Colegio de Postgraduados

# Evaluation of the Growth of Black Mangrove (*Avicennia germinans*) Established in Plantations on a Technosol Soil

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**ABSTRACT**

**Objective**:To evaluate the growth of black mangrove (*Avicennia germinans* L.) in a nine-hectare plantation located in the Ejido La Solución Somos Todos, Paraíso, Tabasco, by assessing the height and diameter of plants established on Tecnosol soils.

**Design/Methodology/Approach**: The plantation was established at a density of 625 plants per hectare. A Completely Randomized Design (CRD) was employed across three plots exhibiting similar edaphic characteristics. In each plot, 69 plants were randomly selected for monitoring. Measurements were conducted six months after planting using a graduated wooden ruler for height and a vernier caliper for diameter. ANOVA was applied to evaluate significant differences between plots, followed by Tukey's test for multiple comparisons.

**Results**: revealed statistically significant differences in plant growth. Plot 3 recorded the highest average height (75.08±14.3 cm), while Plot 2 showed the greatest average diameter (0.46±0.272 cm). In contrast, Plot 1 exhibited the lowest growth performance (45.33±16.6 cm). These differences were directly associated with site quality despite the common use of landfill soils, certain areas offered more favorable conditions than others. The observed variation underscores the complexity of environmental dynamics influencing mangrove development.

**Study Limitations/Implications**: A key limitation of this study lies in the influence of uncontrolled external factors, emphasizing the need for ongoing, long-term monitoring.

**Findings/Conclusions**: Black mangrove growth is highly dependent on soil characteristics, moisture levels, solar radiation, and salinity.

**Keywords**: black mangrove, height, diameter, sampling plots.

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## INTRODUCTION

In Mexico, mangroves cover an extensive area of approximately 905,000 hectares, distributed across 17 coastal states, with the largest extensions found in Sinaloa, Veracruz, Campeche, and Quintana Roo. This ecosystem faces serious threats from human activities such as urbanization and tourism, which negatively impact both its extent and ecological

quality, rendering it a vulnerable ecosystem (CONABIO, 2022). In the Gulf of Mexico, urban and port expansion has significantly reduced mangrove areas, disrupting their structure and function in regions like Tamaulipas, Veracruz, and Tabasco (Basáñez *et al.*, 2021). Black mangrove, with its aerial roots or pneumatophores, has developed specialized mechanisms to tolerate extreme saline conditions, expelling excess salt through leaf glands (Hernández *et al.*, 2024). As a pioneering species, it facilitates the colonization of intertidal zones and enhances the surrounding vegetation, which is crucial for coastal stability and erosion mitigation (Cobacho *et al.*, 2023). This species is also found along the Gulf Coast of the United States, extending as far north as Louisiana and Florida, making it the most cold-tolerant mangrove species in North America (Osland *et al.*, 2020). The distinct features of black mangrove, such as its thick, leathery leaves, enhance its resilience in hostile environments and contribute to carbon and organic matter accumulation in coastal soils key factors for soil quality and ecosystem stability (Monroy *et al.*, 2024; Núñez-Ravelo *et al.*, 2021; Murphy *et al.*, 2020). These soils also benefit from the transformation processes of organic matter and carbon, which are influenced by climate and hydroperiod, contributing to the sustainability and functionality of these ecosystems (Barreto *et al.*, 2016). Variability in nutrient availability and salinity also plays a significant role, affecting mangrove species' productivity, which responds differently depending on the limiting nutrient in the environment (Whigham *et al.*, 2009). Therefore, the growth of mangrove seedlings is heavily influenced by soil characteristics and hydrological connectivity, which support development in mangrove forests (Numbere, 2021). During the early stages of growth, this species requires soils with low salinity and essential nutrients such as nitrogen, phosphorus, and potassium to achieve proper development (Matto *et al.*, 2023). The growth of black mangrove (*Avicennia germinans*) in the Ejido La Solución Somos Todos, Paraíso, Tabasco, is vital for the preservation of coastal ecosystems. This mangrove plays a crucial role as a natural barrier against erosion and storm surges, while also contributing significantly to carbon sequestration, climate regulation, and biodiversity conservation. This study aims to evaluate the growth of black mangrove (*Avicennia germinans*) in reforested plots located within the Ejido La Solución Somos Todos, Tabasco, through measurements of height and diameter in individuals distributed across four plots established on Tecnosol soils. The primary objective of this research was to assess the growth of black mangrove (*Avicennia germinans* L.) in a nine-hectare plantation in the same ejido.

