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Article

Evaluación de plantaciones de *Tabebuia rosea* (Bertol.) DC. y *Swietenia macrophylla* King en el Centro-Occidente de México

Assessment of *Tabebuia rosea* (Bertol.) DC. and *Swietenia macrophylla* King plantations in Central-Western Mexico

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Resumen

El éxito en el establecimiento y desarrollo de las plantaciones forestales depende de que las especies sean las adecuadas para las condiciones edafoclimáticas de los sitios de plantación. El objetivo de este estudio fue evaluar la supervivencia y crecimiento de plantaciones de 12 años con *Tabebuia rosea* (rosa morada) y *Swietenia macrophylla* (caoba), en cuatro localidades de Jalisco, Colima y Nayarit. Se determinó la diferencia estadística entre localidades con análisis de varianza y prueba de comparación de medias de *Tukey*, para las variables supervivencia, diámetro normal, altura, volumen y sus incrementos medios anuales. Los resultados indican que la supervivencia de *T. rosea* varió de 35 a 82 % y en *S. macrophylla* entre 79 y 83 %. Hubo diferencias significativas ($p < 0.05$) entre localidades en las variables de crecimiento. *T. rosea* destacó por su diámetro normal, altura y volumen en la localidad IV (Costa de Jalisco), mientras que *S. macrophylla* tuvo un mejor desarrollo en diámetro normal y volumen en la localidad II (El Verdineño); posiblemente, por el efecto del tipo de suelo en estos sitios. Los resultados sugieren que lugares bajo condiciones edafoclimáticas similares a esas localidades son aptos para el establecimiento de plantaciones forestales con ambas especies tropicales en el Centro-Occidente de México.

Palabras clave: Caoba, crecimiento forestal, plantaciones tropicales, rosa morada, silvicultura, supervivencia.

Abstract

The success in the establishment and development of forest plantations depends on the fact that species are appropriate for the agroclimatic conditions of plantation sites. This study aimed to evaluate the survival and growth of 12-year forest plantations with *Tabebuia rosea* (rosy trumpet), and *Swietenia macrophyll*a (Mahogany tree), established in four localities in the states of *Colima, Nayarit*, and *Jalisco*. Statistical differences in survival, normal diameter, height, volume, and their annual increments were assessed among species and localities through analysis of variance and Tukey-test. Results indicated that the survival of *T. rosea* ranged from 35 to 82 %, whereas in *S. macrophylla* it ranged from 79 to 83 %. There were significant differences among localities ($P < 0.05$) in the evaluated growth variables. *T. rosea* stood out by its normal diameter, height, and volume in locality IV (Coast of *Jalisco*), whereas *S. macrophylla* had a better development in normal diameter and volume in locality II (*El Verdineño*), possibly by the effect of soil type in these sites. These results suggest that sites with edafoclimatic conditions similar to these localities are appropriate for the establishment of forest plantations with both tropical species in central-western Mexico.

Key words: Mahogany tree, forest growth, tropical plantations, rosy trumpet, silviculture, survival.

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Introduction

Commercial forest plantations (CFP) are an alternative to reduce pressure on forests, ensure the supply of raw materials to the forestry industry and generate environmental services such as decreased erosion, increased infiltration, carbon sequestration, refuge for flora and fauna, contribution of economic resources and sources of rural employment (Guerra and Galicia, 2017).

The species to be introduced must be right to fit in the edaphoclimatic conditions of the region, they should have high yield of raw material, be profitable and interesting to producers or investors (Arteaga and Castelán, 2008), in order to become successful in the establishment and development of forest plantations.

In addition, it is necessary to use high-quality seed and plant and have timely silvicultural management, decisions that will be better if they are based on results of experimental plantations or technically evaluated plantations, since they constitute a tool to improve the planning of the establishment and management of CFP (Pérez *et al.,* 2012).

