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Original article

Growth of guaiacum (Guaiacum sanctum L., Zygophyllceae) under different levels of shade

Crecimiento de guayacán (Guaiacum sanctum L., Zygophyllceae) bajo diferentes niveles de sombra

Crescimento de guaiacum (Guaiacum sanctum L., Zygophyllceae) sob diferentes níveis de sombreamento

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SUMMARY

Due to the economic value of its wood, *Guaiacum G. sanctum* L. has been overexploited, placing it at risk of extinction. Due to its slow growth, it causes a slow recovery in its population. The objective of this study was to evaluate the growth of *G. sanctum plants* under different shade intensities. A completely randomized design with four treatments was used. The variables evaluated were height, basal diameter, and survival over a period of 153 days. An analysis of variance was performed to detect differences between treatments using Infostat 2020 software. Survival did show differences between treatments, while at the end of the evaluation period, statistical differences were observed between treatments in the total increase in height ($p = 0.0196$), with the full sun treatment obtaining the greatest increase (17.07 ± 14.95 cm); in the case of diameter, statistical differences were only observed in the average increase ($p < 0.001$) between treatments, with the 35% shade treatment obtaining the greatest average increase (5.21 mm). The results indicate that the increase in height and diameter of *G. sanctum* occurs under conditions of greater luminosity, considering the shade of the treetops that influences the search for light in the increase in height and the shade that can be had allows the increase in diameter.

Keywords: native flora, threatened, reforestation, overexploitation, survival.

RESUMEN

Debido al valor económico de su madera, *Guaiacum sanctum* L. ha sido sobreexplotada, colocándola en riesgo de extinción. Debido a su lento crecimiento, ocasiona una recuperación lenta en su población. El objetivo de este trabajo fue evaluar el crecimiento de plantas de *G. sanctum* bajo diferentes intensidades de sombra. Se utilizó un diseño completamente al azar con cuatro tratamientos. Las variables evaluadas fueron altura, diámetro basal y la supervivencia en un periodo de 153 días. Se realizó un análisis de

varianza para detectar si hay diferencias entre los tratamientos utilizando software Infostat 2020. La supervivencia si mostró diferencias entre tratamientos, mientras que al final del periodo de evaluación se observaron diferencias estadísticas entre tratamientos en el incremento total de la altura (p=0.0196), donde el tratamiento a pleno sol obtuvo el mayor incremento (17.07 ± 14.95 cm); en el caso del diámetro, solo se observaron diferencias estadísticas en el incremento promedio (p<0.001) entre tratamientos, siendo la sombra del 35 % en donde se obtuvo el mayor incremento promedio (5.21 mm). Los resultados indican que el incremento en altura y diámetro de *G. sanctum* se da en condiciones de mayor luminosidad, considerando la sombra de las copas de los árboles que influyen en la búsqueda de la luz en el incremento de la altura y la sobra que se puede tener permite el incremento en el diámetro.

Palabras clave: flora nativa, amenazada, reforestación, sobreexplotación, supervivencia.

RESUMO

Devido ao valor econômico de sua madeira, o *Guaiacum sanctum* L. tem sido sobreexplorado, colocando-o em risco de extinção. Devido ao seu crescimento lento, isso resulta em uma recuperação lenta de sua população. O objetivo deste estudo foi avaliar o crescimento de plantas de *G. sanctum* sob diferentes intensidades de sombreamento. Utilizou-se o delineamento inteiramente casualizado com quatro tratamentos. As variáveis avaliadas foram altura, diâmetro basal e sobrevivência ao longo de um período de 153 dias. Uma análise de variância foi realizada para detectar diferenças entre os tratamentos utilizando o software Infostat 2020. A sobrevivência apresentou diferenças entre os tratamentos, enquanto ao final do período de avaliação, foram observadas diferenças estatísticas entre os tratamentos no aumento total da altura (p = 0,0196), com o tratamento a pleno sol obtendo o maior aumento (17,07 ± 14,95 cm); No caso do diâmetro, diferenças estatísticas foram observadas apenas no aumento médio (p < 0,001) entre os tratamentos, sendo o maior aumento médio (5,21 mm) observado na área sombreada a 35%. Os resultados indicam que o aumento da altura e do diâmetro de *G. sanctum* ocorre em condições de maior luminosidade. Considerando a sombra das copas

das árvores, que influencia a busca por luz e aumenta a altura, a sombra disponível permite o aumento do diâmetro.

