

## **Plant growth and biomass distribution on *Guadua angustifolia* Kunth in relation to ageing in the Valle del Cauca – Colombia**

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Samples from complete *Guadua angustifolia* clumps, with different ages, on the southeastern flank of the Cauca River valley (Colombia) were chosen for this study. Estimates of the accumulated biomass (>50 metric tons CO<sub>2</sub> ha<sup>-1</sup> during 6 years) and its redistribution into different organs were obtained. The aerial portions (culm, branches, foliage leaves, and caulinar leaves) accumulate 80.1% of the total biomass and CO<sub>2</sub> fixation, and the rhizome 19.9% of these. Mathematical functions that describe its growth as a function of chronological time on number of organs, fresh and dry weight, and leaf area measurements were developed.

The atmospheric concentration of carbon dioxide has increased during the last five decades, mainly as a consequence of the combustion of fossil organic matter (coal, oil) and non-fossil matter (forests) resulting from antropogenic activity (IPCC 1996). According to Goodess *et al* (1992), the CO<sub>2</sub> rate increases 1.8 μmol (CO<sub>2</sub>) mol<sup>-1</sup>(air) year<sup>-1</sup>, equivalent to 0.5% year<sup>-1</sup>. Estimates indicate that in 100 years if the increasing rate is maintained, the environmental CO<sub>2</sub> will reach values of 650 -700 μmol (CO<sub>2</sub>) mol<sup>-1</sup>(air). This could cause an increase in the average global temperature of 1.5 C to 4.5 C (Saratlabai *et al.* 1997; IPCC 1996).

Renewable biomass cultivated as a carbon sump can be managed in short rotation shifts, using it for the production of long-term consumption goods and for construction. Because of its low contents of sulfuric pollutants, plant biomass might be converted into energy, heat and liquid or gas fuels without great hazards to environment (GIECC 2000a).

The Clean Development Mechanisms (CDM) is the only instrument that links developed countries to the reduction of emissions, and which could lead those countries to invest resources by sowing plantations with high potential to fix atmospheric carbon dioxide.

*G. angustifolia* is one of the tropical species that have been identified as having great potential

to fix atmospheric carbon dioxide. It is one of the 3 largest bamboo species and one of the most important in the world. Because of its physical/mechanical properties it may be used to manufacture long lived products such as houses, furniture, handicrafts, agglomerates, veneers, floors, etc. (Londoño 1998a). *Guadua angustifolia* can increase its height up to 21 cm day<sup>-1</sup> and emerges from the ground with a constant diameter up to 22 cm. Culms reach their final height in the first 6 months of growth, and come to maturity when they are 4 to 5 years old. Optimum growth is reached between 500 and 1500 m of altitude, with a rainfall of 1200-2500 mm per year<sup>-1</sup>, temperatures between 18°C and 24°C, and 80-90% relative humidity. It adapts well to extreme rainfall conditions of Colombian tropical rain forests (more than 10000 mm per year<sup>-1</sup>) but not under very dry conditions (<800 mm per year) (Londoño 1998b). The ideal composition of culms in a *Guadua* plantation has been estimated to be 10% new shoots, 30% young culms, 60% mature and over mature culms and no dry ones, with a density between 3000 to 8000 culms per ha. The diameter diminishes as culm density increases (Londoño 1998b; CVC 2000).

In Colombia, *G. angustifolia* covers an approximate area of 51500 ha, 46261 ha of which are wild and 5260 ha are cultivated. The Valle del Cauca Department, has the largest

Table 1. Location and planting year of the sampling plots.

Plot	Municipality	Township	Sub-basin river	Altitude m.a.s.l	Planting Year	Semester
Katanovo	El Cerrito	San Antonio	Nima-Amaime	967	1995	B
B. Municipal	Palmira	Área Urbana	Nima-Amaime	1107	1996	A
Tarjo 2	El Cerrito	San Antonio	Nima-Amaime	964	1997	A
Canta Claro	Pradera	La Buitrera	Bolo-Fraile-Desb.	1189	1997	B
Las Vegas	Palmira	Guanabanal	Nima-Amaime	-	1998	B
Bella Vista	El Cerrito	El Paraíso	Nima-Amaime	1389	1999	A
El Palomar	Pradera	El Recreo	Bolo-Fraile-Desb.	1232	1999	B
La Playa	Florida	El Tamboral	Bolo-Fraile-Desb.	1415	2000	A
Normandía	Palmira	Aguaclara	Bolo-Fraile-Desb.	-	2000	B

area of wild guadua plantations (7960 ha), and has contributed the largest reforested area of this species (1830 ha) (Londoño 1998a; CVC 2000).

