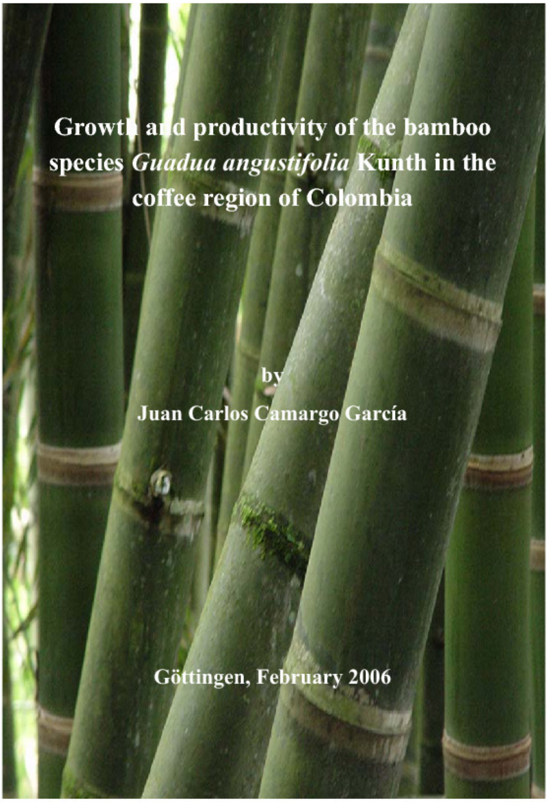
Juan Carlos Camargo Garcia (Autor)

Growth and productivity of the bamboo species Guadua angustifolia Kunth in the coffee region on Colombia



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1. Introduction

Bamboo species have a long history as a multipurpose and widely used renewable resource. Particularly in Asia, bamboos are a source of material for construction, tools and implements for agriculture, pulp for paper, handicrafts, and are also used for soil conservation (BANIK 1999). In addition, bamboo is also popular because its shoots are fit for human consumption (RAZAK 2001).

Bamboo is the base for a wide range of industries that provide the livelihoods for the rural poor mostly in the unorganised sector. In India, the industry is estimated to supply income to 0.5 million people, most of whom are employed by small-scale processing enterprises (HANUMAPPA 1996).

The world bamboo forest area covers about 20 millions ha (ZHOU et al. 1994), with 90 genera and 1200 species (LONDOÑO 1990). Only in America, there are 440 native species, of which 320 are woody (HIDALGO 2003). Within woody bamboos is the genus Guadua (JUDZIEWICZ et al. 1999). This genus contains the largest bamboos from the Americas, which have significant social, economic and cultural importance. These include 30 species widespread from Mexico to Argentina from sea level up to 1800 m.a.s.l. (LONDOÑO 1990).

American woody bamboos have been classified into two groups based on their habit requirements. The first group includes species from genera such as Guadua, Elytrostachys, Olmeca, Elemoucaron, Criciuma, Apoclada, Atractantha and Athroostachis, which are found at elevations below 1500 m (Lowlands). The second group contains species from the genera Aulonemia, Neurolepis and Colanthelia, which are located above 1500 m (JUDZIEWICZ et al. 1999).

The species *Guadua angustifolia* Kunth (*G. angustifolia*) is a woody bamboo. It has its natural habitat in Colombia, Ecuador, and Venezuela, but it has also been introduced to other countries in Central and South America, Europe and Asia. In Colombia, specially in the coffee region, this bamboo species represents an important natural resource, traditionally being used by farmers to build long-lived products such as houses, furniture, handicrafts, agglomerates, veneers and flooring (LONDOÑO 1998a). Its culms are an ideal construction material with a high percentage of fibres and excellent structural properties such as high resistance to weight-ratio, high capacity to absorb energy and excellent flexibility. As a result, houses made of *G. angustifolia* are very resistant to earthquakes (LONDOÑO et al. 2002; GUTIERREZ 2000).