## MATERIALS AND METHODS

### Area of study

The study was conducted in 2022 within the black mangrove forest lands of the UMA (Unit for the Conservation, Management, and Sustainable Use of Wildlife) La Solución Somos Todos, located in the Ejido La Solución Somos Todos, Nicolás Bravo 2$^{nd}$ Section, Paraíso, Tabasco, situated between the coordinates 93° 08' 24" and 93° 03' 36" west longitude, and 18° 18' 36" and 18° 22' north latitude. The soils in the area correspond to Hypersalic Gleyic Solonchak (Sodic) SChsgl(so), Spolic (Humic) Technosol TCsp(hu), and Eutric Gleysol. The climate is warm and humid with abundant summer rainfall, with the warmest months being from May to August (Palma *et al.*, 2007).

**Experimental design**

A Completely Randomized Design (CRD) was used to evaluate differences in height and diameter of black mangrove (*Avicennia germinans* L.) plants across the three monitoring plots. In each plot, measurements were taken from 69 randomly selected plants, totaling 207 plants analyzed. The plantation covered a total area of 9 hectares along a 3.9 km strip of reclaimed soil.

**Black Mangrove Seed Collection, Germination, and Transplanting Process**

The black mangrove seeds were collected in the Ejido La Solución Somos Todos from physiologically and sexually mature trees native to the same mangrove zone within the community. Seeds were carefully selected, discarding those with visible damage caused by insects, microorganisms, or other factors that could compromise their viability (González-Hernández *et al.*, 2016). A total of 750 seeds were selected and sown in germination beds. These beds were constructed using locally sourced rustic materials and filled with fine sand to improve drainage and create a suitable environment for germination. The germination beds measured 10 meters in length and 1.20 meters in width, filled to a height of 20 cm. Seeds were sown using the "broadcasting" technique, which involves scattering seeds uniformly over the prepared surface, followed by watering to maintain the moisture necessary for germination (Cuellar *et al.*, 2023). After germination, 450 seedlings were carefully transplanted into bags filled with appropriate substrate to continue their development in the nursery. This step ensured that the seedlings grew in a controlled environment, protected from external stressors. The final transplant into the monitoring area was carried out once the seedlings reached a height of 30 cm and had developed at least six leaves (Reyes & Tovillas, 2002).

**Determining the number of black mangrove plants for monitoring**

The plots were established at three different sites, and to determine the number of black mangrove (*Avicennia germinans* L.) plants to be evaluated, a sample size calculation formula was used. Each monitoring plot was established with 150 uniformly distributed plants. Every selected plant was consecutively numbered and marked with a visible tag. In this way, the plants were identified from 1 to 207, facilitating the monitoring process and data collection. From the total, a representative sample of 69 plants was selected for monitoring.

**Experimental design**

A Completely Randomized Design (CRD) was employed to assess differences in height and diameter among 69 randomly selected black mangrove (*Avicennia germinans* L.) plants in each plot. The number of plants to be evaluated was calculated following Cortés *et al.* (2014), ensuring that the data were representative, with a defined confidence level and controlled margin of error. The three plots were established within the 3.9 km of the reforested area and were randomly located. This approach enabled the identification of differences in average growth among plots. Due to the irregular shape of the terrain strip, the plots were modified to dimensions of 120 meters in length by 20 meters in width.

Figure 1 illustrates the dimensions of each plot, with 150 reforested black mangrove plants measured for height and diameter.

**Black Mangrove Seed Collection, Germination, and Transplanting Process**

The black mangrove (*Avicennia germinans*) seeds were collected in the Ejido La Solución Somos Todos, from an area that ensured seed quality. After collection, seeds were carefully selected, discarding any that showed visible damage caused by insects, microorganisms, or other factors that could compromise their viability (Cuellar *et al.*, 2023). Once selected, the seeds were sown in germination beds prepared at the community nursery of the ejido, with the objective of providing optimal conditions for seedling development. The germination beds were constructed using wooden supports and filled with fine sand to enhance drainage and create a suitable germination environment. The dimensions of the beds were 10 meters long by 1.20 meters wide and were filled with a sand layer approximately 20 cm high. The beds were protected under 60% shade mesh within the nursery. Seeds were sown using the "broadcasting" technique, which consists of evenly scattering them over the prepared surface, followed by watering to maintain the moisture necessary for germination (Cuellar *et al.*, 2023). After germination, the seedlings were carefully transplanted into individual