Palavras-chave: flora nativa, ameaçada, reflorestamento, sobreexploração, sobrevivência.

INTRODUCTION

Mexico is one of the megadiverse countries in the world, which currently faces environmental problems such as the overexploitation of its natural resources, fragmentation and loss of habitat and biodiversity, species extinction, and soil degradation, among others (Boyer and Cariño, 2013; Morales *et al*., 2014; Navarro-Sigüenza *et al*., 2014; Morrone, 2019). *G. sanctum* is a timber tree at risk of extinction due to deforestation for agriculture and livestock (Mendoza-Arroyo *et al* ., 2011; López *et al*., 2012; Zúñiga-Ortiz, 2015). The habitat of *G. sanctum* is in decline, mainly due to deforestation associated with increasing human populations and the conversion of forests into multiple-use areas by humans; which is why it is on the red list of threatened species of the International Union for Conservation of Nature (IUCN, 2025) and is also listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2024; CONABIO, 2021). This situation is aggravated because *G. sanctum* It is a slow-growing species (Fumero, 2021); therefore, it is necessary to understand the factors that affect its growth, influenced by its genetic characteristics and its interaction with the environment, such as climate, soil and topography, which together refer to the quality of the site (Prodan, 1997). This species is classified as shade-tolerant, possibly due to its slow-growth characteristic and its resistance to drought (Daley and Zimmerman, 2008). Given its slow growth, *G. sanctum* It can reach ages greater than 1000 years (Wendelken and Martin, 1987). Vester and Navarro (2007) mention that at the plant level its relative growth rate is higher in open areas than under shade, and in observations made in the botanical garden "Dr. Alfredo Barrera Marín" in Puerto Morelos, Quintana Roo, Mexico, it was shown that individuals older than 15 years do not have sizes greater than 1.5 m in height and 1 cm in diameter.

On the other hand, Cordero and Boshier (2003) mention that *G. sanctum* branches a lot in full sunlight, so it can form several main axes, consequently, it is not recommended for pure plantations in monocultures, however, it is recommended in mixed plantations under some lateral shade to achieve optimal development of the stem; for example, mixed with medium and fast growing species, which provide the necessary shade during its establishment and development. This has been observed in natural areas, where *G. sanctum* It is typical of the dry forest, where it grows associated with other species such as *Astronium graveolens* Jacq (rum rum), *Tabebuia ochracea* (Cham.) Standl (yellow cortez), *Sideroxylon capiri* Pittier (tempisque), among others. In Nicaragua, it is a representative tree of very dry and hot areas, associated with *Caesalpinia coriaria* (Jacq.) Willd and *Haematoxylon brasiletto* H. Karst; grows at low elevations from five meters above sea level very close to the coast to 700 meters above sea level, with dry to semi-arid climates and rainfall less than 1,500 mm per year; it develops in rocky and limestone terrain, especially on moderate to steep slopes (Cordero and Boshier, 2003).

For his part, Ferrufino *et al* . (2016) mention that this species, during its early stages or years of growth, establishes itself at high densities, which is why it presents a grouped spatial distribution pattern. However, there is little information about its growth under different shade conditions, so the objective of the present study was to evaluate the growth response of *G. sanctum plants* established under different shade intensities. It is hypothesized that plant growth in diameter and height will not be the same at different levels of shade.

MATERIALS AND METHODS

The experiment was carried out in the agroforestry research area of the Technological Institute of Chiná , located in the town of Chiná , Campeche, Mexico, at coordinates 19°46'13"N 90°30'12"W, the predominant climate is warm subhumid with an average annual temperature of 27 °C (García, 2004). This experiment was established in November 2017 and the evaluation period was 153 days.

