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Article

Valoración dasométrica y producción de biomasa en *Gmelina arborea* Roxb. ex Sm. establecida en plantaciones puras y mixtas

Mensuration assessment and biomass production in *Gmelina arborea* Roxb. ex Sm. established in pure and mixed stands

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Resumen:

Gmelina arborea (melina) es una especie forestal muy apreciada por su rápido crecimiento, además es de multipropósito por los diversos usos de su madera. El establecimiento de melina en plantaciones puras (PP) ha propiciado la realización de estudios dasométricos y de biomasa; por ende, en México también se han implementado, como alternativa, las plantaciones mixtas (PM); aunque estas están poco documentadas. Los objetivos del presente estudio fueron evaluar y comparar la altura total (*H*), diámetro (*DAP*), área basal estimada (*AB*), volumen (*V*) y biomasa de *G. arborea* en PP y PM de 15 años, ubicadas en el estado de Nayarit. Se consideraron tres parcelas de 1 000 m^2, en las que se midieron a los individuos de la especie de interés el *DAP*, *H*, *V* y biomasa; asimismo, se recolectaron muestras de suelo. Los árboles de *G. arborea* en PM pesentó incrementos de 5.8 cm en el *DAP*, 0.04 m^2 en *AB*, 12.2 % en la biomasa de hojas, 8.8 % en la de ramas, 7.7 % en fuste, 10 % en raíz y 7.6 % en la biomasa total por árbol; lo cual se corroboró con el análisis de ANOVA y la prueba de *Tukey*. La diferencia en densidad entre las plantaciones indicó un mayor rendimiento en biomasa para la PP (17.9 %). Mejores parámetros dasométricos y producción de biomasa, se asociaron a suelos con pH > 6 y relación C/N > 20. El óptimo rendimiento de *G. arborea* dependerá del arreglo forestal, el manejo y las características edáficas.

Palabras clave: Crecimiento, ecuaciones alométricas, *Gmelina arborea* Roxb. ex Sm., incremento medio anual, propiedades del suelo, volumen.

Abstract:

Gmelina arborea (melina) is a forest species highly appreciated for its fast growth, moreover, it is considered multipurpose because of the many uses of wood. The establishment of the species in pure stands (PS) has led to various biomass and mensuration studies; therefore, mixed plantations (PM) have also been established as an alternative in Mexico, although they have been little documented. The aim of the study was to evaluate and compare the total height (*H*), diameter *(DBH)*, basimetric area *(BA)*, volume (*V*) and biomass of *G. arborea* established in 15-year old PP and PM in the state of *Nayarit*. Within the plantations, three 1 000 m^2 plots were established, in which *DBH, H*, *V* were measured as well as tree biomass and *AB* were estimated. Within the sampling units, soil samples were collected. The *G. arborea* in PM increased in 5.8 cm in *DBH*, 0.04 m^2 in *AB*, 12.2 % in leaf biomass, 8.8 % in branches, 7.7 % in stem, 10 % in root and 7.6 % in total biomass per tree which was corroborated by ANOVA and Tukey's test. The difference in density between the plantations indicated a higher yield in biomass of the PP (17.9 %). Improved mensuration parameters and biomass production were associated to soils with pH > 6 and C:N ratio > 20. The optimal yield of *G. arborea* will depend on the forest arrangement, management and soil characteristics.

Key words: Growth, allometric equations, *Gmelina arborea* Roxb. ex Sm., mean annual increase, soil properties, volume.

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Introduction

Gmelina arborea Roxb ex Sm. (*melina*) belongs to the Lamiaceae family, is native to the southeast of Australia and Asia, and it grows in very humid to dry ecosystems (Dhakulkar *et al*., 2005; GRIN, 2019). In addition, as it is a fast growing species, tolerant to temperatures between 18 and 35 ºC, precipitation of up to 2 286 mm (easy adaptation) and the multiple uses of its wood, it is highly appreciated in forest markets, which has encouraged its introduction in much of the world (Onyekwelu, 2004; Dudhane *et al*., 2011).

In the last decade, pure plantations (PP) have been highly documented, but mixed plantations (PM) lack updated information (Kaul *et al*., 2010; López *et al*., 2010). Some bibliographic citations indicate that PM promote recovery of degraded soils, although they are less efficient in biomass production (Chaturvedi and Raghubanshi, 2015). In addition, ecologically they are more important than PP, since they are made up of a greater diversity of tree species per unit area, but their yields will depend on the degree of soil disturbance (Forrester *et al*., 2013).

In Mexico, *G. arborea* was introduced in the middle of 1999 in PP located in the states of *Guerrero, Campeche, Tabasco, Veracruz, Quintana Roo, Chiapas, Oaxaca, Nayarit* and *Yucatán,* where they stand for 12.8 % of the surface area covered by tropical species in the country (around 19 000 ha) (Conafor, 2012).

