EARLY GROWTH IN VOLUME AND HEIGHT OF *BOMBACOPSIS QUINATUM* IN COSTA RICA PLANTATIONS

P. R. Hannah

Department of Forestry, University of Vermont, School of Natural Resources, Burlington, Vermont 05405, USA. E-mail: phannah@midcoast.com

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HANNAH, P. R. 2003. Early growth in volume and height of *Bombacopsis quinatum* in Costa Rica plantations. Five pochote (*Bombacopsis quinatum*) plantations were sampled in Costa Rica using stem analysis methods to determine annual volume increment and patterns of height growth. Based on regressions relating cumulative stem volume to current diameter and age, and utilising the diameter tally of trees on plots, the cumulative total stem volume (inside bark) per hectare for stems on plots at time of sampling was determined for each site. Estimates of total stem volume ranged up to 110 m^3 ha^{-1} in nine years. A 28-year-old stand with considerably fewer trees per hectare due to mortality of alternate rows of plantain and limited harvesting has a total stem volume of 170 m^3 ha^{-1}. Tree volume equations are presented. Regressions were also derived to relate cumulative volumes in previous years to diameter of trees in the respective year. Methods are discussed for developing this relationship.

Key words: Pochote - cumulative volume growth - height growth - Costa Rica pochote plantation growth

HANNAH, P. R. 2003. Pertumbuhan awal isipadu dan ketinggian *Bombacopsis quinatum* di ladang Costa Rica. Lima ladang pochote (*Bombacopsis quinatum*) disampel di Costa Rica menggunakan kaedah analisis batang untuk menentukan pertambahan isipadu tahunan dan pola pertumbuhan ketinggian. Berdasarkan regresi yang mengaitkan isipadu batang kumulatif dengan diameter dan umur semasa pokok, di samping menggunakan catatan diameter pokok di petak, jumlah kumulatif isipadu batang sehektar bagi batang di petak pada masa pensampelan ditentukan bagi setiap tapak. Anggaran isipadu jumlah batang berjulat sehingga 110 m^2 ha^{-1} dalam tempoh sembilan tahun. Dirian berumur 28 tahun yang tidak mempunyai banyak pokok akibat kematian pokok plantain dan penebangan terhad mempunyai jumlah isipadu batang sebanyak 170 m^3 ha^{-1}. Persamaan isipadu pokok dibentangkan. Regresi dibuat untuk mengaitkan isipadu kumulatif tahun-tahun terdahulu dengan diameter pokok bagi tahun berkenaan. Kaedah untuk membangunkan kaitan ini dibincangkan.

Introduction

Pochote (*Bombacopsis quinatum*) is a tree that occurs naturally from southern Honduras to Venezuela and Columbia and is most commonly found in seasonally dry areas within its range. In Costa Rica pochote is most abundant in Guanacaste

Present address: 13 Devoe Rd, Bristol, ME 04539, USA

and Puntarenas provinces and usually occurs as a scattered tree in the forest, along fencerows, and occasionally in pastureland. Pochote is a wood with many uses, from crafts to construction, and its unique properties make it much in demand. Kane *et al.* (1993) discuss the ecological requirements and silviculture of pochote.

Due to the growing interest in planting pochote the Tree Crops Project (Madelena) at the Center for Tropical Agriculture Research and Education (CATIE) in Turrialba, Costa Rica conducted studies on yield potential and response of pochote to silvicultural practices. A major effort was devoted to growth and yield models for pochote. This study of individual tree growth using stem analysis measures was aimed at quantifying volume increase on a yearly basis for trees in young plantations, and providing information for development of growth models.

Materials and methods

Sampling technique

Five pochote plantations in Guanacaste and Puntarenas provinces were selected for study at Dulce Nombre, Pta. Carillo, Jicaral, and Juanilama near Esparza. The stands all looked similar in appearance to that shown in Figure 1. Navarro (1988) previously sampled three of the stands, developed site index curves, and related site index to various site conditions. Most of the sampled plantations in this study appeared to have an original spacing of 2 × 2 m. Spacing was variable due to mortality or occasional harvest of some trees except in a young stand at Bosque Carillo near Pta. Carillo where all planted trees remained. All stands but the Bosque Carillo stand have endured some degree of grazing. In the 28-year-old plantation at Juanilama the spacing was about 3.5 × 6.5 m following mortality of interplanted rows of plantain and harvest of some trees.