Biomass contribution of *G. angustifolia* to the soil biomass is around 10 tons per ha per year, and dry matter accumulation reaches 76.6 tons per ha including culms, branches, foliage leaves and cauline leaves (De Wilde 1993). Most of the studies on nutrient extraction and composition of culms have been focused on recycling of nutrients and fertilization (Shanmughavel & Francis 1996; 1997; De Wilde 1993). No reports on growth analysis (accumulation and distribution of dry matter) or CO<sub>2</sub> fixation for photosynthetically active area were found in the literature.

The objective of this research is to study basic aspects of the biomass accumulation of *G. angustifolia* in order to establish the potential of this species as atmospheric carbon dioxide fixer, following classical growth analysis.

## MATERIALS AND METHODS

### Location and planting year of the sampling sites

Samples were taken from the southeastern flank of the Cauca River valley. The municipality, township, sub-basin river, altitude and establishing year from the 9 reforested sites of *G. angustifolia* are shown in Table 1. The measure was done during June and August of 2001, corresponding with a dry season in this zone.

During the 3 months period of sampling, 5 clumps of *G. angustifolia* in each nine (9) farms, planted during 1995 to 2000 (72 months or 2190 days) were harvested.

### Sampling and measurement of the response variables

In clumps from 6 to 36 months old (1080 days) were measured fresh weight, dry weight, leaf area, culm number and height. Rhizome fresh weight was determined using a digital balance (Mettler 16E), material was chopped and dried down to constant weight in a DIES-640 oven with an air recycling system at 80°C.

In clumps older than 1080 days only 3 new shoots, 3 young culms and 5 mature culms of each clump with its rhizomes were sampled. Culms were cut in two or three segments of the same length, depending on total height, and the diameter in the middle of each segment was measured, weighed and a 10 cm long sample from the middle was weighed and dried to constant weight.

Fresh weight of branches, cauline leaves and culm leaves were measured using a 200 g sample of both branches and leaves dried to constant weight. Leaf area was measured with a Delta T-Device. Fresh weight, dry weight and leaf area were measured on three early shooting culms, three young culms and five mature culms. Rhizome dry weight was measured on 200 g samples.

Data processing was carried out using MS Excel, Sigma Plot 5.0 and SAS.