In soils of loamy-clay texture and neutral pH, *G. arborea* reaches 20.9 m in total height (*H*), 26 cm in (*DBH*), a volume (*V*) of 550.5 m^3 ha^{-1} and produces up to 142.1 Mg ha^{-1} biomass at the age of 15 years (Sales *et al*., 2005; Onyekwelu *et al*., 2006).

In this investigation, it was postulated as a hypothesis that *G. arborea* in PM improves some mensuration parameters and increases the production of individual biomass by component (leaves, branches, stem and root). In this context, the objectives of the study were to evaluate and compare the *H, DBH*, basimetric area (*AB*), *V* increases in the mensuration variables and biomass production in *G. arborea* individuals established in 15 year PP and PM, in addition to the properties of the soil. The measurement of biomass in the field, allowed the formulation of allometric equations that will facilitate the inventory of biomass by the indirect route in future studies of biomass related to *melina*.

Materials and Methods

Study area

The evaluated plantations (PP and PM) are geolocated at 21°43'35.7" N; 105°06'47.1" W and 21°43'38.3" N; 105°06'46.4" W, within the *Santiago Ixcuintla* municipality, in the state of *Nayarit* (Figure 1). Its establishment dates from June 2001 and they belong to the *Agroforestales Nayarita* company. The area has a subhumid warm climate, with summer rains, of medium humidity [Aw_1(w)], according to the Köppen classification modified by García (1987); the annual average temperature is 24.4 °C, the maximum occurs between April and July (Inegi, 2017); with a total annual precipitation of 1 529 mm with variations between the driest and the rainiest period from 1 085 to 2 367 mm (Inegi, 2017). In regard to altitude, it is located between 0 - 800 masl.

