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Production of açaí seedlings under different shade levels and controlled release fertilizer

James Maciel de Araújo[1], Romeu de Carvalho Andrade Neto[2], Ueliton Oliveira de Almeida[3], João Paulo Marim Sebim[4], Marcos Giovane Pedroza de Abreu[5], David Aquino da Costa[3]

[1] Universidade Federal do Acre, Campus Floresta, Cruzeiro do Sul, Acre, Brasil. E-mail: jamesagro3@gmail.com

[2] Empresa Brasileira de Pesquisa Agropecuária, Embrapa Acre, Rio Branco, Acre, Brasil. E-mail: romeu.andrade@embrapa.br

[3] Instituto Federal do Acre, Tarauacá, Acre, Brasil. E-mail: uelitonhonda5@hotmail.com, david.agronomia@hotmail.com

[4] Universidade de São Paulo, Escola Superior de Agricultura Luiz de Queiroz, Campus Piracicaba, Piracicaba, São Paulo, Brasil. E-mail: joaopaulo_sebim@hotmail.com

[5] Universidade Estadual Paulista Júlio de Mesquita Filho, Campus Botucatu, Botucatu, São Paulo, Brasil. E-mail: marcosabreu2009@gmail.com

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ABSTRACT

This study aimed to evaluate the production and quality of açaí seedlings regarding the presence and absence of controlled-release fertilization under different shading levels. The study was conducted at the experimental field of Embrapa - Acre, using a completely randomized design in a 4 x 4 factorial arrangement. The factors included four evaluation periods (60, 120, 180, and 240 days after transplanting) and four shading environments (20%, 30%, 50%, and 75%), along with the presence or absence of controlled-release fertilization. The following variables were analyzed: plant height, stem diameter, number of leaves, dry mass of leaves, stem, root, and total dry mass, as well as the seedling quality index and foliar levels of macro and micronutrients. The growth and development of açaí seedlings are influenced by the evaluation periods, shade environments, and the use of fertilization. Fertilization with controlled-release fertilizer and environments with30% and 50% shading improved the quality of açaí palm seedlings.

Keywords: Açaí palm, *Euterpe oleracea*, *Arecaceae*, Western Amazon.

Produção de mudas de açaizeiro em níveis de sombreamento e fertilizante de liberação controlada

RESUMO

O objetivo deste estudo foi avaliar a produção e qualidade de mudas de açaizeiro de touceira em relação à presença e ausência de adubação de liberação controlada em diferentes níveis de sombreamento. O estudo foi conduzido no viveiro do campo experimental da Embrapa - Acre, utilizando um delineamento completamente aleatorizado em um esquema fatorial 4 x 4. Os fatores incluíram quatro períodos de avaliação (60, 120, 180 e 240 dias após o transplantio) e quatro ambientes de sombreamento (20%, 30%, 50% e 75%), juntamente com a presença ou ausência de adubação de liberação controlada. Foram avaliadas a altura da muda, diâmetro do caule, número de folhas, massa seca das folhas, massa seca do caule, massa seca da raiz e massa total, além do índice de qualidade das mudas, e teores foliares de macro e micronutrientes. O crescimento e desenvolvimento das mudas de açaizeiro são influenciados pelos períodos de avaliação, ambientes de sombra e pelo uso de adubação. A adubação com fertilizante de liberação controlada e ambientes de sombreamento de 30% e 50% resultaram em uma melhoria na qualidade das mudas.

Palavras-chave: Açaizeiro de touceira, *Euterpe oleracea*, *Arecaceae*, Amazônia Ocidental.

1. Introduction

Among the main species of the genus Euterpe recorded in Brazil, the açaí palm (*Euterpe oleracea* Mart.) has stood out economically due to its high production yield in fruits and other plant products (Ximenes et al., 2020; Ramos et al., 2019). This palm tree is native to the Amazon region and belongs to the family Arecaceae (Oliveira et al., 2020). The fruit is the main product of this species and is used to obtain the açaí pulp (Santana et al., 2014).