In each of the five plantations an area with typical stocking for the stand was selected for sampling. A circular 400 m^2 plot (200 m^2 at Pta. Carillo and Bosque Carillo) was established and diameter of all trees on the plot measured at 1.3 m. Up to four trees, representing the range of diameters in the plot, were felled for stem analysis. Small cross section discs were cut from along the stem. The first disc was taken near ground line, the next at 1.3 m, and, subsequently, at every 2 m above this point. Distance from the ground to each disc, and total tree height were measured.

Data analysis

On each disc measures of bark thickness and cumulative annual radial increments in millimeters were made along a line of average radius starting from the outside bark surface to the center of the tree. These data, and distances from the ground to each disc, were entered to a microcomputer. Using a Fortran program the Smalian formula was used to compute annual volume increments in each segment, then combined for all segments in the stem to determine cumulative volumes since time of planting (McNab 1989). Cumulative stem volume data for all sampled trees on each plot were then used to derive a regression equation for each plot relating stemwood volume (inside bark) in cubic decimeters at each previous tree age to current tree diameter and the appropriate tree age. A test of both linear, quadratic and log models revealed the best fit was a combined variable model of the form:

$$\text{volume } (dm^3) = b \text{ (current diameter} \times \text{age)}$$

where

b = coefficient for a plantation.

This regression model was used to derive the b coefficients of Table 1 for each study plot.

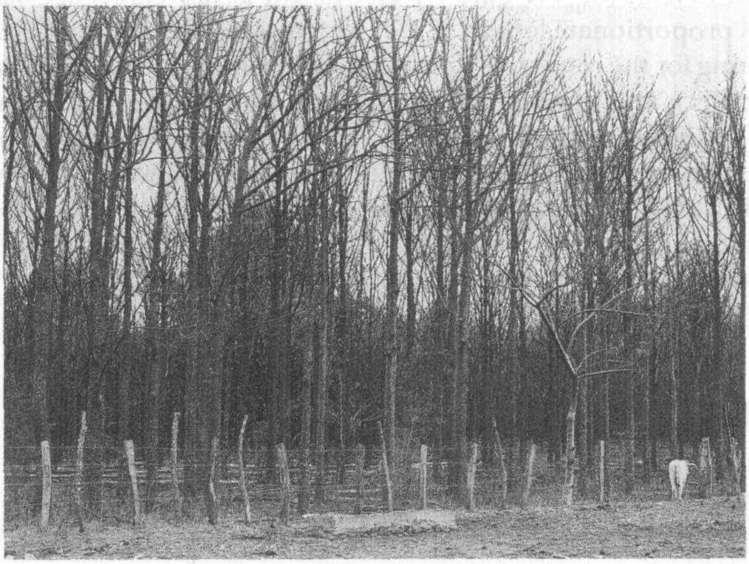

Figure 1 Eight-year-old pochote plantation sampled at Dulce Nombre

Volume based on tree diameter at earlier ages

A further objective was to have estimates of volume at younger ages based on tree dbh outside bark at the respective younger age. To do this measures of bark thickness at earlier ages were made on smaller discs with fewer rings from further up the stem of the same sample tree to approximate bark thickness at a younger age. Appropriate bark thickness measures were then added to breast height radial measures for each tree at previous ages to estimate the outside bark diameter.

To make estimates of volume in m^3 ha^{-1} the plot tallies of tree diameters at previous ages were needed for each plantation. Using the predicted previous diameters for the sampled trees additional regression equations were derived for each plot relating diameter at earlier ages to current diameter at time of sampling (maximum dbh), and to age, age^2, and maximum dbh × age. Maximum diameter of each tree was used to set the starting point for decreasing diameter over time and to stratify the sample, assuming a large tree had a different growth pattern than a small tree of the same age. These equations were then applied to the list of current tree diameters for sample plots to compute lists of tree diameters at earlier ages. Regression equations for each plot were then computed relating tree volume to estimated previous dbh and dbh^2 outside bark. These equations were used with the appropriate diameter lists to estimate volume (m^3 ha^{-1}) at 5- and 2-year intervals for each plantation.

