[c]		Rotation Age
			LEV (USD ha^{-1})	IRR (%)	LEV (USD ha^{-1})	IRR (%)	
Cuivá Plains	220	42	-1,551±395	3.3±1.0	385±421	7.5±0.7	15
Northern Plateau	231	43	-885±237	4.9±0.5	979±385	8.5±0.6	16
Barbosa	234	40	-1,089	4.4	656	7.9	17
Eastern Antioquia	236	38	-976±819	4.5±2.1	1,703±311	9.7±0.5	14
Caldas	243	32	-1,790	2.6	---	---	15

[a] It was found through the cost distance analysis that mill 4 (Medellín) would not be a profitable option for transporting the timber products. Therefore, it was excluded in the summary of the results.
[b] At the rotation age.
[c] Only those tracts with positive LEV were included for the average.

Figure 5 shows how IRR is affected by timber production and the distance to the mills. If income tax exemption is considered, the IRR exceeded the discount rate in 18 (67%) of the tracts (positive LEVs were obtained). All these tracts were located within 45 km from a mill. Values between 27 and 71 km have been reported as maximum distance to the mill for ensuring profitability in Colombia (CIIEN, 2011). Nevertheless, not all the tracts situated within 45 km from a mill surpassed the discount rate used in the financial analysis. Forest productivity also had an important influence on the returns. For this species and region, a volume higher than 237 m^3 ha^{-1} (average MAI of 16 m^3 ha^{-1} $year^{-1}$) would guarantee an IRR higher than 6.8% if income tax exemption were considered. However, this is not a static result. Higher distances to the mills can be compensated by higher productivity, as well as lower productivity can be compensated by a shorter distance to the mills. Figure 6 shows similar relationships for the LEV.

Small variations in the optimal rotation age were observed as a result of changes in costs and incomes. The optimal rotation varied from 13 to 15 years for scenarios 1 to 6 in Table 4. By considering the income tax exemption (scenario 7 in Table 4), a higher variation was observed, the optimal rotation age was in the range 13-17 years with an average of 15 years.

Sensitivity analysis – Simultaneous changes

The analysis of scenarios due to multiple changes in costs and incomes suggests that either a 5% reduction in costs or a 10% increase in incomes is required to obtain positive LEVs when simultaneous variations are considered as alternative scenarios. Nevertheless, a positive LEV was obtained for only 1 out of the 27 tracts of the study area when considering the 5% reduction in costs, and when a reduction of the 10% in costs was simulated, three tracts with a positive LEVs were obtained. A reduction of 15% in costs would be required to achieve higher LEVs up to 462 USD ha^{-1}, whereas a 15% increase in incomes would generate LEVs up to 429 USD ha^{-1}. This is a reasonable price to be paid for land in the region, where forest lands are considered marginal after long-term use in agriculture or livestock.