Açaí juice is the result of fruit processing and is considered a nutraceutical food rich in proteins, fibers, lipids, vitamin E, and minerals, also containing high levels of anthocyanins, pigments that are beneficial for health, blood circulation, and protection against arteriosclerosis (Silvestre et al., 2016; Yuyama et al., 2011). According to data from the Brazilian Institute of Geography and Statistics (IBGE, 2023), Brazil was responsible for a production of 1,485,113 tons of açaí harvested in 208,111 hectares, with a production yield of 7,136 kg per hectare. In Brazil, the northern state of Pará is responsible for the largest açaí production in the country, with 1,388,116 tons, which represents 93.47% of the entire national production (IBGE, 2023).

In recent years, the demand for açaí fruit has significantly increased due to the widespread promotion of its flavor and benefits, pressuring native açaí groves, mainly because a large portion of açaí production comes from extractivist practices (Yamaguchi et al., 2015; Farias Neto et al., 2011). According to the same authors, there is a need to overcome seasonality and increase fruit supply, which requires introducing, improving, and developing technologies that can contribute to increasing productivity, e.g., the production of high-quality seedlings.

The seedling formation stage is another important factor in the production chain of açaí-based products (Aguiar et al., 2011). If, on the one hand, seedlings with longer formation periods tend to exhibit greater aboveground and root growth, which can contribute to early flowering and, consequently, shorten the production cycle, directly impacting crop productivity, on the other hand, this longer formation period tends to increase production costs (Zaccheo et al., 2013).

Since the formation time of açaí seedlings can vary from four to eight months, depending on the management practices adopted (Pias et al., 2015), it is important to seek practices that, when combined, shorten the production time with the lowest possible cost. Different species show different growth and development responses based on the percentage of shade provided by the material used in the nursery (Santos et al., 2014; Reis et al., 2016; Almeida et al., 2018) due to their specific metabolic responses (Dapont et al., 2016).

In addition to a favorable protected environment, it is necessary to provide suitable conditions for the seedlings to absorb essential nutrients, which is possible when the nutrients are well distributed and in appropriate proportions in the substrate (Sousa et al., 2004). Low-soluble, controlled-release fertilizers have been widely used by nurseries in the seedling production phase as they have the advantages of reducing operational costs with topdressing, leaching losses, and, depending on the release time, providing the nutrients needed throughout the seedling formation phase (Lubkowski and Grzmil, 2007).

From this perspective, this study aimed to evaluate the production and quality of açaí seedlings in relation to the presence and absence of controlled-release fertilization under different shading levels.

2. Material and Methods

The experiment was set up and conducted at the experimental field of Embrapa Acre, in the municipality of Rio Branco, AC (10º1'30"S, 67º42'18"W), at an approximate elevation of 160 m a.s.l., from November 2016 to September 2017. According to Köppen, the local climate of the region is classified as tropical monsoon (Am), with an average temperature of 25 °C and an average rainfall of 2.050 mm (Alvares et al., 2013). AK174 dataloggers were installed in each nursery to record the temperature (maximum, minimum, and average) and relative humidity (Figure 1).

The substrate used was the top layer of a red Ultisol (0-20 cm), which was sieved to remove impurities and break up the soil. After this process, samples were taken for chemical analysis at the Embrapa Acre Soil Laboratory. The experiment was set up in a completely randomized block design in a 4x2 factorial arrangement with three replications and 10 plants per plot. The treatments consisted of the presence and absence of substrate fertilization combined with four shading levels: 20%, 30%, 50%, and 75%.

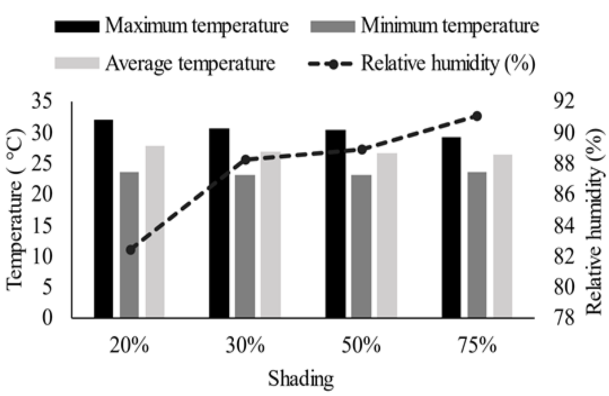

Figure 1. Maximum, minimum, and average temperature and relative air humidity recorded in the study environments (shading houses) during the experiment period.

