



## **Estimación de carbono acumulado en *Gmelina arborea* Roxb. en Tlatlaya, Estado de México mediante ecuaciones alométricas**

### **Accumulated carbon estimation in *Gmelina arborea* Roxb. from Tlatlaya, Estado de México with allometric equations**

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#### **Resumen**

Con base en la capacidad de almacenamiento de carbono de las especies forestales, se estimó el carbono acumulado en una plantación de 8 ha, de *Gmelina arborea* de diferentes edades, establecida en 2014, por medio de variables dasométricas y ecuaciones alométricas; dicha plantación se ubica en Tlatlaya, Estado de México, a 694 msnm, con una pendiente de 40 % y una densidad de 1 040 árboles ha<sup>-1</sup>. Se trabajó en ocho parcelas permanentes de muestreo, circulares de 400 m<sup>2</sup> y un radio de 11.28 m, en las cuales se contabilizaron 207 árboles. Se realizó un análisis de varianza y se comparó con la prueba de medias de *Tukey* ( $p < 0.05$ ). Los resultados indican que el incremento del DAP fue de 0.75 cm y la altura de 0.54 m en el periodo de medición (seis meses); la biomasa se distribuye en el fuste (72.54 %), ramas (18.37 %) y raíz (9.09 %) del arbolado. El carbono acumulado en los componentes del árbol mostró diferencias estadísticas significativas en las edades evaluadas. A los tres años el carbono acumulado en el fuste fue de 6.07 t ha<sup>-1</sup>, en las ramas, de 1.49 t ha<sup>-1</sup>, en la raíz de 0.76 t ha<sup>-1</sup> y el carbono total acumulado, de 8.31 t ha<sup>-1</sup>. Se concluye que los valores manejados de las variables predictoras en la ecuación ajustada para estimar el carbono acumulado en la plantación de *G. arborea* varían por factores como la edad, las condiciones edafoclimáticas, las prácticas silvícolas y la densidad del arbolado.

**Palabras clave:** Biomasa, manejo forestal, modelo matemático, plantación forestal, secuestro de carbono, servicios ambientales.

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## Introduction

One of the options to mitigate climate change is carbon capture and storage because of its high potential to reduce greenhouse gases in the atmosphere (Benea, 2017). Carbon is absorbed by vegetation with photosynthesis and by the soil of ecosystems through the dynamics of carbon, which consists of the contributions of dead plant material, its loss by mineralization and its accumulation by humification; therefore, this component stores the largest amount of the element (IPCC, 2015).

The importance of the biomass of tree species in carbon storage has been recognized for several decades (Bohre *et al.*, 2013); in this context, forest plantations are particularly valuable (Rasineni *et al.*, 2011) and, even more, when fast-growing taxa are incorporated (Norby *et al.*, 2005).

There is a potential for carbon uptake in biomass that could preserve carbon for decades in the wood. In addition, the use of biomass for energy purposes, from waste by-products from wood or crops, or from cultivated trees expressly intended for that purpose, could lead to a reduction in net greenhouse gas emissions if fossil fuels will be replaced (IPCC, 2015).

Mexico has an established area of commercial forest plantations of 270 000 ha of the main timber species, among which *Gmelina arborea* Roxb. occupies 24 061 ha<sup>-1</sup> (Conafor, 2014).

At international level, several studies have been developed aimed at estimating the carbon stored in plantations of *G. arborea* with the use of allometric equations. In India, Bohre *et al.* (2013) calculated the accumulated carbon worked with the normal diameter (1.30 m) and the total height as predictive variables. In Colombia, Melo (2015) with models based on processes such as photosynthetically active radiation; temperature; the availability of water in the soil, among others, estimated the carbon stored. In that same country years later, Patiño *et al.* (2018) estimated the carbon stored according to the normal diameter (1.30 m) in a five years old. In Mexico, Cámara *et al.* (2013) determined the carbon stored in plantations four years old established in *Tabasco*. Although research has been carried out that evaluates the

