Biomass generation and Carbon fixation in Guadua Bamboo*: Guadua angustifolia* Kunth.

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Abstract

In Mexico bamboo grows in many aspects; forestry, plantations, propagation, evaluation not only in native but also in exotic bamboo species with high economical potential, construction, biomass production, charcoal, clean energy, engineered wood and cellulose. Among the most important research done in Mexico is the biomass production and carbon sequestration in *Guadua angustifolia*. This research was done during more than 7 years.

In terms of biomass production in this research, a number of commercial plantations existing in different localities in Mexico were selected. They were studied by place and ultimately an average was arrived at for five (5) repetitions sown at 6 m x 6m and putting fertilizers using the dynamic of nutrients extraction discovered to *Guadua angustifolia*. Among the plantations selected in each of the localities, clumps were chosen at one year, two years, and thus successively until seven years of age. The biomass was calculated and wet weight was recorded in every part of the plant and consequently in the clump. The biomass average results obtained shown that by the end of the seventh year a clump reach 2145.3kg. From this it may be concluded that *Guadua angustifolia* produces 596.39 tons/Ha of green biomass at seven years and under the sowing distance referred before. The average is 85.19 ton/ha/year.

In terms of capture of Carbon, *Guadua angustifolia* as a tropical and giant bamboo is an excellent bamboo to fix it. A clump fixates an accumulated total of 539.1 kg of carbon during seven year period. The amount accumulated each year during this research indicates that by the seventh year the accumulated amount was 149.9 tonsC/ha., which in turn means that at that age each hectare planted with captures 21.41 tons C/ha/year equivalent to 78.5 tons CO_2 /ha/year.

Introduction

Global warming is an outcome of massive emissions of greenhouse gases, as a result of increasing concentrations in the atmosphere and, as a consequence, a high percentage of the heat that enters the earth's atmosphere is trapped within the atmosphere, thereby raising the temperature on the planet. This phenomenon is known as the greenhouse gas effect.

Among the greenhouse gases, carbon dioxide (CO_2) is the most significant, as its concentration represents between 66% and 70% of the total gases. In the search for solutions to global warming, a number of strategies have been drawn up, such as the use of alternative energies or the development of forestry projects that contribute to mitigate the impact generated by carbon dioxide emissions.

Forestry projects with trees and bamboos contribute to mitigating the greenhouse effect through the process of photosynthesis, in which one of the raw materials is CO_2, which is thereupon transformed into

more complex products such as cellulose, starches and so on. Through this process, the carbon dioxide which would otherwise go directly into the atmosphere is fixed in the plant's total biomass.

Objective of the investigation.

Quantify a *Guadua angustifolia* grow, biomass production and carbon fixation in commercial plantations in different localities in Mexico during seven years.

Background.

In 1992, during the Earth Summit held in Rio de Janeiro, Brazil, the Framework Convention on Climate Change was drawn up, with the goal of stabilizing the concentration of greenhouse gases. The Convention appointed a Conference of Parties (COP) as its highest organization.

At the third meeting of the COP, held in Kyoto, Japan, in 1997, 38 western industrialized nations and another 11 from Eastern Europe were legally obligated to take the necessary measures to lower the concentration of greenhouse gases to a level 5.2% lower than the emissions existing in 1990 by the years 2008 and 2012, respectively. The Kyoto Protocol went into effect in 2005.

The Protocol designed three cooperation mechanisms in order to assist the industrialized countries in complying with their greenhouse gas reduction goals. These are as follows:

1) International trade: countries may trade in emissions, thus allowing for the transfer of part of the "emissions permitted".

2) Joint implementation (JI): This allows countries to claim credits for emissions reductions by transferring "emission reduction units" between industrialized countries.

3) Clean Development Mechanism (CDM): This allows for generating emission reduction projects that help developing countries to achieve sustainable development and receive emissions reduction certificates that can be sold to companies or industrialized countries that produce greenhouse gases.

This last mechanism provides the private sector and industrialized countries the opportunity to reduce emissions anywhere in the world and to add these reductions to their own goals.

Among other alternatives, forestation and reforestation are included as CDM activities, as sumps and fixators of CO_2 emissions.

Bamboos are good to be included as CDM activities and they have some advantages over other forest species as:

In this case, Bamboo Guadua: *Guadua angustifolia* is a self-regenerating plant, with proper management and harvests using the culling system, the permanent biomass generation and consequently capture of CO_2 is guaranteed. This is not the case with other species, where upon being harvested the process needs to be start over.