Eight treatments were applied in total, and four growth evaluations were performed 60, 120, 180, and 240 days after transplanting. The substrate with fertilizer received 7.5 kg m^{-3} of 15-9-12 Osmocote® containing micronutrients (Mg 1.3, S 6, Cu 0.05, Fe 0.46, Mn 0.06, and Mo 0.02), with a release period of eight months (8M). Pre-germinated açaí seeds of the cultivar BRS-Pará were used for planting. The seeds were transplanted to 3-L polyethylene bags containing substrate with controlled-release fertilizer and substrate without fertilizer. A micro-sprinkler irrigation system was used to achieve a substrate moisture level at 75% of field capacity. Manual weed control was carried out every two weeks to manage weed growth in the bags.

The biometric evaluations of açaí seedlings were conducted 60, 120, 180, and 240 days after transplanting. Plant height (PH) was measured using a ruler from the base of the stem to the tip of the last fully opened leaflet. The number of leaves (NL) was counted by including all physiologically active leaves. The stem diameter (SD) was measured at a height of 1 cm from ground using a caliper. Destructive growth assessments were carried out after the biometric evaluations.

This involved measuring the dry mass of leaves (DML), stem (DMS), roots (DMR), and the total dry mass (TDM). The different plant parts (roots, stem, and leaves) were separated, placed in paper bags, and dried to constant weight in a forced-air oven at 70 °C. Subsequently, the dried plant parts were weighed. The seedling quality index, also known as the Dickson index (SQI), was determined based on the plant height (PH), stem diameter (SD), shoot dry mass (SDM), root dry mass (RDM), and total dry mass (TDM) using the following equation:

$$\mathrm{SQI} = \frac{\mathrm{TDM(g)}}{(\mathrm{PH(cm)}/\mathrm{SD(mm)}) + (\mathrm{SDM(g)}/\mathrm{RDM(g)})}$$

Where: TDM is the total dry mass; PH is the plant height; SD is the stem diameter; SDM is the shoot dry mass; RDM is the root dry mass. The Dickson index is a measure of seedling quality that takes into account both the size and biomass of the plant. Higher values of this index indicate better seedling quality. Composite samples of all plants from each plot (10 plants) were used to assess the levels of macro- and micronutrients absorbed by the plants. The samples were ground using a Willey mill and analyzed. Nitrogen was determined using the Kjeldahl method. Phosphorus, boron, and sulfur were analyzed using ultraviolet (UV) spectrophotometry. Potassium, calcium, magnesium, zinc, copper, manganese, and iron were analyzed using atomic absorption spectrophotometry (AAS), following the Möller and Trornhill (1997) method.

The data obtained were subjected to the assumptions of ANOVA (analysis of variance) and subsequently analyzed to study the isolated effects or interactions between the investigated factors. A significance level of 5% was used, and the F-test was employed in the statistical analysis. For the qualitative data, the means were compared using the Tukey test at a 5% probability level. The effects of the time periods were adjusted by regression analysis.

3. Results and Discussion

The cultivation environments and evaluation periods showed significance for the growth characteristics expressed in plant height, stem diameter, and number of leaves, both individually and in interaction, except for plant height and the number of leaves in the absence of controlled-release fertilization, in which no significant interaction occurred ($p<0.05$) (Table 1). Plant height followed a linear regression model based on the evaluation periods and cultivation environments, both with the controlled-release fertilizer (Figure 2B) and without it (Figure 2A).

Table 1. Summary of the analysis of variance for plant height (PH), stem diameter (SD), and number of leaves (NL) of açaí palm seedlings at different evaluation periods and shading conditions with the presence or absence of controlled-release fertilization.

Sources of variation	GL	Mean Square					
		PH		SD		NF	
		Presence	Absence	Presence	Absence	Presence	Absence
Periods (P)	3	15808*	3904*	3689*	1569*	344*	300.2*
Shading (S)	3	1019*	588*	114*	9.96*	10*	2.29^{ns}
P x S	9	75.41*	18.17*	20*	2.59*	1.9*	2.39*
Block	2	66.14	103	1.25	34.55	0.08	6.8
Residual	456	23.84	13.64	3.75	1.11	0.23	3.73
CV (%)	-	18.69	19.44	18.14	13.38	14.51	68.86
Mean	-	26.12	19.01	10.67	7.87	3.33	2.80

Significance at 5% and; ns - non-significant according to the F-test. ** coefficient of variation.