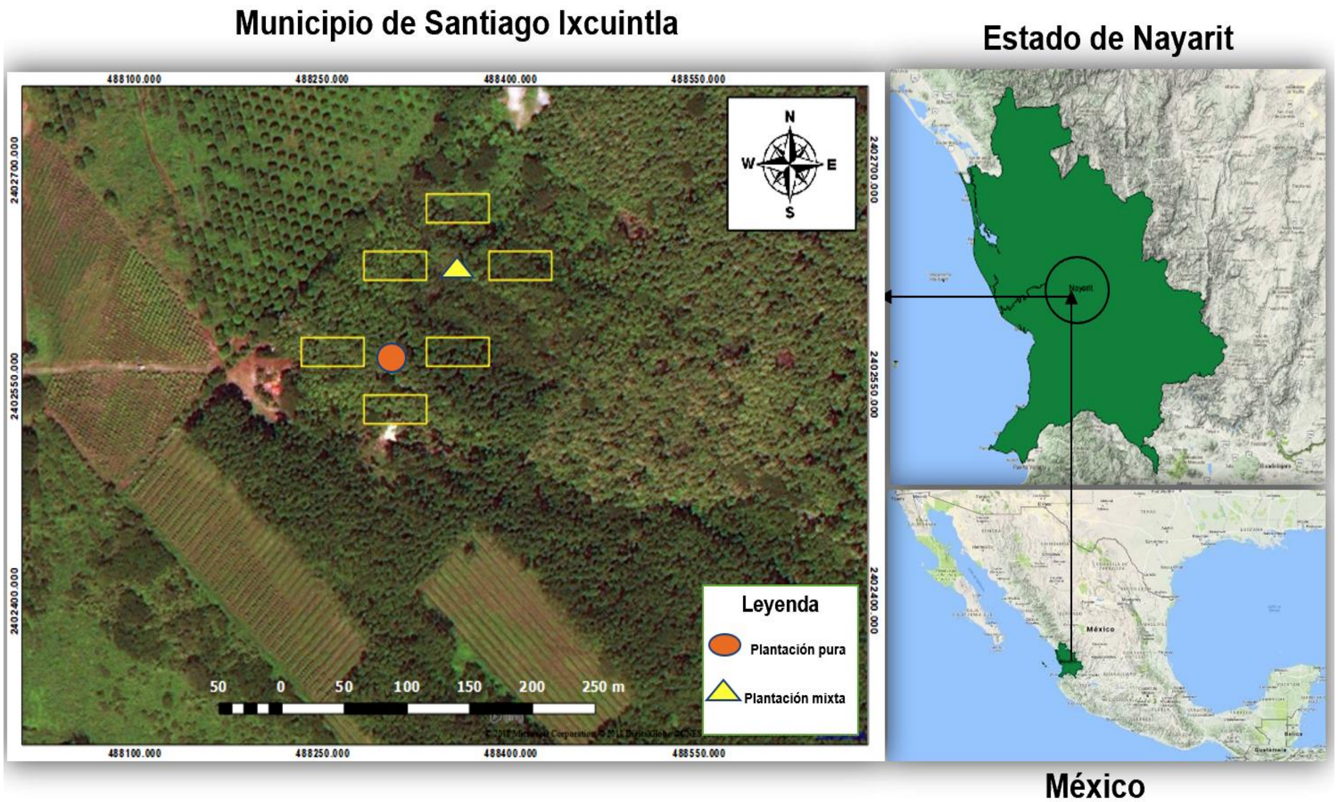


Figure1. Geolocation of 15 year pure and mixed commercial *Gmelina arborea* Roxb. ex Sm. plantations in the State of *Nayarit*, Mexico.

In the plantations pre-establishment (use of existing vegetation, weed control and controlled burning), a physical and chemical analysis of the soils was made, from 30 collected samples distributed in zig-zag (10 m distance between holes) at a depth of 30 cm in the forest production plots. The determined texture was clay loam with an organic matter content of 2.5 % and pH between 5.7 - 6. Regarding fertility, the concentration of total N (0.07 %), Mn (0.007 %) and available Cu (0.004 %) was medium, very low in P (0.001 %) and high in K (5 %), Ca (69 %), Mg (0.9 %), available Fe (0.06). One month before planting, to compensate the deficiencies and increase the concentration of macronutrients, 2 Mg ha^{-1} of agricultural lime were applied to neutralize the pH, 2 Mg ha^{-1} of chicken manure, 50-120-25 fertilizers (NPK) mixed with 250 kg of diammonium phosphate (NH_4) $2HPO_4$, 20 kg of potassium chloride (KCl) and 24 kg of potassium sulfate (K_2SO_4).

In the present investigation, the type of plantation with an area of 12.8 ha for PP and 20.4 ha for PM was considered as treatment; the distance between them was 5 m. The used seedlings were 20 cm tall and 8 mm in diameter; the plantation system was the real frame at 3 × 3 m spacing between seedlings, for a density of 1 111 trees ha^{-1}. The number of initial trees in the PM was 455 from *Pseudosamanea guachapele* (Kunth) Harms (*guayaquil)*, 356 from *Cordia alliodora* (Ruiz & Pav.) Oken (*laurel)* and 300 from *G. arborea*. In both the PP and the PM, partial cuts were practiced: two in the PP (5 and 10 years old) and one in the PM (7 years old). In 2016, the final density was 273 trees ha^{-1} in the PP and 250, 190 and 163 trees ha^{-1} corresponding to *P. guachapele*, *C. alliodora* and *G. arborea* in the PM.

Measurement of mensuration variables, biomass and soil collection

In the two types of evaluated plantations, three rectangular 40 × 25 m plots (1 000 m^2) were distributed in random blocks. In each one, the height of all the trees was measured with a Haga hypsometer, and *DBH* with a Forestry Suppliers Inc., 800-647-5368 diameter tape. The basimetric area (*AB*) was estimated from the data of 15 trees per sampling unit, with equation (1):

$$AB = \left(\frac{\pi}{4}\right) D^2 \quad (1)$$

Where:

AB = Basimetric area (m^2)

D = *DBH* (cm) (Arteaga and Castelán, 2008)

The volume was estimated with data from 15 trees felled in each plantation. The stem was cubed according to Smalian (Cancino, 2006) and the calculation was made with equation (2):

$$V = \frac{A_b + A_s}{2L} \tag{2}$$

Where:

V = Volume of the log (m^3)

A_b = Basimetric diameter (largest) of the log (cm)

A_s = Diameter at the smallest side of the log (cm)

L = Length of the solid log

$L = L_2 - L_1$ (m) (Cancino, 2006)

The annual mean increment (*IMA*, for its acronym in Spanish) of the measured variables was obtained from dividing their average with the age of the plantation by the following formula (3):

$$IMA = \frac{\mathrm{DDV}}{Edad} \tag{3}$$

Where:

IMA = Annual mean increment

DDV = Diameter, total height, basimetric area and volume (cm, m, m^2 y m^3)

In each plantation, 15 *G. arborea* trees were felled, which were selected randomly according to the diameter size, the biomass of leaves, branches, stem and root was weighed with an electric hanging Rhino BAC-300 scale of 300 kg ± 100 g capacity (Parada *et al*., 2010). In each of the plots located in the two types of plantations, nine soil samples were collected distributed in zig-zag (10 m distance between holes) at a depth of 45 cm. The measurements and collections were made in December 2016.

