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Minimum required rotation age for get profit in small-scale forest plantations of *Schizolobium parahyba*

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Abstract

Encouraged by international co-operations and private investment firms, farmers in the Bolivian lowland are incorporating small-scale forest plantations their productive system, for income generation from timber. *Schizolobium parahyba*, *Eucalyptus* spp. and recently *Tectona grandis* are mainly used because of their fast growth and potential to produce benefits within a short time horizon. However, issues such as economic return, market access, timing of thinning and productivity are still unknown. This study's objectives are to discuss the economic fundamentals of plantation forestry with *S. parahyba*, using the land expectation value (LEV) (Faustmann formula). Growing functions are calculated using data from permanent plots established by the Agricultural Tropical Research Centre (CIAT). It considers sales at local market conditions. Optimal biological, optimal economic and minimum economic rotations are estimated. In addition, a sensitivity analysis with varying discount rate and stumpage price is made. The analysis demonstrate that the optimal biological, optimal economic and minimum economic rotation ages are 38, 23 and 13 years, respectively, but the last one could diminish to 6 years if the market accepted logs of smaller diameter. Increasing capital costs reduce the LEV value logarithmically, and increases in timber price shift up the LEV and reduce the rotation age.

Key words: Bolivia, *Schizolobium parahyba*, small-scale forest plantations, maximising profit, minimum rotations.

Introduction

In the lowlands of Bolivia, in the regions of Santa Cruz and Cochabamba, small and medium-scale farmers have begun to invest in forest plantations in small areas. Some of them are doing it with external support and others by own effort. Little is known about yield, price and markets for wood from plantations in Bolivia, however, the investors are hoping for good profit. The most used species is *Schizolobium parahyba*, because of its fast growth. Currently, the local industry is utilising this species from the natural forest to make veneer. Timber of *S. parahyba* from forest plantations has not yet been sold.

S. parahyba is a typical light demanding pioneer species which invades gaps in the natural forest. It belongs to the *Caesalpinaceae* family and has two subspecies (*S. var. amazonicum* and *var. parahyba*). It is native to America and has a distribution range from Brazil to Mexico, being most abundant in the Amazon. In Bolivia this species is found in the departments of Santa Cruz, Cochabamba, La Paz, Beni and Pando, in areas with precipitation of up to 1000 mm. per year. *S. parahyba* reaches between 25 to 40 m in height and has a cylindrical and well formed stem of almost 100 cm of diameter at the breast height (DBH) (Justiniano et al., 2001). Maldonado and Escobar (2000) reported that in Colombia *S. parahyba* can reach 46 m in height and 80 cm DBH, and Justiniano et al. (2001) have estimated its life cycle to be 60 years.

The current forest plantations in the lowland of Bolivia are being established by small-scale farmers and by citizens who see an interesting alternative of investment. International co-operations and private investment firms are encouraged to do that. In the colonized areas, where the plantations are mostly located, the plot sizes are typically 20 ha.

On the plots approximately 5 ha is destined to agricultural uses, 5 ha to cattle and the remaining 10 ha is left for future use.

The objectives of this study are: a) to calculate the optimal biological, optimal economic and minimum economic rotation age for *S. parahyba*, and b) to build a matrix for decision making when choosing a rotation age, taking into account the discount rate and stumpage price. The study area is classified as subtropical region, with rainfall between 1420 to 2800 mm/year and 23 to 24°C of temperature (Aguirre, 2002).

Methodology

Grow function

The growth data for *S. parahyba* in forest plantations of 1 – 25 years of age (Table 1) were collected by the Agricultural Tropical Research Centre (CIAT) in Santa Cruz, Bolivia (Aguirre, 2002). Data on *S. parahyba* growth in natural forests were obtained from Justiniano et al. (2001) and Maldonado and Escobar (2000), in order to build growth functions for the complete estimated life cycle. Data were plotted to find regression equations between age and diameter, and between age and height.