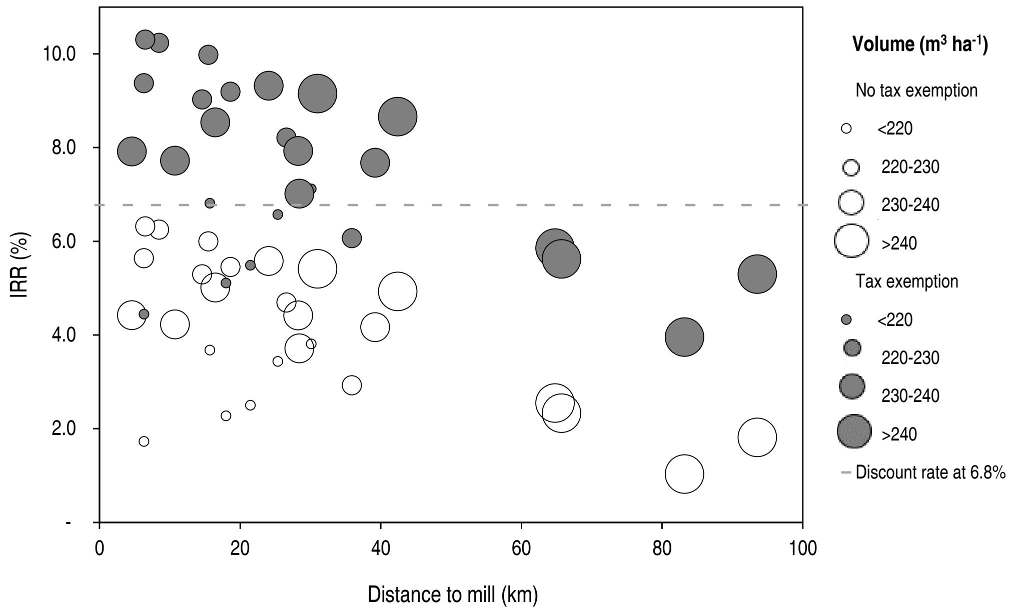

Figure 5. Relationship between the distance to the mill, volume and Internal Rate of Return (IRR).

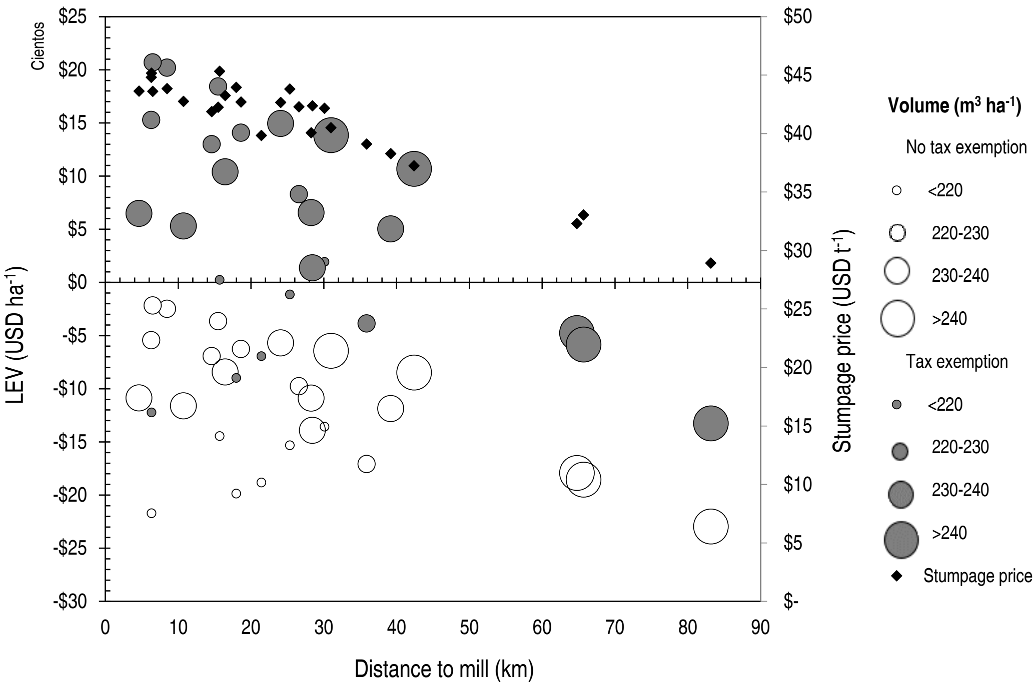

Figure 6. Relationship between the distance to the mill, volume, stumpage price, and Land Expectation Value (LEV).

New scenarios were evaluated considering the income tax exemption (33%) and simultaneous changes in costs and incomes. It was found that in the Northern Plateau, Barbosa, and Eastern Antioquia, average positive LEVs can be obtained without a decrease in costs or an increase in incomes. Tracts located around Northern Plateau and Barbosa can be classified as the most suitable areas for establishing new forest plantations in the region. The

Eastern Antioquia is also a promising geographical area in terms of the average LEV. However, higher variability of the LEV was observed in this region.