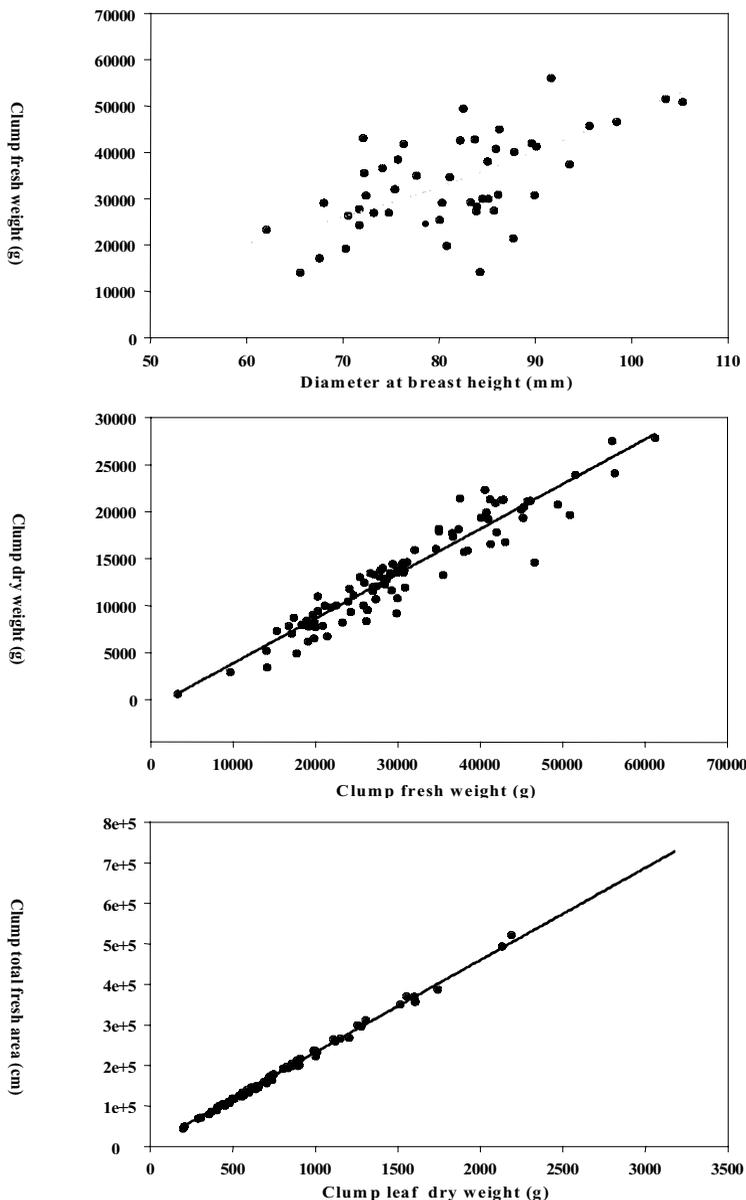


Figure 1. Linear relationships between: a. DBH/ clump fresh weight; b. whole plant fresh weight / whole plant dry weight; c. clump leaf dry weight / clump total leaf area. Fitted model (center line) and confidence limits (0.95).

## RESULTS AND DISCUSSION

Although the correlation coefficient ( $r$ ) between total fresh weight and the diameter at 1.5 m height (DBH) seems to be high (0.67), only 45% of the whole fresh weight can be explained by the variation of DBH in *G. angustifolia*.

Nonetheless, the magnitude of  $r$  is statistically significant ( $p < 0.0001$ ). This result seems to indicate a rough tendency to linearity of total fresh weight as a function of DBH although it is not sufficient to estimate accurately total fresh weight on DBH basis. This can be illustrated because most of the points fall outside of