Table 1: Growth data of *Schizolobium parahyba* in Santa Cruz, Bolivia¹

No	Age (years)	DBH (cm)	Height (m)	No	Age (years)	DBH (cm)	Height (m)	No	Age (years)	DBH (cm)	Height (m)
1	0.1	0.0	0.9	14	3.6	12.6	10.3	27	5.5	24.3	15.8
2	1.0	9.1	6.9	15	3.7	14.4	21.3	28	5.7	19.0	10.9
3	1.2	6.0	4.4	16	3.8	15.8	10.6	29	6.7	24.9	14.8
4	1.2	10.2	8.0	17	3.8	14.0	11.8	30	6.8	26.3	20.2
5	1.6	5.3	4.3	18	4.4	17.1	11.7	31	6.9	22.6	15.2
6	1.9	9.0	6.3	19	4.4	17.7	10.8	32	7.3	23.5	17.4
7	1.9	10.6	8.0	20	4.8	15.5	13.6	33	8.0	27.2	20.4
8	1.9	10.8	9.0	21	4.8	16.7	14.9	34	8.7	25.5	20.3
9	2.0	12.3	11.3	22	4.9	14.8	12.5	35	9.9	26.8	19.5
10	2.0	8.4	6.5	23	4.9	15.3	13.0	36	24.8	70.3	28.0
11	2.1	14.4	13.6	24	5.0	18.5	13.5	37*	50.0	80.0	35.0
12	2.3	12.8	12.8	25	5.1	13.5	10.6	38**	60.0	100.0	40.0
13	3.3	12.0	12.3	26	5.4	19.2	16.2				

Source: Aguirre (2002)

DBH: Diameter at breast height

Later the expected diameter and height are calculated for up to 50 years rotation age. The volume was estimated using the Schumacher and Hall model (Eq. 1) cited by Ruiz (2003) and a theoretical model representing grow of an individual tree was found. The mean annual increment (MAI) was estimated through dividing the volume of a tree with the stand age (Eq. 2). The current annual increment (CAI) was estimated by subtracting the volume of the previous year (Vt-1) from the volume in year t (Vt) (Evans and Turnbull, 2004) (Eq. 3).

¹ Data for no. 1 to 36 were taken from permanent samples plots (Aguirre, 2002), data for no. 37 and 38 are theoretical data based on observation in natural forest (Maldonado and Escobar, 2000; Justiniano et al. 2001).

(1) $V = \frac{\pi}{4} D^2 * H * Ff$ Where:
V = stumpage in m³/tree
D = diameter at breast height in cm
H = commercial height in m (assuming 50 % of total height)
Ff = form factor (0.65)

(2) $CAI = V_t - V_{t-1}$ V_t = volume in m³/ha in year t;
V_{t-1} = the volume in the previous year

(3) $MAI = \frac{V_t}{A_t}$ A_t = the age of the stand in year t

Optimal biological rotation

The largest increment in the volume of the tree occurs when the CAI falls to the MAI level, therefore the point of intersection between both curves, where the MAI equals the CAI, is the optimal biological rotation age. After this point the MAI starts to decrease gradually (Evans and Turnbull, 2003).

Optimal economic rotation

Cash flow was calculated for the regular activities carried out in plantations, like soil preparation, fence, seedlings establishment, weeding, pruning and thinning. It was assumed that the land is bare and that there are no harvesting costs because the timber is sold as standing trees. The costs were adapted from Ruiz (2003), AD/BOL/97/C23 (2004) and from the author's experience (Table 2). The land value is not taken in account. The current timber price of *S. parahyba* at the local market is USD 12/m³ stumpage value, found through direct information. At the same time it was assumed that there are no incomes from early thinning because the wood is not good for firewood and is only used for plywood. The minimum diameter accepted by the buyers in the standing trees is above 40 cm DBH, so this is the minimum commercial diameter assumed. Normally, the plantation owner sells the standing trees to middleman, who cut the stand and transport the logs to sawmills.

Table 2: Estimated cost of establishment and maintenance of a forest plantation (USD/ha)

Tasks	Years					total
	0	1	2	3	8	
Establishment (seedlings, transport, soil preparation and plantation. Initial density of 1111 trees/ha (USD/ha)	556					
Clearing (3 times per year) (USD/ha)		51	51	51		
Pruning (USD/ha)			8	8		
Thinnings, leaving a final density of 277 trees/ha (USD/ha)				30	175	
Total (USD/ha)	556	51	59	89	175	950

(Costs are in constant collars at 2006)

The management regime assumed is an initial density of 1111 trees/ha, two thinning to get a final density of 277 trees/ha, and pruning and clearing in the three firsts years (Aguirre, 2002).