Guadua angustifolia grows much faster than other forest species. It has a rhizome clumper, which is a permanent storage site for photosynthesis products. This means that a significant percentage of carbon dioxide is captured, with the added advantage that these are not removed when harvesting.

Further, the periodical selective harvest increases the yields of guadua plantations. This implies the plant has a greater physiological dynamic.

Depending upon uses to be made of the guadua culms, the harvest can begin earlier than is the case with other forest species.

Guadua needs to be planted only once, and with good management becomes a permanent plantation.

A large number of long-lasting transformed products can be obtained from guadua, which means CO_2 would be fixed for long periods of time. This degree of versatility is an advantage when compared to other forest species.

Related to the investigations in *Guadua angustifolia* as a biomass producer and Carbono fixation, Riaño *et al* (2002) carried out a study in plantations in the province of Valle del Cauca, Colombia, in order to determine the accumulated biomass in relation to its age. The measurements took place using plants aged from 6 to 72 months. The sample plants used were measured in their entirety, including rhizomes and roots.

The initial planting took place with a density of 400 plants per hectare. After six years a total of 8,640 stems were produced. The biomass produced measured as dry weight was 108.7 ton/ha.

The research described in the foregoing had for an end result that the sequestration of carbon under the circumstance described is of 54.3 tons/ha over six years.

Methodology of the investigation in México.

In two commercial plantations of *Guadua angustifolia* sown at 6m x 6m and with commercial management, located in the towns of Reform and Tapachula, Chiapas, Mexico was established this research to measure grow of the clump, biomass produced and carbon fixation every year.

The design was completely randomized with 5 repetitions, 3 of them in Reforma and two in Tapachula. The repetitions consisted of blocks of 20 Ha.

In each repetition at the moment of the plantation was established, completely random were marked 14 clumps to be removed totally out the soil, 2 clumps per year over a period of seven years.

Method for calculating the growth of the clumps.

In every marked clump, every year was counted and recorded the number of culms in the clump and registered the highest height and larger diameter of culm.

Method for calculating biomass

In the first year, 2 clumps scored with 1 year old per repetition were pulled entirety out the soil. The clumps were dismembered in plants and in every one of them were separated their organs. Wet weight was recorded for roots, rhizomes, culms, cauline leaves, branches and typical leaves. Then, was obtained the total wet weight per organ, plant, clump, and repetition. Using this methodology the wet biomass was obtained in every repetition in Reforma and Tapachula and finally the average of biomass per year.

This process was repeated every year until seven year of age of the plantations.

Method for calculating the Carbon fixated.

Once the total wet weight was recorded for each plant and by organ and consequently by clump, repetition and locality, vegetative samples consisting of a kilogram were gathered of each organ component. These were taken to a laboratory, where dry weight by organ, plant, clump, repetition and locality was obtained. The wet samples were placed in an oven at 80 degrees Celsius and were weighed periodically until the weight was stabilized. This final data is crucial to know the Carbon fixed by organ , plant and clump depending of the year of age.

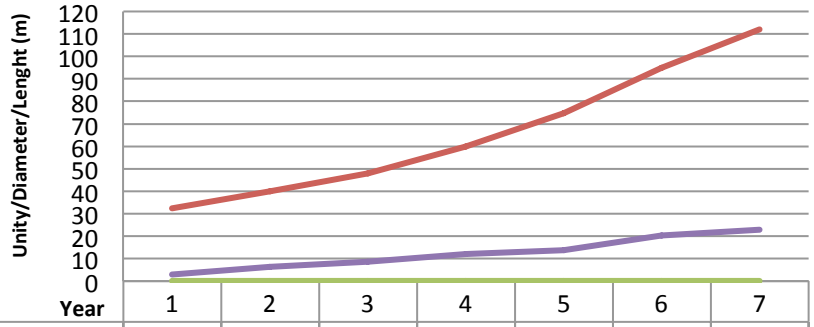
This process was repeated every year until seven year old of the plantation.

Result and discussions.

Growth of the clumps.

Vegetative measurements were made of clumps taken from plantations every year. The Average growth of a clump in Mexico in *Guadua angustifolia* during seven years is showed. Diagram 1.