Fast growing, high commercial value native species can maximize CFP production. *Tabebuia rosea* (Bertol.) DC. (Rosy trumpet) and *Swietenia macrophylla* King (Mahogany) are two economically important native species that have become established in CFPs in central-western Mexico. Rosy trumpet is used in the manufacture of furniture, handicrafts, in herbalism and with ornamental use (Pineda *et al.,* 2016), while mahogany is considered a precious wood from its grain. It is used as an ornamental, medicinal, tannin or coloring, in musical instruments, turned articles and handicrafts. Due to its durability, it is also used in the manufacture of light boats (Negreros *et al*., 2014).

In order to have the technical and scientific bases to develop a correct planning for the establishment and management of new CFPs with these species, it is necessary to determine the survival and growth under different edapho-climatic conditions of the plantation sites. The objective of this work was to evaluate the survival, growth and increases of forest plantations with *T. rosea* and *S. macrophylla*, 12 years after they were established in the states of *Colima, Nayarit* and *Jalisco*. The proposed hypothesis is the existence of differences in the growth and increase of both species according to the edapho-climatic conditions of the plantation sites.

Materials and Methods

Study area

The evaluated forest plantations are located on lands that belong to the *Centro de Investigación Regional Pacífico Centro* (Central Pacific Regional Research Center) (CIR Pac for its acronym in Spanish) of INIFAP in four localities located in the states of *Colima, Nayarit* and *Jalisco* (Figure 1), where plots were divided with 288 *T. rosea* and 288 *S. macrophylla* trees, under a planting density of 625 trees ha^{-1}, with a real frame design with 4 × 4 m spacing, in both species. The seeds were collected from natural populations near each locality. In the first one, I (*Tecomán*), the recently established plantations were attacked by the *arriera* ant (*Atta* sp.), which could have influenced the establishment and growth of the species. The edapho-climatic conditions of the four localities are in Table 1.

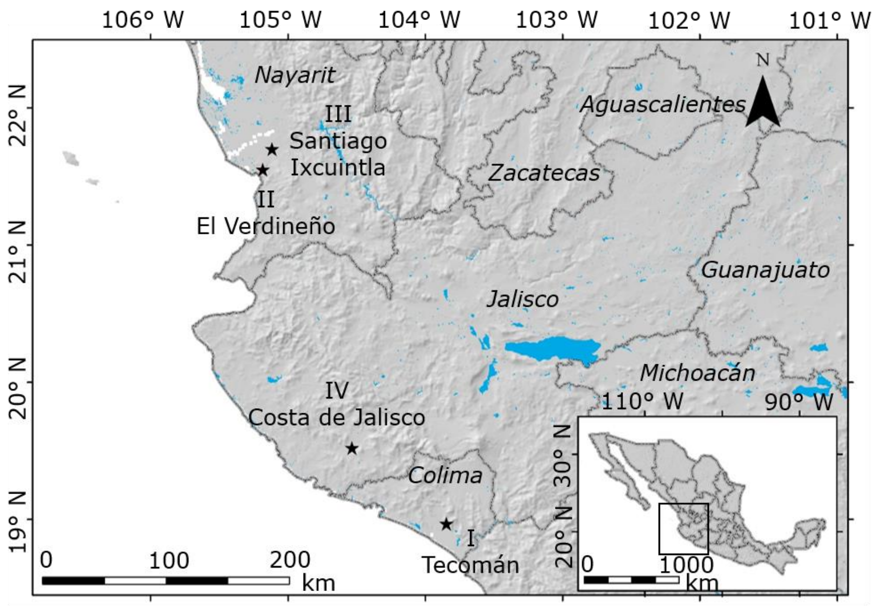

Figure 1. *Tabebuia rosea* (Bertol.) DC. and *Swietenia macrophylla* King assessed plantations in central-western Mexico.

Table 1. Location and edapho-climatic conditions of the localities with *Tabebuia rosea* (Bertol.) DC. and *Swietenia macrophylla* King plantations oin central-western Mexico.