The model used to estimate the profitability of the plantations was the Land Expectation Value (LEV), based on the Faustmann formula. Klemperer (2003) explains that this formula is used for calculating the present value of a stand assuming infinite rotations, giving a value that represents the maximum that an investor her is willing to pay for bare land (WPL_{∞}) to use it for forest plantations indefinitely, earning at least a minimum acceptable return rate (MAR) over the invested capital. Therefore, a reforestation project would be acceptable if the WPL is greater or equal to the land price. In this model the land is the only asset (Navarro, 2006). The optimal economic rotation was found by identifying the year in which the stand reaches the highest WPL_{∞} value.

$$(4) \quad WPL_{\infty} = \frac{\sum_{t=0}^n \frac{R_t}{(1+r)^t} - \sum_{t=0}^n \frac{C_t}{(1+r)^t}}{1 - (1+r)^{-n}}$$

Where:
 R_t = income from timber sold in year t
 $1/(1+r)^t$ = the discount factor ($r = \text{MAR} = 6\%$)
 C_t = the costs in year t
 $1/1-(1+r)^{-n}$ = the perpetuity factor ($n = \text{rotation}$)

Minimum economic rotation

The minimum economic rotation age corresponds to the year when the trees reach the minimum trade diameter and the WPL_{∞} value is positive. This can be interpreted as the minimum period required for obtaining profit.

Sensitivity analysis

New WPL_{∞} values are found by applying variations in the discount rate and in the timber price, in order to evaluate the influence of this variation on the optimal and minimum economic rotation age.

Matrix for decision making in the short run

In a scenario where small-scale plantations are established by farmers in poor rural areas it is necessary to use the following assumptions:

Assumption 1: A small-scale farmer, whose livelihood depends on his annual production, cannot wait too long for harvesting the timber, even though the optimal rotation length will be longer. It means that the producer is going to sell the trees when they reach the minimum trade diameter.

Assumption 2: The timber is going to be sold as stumpage to local buyers.

A factorial interaction was made with the following variables: stumpage price, discount rate and short rotations. It was assumed that the farmer already owns the land and that he will carry out plantations in perpetuity, so the land cost was not taken in account. The mathematical model was:

$$(5) \quad C = r * p * t$$

Where:
 C = possible combinations
 r = discount rate (3%, 6%, 9% and 12%)
 p = stumpage price in USD/m³ (9, 12, 15, 18)
 t = rotation length in years (13 to 23)

Values of WPL_{∞} for all possible combinations were calculated to generate a matrix for decision making. Also, the equivalent annual annuity (EAA) was calculated in order to compare the investment in plantations with other land uses (Klemperer, 2003).

$$(6) \quad EAA = NPV \frac{r}{1 - (1+r)^{-t}} = WPL_{\infty} * r$$

Where: EAA is Equivalent Annual Annuity;
 WPL_{∞} is willingness to pay for land;
 r is the discount rate and t is the rotation age

Results and discussion

Optimal biological rotation

The best fit between diameter at breast high (DBH) and age was obtained with a third degree polynomial (Equation 7, Fig. 1). The curve representing the relationship between height and age (Equation 8) is based on a logarithmic model (Vera and Poulin, 1994). Equations 7 and 8 allow us to develop the theoretical growth model for *S. parahyba* (Equation 9, Fig. 2) as a function of age.

- (7) $D = 0.0001A^3 - 0.0447A^2 + 3.7923A$ Where:
 $R^2 = 0.9637$ D = diameter in cm; A = age in years, and 0.0001; 0.0447; 3.7923 are parameters
- (8) $H = 6.3104 \ln A + 5.1821$ H = height in m; A = age in years, and 6.3104; 5.1821 are parameters
- (9) $V = 0.00008A^3 + 0.0066A^2 + 0.0078A$ V = volume in m³/tree; A = age in years, and 8E-05; 0.0066; 0.0078 are parameters
 $R^2 = 0.9992$