Although in Colombia this bamboo species has been economically important, information that permits an adequate management of this resource is still scarce. There is a lack of basic information on the dendrometric attributes of *G. angustifolia* culms, on stand variables as well as on stand management options. In contrast, other aspects such as stand productivity, performance in different environments and interactions between stand management and environmental factors such as site, soil and climate have been studied (GARCIA 2004; HINCAPIE & PENAGOS 1994). Nevertheless, the results obtained so far do not show a clear trend and it is not yet possible to develop scientifically based silvicultural management options from them.

Management of *G. angustifolia* stands has been applied especially to natural stands. For plantations of *G. angustifolia,* the growth and population dynamics are basically unknown as are silvicultural options. Recently, studies carried out on *G. angustifolia* natural stands have pointed out important changes in population dynamics when the stands are under different harvesting schemes in terms of intensity and frequency (MORALES 2004a). However, it is necessary to find out which are the most appropriate response variables for silvicultural treatments and those that best represent stand dynamics and productivity.

Improvement of the knowledge about dendrometric and stand variables, productivity, growth and silvicultural treatments will be helpful for stand management planning and also for silvicultural and ecological research. This will contribute to the sustainable development and management of this resource in the coffee region of Colombia.

1.1 *Status of forestry and bamboo resources in Colombia*

In Colombia forests cover about 64 million ha (56% of the total area) and about 10 million ha of this area correspond to protected areas (DUQUE 2003). In 1995 forest plantations covered 265,000 ha, 38% of them for profit and 62% for protection (SANCHEZ et al. 2001). Most of the forest plantations area (80%) is composed of species such as *Pinus sp., Cupressus sp.* and *Eucalyptus sp*. Other native species planted in low proportion are: *Cariniana pyriformis, Alnus jorullensis, Cordia alliodora, Cordia gerascanthus, Tabebuia rosea* and *Ceiba pentandra* (DUQUE 2003).

Estimates of land cover changes show that approximately 91,900 ha of forest are logged every year (IDEAM 1996). In 1998, 1,496,034 m^3 of timber were legally extracted from natural forests and 982,228 m^3 from forest plantations (MINAMBIENTE 1999). However, about 27,000,000 m^3 of timber and timber products were imported in 2001 (DUQUE 2003). Therefore, it would be necessary to optimise natural forest management and to integrate new forest areas into adequate silvicultural management. In this way, timber productivity could increase and the balance between supply and demand of timber and forest products could be improved.

In Colombia there are 95 known bamboo species comprising 19 genera, 9 woody and 10 herbaceaous (LONDOÑO 1990). The Guadua genus is economically the most important and the species *G. angustifolia* has been essential for rural communities (LONDOÑO 2004). This species covers an approximate area of 51,500 ha, of which an estimated 46,000 ha are natural stands and 5,300 ha are plantations (CARDER 2000). During a recent inventory study, an estimated area of 28,000 ha covered by Guadua has been identified in the coffee region alone (MORALES & KLEINN 2004).

Although the manufacturing and the added value processes carried out using *Guadua* culms are conduced by weak and informal enterprises (HELD 2005), the productivity of *Guadua* stands may still be economically important. Also, investigations on European bamboo markets evidently point out that markets for industrial bamboo products are expanding (BECKER 2004).

Some estimates in the coffee region show that 2,509,100 culms were harvested between 1994 and 2001. The market value of these culms was estimated to be U$2,509,100 (BERNAL 2002). Stand productivity has been estimated to be around 700 mature culms per ha per year. That means an income of approximately U$ 698 per ha per year (CARDER 2000). MORALES (2004b) showed that the profitability of managed *Guadua* stands may be high in most cases. However, this depends on site conditions, harvesting frequency and intensity. In addition, this profitability is highly sensitive to changes in activities conducted during harvesting and to market prices. Nevertheless, it is important to point out that most of the *Guadua* stands in the Colombian coffee region have not had adequate silvicultural management (CAMARGO et al. 2003) and that high productivity and profitability are recorded only when *Guadua* stands are under an adequate silvicultural management. Therefore, high profitability should be a consequence of good forest planning and silvicultural management as it has been successfully shown for managed *Guadua* stands (CASTAÑO 1987; MORALES 2004a).