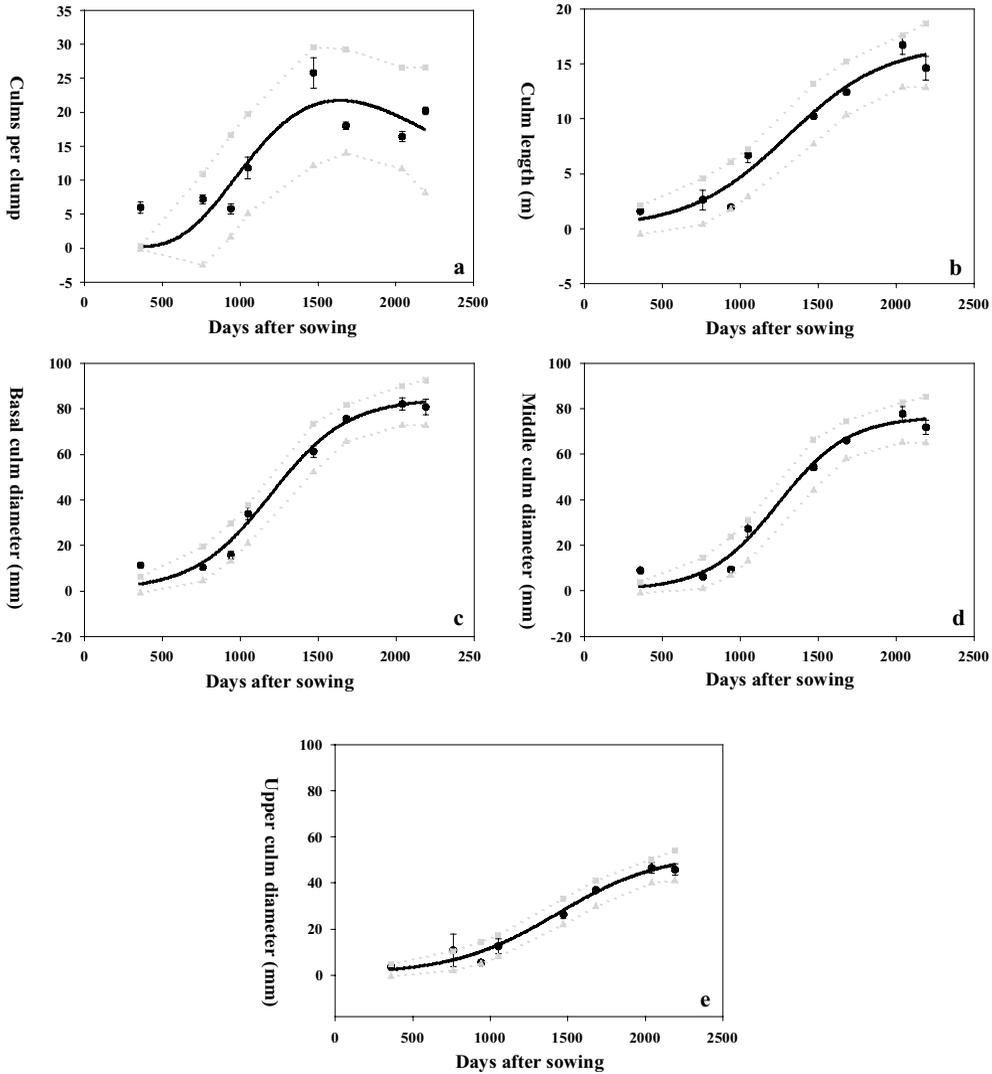


Figure 2. Growth models for: a. culms per plants; b. culm length; c. lower culm diameter; d. middle culm diameter; e. upper culm diameter. Vertical bars standard error. Fitted model (center line) and confidence limits (0.95)

confidence limits at  $p < 0.05$  (Fig.1a). The behavior of clump fresh weight as a function of DBH can be described as follows:

$$CFW = -25474.8 + 705.09 \text{ DBH}$$

Where: CFW = clump fresh weight in g  
 DBH = Diameter in mm at breast height (1.5 m)

A closer relationship was found between clump total dry weight and clump total fresh

weight (Fig. 1b). The observed dispersion of points can be explained by the effect of the water content variability inside the plant tissues. The linear tendency of clump total dry weight as a function of total clump fresh weight is described by

$$CDW = -1.007 + 0.476 \text{ CFW}$$

Where: CDW = clump dry weight (g)

Table 2. Characteristics of the exponential functions describing length and diameter of the culm (at lower, middle and upper third) as function of time (days after sowing).

F	a	b	Xo	r <sup>2</sup>	p
Culm length (m)	16.7	313.27	1310.4	0.96	0.0004
Lower diameter (mm)	84.07	245.83	1203.55	0.98	< 0.0001
Meddle diameter (mm)	76.17	224.73	1252.01	0.98	< 0.0001
Upper diameter (mm)	52.49	334.4	1438.32	0.98	< 0.0001

The correlation coefficient ( $r = 0.95$ ) and determination coefficient ( $r^2 = 0.90$ ) indicate that the biomass accumulation in the total clump of *G. angustifolia* can be estimated on the basis of total fresh weight of the clump.

Regression analysis of clump total leaf area as a function of total leaf dry weight ( $r = 0.99$  and  $r^2 = 0.99$ ) indicate that clump leaf dry weight is a useful variable to estimate clump total leaf area. Linearity of the clump leaf area is described by:

$$CLA = 2337.70 + 227.73 \text{ CLDW}$$

Where: CLA = Clump total leaf area (cm<sup>2</sup>)

CLDW = Clump leaf dry weight (g)

### Growth analysis

#### *Culms per clump*

This variable is described by:

$$C = ae^{\left[0.5 \ln \left(\frac{x-x_0}{b}\right)\right]^2}$$

Where: C = culms per clump; a = 21,6; b = 0,4; X<sub>0</sub> = 1648,9; X = Time after planted.

The determination coefficient is  $r^2 = 0.72$  ( $r = 0.85$ ). Although  $r^2$  can explain 72% of the variability due to the effect of time on culm

number, the confidence limits ( $p < 0.05$ ) seems to be very broad (Fig. 2a). This result can be explained because samplings were affected by different climate conditions registered along time. The maximum number of culms per clump is achieved around 1650 days after planting, and then it diminishes because the culms reached maturity and were harvested.