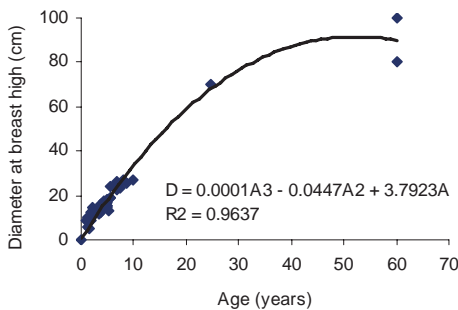


Figure. 1: Diameter (DBH) growth curve

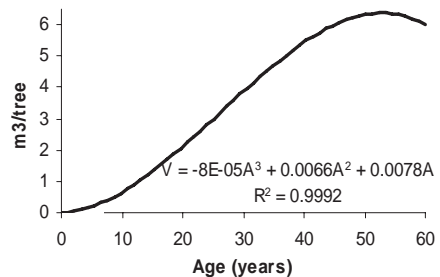


Figure. 2: Volume growth curve for an individual tree

The results from the calculation of the volume of an individual tree allowed a graphical intersection analysis between the MAI curve and the CAI curve. The intersection occurs when the tree reaches its maximum volume increment at 38 years of age (Fig. 3), thereafter it starts to decline. In Table 3 it can be seen that, the value of the MAI reaches 37.87 m³/ha at that age. Thereby, from a productivity point of view, the best moment to harvest the timber is at 38 years of age.

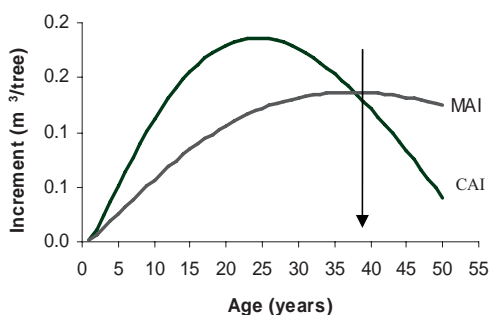


Figure. 3: Optimum biological rotation of *S. Parahyba*

Optimal and minimum economic rotations

Table 3 contains all data required for the calculation of different variables. Data in columns 2, 3 and 4 were calculated with equations 7, 8 and 1, respectively. Data in column 5 are the density of plantation assumed (starting with 1111, first thinning in year 3 and a second thinning in year 8, leaving a final density of 277 trees/ha). Column 6 contains volume/ha (column 4 times column 5). Data in columns 7 and 8 were calculated with equations 2 and 3, respectively. Column 9 contains the costs of establishment and maintenance (Table 2). Data in column 10 correspond to compound future value of the investment with 6 % rate of discount. Column 11 contains the revenue for timber sale at USD 12/m³. Column 12 corresponds to the net income (column 11 minus column 10). Column 13 contains the willingness to pay for land value (WPL_{∞}) assuming reforestation in perpetuity, and Column 14 shows the internal rate of return (IRR).

It can be seen in Table 3 that the WPL_{∞} is negative at year 5 (-USD 2973/ha), and shifts to positive in year 6 (USD 454/ha), reaching its maximum value (USD 1988/ha) at year 23. Hereafter the WPL_{∞} begins to decrease. In the year 38 the WPL_{∞} is only USD 1151/ha.

Four points can be highlighted in Table 3:

In year 6, as long as there are buyers for trees of 20 cm DBH (column 2), the investors can recover their money and earn something additional at 9.20 % of internal rate of return (column 14). Notice that the WPL_{∞} has the lowest positive value (column 13). Notice also that in the local market buyers don't accept trees below 40 cm of diameter², so this is an unrealistic return because there is no real market.

In year 13 the stand reaches the minimum commercial DBH (column 2) of 40 cm and therefore the investors get the real net income of USD 1356/ha (column 12) and with 11.13 % IRR. This is called the "minimum economic rotation".

In year 23 the stand reaches the maximum value in terms of WPL_{∞} (USD 1988/ha) although the IRR is lower. At the same time, the investors get a net income of USD 5604/ha. This is the best year to cut the trees and restart the rotation. Therefore 23 years is the optimum economic rotation. Harvesting after, or before, year 23 gives lower income.

