AGRONOMY SCIENCE AND BIOTECHNOLOGY

RESEARCH ARTICLE

Initial growth and quality of jussara palm seedlings cultivated in biosolid-based substrates

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ABSTRACT

All palms present ornamental appeal and may be widely used in landscaping, especially the native ones because of their ecological importance, such as the jussara palm (*Euterpe edulis* Mart.). In this sense, aiming at maximum plant development in the urban environment, it is necessary to use high-quality seedlings; the substrate is one of the key factors that directly influence it. The objective of this study was to evaluate the initial growth of jussara palm seedlings cultivated in biosolid-based substrates, which is a material of good characteristics besides attending sustainability issues. The experimental design was entirely randomized with six treatments consisted of substrates composed by biosolid (BIO) and subsoil (SS) at different proportions (v:v): 100% SS - control; 20% BIO + 80% SS; 40% BIO + 60% SS; 60% BIO + 40% SS; 80% BIO + 20% SS; 100% BIO. Seedlings were cultivated in a greenhouse and evaluated according to the following variables: height of aerial part; root length; collar diameter; leaf number; dry mass of aerial part and of roots; total dry mass; chlorophyll content; height of aerial part/collar diameter rate; dry mass of aerial part/dry mass of roots rate; and Dickson Quality Index. There was a significant effect ($p < 0.05$) for all evaluated characteristics. The biosolid, combined with subsoil, may be used for 20% and 40% substrate composition, as it is potentially appropriate for jussara palm seedling production. Higher proportions were toxic to seedling growth.

Keywords: *Euterpe edulis*, Arecaceae, organic compost, sewage sludge, nursery, sustainability.

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INTRODUCTION

Palms, belonging to the Arecaceae family, besides having great ornamental potential, are among the most used plants in Brazilian landscapes (Cardoso et al., 2021). The use of jussara palm (*Euterpe edulis* Mart.) as an ornamental plant in the urban environment brings benefits related to conservation biology and consolidates its insertion as a native species. In this sense, its use is encouraged with the aim to build functional landscapes that benefit biodiversity conservation. Furthermore, it may become a strategy to fight its decline effects in natural areas once the uncontrolled extraction of its palm heart placed the species at serious extinction risk (Rocha, Manhani, Machado, & Soares, 2022).

However, the urban environment presents adverse conditions for plant appropriate development so the use of high-quality seedlings is fundamental as plants must endure unfavorable conditions after planting to develop and grow. Such seedling quality is directly related to the substrate type and composition (Carvalho et al., 2021; Souza et al., 2022). Although there are many available commercial substrates of high quality, it is possible to observe that seedling production in Brazil, especially at nurseries, is made using substrates coming from different raw materials which are usually prepared on site (Ferraz et al., 2022).

Nowadays, there is a gradual interest for several organic residue to be used as cultivation media and alternative sources of plant nutrients due to increasing awareness about environmental issues so more eco-friendly practices are adopted (Gashua et al., 2022; Mechergui et al., 2022). Among such residue, the biosolid is highlighted – it is a semi-solid sludge coming from wastewater treatment and it is frequently used as an agricultural fertilizer (Deus et al., 2020).

Biosolid is rich in organic matter and nutrients, and may be used as a conditioner of physical, chemical, and biological soil properties. It presents high ability to replace partially or totally the use of substrates and fertilizes by attending plant nutritional requirements (Abreu Júnior et al., 2017; Araújo et al., 2020; Djandja, Wang, Wang, Xu, & Duan, 2020) as it has high nutrient contents, especially nitrogen and phosphorus, so it may promote some savings with commercial substrates and chemical fertilizers, especially of phosphorus extracted from phosphate rocks as it is a non-renewable resource which is actually under decline (Antonkiewicz et al., 2020). Besides being a component of good characteristics, it also attends the sustainability basis as it is a renewable natural material. Furthermore, its use avoids either incineration or residue accumulation what contributes to the minimization of environmental impacts (Souza et al., 2022).

