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Morphophysiology and quality of *Alibertia edulis* seedlings grown under light contrast and organic residue[1]

Morfofisiologia e qualidade de mudas de *Alibertia edulis* cultivadas sob contrastes luminosos e resíduo orgânico

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HIGHLIGHTS:
The use of chicken manure contributes for seedling Alibertia edulis *production.*
A. edulis *seedlings presented physiological adjustments in the two light contrasts.*
For quality A. edulis *seedlings should use 6.24 g CM kg^{-1} under shade or 4.16 g CM kg^{-1} under full sun.*

ABSTRACT: Organic residue in the substrate and the availability of light influence the production of high-quality seedlings for ex situ cultivation of native forest species. This study aimed to evaluate the effect of doses of chicken manure incorporated in the soil and shading levels on the morphophysiological responses and quality of *Alibertia edulis* (Rich.) A. Rich seedlings. Five doses of chicken manure (CM) were tested, 0.00, 2.08, 4.16, 6.24, and 8.32 g CM kg^{-1} soil, under two shade conditions, 0% (full sun) and 50% shading. At 215 days after transplanting, the maximum height obtained for *A. edulis* was 47.35 cm with 5.64 g CM kg^{-1} soil under 50% shade. Shaded seedlings had a higher number of leaves. The maximum leaf and root areas were 796.64 and 118.83 cm^2 with 5.32 and 4.21 g CM kg^{-1} soil, respectively, both under 50% shade. Seedlings in 0% shade had lower physiological indices. Shading levels did not affect stomatal limitation, but CM contributed to physiological efficiency. Shoot biomass was higher under 50% shade with higher CM doses. The highest quality indexes occurred with 3.98 and 6.28 g kg^{-1} CM under 0 and 50% shade, respectively. *A. edulis* seedlings responded positively to the addition of CM to the soil and presented plasticity under contrasting light conditions. *A. edulis* seedlings produced under 50% shading with the addition of 6.24 g CM kg^{-1} soil presented high morphophysiological and seedling quality indicators. The addition of 4.32 g CM kg^{-1} soil contributed to high seedling quality under full sun conditions.

Key words: chicken manure, Dickson quality index, shading, physiological adjustment, stomatal limitation

RESUMO: O uso de resíduo orgânico no substrato e a disponibilidade de luz influenciam na obtenção de mudas de elevada qualidade para o cultivo ex situ de espécies florestais nativas. Objetivou-se com este estudo avaliar o efeito de doses de cama de frango incorporadas ao solo e níveis de sombreamento sobre as respostas morfofisiológicas e qualidade de mudas de *Alibertia edulis* (Rich.) A. Rich. Foram estudadas cinco doses de cama de frango (CF): 0,00; 2,08; 4,16; 6,24 e 8,32 g kg^{-1} sob duas condições de sombreamento: 0% (pleno sol) e 50% de sombreamento. Aos 215 dias após o transplantio, a máxima altura da *A. edulis* foi 47,35 cm com 5,64 g CF kg^{-1} solo sob 50% de sombreamento. Mudas sombreadas tiveram maior número de folhas. A máxima área foliar e radicular foi de 796,64 e 118,83 cm^2 com 5,32 g e 4,21 g CF kg^{-1} solo, respectivamente, ambos sob 50% de sombra. Mudas sob 0% de sombra tiveram menores índices fisiológicos. Os níveis de sombreamento não afetaram a limitação estomática, mas a CF contribuiu na eficiência fisiológica. As biomassas da parte aérea foram maiores sob 50% de sombra com maiores doses de CF. Os maiores índices de qualidade ocorreram com 3,98 e 6,28 g CF kg^{-1} solo sob 0 e 50% de sombra, respectivamente. Mudas de *A. edulis* responderam positivamente à adição de CF ao solo e apresentaram plasticidade às condições contrastantes de luz. Mudas de *A. edulis* produzidas em 50% de sombra com adição de 6,24 g CF kg^{-1} solo apresentaram maiores indicadores morfofisiológicos e qualidade de mudas. A adição de 4,32 g CF kg^{-1} solo contribuiu na qualidade de mudas sob pleno sol.

Palavras-chave: cama de frango, índice de qualidade de Dickson, sombreamento, ajustes fisiológicos, limitação estomática

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Introduction

Marmelo-do-cerrado (*Alibertia edulis* (Rich.) A. Rich, Rubiaceae) is a native species widely distributed in the phytophysiognomies of the savanna in Brazil. The species exhibits ecological characteristics that are useful to recover degraded areas. Their fruits are food sources consumed in natura and as candies, jellies, and unprocessed juices.

However, the composition and distribution of biodiversity in the phytophysiognomies of this region is declining owing to inadequate collection or deforestation. Therefore, planning the ex situ cultivation of *A. edulis* is necessary to introduce it into production systems on a sustainable basis, such as the enrichment of forests and recovery of degraded areas, that is, environments characterized by different light gradients and stressful.

Plants tend to exhibit different mechanisms when exposed to different luminous conditions; for example: under full sun, plants have high CO_2 assimilation rates and adjustments of leaf metabolism (Major & Mosseler, 2020; Santos et al., 2020a), whereas in a shaded environment, there is an increase in vegetative characteristics (Mditshwa et al., 2019), metabolic processes, and biomass production as the plants are under limiting light conditions.

Native tree species have a long growing cycle, and the gradual release of nutrients contained in organic residues, such as chicken manure (CM) (Santos et al., 2020b; Goelzer et al., 2021), present in substrate formulations can improve the microbiological, physical, and chemical attributes of the substrate (Wolschick et al., 2018; Silva et al., 2019), thereby providing adequate conditions for regulating physiological indices and increasing photoassimilates for plants.

To test the hypothesis that *A. edulis* presents adjustments to different luminous conditions and that the addition of CM to the substrate can positively contribute to the robustness of seedlings of this species, this study aimed to evaluate the effect of CM doses on the morphophysiological responses and quality of *A. edulis* seedlings produced under different shading levels.

Material and Methods

The experiment was carried out at the Faculdade de Ciências Agrárias, Universidade Federal da Grande Dourados (UFGD), Dourados, MS, Brazil. According to the Köppen classification, the climate of the region is CWa with hot summers with a rainy season, winters with moderate temperatures, and a dry season (Fietz et al., 2017).