In all of the evaluated scenarios, the LEV was more sensitive to changes in costs than incomes (represented either on a stumpage price or a volume increase). The original theoretical representation of the LEV (Amacher *et al*., 2009), can be used to explain why changes in costs affect the LEV to a greater extent than changes in incomes:

$$LEV_0=\frac{PVe^{-rt}-C}{1-e^{-rt}} \tag{8}$$

Where LEV_0 is the LEV without modification in cost or income, P is the timber price, V is the total stand volume (yield), r is the continuously compounded return rate, t is the rotation age, and C is the costs of establishment and management (lump-sum). If the income is increased by a factor of α, LEV can be written as:

$$LEV_1=\frac{\alpha PVe^{-rt}-C}{1-e^{-rt}}, \tag{9}$$

The relative change of the LEV (Δ_p), expressed as Equation 9 minus Equation 8, and expressed in relative terms of Equation 8, can be written as:

$$\Delta_p=\frac{(LEV_0-LEV_1)}{LEV_0}=\frac{PV(1-\alpha)}{\boldsymbol{PV-Ce^{rt}}} \tag{10}$$

If we define $LEV_2=\frac{PVe^{-rt}-\alpha C}{1-e^{-rt}}$, and calculate a similar relative change for the costs (Δ_c), the following expression is obtained:

$$\Delta_p=\frac{(LEV_0-LEV_2)}{LEV_0}=\frac{Ce^{rt}(1-\alpha)}{\boldsymbol{PV-Ce^{rt}}} \tag{11}$$

The term (1-α)/(**PV-C*e*^{rt}**) appears in Equations 10 and 11, therefore, the potential effect of changes in costs or incomes is determined by analyzing how different PV and Ce^{rt} are. If these factors were estimated for the tracts in the study area at the rotation age (which implies the estimation of the future value of all the costs, C), costs are lower than the present value of the incomes. Nevertheless, the factor PV is less than 1.5 C and given that the factor e^{rt} varies in the range 2.4-3.8, for the rate of return (r=6.8%) and the optimal rotation age (t=T) found in this study (13–15 years), the factor Ce^{rt} will be always higher than the factor PV. Therefore, it can be concluded that variations in costs (Δ_c) have a bigger influence on the LEV than variations in incomes (Δ_p).

This lower rotation age (13-15 years) was found to be the main cause of the differential effects of variations in costs and incomes on the LEV. These values are nonetheless consistent with the optimal rotation age found by Restrepo *et al.* (2012) for *P. patula* in Colombia, varying from 12 to 14 years.

Equations 10 and 11 can also be used to explain how changes in the costs or incomes can differently affect the LEV in the study area. From these equations, it can be seen that Δ_p and Δ_c are a function of P, V, C and t. For simplicity, if it is assumed that the factor PV is constant, Δ_p will be a function with a vertical asymptote at $t_\alpha=ln\left(\frac{PV}{C}\right)\times\frac{1}{r}$. It was found that Δ_p will differ for each rotation age according to its location relative to the asymptote t_α. If $t>t_\alpha$, Δ_p decreases exponentially as t increases. If $t<t_\alpha$, Δ_p increases exponentially as t increases. As explained before, the relation PV/C is lower than 1.5 for all the tracts, leading to values for t_α lower than 6. Since $t>t_\alpha$ (t is between 13-15 and t_α is <6), the magnitude of Δ_p decreases as the rotation age increases.

Figure 7 indicates that tracts with higher optimal rotation age(i.e., tracts with lower incomes due to the low productivity, lower stumpage price, or a combination of both), are less sensitive to changes in incomes (lower Δ_p). On the contrary, those tracts with higher incomes (lower rotation age), are more sensitive to changes in the incomes (higher Δ_p). Considering a non-constant increasing factor PV would lead to increases in Δ_p. Figure 7 shows both the effect of the rotation age and the factor PV on the LEV change after applying a 1.1 factor increase in incomes. The same conclusion can be drawn for changes in costs. Similar asymmetry in the LEV was observed by Restrepo and Orrego (2015) for teak plantations in Colombia. The confidence interval estimated for the LEV in their study was considerably wider when lower rotation ages were considered. The

