

Quality of African mahogany seedlings in substrates with soils from the Cerrado biome

Qualidade de mudas de mogno africano em substratos com solos do bioma Cerrado

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ABSTRACT

The organic residues can be used in the composition of substrates, but there is a need to demonstrate the technical efficiency of organic residues. The objective was to evaluate substrates composed of varying proportions of soil of different texture and organic residues, in order to obtain good quality African mahogany seedlings. The experiment was carried out in two stages, one in a forest nursery and the other in the field, both located in the Cerrado biome, Western Maranhão, Northeast region of Brazil. The design was in randomized blocks, with eleven treatments and seven replications. The morphological variables of growth and quality were evaluated for 105 days in the nursery and 270 days in the field. The results showed that all substrates produced seedlings with adequate robustness and Dickson quality index. The seedlings produced in substrates with proportions ranging from 70 to 30% of soil, 15 to 30% of tanned cattle manure and 15 to 20% of carbonized rice husks presented a better quality standard, considering the higher values of nutrient content, morphological characteristics and Dickson quality index. However, when planted in the field, only seedlings that were produced in substrates with clayey textured soil, with up to 20% of carbonized rice husk, showed greater growth in height, as the substrate remained adhered to the root when removed from the container. Therefore, the adherence of the substrate to the root system of the seedlings was the main factor for the greater growth of the seedlings under field conditions.

Index terms: *Khaya senegalensis*; tanned cattle manure; seedling production; clayey textured soil; carbonized rice husk.

RESUMO

Os resíduos orgânicos disponíveis na região Oeste do Maranhão, Brasil, são abundantes, devido à atividade agropecuária. Estes podem ser utilizados na composição de substratos para produção de mudas de mogno africano, porém há necessidade de demonstrar a eficiência técnica de resíduos orgânicos com solos da região. O objetivo foi avaliar substratos compostos de proporções variáveis de terra de diferente textura e resíduos orgânicos, para a obtenção de mudas de mogno africano de boa qualidade. O experimento foi conduzido em duas etapas, uma em viveiro florestal e outra no campo, ambos localizados no bioma Cerrado, Oeste do Maranhão, região Nordeste do Brasil. O delineamento foi em blocos casualizados, com onze tratamentos e sete repetições. As variáveis morfológicas de crescimento e qualidade foram avaliadas por 105 dias no viveiro e 270 dias no campo. Os resultados demonstraram que todos os substratos produziram mudas com índice de robustez e índice de qualidade de Dickson adequados, e as mudas de mogno africano produzidas nos substratos com proporção que varia entre 70 a 30% de solo, 15 a 30% de esterco bovino curtido e 15 a 20% de casca de arroz carbonizada apresentaram melhor padrão de qualidade considerando-se os maiores valores de teor de nutrientes, características morfológicas e índice de qualidade de Dickson. No entanto, ao serem plantadas no campo, apenas as mudas que foram produzidas nos substratos com terra de subsolo de textura argilosa, com até 20% de casca de arroz carbonizada, apresentaram maior crescimento em altura, pois o substrato permaneceu aderido à raiz ao serem retirados do recipiente. Portanto, a aderência do substrato ao sistema radicular das mudas foi o fator preponderante para o maior crescimento das mudas em condições de campo.

Termos de Indexação: *Khaya senegalensis*; esterco bovino curtido; produção de mudas; solo de textura argilosa; casca de arroz carbonizada.

INTRODUCTION

The increased demand for wood has encouraged the forest sector in Brazil, which has promoted a significant increase in areas with commercial plantations of noble

species (França et al., 2016). African mahogany (*Khaya senegalensis* A. Juss), the main substitute for Brazilian mahogany (*Swietenia macrophylla*), also popularly known as “Green Gold”, is currently one of the most profitable

hardwoods for investors and rural producers (França et al., 2016; Grupioni et al., 2018).

Due to its adaptive capacity and resistant wood, the planting of African mahogany has shown good results throughout the national territory, in different edaphoclimatic conditions (Ribeiro; Scolforo; Soares, 2017). As a result, the cultivation of this species has grown significantly in Brazil (Reis; Oliveira; Santos, 2019). According to the last agricultural census, the area of forest planted with African mahogany was greater than 37 thousand hectares, with the majority located in the North and Northeast regions of the country (Instituto Brasileiro de Geografia e Estatística - IBGE, 2017).

Seedlings production of tree species is one of the most important activities to the establishment of forest plantings, since the seedlings quality has influence on the future plant development (Dionisio et al., 2021). In this context, the demand for African mahogany seedlings with a high standard of quality is growing. Quality seedlings are defined as those capable of withstanding the adverse conditions that may occur after planting. A quality seedling should have characteristics that provide a high chance of survival and rapid initial growth in the field (Auca et al., 2018). The production of seedlings considered to be of good quality depends on several factors, including the composition of the substrates (Araújo et al., 2020; Haase et al., 2021), substrate humidity, substrate porosity, temperature, recipient volume, irrigation, fertilization, and the seedlings management in the forest nursery (Costa et al., 2015; Marques et al., 2018). Root initiation and rooting, biomass accumulation and quality indicators are directly related to the chemical, physical and biological characteristics of the substrate (Delarmelina et al., 2014; Othman et al., 2019; Araújo et al., 2020; Haase et al., 2021).

In visits carried out by the authors to foresters in western Maranhão, it was found that commercial substrates for the nursery phase available on the market have a high cost, which has led forest seedling producers to use soil and organic materials available locally. Typically, land for nursery production has high density values, poor drainage and low fertility, as they are extracted from the B horizon of weathered soils (Haase et al., 2021). For this reason, there is a need to generate results that demonstrate the technical efficiency of mixtures of organic materials with representative soils in the region.

In this context, the Cerrado dominates the natural landscape of Maranhão, as it occupies 64.1% of the state's territory. Inserted in this biome, the western region of Maranhão stands out due to the economic dynamics of

the sectors directly and indirectly linked to livestock, grain cultivation and planting of forest species (Instituto Maranhense de Estudos Socioeconômicos e Cartográficos - IMESC, 2020).

