Comunicata Scientiae
Horticultural Journal

ORIGINAL ARTICLE
published: 07 August 2023
https://doi.org/10.14295/CS.v14.3988

Shading and controlled-release fertilizer in the production of *Oenocarpus bataua* Mart. Seedlings

James Maciel de Araújo[1], Romeu de Carvalho Andrade Neto[2], Maria Júlia da Silva Rodrigues[3], Márcia da Costa Capistrano[1], Eduardo Pacca Luna Mattar[1], Ueliton Oliveira de Almeida[3], Aureny Maria Pereira Lunz[2]

[1]Federal University of Acre, Rio Branco, Brazil
[2]Brazilian Agricultural Research Corporation (Embrapa), Rio Branco, Brazil
[3]Institute of Agricultural and Forestry Defense of Acre, Rio Branco, Brazil
*Corresponding author, e-mail: romeu.andrade@embrapa.br

Abstract

When associated an adequate shading and nutrition the seedlings to reach characteristics that allow them to survive in the field and increase production. Thus, this work aimed to evaluate the production of *Oenocarpus bataua* seedlings in response to different shade environments and controlled-release fertilizer doses. The study was carried out from at the Embrapa nursery located in the municipality of Rio Branco, Acre state. The experimental design was complete randomized blocks with three replications and six plants per plot. The treatments were distributed according to a 4 x 5 factorial scheme, i.e., four shade environments (20%, 30%, 50% and 75%) and five CRF doses (0.0, 1.5, 3.0, 4.5 and 6.0 kg m^{-3}) mixed with the substrate. Biometric, biomass and quality variables were evaluated at 305 days after transplanting. The ANOVA was applied for the qualitative factor and regression analysis was performed for the quantitative factor, both at 5% probability. The treatments were grouped by analyzing canonical variables, a multivariate statistical and realized the Pearson's correlation between variables was determined through correlation networks. The shading environment and the controlled-release fertilizer positively influenced the growth and quality of *Oenocarpus bataua* seedlings. The seedlings of *Oenocarpus bataua* have better biometric characteristics produced in a nursery with 50% shading. *Oenocarpus bataua* seedlings show better quality when 3.88 kg m^{-3} of controlled release fertilizer are used.

Keywords: amazonia, forest nursery, plant propagation, seedling nutrition, rainforest

Introduction

The pataua palm tree (*Oenocarpus bataua* Mart.) is one of the most common species in South America (Guarín et al., 2014), being the seventh most abundant in the Amazon and one of the most used palm trees, mainly for fruit extraction (Isaza et al., 2016).

The species main product is the fruit from which juice and oil are extracted, having a high nutritional value and that can be used in cooking, cosmetics manufacturing and biodiesel production (Hidalgo et al., 2016; Garzón et al., 2013; Ocampo-Duran et al., 2013). Its leaf extract is rich in antioxidants, is non-cytotoxic, and can have dermatological or pharmaceutical applications (Leba et al., 2016).

Therefore, it is evident that the exploitation of this species shows itself as an economic alternative, as it allows the generation of income from its products and by-products, social, by providing employment generation, and environmental, since it can be planted in monoculture or as a component of agroforestry systems.

(Grossnickle and MacDonald, 2018) report that high quality seedlings, determined from their biometric characteristics, are more likely to establish themselves in the field. Thus, the use of appropriate technologies is essential to produce quality seedlings, including choosing the appropriate shade environment and determining the dose of fertilizer to be applied, since, according to (Oliveira et al., 2019), light and fertilization are environmental factors that also influence plant growth and development. (Silva et al., 2018) demonstrated that the development of *O. bataua* seedlings is influenced by the environment, such as substrate and luminosity.

Artificial shading is a technique that aims to provide adequate environmental conditions, especially light, humidity and temperature to seedlings so that they reach an adequate standard of quality and vigor and

Received: 18 April 2022
Accepted: 10 April 2023

are able to go into the field with the maximum possibility of adapting to field conditions and mortality is as low as possible.

In general, the seedlings are nourished by the nutrients incorporated at the time of substrate preparation and, in addition, through cover fertilization, practices that are often inefficient and expensive, mainly because labor has been scarce, and contaminate the environment due to leaching of toxic elements. As an alternative, more technified producers have used controlled-release fertilizers that have numerous advantages, such as providing plants with what they need over time (Soti et al., 2015) and being sustainable (Vejan et al., 2021).

Considering the scarcity of biometric information and indicators of a minimum standard of seedling quality, and that the appropriate environment and the correct dose of fertilizer influence plant growth and development, the objective of the study was to study shading and doses of controlled-release fertilizer on the production of *O. bataua* seedlings.

Material and methods

The study was carried out from April 2016 to April 2017 at a nursery located in the municipality of Rio Branco - AC Brazil, at the coordinates 10°01'24" S and 67°42'04" W and an altitude of approximately 159 m (Google Earth, 2021). The city's climate is classified as Am (monsson) according to the Köppen classification (Alvares et al., 2013) with an annual average temperature of 25.1 °C (Alvares et al., 2013), relative humidity of 85.8% and rainfall 2,012 mm per year (Sousa, 2020). The data related to temperatures and relative air humidity recorded in the environments (shadehouses) during the experiment were obtained through Datalogger AK 174® (**Figure 1**).

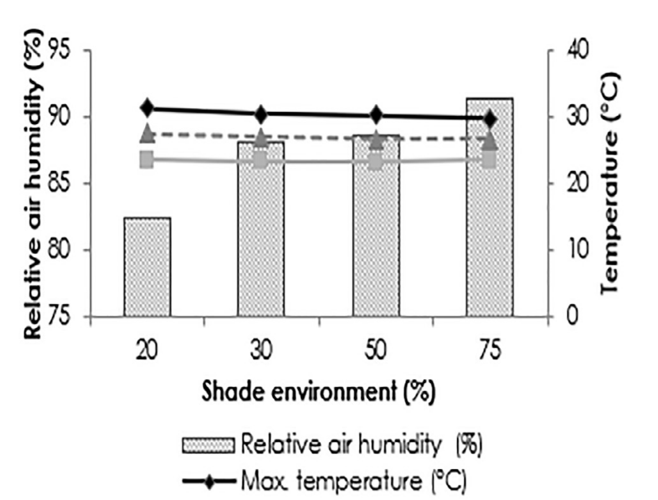

Figure 1. Maximum, minimum and average temperature, as well as relative air humidity recorded in the environments (shadehouses) in the total period of conducting the experiment (Source: Almeida et al., 2018).