Height-age equation

Height-age data from the largest sampled trees on each plot were used to derive a regression equation and estimate height at age 10 and designated as site index at base age of 10 years (SI_{10}) (Figure 1). Tree height at any earlier age was estimated by adding a proportionate length of the last 2-m sampled segment that included the growth ring for the respective age. Height and age to a previous leader terminus were used where identifiable. The equations were finally used to extend the curves of young plantations to age 10 and assign a SI_{10} value to each plot. The site index curve by Navarro & Martinez (1989) is also shown for comparison.

Finally, in a third approach to estimate previous tree volumes in dm^3, the data for trees from all plots were combined to derive a more general equation relating previous volumes to their respective dbh and dbh^2, associated age, and SI_{10} as estimated from Figure 2.

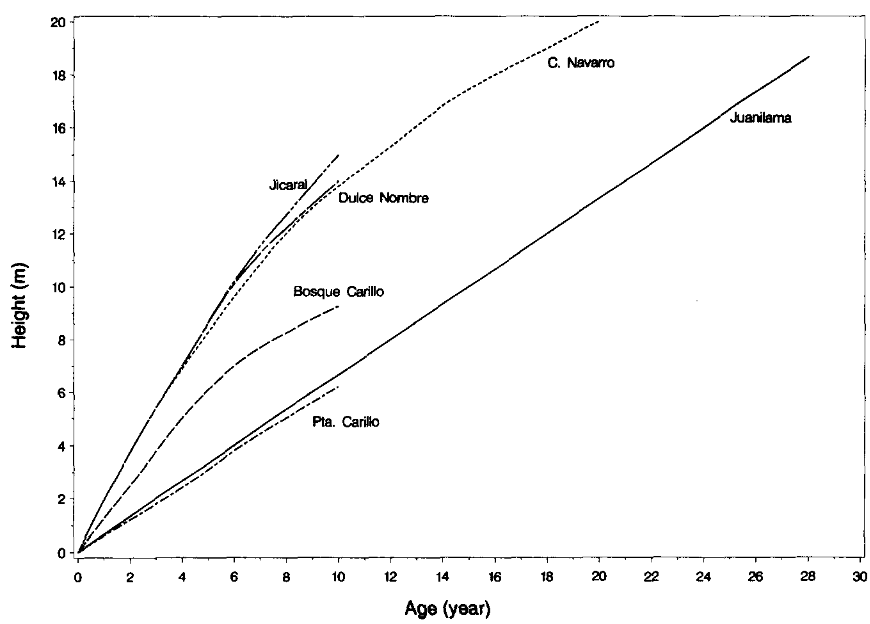

Figure 2 Average height growth curves for five pochote plantations in Guanacaste and Puntarenas Provinces, Costa Rica based on stem analysis

Results

The b coefficients of Table 1 enabled computing of total stem volume inside bark of an individual tree based on the current tree diameter and current age. One can also compute tree volume at earlier ages from current diameter and the earlier age. These equations were used with the plot tallies of tree diameters for the sample plot of each plantation to compute stem volume (m^3 ha^{-1}) inside bark at different stand ages (Table 2). Data in Table 2 and the equations of Table 1 to derive it were judged among the regression models tested to give the best estimates of stem volume in an individual tree and, by summation of all trees, the volume per hectare.

Table 1 b coefficients to compute total stem volume (inside bark) of pochote trees in five plantations in Costa Rica based on current diameter and previous ages expressed as a variable (current dbh x age)

Plantation	Age (year)	No of trees sampled (year)	b coefficient for variable (current diameter × age)	Standard error	R^2
Bosque Carillo	6	2	0.48184	0.056	0.81
Pta Carillo	6	3	0.57907	0.048	0.86
Dulce Nombre	8	4	0.57326	0.037	0.88
Jicaral	10	4	0.98751	0.067	0.82
Juanilama	28	3	0.53499	0.018	0.19

Table 2 Total volume (inside bark) of stemwood (m^3 ha^{-1}) for five pochote plantations in Costa Rica (sampled May 1989) based on coefficients of Table 1