Therefore, the objective was to evaluate the technical efficiency of substrates composed of soil of different textures, from representative soils of the Cerrado of Maranhão biome, mixed with variable proportions of organic residues available in the western region of the state, to obtain good quality African mahogany seedlings.

MATERIAL AND METHODS

The experiment was carried out on a farm, inserted in the Cerrado biome, located in the municipality of Porto Franco, in the west of the state of Maranhão, Northeast Region of Brazil, between the geographic coordinates latitude 6°17'23.78"S and longitude 47°21'54.47"O (Figure 1), altitude of 162 m. In the region, the hot and humid tropical climate prevails (Aw) (Köppen, 1948). This region is characterized by the occurrence of a rainfall regime with two well-defined seasons. The rainy season is concentrated between the months of December to May, with an annual average of 1500 mm of precipitation. The dry season period is from June to November, with an average of 17 mm monthly.

For the stage of evaluation in the nursery and, later, in the field, a statistical design in randomized blocks was adopted, with eleven treatments and seven replications, totaling 77 experimental units for each stage. For the composition of the treatments, two representative soils of the western region of Maranhão (Infraestrutura Nacional de Dados Espaciais - INDE, 2020), carbonized rice husk (CRH), tanned cattle manure (CM) and commercial substrate (CS). Table 1 describes the combinations and proportions of materials adopted to compose the substrates.

The soils were classified at the site as "Latossolo Vermelho" (Brazilian classification, similar to Oxisoil in the Soil Taxonomy and Ferralsols in the WRB), clayey texture, and "Neossolo Quartzarênico" (Brazilian classification, similar to Entisols in the Soil Taxonomy and Arenosols in the WRB), sandy texture (Empresa Brasileira de Pesquisa Agropecuária - EMBRAPA, 2018). The soil was collected in the subsurface layer, between 20 and 30 cm deep, dried in the air, sieved in a 2 mm mesh and submitted to analyzes for chemical and granulometric characterization in the University's Soil Fertility Laboratory (Table 2).

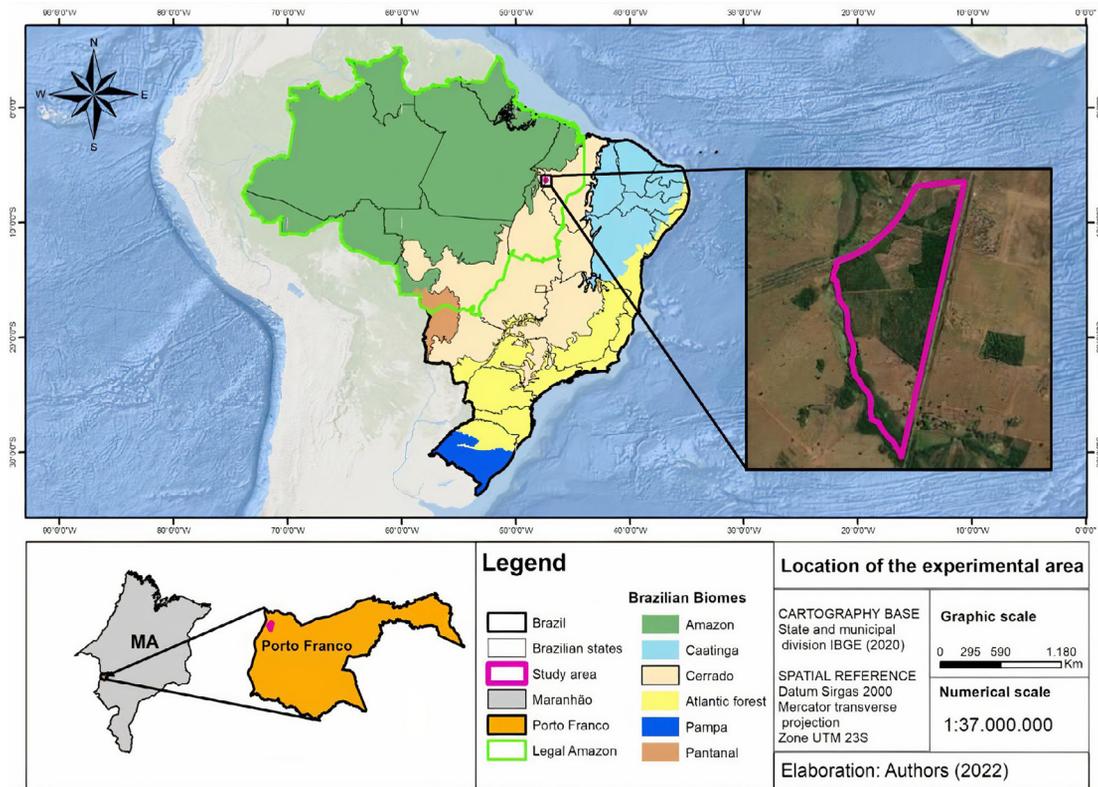


Figure 1: Location of the experimental area, inserted in the Cerrado biome, in the municipality of Porto Franco, West of the State of Maranhão, Northeast Region of Brazil.

Table 1: Proportion of clayey and sandy texture soil and organic residues used for the composition of substrates.

Identification of treatments	Proportion of soil and organic residues		
	CS	CM	CRH
T1	100	0	0
T2	70	15	15
T3	50	30	20
T4	30	45	25
T5	10	60	30
T6	Commercial forest substrate		
	SS	CM	CRH
T7	100	0	0
T8	70	15	15
T9	50	30	20
T10	30	45	25
T11	10	60	30

*CS: clayey soil; SS: sandy soil; CM: cattle manure; CRH: carbonized rice husk.

The tanned cattle manure, collected in the farm’s own corral where the experimental area is located, was air-dried and submitted to sieving in a 2 mm mesh. The rice husk came from a rice processing plant in the region and was carbonized on the farm. The commercial forest substrate, suitable for the production of seedlings of forest species, was purchased from the local trade. According to the manufacturer, its composition includes: vermiculite, *sphagnum peat*, rice husk, pine bark, coconut fiber and pine bark.