The biosolid use has shown positive results regarding seedling production of different palm species such as jussara (Silva et al., 2015), bottle palm (Berilli et al., 2018), king palm (Ferreira, Souza, Muniz, Ferreira, & Pivetta, 2021), and queen palm (Souza et al., 2022), as well as several tree species (Abreu Júnior et al., 2017; Caldeira, Favalessa, Delarmelina, Gonçalves, & Moura, 2018; Abreu, Alonso, Melo, Leles, & Santos2019; Carvalho et al., 2021). However, further studies are necessary to precisely define its proportion in substrate composition.

The objective of this study was to evaluate the initial growth and quality of *Euterpe edulis* seedlings cultivated in biosolid-based substrates.

MATERIAL AND METHODS

The experiment was conducted in a greenhouse coated with a 50% black shading net, in São Paulo State, Brazil (21°15’02’’ S, 48°16’47’’ W, at 600 m altitude).

According to the Köppen classification, the climate location is of Cwa type (humid subtropical, with dry winters and rainy summers). Minimum, mean, and maximum temperatures are, respectively, 19.8, 24.5, and 32.5 ºC.

The experimental design was entirely randomized with six treatments, four replications, and 10 plants per parcel. The treatments were composed by substrates prepared from subsoil (SS) and biosolid (BIO) at different proportions (v:v): 100% SS (control); 80% SS + 20% BIO; 60% SS + 40% BIO; 40% SS + 60% BIO; 20% SS + 80% BIO; 100% BIO. These proportions were defined according to Souza et al. (2022) when evaluating the initial growth of *Syagrus romanzoffiana* palm seedlings. Both biosolid and subsoil were sifted through a 3-mm sieve and homogenized afterwards according to the treatments.

The biosolid, already prepared for agricultural use, was provided by the Sewage Treatment Station located in Botucatu county, São Paulo State. It was classified as Class A according to Conama Resolution 375/2006 (Conselho Nacional do Meio Ambiente [CONAMA], 2006). Analysis of its chemical composition was performed at the Laboratory of Fertilizers and Residue belonging to the Center of Research & Development in Soils and Environmental Resources at the Agronomic Institute (IAC), located in Campinas county, São Paulo State, and presented the following results: organic carbon = 21.7% (m m^{-1}); total cobalt = <0.001²% (m m^{-1}); CEC = 500 mmol kg^{-1}; S = 3.3% (m m^{-1}); Fe = 4.4% (m m^{-1}); P = 3.4% P_2O_5 (m m^{-1}); Mg = 0.22% (m m^{-1}); N = 3.7% (m m^{-1}); pH ($CaCl_2$) = 5.3; K = 0.12% K_2O (m m^{-1}); C/N = 5.86; and heavy metals: As = 3.9 mg kg^{-1}; Cd = 1.6 mg kg^{-1}; Pb = 24.6 mg kg^{-1}; Cr = 96.8 mg kg^{-1}; Hg = <1.0 ^{2} mg kg^{-1}; Ni = 28.5 mg kg^{-1}; Se = <1.0^2 mg kg^{-1}; Ba = 296 mg kg^{-1}; and Na = 678 mg kg^{-1}.

The subsoil was collected at 20-40 cm depth, classified as a dystrophic Red Latosol (Oxisol) with a clayey texture (Santos et al., 2018), presenting the following chemical characteristics: P_{resin} = 1 mg dm^{-3}; K^+ = 7 mmol dm^{-3}; Ca^{2+} = 21 $mmol_c$ dm^{-3}; Mg^{2+} = 6 $mmol_c$ dm^{-3}; H + AL = 20 $mmol_c$ dm^{-3}; SB = 28 $mmol_c$ dm^{-3}; CEC = 48 $mmol_c$ dm^{-3}; V = 58%; OM = 9 g dm^{-3}; pH ($CaCl_2$) = 6.3.