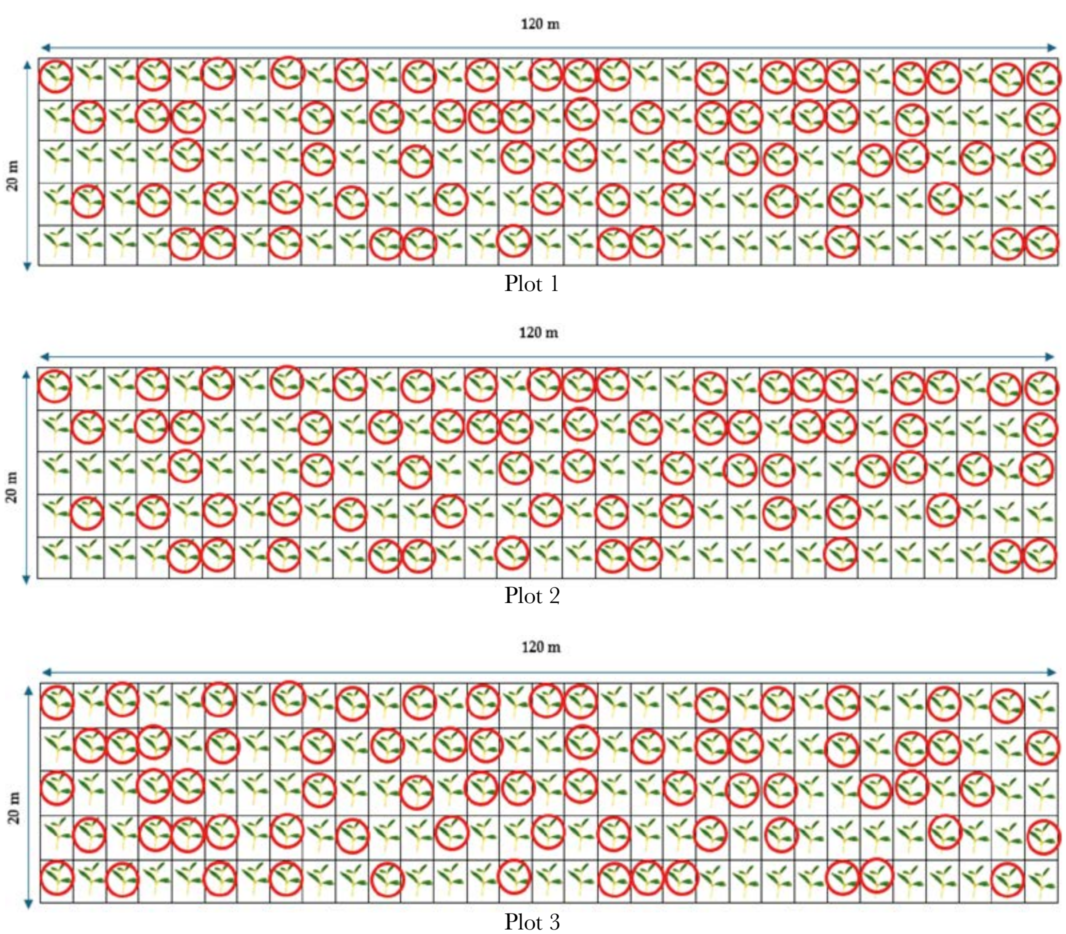


**Figure 1**. Distribution of the 150 black mangrove plants per plot, with the 69 plants randomly selected for height and diameter measurements.

bags with prepared substrate to continue their development within the nursery. This step allowed the seedlings to grow in a controlled environment, protected from external factors. The final transplant to the monitoring area was carried out once the seedlings reached an appropriate developmental stage, with at least six fully formed leaves, ensuring survival and optimal growth in their new habitat (Reyes and Tovillas, 2002).

**Delimitation and Design of Plots for Monitoring Black Mangroves**

A total of three plots were established, each measuring 120 meters in length and 20 meters in width, located on land with similar characteristics, specifically featuring the soil type known as Tecnosol. These plots were strategically distributed across representative sites to ensure that they adequately reflected the conditions of the area under evaluation. The plots were established within a nine-hectare reforested area. Each plot included 150 black mangrove (*Avicennia germinans*) individuals, uniformly distributed to ensure an even spatial arrangement of the plants across the terrain. From the 150 plants in each plot, a random sample of 69 was selected for monitoring in order to obtain a representative sample of growth performance. To facilitate the identification and tracking of each selected plant throughout the study period, a unique number was assigned to each. A plastic tag with the corresponding number was attached to each plant, loosely fastened to avoid interfering with stem diameter growth. The use of consecutive numbering allowed for precise and organized control during the monitoring process of black mangrove growth.