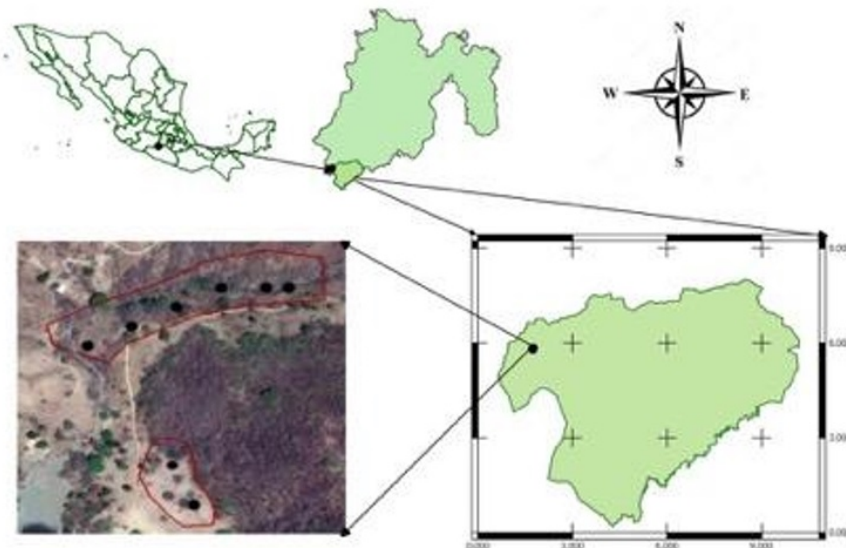
accumulated carbon of *G. arborea* for some regions, the storage potential of plantations established in the State of Mexico with this species still needs to be evaluated.

Therefore, the objective of the study described below was to estimate the carbon accumulated from mensuration variables and allometric equations in a *Gmelina arborea* plantation of different ages established in *Tlatlaya*, State of Mexico.

## Materials and Methods

### Study area

The study was carried out in the commercial forest plantation (PFC, for its acronym in Spanish) of *G. arborea* located in the *Las Piñas* farm, *Tlatlaya* municipality, State of Mexico (Figure 1). The region is part of the *Sierra Madre del Sur* physiographic province and the Depression of the *Balsas* River subprovince (Inegi, 2009). The geographical coordinates of the area of interest are 18°22' N and 100°04' O; its average altitude is 694 m and has a slope of 40 %.



**Figure 1.** Location of the study area in *Tlatlaya* municipality, State of Mexico.

The trees are planted with a 3.10 m × 3.10 m spacing, which make up a density of 1 040 ha<sup>-1</sup> trees in an area of eight hectares established in 2014. The types of soil in the area are Phaeozem (37.34 %), Regosol (34.5 %), Leptosol (10.1 %), Luvisol (10.1 %), Cambisol (6.5 %), Vertisol (0.76 %) and Fluvisol (0.31 %) (Inegi, 2009). The climate is of the Aw<sub>1</sub> type, warm subhumid with rains in summer and mean humidity of 70.88 %; and of the Aw<sub>2</sub> type, warm subhumid with rains in summer, medium humidity (20.14 %), average annual temperature from 18 °C to 28 °C and annual rainfall, 1 000 mm to 1 500 mm (Inegi, 2009).

### **Mensuration data**

Field data collection was carried out in 2016 and 2017, at 2.4, 2.6, 2.8 and 3 years after planting. A systematic sampling was used, through which eight permanent circular sampling plots with a radius of 11.28 m (400 m<sup>2</sup>) were established, which in total formed an inventoried area of 3 200 m<sup>2</sup>, corresponding to a sampling intensity of 4 %. In total, an inventory of 207 trees of the plantation was obtained, of which DAP data were recorded at 1.3 m (d<sub>1.3</sub>) by means of a Haglof Sweden<sup>®</sup> calipper, and the total height with the Nikon Forestry Pro<sup>®</sup> hipsometer. With the variables obtained in the inventory, data were obtained regarding the basimetric area and the stem volume with the cubication equation of Rodríguez and Castañeda (2014) (Equation 1), in addition to the trunk biomass, branch biomass, foliage biomass, total aerial biomass, carbon in the trunk, carbon in branches, carbon in foliage and total carbon of the tree, to estimate the carbon accumulated in the aerial part of the plantation 2.4, 2.6, 2.8 and 3.0 years.

$$V = \frac{\pi}{4} \cdot D^2 \cdot h \cdot ff \quad (1)$$

Where:

$V$  = Volume ( $m^3$ )

$D$  = Diameter (m)

$h$  = Total height (m)

$ff$  = Shape factor (0.46)

### **Estimation of aerial biomass (shaft and branches) and accumulated carbon**

Biomass was quantified with a non-destructive sampling of the components of each *Gmelina* tree that make up the plantation (shaft and branches) (Ordóñez *et al.*, 2001; López *et al.*, 2016). For the aerial biomass, the equations proposed by Arias *et al.* (2011) for plantations of the same species in Costa Rica (equations 2 and 3):

$$B_{fuste} = 0.075 \cdot (d)^{2.4167} \quad (2)$$

$$B_{ramas} = 0.1001 \cdot (d)^{1.662} \quad (3)$$

Where:

$d$  = Normal diameter (cm)

$B_{fuste}$  = Stem biomass (kg)

$B_{ramas}$  = Branch biomass (kg)

## **Root biomass / total biomass ratio (R / T)**

Fonseca *et al.* (2009) used the value of 0.10 of Mac Dicken (1997), which is a conservative value, to estimate the biomass of native species in plantations and secondary forests in *Costa Rica*.

## **Conversion Factor (FC)**

**Conversion factor from ton of biomass (dry matter) to ton of carbon (tC).** It is the of mass carbon per cent of wood; 50 % carbon; 41 %, oxygen; 6 %, hydrogen; 1 %, nitrogen and 2 %, ash, so the amount of carbon per ton of biomass (dry matter) is close to 500 kg (50 %) (Norberto, 2006). For the present study, the value of 0.4 was considered, which coincides with that referred for young *Gmelina* plantations (between 4 and 15 years) by Cubero and Rojas (1999) who calculated an interval between 0.32 and 0.4.

## **Statistical Analysis**

The data were subjected to an analysis of variance (Anova) and comparison of Tukey means ( $<0.05$ ) with the *Statistica* statistical program (Guisande *et al.*, 2013) to determine the statistical difference in the PFC of *G. arborea* at different ages.

## **Results**

Based on the forest inventories carried out in December 2016, February, April and June 2017, the PFC is established in an area of 8 ha, with the following characteristics:

## Mensuration variables

The analysis of variance showed a high significant difference in the variables normal diameter and total height in the ages considered of the PFC with a probability ( $p < 0.005$ ). The comparison of Tukey means shows that the diameter of the plantation at different ages is statistically different (Table 1).

**Table 1.** Mean comparison of the mensuration data of *Gmelina arborea* Roxb. in Tlatlaya, Estado de México.

Age (years)	Normal diameter (cm)	Height (m)	Basimetric area ( $\text{m}^2 \text{ha}^{-1}$ )	Stem volume ( $\text{m}^3 \text{ha}^{-1}$ )
2.4	7.89 a	5.68 a	5.43 a	15.09 a
2.6	8.12 b	5.80 b	5.74 b	16.31 b
2.8	8.33 c	5.92 c	6.04 c	17.54 c
3.0	8.64 d	6.22 d	6.46 d	19.63 d

\*Different letters in the columns mean significant differences ( $p < 0.05$ ).

The increase in normal diameter in the PFC between 2.4 and 3.0 years was 0.75 cm, with a significant difference (Table 1).

The total height of the trees also showed significant differences in the ages of measurement, with an increase of 0.54 m (Table 1).

With respect to the basimetric area, in addition to the significant differences in the ages, it recorded an increase of  $1.03 \text{ m}^2 \text{ha}^{-1}$  from 2.4 to 3.0 years of planting.

The stem volume exhibited significant differences ( $p \leq 0.00$ ) with a probability of ( $p < 0.05$ ) in the analysis of variance. The Tukey mean comparison test indicated significant statistical difference in ages and an increase of  $4.55 \text{ m}^3 \text{ha}^{-1}$ .

## Stem, branches, root and total biomass

The stem biomass showed significant differences in the measurement ages; this component represents 72.10 %, 72.41 %, 72.67 % and 73 % of the biomass at 2.4, 2.6, 2.8 and 3.0 years, respectively, also showed an increase of 2.85 ton ha<sup>-1</sup> (Table 2).

