



MORPHOLOGICAL AND PHYSIOLOGICAL CHARACTERISTICS OF AFRICAN MAHOGANY (*Khaya senegalensis*) SEEDLINGS IN SUBSTRATE WITH POULTRY MANURE

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ABSTRACT

Purpose: Evaluate the morphophysiological characteristics of *Khaya senegalensis* seedlings, after being cultivated in substrates with poultry manure.

Method/design/approach: The experiment was conducted in a greenhouse for 90 days. During this period, the seedlings were subjected to doses of 0, 5, 10, 15, 20 and 25 grams of poultry manure. At the end, they were evaluated for net photosynthetic rate, transpiration rate, transpiration rate, vapor pressure deficit, stomatal conductance and intercellular CO₂ concentration. Then, measurements of height, diameter and biomass were performed.

Results and conclusion: The dose of 25 grams provided the best conditions when analysing the physiological characteristics, which resulted in greater growth and greater dry mass production of *K. senegalensis* seedlings.

Research implications: These results show that, for the seedlings to grow in a substrate containing poultry manure, firstly, there are improvements in the physiological conditions of the plants, which are reflected in faster growth. Therefore, there is a need to study the type of manure and the dose that is applied, before recommending a type of substrate.

Originality/value: Use of organic waste for seedlings production, which is an environmentally correct destination.

Keywords: Seedlings Production, Organic Manures, Plants Physiology, Plants Morphology.

CARACTERÍSTICAS MORFOLÓGICAS E FISIOLÓGICAS DE MUDAS DE MOGNO AFRICANO (*Khaya senegalensis*) EM SUBSTRATO ACRESCIDO DE ESTERCO DE AVES

RESUMO

Objetivo: Avaliar as características morfofisiológicas de mudas de *Khaya senegalensis*, após serem cultivadas em substratos com esterco de aves.

Referencial teórico: Baseado em artigos científicos encontrados em sites de buscas e em livros da área de fisiologia e silvicultura. Isso para embasar a explicação de como as características fisiológicas das mudas foram influenciadas pelo tipo de substrato e como podem ter contribuído para as características morfológicas dessas plantas.

Método: O experimento foi conduzido em casa de vegetação por 90 dias. Durante esse período, as mudas foram submetidas as doses de 0, 5, 10, 15, 20 e 25 gramas de esterco de aves. Ao final, foram avaliadas quanto a taxa

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líquida fotossintética, taxa transpiratória, taxa de transpiração, déficit de pressão de vapor, condutância estomática e concentração intercelular de CO₂. Em seguida, foram realizadas as medições de altura, diâmetro e biomassa.

Resultados e conclusão: A dose de 25 gramas proporcionou as melhores condições ao analisar as características fisiológicas, o que implicou em maior crescimento e maior produção de massa seca das mudas de *K. senegalensis*.

Implicações da pesquisa: Esses resultados permitem verificar que, para que ocorra o crescimento das mudas em substrato contendo esterco de aves, primeiramente, acontecem melhorias nas condições fisiológicas das plantas, que se refletem em crescimento mais rápido. Existindo, portanto, a necessidade de estudar o tipo de esterco e a dose que é aplicada, antes de recomendar um tipo de substrato.

Originalidade/valor: Utilização de resíduos orgânicos para a produção de mudas, sendo esta, uma destinação ambientalmente correta.

Palavras-chave: Produção de Mudas, Resíduos Orgânicos, Fisiologia de Plantas, Morfologia de Plantas.

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1 INTRODUCTION

African mahogany (*Khaya senegalensis*) is a tree species of African origin, belonging to the Meliaceae family, the same as native mahogany (*Swietenia macrophylla*), andiroba (*Carapa guianensis*) and cedar (*Cedrela fissilis*) (Pinheiro et al., 2011). This species was introduced in Brazil with the aim of replacing Brazilian mahogany, as it is resistant to the pest. According to information from the Brazilian Association of African Mahogany Planters, there are more than 10,000 hectares planted in the country, aged 1 to 7 years, whose main objective is timber production (Abpma, 2020).

K. senegalensis not only meets the demand for wood products, but also for medicinal substances, especially antifungal, anti-inflammatory, malaria preventive and insecticide compounds (Zhang et al., 2009). These characteristics help to understand why plantings of this species have increased, however, to obtain quality plantings, there is a need to obtain quality seedlings. In view of this, there is a need to understand more about obtaining seedlings and/or establish more appropriate and faster ways to obtain them.

Therefore, developing studies regarding the production of seedlings and how to increase their quality is necessary, as they will influence the quality of the tree and wood produced. In this process, one of the factors to consider is the substrate, whose chemical and physical compositions will be directly related.

According to Gonçalves et al. (2012) the substrate has the role of supporting plants and providing adequate chemical and structural conditions for the development of roots and shoots.



Therefore, its dose and/or quantity is one of the most important requirements (Barbosa et al., 2014). In this context, organic waste comes into play, which can be used in the composition of specific substrates for the production of *K. senegalensis* seedlings.