Treatments

The research used a completely randomized design with four treatments: full sun (0% T1), 35%, (T2), 60% (T3) and 90% (T4) shade, with five replications. For shade, polyethylene shade mesh was used, which was placed on a metal structure with dimensions of 1x1 m, which covered the roof and the four sides of said structure to prevent the entry of direct light. For each treatment, five plants (each plant is considered a replicate) of *G. sanctum were used* , taking each of the plants as an experimental unit, these were 3 months old, which were obtained from a previous work on pre-germinative treatments (Mex-Villalobos *et al*., 2021), which were transplanted into black polyethylene bags with a capacity of 2 kg. The substrate was Tzequel type soil (lithic Leptosol); constant watering prevented moisture loss in the substrate.

Variables evaluated

Once the plants were placed within the different shade structures, the basal stem diameter at substrate level (mm) was measured using a Cadena® A020 digital caliper. Total height (cm) was measured with a graduated ruler from the substrate level to the plant apex. These measurements were taken every seven days, recording 12 data points over a period of 153 days. The height and diameter data were used to calculate the average and total increments for each seven-day period. The survival percentage of plants established for each treatment was recorded by counting live and dead plants.

It was observed that the data do not meet the assumption of normality according to the Shapiro-Will test, $p<0.05$, so to determine the effect of the treatments on the variables evaluated, the non-parametric Kruskal Wallis test was used, which allows comparing the means to identify differences between treatments in the statistical software INFOSTAT 2020 (Di Rienzo *et al*., 2020).

RESULTS AND DISCUSSION

Survival

Seedling survival was different in each of the treatments, observing at the end of the evaluation period that T2 and T3 had 100% survival, followed by T4 with 80%, with T1 being the lowest with only 20%.

In the case of growth variables, the basal diameter showed significant differences between treatments ($p < 0.0001$), where the best treatment was T2 (C) with a standard deviation of 3.66 ± 1.21 mm, followed by T1 (3.08 ± 1.38), T4 (2.60 ± 0.29), and finally the lowest value was obtained by T3 with 2.52 ± 0.61 mm (Figure 1). These results show that this variable requires a certain level of shade for its growth. On the other hand, the height variable did not show significant statistical differences ($p = 0.15151$) (Figure 1).

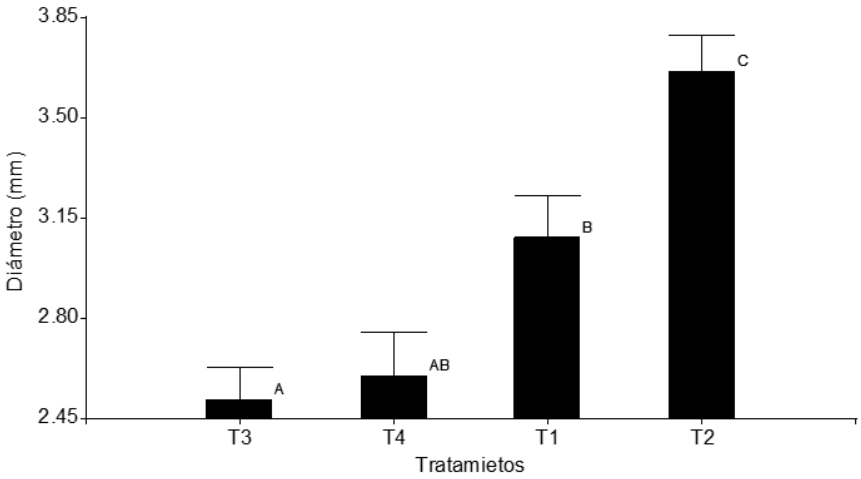

Figure 1. *- Growth in diameter of Guaiacum seedlings sanctum L. under different shade levels (153-day period). T1: full sun, T2: 35% shade, T3: 60% shade, T4: 90% shade. A: No significant differences; B, C: Significant differences*

