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Stand growth scenarios for *Bombacopsis quinata* plantations in Costa Rica

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Abstract

In total 60 plots of approximately 80 trees each (including missing trees) were measured, with ages between 1 and 26 years. The main objective of this study was to develop intensive management scenarios for *B. quinata* plantations in Costa Rica to ensure high yielding of timber wood. The scenarios were based on a fitted curve for the relationship of DBH, and total height with age. A criterion of maximum basal area (18, 20, 22 and 24 m^2 ha^{-1}) was used to simulate different site qualities. Plantation density was modeled as a function of the crown area occupation of the standing trees.

The scenarios consist of rotation periods between 23 and 30 years, final densities of 100–120 trees ha^{-1}, mean DBH between 46 and 56 cm, and mean total heights of 30–35 m. The productivity at the end of the rotation varies between 9.6 and 11.3 m^3 ha^{-1} per year, yielding a total volume at the end of the rotation of 220–340 m^3 ha^{-1}. The scenarios presented here may provide farmers and private companies with useful and realistic growth projections for *B. quinata* plantations in Costa Rica.

Keywords: Productivity; Stand competition; Intensive management; Crown area; Basal area management

1. Introduction

Fast growing and high yielding tree plantations are becoming an important source of wood in the tropics. In these areas the need to increase wood productivity is becoming an important task. *Bombacopsis quinata* is a valuable and fast-growing native tree species of Central America widely used in plantation programs throughout the region. In Costa Rica, commercial planting of the species has been encouraged by government incentive programs, reaching 14 900 ha (approximately 12.3% of the total reforested area in the country) by the end of 1997 (Sage and Quiros, 2001). Now it is necessary to develop appropriate silvicultural techniques for their management.

B. quinata is a deciduous species that occurs naturally in seasonally dry forests, from southern Honduras to central Venezuela in widely dispersed populations of varying sizes. It occurs at elevations from sea level to 900 m, in areas where annual precipitation ranges from 800 mm (northern Colombia)

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to 3000 mm (Cabo Blanco, Costa Rica). A strong, well-defined dry season of 2–6 months characterizes its natural range (Chaves and Fonseca, 1991; Kane et al., 1993; Rojas, 1981; Urueña, 1999; Vásquez and Ugalde, 1995). Suitable soils for this species include non-compact, deep, with high natural fertility, sandy texture, neutral or acid pH, and on flat sites with good drainage (CATIE, 1991).

Trees can reach 40 m of height and more than 1.0 m of diameter at breast height (DBH) in natural forests (Kane et al., 1993). The heartwood is reddish in color and the sapwood a cream or white hue. The wood is known for its durability and workability. It is used for furniture, doors, window and ceiling frames, roof construction, interior paneling, particleboard, plywood and veneer (Kane et al., 1993; Urueña, 1999).

Projects and private companies in Central America urgently need relevant information about the growth and productivity of this widely used species for reforestation, recognized for its rapid growth rate and its wood quality. Determining production at the end of the rotation is particularly necessary in the case of advanced aged plantations (over 20 years). Nowadays the scenario for this species has turned uncertain, since wood quality and yielding are being lower than expected (e.g. heartwood proportions less than 20%, harvest volume at rotation of 60–70% of its potential). Therefore, it is necessary to improve the quality and productivity by means of intensive management systems.

Spatial competition plays a decisive roll for the adequate development of forest stands. One means of evaluating the effect of competition is to monitor tree development. The size and spatial distribution of the canopy are causally related to the amount of light intercepted by the leaves. This relationship has been used to develop better understanding of how the productivity of plantations can be measured in terms of light energy conversion into biomass (Beadle, 1997; Lonsdale and Watkinson, 1983). Therefore it is important to study adequate plantation densities that are needed by the crown to develop an optimal tree growth on the one hand, and to fully utilize the site for maximum production of desire usable volume on the other (Suri, 1975; Krajicek et al., 1961; Ashton et al., 1989; Prodan et al., 1997).

Research was carried out on *B. quinata* plantations in Costa Rica with the aim of developing indicators of competition within a stand, such as basal area (BA), current and mean annual increments (CAI, MAI) in DBH and total height, and crown area. The main objective of this study was to develop intensive management scenarios for *B. quinata* plantations to ensure high yielding of timber wood.