Diagram 1. GROWTH OF A Guadua angustifolia CLUMP



Year	1	2	3	4	5	6	7
# Stems/Clump	32.4	40.1	48	60	74.6	95	111.9
Thickest diameter (m)	0.0192	0.036	0.0469	0.0702	0.0943	0.11	0.135
Greatest Length (m)	2.83	6.25	8.53	12.1	13.9	20.3	23

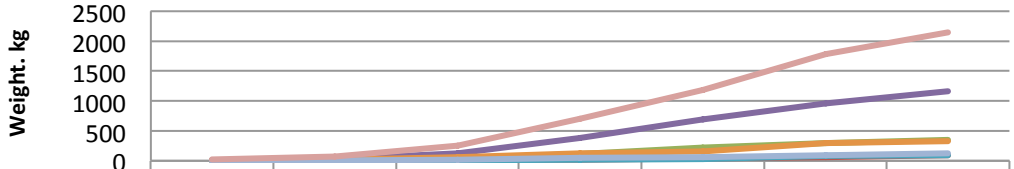
Fuente: Hormilson Cruz Rios. Bambu Guadua: *Guadua angustifolia* Kunth. Editorial Colmex. 720 page. 2009

At the aforementioned distance of 6 x 6 m with application of fertilization, the clump produces 111.9 stems during seven years. With 278 clumps/ha, the production are 30996 stems/ha with many different diameter classes. In this production, the 60% of the stems have less than 7 cm in diameter and is important to note that when the plantation is seven years old, much of culms have cut or died specially those were recorded when they were 1 and 2 years old.

Biomass production.

The biomass generation per organ, plant and clump and per age of the plantation is shown. (Diagram 2).

Diagram 2. AVERAGE GREEN WEIGH ACCUMULATED BY ORGAN, CLUMP AND YEAR.



Years	1	2	3	4	5	6	7
Roots	1.53	9.35	15.9	19.1	38.1	60.1	97
Rhizomes	3.98	7.3	33.9	114.2	216	293.4	350
Culms	10.9	30.5	125.5	383.3	688	959	1159.7
Cauline leaves	1.38	2.68	5.7	13.8	29.3	81	90
Branches	3.69	13.8	56.6	128.3	158.2	299.3	323.7
Typical leaves	1.08	4.13	13.9	47.4	56.2	92.9	125
Total/clump	22.56	67.76	251.5	706.1	1185.8	1785.7	2145.4

Fuente: Hormilson Cruz Rios. Bambu Guadua: *Guadua angustifolia* Kunth. Editorial Colmex. 720 page. 2009

As reflected in under the conditions, over a six-year period a clump of *Guadua angustifolia* will on average accumulate a wet biomass of 1785.7 kg., reaching 2145.4 kg by the end of the seventh year when the plantation reaches maturity.

A single clump of *Guadua angustifolia* acquires a little over two tons in weight in seven years. From this it may be concluded that one ha of *Guadua angustifolia* sown 6m x 6m and under a fertilization program, produces 594.39 tons/ha of green or wet biomass at seven years of having been planted.

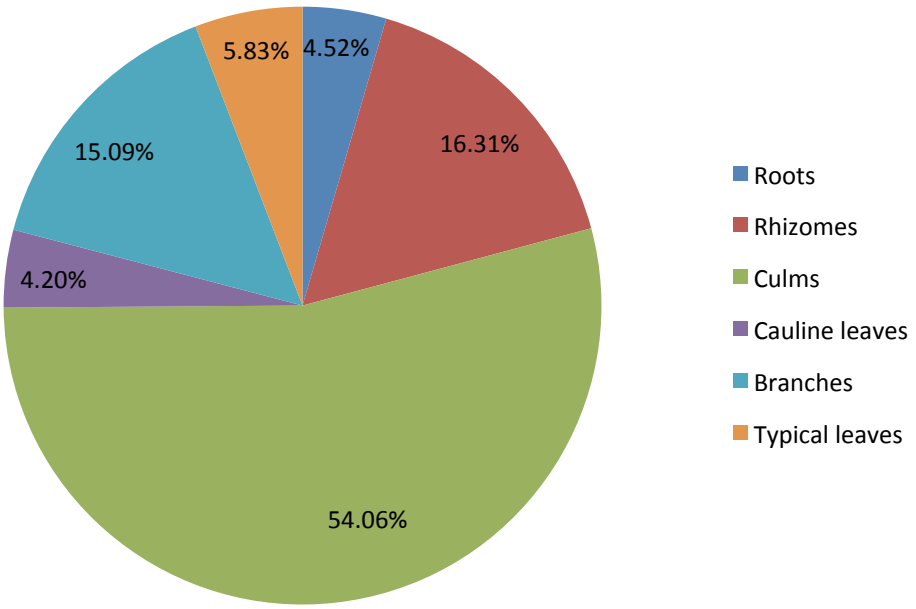
The average of wet biomass produced by year is 84.91 ton/ha but definitively the values increases after 4 years of age of the clump.