The use of waste such as poultry litter in the production of seedlings, for example, is an alternative both to improve the characteristics of the substrate and to reduce costs. Some authors have stood out regarding studies relating the production of seedlings from substrates made up of poultry manure or chicken litter. Like Trazzi et al. (2013) who made the relationship between the growth of *Tectona seedlings grandis* and the use of chicken litter and found that the greatest gain in dry mass of seedlings occurred in treatments in which 35% of chicken litter was used.

Therefore, the study aimed to analyze the morphophysiological aspects of African mahogany (*K. senegalensis*) seedlings grown in substrates made up of different doses of bird manure.

2 THEORETICAL FRAMEWORK

The theoretical framework was based on scientific articles and books published in the areas of Physiology and Forestry. For a better understanding of the study carried out, it will consist of some items characterizing the species studied, the properties of the substrates with an emphasis on chicken litter or poultry manure and the use of this type of residue in the production of seedlings.

2.1 KHAYA SENEGALENSIS

African mahogany (*Khaya senegalensis*) is a forest species native to countries such as Côte d'Ivoire, Ghana, Benin, Nigeria and southern Cameroon; occurring from 0 to 450 m altitude, normally in humid valleys (Silva, 2010). It is a deciduous tree that reaches between 15 and 20 m in height, reaching up to 35 m, with a diameter at breast height (DBH) of up to 100 cm, with a trunk without branches (Lamprecht, 1990).

Plantings with African mahogany, in Brazil and around the world, are expanding. In Brazil, according to information from the Brazilian Association of African Mahogany Planters, there are more than 10,000 hectares planted, aged 1 to 7 years, whose main objective is timber production (Abpma, 2016). The implementation of *K. senegalensis* in forest systems is an economically viable practice and presents environmental benefits (Castro, 2008).



According to Silva (2018), the species can be used in various management systems, however, it presents greater development in diameter and total height when managed in agroforestry systems. Therefore, the wood of *K. senegalensis* can be employed in carpentry, joinery, furniture manufacturing, ship building and decorative laminates. It is also suitable for buildings, floors, interior decoration, vehicle bodies, toys, innovations, railway sleepers, turned works and cellulose pulp (Mathias, 2020).

2.2 THE SUBSTRATE IN SEEDLING PRODUCTION

In order to successfully implement a forest plantation, regardless of the species, attention must be paid to the quality of the seedling produced (Reis et al., 2019). Within the seedling production phase, the choice of substrate, its dose and/or quantity, is one of the most important requirements to achieve this quality (Barbosa et al., 2014). It can also influence the final cost of the seedling (Cruz et al., 2016).

According to Silva Júnior et al. (2018), substrates are considered a highly influential factor on the plants' development capacity, because they are responsible for providing physical support to the root system and conditions to adequately meet the seedling's water and nutritional demands (Siqueira et al., 2018).

There is no perfect substrate for all conditions and species. It is advisable to use components of a substrate in the form of a mixture, as they may present characteristics that are not suitable for the plant when used alone (Caldeira et al., 2011). However, the formulation of substrates generally involves products available in a region, making the product cheaper and, in this way, justifying the use of this product in the basis of substrates, in addition to, environmentally, providing a suitable destination for different types of substrates. waste (Ribeiro et al., 2018).

For Pagliarini et al. (2012) the ideal substrate must present: uniformity in composition, being free of pests, pathogenic organisms and weeds. However, Menezes Júnior et al. (2000) add that it must also provide good aeration, to allow the diffusion of oxygen to the roots; good water storage capacity; low resistance to root penetration; and good resistance to loss of structure.

The use of organic waste in the composition of substrates for growing seedlings significantly contributes to aeration, water retention capacity and the formation of a physical structure suitable for root development (Santos et al., 2010). Pereira et al. (2010) also emphasize



the favoring of the development of mycorrhizae and buffer reactions that avoid changes in pH, in addition, the addition of organic residues to the substrate can suppress certain pathogens.

2.3 CHICKEN LITTER OR POULTRY MANURE IN THE PRODUCTION OF FOREST SPECIES SEEDLING

The use of organic compounds such as poultry litter, also called bird manure, in the production of seedlings, are alternatives that reduce the cost of production, being important for agroecological and organic production systems (Brugnara, 2015).

This type of material is rich in nutrients such as P, K and N, due to the concentrated feed that the birds receive. Among these nutrients, N stands out, due to the high protein content of the feed (Minho et al., 2012). Therefore, the levels of N, P and K, respectively, can reach high values, of 36.5g, 13.3g and 33.6g kg⁻¹ (Virtuoso et al., 2015), as well as high levels of Ca and Mg, these being quite variable depending on the origin: meat birds or layers (Ribeiro et al., 2018). Therefore, it has higher nutritional levels than the waste of other domestic animals (Serrano et al., 2011).