A 40 days after sowing in a seed bed filled with sand, the *Oenocarpus bataua* seedlings were transplanted to containers with volumetric capacity of 3 liters, containing substrate composed of soil (Ultisol) superficial layer with the following chemical characteristics: pH (H_2O) = 4.9; Ca = 2.92 cmolc dm^{-3}; Mg = 0.82 cmol$_c$ dm^{-3}; K = 0.07 cmol$_c$ dm^{-3}; Al+H = 3.69 cmol$_c$ dm^{-3}; P = 38.22 mg L^{-1}; CEC (pH7) = 7.50 cmol$_c$ dm^{-3}; BS = 50.74%; organic matter = 11.89 g kg^{-1} (Almeida et al., 2018).

The experiment was designed in randomized blocks with three replications and six plants per plot whose treatments were distributed in a 4 x 5 factorial scheme, i.e., four shaded environments (20%, 30%, 50% and 75%) and five doses (0 .0, 1.5, 3.0, 4.5 and 6.0 kg m^{-3} of substrate) of Osmocote® 15-09-12 8M controlled-release fertilizer (CRF) (8 months of release) containing 15% N; 9% P_2O_5; 12% K_2O; 1.3% Mg; 6%S; 0.05% Cu; 0.46% Fe; 0.06% Mn; 0.02% Mo.

The experiment was irrigated by a micro sprinkler system and the weeds were manually controlled.

The following characteristics were evaluated after 305 days of transplanting: plant height (H), stem diameter (D), height-to-diameter ratio (RHD), number of leaves (NL), leaf dry mass (LDM), stem dry mass (SDM), root dry mass (RDM), shoot dry mass (SMT), total dry mass (TDM) and Dickson quality index (DQI).

The plant height was measured between the surface of the container substrate and the point of emission of the highest leaf; the stem diameter at 1 cm from the soil surface with a digital caliper, and; the number of leaves by counting. The seedlings were removed from polyethylene bags, washed in clean and running water to remove substrate remains and then separated into leaves, roots and stem to determine their dry masses in a forced air circulation oven at 65 °C.

The Dickson seedling quality index (DQI) was determined using formula (Dickson et al., 1960):

$$DQI = \frac{TDM(g)}{(H(cm) / D(mm) + (STM(g) / RDM(g))}$$

where:

TDM: total dry mass (sum of SMT and RDM);

H: plant height;

D: stem diameter;

SMT: shoot dry mass (sum of SDM and LDM);

RDM: root dry mass.

Data related to shading environments were subjected to analysis of variance and the data related to controlled-release fertilizer doses were subjected to regression analysis.

The treatments were grouped by analyzing canonical variables (Cruz et al., 2012). In addition, Pearson's correlation | rij | between variables was determined through correlation networks (Epskamp et al., 2012).

The ANOVA, regression and the means tests were performed using the SISVAR software program (Ferreira, 2011). The multivariate and correlation analyzes were performed using RBio software (Bhering, 2017).

Results and Discussion

It's observed in **Table 1** that stem diameter (D), height-to-diameter ratio (RHD), root dry mass (RDM), shoot dry mass (SMT), total dry mass (TDM) and quality index (DQI) were significant in isolation for both the shading environment (SE) and the doses of controlled-release fertilizers (FD) and, therefore, a test of means was applied for the SE (**Table 2**), qualitative factor, and regression for the FD (Figures 2B, 2C, 2E, 2F and 2G), quantitative factor. The number of leaves (NL), the leaf dry mass (LDM) and the stem dry mass (SDM) were significant only for the SE (**Table 1**) and, therefore, a comparison test of means was performed, as shown in (Table 2). The significant interaction between SE and FD occurred only for height (H) and root dry mass (RDM) (Table 1) and, therefore, only these variables were split.

Shading of 30% resulted in seedlings with a larger stem diameter (D) (Table 2). Shading of 50% promoted a greater number of leas (NL), leaf dry mass (LDM), stem dry mass (SDM), shoot dry mass (SMT), and total (TDM) dry mass, as well as DQI, however without differing from the 30% shading in relation to the NL, LDM, SDM and SMT variables. The 75% shading resulted in seedlings with a higher RHD.

When unfolding the interaction between SE x FD for the variable H, only the 50% and 75% environments were significant (**Figure 2**A). Thus, the adjustment of the doses of controlled-release fertilizers followed a quadratic behavior, both in the 50% environment, with a maximum H value of 15.88 cm at the dose of 3.52 kg m^{-3}, and in the 75 %, with a maximum H of 19.29 cm at a dose of 3.19 kg m^{-3}.

When unfolding the SE X FD interaction for the RDM variable, only the 50% environment was significant and a quadratic fit of the regression was observed with a maximum RDM of 3.27 g, at a dose of 4.96 kg m^{-3} (Figure 2D).