Each material was weighed and manually mixed until complete homogenization, according to the treatments. The substrate combinations described in Table 2 were used to fill polyethylene bags with a capacity of one dm³. Each bag was tapped three times against the ground in order to thicken the particles. After filling the containers, the substrate was submitted to water saturation and kept at rest to drain excess water. In three samples of each treatment, an undisturbed sample in a metallic ring was collected in order to determine the overall density and total porosity of each substrate (Teixeira, 2017).

Table 2: Chemical and granulometric composition of soil samples from the clayey and sandy texture soil, collected between 20 and 30 cm deep, and of the organic materials used for the composition of the substrates.

Characteristics		CS	SS	CM	CRH
pH water ₂		6.1	5.2	6.00	6.5
P Mehlich	mg.dm ⁻³	1.5	0.5	780	135
Organic matter	g.dm ⁻³	18	9.0	205	248
Ca		5.2	0.3	14.4	2.8
Mg		1.4	0.1	5.4	1.0
K		0.39	0.06	11.7	2.8
Al	cmol _c .dm ⁻³	0.1	0.8		
H+Al		2.8	2.2		
SB		6.99	0.46		
CEC		7.09	1.26		
V	%	71	17		
Total sand		325	800		
Silt	g.dm ⁻³	100	50		
Clay		575	150		

* CS: clayey soil; SS: sandy soil; CM: cattle manure; CRH: carbonized rice husk.

The species used was African mahogany, whose seeds (Figure 2B) were randomly collected on the ground, under the canopy of twenty 17-year-old matrix trees (Figure 2A), in the natural dispersion phase of the fruits, in the municipality of Açailândia - MA, 167 km away from the experimental area. Seeds were collected in September 2019, with a high degree of purity (100%) and germination rate (100%), evaluated according to the methodology described in Brasil (2009). The African mahogany seeds presented, on average, 2 cm wide, 3 cm long and 50 seeds weighing 18.5 g.

The sowing of the two stages of evaluation was carried out in the farm's own forest nursery. The nursery has an area of 40 m², covered with shade net, capable of intercepting 50% of the light (Figure 2C). The temperature and humidity recorded in the nursery during the experiment were, on average, 31.4 °C and 72%, respectively. One seed per experimental unit was used. The seeds germinated, on average, 10 days after sowing, in all treatments (Figure 2D). Irrigation was maintained three times a day at intervals of 6h, with water obtained from an artesian well.

After 30 days of planting, the seedling evaluation period began, at 15-day intervals, totaling six records. The morphological characteristics and their relations were: height (H), from its base to its last bifurcation, aided by a millimeter ruler, and collar diameter (D), determined with

a digital caliper. Robustness index (H/D) and Dickson quality index (DQI) were evaluated according to (Dickson et al., 1960). After 105 days of sowing, a destructive analysis of the seedlings was carried out to obtain biomass. The seedlings were removed from the substrate, sectioned into aerial part (leaves and stem) and roots (Figures 2E, F and G). The morphological variables of growth and quality were evaluated for 105 days in the nursery and 270 days in the field (Figures 2H and I).

The roots were washed under running water over a 1 mm mesh sieve to capture the loosened roots. The plant material was taken to the forced air circulation oven at 65°C until constant weight. After drying, it was weighed on an analytical balance with a precision of 0.0001g to obtain aerial part dry mass (DM), root dry mass (RDM) and total dry mass (TDM). The determination of the nitrogen, phosphorus, potassium, calcium and magnesium in the leaves obtained in the middle third of the seedlings was performed (Teixeira, 2017).

The field evaluation stage was carried out in an area close to the nursery, whose soil was classified as "Latossolo Vermelho" (Table 2). The area was used for extensive livestock, with the presence of brachiaria (*Urochloa brizantha*), without a history of mineral fertilization or use of limestone. Before planting, the grass was mowed and kept on the soil surface.



Figure 2: African mahogany matrix trees (A), African mahogany seeds (B), seedling production nursery (C), African mahogany plants 10 days after sowing (D), African mahogany plants 105 days after sowing (E), aerial part (F) and root (G) and seedlings at 270 days in the field (H and I), inserted in the Cerrado biome, in the municipality of Porto Franco, West of the State of Maranhão, Northeast Region of Brazil.

The treatments were arranged in the field in randomized blocks, each row consisting of a block containing all treatments distributed randomly. The distance between the holes was three meters between plants and five meters between rows.

Survival rate, height (H) and diameter (D) were evaluated nine months after planting. Height determination was performed with a graduated ruler for a reach of up to three meters. The diameter was determined with a digital caliper.

To ensure the analysis of variance assumptions (ANOVA), the results were first checked for normality and homoscedasticity using the Shapiro-Wilk ($p < 0.05$) and Bartlett ($p < 0.05$) tests, respectively. Once these premises were met, the results were analyzed using ANOVA through the R software version 3.5.2, and in the case of significant differences, the averages were compared using the Scott Knott test ($p < 0.05$). Pearson's correlation test was applied between the nutrient content and DM variables.

RESULTS AND DISCUSSION

The mean values of density and total porosity of the formulated substrates varied according to the soil texture

and the amount of organic residues, especially influenced by CRH (Table 3). Substrates composed with 100% soil (T1 and T7) presented the highest values of density (0.87 and 0.91 g.cm^{-3}). The substrates composed of 10% soil, 60% CM and 30% CRH and the commercial substrate (T5, T11 and T6) ranged from 0.32 to 0.38 g.cm^{-3} . In these substrates, porosity ranged from 84 to 89%, with the highest values compared to the other treatments.

The density in substrates that were composed of 70% soil, 15% CM and 15% CRH (T2 and T8), 50% soil, 30% CM and 20% CRH (T3 and T9) and 30% soil, 45% CM and 25% CRH (T4 and T10) ranged between 0.51 and 0.59 g.cm^{-3} , and porosity between 67 and 74%. The forest substrates, considered suitable for the production of seedlings in the nursery stage, must have density values between 0.40 and 0.50 g.cm^{-3} and porosity between 75 and 85% (Bunt, 1973).