In a study in which they tested different substrates for the production of *Tectona seedlings grandis*, Trazzi et al. (2013) found the greatest gain in dry mass, height and diameter in treatments consisting of chicken litter. Recommending a proportion of 35% chicken litter to substrate. Same proportion recommended by Faria et al. (2016) for the production of *Mimosa setosa seedlings*.

In other research, Gonçalves et al. (2013) observed *Acacia seedlings farnesiana* with better quality in substrate containing at least 20% poultry manure and 40% cattle manure. Similar situation to that observed for *Eucalyptus dunnii*, in which Menegatti et al. (2017) recommended the use of 20% poultry litter in the total substrate volume. And, from Andrade et al. (2014), who recommended 20% chicken litter in the composition of the substrate for the production of *Annona seedlings muricata*.

3 METHOD

The experiment was carried out in the greenhouse of the Faculty of Agronomy of the University of Cuiabá, Beira Rio I campus, in Cuiabá – Mato Grosso, located at coordinates 15°37' 28"S and 56°05'11"W. The region's predominant climate is tropical savannah, according to the Köppen classification.



The soil used was the dystrophic Red Oxisol with sandy loam texture, collected in the native Cerrado area of the Federal Institute of Mato Grosso, São Vicente da Serra *campus*. After collection, a sample of this soil was taken, air dried, sieved through a two mm mesh and subjected to chemical and granulometric characterization (Table 1).

Table 1

Chemical and granulometric characterization of the dystrophic Red Latosol used in the experiment, before applying the residues

pH	K	P	H+Al	Al	Here	mg	SB
CaCl ₂	mg dm ⁻³		cmol _c dm ⁻³				
4.50	70.20	1.43	6.25	0.25	1.92	0.67	2.77
CTC _T	t	V	m	MO	Sand	Silt	Clay
	effective						
cmol _c dm ⁻³		%		g kg ⁻¹			
9.02	3.02	30.71	8.28	34.61	538	54.30	407.70

pH in CaCl₂ – ratio 1:2.5; P and K – in Mehlich; H+Al – in calcium acetate pH7.0; Al, Ca and Mg – in 1N KCl; SB – sum of bases; CTC_T – total cation exchange capacity; effective t – effective cation exchange capacity; V – base saturation; m – aluminum saturation; MO – organic matter; Sand, silt and clay – hydrometer method. Source: Prepared by the authors (2022).

Vitaplan® poultry manure was purchased commercially from a nursery area and is a simple class A organic fertilizer. According to the supplier, this fertilizer contains poultry manure with limestone, processed and decomposed shells and vermiculite expanded, 1% total N, pH 5.5, 20% total organic carbon (TOC) and cation exchange capacity (CEC) of 2.0 cmol_c dm⁻³.

K. senegalensis seedlings were produced from seeds purchased commercially from the accredited nursery Sementes Caiçara. According to the supplier, these seeds were obtained in the 2019 harvest, being sold with a guarantee of 99.8% purity, and a germination rate of 84%.

The seeds were subjected to overcoming dormancy by immersing them in water at room temperature for 24 hours, as recommended by the seller. After overcoming, the seeds were left to germinate in tubes with a capacity of 240 cm³, filled with soil, the same used for the experiment. After 20 days, the seedlings were around 10 cm tall and were transplanted to the treatments tested in the experiment, in 30x40 cm plastic bags, with a capacity of two kilos of substrate.

The treatments tested in this experiment consisted of doses of cattle manure, as follows: control (no addition of manure); 5 g (10 g kg⁻¹); 10 g (20 g kg⁻¹); 15 g (30 g kg⁻¹); 20 g (40 g kg⁻¹) and 25 g (50 g kg⁻¹) of manure. The six treatments were arranged in a completely randomized design, with six replications, totaling 36 sample units. Samples of the prepared



mixtures were characterized regarding their chemical composition and the results can be seen in Table 2.

Table 2

Chemical characterization of the substrate, after adding doses of poultry manure

Characteristics	Dose (g)				
	5	10	15	20	25
pH (CaCl ₂)	5,20	5,20	5,30	5,60	5,60
P (mg dm ⁻³)	14,8	19,8	32,8	40,9	46,7
K (mg dm ⁻³)	66,7	96,0	109,1	135,3	148,3
Ca (cmol _c dm ⁻³)	3,40	3,50	3,85	4,60	5,20
Mg (cmol _c dm ⁻³)	1,23	1,25	1,39	1,54	1,68
Ca+Mg (cmol _c dm ⁻³)	4,63	4,75	5,24	6,14	6,88
Al (cmol _c dm ⁻³)	0,00	0,00	0,00	0,00	0,00
H (cmol _c dm ⁻³)	4,90	4,60	4,72	4,47	4,32
SB (cmol _c dm ⁻³)	4,80	5,00	5,52	6,49	7,26
CTC _T (cmol _c dm ⁻³)	9,70	9,60	10,24	10,96	11,58
t effective (cmol _c dm ⁻³)	4,80	5,00	5,52	6,49	7,26
V (%)	49,5	52,1	53,9	59,2	62,7
m (%)	0,00	0,00	0,00	0,00	0,00
MO (gdm ⁻³)	34,9	34,5	36,0	37,5	39,0

pH in CaCl₂ – ratio 1:2.5; P and K – in Mehlich ; H+Al – in calcium acetate pH7.0; Al, Ca and Mg – in 1N KCl ; SB – sum of bases; CTC_{pH7.0} – total cation exchange capacity; effective t – effective cation exchange capacity; V – base saturation; m – aluminum saturation; MO – organic matter.