**Table 2.** Comparison of the means of stem, branches, root and total biomass of *Gmelina arborea* Roxb. established in Tlatlaya, State of Mexico.

Age (years)	Stem biomass (ton ha <sup>-1</sup> )	Branch biomass (t ha <sup>-1</sup> )	Aerial biomass (t ha <sup>-1</sup> )	Root biomass (t ha <sup>-1</sup> )	Total biomass (t ha <sup>-1</sup> )
2.4	12.32 a	3.21 a	15.53 a	1.55 a	17.09 a
2.6	13.19 b	3.37 b	16.56 b	1.66 b	18.21 a
2.8	14.00 c	3.51 c	17.51 c	1.75 c	19.27 c
3.0	15.17 d	3.72 d	18.89 d	1.89 d	20.78 d

\*Different letters in the columns mean significant differences ( $p < 0.05$ ).

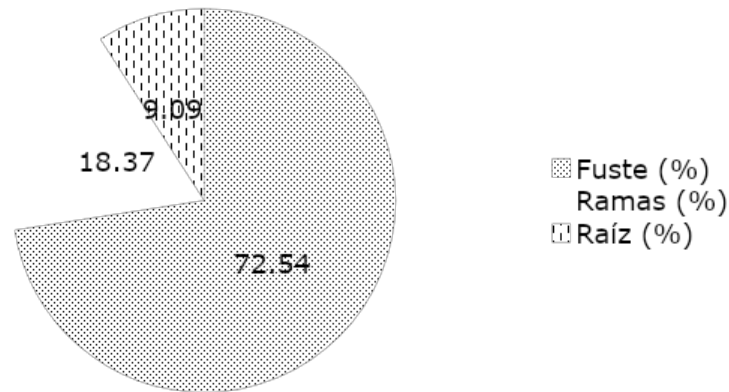
Branch biomass showed significant differences in the different ages, which represents 18.81 %, 18.50 %, 18.24 % and 17.91 % of biomass at 2.4, 2.6, 2.8 and 3.0 years, respectively (Table 2).

Root biomass, which represents 9.09 % of the total woodland biomass, also registered significant differences (Table 2).

In general, the components of the total biomass (stem, branches and root) show a similar distribution in the different ages studied (Figure 2).







**Figure 2.** Distribution of the total tree biomass components of *Gmelina arborea* Roxb. from the PFC established in Tlatlaya, State of Mexico.

### **Stem, branches, root and total carbon**

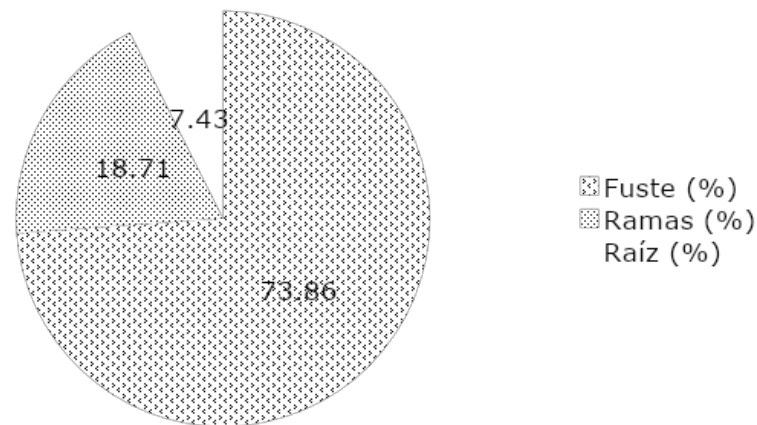
The result of the Tukey averages test for the carbon accumulated in the woodland components (stem, branches, aerial and total) in the four measurement ages showed significant differences except for the carbon accumulated in the root at 2.6 and 2.8 years, which showed no significant differences (Table 3). The stem stores 73.86 % of carbon accumulated at different ages, followed by the branches with 18.71 % and the root that stores carbon in a smaller proportion (7.43 %). It is observed that the accumulation of carbon in the components (stem, branches and root) has a similar distribution in the different measured ages of *G. arborea* trees (Figure 3).



**Table 3.** Comparison of means, carbon in stem, branches, root and total of *Gmelina arborea* Roxb. established in *Tlatlaya*, State of Mexico.