2. Materials and methods

B. quinata plantations in private farms were evaluated in several zones of Costa Rica (Fig. 1), including the following sites (and provinces): Garza, Sámara, Hojancha, and Tempisque (Guanacaste); Jicaral, Parrita, Barú, Palmar Norte, and Buenos Aires (Puntarenas); Guápiles (Limón). In total 60 plots of approximately 80 trees each (including missing trees) were measured, with ages between 1 and 26 years.

The development of the scenarios was based on a fitted curve for the relationship of DBH, and total height with age. For this, individual trees (715 registers of DBH and 521 of total height) were selected from the database, which corresponded to the upper 4th quarter for DBH and to the upper half for total height (data previously classified in descending order). The reason for a sub selection of data was to evaluate plantations with medium to high growth rates only, and discard plantations with no management and marginal growth rates. Figs. 2 and 3 present the DBH and total height curves used for the growth scenarios.

A maximum BA criterion was intended to represent different site qualities. Maximum BA of 18, 20, 22 and 24 $m^2\,ha^{-1}$, for an initial plantation density of 1111 trees ha^{-1}, were defined for the development of the management scenarios. To keep the BA under the defined limit for each scenario, non-selective thinning (mean DBH after thinning = mean DBH before thinning) was simulated to reduce it when the maximum was reached. Thinning intensities varied between 40 and 50% of the standing trees. A form factor of 0.40, obtained from field measurements, was used to calculate total volumes.

Plantation density was modeled as a function of the crown area occupation of the standing trees. It was considered that the maximum stand density was reached when the plantation area was fully occupied by the crowns. For this, a model developed by Pérez and Kanninen (in press) was used to estimate crown

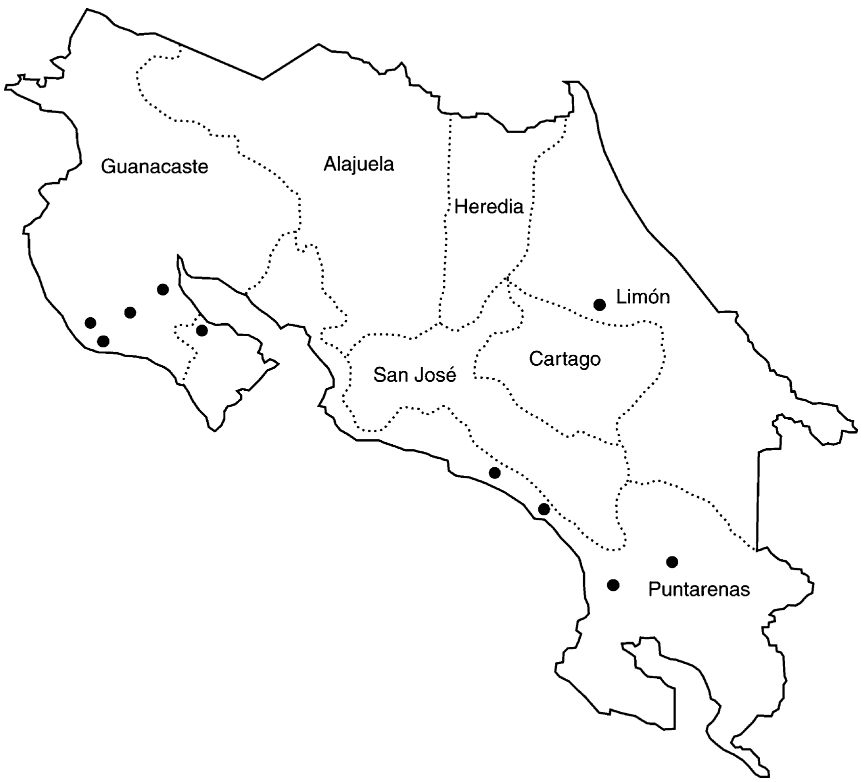

Fig. 1. Location of the sites where *B. quinata* plantations were evaluated in Costa Rica.