The experiment was performed in plastic pots with a capacity of 4.2 dm^3, filled with substrate comprising an Oxisols soil (United States, 2014), which corresponds to a Distroferric Red Latosol in the Brazilian Soil Classification System (EMBRAPA, 2018). Five CM treatments (0.00, 2.08, 4.16, 6.24, and 8.32 g CM kg^{-1} soil) semi-composted with a rice husk base were incorporated into the soil as described by Santos et al. (2020b). The pots were placed under two shade levels: full sun (0%) and shaded (50%). The treatments were arranged in a 5 × 2 factorial scheme in a randomized block design with four replicates, and four plants comprised a single experimental unit.

A black-colored screen with 50% shade - Sombrite®, was used for shading. Full sun and shaded environments exhibited the following conditions, on average, at the end of the cultivation cycle: temperature, 31.62 and 28.42 °C; relative air humidity, 65 and 78%; water vapor pressure deficit according to Sadler & Evans (1989), 4.36 and 2.33 kPa; atmospheric CO_2 concentration – C_a, 419.00 and 423.30 ppm; and photosynthetically active radiation – PAR, 1,245.25 and 560.12 μmol m^{-2} s^{-1}; respectively.

The soil used to prepare the substrates had the following chemical attributes: pH in $CaCl_2$ = 6.2; P = 1.7 mg dm^{-3}; Ca = 6.7 $cmol_c$ dm^{-3}, K = 3.0 $cmol_c$ dm^{-3}; Mg = 1.8 $mmol_c$ dm^{-3}; Al = 0.08 $mmol_c$ dm^{-3}; H + Al = 29.9 $mmol_c$ dm^{-3}; sum of bases = 12.9 $mmol_c$ dm^{-3}; cation exchange capacity = 42.4 $mmol_c$ dm^{-3}, and base saturation (V%) = 60.5. The semi-composted CM was obtained from an aviary in Dourados, MS, Brazil, after the production of five batches of broiler chicken and had the following chemical attributes: pH = 7.50, N = 23.90 g kg^{-1}, P = 15.36 g kg^{-1}, K = 20.00 g kg^{-1}, Ca = 19.15 g kg^{-1}, Mg = 6.95 g kg^{-1}, S = 18.65 g kg^{-1}, C = 260 g kg^{-1}, organic matter = 447.00 g kg^{-1}, C/N ratio = 10.87, and humidity = 11%.

Mature fruits of *A. edulis* were harvested randomly from mother plants (Figures 1A and D) in the Cerrado area (Farm Santa Madalena, 18° 07' 03" S, 54° 25' 07" W, altitude of 452 m) in Dourados, Mato Grosso do Sul state, Brazil. A specimen was deposited in the DDMS Herbarium of the Universidade Federal da Grande Dourados (UFGD), with voucher No. 4649. Access to genetic heritage was registered under no. A9CDAAE.

After fruit processing (Figures 1D and E), the seeds were immersed in 2% sodium hypochlorite for 5 min (Santos et al., 2020b), and were sown immediately afterward in 128-cell expanded polystyrene trays, filled with Bioplant® substrate having the following characteristics: pH in $CaCl_2$ = 5.75, P = 65.70 mg dm^{-3}, K = 1.60 $cmol_c$ dm^{-3}, Ca = 23.80 $cmol_c$ dm^{-3}, Mg = 12.40 $cmol_c$ dm^{-3}, Al = 0.00 $cmol_c$ dm^{-3}, H + Al = 4.20 $cmol_c$ dm^{-3}, sum of bases = 39.80 $cmol_c$ dm^{-3}, cation exchange capacity = 42.10 $cmol_c$ dm^{-3}, and base saturation (V%) = 64.80. The trays were maintained under Sombrite® with 50% luminosity retention and daily irrigation in a nursery at the Faculdade de Ciências Agrárias, UFGD. When the seedlings attained an average height of 6.0 cm (60 days after sowing) (Figure 1F), they were transplanted to plastic pots.

The culture treatments during the experimental period included daily irrigation to maintain 70% of the water retention capacity in the substrate, as determined by the water content retained after draining according to Souza et al. (2000), where the pots were weighed using an analytical balance. Base fertilization with fertilizers was not performed to determine the direct effect of CM doses on the soil and plants. In addition, two sprays of neem oil (*Azadirachta indica* A. Juss.) at 3% were applied owing to the incidence of whitefly and cochineal, with effective control.

Samples of each combination of substrate under the different shading levels were collected to characterize their chemical attributes (Table 1) according to the methodology of Silva (2009).

At 215 days after transplanting, the following characteristics were evaluated:

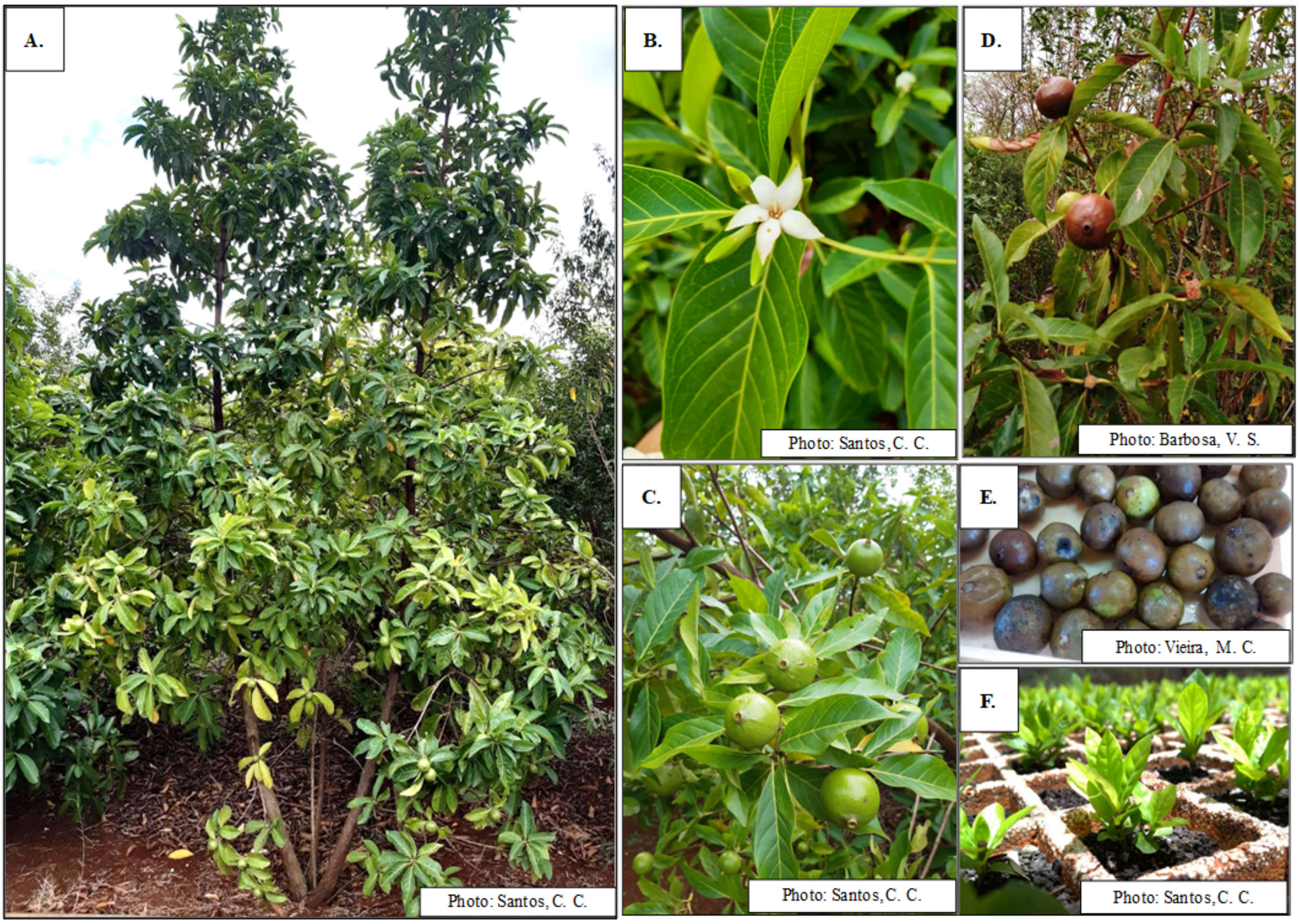


Figure 1. Adult plant (A), flowers (B), green fruits (C), mature (D–E) and seedlings (F) of *A. edulis* in Dourados, MS, Brazil

Table 1. Chemical attributes of substrate for production *A. edulis* seedlings produced with doses of chicken manure (CM) and/or under 0 and 50% shade, at 215 days after transplanting

CM	pH	P	K	Ca	Mg	Al	H + Al	SB	CEC	O.M.	V
(g kg^{-1})	H_2O	(mg dm^{-3})	(cmol$_c$ dm^{-3})							(%)	
					0% shade						
0.00	6.24	1.82	0.32	3.89	1.46	0.00	2.30	5.74	8.04	0.82	70.13
2.08	6.75	2.58	0.58	4.81	2.10	0.00	2.20	7.45	9.69	2.41	77.35
4.16	6.66	4.62	0.71	3.84	1.83	0.00	1.98	6.38	8.36	1.25	76.31
6.24	6.66	5.63	0.59	4.67	1.82	0.00	2.35	6.81	9.44	0.60	75.10
8.32	6.54	5.12	0.66	4.37	2.06	0.00	2.55	6.74	9.64	0.57	73.38
					50% shade						
0.00	6.28	4.11	0.27	4.57	2.06	0.08	2.44	7.01	9.45	0.74	74.23
2.08	6.78	3.85	0.55	4.92	2.08	0.00	2.10	7.55	9.65	2.19	78.13
4.16	6.81	5.63	0.55	4.02	2.04	0.00	2.05	6.61	8.66	0.74	76.36
6.24	6.82	4.62	0.54	4.02	1.86	0.00	1.97	6.43	8.39	1.11	75.96
8.32	6.42	5.38	0.67	4.44	1.83	0.00	2.34	6.82	9.29	1.34	74.20

SB - Sum of bases; CEC - Cation exchange capacity; O.M. - Organic matter; V (%) - Base saturation

Initial growth: Seedling height (H) was measured using a ruler graduated in mm, with the standard of measurement as the distance between the collar and the inflection point of the highest leaf. The stem diameter (D) was determined using a digital caliper (0.01 mm), and the height/diameter ratio was calculated.

Leaf area, production, and biomass: The seedlings were harvested, removed from the pots, washed to remove excess substrate from the root part, and the leaves, stems, and roots were separated. The leaf and root surface areas were evaluated using an area integrator (LI-COR, 3100 C – Area Meter). Subsequently, the organs were dried in an oven with forced airflow at 60 ± 5 °C until a constant weight was obtained for the dry mass and were then weighed on a millesimal precision scale (0.0001 g).

Data on leaf area and dry mass were used to determine the physiological indices including specific leaf mass, leaf area ratio, and specific leaf area were calculated according to Hunt (2017).

Stomatal limitation value (SL): was calculated by the Eq. 1 (Song et al., 2020):

$$SL = 1 - \left(\frac{Ci}{Ca}\right) \tag{1}$$

where:

C_i - intercellular CO_2 concentration (mmol m^{-2} s^{-1}); and,

C_a - atmospheric CO_2 concentration (ppm).

The data C_i and C_a were quantified using the infrared gas analyzer (IRGA), ADC, model LCi PRO (Analytical Development Co. Ltd., Hoddesdon, U.K.) between 8 and 11 a.m., considering the environmental conditions of each luminous environment.

Dickon quality index (DQI): using HDR, aerial part/root ratio (APRR), and total dry mass (TDM) were calculated (Dickson et al., 1960) using the following Eq. 2:

$$DQI = \frac{TDM}{(HDR + APRR)} \tag{2}$$

Data were subjected to analysis of variance, and when significant (F test, $p \leq 0.05$), the means for shading treatments were compared using the Student's t-test. Regression analysis (linear or quadratic) was applied to clarify the interactions of shading with varying CM doses in the substrate ($p \leq 0.05$). The software SISVAR 5.6 was used for the analyses. Based on the groupings of the data on the morphophysiological responses of seedlings, cluster analysis was performed using the most distant neighbor method to describe similarities between treatments. The grouping was performed employing Euclidean distances. Analyses were performed using the software PAST 3.21.