Source: Prepared by the authors (2022).

At the end of 90 days, the physiological characteristics of the seedlings were analyzed using a portable photosynthetic measurement system, model LI-6400 XP (LI-COR, Lincoln, NE, USA). The characteristics analyzed were: net photosynthetic rate (A , in $\mu\text{mol m}^{-2} \text{s}^{-1}$), transpiration rate (E , in $\text{mmol m}^{-2} \text{s}^{-1}$), transpiration rate (Tr , in $\text{mmol m}^{-2} \text{s}^{-1}$), vapor pressure deficit ($VpdL$, in kPa), stomatal conductance (g_s , in $\mu\text{mol m}^{-2} \text{s}^{-1}$) and intercellular CO₂ concentration (C_i , in $\text{mmol m}^{-2} \text{s}^{-1}$). For this characterization, two seedlings were analyzed and measurements were carried out at the beginning of the day, until 9:00 am, to avoid possible climatic interference.

After measuring the physiological characteristics, morphological analyzes of the seedlings were carried out on all seedlings (six replications), namely: height, with a graduated ruler, from the surface of the substrate to the last leaf, measured in centimeters; and neck diameter, with a digital caliper, in the region of insertion between the aerial part and the root part, measured in millimeters. Then, the seedlings were harvested, sectioned into aerial parts and root parts, washed in running water to remove the substrate. These plants were taken to a circulation oven at 65 °C and as soon as they had a constant weight, they were weighed on an



analytical balance with a precision of 0.01 g, to obtain the dry mass of the aerial part (MSPA, in grams) and the dry mass of the root part (MSPR, in grams).

To analyze the development of seedlings in relation to manure doses, the data were adjusted using a linear regression model, containing the residue doses as an independent variable and, as a dependent variable, the morphological and physiological variables. Statistical analyzes were carried out using the R software and, to compare means, the Tukey test at 5% probability was used.

4 RESULTS AND DISCUSSIONS

4.1 BIRD MANURE ON THE MORPHOLOGICAL CHARACTERISTICS OF *K. SENEGALENSIS* SEEDLING

The use of bird manure in the composition of the substrate and its effects on the morphological characteristics of *K. senegalensis* seedlings are presented in Table 3 and Figure 1.

Table 3

Comparison test of means for height, diameter, aerial part dry mass (MSPA), root dry mass (MSPR) and total dry mass (MST) of African mahogany seedlings subjected to doses of poultry manure

Dose (g)	Variable				
	Height (cm)	Diameter (mm)	MSPA (g)	MSPR (g)	MST (g)
0	36.18d	4.19b	4.78c	2.94 to	7.73d
5	45.47c	4.40 b	5.52 bc	2.94 to	8.46c
10	54.18b	4.94 ab	6,20 ab	2,56 a	8,76 bc
15	58,20 ab	5,03 ab	5,94 ab	2,86 a	9,20 ab
20	66,43 a	5,08 ab	6,45 a	2,88 a	8,94 ab
25	55,30 b	5,46 a	6,52 a	3,11 a	9,64 a
pa	0,00001**	0,0016*	0,00001**	0.4152ns	0.00001**
CV (%)	9.31	10.43	8.18	15.12	4.30

** Significance less than 1% probability of error;

* Significance less than 5% probability of error;

^{ns} Not significant;