Low-solubility fertilizers have shown good results in the formation of different fruit species, as observed by Almeida et al. (2018) in single-species açaí palm seedling (*Euterpe precatoria*), as they have advantages over conventional fertilizers, e.g., a specific release period. These characteristics are essential for nurserymen to choose the fertilizer according to the time required for the formation of the specific plant species, minimizing nitrogen losses, reducing substrate salinization damage, and decreasing labor with topdressing fertilization (Costa et al., 2011). As observed in Figure 2, açaí seedlings are influenced by shaded environments as restricted light conditions lead to plant etiolation due to hormonal imbalance caused by this physiological stress (Veglio, 2010).

The growth and development of the açaí palm in its natural habitat takes place in an understory area, which creates conditions for the formation of a microclimate, favoring stomatal opening for gas exchange and reducing the loss of water through leaf transpiration, resulting in greater photosynthetic efficiency and cell turgor, which is essential for plant growth (Walters et al., 1993). Under these conditions, chlorophylls absorb light at a wavelength between 600 and 700 nm, being responsible for converting light energy into chemical energy (Taiz et al., 2017).

A linear regression was observed for the number of leaves (Figure 3), with the 75% shading environment promoting a higher number of leaves 240 days after transplanting without the controlled-release fertilizer (Figure 3A). However, with the use of controlled-release fertilization, the 50% and 75% shading environments resulted in a higher number of 5.64 and 5.4 leaves, respectively, at 240 days. The higher number of leaves observed in the shadier environments throughout the evaluation period of the experiment may be related to the plants' higher photosynthetic efficiency due to favorable conditions, resulting in increased carbohydrate accumulation and accelerated leaf emergence (César et al., 2014).

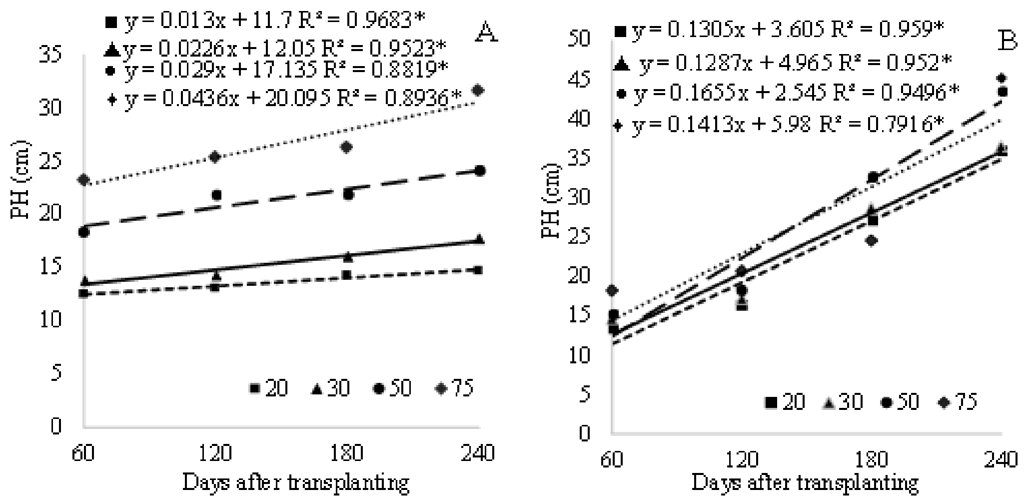

Figure 2. Plant height (PH) of açaí palm seedling under different shading conditions, without controlled-release fertilizer (A) and with controlled-release fertilizer (B) over a period of 240 days.