1.2 General description of the species Guadua angustifolia

According to taxonomical classification, this bamboo belongs to the Angiosperm sub-division, Monocotyledonous class, Glumifloral order, Poaceae family, Guadua genus and *angustifolia* Kunth species. In Colombia four ecotypes have been described, namely “Macana”, “Cebolla”, “Cotuda”, “Castilla” and also two varieties: “Rayada Negra” and “Rayada Amarilla”. Ecotypes as well as varieties have differences regarding morphological characteristics and timber quality (CRUZ 1994).

Rhizomes of *G. angustifolia* are pachymorph with a sympodial branching pattern. They can be very long, hence stand harvesting and management tends to be easier than for other bamboo species (LONDOÑO 2004). In addition, as with other bamboos, culms at different stages of development occur within a single stand. This affects the decisions on silvicultural management (CASTAÑO 2001; LONDOÑO 1998b). The different stages of culm development are described in Table 1.

Table 1. Characteristics of different stages of culm development of *G. angustifolia.*

Stage of Development	Example
Shoot Begins with the emergence of the new shoot and ends when it reaches its maximum height. Shoots are always protected by culm sheaths, branches and foliage are not developed while the shoot is elongating (LONDOÑO 1998b). *Duration of stage:* about 6 months (DAVID & DAZA 1994; MORALES 2004c).	
Young Starts when culm sheaths detach. The colour of the culms is intense green and the development of branches and foliage leaves occurs (LONDOÑO 1998b). *Duration of stage*: from 11 to 15 months (DAVID & DAZA 1994; MORALES 2004c).	
Mature This stage is characterised by a change of culm colour from a bright green colour to a more opaque green, gradually turning grey as lichen, fungi, and mosses (white and grey in colour) grow on the culm surface. This stage is the most suitable for harvesting (LONDOÑO 1998b). *Duration of stage*: about 17 to 20 months (DAVID & DAZA 1994; MORALES 2004c).	
Over-mature Culms start to senesce and pink fungi appear on the culm surface. Branches at the middle portion of the culm begin to dry (LONDOÑO 1998b). These culms may be considered for harvesting. *Duration of stage*: about 60 to 88 months (DAVID & DAZA 1994; MORALES 2004c).	
Dry The culms turn yellow and branches and leaves are dry. This is the last stage. Later on culms die. Usually, most of the dry culms are found dead. Culms are also harvested but they lack commercial value. *Duration of stage*: about 9 to 10 months (DAVID & DAZA 1994; MORALES 2004c).	

The stage of maturity and the unique growth pattern of bamboos should be considered when productivity is to be evaluated and also when forest mensuration techniques are applied to bamboo. The maturity of the bamboo culm is the result of a process of primary growth through which culms reach their maximum diameter, elongation of internodes and subsequent hardening through lignification (LIESE 1995). If the characteristics of *G. angustifolia* culms at each stage of development are taken into account, it may be said that growth occurs during the first stage of development (shoots). Being a monocotyledon, bamboo does not possess a vascular cambium, consequently each culm emerges with a fixed diameter and culm growth may be defined as the increase in height and wood maturity (JUDZIEWICZ et al. 1999), unlike trees, where diameter can be used as an indicator of maturity.

In bamboos the fibres, which are thick-walled and lignified, provide internal support and are the main cellular structures responsible for the hardness of the internode (LIESE 1991). Bamboo culms are composed of about 50% parenchyma, 40% fibres and 10% vascular tissue (LIESE 1987). Culm growth only occurs longitudinally whereas in trees it is also radial. Bamboos have hollow internodes with a well defined lacuna and a culm wall thickness which varies considerably from species to species (JUDZIEWICZ et al. 1999). Naturally, these special features also occur in *G. angustifolia* and they should be taken into account for its mensuration.

2. Problem statement

2.1 Growth, quality, productivity and silviculture of G. angustifolia: Present state of knowledge and special considerations

2.1.1 Growth and dendrometric variables

The growth patterns of bamboos and trees are completely different; therefore some aspects should be considered when bamboo growth is expressed through dendrometric variables. As previously mentioned, *G. angustifolia* is a monocot and lacks a vascular cambium, consequently each culm emerges with a fixed diameter and achieves its final height within six or seven months (JUDZIEWICZ et al. 1999) and hence differences in culm diameter or culm length are not strongly associated with age as it is usually seen in trees.