In year 38 the stand reaches the maximum growth rate (MAI of 0.1367 m³/tree). From a production point of view this is the best year to cut the trees, however, the WPL_{∞} (USD 1151/ha) is lower than in year 23. Also the IRR is lower (8.29 %), even though in terms of

² Personal communication with buyers in Bolivia

net income it seems be better because it reaches a higher value (USD 9385/ha), but from an economic point of view keeping the investment beyond year 23 means to decrease its worth because of the time (opportunity cost).

In Bolivia, the wood industry is still based on large diameters, because the logs from natural forest are of 50 cm of diameter, reaching even 150 cm. For timber from forest plantations the machines might be adapted to small diameter logs. For example, in Colombia the minimum diameter for *Tectona grandis* is 17 cm (Ladrach, 2005) and in Ecuador is 20 cm (Alder, 2006).

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Age	DBH	GH	Volume	Density	Volume	CAI	MAI	Cost	Com. Cost	Harvest	Net income	WPL	IRR	(%)
years	(cm)	(m)	m ³ /t	planta	(m ³ /ha)	m ³ /t	m ³ /t	USD/ha	USD/ha	USD/ha	USD/ha	USD/ha	USD/ha	(%)
0								-576	576					
1	3,7	5	5,2	0,00	1111	2	0,00	0,00	-51	662	0	-662		
2	7,4	1	9,6	0,01	1111	15	0,01	0,01	-59	760	0	-760		
3	10,12	1	10,12	0,04	1111	41	0,02	0,01	-89	895	0	-895		
4	14,13	1	14,13	0,07	555	41	0,04	0,02		949	0	-949		
5	17,15	3	17,15	0,12	555	69	0,05	0,02		1005	831	-174	2973	
6	21,16	5	21,16	0,19	555	105	0,06	0,03		1066	1256	190	454	9,20%
7	24,17	5	24,17	0,27	555	147	0,08	0,04		1130	1766	636	1263	13,5%
8	27,18	3	27,18	0,35	555	197	0,09	0,04	-175	1373	2358	986	1365	13,5%
9	30,19	0	30,19	0,45	277	126	0,10	0,05		1455	1512	57	82	3%, 6,54%
10	33,19	7	33,19	0,57	277	157	0,11	0,06		1542	1883	341	431	8,48%
11	36,20	3	36,20	0,69	277	191	0,12	0,06		1635	2289	654	728	9,76%
12	39,20	9	39,20	0,82	277	227	0,13	0,07		1733	2726	993	981	10,5%
13	41,21	4	41,21	0,96	277	266	0,14	0,07		1837	3193	1356	1197	11,1% M ER
14	44,21	8	44,21	1,11	277	307	0,15	0,08		1947	3686	1739	1379	11,4%
15	47,22	3	47,22	1,26	277	350	0,16	0,08		2064	4203	2140	1532	6%, 11,6%
16	49,22	7	49,22	1,43	277	395	0,16	0,09		2188	4742	2554	1658	4%, 11,7%
17	52,23	1	52,23	1,59	277	442	0,17	0,09		2319	5299	2980	1761	2%, 11,7%

18	54, 23, 36 4	1,77	277	489	0,17	0,10	2458	5873	3415	1841	11,6	7%
19	56, 23, 60 8	1,94	277	538	0,18	0,10	2605	6460	3854	1903	11,5	8%
20	58, 24, 77 1	2,12	277	588	0,18	0,11	2762	7058	4296	1946	11,4	5%
21	60, 24, 85 4	2,31	277	639	0,18	0,11	2928	7664	4737	1974	11,3	1%
22	62, 24, 86 7	2,49	277	690	0,18	0,11	3103	8277	5174	1987	11,1	5%
23	64, 25, 79 0	2,68	277	741	0,19	0,12	3289	8894	5604	1988	10,9	7% OE R
24	66, 25, 65 2	2,86	277	793	0,19	0,12	3487	9512	6025	1976	10,7	9%
26	70, 25, 14 7	3,23	277	895	0,19	0,12	3918	1074	6827	1924	10,4	2%
28	73, 26, 33 2	3,60	277	997	0,18	0,13	4402	5	1196	1838	10,0	5%
30	76, 26, 24 6	3,95	277	1095	0,18	0,13	4946	0	1314	1727	9,68	%
32	78, 27, 86 1	4,29	277	1189	0,17	0,13	5557	3	1427	1598	9,31	%
34	81, 27, 20 4	4,62	277	1279	0,16	0,14	6244	6	1534	1456	8,96	%
36	83, 27, 26 8	4,92	277	1362	0,15	0,14	7016	8	1634	1306	8,62	%
37	84, 28, 19 0	5,06	277	1402	0,14	0,13	7437	8	1681	1229	8,46	%
38	85, 28, 05 1	5,19	277	1439	16	67	7883	8	1726	1151	8,29	% O BR
39	85, 28, 84 3	5,32	277	1475	0,12	0,13	8356	5	1769	1073	8,14	%
40	86, 28, 57 5	5,44	277	1508	84	65	8858	8	1809	995	7,98	%