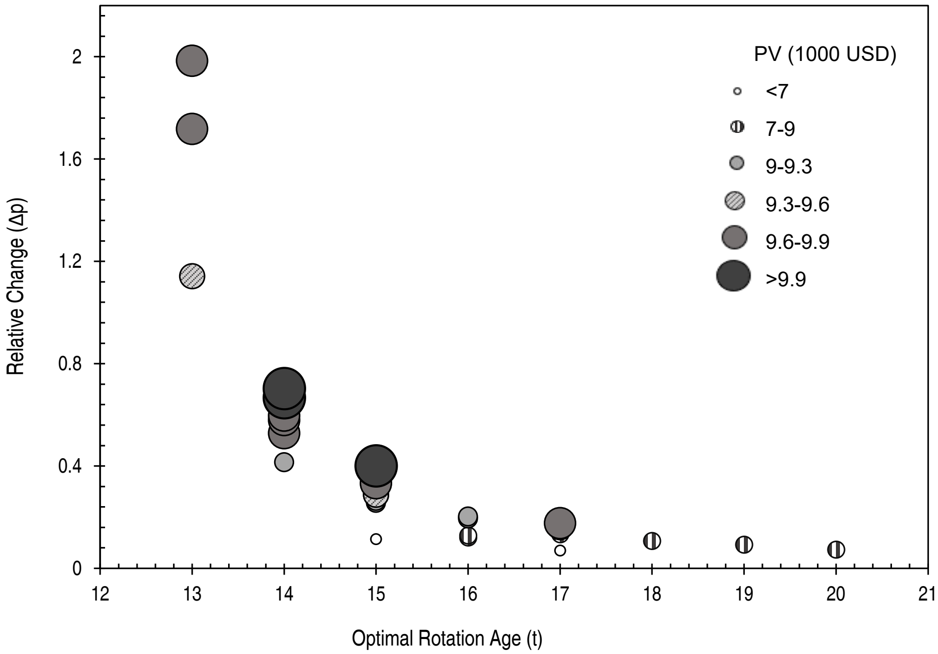

Figure 7. Effect of the optimal rotation age and income factor (PV) on relative change in incomes (Δ_p)

previous analysis showed that from an investment perspective, it is crucial to determine how sensitive the investment is to possible changes in factors such as the establishment costs, timber price, and volume. In general, for highly productive sites, it is more critical to determine the variations accurately in incomes and costs since this potential variability will have substantial effects on the profitability of the timberland investment. For those sites with either low productivity or low timber prices, the analysis of variations in incomes and costs are not expected to be relevant compared to more productive sites.

According to the results from this research, the priority areas for the establishment of new *P. patula* commercial plantations are located around the Northern Plateau and the Eastern Antioquia. Nonetheless, other factors can influence the decision to establish new forest plantations, such as the opportunity cost of the land reflected in the land price. According to Niskanen (1998), and from an economic perspective, forest plantations should be established on sites with a low opportunity cost since higher yield rates might not compensate for the increase of the opportunity cost of more productive land. This is relevant for the area around Eastern Antioquia, where urban development and physical expansion of the city of Medellín are already occurring (López *et al*., 2010).

CONCLUSIONS

Site selection studies for establishing new commercial plantations should integrate both biophysical and financial analyses. Biophysical analyses are critical to identifying the spatial variability of the local productivity, but instead of being the final decision criterion, these studies are the starting point to perform a comprehensive analysis that includes financial analysis. This analysis allows for the identification of profit variability as well as the assessment of the critical factors that affect income, and ultimately influence the site selection from an investor perspective.

It was found for *P. patula* in Antioquia that under the current conditions of costs, productivity, and stumpage price, a positive LEV cannot be obtained unless government subsidies are provided. An MAI higher than 16 m^3 ha^{-1} $year^{-1}$, a distance less than 45 km to the mill, and a stumpage price higher than 35 USD t^{-1}, seem to be critical determinants for a profitable timberland investment. A government incentive, in the form of the income tax exemption, was found to be critical for the profitability of potential timberland investments. Without this subsidy, a reduction of 20% in costs or an increase in productivity of the same proportion, would be required to obtain IRRs higher than a discount rate of 6.8%.