The highest amounts of biomass begin to be generated from the fourth year of age of the plantation and this is because the rhizomes are already bigger and the branches and culms start getting more rapidly in diameter and height. At seven years old the plantation gets the maturity and the biomass production is stabilized and not continues growing in the same percentage.

At seven years of life the accumulated weight of the culms is the most significant factor among the plants organs with the rhizomes being the second most important producers of biomass.

In percentage terms, the culms contribute 54.1% of the total green weight of the clump, followed by rhizomes at 16.3%. Between the two they contribute 70.4% of the plant's total green weight. (Diagram 3)

Diagram 3. ACCUMULATED PERCENTAJE IN WET WEIGHT IN A CLUMP

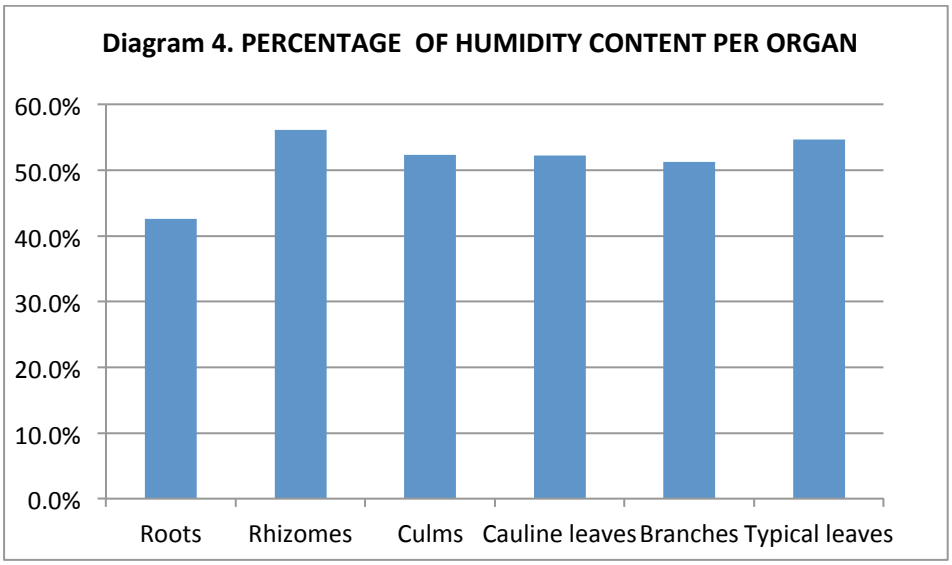


Fuente: Hormilson Cruz Rios. Bambu Guadua: *Guadua angustifolia* Kunth. Editorial Colmex. 720 page. 2009

Carbon fixation.

Moisture contents by organ in *Guadua angustifolia*

The moisture content by organ was obtained in the laboratory. (Diagram 4)



Fuente: Hormilson Cruz Rios. Bambu Guadua: *Guadua angustifolia* Kunth. Editorial Colmex. 720 page. 2009

The humidity contents in the organs determined that some have a higher than others and that this varies in percentage terms, depending upon the age of the plant and of each of its component organs

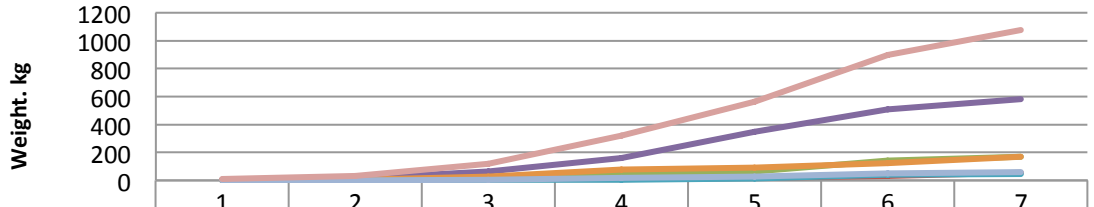
At 56.1%, rhizomes are the part of a plant with the highest contents of moisture, followed by typical leaves at 54.7%. Culms and cauline leaves are practically equal, at 52.3% and 52.2%, respectively, while the plant organs with the least amount of moisture are the roots, with 42.6%.

The average of the humidity content in the clump is 51.53%.