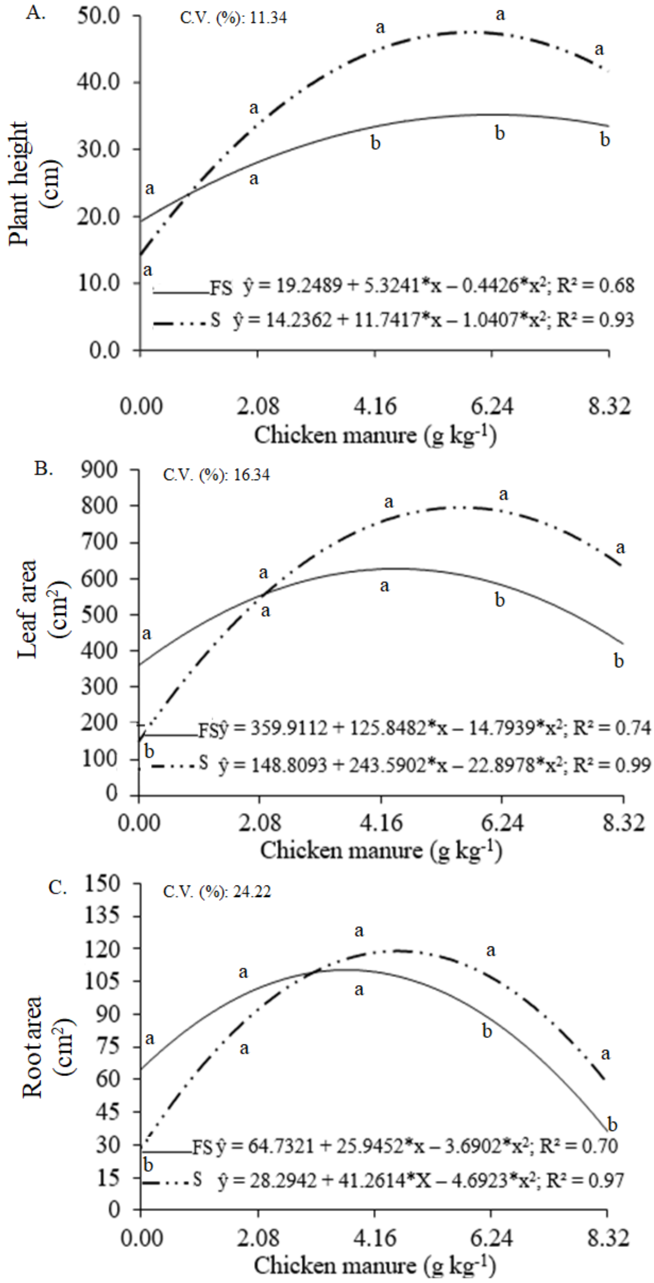
Results and Discussion

Alibertia edulis seedlings exhibited morphophysiological adjustments to light gradients and CM influenced the initial growth of seedlings. The height of *A. edulis* seedlings was influenced by the interaction of the factors under study, showing quadratic relationships at both shade levels. The maximum heights were 47.35 and 35.14 cm with the addition of 5.64 and 6.01 g CM kg^{-1} soil, under 50 and 0% shade, respectively (Figure 2A).

The highest seedling height in the shaded environment can be explained by the fact that the species belongs to the ecological succession group of initial secondary species (Leles et al., 2011) that optimize environmental resources. The lower height under full sun may be associated with hormonal imbalance because, under high irradiance, auxins tend to undergo degradation (Chandler, 2016), reducing the elongation of internodes and morphometric aspects of the plant.

The leaf and root areas were influenced by interactions between factors, with maximum values of 796.64 and 118.83 cm^2 with the addition of 5.32 and 4.21 g CM kg^{-1} soil, respectively, both under the shaded environment (Figures 2B and C, respectively). Shaded plants tend to increase the number of leaves per unit area, aiming to maximize their ability to intercept light and potentiate photosynthetic activity (Santos et al., 2019).

Furthermore, under conditions of low light availability, some species tend to invest a high proportion of photoassimilates in increasing leaf area to maximize the capture of available light (Bartieres et al., 2020), similar to the number of leaves. Regarding CM, an increase in nutrients in the soil contributed substantially to the production of photoassimilates, distribution, and increase in vegetative organs owing to improvements in the chemical, physical, and microbiological attributes of the substrates.



* - Significant at $p \leq 0.05$ by F test; Means with equal letters do not differ statistically from each other by t test at $p > 0.05$); C.V. – Coefficient of variation; FS – full sun (0% shade); S – shading (50% shade)

Figure 2. Plant height (A), leaf area (B) and root area (C) of *A. edulis* seedlings produced with doses of chicken manure (CM) under 0% (FS) or 50% (S) shade

The largest root areas were found in the shaded seedlings (Figure 2C), which was related to water use efficiency. In this study environment, plants lose less water because of transpiration owing to a low water vapor pressure deficit (2.33 kPa). Furthermore, the addition of CM likely enabled the production of seedlings under 0 and 50% shading; however, at different doses, improvement in the physical attributes of the substrate would differ, as organic residues added to the soil act to reduce soil density owing to the conditioning effect (Santos et al., 2020b) and thus favor the development of the root system. Contin et al. (2021) reported that under condition of low light availability in the environment, plants invest in aerial part characteristics to ensure the partitioning of photoassimilates and carbon balance. This is consistent with the observations in *A. edulis* in the current study.

Stem diameter was influenced only by CM doses, with linear growth exhibiting the largest diameter of 8.12 mm with 8.32 g CM kg^{-1} soil (Table 2). The increased stem diameter with organic residue application favors improved translocation of photoassimilates for seedlings. Although leaf nutrient content was not quantified in *A. edulis* seedlings, this result may be associated with the increase in nutrients contained in organic residues, especially K (Table 1), as this nutrient contributes to plant tissue structuring and increase in mass (Cavalcante et al., 2019).