Table 1. Analysis of variance for plant height (H), stem diameter (D), height-to-diameter ratio (RHD), number of leaves (NL), leaf dry mass (LDM), stem dry mass (SDM), root dry mass (RDM), shoot dry mass (SMT), total dry mass (TDM) and Dickson quality index (DQI) of (*Oenocarpus bataua* seedlings) evaluated at 305 days after transplanting in response to shading environment (SE) and controlled-release fertilizer doses (FD)

Source		SE	FE	SE x FD	Block	Residual	CV (%)
d.f.		3	4	12	2	337	-
Mean square (MS)	H	670.67*	45.65*	17.96*	9.74	2972	20.61
	D	69.72*	15.12*	2.68^{ns}	0.99	3.34	16.88
	RHD	1.62*	0.12*	0.03^{ns}	0.03	0.01	14.20
	NL	28.64*	0.39^{ns}	0.31^{ns}	0.13	0.24	13.02
	LDM	273.19*	92.31^{ns}	15.14^{ns}	0.45	20.60	16.89
	SDM	239.33*	25.63^{ns}	10.65^{ns}	2.16	6.76	14.96
	RDM	74.37*	12.09*	8.09*	0.58	4.80	13.74
	SMT	27.51*	5.80*	1.12^{ns}	0.05	1.06	13.94
	TDM	38.89*	8.00*	2.16^{ns}	0.11	1.24	11.34
	DQI	2.25*	0.29*	0.18^{ns}	0.07	0.11	14.71

* Significant at 5%; ns: non-significant.

Table 2. Stem diameter (D), height-to-diameter ratio (RHD), number of leaves (NL), leaf dry mass (LDM), stem dry mass (SDM), shoot dry mass (SMT), total dry mass (TDM) and seedling quality index (DQI) of *O. bataua* seedlings in response to shading environment (SE)

SE (%)	D (mm)	RHD	NL	LDM (g)	SDM (g)	SMT (g)	TDM (g)	DQI
20	10.33c	1.16c	3.95a	3.55c	2.16b	5.71c	8.10 c	2.28b
30	11.95a	1.07c	3.94a	4.7ab	3.33a	8.03a	10.35b	2.29b
50	11.07b	1.36b	3.90a	5.26a	3.57a	8.83a	11.81a	2.73a
75	9.96c	1.81a	3.37b	4.41b	2.52b	6.94b	9.05 c	1.78c

Means followed by the same letter do not differ from each other by the Tukey test at 5% significance

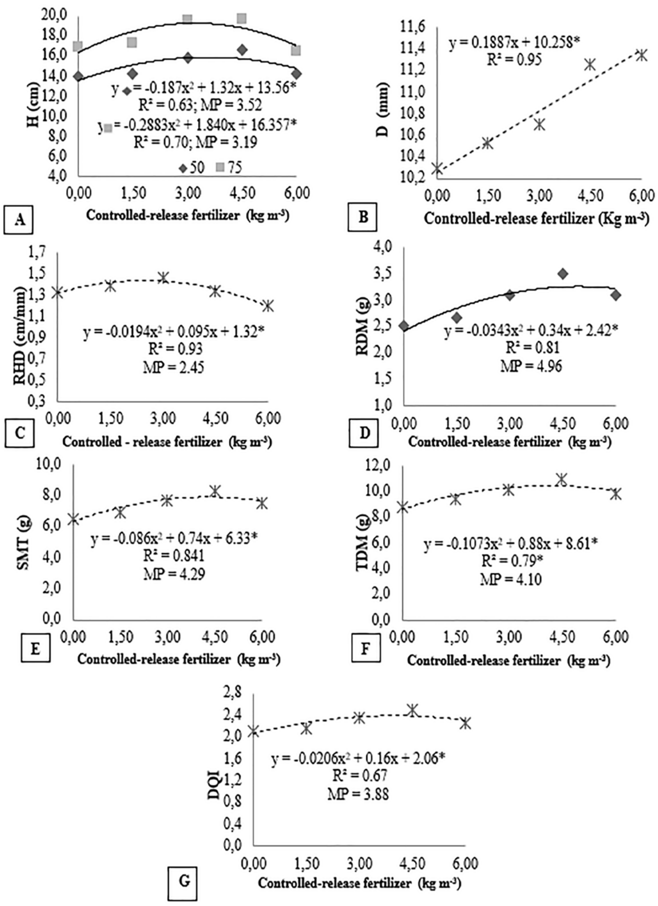

Figure 2. A: Hight (H), B: stem diameter (D); C: height-to-diameter ratio (RHD); D: root dry mass (RDM); E: shoot dry mass (SMT); F: total dry mass (TDM) and G: seedling quality index (DQI) of *O. bataua* seedlings in response to shading environment (SE) and controlled-release fertilizer doses (FD). MP: Maximum point

Regardless of the shading environment, the doses of controlled-release fertilizer showed a quadratic adjustment in relation to RHD (Figure 2C), SMT (Figure 2E), TDM (Figure 2F) and DQI (Figure 2G), with the maximum doses, respectively for the aforementioned variables, 2.45 kg m^{-3}, 4.29 kg m^{-3}, 4.10 kg m^{-3} and 3.88 kg m^{-3}. For D variable was observed a fit linear (Figure 2B).

The results shown by the ANOVA and regression are confirmed by the conjoint multivariate analysis using canonical variables (**Figure 3**). Therefore, treatments with 50% shading in doses above 3 kg m^{-3} had a greater influence on the morphological variables of the seedlings, with the exception of the more shaded environment since it had an influence on H and RHD regardless of the dose used. The first two canonical variables were statistically significant ($p<0.001$), explaining 71.2% of the total variation in the data and better represented and explained the joint variation of the morphological variables depending on the treatments.

The correlation networks indicated that a greater number of variables correlate strongly and negatively (rij ≤ -0.6) when the shading (SE) was individually analyzed (**Figure 4**A), differently from the fertilizer doses (FD) (Figure 4B) and SE x FD interaction (4C). Thus, there were strong and negative correlations between H and NL, H and RDM, H and DQI, as well as between RHD and RDM, RHD and NL, RHD and DQI when considering the shading factor alone. Weak and negative correlation was observed between RHD and NL regarding the fertilizer dose factor, but strong and negative when considering SE x FD.

Considering the global results, the shading and plant nutrition influence the morphological features of *O. bataua* seedlings, because, according to (Wang et al., 2020), these factors act significantly in the performance of photosynthesis with consequent accumulation of energy and conversion into structural carbon for the formation of leaves, roots, stem development with reflections on the content of dry matter.