#### *Culm length and basal, middle and upper diameter*

The behavior of these variables can be described following the logistic function

$$F = \frac{a}{1 + e^{-\frac{(x-x_0)}{b}}}$$

The statistics for the different variables are registered in Table 2.

The culm length and similarity of the different culm diameter sections along time, seems to indicate that the different plantations from which the samples were chosen are originated from the same clone, and indicate that this clone has a high genetic stability at different localities. These results suggest also that the culm diameter at different heights can be estimated as a function of time for the different localities

Table 3. Characteristics of exponential models describing accumulation of dry matter in rhizomes, new shoots, whole leaf area and whole clump as function of time (days after planting).

Variable F	Xo	r <sup>2</sup>	p
Rhizome (g)	1672.96	0.97	0.0002
Culm (g)	1662.90	0.98	< 0.0001
Branch (g)	1063.06	0.97	0.0001
Culm Leaves (g)	1092.48	0.99	< 0.0001
Foliage Leaves (g)	1055.96	0.91	0.0023
New Shoot (g)	1614.29	0.97	0.0001
Whole Clump (g)	1611.90	0.97	0.0001
Clump total leaf area (m <sup>2</sup> )	1070.20	0.93	0.0012

Table 4. Weight organs ratio and leaf area ratio for *Guadua angustifolia* through time.

Days after planting	Rhizome ratio g g <sup>-1</sup>	Culm ratio g g <sup>-1</sup>	Branch ratio g g <sup>-1</sup>	Culm leaves ratio g g <sup>-1</sup>	Foliage leaves ratio g g <sup>-1</sup>	Leaf area cm <sup>2</sup> g <sup>-1</sup>
360	0.18	0.29	0.26	0.003	0.26	49.02
760	0.20	0.36	0.24	0.020	0.20	46.54
940	0.24	0.36	0.27	0.002	0.14	37.92
1050	0.57	0.51	0.28	0.010	0.20	36.91
1470	0.18	0.67	0.09	0.008	0.06	13.29
1680	0.19	0.69	0.07	0.007	0.04	9.90
2040	0.18	0.73	0.06	0.005	0.03	7.55
2190	0.19	0.72	0.05	0.004	0.04	8.35