The height/diameter ratio (HDR) was influenced by the factors evaluated in the study, with a high value (5.46) found under 4.95 g CM kg^{-1} soil and in 50% shade (5.32) (Table 2). Chicken manure in soil was observed to favor an increase in growth in a balanced manner because growth in height was accompanied by an increase in dry mass and diameter under the same growing conditions, ensuring the robustness and stability of seedlings.

Increased HDR indicate plant etiolation as a function of cultivation conditions in the initial growth phase in a nursery, and may present the probability of damping under conditions after transplanting (Sousa et al., 2022). Although high under shaded conditions, the values for *A. edulis* seedlings were within the established standards, which is an important indicator for obtaining high-quality seedlings.

The benefits of organic residue to the soil on growth indicators are associated with increased microbiological activity and physical improvements in the soil (Volpiano et al., 2022), in addition to favoring the increase in nutrient content, such as that of N and K. These nutrients were present in the CM applied to *A. edulis*; N is associated with vegetative growth (Osorio et al., 2014), whereas K affects tissue structure (Cavalcante et al., 2019).

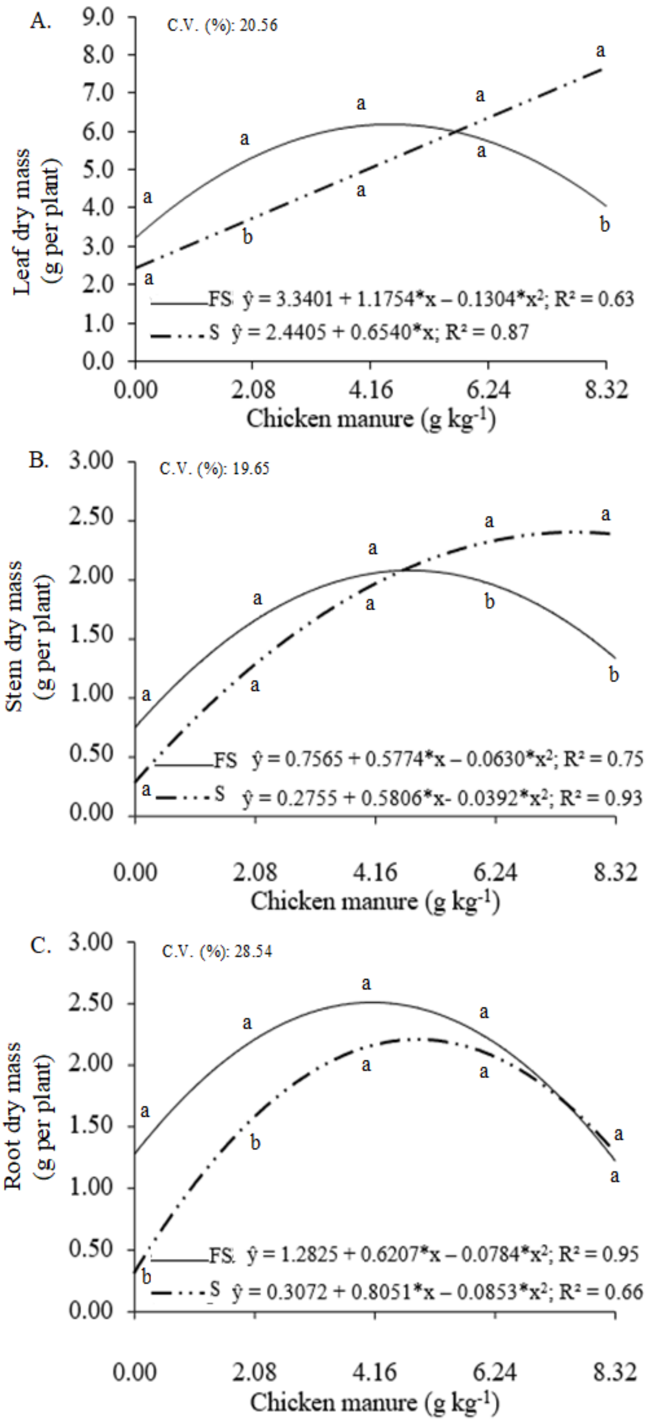
The aerial part/root ratio (APRR), was only influenced by the luminous environment (Table 2). The higher APRR (4.19) in the shaded environment was owing to the ability of the species to invest in the mass production of tissues in different organs to maintain physiological processes and increase aerial parts in response to water absorption and maintaining water-use efficiency (Castro & Newton, 2015).

Table 2. Stem diameter - D, height/diameter ratio – HDR and aerial part/root ratio – APRR of *A. edulis* seedlings produced with doses of chicken manure (CM) and under 0 and 50% shade

D (mm); C.V. (%): 17.29	
$\hat{y} = 5.0000 + 0.4187^{*}x$; $R^2 = 0.71$	
HDR; C.V. (%): 20.06	
$\hat{y} = 3.8173 + 0.6655^{*}x - 0.0671^{*}x^2$; $R^2 = 0.84$	
0% Shade	50% Shade
4.38 ± 0.73 b	5.32 ± 0.80 a
APRR; C.V. (%): 17.56	
0% Shade	50% Shade
3.66 ± 0.37 b	4.19 ± 0.29 a

* - Significant at $p \leq 0.05$ by F test; Means with equal letters on the line do not differ statistically from each other by the t test at $p > 0.05$); C.V. – Coefficient of variation; Means are followed by the ± standard deviation

The leaf, stem, and root dry masses were influenced by interactions among the factors under study (Figure 3). Leaf dry mass showed a linear trend, with a high value of 7.88 g per plant, in 8.32 g CM kg^{-1} soil under 50% shade (Figure 3A). Under 0% shade, the response of seedlings followed a quadratic model, with a maximum value (5.95 g per plant) with 4.98 g CM kg^{-1} soil (Figure 3A). The maximum stem dry mass was 2.42 g per plant in 7.40 g CM kg^{-1} soil under 50% shade (Figure 3B). Increasing the amount of added CM contributed to an increase in nutrients, especially N, thereby ensuring vegetative growth.



* - Significant at $p \leq 0.05$ by F test; Means with equal letters do not differ statistically from each other by the t test at $p > 0.05$; C.V. – Coefficient of variation; FS – full sun (0% shade); S – shading (50% shade)

Figure 3. Leaf (A), stem (B) and root (C) dry mass of *A. edulis* seedlings produced with doses of chicken manure (CM) under 0% (FS) or 50% (S) shade

These high values were also correlated with increased height, number of leaves, and leaf area under the same light conditions.