Height and diameter

Regarding the average increase in height and diameter, these variables showed statistically significant differences between treatments (P=0.0002 and P<0.0001 respectively). In the case of height, the greatest average increase (1.56 ± 1.16 cm) was obtained in treatment T1 (full sun), followed by T2 (35% shade) (1.05 ±0.74 cm), the

lowest average increases were obtained in T3 and T4 (Figure 2). In the case of diameter, the greatest average increase was obtained in T2 (35% shade) (0.26±0.12 mm), followed by T1 (0.25±0.19 mm), however, between these two treatments no statistical differences were observed, as well as between treatments T3 (0.08 ± 0.04) and T4 (0.10 ± 0.07) where T3, (Figures 2 and 3).

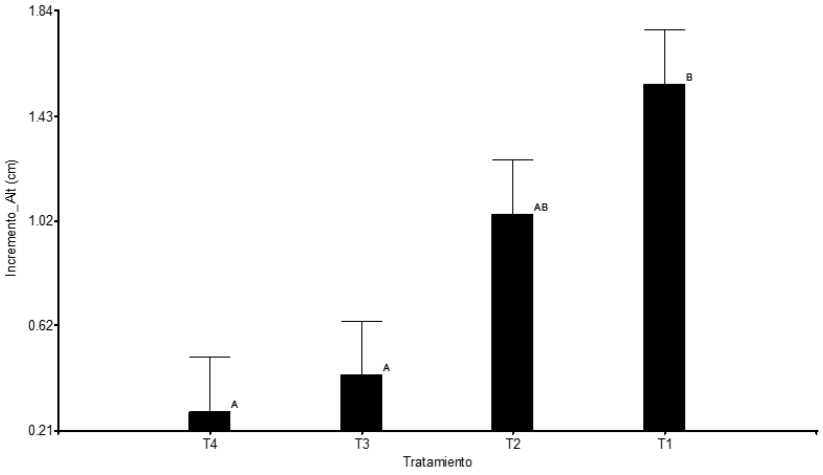

Figure 2. *- Average height increase of Guaiacum seedlings sanctum L. under different shade levels. T1: full sun, T2: 35% shade, T3: 60% shade, T4: 90% shade. A: No significant differences; B: Significant differences.*

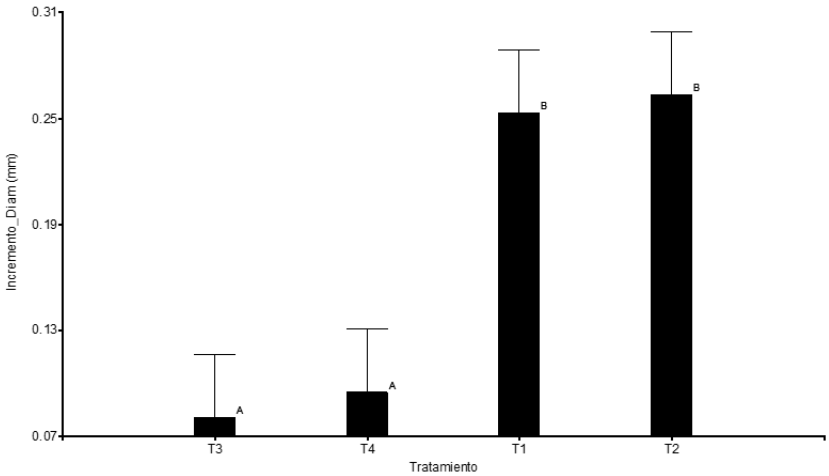

Figure 3. *- Average increase in diameter of Guaiacum seedlings sanctum L. under different shade intensities. T1: full sun, T2: 35% shade, T3: 60% shade, T4: 90% shade. A: No significant differences; B: Significant differences*

At the end of the measurement period, in the total increase, only statistical differences were identified in the height variable (P = 0.0196). The greatest increase was obtained in T1 (full sun) (17.07 ± 14.95 cm), followed by T2 (35% shade) (11.56 ± 9.03), T3 (4.77 ± 2.74), and the smallest increase was obtained in T4 (90% shade) (2.07 ± 1.85) (Figure 4).