Locality/state	Coordinates	Altitude (masl)	Climate	Mean temperature (°C)	Precipitation (mm)	Soil type and texture
I C. E. Tecomán, Colima	18°55′ N 103°53′ W	40	sub-humid warm	26	750	Chernozem, loam
II S. E. El Verdineño, Nayarit	21°33´ N 105°11´ W	50	sub-humid warm	24	1,200	Gleysol, Sandy loam
III C. E. Santiago Ixcuintla, Nayarit	21°42′N 105°07′ W	60	Sub-humid-warm	24	1,200	Cambisol, Sandy loam
IV S. E. Costa de Jalisco, Jalisco	19°31′ N 104°32′ W	298	sub-humid-warm	25.2	1,012	Haplic Phaeosem, silt-clayey

Source: Rueda (2008).

C. E.=Experimental field; S. E.=Experimental Site

Data collection

In each of the plots of the localities of the study area, an inventory was made of the surviving trees that were established 12 years ago. The height (m) of all trees was measured with a Suunto model Pm5 / 360pc clinometer and the normal diameter (cm) at a height of 1.30 m with a Jackson MS brand diametric tape, Forestry Suppliers Inc model; in the case of bifurcated trees, the diameter was measured below 1.30 m (2 % of the surviving trees), and it was decided to take them as two specimens (A and B). The volume of each tree was estimated according to the methodology of Romahn and Ramírez (2010), in which the trees were subdivided into logs or sections by measurements with the RL000 model Bitterlich relascope, and their volume was calculated with Smalian's equation:

$$V = \frac{(S_1 + S_2) * L}{2}$$

Where:

V = Log volume (m³)

S_1 = Upper area of the log (m²)

S_2 = Lower area of the log (m²)

L = Length of the log (m)

The volume of the tree was calculated with the sum of the estimated volume of each of the logs. Subsequently, the volume per hectare of each locality by species was estimated, by multiplying the average volume by the density of the trees.

Finally, the mean annual increment in normal diameter (IMAD, for its acronym in Spanish), the mean annual increment in height (IMAA, for its acronym in Spanish) and the mean annual increase in volume ha^{-1} (IMAV, for its acronym in Spanish) were estimated, dividing the values of normal diameter, height and diameter between the 12 years that the plantations have.

Information processing and analysis

The normality of the data was verified by means of a Shapiro-Wilks test in each species for the variables normal diameter (*T. rosea*: $p = 0.0103$; *S. macrophylla*: $p = 0.0023$), height (*T. rosea*: $p = 0.1594$; *S. macrophylla:* $p = 0.2706$) and volume (*T. rosea*: $p = 3.11 \times 10^{-5}$; *S. macrophylla*: $p = 7.146 \times 10^{-7}$). Homogeneity of variances was evaluated using a Bartlett test for normal diameter (*T. rosea*: $p = 0.4989$; *S. macrophylla*: $p = 0.0193$), height (*T. rosea*: $p = 0.5341$; *S. macrophylla*: $p = 0.0471$) and volume (*T. rosea*: $p = 7.471 \times 10^{-3}$; *S. macrophylla*: $p = 1.725 \times 10^{-8}$).

The variables were transformed with natural logarithm to be normalized in both species: normal diameter *(T. rosea:* $p = 0.1123$; *S. macrophylla:* $p = 0.0551$*),* height *(T. rosea:* $p = 0.2601$*; S. macrophylla:* $p = 0.4771$*)* and volume *(T. rosea:* $p = 0.275$*; S. macrophylla:* $p = 0.0497$*),* reaching more homogeneous variances in the normal diameter *(T. rosea:* $p = 0.1235$*; S. macrophylla:* $p = 0.0337$*),* height *(T. rosea:* $p = 0.5191$*; S. macrophylla:* $p = 0.7677$) and volume *(T. rosea*: $p = 0.0981$*; S. macrophylla:* $p = 0.437$).

The analysis of variance (anova) and a comparison of means with the Tukey test were carried out to evaluate differences in normal diameter, height and volume, among localities for each species and between species by locality, with 95 % of confidence level in the R programming language version 3.4.3 (R Core Team, 2017). The statistical model (Norman and Steiner, 1996) is described below:

$$Y_{ij} = \mu + A_i + E_{ij}$$

Where:

Y_{ij} = Variable that represents the value of the response in the *j-th* observation of the *i-th treatment*

μ = Constant of the mean response of *Y* variable

A_i = Effects of *i* treatment (*i* = 4 localities or 2 species)

E_{ij}= Experimental error

Results

Survival

T. rosea's survival was lower in locality I with 35 % and in the rest of them it was 70 to 82 %. In *S. macrophylla*, the range of variation was lower, from 79 to 83 % survival, and the highest percentage was recorded in locality I (Table 2).