The substrate density is influenced, by soil texture, nature and amount of organic matter, particle size and arrangements, bulk density of the materials used, total porosity and its distribution, packaging and the pressure applied when filling the containers (Othman et al., 2019;

Haase et al., 2021). The addition of CRH, which has great lightness and volume, promoted a decrease in density and an increase in porosity in the substrates evaluated in this study. However, 30% of CRH in the composition made the substrate very porous, with excessive drainage and loose clod. Therefore, this result indicates that substrates with proportions greater than 30% of CRH may become unfeasible for the nurseryman, as they demand greater frequency and quantity of water for irrigation.

Table 3: Mean values of global density and total porosity of substrates composed of different proportions of soil with clayey and sandy texture, cattle manure and carbonized rice husk.

Treatments	Porosity (%)	Porosity (%)
T1	0.87±0.02 a	45.9±2.4 c
T2	0.56±0.07 b	71.3±4.6 b
T3	0.53±0.05 b	72.8±6.2 b
T4	0.51±0.09 b	74.3±6.5 b
T5	0.37±0.03 c	89.0±4.3 a
T6	0.32±0.04 c	85.1±3.9 a
T7	0.91±0.09 a	43.7±3.0 c
T8	0.55±0.04 b	67.3±2.7 b
T9	0.57±0.03 b	68.6±3.4 b
T10	0.59±0.04 b	69.5±4.8 b
T11	0.38±0.03 c	84.4±1.8 a

Means followed by the same letter in the column do not differ from each other by the Scott Knott test ($p < 0.05$).

Normally, low-density substrates, such as incinerated materials, increased the macroporosity of the mixtures and reduced the substrate's water-holding capacity (Caldeira et al., 2013; Faria et al., 2013). According to the authors, low density of this residue is an important characteristic to increase the total porosity of the substrate, in order to allow greater drainage of irrigation water.

In contrast, the addition of CM to the mixture promoted an increase in substrate density and a decrease in porosity, as it is a denser material. Steffen et al. (2010), evaluated the efficiency of different substrates made up of carbonized rice husks and cattle manure humus, and reported that humus had higher density and water retention. Thus, the substrates that provided density and porosity values closer to those considered adequate were T2, T3, T4, T8, T9 and T10. This result indicates that the texture of the soil has the characteristics of density and porosity influenced by the addition of organic residues.

Although the clod stability has not been evaluated, the substrate T1, when dry, became very cohesive, and the substrates T5, T7, T8, T9, T10 and T11 did not form firm clods, which makes it difficult for the nurserymen to handle and transport the seedlings. The use of small tubes for seedlings production in forest nurseries can improve several steps of the process as cheaper transport of seedlings to the field and easier handling and better ergonomic conditions for forest workers (Dionisio et al., 2021).

The mean values of N, P, K, Ca and Mg contents in the leaves of the middle third of the African mahogany seedlings, at 105 days after planting, showed a significant difference between treatments (Figure 3).

No treatment promoted symptoms of N, P, K, Ca and Mg deficiency in African mahogany seedlings. African mahogany belongs to the climax ecological group and, according to Lambers and Poorter (1992), the slow-growing species, characteristic of this successional group, present low response to nutrient supply and adaptation to low fertility soils.

In addition to the ecological group, the external nutrient requirement may be related to the size and weight of the seeds, which have the essential elements in the form of reserve compounds. These can meet the nutritional demand in the initial stage of plant growth (Silva et al., 2017). The African mahogany seeds presented, on average, 2 cm wide, 3 cm long and 50 seeds weighing 18.5 g, and may have represented an important source of nutrients in the growth of seedlings.

Although the response to fertilization is incipient for slow-growing forest species, the introduction of organic residues to the substrate composition promoted higher contents of the evaluated elements. The N content in African mahogany produced in treatments T6, T1 and T7, corresponding to commercial substrate and 100% clayey and sandy soil, had the lowest averages, ranging between 2.44 and 3.12 g kg⁻¹. In substrates T5 and T11, composed of 10% of both clayey and sandy soils and 90% of organic residues, they also presented low values of foliar N. Although these substrates were composed of organic residues, in addition to the organic matter present in the soil (Table 2), the N made available may have been lost by leaching, since in T5 and T11, the porosity was 89 and 84.4%, respectively (Table 3).

The N contents observed in the treatments mentioned above were lower than those verified by Souza et al. (2010), who reported 5.10 g kg⁻¹ in African mahogany seedlings grown in soil with 43.44 g.dm⁻³ of organic matter. Meanwhile, this value was similar to those found in substrates T2, T3, T4, T8, T9 and T10, average was 5.28 g kg⁻¹. The N and K are the most-required nutrients during the initial phase of mahogany growth and development (Souza et al., 2020).