<b>Age (years)</b>	<b>Stem (ton ha<sup>-1</sup>)</b>	<b>Branches (t ha<sup>-1</sup>)</b>	<b>Aerial (t ha<sup>-1</sup>)</b>	<b>Root (t ha<sup>-1</sup>)</b>	<b>Total (t ha<sup>-1</sup>)</b>
2.4	4.93 a	1.29 a	6.21 a	0.16 b	6.37 a
2.6	5.28 b	1.35 b	6.62 b	0.66 a	7.29 b
2.8	5.60 c	1.41 c	7.01 c	0.70 a	7.71 c
3.0	6.07 d	1.49 d	7.56 d	0.76 c	8.31 d

\*Different letters in the columns mean significant differences ( $p < 0.05$ ).

**Figure 3.** Distribution of the components of total carbon accumulated in trees of *Gmelina arborea* Roxb. of the PFC established in *Tlatlaya*, State of Mexico.

## Discussion

Based on the above, it was estimated that the *G. arborea* trees of the PFC presented an increase in normal diameter of 0.75 cm and an increase in height of 0.54 m, over a period of six months with significant differences; the total height is 6.22 m and the average DBH is 8.64 cm at 3.0 years, with a density of 1,040 ha<sup>-1</sup> trees; Cámara *et al.* (2013) report a total height of 5.96 m and an average DBH of 11.04 cm in a four-

year-old *G. arborea* plantation at a density of 906 ha<sup>-1</sup> trees established at 20 masl in the state of *Tabasco*; described that the total height and the DAP influence the amount of biomass and carbon accumulated in the woodland; these results are different from those obtained in *G. arborea* established at 694 m; Jiménez (2016) recommends doing the first thinning in plantations of this species under an intensity of 50 to 25 % at three or four years and indicates that the objective is to favor the most vigorous trees, with good shape, which will be left to the final crop at the age of 10 to 12 years with a density of 277 to 416 ha<sup>-1</sup> trees, respectively.

The biomass of the stem component was 72.54 %, branches 18.37 % and 9.09 % root in general in the plantation at the different ages evaluated, these results are consistent with those reported by Emanuelli and Milla (2014) who indicate that the fuste component contributes between 55-70 %, and the leaves component between 10-37 %, the distribution of biomass by components in *G. arborea* trees coincides with López *et al.* (2016), these authors obtained an average of 70.20 % in the stem component and 29.83 % in the branches component and state that the results showed significant statistical differences in plantations of *Hevea brasiliensis* Müell. Arg. of different ages, established in *Tabasco*, Mexico.

The carbon accumulated in the woodland components of the *G. arborea* plantation at three years was 6.07 t ha<sup>-1</sup> in the shaft, 1.49 t ha<sup>-1</sup> in the branches, 0.76 t ha<sup>-1</sup> in the roots and 8.31 ton ha<sup>-1</sup> of total accumulated carbon, this result lower than that of Cámara *et al.* (2013) who determined that the carbon stored is 15.54 t ha<sup>-1</sup> in four-year-old *G. arborea* plantations with a density of 906 ha<sup>-1</sup> trees in *Tabasco*; likewise, it differs from what was recorded by Melo (2015), who estimated with allometric equations and process-based models (photosynthetically active radiation, temperature, availability of water in the soil, etc.), which the forest plantation of *G. arborea* with a density of trees with 1100 six-year-old ha<sup>-1</sup> trees established in Colombia at an altitude of 595 m, it stores 24.39 t ha<sup>-1</sup>; Patiño *et al.* (2018) estimated the carbon capture in the biomass of *G. arborea* in a Colombian plantation at an altitude of 250 m with a density of 1 111 ha<sup>-1</sup> trees; their predictor variable was the

DAP in the adjustment of allometric equations and they determined that at the age of five years the carbon stored is 41.6 t ha<sup>-1</sup>.

Several investigations have been carried out to estimate the carbon accumulated by adjusting allometric equations for different species, among which those carried out by Díaz *et al.* (2007) who adjusted a two-parameter equation in which they used as a predictor variable the normal diameter to estimate carbon in *Pinus patula* Schiede ex Schltdl. & Cham., concluded that the carbon stored in the woodland components is distributed in the stem with 78.82 %, and in the branches and foliage component with 16.11 %. This distribution of carbon stored in the components is similar to that obtained in the plantation of *G. arborea* studied, since the stem stores 73.86 % and foliage 18.71 %.