Laboratory procedures

The leaves, branches, stem and root of *G. arborea* were dried in an Terlab S.A. de C.V. oven at 70 ± 3 ºC, until achieving a constant weight; subsequently, they were ground and sieved with a number 60 mesh. The dry biomass was determined by equation (4):

$$BS = Pf - Ps \tag{4}$$

Where:

BS = Dry biomass (kg)

Pf = Fresh weight (kg)

Ps = Biomass dry weight (kg) (Parada *et al.,* 2010)

The allometric equations were built based on the principles described by Segura and Andrade (2008). Based on the dry biomass by component (n = 30), allometric equations of two inputs were generated, using multiple regression models, in which the predictor variables were *DBH* and *H.*

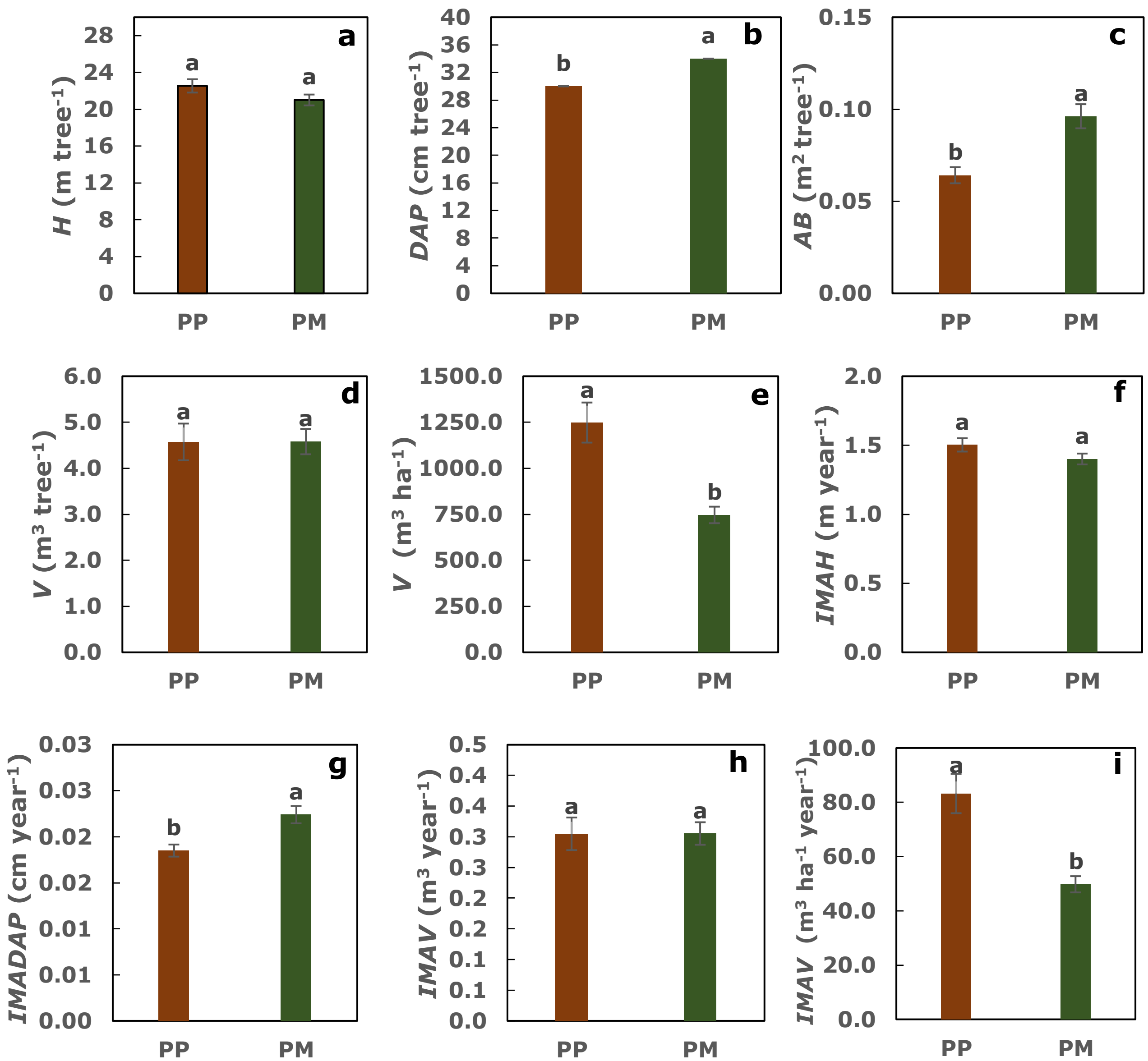
The physical and chemical properties of the soil were determined following the NOM-021-RECNAT-2000 standard (Semarnat, 2002): texture (Bouyoucos Hydrometer), bulk density (*Da*) (clod method), pH in water in relation 1: 2 (Orion Star A210 potentiometer), Cation exchange capacity (*CIC*) (Ammonium Acetate solution), Electrical conductivity (*CE*) (Electrical conductivity), Organic carbon by combustion at 900 ºC (Shimadzu TOC 5050-A), Organic matter (*MO*), multiplying the percentage of average C by the *MO* (58 %), total N by combustion at 900 ºC (Leco TruSpec^{TM} Micro elemental analyzer) and the C / N ratio of the soil as indicated by its expression.