Dry matter by organ in *Guadua angustifolia*

If the humidity content in the clump is 51.53%, this permit deduces that the average dry weight for a clump is 48.47%. The amount of dry matter in kilograms produced by every organ in a full-grown plant and clump is showed. (Diagram 5)

Diagram 5. ACCUMULATED DRY WEIGHT CONTENTS BY ORGAN AND YEAR IN A CLUMP OF *Guadua angustifolia*. (Kg)



Years	1	2	3	4	5	6	7
Roots	1.07	5.13	9.01	11.1	20.1	32.8	53.5
Rhizomes	1.9	3.28	14.7	49.8	65.9	142.4	169.1
Culms	4.61	14.3	61.8	158.2	347.4	509.3	581.3
Cauline leaves	0.71	1.29	2.72	6.13	13.3	39.1	45.1
Branches	1.52	6.18	25.4	76.5	90.3	122.8	170.2
Typical leaves	0.44	1.82	6.13	17.7	27.7	50.5	59
Total/clump	10.2	32	119.8	319.4	564.7	896.9	1078.2

Fuente: Hormilson Cruz Rios. Bambu Guadua: *Guadua angustifolia* Kunth. Editorial Colmex. 720 page. 2009

One clump of *Guadua angustifolia* generates 1078.2 kg of weight or dry matter over a seven-year period. The culms make the largest contribution, with a total of 581.3 kg of dry matter per clump. The branches and rhizomes produce almost the same amount of dry matter in the plant and consequently in the clump. The roots produce the least dry weight, with 53.5 kg.

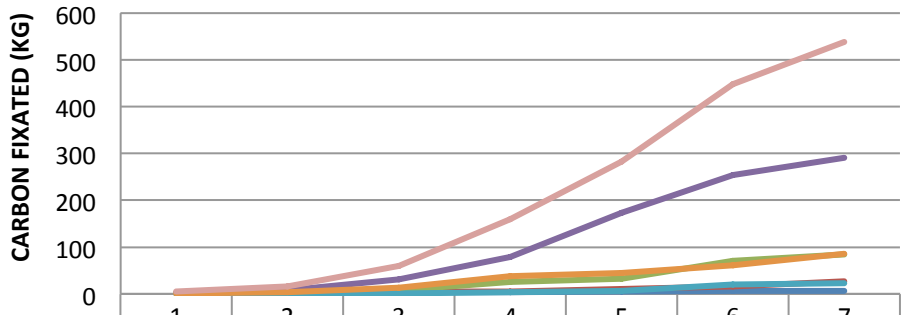
The average is 154.0 kg of dry matter per clump/year considering seven years period.

It is important to point out that the more dry matter a plant contributes, the more carbon it will have captures.

Carbon accumulated by organ in *Guadua angustifolia*.

The basis on which to determine the amount of carbon captured in a clump is the dry matter produced by each organ, as it is assumed that 50% of that is the carbon fixated by the plant. (Diagram 6).

Diagram 6. AMOUNT OF ACCUMULATED CARBON FIXATED BY ORGAN AND YEAR IN A CLUMP OF Guadua angustifolia



	1	2	3	4	5	6	7
Age (years)	1	2	3	4	5	6	7
Roots	0.53	2.56	4.51	5.57	10	16.4	26.8
Rhizomes	0.95	1.64	7.36	24.9	32.9	71.2	84.5
Culms	2.3	7.15	30.9	79.1	173.7	254.6	290.7
Cauline leaves	0.35	0.64	1.36	3.06	6.63	19.5	22.5
Branches	0.76	3.09	12.7	38.3	45.2	61.4	85.1
Total clump. (kg)	5.12	16	59.9	159.7	282.3	448.5	539.1

Fuente: Hormilson Cruz Rios. Bambu Guadua: *Guadua angustifolia* Kunth. Editorial Colmex. 720 page. 2009

A clump of *Guadua angustifolia* fixates an accumulated total of 539.1 kg of Carbon by the end of year seven, meaning that the average for the year is of 77.01 kg of carbon per clump. There is an accelerated increase in carbon fixation from the time of planting up to the fourth year of age, at which point the plant begins to stabilize these amounts, as it is already vegetative and physiologically fully developed.

Of the total Carbon fixates, the culms participate with the 53.9% following by the branches with 15.8% and rhizomes with 15.7%.

Carbon accumulated by hectare.