Table 2. Survival, normal diameter, height, volume per hectare and mean annual increases of forest plantations with *Tabebuia rosea* (Bertol.) DC. and *Swietenia macrophylla* King in *Colima, Nayarit* and *Jalisco*, 12 years after they were established.

Species	Locality			
	I ***Tecomán (Colima)***	**II** ***El Verdineño (Nayarit)***	**III** ***Santiago Ixcuintla (Nayarit)***	**IV** ***Costa de Jalisco (Jalisco)***
Survivai (%)				
Tabebuia rosea (Bertol.) DC.	35	80	70	82
Swietenia macrophylla King	83	79	79	82
Density (trees ha^{-1})				
Tabebuia rosea (Bertol.) DC.	218	500	437	512
Swietenia macrophylla King	518	493	493	512
Normal diameter (cm)				
Tabebuia rosea (Bertol.) DC.	19.87^a	14.17^a	17.92^a	27.96^b
Swietenia macrophylla King	17.04^a	21.89^b	15.02^a	15.96^a
IMAD (cm year^{-1})				
Tabebuia rosea (Bertol.) DC.	1.65^a	1.18^a	1.49^a	2.33^b
Swietenia macrophylla King	1.42^a	1.82^b	1.25^a	1.33^a
Height (m)				
Tabebuia rosea (Bertol.) DC.	9.31^a	9.49^a	7.16^b	10.00^a
Swietenia macrophylla King	7.74^a	7.48^a	8.00^a	7.04^b
IMAA (m *year*$^{-1}$)				
Tabebuia rosea (Bertol.) DC.	0.77^a	0.79^a	0.59^b	0.83^a
Swietenia macrophylla King	0.64^a	0.62^a	0.66^a	0.58^b
Volume (m^3 ha^{-1})				
Tabebuia rosea	27.41^a	35.94^a	38.39^a	128.03^b
Swietenia macrophylla King	49.28^a	55.92^b	34.64^a	32.27^a
IMAV (m^3 ha^{-1} year^{-1})				
Tabebuia rosea (Bertol.) DC.	2.28^a	2.99^a	3.19^a	10.66^b
Swietenia macrophylla King	4.10^a	4.66^b	2.88^a	2.68^a

IMAD = Mean annual increase in normal diameter; IMAA = Annual mean increase in height; IMAV = Annual average increase in volume; ^{a} = Locality without significant difference; ^{b} = locality with significant difference, according to Tukey's test between localities.

Average annual growth and increment in normal diameter

In *T. rosea,* the normal diameter ranged from 14.17 to 27.96 cm and in *S. macrophylla* from 15.02 to 21.89 cm. Significant differences were identified between localities in both species, since in *T. rosea* ($p = 9.78 \times 10^{-16}$), locality IV recorded statistically the highest normal diameter, a site that is distinguished by the highest altitude (298 masl) and soil type, Haplic Phaeozem. The normal diameter in *S. macrophylla* was significantly higher ($p = 2 \times 10^{-16}$) in locality II, which has Gleysol soil.

In each locality there were significant differences between both species (locality I: $p = 4.84 \times 10^{-3}$; locality II: $p = 6.15 \times 10^{-14}$; locality III: $p = 3.3 \times 10^{-3}$; locality IV: $p = 2 \times 10^{-16}$), being *T. rosea* the one that stood out with respect to *S. macrophylla*, except in locality II where the latter obtained a greater normal diameter.

The IMAD variable presented significant differences between localities; in *T. rosea* the values varied between 1.18 and 2.33 cm year^{-1}, with the highest value in locality IV ($p = 9.78 \times 10^{-16}$); in *S. macrophylla* the IMAD ranged from 1.25 to 1.82 cm year^{-1}, with a higher value in locality II ($p = 2 \times 10^{-16}$) (Table 2).