Figure 4 shows the ranking between years 13 to 23, which period contains all rotations with increasing WPL_{∞} . The longer the rotation within this period, the higher is the WPL_{∞} value.

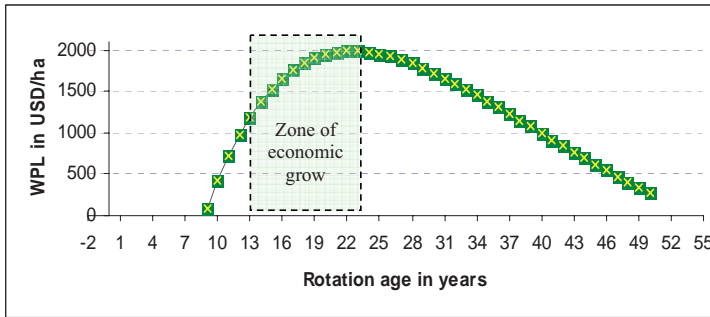


Figure. 4: Willingness to pay for land curve for *S. parahyba*

Data on volume increment in Table 3 are concordant with the findings by Ruiz (2003) who reports a MAI of 27.5 m³/ha at 17 years, although he suggests an optimal economic rotation of 17 years instead of 23 years. Another study made by the Project AD/BOL/97/C23 (2004) about of plantations with *S. parahyba* in the tropical area of Cochabamba estimates the MAI to be about 31 m³/ha at 12 years rotation age and a NPV of 2890 USD/ha. Alder (2006) found that in full stocking plantations of *S. parahyba* in Ecuador, the MAI was 20m³/ha at 20 years, but it continued to increase with time. In studies in Colombia it is reported that *S. parahyba* reaches a diameter of even 80 cm, heights of up to 46 m, a mean clean stem of 20 m, and a commercial volume of 7 m³/tree (Maldonado and Escobar, 2000). These data show that the capacity of *S. parahyba* to produce timber is comparable with the productivity of *Gmelina arborea*, which grows about of 40 m³/ha per year in Indonesia and 50 m³/ha per year in Costa Rica (Ladrach, 2004).

Column 13 of Table 3 shows the net income at year *t*. If the minimum commercial diameter were 20 cm, USD 190/ha worth be obtained in year 6 and major returns postponing the cutting to next years. However, all values in year 1 to year 12 are unrealistic due there still not being a market for logs of small diameter. After year 13, the calculation don't include income for the last thinning because it is assumed that the logs are not sold, so the net income now is realistic and represent the liquid money (it is discounting the compounded costs at year *t*) that investors would receive by harvesting the timber in the year *t*. After year 13 the real net income increases in absolute terms until year 38, but it decreases in relative terms.

Rotation age	Discount rate										
	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	
6 years	1850	1152	733	455	257	109	-5	-97	-171	-233	
13 years	4116	2645	1772	1197	793	495	268	90	-52	-168	
23 years	7390	4623	3017	1988	1286	788	423	149	-60	-221	
38 years	7047	3910	2185	1151	497	70	216	-410	-544	-637	

Sensitivity analysis

The results of the sensitivity analysis show that when the discount rate decreases, the WPL_{∞} value increases exponentially (Fig. 5, Table 4). Moreover, the optimal economic rotation (OER) and the minimum economic rotation (MER) are extended (Fig. 6). This means that decreasing opportunity cost of the investment, as represented by the discount rate, allows the investment to run for a longer period. An increase of the discount rate yields the opposite effect. The investment becomes unprofitable for discount rates 10 %. Navarro (2006) found similar results for *Gmelina arborea* plantations in Costa Rica.