The differences in *DBH*, *H*, *AB*, *V*, the increments and total biomass production and by component among individuals and plantations, as well as soil physical and chemical properties among individuals and plantations, were analyzed by ANOVA. Tukey's mean comparison test ($p \leq 0.05$) was used to identify the differences between the means of each variable evaluated in the PP and PM. The normality of the means was analyzed using P-P Plot charts. SAS v9.0 statistical program (SAS Institute, 2009) was used for the procedures.

Results and Discussion

Growth of *Gmelina arborea* in pure and mixed plantations

Figure 2 shows the statistical differences of the contrasted variables between individuals and plantations. Although *H* (Figure 2A; p = 0.106), *V* (Figure 2D; p = 0.964), *IMAH* (Figure 2F; p = 0.124) and *IMAV* (Figure 2H; p = 0.873), the average per tree of *G. arborea* between PP and PM was statistically similar; in PM the species was characterized by increasing its *DBH* by 5.8 cm tree^{-1} (Figure 2B; p = 0.0001), *AB* by 0.04 m^2 tree^{-1} (Figure 2C; p = 0.0001) and its *IMADAP* by 0.01 cm year^{-1} (Figure 2G; p = 0.002). Overall, the net productivity (Figure 2E; p = 0.0001) and the *IMAV* ha^{-1} (Figure 2; p = 0.0001) between individuals was around 21 % higher in PP, whose determining factor was the density of trees of the species by surface area.



*Means with different letters in each bar (standard error) are statistically different (*Tukey,* $p \leq 0.05$). a) Total height (*H*); b) diameter at breast height (*DBH*); c) Basimetric area (*AB*); d) Volume (*V*); e) Volume per area (*V*); f) Annual average increase in total height (*IMAH*); g) Annual average increase in diameter (*IMADAP*); h) Annual average increase in volume (*IMAV*); i) Annual average increase in volume per area (*IMAV* $ha^{-1}yr^{-1}$).

Figure 2. Growth of *Gmelina arborea* Roxb. ex Sm. established in 15 year- old pure and mixed plantations in the state of *Nayarit*.

It became evident that when *G. arborea* grew in the PM, it improved its dendrometric characteristics associated with diameter; although *H, V*, *IMAH* and *IMAV* were statistically similar, and, consequently, the productivity in the PP was higher, mainly due to the density of trees of the evaluated species. However, the results exceed those documented by other authors in plantations of the same age. Onyekwelu *et al.* (2006) in *Nigeria* register an *H* = 20.9 m tree^{-1}, *DBH*= 26.2 cm tree^{-1}, *AB* = 50.5 m^2 ha^{-1} and *V* = 550.5 m^3 ha^{-1}; and Espinoza-Durán and Moya (2013) in *Costa Rica* reported an *H* = 14.9 m tree^{-1}, *DBH* = 30.9 cm tree^{-1}, *V* = 240.1 m^3 ha^{-1}. In Mexico, values of 14.5 m tree^{-1} have been cited for *H; DBH* =19.3 cm tree^{-1}; *AB* = 22.5 m^2 ha^{-1}; and *V* =270 m^3 ha^{-1} (Martínez-Zurimendi *et al*., 2015).

In regard to *IMA*, the productivity estimated in the present study was higher than those obtained by Moya (2004) (40 m^3 ha^{-1} year^{-1}) in *Costa Rica*; Vanclay *et al.* (2008) in the Philippines (29 m^3 ha^{-1} year^{-1}) and Martínez-Zurimendi *et al.* (2015) in Mexico (7.5 to 33.2 m^3 ha^{-1} year^{-1}).

Forestry practices and site conditions play an important role in the growth of *G. arborea*. Timely plantation management and good soil conditions benefit the dendrometric increase and productivity of the species (Swamy *et al*., 2003; Rojas *et al*., 2004; Martínez-Zurimendi *et al*., 2015).

Allometric equations for biomass estimation in *Gmelina arborea*

Table 1 shows the equations generated to estimate biomass in *G. arborea*. Multiple regression analyzes optimized by Box-Cox transformations related *DBH* and *H*; in turn, the direct measurement of biomass also favored obtaining values of $R^2 \geq 0.9$ in leaves, branches, stem, root and total biomass, with a standard error of ≤ 1.