In addition, with CM incorporation in the soil, there is an increase in beneficial microorganisms that accelerate nutrient cycling (Mierzwa-Hersztek et al., 2018), which promotes an increase in biomass. The improved growth of seedlings observed under the highest doses of CM was because of the better growth and root area conditions, indicating rhizosphere exploration and mass input. This is related to the fact that organic matter improves the physical attributes of soil, mainly by favoring stability, aggregation, and reduction in particle density (Wolschick et al., 2018), especially because the soil used in this experiment was an Oxisols with a clay texture.

The maximum root dry mass was 2.51 g per plant with 3.95 g CM kg^{-1} soil under 0% shade (Figure 3C). Increase in root mass is a mechanism used for better exploration of the rhizospheric area and optimization of water resources under full sun conditions. Regarding the organic residues, seedlings of *Alibertia sessilis* Schum., a native species, also showed an increase in the mass of different organs when CM was incorporated into the substrate (Mota et al., 2017), demonstrating that the addition of this organic residue contributes to the production of native tree species seedlings. However, high doses of CM reduced the potential for stem and root mass production in *A. edulis* seedlings. Similarly, Silva et al. (2019) evaluated *Enterolobium contortisiliquum* Vell. seedlings and verified that application of increasing doses of CM to the substrate negatively affected root mass production.

The leaf area ratio was influenced only by CM doses, with a maximum leaf area ratio of 119.05 cm^2 g^{-1} with the addition of 3.44 g CM kg^{-1} soil (Table 3). A higher leaf area ratio indicates a greater capacity for plants to grow and presents a higher proportion of photosynthetically active tissue in the leaf area (Santos et al., 2019); therefore, there is no limitation on leaf metabolism. These results can be attributed to the high chlorophyll index and leaf area observed with the addition of CM to the substrate. Stomatal limitation (SL) was affected only by CM doses and showed a quadratic relationship, in which the maximum calculated SL value (0.44) was obtained with 6.24 g CM kg^{-1} soil and the lowest values (0.33 and 0.40) occurred with 0.0 and 8.32 g CM kg^{-1} soil, respectively (Table 3).

Although shading levels did not affect the stomatal limitation (SL) of *A. edulis* seedlings, further confirming their physiological plasticity, the use of CM contributed to the stability of photosynthetic metabolism. When there is an increase in SL, there is a decline in intercellular CO_2 concentration, indicating higher carboxylation and photosynthesis efficiency (Berry & Downton, 1982; Song et al., 2020), that is, conversion into photoassimilates owing to improvements in the chemical attributes of the substrate and possibly nutritional status of *A. edulis* seedlings.

Table 3. Stomatal limitation (SL), leaf area ratio (LAR), specific leaf mass (SLM) and specific leaf area (SLA) of *A. edulis* seedlings produced with doses of chicken manure (CM) and under 0 and 50% shade

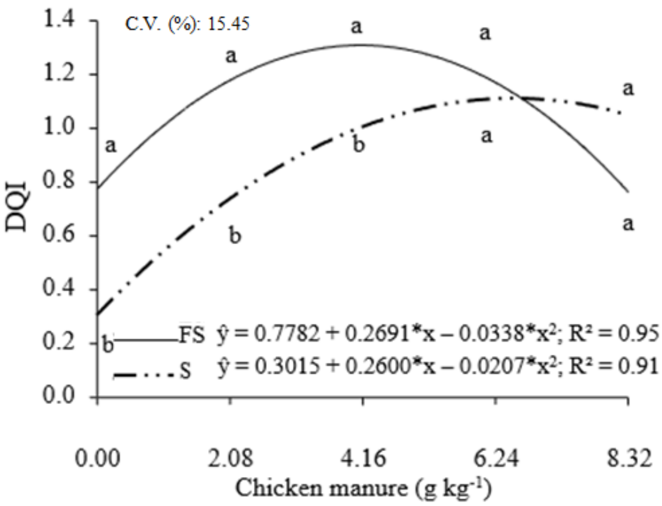
SL; C.V. (%): 10.95	
$\hat{y} = 0.3438 + 0.0356^{*}x - 0.0029^{*}x^2$; $R^2 = 0.94$	
LAR (cm^2 g^{-1}); C.V. (%): 20.65	
$\hat{y} = 104.6563 + 8.3485^{*}x - 1.2104^{*}x^2$; $R^2 = 0.92$	
SLM (g cm^{-2}); C.V. (%): 13.76	
0% Shade	50% Shade
4.02 ± 0.0017 b	5.25 ± 0.0004 a
SLA (g cm^{-2}); C.V. (%): 22.08	
0.59 ± 0.07 b	0.63 ± 0.09 a

* - Significant at p ≤ 0.05 by F test; Means with equal letters on the line do not differ statistically from each other by the t test at p > 0.05; C.V. – Coefficient of variation; Means are followed by the ± standard deviation

The largest specific leaf area and specific leaf mass were observed in shaded seedlings (Table 3), demonstrating that *A. edulis* seedlings converted a greater amount of photoassimilates per unit of photosynthetic area, verifying the hypothesis that cultivation under full sun conditions causes changes in morphophysiological responses. An increase in these indices indicates the adaptive ability of leaf tissues to optimize light capture (Moura et al., 2022) as a function of reduced incident radiation.

The DQI was influenced by the interaction between the factors under study, with the highest index values of 1.31 and 1.11 with 3.98 and 6.28 g CM kg^{-1} soil under 0 and 50% shade, respectively (Figure 4). The obtained high DQI values indicate that *A. edulis* presents morphophysiological adjustments to contrasting light conditions; that is, under both conditions of light availability, this species ensures stability in development and use of available resources regulating leaf metabolism and increasing photoassimilates. This species requires the supply of organic matter to the soil, represented here by the use of CM, to express its physiology and growth potential. The DQI values vary according to several factors such as plant age, species, and genetics.