In this context, it can be said that if the investor has own capital and expects at most a 4 % of rate of return by saving the money in the bank, he will prefer to invest in plantations. In the other hand, if he has to take a loan, the interest rate might be up to 10 %.

Table 4: Variation of WPL_{∞} for different rotation ages and discount rates

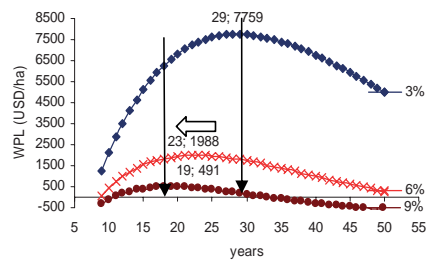
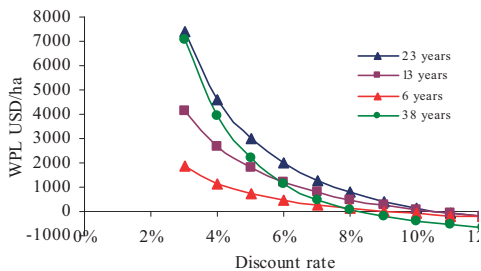


Figure 5: LEV variation by changing the discount rate

Figure 6: Change of optimal economic rotation by varying the discount rate

Figure 7 shows indirectly that for each dollar of increment in the timber price, the WPL_{∞} rises to 235 USD/ha for the minimum economic rotation, 263 USD/ha for the optimum economic rotation and 176 USD/ha for the optimum biological rotation. So, in the economic growth zone (Fig 4), the higher the price, the higher WPL_{∞} is. For a 6 years rotation the business becomes unprofitable with stumpage prices equal to or less than 10 USD/m³. As a reference, the stumpage price for *Gmelina arborea* in Costa Rica is USD 13.5/m³ when the stand is 6 years old at 6 years and USD 25/m³ at 12 years (Ladrach, 2002). Increments in the price have not influenced the rotations length.

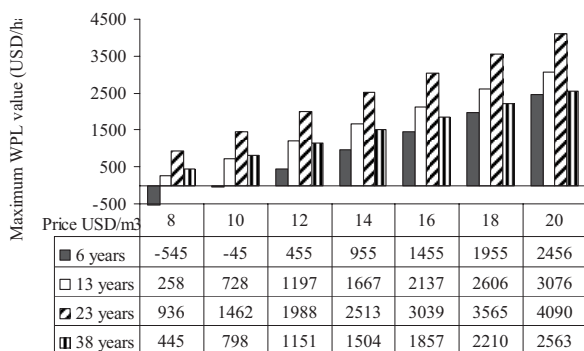


Figure. 7: WPL ∞ variation by changing stumpage price

Matrix for decision making in the short run

Short rotations, in this case the minimum economic rotation of 13 years, are interesting not only because the small-scale farmers are not willing to wait for long periods, but also because the organisations that are promoting forest plantations are adopting rotations between 12 to 15 years (AD/BOL/97/C23, 2004).

Using Equation 5 and the levels of variation for the rotation, discount rate, and stumpage price, 176 possible combinations were identified. In Table 5 are presented the WPL ∞ value and the equivalent annual annuity (EAA) of all combinations. The higher values of WPL ∞ are obtained with prices of 18 USD/m³ and discount rate of 3% for all rotations between 13 and 23 years. With discount rates from 3 % to 6 %, any rotation is profitable at any price between 9 and USD 18 /m³. With discount rate of 9 % all combinations are profitable except when the price is 9 USD/m³ and the rotation is 13 or 14 years. Discount rate of 12 % makes the rotations profitable only if the sales price of the timber is USD 15/m³ or more, prices below this value give negative WPL ∞ .