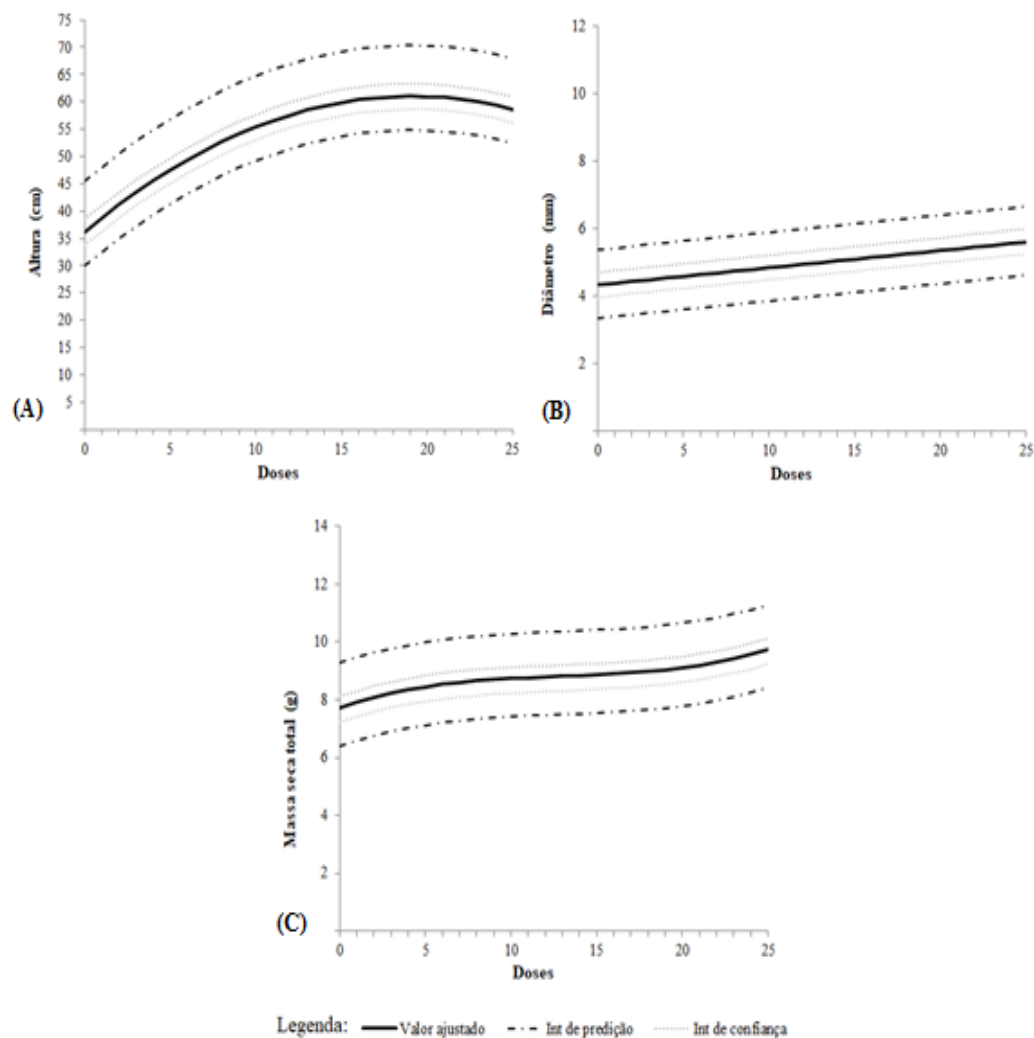
Means followed by the same lowercase letter vertically do not differ statistically from each other, using the Tukey test at a 5% error probability level.

Source: Prepared by the authors (2022).



Figure 1

Growth curves for the morphological variables of African mahogany seedlings as a function of doses of poultry manure. (A) diameter; (B) height and (C) total dry mass.



Source: Prepared by the authors (2022).

Height growth was influenced by the addition of bird manure to the composition of the substrate for the production of African mahogany seedlings, mainly at a dose of 20 g, which allowed 45.5% greater growth compared to that observed at a dose of 0 g. It can be seen that, for this morphological characteristic, growth increased up to the dose of 20 g, before decreasing again at the dose of 25 g. This can also be analyzed in Figure 1, where the adjustment of a quadratic equation is observed, whose coefficients are presented in Table 4. Demonstrating that the addition of poultry manure in doses greater than 20 g can be harmful.



Table 4

Regression coefficients for estimating the morphological variables of African mahogany seedlings subjected to doses of poultry manure

Variables	β_0	β_1	β_2	β_3	r^2	pa
Height	36.21**	2.59**	-0.06**	-	0.84	<0.0000001**
Diameter	4.33**	0.05**	-	-	0.79	0.00037**
MST***	7.73**	0.20**	-0.01**	0.0003*	0.86	<0.0000001**

** Significance less than 1% probability of error;

* Significance less than 5% probability of error;

*** MST – total dry mass. Relationship of parameters for aerial dry mass and root dry mass.

Source: Prepared by the authors (2022).

However, seedlings with an average height of more than 30 cm were observed, which in general, the literature indicates to be an ideal value to ensure quality seedlings for planting in the field (Gonçalves et al., 2000; Paiva and Gomes, 2000; Xavier et al., 2009). However, in treatments with poultry manure, this value was probably reached more quickly. Therefore, the highest doses of manure were the most efficient for height growth. Another observation is that manure contributed significantly to the growth in seedling height in relation to the control (dose 0), which indicates that there was an improvement in soil conditions.

Comparatively, this growth in height was higher than that observed in Da Ros et al. (2018) when studying the growth of African mahogany (*K. ivorensis*) seedlings subjected to substrates containing wastewater from pig farming, as these authors observed an average of 23.7 cm, after 128 days of sowing. In addition to being superior to that obtained by Cruz et al. (2016) who, when analyzing substrates with tanned cattle manure, obtained an increase of up to 19.37 cm in the height of *Spondias tuberosa plants*, when compared to those that did not have manure in their composition.

As for diameter, the dose of 25 g provided the highest average (5.46 mm), making it possible to adjust an increasing linear equation. At this dose, growth was 23.3% higher than that observed in the control treatment (4.19 mm). Corroborating that the addition of poultry manure can improve the conditions for the growth of *K. senegalensis seedlings*. According to Smiderle et al. (2018) research work with forest species has found that seedlings with greater height and greater stem diameter had greater potential for initial growth in the field.