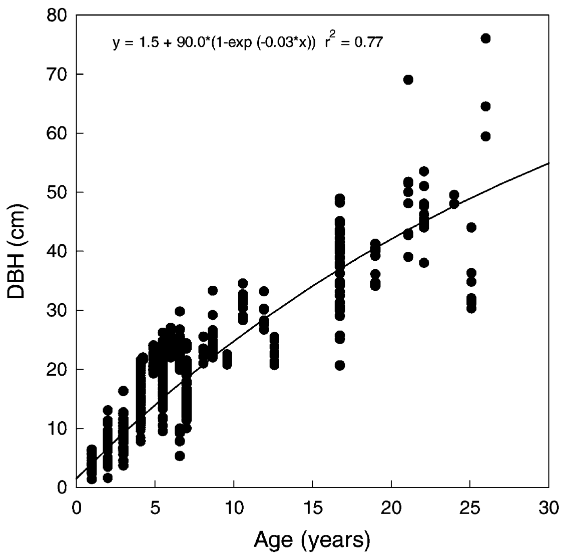

Fig. 2. Fitted model for the relationship between age and DBH implemented in the development of the scenarios for *B. quinata* plantations in Costa Rica. Data correspond to the selection of the 4th quartile from the total sample information.

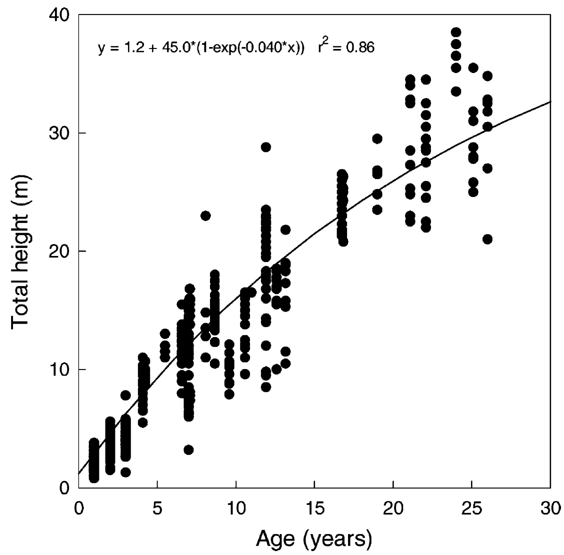

Fig. 3. Fitted model for the relationship between age and total height implemented in the development of the scenarios for *B. quinata* plantations in Costa Rica. Data correspond to the selection of the 3rd and 4th quartile from the total sample information.

diameter from DBH (Eq. (1)).

$$\log_{10}(\mathrm{CD}) = -0.177 + 0.689 \log_{10}(\mathrm{DBH}) \quad (r^2 = 0.60) \tag{1}$$

where CD is the crown diameter (m); DBH the diameter at breast height (cm).

Assuming the crown to be a geometric circle, crown area was calculated using Eq. (2)

$$\mathrm{CA} = \left(\frac{\pi}{4}\right) \times \mathrm{CD}^2 \tag{2}$$

where CA is the crown area (m^2); CD the crown diameter (m).

3. Results

Management scenarios with rotation periods between 23 and 30 years of age were developed, with final densities of 100–110 trees ha^{-1}, mean DBH between 49 and 55 cm, and mean total heights of 30–33 m. The productivity at the end of the rotation varied between 9.4 and 11.1 $m^3 ha^{-1}$ per year, yielding a total volume of 236–332 $m^3 ha^{-1}$. The summary of the stand growth scenarios is presented in Table 1.

The scenario with the maximum BA criterion of 24 $m^2 ha^{-1}$ is considered to be an intensive management scenario that can be implemented in medium to high quality sites for *B. quinata* plantations in Costa Rica. In this scenario, four thinnings with intensities between 40 and 50% (of the standing trees) simulate the intensive management. The BA is reduced from 11.9 to 5.9 $m^2 ha^{-1}$ on the first thinning at the age of 4 years, followed by three consecutive thinnings where 11.3, 10.2 and 9.9 $m^2 ha^{-1}$ are extracted at ages of 9, 15 and 21 years, respectively (Table 2, Fig. 4).

The final harvest is projected to 30 years, ending with 100 trees ha^{-1}, a mean DBH of 54.9 cm and

Table 1
Summary of the stand growth scenarios developed for *B. quinata* in Costa Rica[a]