Cluster analysis verified that there was high similarity between the same CM doses within each light environment (Figure 5). Thus, four groups were formed, in which treatments without the addition of CM (0.00 g kg^{-1}) were isolated from the others (G1). When considering hierarchical groups, the shortest Euclidean distances occurred between 2.08 g CM kg^{-1} soil in both environments (3.01), followed by 4.16 g CM kg^{-1} under 50% shade and 6.24 g CM kg^{-1} under 0% shade with a value of 4.21.



* - Significant at p ≤ 0.05 by F test; Means with equal letters do not differ statistically from each other by the t test at p > 0.05; C.V. – Coefficient of variation; FS – full sun (0% shade); S – shading (50% shade)

Figure 4. Dickson quality index (DQI) of *A. edulis* seedlings produced with doses of chicken manure (CM) under 0% (FS) or 50% (S) shade

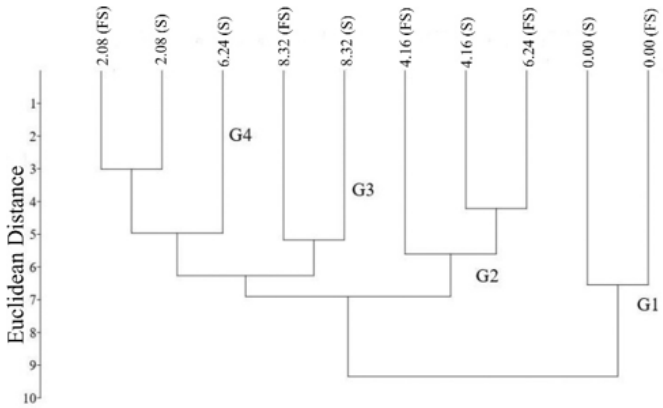


Figure 5. Hierarchical groups (G1, G2, G3 and G4) based on the Euclidean distance between the characteristics evaluated in *A. edulis* seedlings produced with CM (0.00, 2.08, 4.16, 6.24, and 8.32 g CM kg^{-1} soil), under 0% (FS) or 50% (S) shade

The addition of organic residue improved the chemical, physical, and microbiological attributes of the substrates and resulted in corresponding improvements in seedlings exhibiting better results for the production indicators than those of seedlings grown without CM. The results demonstrated that the use of CM in soil favored the production of *A. edulis* seedlings, as these showed greater similarity.

Based on these results, the addition of CM to the soil was demonstrated to be a promising strategy, mainly by contributing to the chemical attributes of the substrate and consequently to the physiology and growth of *A. edulis* seedlings under the evaluated light gradient. Furthermore, the potential of the species for planting in areas with different features, such as open (0% shade) and understory (50% shade), was verified. Considering its morphophysiological plasticity under different shading levels, the utility of the seedlings in both environments was evidenced by the good DQI values. Studies involving the ex situ cultivation of native fruit species from the Brazilian Cerrado are of paramount importance to conserve biodiversity in silvicultural activity and genetic resources for food, medicinal, and ecological purposes.

Conclusions

1. *Alibertia edulis* seedlings produced under 50% shading and with the addition of 6.24 g CM kg^{-1} soil presented improved morphophysiological and seedling quality indicators.

2. The addition of 4.32 g CM kg^{-1} soil contributed to the high quality of seedlings under full sun.

3. Light contrasts had no influence, but varying doses of CM contributed to stomatal physiological efficiency of *A. edulis* seedlings.

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Literature Cited

Bartieres, E. M. M.; Scalon S. P. Q.; Dresch, D. M.; Cardoso, E. A. S.; Jesus, M. V.; Pereira, Z. V. Shading as a means of mitigating water deficit in seedlings of *Campomanesia xanthocarpa* (Mart.) O. Berg. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, v.48, p.234-244, 2020. https://doi.org/10.15835/nbha48111720

Berry, J. A.; Downton, W. J. S. Environmetal Regularion of Photosynthesis. Berlin: Springer, 1982. 12p.

Castro, C. C.; Newton, A. C. Leaf and stem trait variation and plant functional types in 113 woody species of a seasonally dry tropical forest. Colombia Forestal v.18, p.117-138, 2015. http://dx.doi.org/10.14483/udistrital.jour.colomb.for.2015.1.a07

Cavalcante, A. C. P.; Cavalcante, L. F.; Bertino, A. M. P.; Cavalcante, A. G.; Lima Neto, A. J. de; Ferreira, N. M. Adubação com potássio e cálcio na nutrição e produção de goiabeira 'Paluma'. Revista Ceresm, v.66, p.54-62, 2019. http://dx.doi.org/10.1590/0034-737X201966010008

Chandler, J. W. Auxin response factors. Plant Cell Environment, v.39, p.1014-1028, 2016. https://doi.org/10.1111/pce.12662

Contin, D. R.; Habermann, E.; Alves, V. M.; Martinez, C. A. Morpho-physiological performance of *Mikania glomerata* Spreng. and *Mikania laevigata* Sch. Bip ex Baker plants under diferrent light conditions. Hoehnea, v.48, p.1-15, 2021. https://doi.org/10.1590/2236-8906-74/2020

Dickson, A.; Leaf, A. L.; Hosner, J. F. Quality appraisal of white spruce and white pine seedling stock in Nurseries. The Forestry Chronicle, v.36, p.10-13, 1960. https://doi.org/10.5558/tfc36010-1

EMBRAPA – Empresa Brasileira de Pesquisa Agropecuária. Sistema brasileiro de classificação de solos. 5.ed. Rio de Janeiro: Embrapa, 2018, 356p.

Fietz, C. R.; Fisch, G. F.; Comunello, E.; Flumignan, D. F. Documentos 138: O clima da região de Dourados, MS. 3.ed. Dourados: Embrapa Agropecuário Oeste, 2017.

Goelzer, A.; Silva, O. B. da; Santos, F. H. M.; Santos, C. C.; Zárate, N. A. H.; Vieira, M. do C. Photosynthetic performance, nutrition and growth of *Campomanesia xanthocarpa* O. Berg. in chicken manure substrate and liming. Floresta e Ambiente v.28, p.1-11, 2021. https://doi.org/10.1590/2179-8087-FLORAM-2020-0005

Hunt, R. Growth analysis, individual plants. Encyclopedia of Applied Plant Sciences, v.8, p.421-429, 2017. http://dx.doi.org/10.1016/B978-0-12-394807-6.00226-4

Leles, P. S. dos S.; Abaurre, G. W.; Alonso, J. M.; Nascimento, D. F. do; Lisboa, A. C. Growth of tree species in defferent planting spacing for forest recovery. Scientia Forestalis, v.39, p.231-239, 2011.