Table 1. Allometric equations for biomass estimation in *Gmelina arborea* Roxb. ex Sm. (n = 30).

Component	Equations	R^2	*Ee*
Leaves	$BSh = 0.634708 * DAP(cm) - 0.148755 * H(m)$	0.937	0.597
Branches	$BSr = 1.37109 * DAP(cm) - 0.105866 * H(m)$	0.970	0.212
Stem	$BSf = 10.8605 * DAP(cm) - 2.56108 * H(m)$	0.996	0.508
Root	$BSra = 3.80779 * DAP(cm) - 0.186516 * H(m)$	0.994	0.197
Total biomass	$BST = 15.5347 * DAP(cm) - 3.68531 * H(m)$	0.963	0.664

BS = Dry biomass (kg tree^{-1}); *h* = Leaves; *r* = Branches; *f* = Stem; *ra* =Root; *T* = Total biomass; *DBH* = Diameter at Breast Height; *H* = Total height; *Ee* = Standard error. The allometric equations considered a significance level of 0.05 % (*Tukey*, $p < 0.0001$).

The allometric equations for biomass estimation in *G. arborea* had R^2 values similar to those reported in India by Swamy *et al.* (2003): leaves R^2 = 0.97, branches R^2 = 0.93, stem R^2 = 0.98, root R^2 = 0.97 and total biomass R^2 = 0.99); Onyekwelu (2004) in *Nigeria*: leaves R^2 = 0.97, branches R^2 = 0.98, stem R^2 = 0.98 and total aerial biomass R^2 = 0.98); and in *Costa Rica*, Arias *et al*. (2011) record values in leaves R^2 = 0.97, branches R^2 = 0.92, stem R^2 = 0.99 and total aerial biomass R^2 = 0.97.

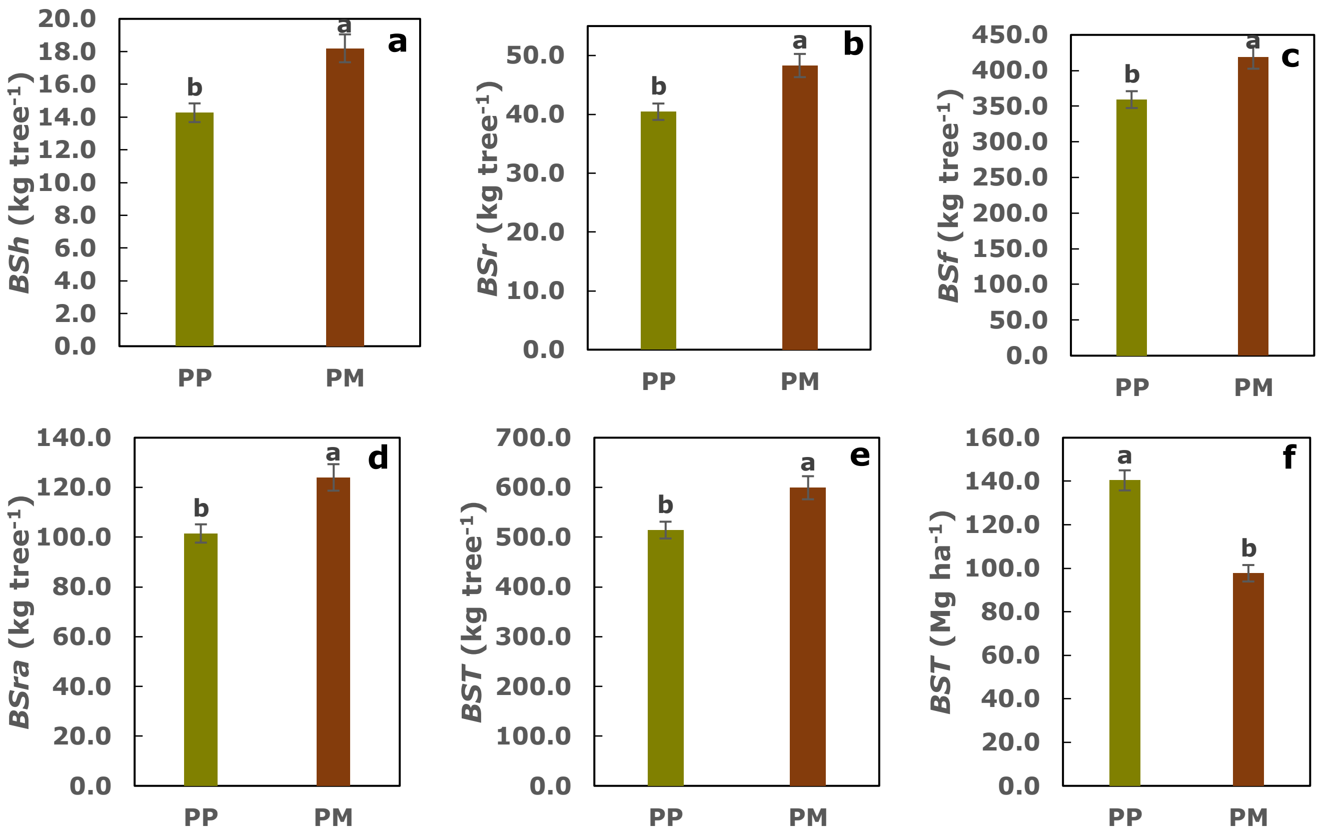
Based on the above, the biomass measurements obtained by the direct method allowed the construction of equations with higher adjustment values than those generated from indirect measurements (Chaturvedi and Raghubanshi, 2015; Ruiz-