These averages were compatible with the recommendations made by Gomes and Paiva (2011), which qualify a seedling for planting in the field when it presents values greater than 2 mm in neck diameter. In this case, all seedlings would be suitable, regardless of the treatment tested. However, if we consider that, possibly, the seedlings subjected to treatments with manure to the substrate have reached this appropriate value, before the seedlings subjected to treatment



without manure, it appears that the addition of this residue is the best option for the production of seedlings. from *K. senegalensis*.

Comparatively, some studies can be highlighted in which poultry manure also improved the substrate conditions for the growth in diameter of seedlings. Trazzi et al. (2013) studied the performance of *Tectona seedlings grandis* in tubes and found that the best results for the diameter of the duct were found in treatments with chicken litter. Bonamigo et al. (2016), studied the growth of *Tocoyena formosa*, and observed the largest collection diameter in the substrate containing earth + sand + chicken litter. Another example is that of Pereira et al. (2010), who tested chicken litter for the production of *Tamarindus indica seedlings* and concluded that the best proportion was 40% chicken litter + 60% subsoil soil, resulting in plants with the greatest growth in height and diameter of the collection.

The greater growth in height at the dose of 20 g and in diameter at 25 g, influenced the greater production of dry mass of the aerial part in these treatments, which was 25.9% and 26.7%, respectively, higher in relation to production at a dose of 0 g. According to Mesquita et al. (2012), the use of manure as organic matter in substrates for the production of seedlings, provides an increase in the number of leaves, which is entirely linked to the development of the plant. Which may have contributed to the results obtained.

Corroborating that the addition of the highest dose of cattle manure favored the growth and development of *K. senegalensis seedlings*, as it possibly increased the levels of nutrients available to the plants, favoring their physiological characteristics and, consequently, the growth and development of the aerial part. For Dias et al. (2008) a possible explanation for this behavior is the fact that organic fertilizer improves the soil structure, allowing better development of the root system. In a study, Silva et al. (2012) observed that substrates with greater total porosity promote greater quality of the root system and, consequently, gave rise to clonal *Eucalyptus seedlings* with greater dry mass of the aerial and root parts.

However, regarding the production of root dry mass, no statistical difference was obtained between the doses tested, despite an average of more than 3 g of dry mass being observed in a dose of 25 g of poultry manure. Although its development is fundamental for the absorption of water and nutrients, which will be used for the growth and development of all parts of the plant.

These data allowed us to obtain a higher average for total dry mass for the seedlings subjected to a dose of 25 g of poultry manure (9.64 g), which was 19.8% higher than the average for the total dry mass of the seedlings. at a dose of 0 g of manure.



4.2 BIRD MANURE ON THE PHYSIOLOGICAL CHARACTERISTICS OF *K. SENEGALENSIS* SEEDLING

The effects of application of doses of poultry manure on physiological characteristics, such as net photosynthetic rate, stomatal conductance, intercellular CO₂ concentration, transpiration rate, vapor pressure deficit and transpiration rate, in *K. senegalensis seedlings*, are presented in Table 5 and Figure 2.

Table 5

Comparison test of means for net photosynthetic rate (*A*), stomatal conductance (*G_s*), intracellular CO₂ concentration (*C_i*), transpiration rate (*E*), vapor pressure deficit (*VpdL*) and transpiration rate (*Tr*) of African mahogany seedlings subjected to doses of bird manure

Dose (g)	Variable		
	<i>A</i> ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	<i>G_s</i> ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	<i>C_i</i> ($\text{mmol m}^{-2} \text{s}^{-1}$)
0	6,10 a	0,047 a	177,40 d
5	1,42 d	0,011 d	181,55 d
10	2,06 d	0,020 c	208,46 c
15	3,12 c	0,026 b	228,72 b
20	3,76 c	0,049 a	242,02 b
25	4,60 a	0,053 a	264,85 a
pa	0,00001**	0,00001**	0,00001**
CV (%)	9.27	8.04	3.53

Dose (g)	Variable		
	<i>E</i> ($\text{mmol m}^{-2} \text{s}^{-1}$)	<i>VpdL</i> (kPa)	<i>Trmmol</i> ($\text{mmol m}^{-2} \text{s}^{-1}$)
0	1,11 b	1.83 d	25.84 c
5	0.38 d	2.74 c	30.62 b
10	0.60 c	2.78 c	30.88 b
15	0.76c	2.85c	31.13b
20	1.45 to	3.06 b	31.49b
25	1.60 to	3.45 to	33.85 to
pa	0.00001**	0.00001**	0.00001**
CV (%)	9.36	2.33	2.51