Cámara *et al.* (2013) worked with equations to quantify the carbon stored in four-year *Eucalyptus europhylla* S. T. Blake plantations established in Tabasco with a 954 trees ha<sup>-1</sup> density and in the *Quercus oleoides* Schltdl. et Cham savanna with a 258 trees ha<sup>-1</sup> density; they determined that the carbon stored was 14.75 t ha<sup>-1</sup> and 68.29 t ha<sup>-1</sup> respectively.

The edafoclimatic characteristics of the study area of the plantation are some of the factors that condition the ability to store carbon, *G. arborea* established in Tlatlaya, State of Mexico at an altitude of 694 m, with a slope of 40 %, and with a density of 1 040 trees ha<sup>-1</sup> the dominant soil is Phaeozem and the average rainfall of 1 000 mm.

Douterlungne *et al.* (2013) determined that the best predictors are the DAP and the diameter of the base in the adjustment of equations to estimate biomass and carbon in plantations for the purpose of restoration of *Guazuma ulmifolia* Lam., *Trichospermum mexicanum* (DC.) Baill., *Inga vera* Wild. and *Ochroma pyramidale* (Cav. ex Lam) Urb. with densities of 1 600 ha<sup>-1</sup> trees established in Chiapas. They concluded that the plantations of *T. mexicanum* and *G. ulmifolia* are more efficient as carbon sinks and that the accumulation rates are not extrapolated to quantify the long-term stored carbon as indicated by Lugo *et al.* (2004); These authors asserted

that the annual biomass and carbon accumulation rate declines with the age of the plantation as competition between trees increases.

Kongsager *et al.* (2013) estimated carbon stored in 21-year-old *Theobroma cacao* L. plantations with a density of 1 097 ha<sup>-1</sup> trees, seven-year-old *Elaeis guineensis* Jacq with a density of 144 ha<sup>-1</sup> trees, *H. brasiliensis* de 12 years and *Citrus sinensis* L. of 25 years with 266 ha<sup>-1</sup> trees established in Ghana at an altitude of 114 m, used allometric equations in which the DBH and the diameter of the base were the predictor variables and conclude that the planting of *H. brasiliensis* has the greatest potential to store carbon (214 t ha<sup>-1</sup>) followed by *T. cocoa* with 65 t ha<sup>-1</sup> carbon. These results are superior to those obtained in three-year *G. arborea* established in *Tlatlaya*, State of Mexico, and represents a potential to store carbon with adequate silvicultural management and practices.

López *et al.* (2016) determined the carbon stored in the aerial biomass of *H. brasiliensis* plantations established in *Tabasco* of different ages with the adjustment of allometric equations and that the carbon varies for each age. Thus, they estimated that in the five-year plantation, the carbon stored was 26.28 t ha<sup>-1</sup> with a density of 491 trees ha<sup>-1</sup>, a result that differs from that obtained for *G. arborea* in *Tlatlaya*, which stores 8.31 ton ha<sup>-1</sup> at three years old.

## Conclusions

The carbon accumulated in the *G. arborea* plantation established in *Tlatlaya*, State of Mexico at three years was 8.31 t ha<sup>-1</sup>, with a density of 1 040 ha<sup>-1</sup> trees.

The distribution of biomass and carbon accumulated in the tree components of the plantation of *G. arborea* showed significant statistical difference for the different ages of measurement.

The values used of the predictive variables in the equation adjusted to estimate the carbon accumulated in the plantation studied of *G. arborea* may vary due to extrinsic and intrinsic factors such as age and forest density.

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## **Conflict of interests**

The authors declare no conflict of interests.

## **Contribution by author**

Ricardo Telles Antonio and Eduardo Alanís Rodríguez: planning and development of field work, data processing and analysis, design and writing of the manuscript; Javier Jiménez Pérez: analysis and processing of the information, structure and revision of the manuscript; Oscar Alberto Aguirre Calderón and Eduardo Javier Treviño Garza: structure and revision of the manuscript.

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