The results determined in this study corroborate (Valadão et al., 2014), as they state that research shows that seedlings perform better when produced between 30% and 50% of shade and is consistent with (Shanley & Medina, 2005) who describe that this species prefers shaded environments at the beginning of development. Therefore, this statement is consistent with the need to study the appropriate environment for the production of quality seedlings. Thus, if, on the one hand, plants may have their photosynthetic process compromised due to low light, which will result in low biomass accumulation caused by an insufficient metabolic rate, on the other

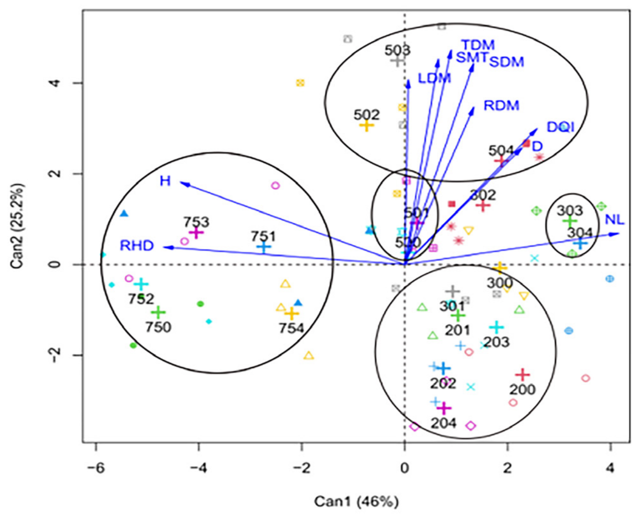

Figure 3. Graphical representation of canonical variables for morphological variables height (H), stem diameter (D), height-to-diameter ratio (RHD), number of leaves (NL), leaf dry mass (LDM), stem dry mass (SDM), root dry mass (RDM), shoot dry mass (SMT), total dry mass (TDM) and Dickson quality index (DQI) of (*Oenocarpus bataua* seedlings) evaluated at 305 days after transplanting in response to shading environment (SE) and controlled-release fertilizer doses (FD). The first two digits represent the shading Environment (20 = 20%; 30 = 30%; 50 = 50%; 75 = 75%) and the last digit indicates the controlled-release fertilizer dose used (0 = 0 kg dm^{-3}; 1 = 1.5 kg dm^{-3}; 2 = 3.0 kg dm^{-3}; 3 = 4.5 kg dm^{-3}; 4 = 6.0 kg dm^{-3}).

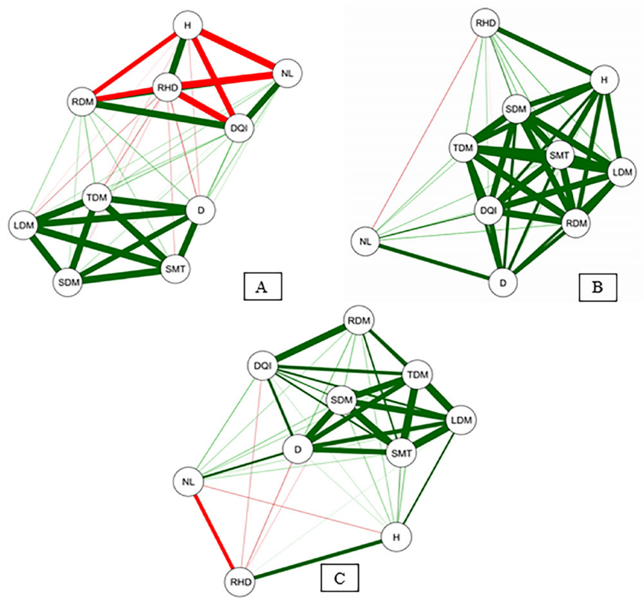

Figure 4. Correlation networks between variables for shading environment SE (A) controlled-release fertilizer, FD (B) and SE x FD interaction (C). (H), stem diameter (D), height-to-diameter ratio (RHD), number of leaves (NL), leaf dry mass (LDM), stem dry mass (SDM), root dry mass (RDM), shoot dry mass (SMT), total dry mass (TDM) and Dickson quality index (DQI).

hand, plants in full sun may accumulate less biomass, probably due to higher transpiration rate associated with higher energy expenditure, which can result in less dry matter accumulation (Pereira et al., 2018).

The results confirm that *O. bataua* does not tolerate direct light exposure, from early growth to juvenile stage (Garzón et al., 2013). Thus, the best initial development of this species in a light-restricted environment follows the trend of other amazonian palms, such as *Euterpe oleraceae* (Dapont et al., 2016; Araújo et al., 2019) and *Euterpe precatoria* (Almeida et al., 2018).

As for seedling nutrition by means of controlled-release fertilizer, the results obtained show that it is essential to nourish of *O. bataua* seedlings, since all the variables analyzed were compromised when the dose was zero. It is worth mentioning that this type of fertilizer is advantageous for use in the humid tropics that have high levels of precipitation that favor the leaching of nutrients.

The efficiency in the use of the controlled-release fertilizer has been proven by several authors in both the seedling production of forest species (Gasparin et al., 2015; Dutra et al. 2016; Almeida et al 2018; Araújo et al., 2019; Silva et al. 2019; Gibson et al., 2019; Murugan et al., 2020; Cabreira et al., 2021).

According to (Reis et al., 2016), the plant height is one of the main biometric parameters for seedling evaluation, as it is easy to measure and non-destructive. However, according to (Araújo et al., 2019), taller seedlings will not necessarily be the best, since light deficiency or excess nitrogen can lead plants to reach greater height, smaller stem diameter and dry mass (etiolation). An effect similar to that of this study was observed by (Santelices et al., 2013), and by (Tsakaldimi et al., 2021), respectively, for *Nothofagus glauca* and *Pinus nigra*, which showed greater height and smaller diameter of the collar as light was limited to the plants.