** Significance less than 1% probability of error;

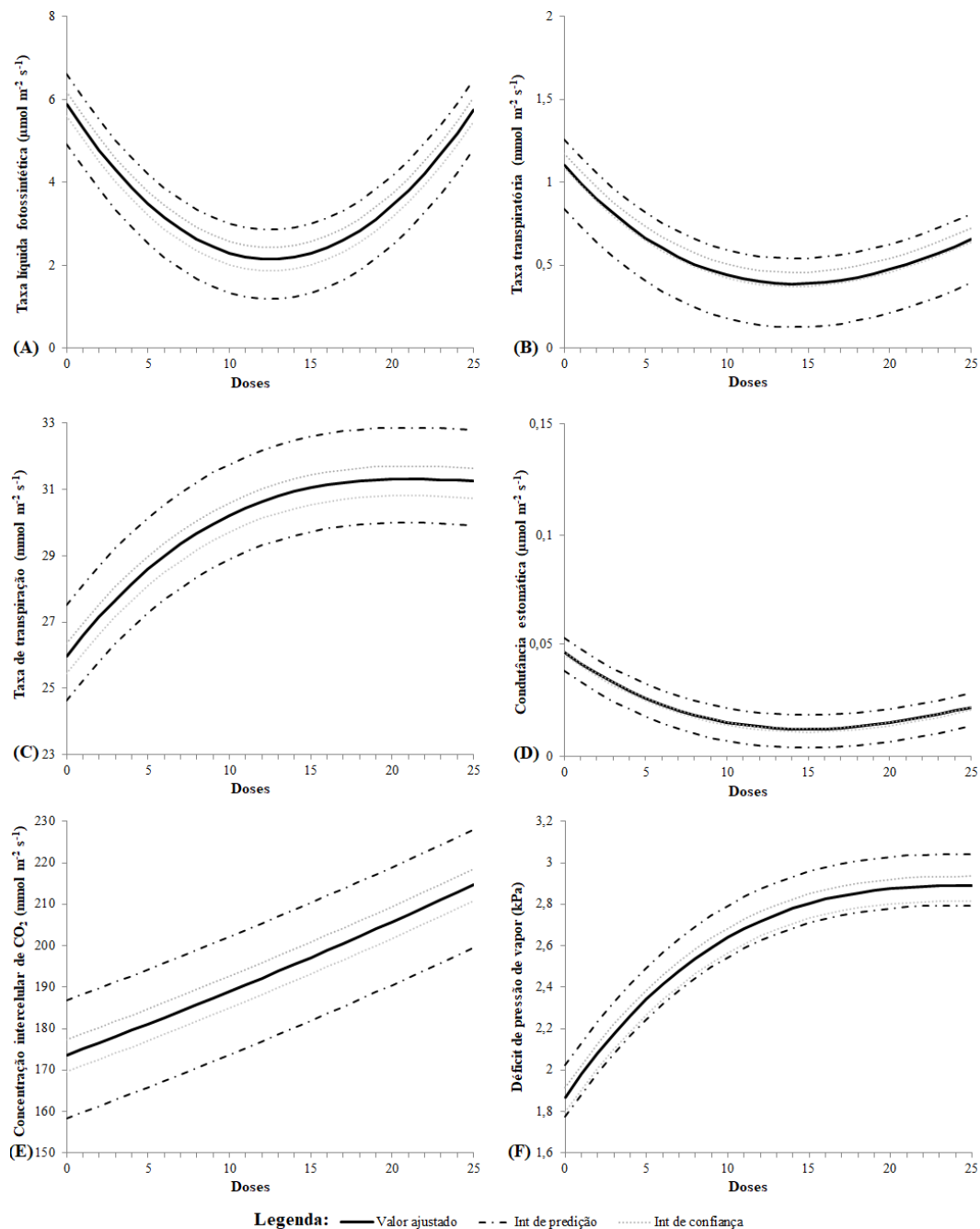
Means followed by the same lowercase letter vertically do not differ statistically from each other, using the Tukey test at a 5% error probability level.

Source: Prepared by the authors (2022).



Figure 2

Growth curves for physiological variables of African mahogany seedlings as a function of doses of poultry manure. (A) Net photosynthetic rate; (B) transpiration rate; (C) transpiration rate; (D) stomatal conductance; (E) intercellular CO_2 concentration; (F) vapor pressure deficit.



Source: Prepared by the authors (2022).

The highest averages for the net photosynthetic rate were observed in treatments with 0 and 25 g of poultry manure. In this case, the averages were increasing when considering the treatments with addition of poultry manure, enabling the adjustment of an increasing quadratic equation for this physiological characteristic (Figure 2) and whose coefficients are in Table 6.



However, in the treatment with manure, this was subsequently reflected in one of the greatest growth in height, diameter and greater production of dry mass.