**Dasometric measurements (height, diameter)**

Measurements of the height and diameter of black mangrove (*Avicennia germinans*) plants were conducted six months after transplanting, with the objective of evaluating their growth under uniform soil conditions, though distributed across different sites. Plant height was measured every three months using a graduated wooden ruler, following the methodology proposed by Castañeda and Palomino (2018). This approach enabled continuous and accurate monitoring of vertical plant growth. Stem diameter was measured with a vernier caliper, as the young mangrove plants had small stem diameters. The measurement methodology followed the procedures described by Rodríguez *et al.* (2018), ensuring precise and consistent data collection throughout the study period. Ongoing monitoring facilitated effective tracking of plant development in each plot.

**Statistical analysis**

Data analysis was conducted using RStudio, version 2024.09.0-375 (RStudio Team, 2024). To compare differences in plant height and stem diameter among the plots, an analysis of variance (ANOVA) was performed. This analysis allowed for the identification of statistically significant differences in plant growth between the plots. Once the ANOVA indicated significant differences, Tukey's multiple comparison test ($\alpha$=0.05, 95% confidence level) was applied to determine specifically which plots differed in terms of plant height and diameter. This approach ensured a detailed and rigorous examination of the data, providing precise insights into the growth patterns of black mangrove across the monitored plots. The results from monitoring the growth of black mangrove (*Avicennia germinans*) revealed statistically significant differences in both height and stem diameter across the three plots. According to the data, Plot 3 exhibited the highest average height (75.08±14.3 cm), followed by Plot 2 (64.79±18.4 cm). In contrast, Plot 1 showed the lowest average height (45.33±16.6 cm). Regarding stem diameter, Plot 2 recorded the largest average diameter (0.46±0.272 cm), while Plot 1 presented the smallest (0.30±0.230 cm) (Table 1). The significant differences in both variables suggest that the black mangrove plants exhibited differential growth responses despite being established in the same soil type (Tecnosol). These variations in plant development among plots may be attributed to several environmental factors. Although the soil type was consistent, Lovelock *et al.* (2007) suggest that growth in mangrove species can be influenced by environmental variables such as light availability, soil moisture, temperature, and wind exposure. Plot 3, which recorded the tallest plants, may have benefited from greater sunlight exposure or improved moisture retention, promoting faster growth compared to Plot 1, where less favorable conditions may have contributed to slower development.

## RESULTS AND DISCUSSION

### Comparison of the average height and diameter of black mangrove plants in different plots

Competition for resources may also play a critical role. Young black mangrove plants often compete intensely for nutrients and water, particularly in soils prone to salinity or drought stress (Anu *et al.*, 2024). It is plausible that plots with higher plant density or greater weed presence experienced increased competition, thereby limiting the growth of the monitored individuals. In this regard, the differences in stem diameter across plots may also reflect unequal competition for available resources (Bolívar *et al.*, 2022) (Table 1).

The results of this study reflect the inherent variability of mangrove ecosystems, which are influenced by both biotic and abiotic factors. As noted by Barbier *et al.* (2011), growth differences in mangrove species can be complex and not always predictable, as they result from dynamic interactions among soil, water, climate, and local biological conditions. The variability in black mangrove growth observed in this study underscores the importance of accounting for these factors when planning mangrove restoration projects, particularly in areas with diverse environmental conditions. Regarding plant growth, Plot 1 showed that the highest concentration of individuals was found within the lower height ranges, suggesting that site-specific conditions were less favorable. Notably, the 70-79 cm height range showed no individuals, indicating that under suboptimal conditions, the seedlings are less likely to survive (Figure 2).

**Table 1**. Comparison of means in the three monitoring plots.

| Parcel | Height | Diameter |
|---|---|---|
| Parcel 1 | 45.33±16.6 (c) | 0.173±0.072 (c) |
| Parcel 2 | 64. 79±18.4 (b) | 0.46±0.272 (a) |
| Parcel 3 | 75.08±14.3 (a) | 0.30±0.230 (b) |