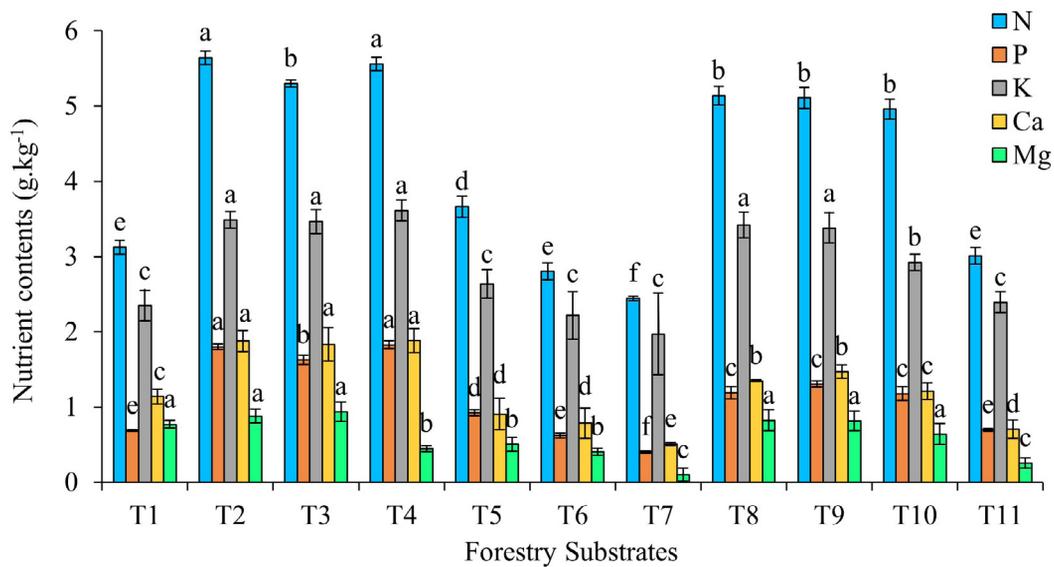


Figure 3: Mean values of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) in the aerial part of African mahogany seedlings at 105 days after planting in different substrates. Means followed by the same lowercase letter do not differ from each other by the Scott Knott test ($p < 0.05$). T1: 100% clayey soil; T2: 70% clayey soil, 15% cattle manure (CM), 15% carbonized rice husk (CRH); T3: 50% clayey soil, 30% CM, 20% CRH; T4: 30% clayey soil, 45% CM, 25% CRH; T5: 10% clayey soil, 60% CM, 30% CRH; T6: commercial substrate; T7: 100% sandy soil; T8: 70% sandy soil, 15% CM, 15% CRH; T9: 50% sandy soil, 30% CM, 20% CRH; T10: 30% sandy soil, 45% CM, 25% CRH; T11: 10% sandy soil, 60% CM, 30% CRH.

Regarding P contents, the treatments that used 100% soil (T1 and T7), 10% soil (T5 and T11) and commercial substrate (T6) presented leaf contents lower than 1.0 g kg^{-1} , statistically inferior to the other treatments. Although the substrates were formulated with soils with low P availability, 1.5 and 0.5 mg P dm^{-3} (Table 2), no treatment promoted symptoms of leaf deficiency. However, the addition of organic residues to the soils promoted higher leaf P content, which ranged from 1.18 to 1.83 g.kg^{-1} in T2, T3, T4, T8, T9 and T10. These findings were similar to that verified by Gonçalves et al. (2005), 1.9 g kg^{-1} , and by Perez et al. (2016), that found average of 1.7 g kg^{-1} , both in the leaves of African mahogany seedlings, and they did not report symptoms of deficiency either.

African mahogany is a species that has low P utilization efficiency (Tucci et al., 2011; Seabra et al., 2018), combined with the fact that they are produced in soils characterized by the low availability of P in forms assimilable by plants. This condition is due to the presence of Fe and Al oxides, and exchangeable Al ions in high concentrations in the weathered soils of the Brazilian Cerrado (Novais et al., 2007).

The foliar K ranged for 1.97 g kg^{-1} (T7) to 3.61 g kg^{-1} (T4). Perez et al. (2016), studied effects of potassium doses on the growth of young African mahogany plants,

related K foliar concentration of 8.05 g kg^{-1} at 180 days of age, in treatment without K fertilization and 0.1 mmol dm^{-3} in the soil. The authors concluded that, the initial stage of mahogany development demand low amounts of potassium, in agreement with results presented in this study, even low K in the foliar tissues did not show symptoms of deficiency.

Leaf contents of Ca and Mg in African mahogany seedlings, in nursery phase, showed average of 1.24 and 0.6 g kg^{-1} , respectively (Figure 3). The Ca is related to membrane and cell-wall integrity of plants, and Mg is required for photosynthesis (Souza et al., 2020; Souza et al., 2010). According to the authors, Ca was the third most-accumulated nutrient in the plants of *K. ivorensis* and *K. senegalensis* with 2.05 and 0.21 g kg^{-1} of Ca and Mg in the seedling of control treatment, without liming or fertilizations.

The availability of nutrients, adequate drainage and moisture retention, promoted by the addition of organic residues to the land, influenced the morphological characteristics of growth of the African mahogany seedlings. The combination of 70% soil and 30% organic residues (T2 and T8), 50% soil and 50% organic residues (T3 and T9) and 30% soil and 70% organic residues (T4 and T10) provided African mahogany seedlings with the highest accumulations of total biomass (Figure 4A).