Scenario (m^2/ha)	Age	Thinning	*N*	Thinning intensity	DBH	Total height	Rem. BA	Ext. BA	Rem. vol.	Ext. vol.
18	4	1	556	50	11.7	7.9	5.9	5.9	17.3	17.3
	8	2	278	50	20.7	13.5	9.4	9.4	48.7	48.7
	12	3	167	40	28.7	14.4	10.8	7.2	78.3	52.2
	17	4	100	40	37.5	23.4	11.0	7.3	104.8	69.8
	25	*Final cut*	*100*	–	*49.0*	*29.6*	*0.0*	*18.8*	*0.0*	*235.5*
20	4	1	611	45	11.7	7.9	6.5	5.4	19.0	15.6
	8	2	306	50	20.7	13.5	10.3	10.3	53.6	53.6
	12	3	183	40	28.7	14.4	11.9	7.9	86.1	57.4
	18	4	110	40	39.1	23.4	13.2	8.8	130.7	87.1
	25	*Final cut*	*110*	–	*49.0*	*29.6*	*0.0*	*20.7*	*0.0*	*249.5*
22	4	1	556	50	11.7	7.9	5.9	5.9	17.3	17.3
	9	2	306	45	22.8	14.8	12.5	10.2	71.6	58.6
	13	3	183	40	30.6	19.4	13.5	9.0	104.0	69.4
	18	4	110	40	39.1	24.3	13.2	8.8	130.7	87.1
	26	*Final cut*	*110*	–	*50.2*	*30.3*	*0.0*	*21.8*	*0.0*	*279.6*
24	4	1	556	50	11.7	7.9	5.9	5.9	17.3	17.3
	9	2	278	50	22.8	14.8	11.3	11.3	65.1	65.1
	15	3	167	40	34.1	21.5	15.2	10.2	131.7	87.8
	21	4	100	40	43.6	26.8	14.9	9.9	165.3	110.2
	30	*Final cut*	*100*	–	*54.9*	*32.6*	*0.0*	*23.7*	*0.0*	*332.4*

[a] Scenario: stand growth scenario, restricted by a maximum basal area ($m^2 ha^{-1}$); age (years): age of the stand; thinning: serial number of the thinning; *N*: plantation density (trees ha^{-1}); thinning intensity (%): thinning intensity based on the number of trees; DBH (cm): mean diameter at breast height; total height (m): mean total height of the plantation; rem. BA ($m^2 ha^{-1}$): remnant (standing) BA of the stand after thinning; ext. BA ($m^2 ha^{-1}$): extracted BA on each thinning; rem. vol. ($m^3 ha^{-1}$): remnant (standing) total volume after thinning; ext. vol. ($m^3 ha^{-1}$): extracted total volume on each thinning.

Table 2
Stand growth scenario developed for *B. quinata* in Costa Rica with a restriction of a maximum basal area of 24 $m^2 ha^{-1}$[a]

Age	Max *N*	Actual *N*	Thinning intensity	DBH	MAI DBH	Total height	MAI height	Rem. BA	Ext. BA	Rem. vol.	Ext. vol.	MAI vol.
1st thinning												
1	4035	1111		4.2	4.2	3.0	2.5	1.5		1.5		1.5
2	2074	1111		6.7	3.4	4.7	2.1	4.0		6.5		3.3
3	1342	1111		9.2	3.1	6.3	1.9	7.5		17.1		5.7
4	973	1111		11.7	2.9	7.9	1.8	11.9		34.6		8.6
2nd thinning												
4	973	556	50	11.7	2.9	7.9	1.8	5.9	5.9	17.3	17.3	4.3
5	755	556		14.0	2.8	9.4	1.8	8.6		30.1		6.0
6	613	556		16.3	2.7	10.8	1.7	11.6		47.6		7.9
7	514	556		18.5	2.6	12.2	1.7	15.0		69.9		10.0
8	442	556		20.7	2.6	13.5	1.6	18.7		97.4		12.2
9	387	556		22.8	2.5	14.8	1.6	22.7		130.2		14.5
3rd thinning												
9	387	278	50	22.8	2.5	14.8	1.6	11.3	11.3	65.1	65.1	7.2
10	344	278		24.8	2.5	16.0	1.6	13.4		84.2		8.4
11	310	278		26.8	2.4	17.2	1.5	15.7		106.0		9.6
12	282	278		28.7	2.4	18.4	1.5	18.0		130.5		10.9
13	258	278		30.6	2.4	19.4	1.5	20.4		157.6		12.1
14	239	278		32.4	2.3	20.5	1.5	22.9		187.3		13.4
15	222	278		34.1	2.3	21.5	1.4	25.4		219.5		14.6
4th thinning												
15	222	167	40	34.1	2.3	21.5	1.4	15.2	10.2	131.7	87.8	8.8
16	208	167		35.8	2.2	22.5	1.4	16.8		152.5		9.5
17	195	167		37.5	2.2	23.4	1.4	18.4		174.6		10.3
18	184	167		39.1	2.2	24.3	1.4	20.0		198.0		11.0
19	175	167		40.6	2.1	25.2	1.4	21.6		222.7		11.7
20	166	167		42.1	2.1	26.0	1.3	23.2		248.5		12.4
21	159	167		43.6	2.1	26.8	1.3	24.8		275.5		13.1
Final cut												
21	159	100	40	43.6	2.1	26.8	1.3	14.9	9.9	165.3	110.2	7.9
22	152	100		45.0	2.0	27.5	1.3	15.9		182.0		8.3
23	146	100		46.4	2.0	28.3	1.3	16.9		199.3		8.7
24	140	100		47.7	2.0	29.0	1.3	17.9		217.2		9.0
25	135	100		49.0	2.0	29.6	1.2	18.8		235.5		9.4
26	130	100		50.2	1.9	30.3	1.2	19.8		254.2		9.8
27	126	100		51.5	1.9	30.9	1.2	20.8		273.3		10.1
28	122	100		52.6	1.9	31.5	1.2	21.8		292.7		10.5
29	119	100		53.8	1.9	32.1	1.2	22.7		312.4		10.8
30	115	100		54.9	1.8	32.6	1.2	23.7		332.4		11.1