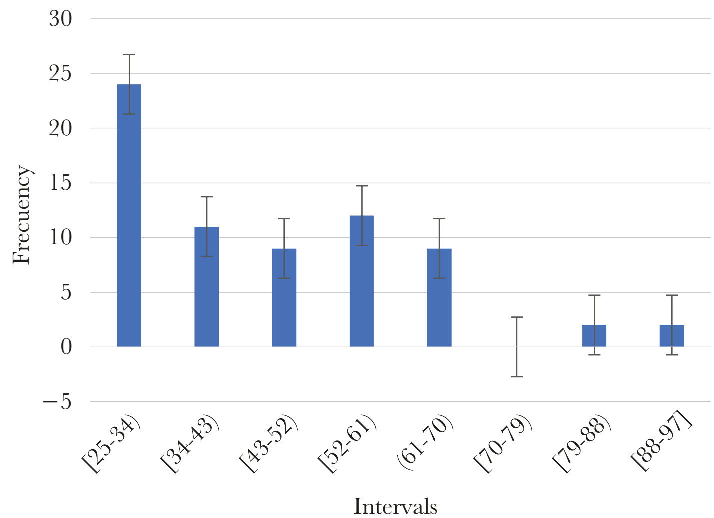


**Figure 2**. Growth of black mangrove monitoring plot 1.

Regarding the group of plants in Plot 2, growth exhibited greater homogeneity, indicating that the evaluated individuals were located in areas with more favorable conditions. Nevertheless, the 62-69 cm height range was the least represented, with only two individuals recorded in that interval (Figure 3).

Plot three exhibited the most favorable growth data for black mangrove plants. From an ecological standpoint, it offered the best site conditions, resulting in more homogeneous plant development (Figure 4). The presence of varying plant heights within a single plot is expected under natural conditions, as both site-specific variables and anthropogenic influences shape plant growth (Genthner *et al.*, 2023). Likewise, plant seasonality plays a critical role in mangrove development. A seedling receiving canopy protection from mature trees tends to exhibit better growth responses than one fully exposed to direct sunlight (González-Hernández *et al.*, 2016). Additionally, since the soil type is classified as a Technosol, inconsistencies in soil properties are to be expected, which are reflected in the variable growth behavior observed in the black mangrove plants (Dewiyanti *et al.*, 2021).

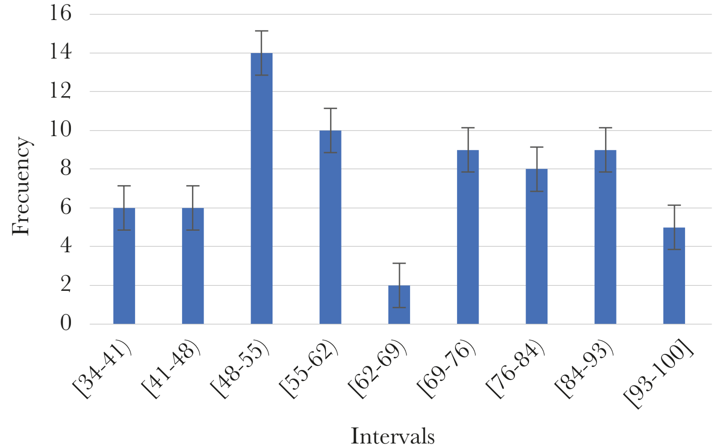


**Figure 3**. Black mangrove growth monitoring plot 2.

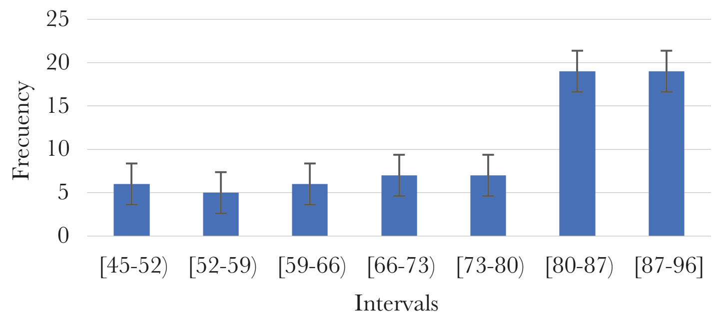


**Figure 4**. Black mangrove growth monitoring plot 3.

## CONCLUSION

Although all plots shared the same soil type, the observed growth response showed statistically significant differences. Height is a direct response to site conditions and anthropogenic impact, suggesting that both factors were present in the three plots. These areas, being in a restoration phase, were previously used as refuge zones for the blue land crab (*Cardisoma guanhumi*), and during crab migration season, they were heavily disturbed by collection activities, which likely impacted plant development. Diameter growth typically follows height gain, especially in heliophilous species like *Avicennia germinans*, where vertical growth is prioritized to access sunlight, and only then does radial growth proceed. Given that the monitored plots had open areas with limited tree cover compared to more developed mangrove zones, plant growth was notably irregular. The growth performance observed in this study is lower than what is typically found in undisturbed black mangrove habitats. Natural mangrove soils maintain consistent moisture levels year-round and have salinity levels within tolerable limits for the species. In contrast, the monitored Technosol exhibited limited water availability during dry months, negatively affecting growth. Future research should aim to characterize the specific soil properties where plantations are established and incorporate additional environmental variables. Understanding the relationship between soil elemental composition and soil type will be essential for optimizing mangrove restoration efforts.

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