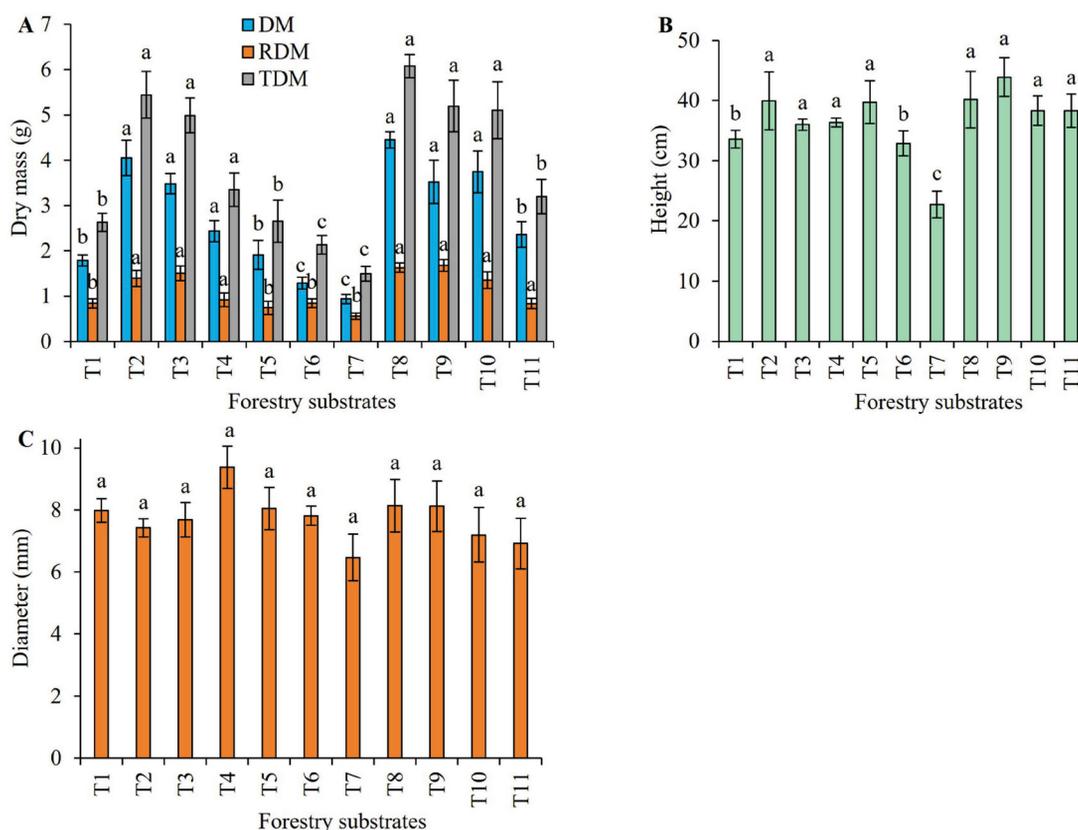


Figure 4: Aerial part dry mass (DM), root dry mass (RDM), total dry mass (TDM) (A) and height (B) and diameter (C) of African mahogany seedlings at 105 days after planting in different substrates. Means followed by the same lowercase letter do not differ from each other by the Scott Knott test ($p < 0.05$). T1: 100% clayey soil; T2: 70% clayey soil, 15% cattle manure (CM), 15% carbonized rice husk (CRH); T3: 50% clayey soil, 30% CM, 20% CRH; T4: 30% clayey soil, 45% CM, 25% CRH; T5: 10% clayey soil, 60% CM, 30% CRH; T6: commercial substrate; T7: 100% sandy soil; T8: 70% sandy soil, 15% CM, 15% CRH; T9: 50% sandy soil, 30% CM, 20% CRH; T10: 30% sandy soil, 45% CM, 25% CRH; T11: 10% sandy soil, 60% CM, 30% CRH.

The observed results indicate that these combinations of substrates promoted greater formation of petiole, leaves and stem, dry mass components and root development (RDM), due availability of nutrients, adequate drainage and moisture retention, promoted by the addition of organic residues to the land. The higher value of the TDM reflects the higher quality of the seedlings produced, as they guarantee the largest surface area for the plants to exploit the nutrients and water in the soil (Othman et al., 2019; Araújo et al., 2020).

The accumulation of biomass is an indicator of the rusticity of seedlings of forest species, as the higher values represent more lignified seedlings, which reflects greater resilience in environments with adverse edaphoclimatic conditions (Gomes; Paiva, 2006; Reyes et al., 2014). The lignification index (LI) is the ratio between total dry

mass and total humid mass that results in a percentage of lignification. Moreover, LI is related to the lignification of the aerial and root tissues of wood species seedlings under stress. As much higher is LI as much higher are lignified the plant tissues. Physical stimuli applied as stem flexion make plants to trigger morphometric responses normally associated to reduction in height and increase in stem collar diameter and dry mass of the root tissues (Volkweis et al., 2014; Dranski; Malavasi; Malavasi, 2015). The response to the mechanical stimulus is called higmomorphogenesis (Jaffe, 1973), which strengthens seedlings during their rustification phase. Tissues lignification has been related to the seedlings performance and survival in the field (Dranski; Malavasi; Malavasi, 2015). Even presenting high rusticity, it is essential a minimum infrastructure in conditions to protect seedlings against attacks of rodents and ants.

Root dry mass can predict the survival and initial growth of seedlings in field planting. The more abundant the root system, the greater the chances of survival (Gomes; Paiva, 2006). The balanced distribution between shoot dry mass and root dry mass makes possible an adequate seedling development, decreasing risks of plant fall in the field (Dionisio et al., 2021).

It was observed that, when removing the seedlings from the container, the substrate of T5, T7, T8, T9, T10 and T11 fell apart, the fine roots were damaged and detached from the seedling. These occurred because these substrates did not form firm clods, but roots were not lost, as the seedlings were taken from the container over a sieve.

The clayey and sandy textured soil without the addition of organic materials (T1 and T7), the substrate composed of 10% soil and 90% organic residues (T5 and T11) and the commercial substrate (T6) provided the lowest values of aerial part and root biomass and, consequently, TDM. These results corroborate Araújo et al. (2020), who observed that the morphological growth characteristics of African mahogany seedlings, in the nursery stage, were influenced by the availability of nutrients in the substrate.

Plant dry mass production is indicative of growth intensity, which is related to mineral nutrition and physical characteristics (Souza et al., 2010; Silva et al., 2012; Seabra et al., 2018). According to the authors, the addition of organic residues has the characteristic of providing more favorable physical and chemical conditions for the development of seedlings. Substrates with greater total porosity promote better quality of the root system and, consequently, generate seedlings with greater aerial part and root dry mass (Silva et al., 2012).

This statement is in agreement with the results obtained in this study, as the treatments that provided the highest TDM were those that presented density and porosity values closer to those considered adequate by Bunt (1973). Furthermore, although species from the final succession classes exhibit lower growth rate and nutrient demand, the proportion of organic residues to soil influenced these characteristics. It was verified a significant correlation between TDM and the contents of N (0.725*), P (0.501*), K (0.681*), Ca (0.478*) and Mg (0.693*).

None of the combinations of clayey or sandy soil with organic residues influenced the diameter of the collar of African mahogany seedlings, in the first 105 days in nursery conditions (Figure 4B). All treatments provided growth in diameter greater than 4 mm. Dias (2006) recommend that a seedling considered of good quality must have collar diameter between 3 and 10 mm.

The results showed that treatments T2, T3, T4, T5, T8, T9 and T10 had a shorter time to seedling formation

(Figure 5). In these substrates, the plants exceeded 30 cm in height at 90 days after planting and reached an average of 39 cm at 105 days. Considering that the height of aerial part of 30 cm as suitable for planting in field conditions, the adoption of these substrates can represent a reduction in production costs, with the possibility of maximizing the use of space in the nursery, even allowing for more seedling production cycles.