Average annual growth and increment in height

The height of *T. rosea* varied between 7.16 and 10.00 m; while that of *S. macrophylla* between 7.04 and 8.00 m. There was a significant difference between localities, in which the height of *T. rosea* was statistically lower ($p = 0.0416$) in locality III, with Cambisol soil, while in locality IV, the height of *S. macrophylla* was significantly lower ($p = 3.64 \times 10^{-14}$).

In each locality, significant differences between species were detected (locality I: $p = 8.71 \times 10^{-5}$; locality II: $p = 5.03 \times 10^{-5}$; locality III: $p = 0.0281$; locality IV: $p =$

2.68×10^{-15}) , where in localities I, II and IV *T. rosea* was higher, while in locality III *S. macrophylla* stood out.

For the IMAA, significant differences were found between localities, in *T. rosea* (p = 0.0416) it ranged between 0.59 and 0.83 m $year^{-1}$, with the highest values in locality IV, and in *S. macrophylla* ($p = 3.64 \times 10^{-14}$) between 0.58 and 0.66 m $year^{-1}$, with the highest IMAA in III (Table 2).

Average annual growth and increment in volume ha^{-1}

The volume ha^{-1} in *T. rosea* ranged from 27.41 to 128.03 m^3 ha^{-1} and in *S. macrophylla* between 32.27 and 55.92 m^3 ha^{-1}. There are significant differences between localities in both species, where *T. rosea* registered a higher volume in IV ($p = 1.95 \times 10^{-10}$) and *S. macrophylla* in II ($p = 2 \times 10^{-16}$).

In localities I, II and IV there were significant differences between species (locality I: p = 0.0166; locality II: $p = 5.18 \times 10^{-6}$; locality IV: $p = 2 \times 10^{-16}$); *T. rosea* was dominant in localities I and II, while *S. macrophylla* was better in localities IV. In III there were no significant differences between species (p = 0.283).

IMAV showed significant differences between localities in both species, since in *T. rosea* ($p = 1.95 \times 10^{-10}$) it varied from 2.28 to 10.67 m^3 ha^{-1} $year^{-1}$, with the best result in locality IV and in *S. macrophylla* ($p = 2 \times 10^{-16}$) between 2.69 to 4.66 m^3 ha^{-1} $year^{-1}$, with the highest value in II (Table 2).

Discussion

Species' growth is the result of the influence of the edapho-climatic characteristics of the plantation sites and their genetics or natural growth (Martínez-Álvarez, 1995). For example, *T. rosea* in early stages is fast growing, but exhibits highly variable bifurcation patterns that can affect growth in height and normal diameter (Borchert and Tomlinson, 1984).

The survival percentages of the plantations in this study were considered high in both species, except for *T. rosea* in locality I. *S. macrophylla's* survival in the study region was lower than 13-year plantations in *Tabasco* (100 %), where higher average annual rainfall prevails, up to 2 290 mm per year and with soils with higher moisture content (Eutric Fluvisol, Cambisol and Mollic Gleysol) (Pérez *et al.,* 2012).

The normal diameter of *S. macrophylla* was greater than plantations of this species in southern *Jalisco* (10.2 cm) (Rueda *et al.,* 2014); while, in *T. rosea* it was similar to 14-year-old plantations from the same region (15 to 24 cm) (Rueda *et al.,* 2010), but the IMAD of this species was higher than in trees of this species in the state de *Guerrero* (0.58 cm year^{-1}), subject to drier conditions (Pineda *et al.,* 2016). However, the normal diameter of both species was lower than 11 and 13-year-old trees of *T. grandis* L. f. in *Nayarit* (25 to 28 cm), where this species grew in lake soils with high moisture content (Luvisol and Solonchak) (Vincent, 2018).

The height of *T. rosea* reached in localities I, II and IV was lower than that registered in a 14-year-old plantation on the *Jalisco* coast (12.8 m) (Distancia *et al*., 2008), and it also surpassed *Cedrela odorata* L. (8.19 m) in plantations of *Tecomán* (Orozco *et al*., 2010), but it was lower than plantations of 11 and 13 years of *T. grandis* in *Nayarit* (15 and 25 m, respectively) (Vincent, 2018). The height of *S. macrophylla* was also lower than plantations between 11-16 years of this same species in *Tabasco* (14-23 m) where the average annual rainfall is higher, which promotes its development (Pérez *et al.,* 2012).