[a] Age (years): age of the plantation; max *N* (trees ha^{-1}): maximum plantation density; actual *N* (trees ha^{-1}): plantation density; thinning intensity (%): thinning intensity based on the number of trees; DBH (cm): mean diameter at breast height; MAI DBH (cm per year): DBH mean annual increment; total height (m): mean total height of the plantation; MAI height (m per year): mean annual increment in total height; rem. BA ($m^2 ha^{-1}$): remnant (standing) BA after thinning; ext. BA ($m^2 ha^{-1}$): extracted BA; rem. vol. ($m^3 ha^{-1}$): remnant (standing) volume after thinning; ext. vol. ($m^3 ha^{-1}$): extracted volume; MAI vol. ($m^3 ha^{-1}$): mean annual increment in volume.

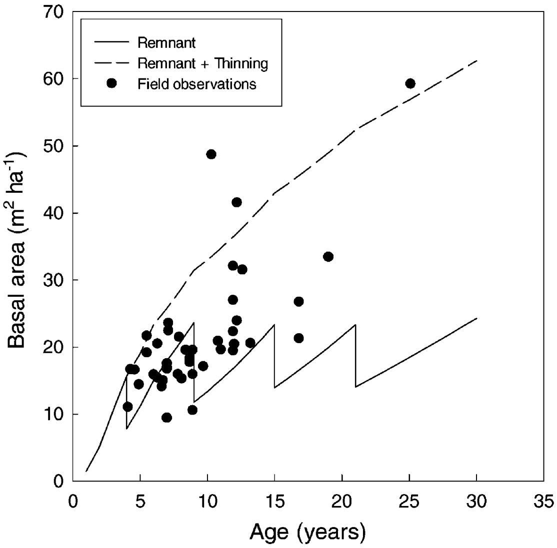

Fig. 4. Remnant BA, and remnant + thinned BA scenario simulated for a *B. quinata* plantation in Costa Rica under a maximum basal area management of 24 m^2 ha^{-1} and an initial density of 1111 trees ha^{-1}. Dots represent the field observations from measured plots.

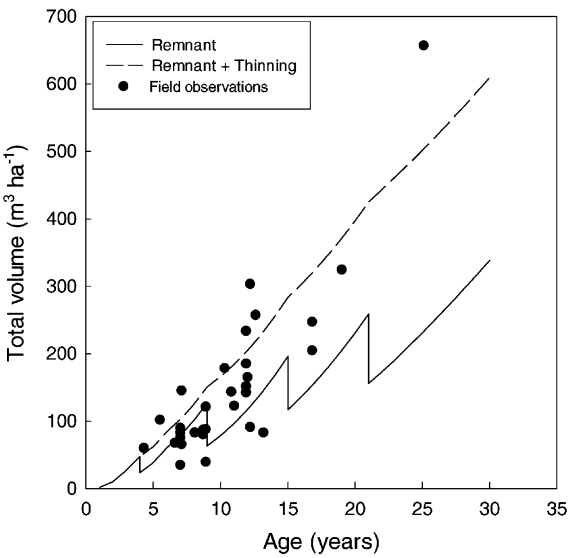

Fig. 5. Remnant total volume, and remnant + thinned total volume scenario simulated for a *B. quinata* plantation in Costa Rica under a maximum basal area management of 24 m^2 ha^{-1} and an initial density of 1111 trees ha^{-1}. Dots represent the field observations from measured plots.

a total height of 32.6 m. This would yield a total volume of 332 m^3 ha^{-1}, for a total volume (including thinnings) of 613 m^3 ha^{-1} (Table 2, Fig. 5).