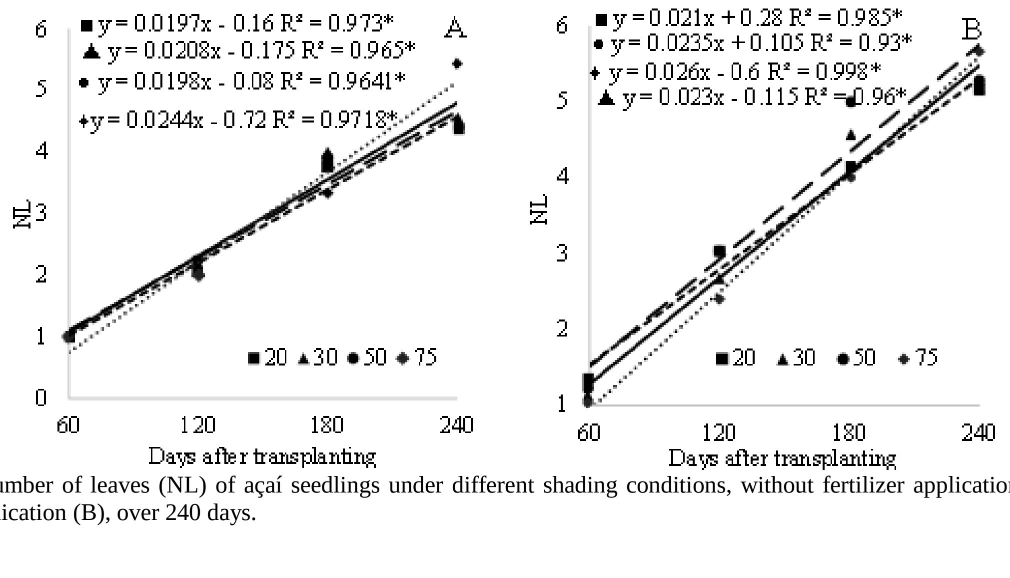

Figure 3. Number of leaves (NL) of açaí seedlings under different shading conditions, without fertilizer application (A) and with fertilizer application (B), over 240 days.

Similar behaviors were observed when using controlled-release fertilizers, as reported in studies on *Euterpe precatoria* (Almeida et al., 2018) and *Euterpe oleracea* (Araújo et al., 2019). Acclimation is the developmental process through which leaves undergo a set of biochemical and morphological adjustments in response to the environment, with some plant species showing developmental plasticity to adapt to a range of different light regimes, allowing them to grow in shaded or sunny environments (Taiz et al., 2017). According to these researchers, this adaptability is important due to differences in habitats, with shaded environments receiving less than 20% of the available photon flux density (PPFD) compared to fully sunny environments and shaded habitats receiving less than 1% of the incident PPFD relative to the top of the canopy.

For the stem diameter of the açaí palm seedlings, an increasing linear effect was observed in the regression until the evaluation carried out 240 days after transplanting, both with and without the use of the controlled-release fertilizer (Figure 4). The largest stem diameter of 19.2 mm was recorded in the 50% shading environment at 240 days with the application of the controlled-release fertilizer (Figure 4A). For most species, etiolation occurs due to the synthesis of hormones that cause the stem to grow excessively and have a reduced diameter when subjected to high shading levels during initial developmental (Whatley and Whatley, 1982).

According to Valladares et al. (2011), some plants tolerant to low-light environments invest in increasing the stem base diameter. It was observed in the present study, as well as by Dapont et al. (2016) for *Euterpe oleracea* and Almeida et al. (2018) for *Euterpe precatoria*, that larger stem diameters were found in shaded environments. The stem diameter of açaí seedlings that received controlled-release fertilization showed a 33% higher increase compared to unfertilized seedlings, demonstrating that the use of chemical fertilization is essential to achieve the recommended standards for high-quality seedlings.

Results observed by Bezerra et al. (2018) and Veloso et al. (2015) in açaí palm seedling production justify the use of chemical fertilization in the substrates. Furthermore, according to Mota et al. (2012), seedlings with a larger stem diameter tend to have a higher survival rate and better development after transplanting, which justifies the use of substrate fertilization for seedling production. The shaded environments and controlled-release fertilization significantly influenced ($p<0.05$) the accumulation of leaf, stem, and root biomass, total dry mass, and the seedling quality index, both independently and through the interaction between environment and fertilizer (Table 2).

The variables of dry leaf mass, stem dry mass, and root dry mass of açaí palm seedlings behave similarly. Upon further analysis of the interaction, it was found that the environment with 50% shading and controlled-release fertilization promoted the best results (Table 3). Fanti and Perez (2003), after evaluating seedlings *of Adenanthera pavonina*, also observed higher dry mass accumulation when using fertilizer and low shading levels. The greater biomass accumulation observed under 50% shading may be related to increased cambial activity, which, in turn, correlates directly with the morphological attributes of the plant (Lopes et al., 2021).