Blandon *et al*., 2019). The proposed expressions may be used for the estimation of biomass in *G. arborea* in future investigations that are carried out under similar climate and soil conditions associated with this study.

The allometric equations by tree component will allow to quantify with certainty the distribution of biomass in the tree, as well as its accumulation while it grows. On the other hand, having an equation to estimate the value of root biomass and its impact on total biomass constitutes an important contribution of the present study, since the root is rarely considered in forest inventories.

Biomass production in *Gmelina arborea*

The biomass production in *G. arborea* per tree and surface area unit was different between the plantation systems. In PM, the biomass of the leaves increased by 12.2 % (Figure 3A; $p = 0.0001$), 8.8 % the biomass of the leaves (Figure 3B; $p = 0.002$) in branches, 7.7 % (Figure 3C; $p = 0.004$) in stem, 10 % (Figure 3D; $p = 0.0006$) in root, and 7.6 % (Figure 3E; $p = 0.002$) in average total biomass per tree, with respect to PP. The biomass distribution showed the following order: 3 % in leaves, 8 % in branches, 69 % in stem and 20 % in the root, which indicated that the stem is the component that produced and accumulated the most biomass (by weight). Consequently, a greater number of *G. arborea* trees per hectare in the PP (273 trees ha^{-1}), gives it 17.9 % (Figure 3F; $p <0.0001$) more yield, than the total production in the PM (163 trees ha^{-1}).



* Means with different letters in each bar (standard error) are statistically different (*Tukey*, p ≤ 0.05). a) Dry biomass of the leaves (*BSh*); b) Dry biomass of the branches (*BSr*); c) Dry biomass of the stem (*BSf*); d) Dry biomass of the root (*BSra*); e) Total dry biomass (*BST*), and f) Total dry biomass per area (*BST*).

Figure 3. Biomass production per tree and area in 15 year- old pure and mixed plantations in *State of Nayarit*.

In the present investigation, it was confirmed that when *G. arborea* grows in PM, it produces greater biomass per component (leaves, branches, stem, root and total biomass), compared to what happens in a PP; in spite of it, by number of trees per hectare it turns out to be the most productive PP. However, these values differ significantly from those recorded in 15-year-old plantations established in the

Philippines and *Nigeria* at 142.1 and 233.7 Mg ha^{-1}, respectively (Sales *et al*., 2005; Onyekwelu *et al*., 2006).

Biomass production in *G. arborea* plantations is usually affected by physiological aspects of the plant (adaptation), forestry management, plantation system and age (Rasineni *et al.,* 2011; Verma *et al*., 2017). Regardless of the type of plantation, pure or mixed, the stem of *G. arborea* is the component with the highest biomass production, which coincides with that documented in other studies (Arias *et al.*, 2011; Cook *et al*., 2014; Goussanou *et al*., 2018).

Poor management and arrangement of species within PM are likely to affect biomass yields in this type of system, due to the overpopulation of trees per unit area (Redondo-Brenes and Montagnini, 2006). This explains the lower production in total volume of *G. arborea* in the PM, in contrast to that recorded in the PP. Therefore, it is important to consider a strategic forestry arrangement in the PM that allows having a greater number of trees of the species when associating it with other taxa; this will obtain better results in biomass and an increase in the productivity of the system.

Physical and chemical soil properties in pure and mixed plantations of *Gmelina arborea*

The soils where the *G. arborea* plantations were established rendered the same texture (loam-clay), bulk density of 1.1 g cm^{-3} ($p = 0.081$), *CE* of 0.04 dS m^{-1} ($p = 0.804$), concentration of total N of 0.8 mg g^{-1} ($p = 0.105$), similar concentration of *MO* (around 3 %, $p = 0.663$), and C between 19 - 20 mg g^{-1} ($p = 0.849$). Despite this, the best pH (6.3; $p = 0.011$) and C / N ratio (25; $p = 0.028$) were recorded in the PM; the *CIC* was higher in the PP soils (41.7 cmol $^{(+)}$ kg^{-1}; $p = 0.040$) (Table 2).