4. Discussion

The crown area occupation was considered when defining intensities and moments of thinning. Nevertheless, this criterion could not be strictly followed, since too many interventions (and too often) would be necessary, being economically unfeasible to perform.

All the variables of the management scenarios, such as plantation density, BA, and total volume, are based on field information collected for this study. The highest final stand density presented in the scenarios is 110 trees ha^{-1}, with a mean DBH of 50.2 cm (scenario managed under a maximum BA of 22 m^2 ha^{-1}). According to the crown area occupation criterion, the maximum stand density at that moment should be 115 trees ha^{-1}. The register of one plantation measured in the field with 618 trees ha^{-1} and 40.4 cm of DBH at the age of 22 years, suggests that, with intensive management, this DBH could be increased to values close to 50 cm.

CATIE (1991) developed a preliminary yield table for *B. quinata* in Costa Rica. The scenario suggests an initial plantation density of 1600 trees ha^{-1}, and a final harvest of 216 trees ha^{-1} with 35.6 cm of DBH at the age of 30 years. This productivity could be similar to that proposed in our scenarios by reducing stand density to concentrate growth on fewer trees.

Navarro and Martínez (1989) report a mean DBH of 49 cm for 40-year-old *B. quinata* plantations in Turrialba, Costa Rica, at densities of 240 trees ha^{-1}. In the present study, trees with DBH of 46 cm were found in plantations without appropriate management, suggesting that, under conditions like those simulated in our scenarios, mean DBH $\geq$ 50 cm could be expected for rotation periods of 30 years.

Basal areas between 18 and 24 m^2 ha^{-1} are common for *B. quinata* plantations in Costa Rica (Navarro and Martínez, 1989; Ugalde, 1997). Vásquez and Ugalde (1995) classify as high-class sites for *B. quinata* those with BA $\geq$ 25 m^2 ha^{-1}, as medium-class sites those between 15 and 25 m^2 ha^{-1}, and low-class sites those with BA $\leq 15\ m^2\ ha^{-1}$. CATIE (1991) recommends carrying out the thinning when the BA reaches between 22 and 25 $m^2\ ha^{-1}$, extracting from 6 to 8 $m^2\ ha^{-1}$ on each intervention. Current simulations extract between 7.4 and 10.5 $m^2\ ha^{-1}$ on each thinning.

Final harvest volumes proposed in the present scenarios vary between 236 and 332 $m^3\ ha^{-1}$. According to field data, this yielding is feasible to obtain in Costa Rica. Ugalde (1997) found volumes of 372 $m^3\ ha^{-1}$ in *B. quinata* plantations of 13 years old growing in Guanacaste, Costa Rica. Melchior et al. (1996) consider that *B. quinata* plantations should produce over 300 $m^3\ ha^{-1}$ at ages close to 30 years and that this volume could be increased with silvicultural management. A preliminary yield table developed by Hughell (1991) for *B. quinata* in Costa Rica suggests a management scenario for rotation periods of 30 years, with projections much more conservative than those developed in this study. According to Hughell (1991), *B. quinata* can produce a final yielding of 113 $m^3\ ha^{-1}$, with final densities of 216 trees ha^{-1} and mean DBH of 36 cm.

The scenarios presented in this paper, and other recommendations of rotation periods of 30 years for *B. quinata* plantations (i.e. Hughell, 1991; Arguedas and Torres, 1992; Urueña, 1999; Kammerscheidt, 1998) should consider the low content of heartwood at those ages (Pérez and Kanninen, in preparation). If the objective is to obtain higher volumes of heartwood, rotation periods for *B. quinata* in Costa Rica should be extended at least to 50 years. For rotation periods of 50 years, for example, trees could reach 60–65 cm of DBH and more than half of the volume could be expected as heartwood.

5. Conclusions

The development of growth scenarios will certainly help to improve the current management of *B. quinata* plantations in Costa Rica. The growth scenarios developed in this study may provide useful and realistic growth projections of *B. quinata* to farmers and private companies. Recommendations include reinforcing present results with more measurements of advanced age plantations, particularly for those older than 20 years.

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