The volume of *T. rosea* trees in locality IV exceeded that of plantations of 11 to 13 years of *T. grandis* (Vincent, 2018) and IMAV, that of *Gmelina arborea* Roxb. ex. Sm. plantations (10.5 m^3 ha^{-1} $year^{-1}$) in sites with poor soils in the state of *Tabasco* (Martínez *et al.,* 2015). In the case of *S. macrophylla*, the volume of the trees was similar to that of an 11 to 13-year-old plantation in *Tabasco* (37-98 m^3 ha^{-1}) (Pérez *et al*., 2012).

The results of this study indicate that *T. rosea* was better in locality IV (normal diameter, height and volume) and *S. macrophylla* in II (normal diameter and volume) and IV (height), which suggests that, the species may have better performance depending on the edaphoclimatic conditions of each particular site (Méndez and Vanegas, 2016). The main different variable between the localities was the type of soil, since the Cambisol (locality II) and Phaeozem (locality IV) would have promoted a better development of the evaluated species.

Cambisols generally stand out for their high content of nutrients such as iron, calcium carbonate and manganese; while the Phaeozem are rich in organic matter, calcium and potassium (Vivanco *et al.,* 2010). It is important to evaluate in subsequent studies, the effect of soil type and precipitation on the development of these tropical species. In the second case, there would be indications that the survival of *S. macrophylla* would be higher in sites with higher mean annual rainfall, such as in *Tabasco* (Pérez *et al.,* 2012), and lower normal diameter in *T. rosea* in drier sites, as in *Guerrero* (Pineda *et al.,* 2016).

This confirms that the performance of tropical species is subject to very specific edapho-climatic conditions. For example, *C. odorata* on the coast of *Jalisco* grows well at elevations close to 300 masl sub-humid warm climate with mean annual rainfall of 1 100 mm and Haplic Phaeozem soil (Rueda *et al.,* 2014), while *G. arborea* in the dry tropics of the state of *Michoacán*, at altitudes of 500 m, warm subhumid climate, Vertisol soil and gentle slopes (Muñoz *et al.,* 2009).

This study made it possible to identify that *T. rosea* and *S. macrophylla* have a broad potential to establish in CFP within the central-western part of Mexico, the first species on the *Jalisco* coast (*La Huerta* region) and the second on the *Nayarit* coast. (*El*

Verdineño region). Therefore, the evaluation of forest plantations constitutes a reliable tool to determine the areas where it should be planted. It is essential to assess which sites meet the edapho-climatic characteristics for other forest species of commercial importance and ecological restoration.

Conclusions

The assessment of variables such as survival, normal diameter, IMAD, height, IMAA, volume and IMAV in experimental plantations of *T. rosea* and *S. macrophylla* in central Mexico allowed to identify that the best locations to establish CFP are the coast of *Jalisco* (locality IV), in the case of the first species, and the coast of *Nayarit* in the case of the second (locality II).

The type of soil could be the determining factor on the differences in the variables between localities, so it is important to know its effect on the development of both tropical species in subsequent studies. In addition, this study confirmed that the species have different performance according to the particular edapho-climatic conditions of the plantation sites, so it is important to weigh the growth and development of the species under specific environmental conditions, prior to their establishment in CFP massive or in restoration plantations.

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Conflict of interest

The authors declare no conflict of interest.

Contribution by author

Agustín Rueda Sánchez: preparation of the project, field sampling and writing of the manuscript; Juan de Dios Benavides Solorio: preparation of the Project and field sampling; J. Trinidad Sáenz Reyes: statistical analysis, writing and review of the manuscript; H. Jesús Muñoz Flores: writing and review of the manuscript; David Castillo Quiroz: writing and review of the manuscript; Jesús Eduardo Sáenz Ceja: statistical analysis and writing of the manuscript.

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