Table 6

Regression coefficients to estimate the net photosynthetic rate (A); transpiration rate (E); transpiration rate (Trmmol); stomatal conductance (Gs); intercellular concentration of CO₂ (Ci) and vapor pressure deficit (VpdL) of African mahogany seedlings subjected to doses of cattle manure

Variables	β_0	β_1	β_2	β_3	r^2	pa
A	6.09**	0.032*	0.00012**	-	0.91	<0.00001**
AND	1,13**	-0,038*	0,0034**	-0,00003*	0,94	<0,00001**
Trmmol	26,07**	0,15**	-0,0007**	-	0,95	<0,00001**
Gs	0,05**	-0,004*	0,0002**	-0,00003*	0,92	<0,00001**
Ci	178,1**	-2,221**	0,2288**	-0,00294**	0,97	<0,00001**
VpdL	1,84**	0,041**	-0.0017**	0.00003**	0.91	<0.00001**

** Significance less than 1% probability of error;

* Significance less than 5% probability of error.

Source: Prepared by the authors (2022).

According to Weerasinghe et al. (2014), the highest values of net photosynthesis in environments with high irradiance are also accompanied by higher rates of leaf respiration in the dark. This may have contributed to the fact that, in the case of the treatment without manure, whose nutritional conditions were inferior, the higher photosynthetic rate did not contribute to greater growth, since the substrate did not allow the plant's high nutritional capacity.

Kirschbaum (2011) corroborates the importance of photosynthesis for plant growth, when he emphasizes that a 30% increase in photosynthetic rate can result in a 10% increase in plant growth. Furthermore, the increase in leaf dry matter is a significant factor for plant growth, since the leaf is the organ responsible for photosynthesis (Tatagiba et al., 2015). Corroborating the results obtained during the analysis of morphological characteristics.

According to Larcher (2006), growth in diameter is directly related to net photosynthesis, which depends on a favorable balance between net photosynthesis and respiration. Characteristics that may have contributed to the results obtained for growth and mass production in plants, as, according to Taiz et al. (2017), as the leaves grow, their capacity to produce photoassimilates increases until they reach maturity.

From these results, it was verified that these treatments also stood out, together with the dose of 20 g, in terms of stomatal conductance, adjusting the quadratic equation. However, regarding intracellular CO₂ concentration, only seedlings at a dose of 25 g stood out with the highest



averages, contributing to the adjustment of the increasing linear equation. These physiological characteristics are related to each other and to the net photosynthetic rate.

According to McDermitt (1990), leaf stomatal conductance can be understood as the rate of passage of water vapor through the leaf stomata. The stomatal opening is the main route through which CO_2 is exchanged from the atmosphere to the leaves. In this way, the opening of the stomata is controlled by complex mechanisms in order to maintain a balance between the absorption of CO_2 and the control of water vapor loss (Taiz and Zeiger, 2013).

This functioning of the stomata constitutes a physiological compromise, as, when open, they allow the assimilation of CO_2 and the loss of water (H_2O). Closing itself reduces the entry of CO_2 to rubisco carboxylation sites inside the chloroplasts and conserves H_2O , reducing the risk of dehydration (Tatagiba et al., 2015). Therefore, higher intercellular concentration values are associated with greater water availability in the soil (Silva et al., 2015). Which, in this case, was favored by the addition of organic matter to the soil, via cattle manure or poultry manure.

Scalon et al. (2011) studying the decrease in water in *Guazuma seedlings ulmifolia*, observed water restriction in the soil aggravated by evapotranspiration, causing partial closure of the stomata, which reduced stomatal conductance which, in turn, resulted in a decrease in transpiration and CO_2 assimilation, reducing the production of photoassimilates. Results that may have been observed in the present case, in a substrate without the addition of manure, as this dried more quickly, due to the lack of increase in organic matter.

Thus, the transpiration rate is another physiological characteristic that can help explain what was observed in the morphological part of plants. It does not always indicate water stress, but rather stomatal closure, which is a strategy used by the plant during the period of greatest demand for water vapor. In this study, the highest averages for transpiration rate were observed in treatments with doses of 20 and 25 g, with an increasing quadratic equation adjustment, indicating that it also contributed to the greater growth and development of *K. senegalensis* seedlings.

Lima et al. (2010), explain that stomatal behavior determines the transpiration demand to which the leaves are potentially subject, controlling their loss of water to the environment, in the form of vapor. In a situation of optimal water availability (field capacity), plants have high transpiration rates so that, as soil water becomes scarce, the plant begins to reduce its transpiration rate to reduce water loss and save energy available in the soil (Silva et al., 2015). Therefore, the highest averages for this characteristic are in seedlings submitted to substrates with manure.



The vapor pressure deficit and transpiration rate were greater for plants at a dose of 25 g, with an increasing quadratic equation adjustment for both. When the air vapor pressure deficit is high and water absorption by the roots does not meet atmospheric demand, there is a decrease in CO₂ availability (Pimentel, 2004). Excessive transpiration can also compromise the availability of water for the plant's vital processes, especially in situations where water availability is reduced (Chaves et al., 2004). This may explain the lower averages for seedling growth characteristics in the treatment without addition of poultry manure.

5 FINAL CONSIDERATIONS

The addition of 25 g of poultry manure to the soil resulted in the obtaining of *K. senegalensis* seedlings with superior quality morphophysiological characteristics.

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