Table 5: Matrix for decision making on investment in plantations with *S. parahyba* using rotations between 13 and 23 years

Discount rate (%)	Price (USD/m ³)	Rotations age in years																					
		13		14		15		16		17		18		19		20		21		22		23	
		W P L	E A A	W P L	E A A	W P L	E A A	W P L	E A A	W PL	E A A	W PL	E A A	W PL	E A A	W PL	E A A	W PL	E A A	W PL	E A A	W PL	E A A
3%	9	24	7	28	8	32	9	35	1	39	1	41	1	44	1	46	1	48	1	49	1	51	1
3%	12	12	2	53	6	46	7	94	0	13	1	79	2	22	3	36	3	23	4	78	4	05	5
3%	15	58	1	64	1	70	2	75	2	79	2	83	2	87	2	90	2	92	2	94	2	96	2
3%	18	20	5	48	3	13	0	13	5	76	0	56	1	06	1	12	0	80	8	97	5	71	0
6%	9	75	2	82	2	88	2	94	2	10	3	10	3	10	3	11	3	11	3	11	3	11	3
6%	12	23	2	46	4	96	6	73	8	00	0	44	1	84	2	20	3	50	4	75	5	95	5
6%	15	49	3	64	3	78	4	88	5	98	5	10	6	11	6	11	6	11	7	11	7	11	7
6%	18	3	0	9	9	0	7	8	3	0	9	48	3	04	6	47	9	77	1	94	2	99	2
9%	9	11	1	48	-4	6	1	46	4	76	7	91	8	0	9	1	9	96	9	84	8	67	6
9%	12	26	2	34	3	40	3	44	4	47	4	48	4	49	4	48	4	47	4	45	4	42	3
9%	15	8	4	5	1	4	6	5	0	4	3	6	4	0	4	4	4	1	2	0	1	2	8
9%	18	65	5	73	6	80	7	84	7	87	7	88	7	88	7	86	7	84	7	81	7	77	7
12%	9	10	9	11	0	11	0	12	1	12	1	12	1	12	1	12	1	12	1	11	0	11	0
12%	12	41	4	33	2	99	8	43	2	71	4	75	5	69	4	51	3	22	0	82	6	33	2
12%	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12%	18	40	4	37	4	34	4	33	4	33	4	33	4	33	4	34	4	36	4	37	4	39	4
12%	9	16	2	13	1	11	1	10	1	10	1	11	1	12	1	14	1	16	2	19	2	22	2
12%	12	8	0	4	6	4	4	5	3	4	2	3	4	6	5	5	7	7	0	3	3	1	7
12%	15	70	8	3	2	1	5	6	5	2	5	7	3	86	0	60	7	29	3	-6	-1	44	-5
12%	18	30	3	34	4	35	4	35	4	34	4	32	3	29	3	26	3	22	2	18	2	13	1
12%	9	7	7	0	1	6	3	7	3	9	2	6	9	8	6	4	2	4	7	0	2	3	6

Conclusions

According to the predictive growth model found in this paper, *Schizolobium parahyba* reaches its maximum growth in plantations at 38 years of age. So, the optimal biological rotation is 38 years.

The willingness to pay for land value (WPL_{∞}) calculated using 6 % as discount rate and USD 12/m³ as stumpage price, reaches its maximum value when the stand has 23 years of age. Therefore, the optimal economic rotation is 23 years.

In the same sense, the stand reaches the minimum diameter accepted by at local market (40 cm DBH) at year 13, and the WPL_{∞} value is positive, so the minimum economically acceptable rotation is 13 years, i.e. this is the minimum period that the investor has to wait to recover his investment.

The sensitivity analysis with varying stumpage price shows that the highest the price, the highest is the WPL_{∞} value. Increments in the capital cost (discount rate) yield a reduction of both the WPL_{∞} and the rotation age. The investment is unviable at discount rates higher than 10 % at the current stumpage prices of USD 12/m³.

Assuming that small-scale farmers are not willing to wait for long rotations to recover their investment in forest plantations, the matrix for decision making allows choosing the best economic rotation in the short run, using the discount rate and the expected stumpage price. For instance, for a discount rate of 6 % and stumpage price 12 USD/m³, 13 years rotation age produces a WPL_{∞} of USD 1197/ha, while for a 15 year rotation age the WPL_{∞} is 1532 USD/ha. The choice has to be taken by the investor.

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