The sensitivity analysis suggests that a reduction in costs has a higher effect on profitability than an equivalent increase in incomes. A significant proportion of these costs originates from transportation due to the topographical characteristic of mountainous regions of Antioquia, where the government poorly maintains roads. An alternative will be to promote scale economies by consolidating the entire study area as a cluster, with a potential annual production of ~1,773,376 m^3 of roundwood. Another alternative will be to increase incomes through silvicultural activities, which can lead to a higher proportion of roundwood large size timber (higher stumpage price). Activities such as fertilization, vegetation control, and thinning are proposed to increase both round wood size and quality. Nevertheless, individual cost analyses should be done to evaluate the trade-off between costs and corresponding incomes. Having an integrated industry that elaborates the end-user product such as laminated boards or paperboard products (as it is the case of the two biggest forest products companies in Colombia), can also increase the profitability by increasing incomes and reducing unitary costs.

The methodology applied allowed for the estimation of the spatial variability of potential profits of *P. patula* in Antioquia. Relatively little information was required to generate the stumpage price map and the volume estimation. The availability of growth models using environmental covariates, along with additional information about transportation costs and timber price, would allow for the replication of this analysis on a broader scale and for different species, which would serve as a guide for future timberland investments in Colombia.

Uncertainty was included through the sensitivity analysis applied to variations in costs and incomes. Long-term time series of the economic variables such as discount rate, timber price, and transportation costs, would be required to complement our risk analysis. Dynamic studies that consider a spatial and temporal variation of these variables are also suggested. Nonetheless, this information is not currently available in Colombia since data associated with commercial forest operation is scarce and collected informally.

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Appendix 1.

Table A1. Detailed costs used in the financial analysis. all the values are in USD ha^{-1}.

	Consumables	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
			Direct Cost				
Workforce	Land preparation	92.0	0.0	0.0	0.0	0.0	0.0
	Marking	73.6	0.0	0.0	0.0	0.0	0.0
	Hole digging	183.9	0.0	0.0	0.0	0.0	0.0
	Seedlings transportation	18.4	0.0	0.0	0.0	0.0	0.0
	Planting	73.6	0.0	0.0	0.0	0.0	0.0
	phytosanitary control	9.2	18.4	18.4	18.4	18.4	18.4
	Fertilizers applications	55.2	64.4	0.0	0.0	0.0	0.0
	Replanting	36.8	0.0	0.0	0.0	0.0	0.0
	Vegetation clearing	183.9	183.9	183.9	92.0	0.0	0.0
	Forest roads maintenance	9.2	9.2	9.2	9.2	9.2	9.2
	Fire protection	92.0	0.0	0.0	0.0	0.0	0.0
	SUBTOTAL	827.7	275.9	211.5	119.5	27.6	27.6
Supplies	Seedlings	187.2	0.0	0.0	0.0	0.0	0.0
	NPK fertilizer	50.3	61.9	82.5	0.0	0.0	0.0
	Ant control	3.0	3.0	3.0	3.0	3.0	0.0
	Borax	11.6	0.0	14.2	0.0	0.0	0.0
	Animal feeding	2.1	0.0	0.0	0.0	0.0	0.0
	SUBTOTAL	254.1	64.9	99.7	3.0	3.0	0.0
	TOTAL	1,081.8	340.8	311.2	122.6	30.6	27.6
			Indirect Costs				
	PPE	41.4	13.8	10.6	6.0	1.4	1.4
	Supplies transport	38.1	9.7	15.0	0.5	0.5	0.0
	Technical assistance	54.0	54.0	54.0	54.0	27.0	27.0
	TOTAL	133.5	77.5	79.5	60.4	28.8	28.4
	TOTAL COSTS	1,215.2	418.3	390.7	183.0	59.4	55.9
			Expenses				
	Administration fees	89.1	28.6	24.8	10.9	2.7	2.5
	TOTAL EXPENSES	89.1	28.6	24.8	10.9	2.7	2.5
	TOTAL COSTS+EXPENSES	1,307.1	446.9	415.5	193.9	62.0	58.4