The fact that *O. bataua* seedlings showed greater height under shading conditions indicates that, under full sun conditions, their development and initial growth may be compromised (Lopes et al., 2013).

According to (Paiva et al., 2003), the stem diameter increases as the cambial activity is stimulated by the carbohydrates supplied from photosynthesis, and this, in turn, is dependent on the light provided to the plants and has been correlated with seedling survival in the field (Stuepp et al., 2020). (Dapont et al., 2016) found the highest values of stem diameter of the species *Euterpe oleracea* in an environment with 40% shade. In the 50% shading, *Euterpe precatoria* seedlings showed a diameter of around 11 mm with a dose close to 5 kg m^{-3} of controlled-release fertilizer (Almeida et al., 2018) whereas *Euterpe oleraceae* presented 19.18 mm when a dose close to 7 kg m^{-3} was used (Araújo et al., 2019). On the other hand, *Acrocomia aculeata* plants do not differ in plant height and diameter when subjected to sun and light (Dias et al. 2018).

Plants tend to have a larger stem diameter under fertilization conditions (Soti et al. 2015; Han et al., 2016; Murugan et al., 2020) which reflects in greater survival when taken to the field, as they present a greater amount of carbohydrates and nutrients stored in this portion of the plant (Tsakaldimi et al., 2013).

RHD is an important variable due to its relationship with seedling survival after transplanting in the field (Smiderle et al., 2017). According to (Haase, 2008), the relationship between height and diameter represents robustness; high ratio indicates that the seedling is thin and, therefore, more subject to the effects of wind, drought and handling; low ratio indicates a more robust seedling. Thus, an adequate relationship between shoot and root attenuates the competitive effect with weeds at the field, in addition to promoting less stress caused by drought (Matos et al., 2021).

However, this relationship must be adequate and established according to the species. Its practical effect is quite interesting, as it is based on two non-destructible and easy-to-measure variables (Nicoletti et al., 2015).

(Sevillano et al., 2016) found that RHD of seedlings of *Fagus sylvatica* and *Quercus robur* tended to increase as shading increased, similar to that detected in seedlings of *O. bataua*. According to these authors, the higher RHD of seedlings under shading conditions is due to the fact that the seedlings prioritized the accumulation of biomass in the aerial part.

Plants with a greater number of leaves tend to produce a greater amount of photoassimilates which will be translocated to different parts of the plant, influencing the increments in height, roots, stem diameter and biomass (Quaresma et al., 2021). Palm trees have many mechanisms to adapt to a shaded environment, such as adjusting leaf angles for better light interception, and producing thicker leaves which contribute to survival, growth and development in environments with restricted light (Sylvester & Avalos, 2013; Amadeu et al. 2016). (Gatti et al., 2011) report that palm trees can acclimate and develop their leaves for different conditions. They reiterate that although the mechanisms involved may be different between palm trees and woody plants, palm trees are better able to adapt to different growing conditions than woody plants.

In the present work it was observed that seedlings fertilized with controlled-release fertilizer obtained an increase in root dry mass (above 38% in relation to the control), which evidences the positive effect of this fertilizer in seedling production.

The highest dry mass of the leaves was in the environments of 30% and 50% with the doses of 9.24 kg of fertilizer per m^3 of substrate and 7.00 kg of fertilizer per m3 of substrate.

Photorespiration in plants with 3C metabolism can reach high rates under high light intensity and temperature conditions, which lead to losses in the incorporation of CO_2, resulting in less accumulated dry mass (Silva et al. 2018).

Biomass is a variable used to evaluate the quality of seedlings and can be correlated with the survival and growth of seedlings in the field, because, when they have a vigorous root system in balance with the aerial part, they can establish and grow better in adverse field conditions, such as in degraded areas (Gibson et al., 2019). For (Tsakaldimi et al., 2013), plants with lower root volume may find it difficult to grow and develop in the final location due to lower water and nutrient absorption.

Seedlings of other palm trees, such as *E. oleraceae* (Conforto & Contin, 2009; Zancheta et al., 2013; Dapont et al., 2016), have shown higher biomass contents when submitted to shading between 16% and 50% of shading. (Araújo et al., 2019), when studying shading levels and doses of controlled-release fertilizer, found higher dry biomass of the stem leaf, root and total in shading conditions similar to that of this study, however, the doses of fertilizer reached almost double that determined in this study.

In was observed that seedlings fertilized with controlled-release fertilizer obtained, respectively, an increase in root dry mass, shoot dry mass and total dry mass of 26%, 20% and 17% in relation to the control, which evidences the positive effect of this fertilizer in seedling production. A positive effect of controlled-release fertilizer has been observed on the accumulation of dry mass in seedlings of forest species (Gasparin et al., 2015; Silva et al., 2019; Gibson et al., 2019; Cunha et al., 2021; Matos et al., 2021).

Despite being an index used worldwide, the DQI varies according to the interaction between genetic and environmental factors. The DQI is positively correlated with the survival (Tsakaldimi et al., 2013) and establishment in the field after transplanting (Santos et al., 2020).

The DQI of *Erythroxylum pauferrense* (Ribeiro et al., 2022) and *Euterpe Oleraceae* (Araújo et al., 2019) seedlings was higher in shade conditions close to 50%.

The higher the DQI, the better the seedling quality (Binotto et al., 2010). In this sense, research results point to an increase in this index when seedlings are subjected to mineral nutrition (Rossa et al., 2013; Rossa et al., 2015; Gibson et al., 2019; Cabreira et al., 2021; Cunha et al., 2021).

For *O. bataua*, until then, there was no established DQI and, therefore, this work is a starting point for establishing a parameter for this species.

Our results are similar to those of (Sevillano et al., 2016) as they observed a positive correlation between shoot and root dry mass, as well as between total dry mass, height and diameter.