Plantation site	Bosque Carillo	Pta Carillo	Dulce Nombre	Jicaral	Juanilama
Stand age (year)	6	6	8	9	28
Trees ha^{-1}	1050	1250	100	550	475
BA (m^2 ha^{-1})	16.1	1250	100	550	475
SI_{10}	9	6	14	15	7
Quadratic mean dbh (cm)	13.3	14.2	18.1	23.44	24.6
Age (year)			Volume (m^3 ha^{-1})		
1	6.6	10.2	10.1	12.3	0.2
2	13.8	20.1	20.3	24.5	12.1
3	19.1	30.2	30.5	36.8	18.2
4	26.6	40.2	40.7	49	24.3
5	32.2	50.3	50.8	61.3	30.3
6	39.6	60.4	60.9	73.5	36.4
7			71.1	85.8	42.4
8			81.3	98	48.5
9				110.3	54.6
10					60.6
15					90.6
20					121.1
25					151.4
28					169.8

Note: BA = basal area; SI_{10} = site index at base age of 10 years

Estimates of volume in each stand at any earlier age than when sampled and based on predicted dbh outer bark at the earlier age, were also computed (Table 3). These volume estimates were based on equations of Table 4. Data for the current volumes in the four youngest plots have reasonable agreement with estimates of Table 2 but estimates of earlier volumes are considerably less. Radial measures on tree segments were the same for both methods of computation and estimates of bark thickness were reasonably close, thus the major explanation for the differences may be primarily in the fitting of a regression line to the data.

Table 3 Total volume (inside bark) of stemwood (m^3 ha^{-1}) for five pochote plantations in Costa Rica based on predictions of previous tree diameters outside bark derived from stem analysis

Plantation site	Bosque Carillo	Pta Carillo	Dulce Nombre	Jicaral	Juanilama
Plantation age (year)	6	6	8	9	28
Trees ha^{-1}	1050	1250	1000	550	475
BA (m^2 ha^{-1})	16.06	19.4	25.7	23.8	39.6
SI_{10}	9	6	14	15	7
Age (year)			Volume (m^3 ha^{-1})		
2	0.5	5	5.1		2.2
4	15.5	24	23.7	7.6	5.4
6	45.1	60.8	53.9	28.6	9.1
8			89.5	70.1	12
9				119.6	
10					17.5
15					39.7
20					64.9
25					84
28					100.4

Note: BA = basal area; SI_{10} = site index at base age of 10 years.

Table 4 Regression equations for stem volume of pochote and tree diameters at previous ages for five study sites in Costa Rica

Equations to compute volumes of Table 3:

Bosque Carillo	Tree volume in $dm^3 = 1.465 - 2.198$ dbh $+ 0.398$ dbh^2	$R^2 = 0.799$
Pta Carillo	Tree volume in $dm^3 = 1.7065 - 0.766$ dbh $+ 0.284$ dbh^2	$R^2 = 0.958$
Dual Nombre	Tree volume in $dm^3 = -0.073 - 0.079$ dbh $+ 0.293$ dbh^2	$R^2 = 0.95$
Jicaral	Tree volume in $dm^3 = 4.398 + 0.196$ dbh $+ 0.395$ dbh^2	$R^2 = 0.956$
Juanilama	Tree volume in $dm^3 = 26.949 - 4.514$ dbh $+ 0.484$ dbh^2	$R^2 = 0.911$

Equations for computing previous tree diameters based on current or maximum tree diameter and earlier tree ages.

Bosque Carillo	Dia = - 3.8978 + 0.2218 max dia + 0.0431 (max dia × age) + 2.3566 age – 0.0987 age^2 $R^2 = 0.988$
Pta Carillo	Dia = 7.6261 + 0.2218 max dia + 0.111 (max dia × age) + 1.544 age – 0.0937 age^2 $R^2 = 0.978$
Dulce Nombre	Dia = - 5.8514 + 0.2206 max dia + 0.1125 (max dia × age) + 2.3566 age – 0.0987 age^2 $R^2 = 0.936$
Jicaral	Dia = - 2.981 – 0.1372 max dia + 0.0544 (max dia × age) - 0.1601 age + 0.1483 age^2 $R^2 = 0.956$
Juanilama	Dia = - 13.6418 + 0.3322 max dia + 0.029 (max dia × age) + 1.1999 age – 0.0316 age^2 $R^2 = 0.906$