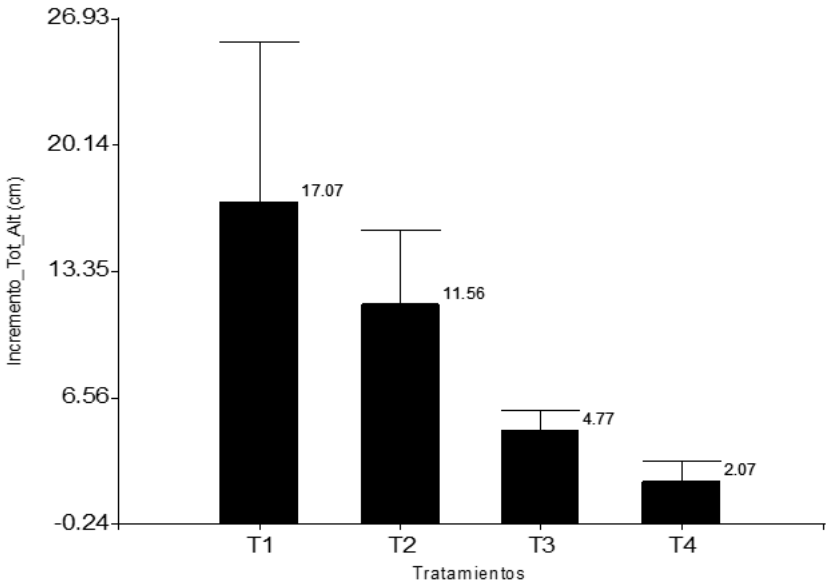

Figure 4. - *Total increase in height of Guaiacum plants sanctum L. under different levels of shade over a 153-day period. T1: full sun, T2: 35% shade, T3: 60% shade, T4: 90% shade*

González *et al* . (2009) mention that probably due to the low competition for resources that open sites have, *G. sanctum plants* They exhibit greater growth than those under closed canopy. This coincides with the results of this study, as the greatest increase in height was obtained in the full-sun treatment, although the greatest growth at the end of the study was observed in diameter under 35% shade, followed by the full-sun treatment. These results provide concrete information regarding the light requirements of this species.

On the other hand, Fumero (2021) mentions that it is important to understand and identify the environmental factors that influence the growth of *G. sanctum* , which would be useful before implementing strategies to increase the population size of this species. López *et al.* (2012) mention that differences in the average height and diameter of the *G. sanctum species* may be due to climatic variables. In Campeche, *G. sanctum* has been identified as an abundant tree species in a state protected natural area (Mendoza-Arroyo

et al., 2011), which has also occurred in other protected natural areas in other Latin American countries (Zúñiga-Ortiz, 2015). It is inferred that the regeneration of this species in protected areas, where different anthropogenic activities are scarce and shaded areas with at least 30% are frequent, allows the recovery of *G. sanctum* populations, as shown by the results of the present study.

CONCLUSIONS

According to the study, the results indicate that *G. sanctum seedlings* require 35% shade to increase in diameter and full sun to increase in height, demonstrating that these conditions can be achieved in clearings within the forest. Furthermore, to ensure early survival, seedlings must be kept in high shade conditions, i.e., shade percentages greater than 60%.

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***Conflict of interest*:**

The authors declare that they have no competing interests.

***Author Contributions*:**

For research articles with multiple authors, a short paragraph specifying their individual contributions should be provided. The following statements should be used: "conceptualization, BBDC and MMMV; methodology, BBDC; software, GRRU; validation, GEMA and NAGV; formal analysis, GEMA and NAGV; investigation, MMMV and MVE; resources, BBDC, FMTAE; data curation, FMTAE; writing: preparation of original draft, BBDC and MVE; writing: review and editing, BBDC and MVE; visualization, BBDC; supervision, EGL; project administration, EGL; funding acquisition, BBDC." See CRediT taxonomy for an explanation of the term. Authorship should be limited to those who have substantially contributed to the reported work.