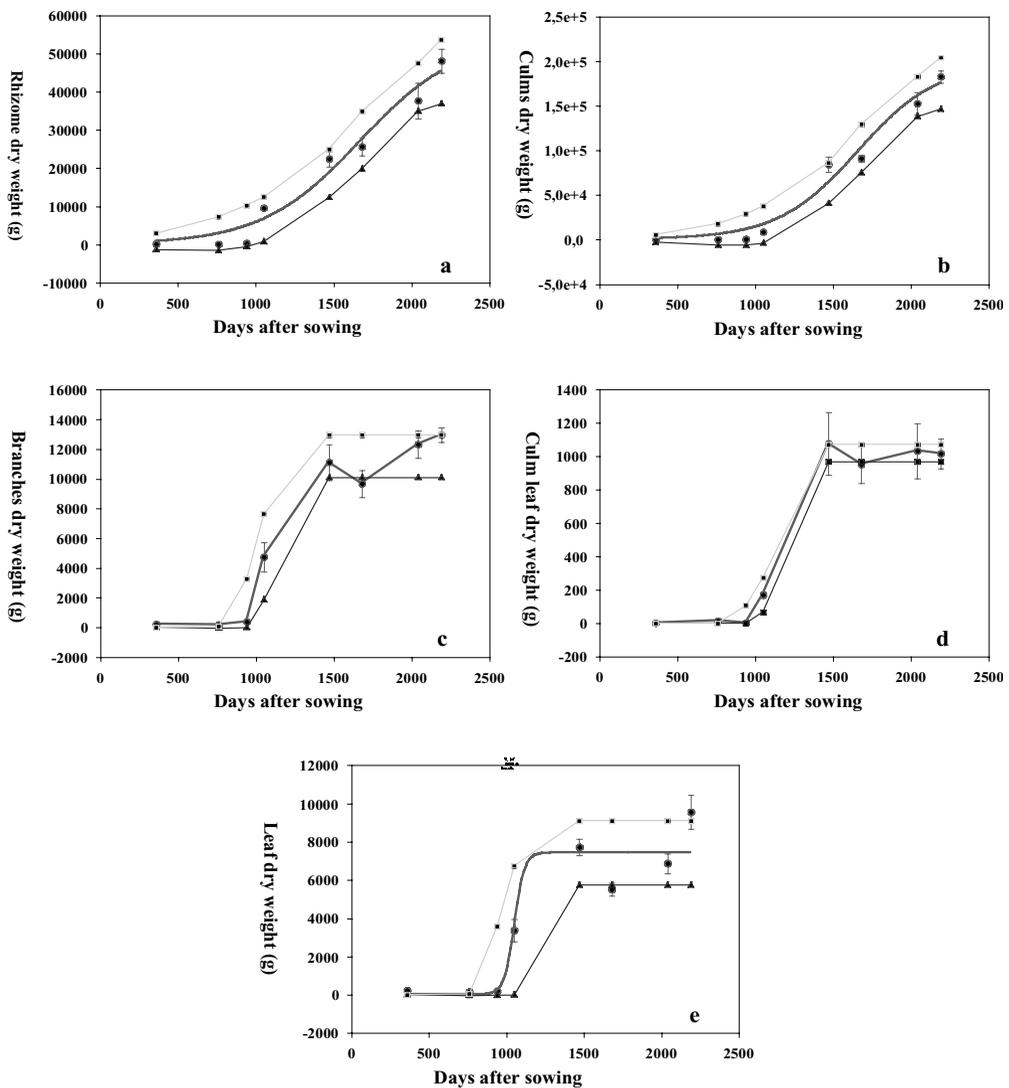


Figure 3. Dry weight growth models for: a. rhizome; b. culm; c. branches; d. culm leaves; e. leaves. Vertical bars standard error. Fitted model (center line) and confidence limits (0.95)

of the Cauca River Valley with a high degree of accuracy (Fig. 2b, 2c, 2d, 2e).

The same logistic function can be used to describe dry matter accumulation in rhizome, new shoots, culm, branches, caulinar leaves, foliage leaves and the whole clumps of *G. angustifolia* as a function of time. For all the measured variables the values of  $r^2$  are higher than 0.91. The minimum value (0.91) was registered for leaves dry weight and it can be explained by a high rate of leaf exchange as was reported by De Wilde (1993) and Shanmughavel & Francis (1996) (Table 3).

Branches, caulinar leaves, foliage leaves and leaf area achieved its maximum growth rate to 1050 days after planting. Meanwhile, rhizome, culm, new shoot and whole clump reached the inflexion point at 1600 days after planting. This delay can be explained because rhizomes and culms are the major organs for dry matter accumulation in the clump and the filling time goes beyond the peak of maximum growth of the assimilates sources. The highest rhizome ratio (0.57) (Table 4) was registered at 1050 days after planting. This result is in accord with the maximum growth rate obtained for branches, caulinar leaves, foliage leaves and leaf area.

During the growth period, the rhizome maintains its relative contribution to clump at an almost constant value of 0.2. Meanwhile, the culm increases its relative contribution from 0.3 to 0.7. These data suggest that in the early stages of growth, the contribution of rhizome and culm reach 50 % of the total biomass and six years later the contribution of rhizome and the culm to the total biomass reaches 90%. From a production and environmental point of view, this value is desirable because at the harvesting time the 90% of the carbon fixed can remain long term as fixed biomass (culms as durable products and the rhizome as underground biomass with slow degradation) (Table 4). Only 10% of fixed carbon is quickly turned over in the biosphere (IPCC 2001).

Branch and leaves weight ratio exponentially decreases up to 0.05, while the contribution of the caulinar leaves does not surpass 0.02

independently of age. Leaf area ratio decreases exponentially from 50 to 8 cm<sup>2</sup> (leaf area) g<sup>-1</sup> (clump dry weight). These results indicate that at the early stages of growth the plant depends completely upon the leaf area to build the carbon chains and metabolites, which allow the growth of each organ. However, the distribution of these assimilates are more efficient with increase of the ageing because the morphological characteristics of the rhizome system guaranteeing a better supply of assimilates from mature culms (with optimum photosynthetic activity) to the new shoots and young culms (which have a limited active photosynthetic area).