Under appropriate shading conditions, seedlings tend to exhibit higher dry mass in their roots, leaves, and stems as the leaf area is larger and therefore suitable for photosynthetic rates (Furqoni et al., 2018). On the other hand, for some species, the greater the shading, the lower the dry mass of the aboveground and root parts, as observed in this study (Oliveira and Perez, 2012).

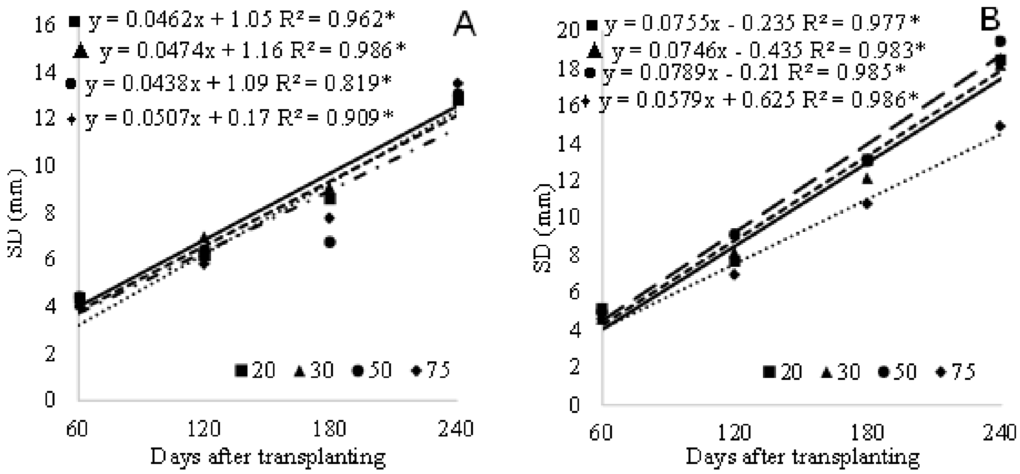

Figure 4. Stem diameter (SD) of açaí palm seedlings under different shading conditions, without (A) and with controlled-release fertilization (B), over a period of 240 days.

Table 2. Summary of the analysis of variance for dry leaf mass (DLM), dry stem mass (SDM), dry root mass (RDM), total dry mass (TDM), and seedling quality index (SQI) of açaí palm seedlings under the presence and absence of controlled-release fertilizer in different shading conditions.

Sources of variation	Mean Square					
	g. l	DLM (g)	DSM (g)	DRM (g)	TDM (g)	SQI
Fertilization (F)	1	999*	332*	147*	384*	4.31*
Shading (S)	3	16.5*	11.4*	29.4*	132*	0.87*
F x S	3	10.3*	4.53*	5.34*	52.41*	0.13*
Block	2	0.44	0.01	1.16	0.87	0.08
Residual	226	0.91	0.77	1.46	6.31	0.03
Mean	-	20.43	33.4	36.66	23.66	38.7
CV ** (%)	-	4.69	2.63	3.3	10.61	0.46

* Significance at 5% and; ns - non-significant according to the F-test. ** coefficient of variation

Table 3. Dry leaf mass (DLM), stem mass (SM), and root mass (RM) of açaí palm seedlings under the presence and absence of controlled-release fertilizer in different shading conditions.

Shading	DLM (g)		SM (g)		RM (g)	
	Presence	Absence	Presence	Absence	Presence	Absence
20%	5.98 Ab	2.31 Ba	3.7 Ab	1.35 Ba	4.44 Aa	2.47 Bab
30%	7.73 Aa	2.82 Ba	4.14 Aab	1.48 Ba	4.59 Aa	2.67 Bab
50%	7.36 Aa	2.62 Ba	4.57 Aa	1.70 Ba	4.71 Aa	2.99 Ba
75%	5.94 Ab	2.83 Ba	2.89 Ac	1.26 Ba	2.61 Ab	1.89 Bb

* Means followed by the same uppercase letter in the row and lowercase letter in the column do not differ significantly according to Tukey's test at a significance level of 5%.

According to Taiz et al. (2017) plants that grow in environments with higher irradiance have thicker leaves compared to those that grow in more shaded environments; palisade parenchyma cells are longer and spongy parenchyma cells are reduced; cuticles are thick; they assimilate more CO2 because they have more rubisco and manage to dissipate excess light energy, which results in higher biomass accumulation. Dapont et al. (2016) observed higher biomass values in environments with higher irradiance at 60% of light.