Seedlings obtained in 100% clayey textured soil and commercial substrate reached 30 cm in height after 90 days after planting. The substrate with sandy textured soil, without addition of organic residues, did not reach 30 cm until 105 days after planting. Regarding the diameter, only substrates with clayey soil (T1, T2, T3, T4 and T5) and substrates T8 and T9 provided a value above 5 cm at 75 days after planting (Figure 5).

Height is one of the parameters adopted for the classification and selection of plants. However, this isolated variable may not represent a good indicator of quality, as a tall seedling with a reduced stem diameter can easily topple over after planting. The ideal seedling should have a thick diameter, as this factor indicates the presence of reserve substances in the plant's internal tissues. This height and diameter relationship reflects the plant's robustness index, in which smaller relations indicate greater capacity of the seedlings to survive in the field (Gomes; Paiva, 2006).

The robustness index values ranged from 3.66 to 5.95 and did not differ between treatments (results not shown). What is indicated is that the seedlings of forest essences present values below 10 (Birchler et al., 1998). The height/diameter relationship of the collar, besides being an indicator of the quality standard of the seedlings, is an indicator to determine the survival capacity in field conditions (Birchler et al., 1998). Therefore, if only this indicator is considered, all substrates were able to produce seedlings with viability for planting in the field.

The DQI of African mahogany seedlings produced in treatments T2, T3, T4, T8, T9 and T10 reached the highest values, and all substrates presented values above 0.3 (Figure 6A). The DQI also represents an indicator of seedling quality, as it considers important characteristics, such as the robustness and balance of the seedling mass distribution (Fonseca, 2002).

Seedlings with DQI values below 0.2 imply a higher mortality rate when transplanted under field conditions, as the higher the height/DM relationship, the less lignified it is (Gomes et al., 2002). The Dickson quality index (DQI), as well as the lignification and robustness index, is considered as seedling quality indicator. In DQI, the seedling vitality and balance of the biomass distribution are taken into account

(Lima Filho et al., 2019). Many authors consider DQI as the main indicator of seedlings' quality standard. This is because the fact that in the DQI's formula is taken into account robustness and the balance of seedlings' biomass distribution, that combines variables of growth and biometric relations (Dickson, 1960; Binotto; Lúcio; Lopes, 2010; Siqueira et al., 2018). Binotto, Lúcio and Lopes (2010) observed that the dry mass variables followed by the stem collar diameter are the most strongly correlated variables to the DQI index. The morphological parameters most used in determining indexes of seedling quality often rely on an intuitive understanding on the part of nurserymen involved. However, for such indices to attain the desired minimum values for each species, it is necessary to understand which methods and techniques favor development of a particular species in the field (Auca et al., 2018).

Therefore, the results indicate that all evaluated substrates promoted the formation of seedlings with viability to

be implanted in the field, based on the RI and DQI values. This result was confirmed by the survival of the African mahogany seedlings implanted in the field until 270 days after planting.

In the field, the plants that showed the greatest growth in height were those obtained in substrates with clayey textured soil T1, T2, T3 and T4 (Figure 6B). This result can be attributed to the fact that the clod, when removed from the container, did not fall apart and remained attached to the root system of the seedlings.

The clod of substrates composed with clayey soil and 30% CRH (T5), and with sandy textured soil (T7, T8, T9, T10, T11), were broken up when removed from the container, damaging the finer roots. Adhering the substrate to the root system, when removing the seedling from the container, prevents dryness and damage to the roots (Steffen et al., 2010). Gomes and Paiva (2006) described that the root system represents a fundamental factor to predict the survival and initial growth of seedlings in field planting.