The amount accumulated each year during this research indicates that by the sixth year the plantation had captured 124.7 tons of C/ha. This allows for the deduction that on average 20.4 tons/year were captured up until the sixth year. It was also shown that for the seventh year the accumulated amount was 149.9 tons/ha, which in turn means that at that age each hectare planted with *Guadua angustifolia* captures 21.41 tons C/year. (Table 1)

Table 1. AMOUNT OF ACCUMULATED CARBON FIXATED BY ORGAN AND YEAR IN A PLANTATION OF Guadua angustifolia (Ton/Ha)

DISTANCE: 6m x 6m.				**POPULATION DENSITY:** 278 plants/ha				
AGE (years)	**ROOTS**	**RHIZOMES**	**CULMS**	**CAULINE LEAVES**	**BRANCHES**	**TYPICAL LEAVES**	**TOTAL TonC./Ha**	**Avg. acc./yr. in tonsC/ha**
1	0.15	0.26	0.64	0.10	0.21	0.06	**1.42**	**1.42**
2	0.71	0.46	1.99	0.18	0.86	0.25	**4.45**	**2.22**
3	1.25	2.05	8.60	0.38	3.53	0.85	**16.65**	**5.55**
4	1.55	6.92	21.98	0.85	10.64	2.46	**44.40**	**11.10**
5	2.79	9.16	48.29	1.84	12.56	3.85	**78.49**	**15.70**
6	4.56	19.80	70.79	5.43	17.07	7.02	**124.7**	**20.78**
7	7.44	23.50	80.81	6.27	23.66	8.20	**149.9**	**21.41**

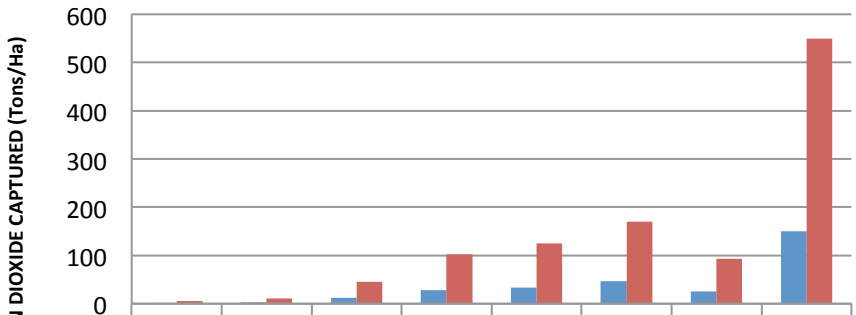
Fuente: Hormilson Cruz Rios. Bambu Guadua: *Guadua angustifolia* Kunth. Editorial Colmex. 720 page. 2009

It is surprising to see how during the first year even very small clumps of *Guadua angustifolia* are able to fixate 1.42 tons of carbon/hectare, however large increases in carbon fixation begin when the plantation is 4 year of age.

Carbon dioxide captures in a commercial *Guadua angustifolia* plantation.

Tons of carbon should be converted to tons of carbon dioxide by using a conversion factor of 3.67 to determine the entire molecule captured. (Diagram 7)

Diagram 7. CARBON DIOXIDE CAPTURED ON A COMMERCIAL PLANTATION OF Guadua angustifolia Kunth



YEAR	1	2	3	4	5	6	7	TOTAL ACCUMULATED
TOTAL CARBON CAPTURED BY YEAR (Tons/Ha)	1.42	3.02	12.21	27.75	34.09	46.18	25.2	149.87
TOTAL CARBON DIOXIDE CAPTURED BY YEAR (Tons/Ha)	5.21	11.08	44.81	101.84	125.11	169.48	92.48	550.02

Fuente: Hormilson Cruz Rios. Bambu Guadua: *Guadua angustifolia* Kunth. Editorial Colmex. 720 page. 2009

Theme: Ecology and Environmental Concerns

Based on the foregoing, a commercial plantation of *Guadua angustifolia* will sequester 21.41 tons/C/ha/yr., equivalent to 78.5 tons/CO2/ha/yr.

Conclusions

Guadua angustifolia is a bamboo with high biomass production.

Guadua angustifolia has a strong potential in the formulation of CDM projects due its high potential in biomass production and CO_2 sequestration.

Guadua angustifolia is a forest species which can be included in forestation and reforestation projects under Clean Development Mechanisms, for the purpose of issuing Emissions Reduction Certificates to be marketed in specialized markets. That would add a very important factor to promote the growing of guadua as a species which contributes to sustainable development.

The adequate estimate of a forest´s biomass is an element of great importance, as it allows for determining The amounts of raw material that one bamboo species can produce to different industrial bamboo projects

With specific financial studies *Guadua angustifolia* is a forest species with can be involved in bio renewable energy projects.

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