For (Gasparin et al., 2015), there is a positive correlation between the stem diameter and root system, reflecting the fast establishment of the seedlings at planting. However, considering the interaction between shading and fertilizer (Figure 4C), the correlation between the aforementioned variables was negative, which can be explained by the need to increase the doses of controlled-release fertilizer since the regression adjustment was linear increasing (Figure 2B).

After studying the effect of shading on seedling production of *Dimorphandra gardneriana* TUL., (Santos-Moura et al., 2018) found positive and significant correlations between RDM and DQI and between SMT and TDM and negative between RDM and H and between DQI and H, similar to this study, when considering shading alone (Figure 4 A).

Root dry matter proved highly correlated with DQI, D, TDM, SDM and LDM in forest seedlings (Binotto et al., 2010). These authors found positive correlations of RDM and LDM with H and D e; DQI with variables H and D. In the first case, according to them, H and Dare indicators of RDM and LDM and, in the second, it helps the nurseries in decision making, because, from two non-destructive variables (H and D), it is possible to predict about the seedling quality.

(Avelino et al., 2021) found that the IQD was positively correlated with the biomass of native forest species, but negative in relation to seedling height. For them, this negative correlation indicates that the plant height contributed little in the value of the DQI.

Conclusions

Under the conditions in which the experiment was carried out, it can be concluded that: 1. The shading environment and the controlled-release fertilizer positively influenced the growth and quality of *Oenocarpus bataua* seedlings; 2. The seedlings of *Oenocarpus bataua* have better biometric characteristics produced in a nursery with 50% shading; 3. *Oenocarpus bataua* seedlings show better quality when 3.88 kg m^{-3} of controlled release fertilizer are used.

References

Almeida, U.O., Andrade Neto, R.C., Lunz, A.M.P., Nogueira, S.R, Costa, D. A., Araújo, J.M. 2018. Environment and slow-release fertilizer in the production of *Euterpe precatoria* seedlings. *Pesquisa Agropécuaria Tropical* 48: 382-389.

Alvares, C.A, Stape, J.L., Sentelhas, P.C., Gonçalves, J.L.M, Sparovek, G. 2013. Koppen's climate classification map for Brazil. *Meteorologische Zeitschrift* 22: 711–728.

Alvares, C.A, Stape, J.L., Sentelhas, P.C., Leonardo, J., Gonçalves, D.M. 2013. Modeling monthly mean air temperature for Brazil. *Theoretical and Applied Climatology* 113: 407–427.

Amadeu, L.S.N., Sampaio, M.B., Santos, F.A.M. 2016. Influence of light and plant size on the reproduction and growth of small palm tree species: Comparing two methods for measuring canopy openness. *American Journal of Botany* 103: 1678-1686.

Araújo, J.M., Andrade Neto, R.C., Oliveira, J.R., Lunz, A.M.P., Almeida, U.O. 2019. Shading and Slow-release fertilizer effects on the growth characteristics of assai seedlings (*Euterpe oleracea*). *Floram* 26: 1-10.

Avelino, N.R., Schilling, A.C., Dalmolin, A.C., Santos, M.S., Mielke, M.S. 2021. Alocação de biomassa e indicadores de crescimento para a avaliação da qualidade de mudas de espécies florestais nativas. *Ciência Florestal*, 31: 1733-1750.

Bhering L.L.R. 2017. A tool for biometric and statistical analysis using the R platform. *Crop Breeding and Applied Biotechnology* 17: 187-190.

Binotto, A.F., Lúcio, A.D.C., Lopes, S.J. 2010. Correlations between growth variables and the dickson quality index in forest seedlings. *Cerne* 16: 457-464.

Cabreira, G.V., Leles, P.S.S., Alonso, J.M., Resende, A.S., Cabreira, W.V., Sousa, T.J.S. 2021. Controlled-Release Fertilizer and Container Volume to Produce *Inga laurina* Seedlings. *Floresta e Ambiente* 28: 1–9.

Conforto, E.C., Contin, D.R. 2009. Desenvolvimento do açaizeiro de terra firme, cultivar Pará, sob atenuação da radiação solar em fase de viveiro. *Bragantia* 68: 979-983.

Cruz, C.D., Regazzi, A.J., Carneiro, P.C.S. 2012 *Modelos biométricos aplicados ao melhoramento genético*. Editora UFV, Viçosa, Brasil. 668 p.

Cunha, F.L., Nieri, E.M., Melo, L.A., Miranda, E.N., Fernades, T.J., Venturin, N. 2021. Efficiency of Slow Release Fertilizers in The Production of *Eucalyptus grandis* Seedlings. *Floresta e Ambiente* 28: e20210059.

Dapont, E.C., Silva, J.B., Alves, C.Z. 2016. Initial development of açaí plants under shade gradation. *Revista Brasileira de Fruticultura* 38: 1-9.

Dias, N.A, Silva, A.I.S., Souza, J.P., Kuki, K.N., Pereira, E. 2018. Acclimation responses of macaw palm seedlings to contrasting light environments. *Scientific Reports* 8: 1-13.

Dickson, A., Leaf, A.L., Hosner, J.F. 1960. Quality appraisal of white spruce and white pine seedling stock in nurseries. *Forest Chronicles* 36: 10-13.

Dtra, T.R., Massad, M.D., Sarmento, M.F.Q. 2016. Fertilizante de liberação lenta no crescimento e qualidade de mudas de canafístula (*Peltophorum dubium*). *Floresta* 46: 491-498.

Epskamp, S., Cramer, A.O.J., Waldorp, L.J., Schmittmann, V.D., Borsboom, D. 2012. Network Visualizations of Relationships in Psychometric Data. *Journal of Statistical Software* 48: 1-18.

Ferreira, D.F. 2011. Sisvar: a computer statistical analysis system. *Ciência e Agrotecnologia* 35: 1039-1042.