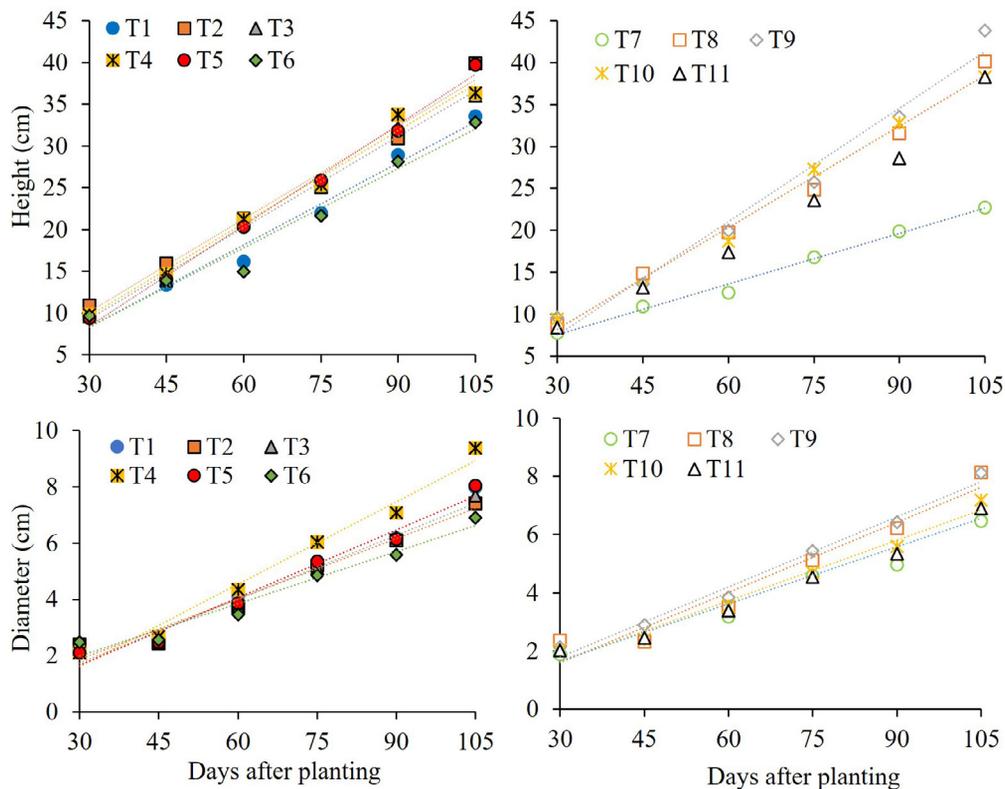


Figure 5: Accumulated growth of African mahogany seedlings at 105 days after planting in different substrates. Means followed by the same lowercase letter do not differ from each other by the Scott Knott test ($p < 0.05$). T1: 100% clayey soil; T2: 70% clayey soil, 15% cattle manure (CM), 15% carbonized rice husk (CRH); T3: 50% clayey soil, 30% CM, 20% CRH; T4: 30% clayey soil, 45% CM, 25% CRH; T5: 10% clayey soil, 60% CM, 30% CRH; T6: commercial substrate; T7: 100% sandy soil; T8: 70% sandy soil, 15% CM, 15% CRH; T9: 50% sandy soil, 30% CM, 20% CRH; T10: 30% sandy soil, 45% CM, 25% CRH; T11: 10% sandy soil, 60% CM, 30% CRH.

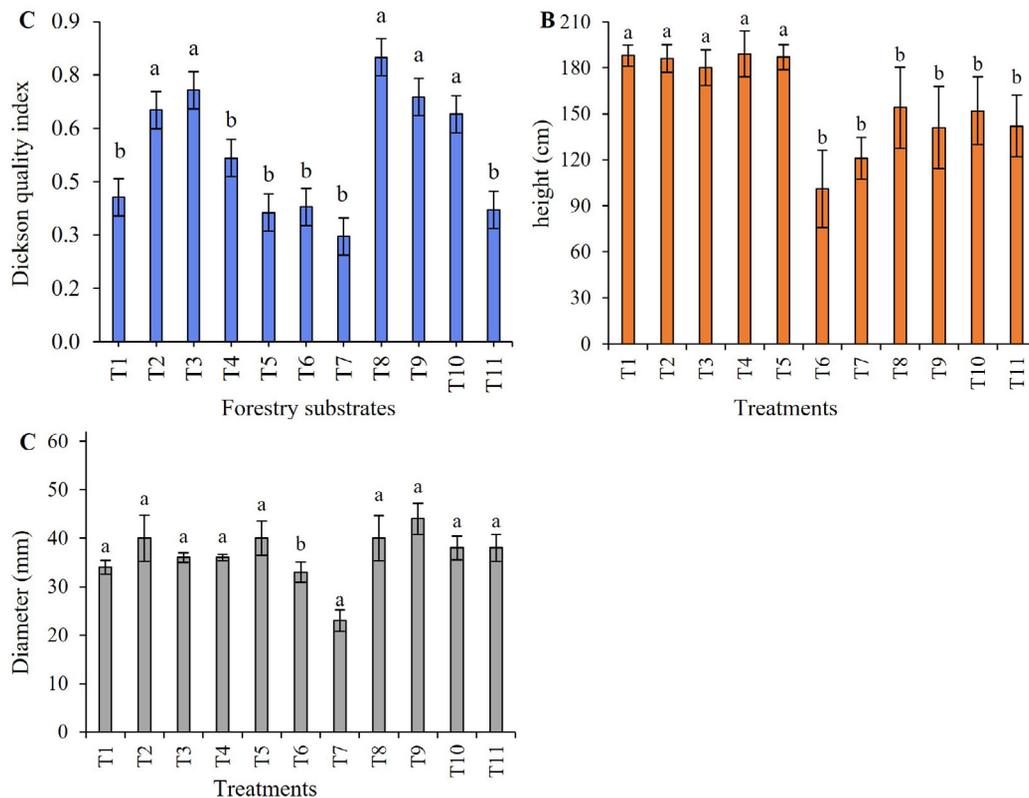


Figure 6: Dickson quality index of African mahogany seedlings at 105 days after planting (A) and height (B) and diameter (C) of African mahogany at 270 days after planted in the field in different substrates. Means followed by the same lowercase letter do not differ from each other by the Scott Knott test ($p < 0.05$). T1: 100% clayey soil; T2: 70% clayey soil, 15% cattle manure (CM), 15% carbonized rice husk (CRH); T3: 50% clayey soil, 30% CM, 20% CRH; T4: 30% clayey soil, 45% CM, 25% CRH; T5: 10% clayey soil, 60% CM, 30% CRH; T6: commercial substrate; T7: 100% sandy soil; T8: 70% sandy soil, 15% CM, 15% CRH; T9: 50% sandy soil, 30% CM, 20% CRH; T10: 30% sandy soil, 45% CM, 25% CRH; T11: 10% sandy soil, 60% CM, 30% CRH.

Thus, the substrates T8, T9 and T10, even with the highest mean values of nutrient content, total dry matter, height and DQI showed slow growth when submitted to biotic and abiotic conditions in the Cerrado of Maranhão. Therefore, the substrates that remained adhered to the root system were those composed of clayey textured soil, and are the most suitable for the production of African mahogany seedlings in the western region of Maranhão, which is characterized by the occurrence of a rainfall regime with two well-defined seasons.

CONCLUSIONS

African mahogany seedlings on substrates with proportions ranging from 30 to 70% of clayey or sandy soil, 15 to 30% of cattle manure and 15 to 20%

of carbonized rice husks presented a better quality standard. However, in the field, only the seedlings produced in clayey soil-based substrates showed greater growth in height. Therefore, the adherence of the substrate to the root system was the main factor for the greater growth of the seedlings under edaphoclimatic conditions of the Cerrado.

AUTHOR CONTRIBUTION

Conceptual Idea: Lucena, A.; Silva, A.; Moraes, C.B.; Methodology design: Lucena, A.; Silva, A.; Moraes, C.B.; Data collection: Lucena, A.; Silva, A.; Silva, G.R.; Data analysis and interpretation: Lucena, A.; Silva, A.; Dionisio, L.F.S.; Sousa G.; Silva, G.R. and Writing and editing: Lucena, A.; Silva, A.; Sousa G.; Moraes, C.B.

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