Further research could be focused on culm, cauline leaves and leaf photosynthetic activity in order to explain their contribution to biomass accumulation. There is evidence (López *et al.*, non published data) of active stomata and significative activity of PEPC, NAD-ME and PPK in culm epidermis tissues. Presence of C<sub>4</sub> syndrome in tissues different to those of Kranz anatomy is reported by Hibberd (2002) in tobacco and celery.

Following our methodology, the carbon fixation estimated for 400 clumps ha<sup>-1</sup> of *Guadua angustifolia*, for a growth period of 2190 days (6 years), is 54.3 ton, where 10.8 ton (19.9%) of CO<sub>2</sub> fixation corresponds to the rhizome and 43.5 ton (80.1%) to the aerial part of the clump (Table 5). The 0.5 international coefficient assumed for timber (Brown 2001) was used in this study.

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Table 5. Dry weight and carbon fixed into different organs of *Guadua angustifolia* (400 clumps ha<sup>-1</sup>).

Organ	Dry weight (ton ha <sup>-1</sup> )	Carbon Fixated (ton ha <sup>-1</sup> )
Rhizome	21.6	10.8
Culm	79.11	39.5
Branches	4.6	2.3
Caulinar leaves	0.4	0.2
Foliage leaves	2.96	1.48
Aerial part	87.07	43.5
400 clumps ha <sup>-1</sup>	108.67	54.3

Number of culms = 8640; clump total leaf area = 67152 m<sup>2</sup>; leaf area index = 6.7

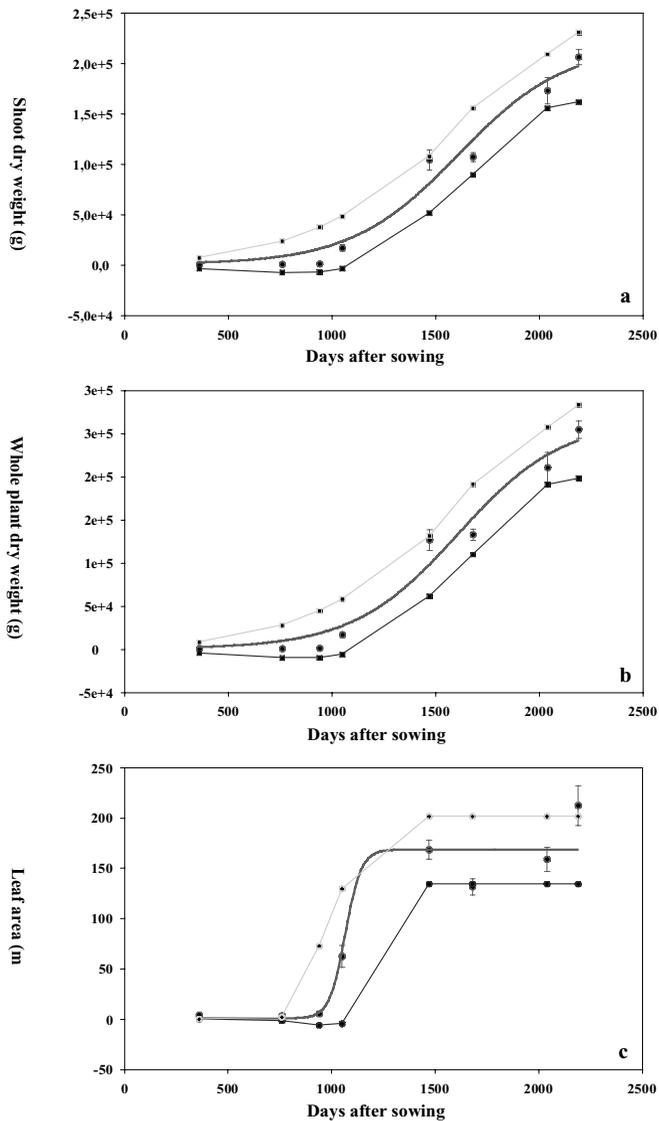


Figure 4. Dry weight and leaf area growth models for: a. shoots; b. whole plant; c. leaf area. Vertical bars standard error. Fitted model (center line) and confidence limits (0.95).

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