Garzón, D.C., Valencia, R., Montúfar, R. 2013. Ungurahu (*Oenocarpus bataua*). In: Valencia, R.R, Montúfar, H., Navarrete, H.B. *Palmas Ecuatorianas: Biología y Uso Sostenible*. Facultad de Ciencias Exactas y Naturales, Pontificia Universidad Católica del Ecuador, Quito, Ecuador. 209-224 p.

Gasparin, E., Araujo, M.M., Saldanha, C.W., Tolfo, C.V. 2015. Controlled release fertilizer and container volumes in the production of *Parapiptadenia rigida* (Benth) Brenan seedlings. *Acta Scientiarum* 37: 473–481.

Gatti, M.G., Campanello, P.I. 2011. Goldstein G. Growth and leaf production in the tropical palm *Euterpe edulis*: Light conditions versus developmental constraints. *Flora* 206: 742-748.

Gibson, E.L., Gonçalves, E.D.O., Ramalho, A., Santos, D., Araújo, E.F., Vinicius, M., Caldeira, W. 2019. Controlled-Release Fertilizer on Growth of *Melanoxylon brauna* Schott Seedlings. *Floresta e Ambiente* 26: e20180418.

Grossnickle, S.C., Macdonald, J.E. Why seedlings grow : influence of plant attributes. *New Forests* 49: 1–34.

Guarín, J.R., Dell Vale, J.I., Sierra, C.A. 2014. Establishment phase, spatial pattern, age, and demography of *Oenocarpus bataua* var . bataua can be a legacy of past loggings in the Colombian Andes. *Forest Ecology and Management* 328: 282–291.

Haase, D.L. 2008. Understanding Forest Seedling Quality : Measurements and Interpretation. *Tree Planters* 52: 24–30.

Han, S.H., AN, J.Y., Hwang, J., Kim, S.B., Park, B.B. 2016. The effects of organic manure and chemical fertilizer on the growth and nutrient concentrations of yellow poplar (*Liriodendron tulipifera* Lin.) in a nursery system. *Forest Science and Technology* 12: 137-143.

Hidalgo, P.S.P., Nunomura, R.C.S., Nunomura, S.M. 2016. Plantas oleaginosas amazônicas: química e atividade antioxidante de patauá *(Oenocarpus bataua mart.)*. *Virtual Química* 28: 271-276.

Isaza, C., Martorell, C., Cevallos, D., Galeano, G., Valencia, R., Balslev, H. 2016. Demography of *Oenocarpus bataua* and implications for sustainable harvest of its fruit in western Amazon. *Population Ecology* 58: 463–476.

Quaresma, E.V.W., Otto, R.P.A., Santos, C.C., Silverio, J.M., Loli, G.H.S., Vieira, M.C. 2021. Shading levels influence the production of *Mentha* x *villosa* Huds. *Revista Brasileira de Engenharia de Biossistemas* 15:127–141.

Leba, L.J., Brunschwig, C., Saout, M., Martial, K., Bereau, D., Robinson, J.C. 2016. Oenocarpus bacaba and *Oenocarpus bataua* Leaflets and Roots: A New Source of Antioxidant Compounds. *International Journal Molecular Sciences* 17: 1-17.

Lopes, E.C., Araujo, E.C., Silva, R., Daher, R.F., Fernandes, M.E.B. 2013. Crescimento de mudas de mangue sob diferentes níveis de sombreamento na península de Ajuruteua. *Acta Amazônica* 43: 291–296.

Matos, D.C.P., Felix, F.C., Gabira, M.M., Aguiar, N.S., Walter, L.S., Mastella, A.D.F., Kratz, D. 2021. Controlled-release Fertilizer in *Cordyline spectabilis* Seedlings Production, a Potential Species of the Asparagaceae Family. *Floresta e Ambiente* 28: e20200047.

Murugan, P., Ong, S.Y., Hashim, R., Kosugi, A., Arai, T., Sudesh, K. 2020. Biocatalysis and Agricultural Biotechnology Development and evaluation of controlled release fertilizer using P (3HB- co -3HHx) on oil palm plants (nursery stage) and soil microbes. *Biocatalysis and Agricultural Biotechnology* 28: 101710.

Nicoletti, M.F., Navroski, M.C., Novack Junior, N.S. 2015. Modelagem de variáveis morfológicas em mudas de *Eucalyptus dunnii*. *Floresta*, 45: 809-818.

Ocampo-Duran, A., Lavado, F.A.P., Lima, C.F. 2013. Aceite de la palma de seje *Oenocarpus bataua* Mart. por su calidad nutricional puede contribuir a la conservación y uso sostenible de los bosques de galería en la Orinoquia Colombiana. *Orinoquia Colombiana, Meta* 17: 215-229.

Oliveira, A.P., Borges, I.V., Pereira, E.C.V., Feitosa, T.A., Santos, R.F., Oliveira-Junior, R.G., Rolim L.A., Viana, L.G.F.C., Ribeiro, L.A.A., Santos, A.D.C., Rolim-Neto, P.J., Almeida, J.R.G.S. 2019. Influence of light intensity, fertilizing and season on the cirsiliol content, a chemical marker of *Leonotis nepetifolia* (Lamiaceae). *PeerJ* 7: e6187.

Paiva, L.C., Guimarães, R.J., Souza, C.A.S. 2003. Influência de diferentes níveis de sombreamento sobre o crescimento de mudas de cafeeiro (*Coffea arabica* L.). *Ciência e Agrotecnologia* 27: 134-140.

Pereira, M.A., Gonçalves, D.S., Souza, P.A., Lucena, F.R., SILVA, R.R., Brondani, G.E. 2018. Luminosity levels affect the initial seedlings growth and nutrient accumulation in *Khaya senegalensis* A. Juss. *Cerne*, 24: 344-351.

Reis, S.M., Marimon Júnior, B.H., Morandi, O.S., Santos, C.O., Oliveira, B., Marimon, B.S. 2016. Desenvolvimento inicial e qualidade de mudas de *copaifera langsdorffii* desf. sob diferentes níveis de sombreamento. *Ciência Florestal* 26: 11-20.