Overall, the use of fertilization more than doubled dry mass accumulation in seedlings compared to unfertilized seedlings (Table 3). Mendonça et al. (2006) found that controlled-release fertilization resulted in the formation of palm seedlings with higher dry mass values compared to the less soluble fertilizer. Araújo et al. (2019) and Martins Filho et al. (2007) also observed a positive effect of fertilization on the açaí palm and peach palm, respectively. The environments with 30% and 50% shading showed higher total dry mass accumulation, with 16.46 g and 16.64 g, respectively, and a better seedling quality index (ID), with 0.74 and 0.67 when using the controlled-release fertilizer (Table 4). Araújo et al. (2019) found a 40% higher ID in açaí palm seedlings fertilized with controlled-release fertilizer in a low-shade environment.

According to the observed results, biomass accumulation in different plant parts was lower in the more shaded environment, indicating that, in brighter environments, there is a higher net assimilation, resulting in higher dry mass accumulation (Larcher, 2000). According to this author, this response can be attributed to the higher photosynthetic capacity of palm trees. Plants subjected to low-shade environments (up to 50%) and showing higher biomass values can be classified as heliophilous (Aguiar et al., 2005). In that regard, Conforto and Contin (2009) reported that *Euterpe oleracea* seedlings subjected to moderate shading levels (30% to 50%) show higher total dry mass accumulation due to the higher efficiency in energy production and allocation.

The higher ID value (0.74) observed in the environment with 30% shading associated with fertilization highlights the importance of combining light and nutrition for the formation of high-quality seedlings. The seedling quality index has been mentioned by various authors as one of the main parameters that define robustness and balance in biomass distribution (Azevedo et al., 2010; Cruz et al., 2011). According to Hunt (1990), the recommended ID for native species should be above 0.2, which is the minimum value indicated for transplanting, although this value can vary depending on numerous factors and their interactions. The foliar contents of N, P, S, Mg, Zn, and Cu were significantly influenced by both the environment and controlled-release fertilization, with p-values below 0.05, unlike K and Ca, which did not show significance (Table 5).

Table 4. Total dry mass (TDM) and seedling quality index (SQI) of açaí palm seedlings in the presence and absence of controlled-release fertilizer under different shading conditions.

Shading	TDM (g)		SQI	
	Presence	Absence	Presence	Absence
20%	14.13 Bb	6.15 Aa	0.66 Aa	0.33 Ba
30%	16.46 Ba	6.98 Aa	0.74 Aa	0.37 Ba
50%	16.64 Ba	7.32 Aa	0.67 Aa	0.35 Ba
75%	11.45 Bc	5.98 Aa	0.34 Ab	0.24 Ba

* Means followed by the same uppercase letter in the row and lowercase letter in the column do not differ significantly according to Tukey's test at a significance level of 5%.

Table 5. Summary of the analysis of variance for the foliar contents of nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), iron (Fe), and copper (Cu) in açaí palm seedlings with the presence and absence of controlled-release fertilization under different shading conditions.

Sources of variation	Mean Square								
	g. l	N	P	K	S	Ca	Mg	Zn	Cu
Fertilization (F)	1	0.84*	0.38*	0.34^{ns}	6.55*	2.04^{ns}	5.55*	296*	12.84*
Shading (S)	3	0.06*	0.02^{ns}	4.02^{ns}	11.03*	4.03^{ns}	0.18^{ns}	11.9*	0.94^{ns}
F x S	3	0.01^{ns}	0.01^{ns}	3.59^{ns}	2.38*	8.62^{ns}	0.88*	1.32^{ns}	1.73^{ns}
Block	2	0.004	0.03	3.31	0.19	0.57	0.08	0.58	0.54
Residual	14	0.004	0.02	2.63	0.66	4.77	0.15	2.68	0.13
Mean		1.53	1.83	15.15	8.59	11.89	2.47	18.0	2.67
CV ** (%)		4.60	8.64	10.74	9.49	18.36	15.96	9.09	39.75

* Significance at 5% and; ns - non-significant according to the F-test.
** coefficient of variation

Table 6 shows that the combination of 30% shading and fertilization resulted in the highest foliar contents of Mg (3.35 g kg^{-1}) and S (10.52 g kg^{-1}). The higher Mg content may be associated with better photosynthetic conditions in the plant since this element stimulates root growth, increasing their length and surface area, which leads to greater water and nutrient uptake and intensifies the transport of sugars from the leaves to the roots through the phloem (Hansel et al., 2021). It was found that seedlings produced under controlled-release fertilization showed higher foliar levels of Mg and S, indicating that the plant significantly responds to mineral fertilization. Similar behavior was observed by Viegas et al. (2009) in *Euterpe oleracea* seedlings with a foliar Mg content of 2.2 g kg^{-1} and by Fernandes et al. (2013) in peach palm (*Bactris gasipaes*) seedlings with a foliar Mg content of 3.6 g kg^{-1}.