Table 2. Physical and chemical soil properties where *Gmelina arborea* Roxb. ex Sm. grows, established in pure and mixed plantations in the state of *Nayarit*.

Physical and chemical properties	**Pure plantation**	**Mixed plantation**
Depth	0-45 cm	0-45 cm
Texture	*Fr*	*Fr*
Da (g cm^{-3})	1.1 a ± 0.01	1.1 a ± 0.01
pH	5.9 b ± 0.04	6.3 a ± 0.02
CIC (cmol $^{(+)}$ kg^{-1})	41.7 a ± 1.1	39.8 b ± 0.9
CE (dS m^{-1})	0.04 a ± 0.003	0.04 a ± 0.001
MO (%)	3.2 a ± 0.01	3.4 a ± 0.04
C (mg g^{-1})	19 a ± 1.1	20 a ± 3.5
N (mg g^{-1})	0.8 a ± 0.1	0.8 a ± 0.4
C/N	19 b ± 2.2	25 a ± 3.7

Fr = Clay-loam, *Da* = Bulk density; *CIC* = Cationic interchange capacity; *CE* = Electric conductivity; C = Carbon; N = Nitrogen, C/N = Carbon-nitrogen ratio. The mean values (± standard error) (n = 6) with different letters in each row are statistically significant (*Tukey*, p ≤ 0.05).

Under the conditions of the present study, the edaphic properties that determined the difference between the PP and PM soils were pH and the C / N ratio.

Investigations carried out in Nigeria and Costa Rica showed a greater growth and biomass production in PP of *G. arborea*, when the texture was loamy-clay, the pH between 5 - 7.5 and bulk density higher than 1 g cm^{-3} (Nwoboshi, 2000; Onyekwelu, 2001; Rojas *et al*., 2004; Onyekwelu *et al*., 2006; Adekunle *et al*., 2011). If the soil conditions are adverse, their individuals grow poorly: crooked stems, low height, highly branched and shrubby; therefore, it is recommended to plant it in deep, moist, well-drained soils without obstacles that interfere with root development (Rojas *et al.,* 2004). The above coincides with the values reported here for the PM; however, it is essential to note that pH has a positive relationship with the availability of nutrients, since it exerts a great influence on the balance of ionic change in the soil due to its effects on erosion, the mineralization of organic matter and the nutrient mobilization (Adekunle *et al*., 2011), which supports the values obtained in the studied soils. Likewise, it is cited that the pH range that favors the vigor of *G. arborea* varies from 6.47 to 7.47, since in these values most of the nutrients essential for plant growth are present, especially N (Onyekwelu, 2001).

A high concentration of edaphic N (natural or synthetic incorporation) guarantees the vigorous growth of *G. arborea* (Rojas *et al*., 2004); however, the C / N ratio of the evaluated soils was very high. When said ratio> 11.5, it is considered that there is excess C and energy, which indicates the immobilization of N by microorganisms, which in turn prevents its use by plants (Gamarra *et al.,* 2018; Salcedo-Pérez *et al*., 2019). Furthermore, in this type of soil the release of nitrogen is very high, which explains the higher biomass yield recorded in the present study, possibly due to the fact that said element is concentrated in the biomass of the species, particularly in the leaves where it acquires greater preponderance.

Conclusions

The growth of *Gmelina arborea* is favored when it develops in mixed production systems (Agroforestry) with different forest species. This condition improves its increase in diameter and biomass production by tree component, due to the effect and pressure exerted by the associated trees and that decrease intraspecific competition in the mixed plantation (PM) compared to a pure plantation (PP), for therefore the hypothesis is accepted.

The proposed two-way allometric equations for estimating biomass in *G. arborea* are relevant to be used in future forest inventories, due to the adjustment values and the standard error obtained.

Biomass production in *G. arborea* depends on site conditions, good forest arrangement, and timely forestry management. The increases were associated with soils with a pH closer to neutrality (> 6) and a C / N ratio (> 20).

The mensuration and biomass production differences of *G. arborea* per area, when comparing both types of plantation; is due to a greater number of trees of the species per area in the PP.

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Conflict of interests

The authors declare no conflicto of interests.

Contribution by author

Bayron Alexander Ruiz-Blandon: design of the project, field work, laboratory, data analysis and interpretation and writing of the document; Efrén Hernández-Álvarez: financing of field work in addition to its implementation and review of the final document; Ramón Rodríguez-Macías: economic contribution and review of the document in different stages; Eduardo Salcedo-Pérez: leader of the project, economic contribution, interpretation of results for the soil component, writing and review of the final document.

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