Ribeiro, J.E.S., Coêlho, E.S., Figueiredo, F.R.A., Pereira, W.E., Albuquerque, M.B., Melo, M.F. 2022. Morphophysiological aspects of *Erythroxylum pauferrense Plowman* seedlings submitted to shading. *Ciência Florestal* 32: 395-416.

Rossa, U.B., Angelo, A.C., Nogueira, A.C., Westphalen, D.J., Bassaco, M.V.M., Milani, J.E.F. 2013. Fertilizante de liberação lenta no desenvolvimento de mudas de *schinus terebinthifolius* e *sebastiania commersoniana*. *Floresta e Ambiente* 43: 93-104.

Rossa, U.B., Angelo, A.C., Westphalen, D.J., Oliveira, F.E.M., Silva, F.F., Araújo, J.C. 2015. fertilizante de liberação lenta no desenvolvimento de mudas de *Anadenanthera peregrina* (L.) speg. (angico-vermelho) e *Schinus terebinthifolius* Raddi (aroeira-vermelha). *Ciência Florestal* 25: 841-852.

Santelices, R., Espinoza, S., Ariza, A.C., Peña-Rojas, K., Donoso, S.R. 2013. Effect of shading and fertilisation on the development of container-grown *Nothofagus glauca* seedlings , a threatened species from central Chile. *Southern Forests* 75: 145–148.

Santos, C.C., Jorge, H.P.G., Dias, L.G.F., Vieira, M.C. 2020. Shading Levels and Substrates Affect Morphophysiological Responses and Quality of *Anadenanthera peregrina* (L .) Speg Seedlings. *Floresta e Ambiente* 27: e20190119.

Santos-Moura, S.S., Alves, E.U., Ursulino, M.M., Bruno, R.L.A., Anjos Neto A.P. 2018. Effect of shading on *Dimorphandra gardneriana* Tul. Seedling production. *Bioscience Journal* 34: 1147–1157.

Sevillano, I., Short, I., Grant, J., O'reilly, C. 2016. Effects of light availability on morphology, growth and biomass allocation of *Fagus sylvatica* and *Quercus robur* seedlings. *Forest Ecology and Management* 374: 11–19.

Shanley, P., Medina, G. 2005. *Frutíferas e Plantas Úteis na Vida Amazônica*. Cifor, Belém, Brasil. 310 p.

Silva, A.C.D., Sousa, A.A., Nascimento, C.R., Smiderle, O.J. 2018. Morfologia e emergência de plântulas de *Oenocarpus bataua* Martius em diferentes substratos e luminosidades. *Revista do Instituto Florestal* 30: 87–94.

Silva, B.L.B., Costa, E., Binotti, F.F.S., Benett, C.G.S., Silva, A.G. 2018. Growth and quality of *Garcinia humilis* seedlings as a function of substrate and shading level. *Pesquisa Agropecuária Tropical* 48: 407-413.

Silva, L.D.D., Lima, A.P.L., Lima, S.F., Silva, R.S., Peniago, G.F. 2019. Controlled-release Fertilizer in the Production and Quality of *Acacia mangium Seedlings*. *Floresta e Ambiente* 26: 1-7.

Smiderle, O.J., Silva, T.D.J., Souza, A.A., Souza, A.G. 2017. Correlação morfológica da qualidade de mudas de maracujazeiro-amarelo com substratos alternativos. *Revista da Jornada de Pós-Graduação e Pesquisa-Congrega* 14: 2747-2758.

Soti, P., Fleurissaint, A., Reed, S., Jayachandran, K. 2015. Effects of Control Release Fertilizers on Nutrient Leaching, Palm Growth and Production Cost. *Agriculture* 5: 1135-1145.

Sousa, J.W. 2020. Características climáticas do município de Rio Branco, Acre, período de 1990-2019. *Scientia Naturalis* 2: 723–740.

Stuepp, C.A., Kratz, D., Gabira, M.M., Wendling, I. 2020.

Survival and initial growth in the field of eucalyptus seedlings produced in different substrates. *Pesquisa Agropecuária Brasileira* 55: e01587.

Sylvester, O., Avalos, G. 2013. Influence of light conditions on the allometry and growth of the understory palm *Geonoma undata* subsp. *Edulis* (Arecaceae) of neotropical cloud forests. *American Journal of Botany* 100: 2357–2363.

Tsakaldimi, M., Ganatsas, P., Jacobs, D.F. 2013. Prediction of planted seedling survival of five Mediterranean species based on initial seedling morphology. *New Forests* 44: 327–339.

Tsakaldimi, M., Giannaki, P., Ivetic, V., Kapsali, N., Ganatsas, P. 2021. Fertilization and Shading Trials to Promote *Pinus nigra* Seedlings ' Nursery Growth under the Climate Change Demands. *Sustainability* 13: e3563.

Valadão, M.B.X., Marimon Junior, B.H., Morandi, P.S., Reis, S.M., Oliveira, B., Oliveira, E.A., Marimon, B.S. 2014. Initial development and biomass partitioning of *Physocalymma scaberrimum* Pohl (Lythraceae) under different shading levels. *Scientia Forestalis* 42: 129-139.

Vejan, P., Khadiran, T., Abdullah, R., Ahmad, N. 2021. Controlled release fertilizer : A review on developments, applications and potential in agriculture. *Journal of Controlled Release* 339: 321–334.

Wang, R., Gui, Y., Zao, T., Ishii, M., Eguchi, M., Li, H.X.T., Iwasaki, Y. 2020. Determining the Relationship between Floral Initiation and Source – Sink Dynamics of Tomato Seedlings Affected by Changes in Shading and Nutrients. *Hortscience* 55: 457–464.

Zancheta, A.A., Mazzini, R.B., Batista, G.S., Melo, R.F., Pivetta, K.F.L. 2013. Growth of *Euterpe oleraceae* seedlings under diferente color nets and light conditions. *Acta Horticulturae* 1000: 293-300.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.