Major, J. E.; Mosseler, A. Interactive effects of water and CO_2 on light response efficiency and gas exchange traits in pine (*Pinus*) and spruce (*Picea*) species. Canadian Journal Forest Research, v.50, p.1194-1205, 2020. http://dx.doi.org/10.1139/cjfr-2019-0437

Mditshwa, A.; Magwaza, L. S.; Tesfay, S. Z. Shade netting on subtropical fruit: Effect on environmental conditions, tree physiology and fruit quality. Scientia Horticulturae, v.256, p.1-13, 2019. https://doi.org/10.1016/j.scienta.2019.108556

Mierzwa-Hersztek, M.; Klimkowicz-Pawlas, A.; Gondek, K. Influence of poultry litter and poultry litter biochar on soil microbial respiration and nitrifying bacteria activity. Waste and Biomass Valorization, v.9, p.379-389, 2018. https://doi.org/10.1007/s12649-017-0013-z

Moura, A. P. C.; Gil, B. V.; Perboni, A. T.; Oliveira, F. L. R.; Sant'anna-Santos, B. F.; Danner, M. A. Morphophysiological adjustments to shade of jaboticaba tree saplings. Revista Ceres, v.69, p.400-407, 2022. https://doi.org/10.1590/0034-737X202269040003

Mota, L. H. de S.; Scalon, S. de P. Q.; Heinz, R.; Dresch, D. M. Substrates and water availability on the emergence and initial growth of *Alibertia sessilis* Schum. Seedlings. Revista Floresta v.47, p.513-522, 2017. http://dx.doi.org/10.5380/rf.v47i4.53083

Osorio, A. I.; Vega, N. W. O.; Diez, M. C.; Moreno, F. H. Nutrient status and vegetative growth of *Vanilla planifolia* Jacks plants as affected by fertilization and organic substrate composition. Acta Agronomica, v.63, p.326-334, 2014. http://dx.doi.org/10.15446/acag.v63n4.40754

Sadler, E. J.; Evans, D. E. Vapor pressure deficit calculations and their effect on the equation combina-tion equation. Agricultural and Forest Meteorology, v.49, p.55-80, 1989. https://doi.org/10.1016/0168-1923(89)90062-2

Santos, C. C.; Franco-Rodriguez, A.; Araujo, G. M.; Scalon, S. de P. Q.; Vieira, M. do C. Impact of phosphorus and quality of *Lippia alba* (Mill.) N. E. Br. seedlings. Revista Colombiana de Ciências Hortícolas, v.13, p.291-302, 2019. http://doi.org/10.17584/rcch.2019v13i2.9023

Santos, C. C.; Jorge, H. P. G.; Dias, L. G. F.; Vieira, M. do C. Shading levels and substrates affect morphophysiological responses and quality of *Anadenanthera peregrina* (L.) Speg seedlings. Floresta e Ambiente, v.27, p.1-10, 2020a. https://doi.org/10.1590/2179-8087.011919

Santos, C. C.; Vieira, M. do C.; Heredia Zárate, N. A.; Carnevali, T. O.; Gonçalves, W. V. Organic residues and bokashi influence in the growth of *Alibertia edulis*. Floresta e Ambiente, v.27, p.1-9, 2020b. https://doi.org/10.1590/2179-8087.103417

Silva, F. C. da. Manual de análises químicas de solos, plantas e fertilizantes. 2.ed. Brasília: Embrapa Informação Tecnológica. 2009.

Silva, R. F. da; Grolli, A. L.; Welter, P. D.; Ros, C. O. da; Scheid, D. L. Poultry litter for the production and quality of *Enterolobium contortisiliquum* Vell. Seedlings. Floresta e Ambiente, v.26, p.1-10, 2019. https://doi.org/10.1590/2179-8087.008017

Song, X.; Zhou, G.; He, Q.; Zhou, H. Stomatal limitations to photosynthesis and their critical water conditions in different growth stages of maize under water stress. Agricultural Water Management, v.241, p.1-12, 2020. https://doi.org/10.1016/j.agwat.2020.106330

Sousa, D. J. P.; Nogueira, G. A. S.; Teixeira, K. B. S.; Monteiro, G. G. T. N.; Brito, A. E. A.; Nascimento, V. R.; Albuquerque, G. D. P.; Oliveira, T. J. M.; Souza, L. C.; Freitas, J. M. N.; Oliveira Neto, C. F.; Okumura. Mitigation of the effects of salt stress in cowpea bean through the exogenous aplication of brassinosteroid. Brazilian Journal of Biology, v.82, p.1-7, 2022. https://doi.org/10.1590/1519-6984.260818

Souza, C. C. de; Oliveira, F. A. de; Silva, I. de F. da; Amorim Neto, M. da S. Avaliação de métodos de determinação de água disponível e manejo da irrigação em terra roxa sob cultivo de algodoeiro herbáceo. Revista Brasileira de Engenharia Agrícola e Ambiental, v.4, p.338-342, 2000. https://dx.doi.org/10.1590/S1415-43662000000300006

United States. Soil Survey Staff. Keys to Soil Taxonomy (12.ed.) USDA NRCS. 2014. Available on: <https://www.nrcs.usda.gov/resources/data-and-reports/web-soil-survey>. Accessed on: Aug. 2022.

Volpiano, C. G.; Lisboa, B. B.; São José, J. F. B. de; Beneduzi, A.; Granada, C. E.; Vargas, L. K. Soil-plant-microbiota interactions to enhance plant growth. Revista Brasileira de Ciência do Solo, v.46, p.1-20, 2022. https://doi.org/10.36783/18069657rbcs20210098

Wolschick, N. H.; Barbosa, F. T.; Bertol, I.; Bagio, B.; Kaufmann, D. S. Long-Term effect of soil use and management on organic carbon and aggregate stability. Revista Brasileira Ciência do Solo, v.42, p.1-13, 2018. https://doi.org/10.1590/18069657rbcs20170393