As in other bamboos, *G. angustifolia* culms are curved in the upper section, which means that the measured height does not correlate with culm growth. For trees, height and length are usually almost identical. In contrast, for this bamboo species culm length and culm height are considerably different (Figure 1). Therefore, the variable of interest is obviously culm length because it is directly related to the commercial product. For trees, diameter is usually measured at breast height, which is fixed at 1.3 m in most countries. This concept is not appropriate for bamboos because diameter varies with the proximity to the nodes. Therefore, it is more appropriate to measure the reference diameter in the *middle* of the internode (i.e. between the nodes) where conventional breast height (1.3m) would be. This means that the diameter is actually measured at slightly different heights (Figure 2).

For bamboo species, models for predicting culm height from diameter are not often used (FU 2001; WATANABE & OOHATA 1980). For *G. angustifolia*, a simple model has been used to predict culm length (*L*) from the perimeter at breast height (*C*), including a constant (*K)*, which has been determined empirically. Culm length is then estimated as $L = C \times K$. Values for K are 0.56 and 0.5837 as reported by ARBELAEZ (1996) and CRUZ (1994) respectively.

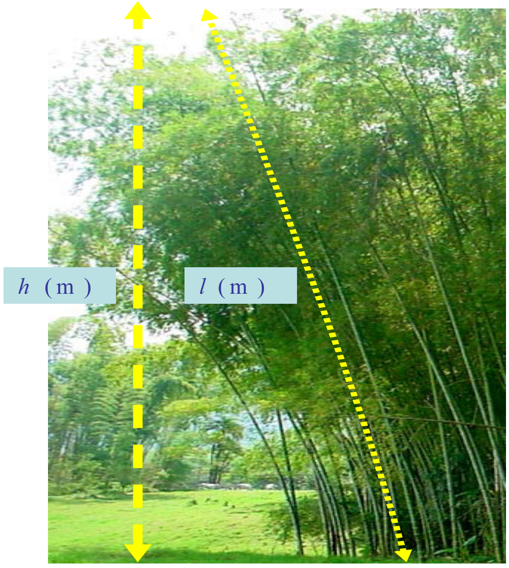

Figure 1. Differences between culm height (*h*) and culm length (*l*).

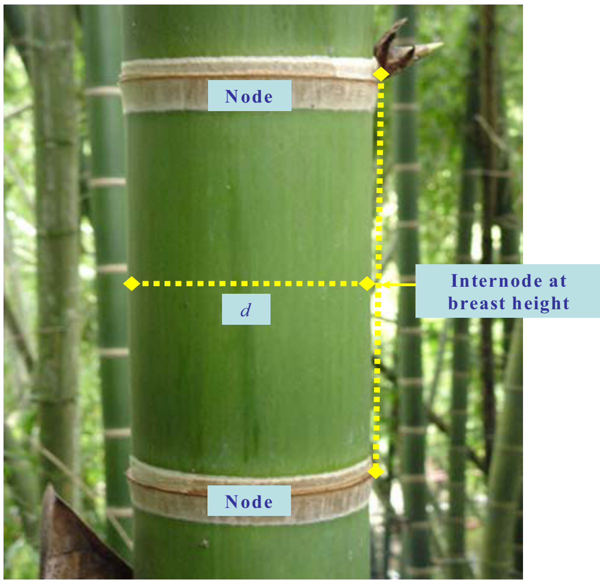

Figure 2. Culm diameter (*d*) variation between internodes.

Another important variable in forestry which can represent not only growth but also productivity is volume. There are few studies on bamboo culm volume. Culm volume is not usually measured because bamboo culms are hollow (FU 2001), thus, estimations only represent *apparent* values of culm volume (apparent volume). In some studies volume estimation has been used for biomass estimation (REID et al. 2004), or in the