The highest foliar levels of N, Cu, and Zn in açaí seedlings were obtained when using controlled-release fertilization, unlike what occurred with P, as the non-fertilized seedlings showed a higher foliar content (Table 7). The higher concentration of these nutrients in açaí seedlings, especially N, may be related to the slow and continuous nutrient release, which reduces losses in their various forms and increases their uptake by the plant. Zamunér Filho et al. (2009), after studying controlled-release fertilizer in rubber tree seedling production, observed an increase in foliar levels of N, P, K, Mg, S, Zn, Mn, and Fe, a situation also observed by Scivittaro et al. (2004) in *Citrus trifoliata* seedlings under controlled-release fertilization.

With regard to the foliar content of N, it was found that seedlings under 75% shading showed a higher increase, amounting to 1.64 g kg^{-1} (Table 8). This result may be associated with reduced solar radiation on the plants, which can limit the formation of essential reducers and sugars for nitrogen assimilation (Lima et al., 2011). According to Schlesinger (1997), 2% of nitrogen fixation by plants occurs through photochemical reactions between nitric oxide gas (NO) and ozone (O3), generating nitric acid (HNO3). With regard to the zinc content, it was found that the environment with 20% shading showed a higher increase, amounting to 20.07 g kg^{-1} (Table 8).

Table 6. Magnesium (Mg) and sulfur (S) contents in the leaves of açaí palm seedlings in the presence and absence of controlled-release fertilization under different shading conditions.

Shading	Mg (g kg^{-1})		S (g kg^{-1})	
	Presence	Absence	Presence	Absence
20%	3.24 Aab	2.05 Ba	9.96 Aa	9.75 Aa
30%	3.35 Aa	1.65 Ba	10.52 Aa	7.86 Bab
50%	2.84 Aab	1.72 Ba	9.35 Aa	7.92 Bab
75%	2.4 Ab	2.55 Aa	6.65 Ab	6.76 Ab

* Means followed by the same uppercase letter in the row and lowercase letter in the column do not differ significantly according to Tukey's test at a significance level of 5%.

Table 7. Contents of nitrogen (N), phosphorus (P), copper (Cu), and zinc (Zn) in the leaves of açaí palm seedlings as a function of the presence and absence of controlled-release fertilization.

Controlled-release fertilizer	N (g kg^{-1})	P (g kg^{-1})	Cu (mg kg^{-1})	Zn (g kg^{-1})
Presence	1.72 a	1.76 b	3.41 a	21.51 a
Absence	1.34 b	2.01 a	1.94 b	14.49 b

* Means followed by the same letter do not differ significantly according to the Tukey test (p>0.05).

Table 8. Nitrogen (N) and zinc (Zn) contents in leaves of açaí palm seedlings as a function of different shade environments.

Shading	N (g kg^{-1})	Zn (g kg^{-1})
20%	1.58 ab	20.07 a
30%	1.47 bc	17.04 b
50%	1.42 c	17.20 b
75%	1.64 a	17.7 ab

* Means followed by the same letter do not differ significantly according to the Tukey test (p>0.05).

4. Conclusions

The growth and development of açaí seedlings are influenced by the evaluation periods, shade environments, and fertilization. Fertilization with controlled-release fertilizers and environments with 30% and 50% shading improved the quality of açaí palm seedlings.

Authors’ Contribution

Everyone participated in the study, where each one, within their expertise, made their respective contributions. James Maciel de Araújo, Romeu de Carvalho Andrade Neto, Ueliton Oliveira de Almeida, and David Aquino da Costa conceptualized the work, were responsible for data collection and analysis, experiment monitoring, and article writing. João Paulo Sebin Marin and Marcos Giovane Pedroza de Abreu contributed to data analysis and article writing.

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