Note: Dia = diameter

Data from all plots were combined to derive a volume equation (Table 5) that would have greater applicability to all sites. This equation, incorporating tree age, current diameter, previous diameters determined using regressions of Table 4, and SI_{10}, was used to compute the volumes of Table 5. This combined data equation generally predicted lower volumes in the Jicaral and Juanilama plantations at the earlier ages than those predicted in Table 2. For the three younger stands the equation predicted considerably higher current volumes than in Table 2 and lower volumes at earlier ages.

A general tree volume equation based on dbh was also computed and is applicable for trees up to 35 cm dbh (Table 5). This equation, based on the stem volume data for all sampled trees, should be of general use in estimating individual tree volumes on a variety of sites.

Table 5 Total volume (inside bark) of stem (m^3 ha^{-1}) in five plantations of pochote in Costa Rica using regression equations based on combined tree data from all five sites

Plantation site	Bosque Carillo	Pta Carillo	Dulce Nombre	Jicaral	Juanilama
Stand age (year)	6	6	8	9	28
Trees ha^{-1}	1050	1250	1000	550	475
BA (m^2 ha^{-1})	16.06	19.4	23.8	23.8	39.6
SI_{10}	9	6	14	15	7
Age			Volume (m^3 ha^{-1})		
2	15	7.6	21.7	10.8	0
4	23	17	35.3	16.1	0
6	50.3	73.2	68.6	34.5	0.9
8			120	70.9	
9				110.1	
10					10.6
15					40.3
20					88.9
25					157.2
28					157.6

Note: BA = basal area; SI_{10} = site index at base age of 10 years.

Equation:

Volume in $dm^3 = 22.2316 + 1.8866\ (age) + 0.1627\ (age^2) - 3.7174\ (earlier\ dbh) + 0.4215\ (earlier\ dbh^2) - 0.9532\ (current\ dbh) + 4.3902\ (SI_{10}\ in\ meters)$ $R^2 = 0.958$

General volume equation:

Volume in $dm^3 = 11.8438 - 3.1976\ (dbh) + 0.4739\ (dbh^2)$ $R^2 = 0.929$

Discussion

Equations of Table 1 to compute volume estimates in Table 2 enable one to calculate the inside bark volume of any tree in the respective plantation, at its present age or any previous age by multiplying the variable (dbh × age) by the appropriate coefficient. The form of this equation enables easy field calculations. As an example of how this equation is used, assume at Jircaral a pochote tree at age 10 years is 15 cm in diameter. Estimated volume of the tree at age 10 is: 15 (dbh) × 10 (age) × 0.98751 = 148 dm^3 or 0.148 m^3. At age 5 the calculation of volume for the tree is: 15 × 5 × 0.98751 = 74 dm^3 or 0.074 m^3. Estimated net volumes for previous years are for the trees that exist today; any mortality volume is not accounted for. Since these are average tree volume equations used to derive stand volume from a list of the trees, it may be possible to apply the equations to tree tallies representing the stocking of younger stands on sites of similar site quality. One is cautioned, however, that changes in tree density associated with age may substantially decrease accuracy of the volume estimates. Volume estimates in Table 2 are most applicable to the plantations sampled. Use of this table may give reasonable estimates of per hectare volumes of other plantations in the vicinity of the respective sampled plot that are on sites of similar site quality and stand density.

The volume estimates in Tables 3 and 5 are based on described methods for obtaining earlier diameters outside bark. A weak point in this analysis is the estimate of bark thickness at each earlier age potentially resulting is substantial deviations from the true volume. For older plantations the equations predicted low or negative volumes at very young ages. A quadratic function apparently decreased volume too abruptly and non-linear models may fit the data better for these age ranges.

Volume estimates in Tables 2, 3 and 5 indicated the potential of stem analysis methodology for computing previous stand volume per unit area based on present stand density, a list of tree diameters, and stand age for plantations. This methodology is useful only for trees that form growth rings permitting measurements of increment over time. Annual diameter measures at several fixed locations on a tree stem could potentially be used to determine yearly diameter increments for trees that do not form annual rings.

Each of the three groups of regressions derived in this study yielded different estimates of volume. Of the many models tested on the data for each plot, the diameter × age model (used for estimates in Table 2) was judged to give the best fit for predicting volume at earlier ages from current diameter. In this equation age varies and current diameter remains constant. With this equation one can estimate current and past volume of a tree based on its current dbh. Equations for volume estimates of Tables 3 and 5 have both diameter and age as independent variables changing over time.

There are some substantial differences in the volume estimates of Tables 2, 3 and 5 particularly for the older plantations. Part of this difference resulted from limitations in the curve fitting to the data with the models used. Nonlinear regression models were not tested. Estimates of previous diameters by the methods described are also subject to error and curve fitting constraints. Field testing of the equations and data in these tables will indicate the volume estimates most appropriate to use and where more data are required to make adjustments.

Volume predictions in this study are based on a sample of 16 trees from five plantations in Guanacaste and Puntarenas provinces. They can be most reliably used in estimating present or past volume of plantations in the vicinity of those sampled, and of a similar age. These tables of estimated yields can be used by managers to aid in their decisions on management actions. Measures of total stem volume ha^{-1} at time of harvest with estimated volumes using the applicable table criteria or equations will give an indication of their validity. The tree volume equations used to derive the tables can be used to estimate total stem volume of individual trees. Until field testing and comparisons with measured yields are made, however, estimates of volumes should be regarded with caution.

There is little data available on volume growth over time for pochote plantations in Costa Rica. Navarro and Martinez (1989) in measures of Costa Rica plantations estimated one 6-year-old stand grew 27 m^3 ha^{-1} $year^{-1}$ and a 40-year-old stand grew 20 m^3 ha^{-1} $year^{-1}$. Hughell (1991) developed a growth model for pochote using data from these and other plantations on average sites to estimate standing volume of 100 m^3 ha^{-1} at age 14. Volume estimates of Table 2 indicate all stands except Bosque Carillo may reach 100 m^3 ha^{-1} by age 14. Volume of 90.9 m^3 ha^{-1} in the Juanilama plantation at age 15 was based on lower stocking due to mortality of plantain but remaining trees no doubt increased growth rate following the mortality. Volume estimates for the plantations of this study indicated pochote was fairly productive on the range of sites that were sampled. Cordero *et al.* (2003) in a simulation study of pochote growth estimated volume yields of 236 to 332 m^3 ha^{-1} on 100 trees ha^{-1} at age 30 years. Thinnings contribute additional volume to the total yield. Cordero *et al.* (2003) cite Ugalde (1997) reporting maximum volume of 372 m^3 ha^{-1} in a 13-year-old plantation and Melchior *et al.* (1996) estimating potential yields of over 300 m^3 ha^{-1} in 30 years. The maximum predicted volume in this study of 170 m^3 ha^{-1} in 28 years, based on stem analysis data, appears conservative by comparison.

Conclusions

This is evidently the first detailed study of volume increment using stem analysis techniques for pochote in plantations on a limited range of sites in Costa Rica. The methodology yields estimates that agree most closely with predictions of Hughell (1991) and considerably less than yields in the scenarios developed by Cordero *et al.* (2003). Comparison of estimates with actual measurements of yield when stands are harvested will define their accuracy or need for revision. The yield estimates of this study should serve as a useful reference base for growth among other plantations of pochote and possibly with plantations of other species that have similar tree form. These yield estimates should have practical application for forest managers in predicting expected yields for pochote in plantations until more comprehensive yield tables or accurate growth and yield models are developed.

Based on results of this study and the potential sources of sampling variation it is suggested that future studies be done in stands within a narrow age range (e.g. 15 ± 2 years) and include more trees per site. Sampling as described herein should be done in stands that represent a wide range of site qualities and that have had similar silvicultural treatments. Stand density or basal area stocking should also be similar, or the data set stratified accordingly. Data from such a sample should provide a good basis for comparison of production among stands. Other species that form annual growth rings could be sampled in a similar manner and enable comparison among species. This methodology should potentially also prove useful in the study of natural even-aged stands.

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