Euterpe edulis fruits were harvested from matrices belonging to the palm collection cultivated at the Experimental Nursery of Ornamental and Forest Species of the College of Agrarian and Veterinarian Sciences of the State University of São Paulo (UNESP/FCAV). Fruit pulp was removed with the help of a steel 3-mm sieve. Seeds were then sown at 2-cm depth in a plastic box (17 × 22 × 50 cm) filled with expanded vermiculite of medium granulometry. Seedlings of 5 ± 1 cm height were transplanted to tubes of 280 cm³ volume capacity filled with the substrates described as the treatments, which were previously moistened to avoid seedling stress. Tubes were then suspended on metal mesh benches at 70 cm above ground.

Seedling irrigation was made by automatic microsprinklers every hour, along one minute; first watering happened at 6 am and, the last one, at 6 pm. Total daily flow reached 12.6 L. Substrates were maintained at 100% water retention capacity, which were determined before experiment beginning by the difference between mass of saturated substrate and of dry substrate, minus plant tube weight.

At 230 days after transplant, the following characteristics were evaluated: height of aerial part (cm), measured from the substrate level up to the last leaf tip; root length (cm), using a graduated ruler and considering the longest root; collar diameter (mm), determined at substrate level with the help of a digital caliper of 0.01 mm accuracy (Western® PRO DC-6); leaf number, considering those total expanded; leaf area (cm^2), using an electronic leaf area meter (Li-3100C, LI-COR®, Lincoln, Nebraska, USA); and chlorophyll content, measured by the ClorofiLOG equipment (model CFL1030, FALKER®). The absorption relations at different frequencies were used to determine the Falker Chlorophyll Index (FCI), which presents great correlations with laboratory measurements and considers the presence of both *a* and *b* chlorophyll types (information provided by the manufacturer).

Dry mass of aerial part (DMAP) and of roots (DMR) were obtained after drying plant material in a forced air circulation oven at 70 ºC up to constant weight, and then weighting it on a precision scale of 0.001 g accuracy (model AY220, SHIMADZU®). Total dry mass (TDM) was determined by summing DMAP and DMR, which results were expressed in g plant^{-1}.

From those values, the following seedling quality variables were calculated: height of aerial part/collar diameter rate (H/CD); dry mass of aerial part/dry mass of roots rate (DMAP/DMR); and Dickson Quality Index (DQI) by the formula:

$$DQI = \left[\frac{TDM}{\frac{H}{CD} + \frac{DMAP}{DMR}} \right].$$

Data were submitted to the residual normality and variance homogeneity tests and, when normal, also to the variance analysis (ANOVA). When significant, the polynomial regression analysis at 5% probability ($p < 0.05$) was performed, and those significant equations with higher determination coefficient (R^2) were chosen. Pearson correlation coefficient (r) ($P < 0.05$) was also calculated among all characteristics. The software R Studio® 4.0.1 (R Core Team, 2021) was used for the statistics.

RESULTS AND DISCUSSION

The biosolid in the substrate composition promoted a significant effect ($p < 0.05$) for all morphological and quality characteristics evaluated for *Euterpe edulis* seedlings.

For height of aerial part, there was a quadratic behavior up to 40% increase in the biosolid substrate composition, decreasing from that point (Figure 1A). The control treatment (100% SS) promoted the lowest mean, what may be associated to the lack of complementary fertilization that negatively affected seedling initial development once soils for seedling production used at nurseries usually present high bulk density, deficient drainage, and low fertility as they are extracted from the B horizon of weathered soils (Soldateli et al., 2020; Haase et al., 2021).

Some palm species showed similar results related to the use of biosolid-based substrates for seedling production, so high biosolid proportions promoted reduced height of aerial part (Silva et al., 2015; Ferreira et al., 2021; Souza et al., 2022). Furthermore, *Euterpe precatoria* palm seedlings produced in alternative substrates composed of organic residue from the Amazon agroindustry (açaí stones, acerola stones, and cupuaçu skin) also had minor values for such characteristic when compared to other substrates (Araújo et al., 2020). Therefore, increment in seedling height of different palm species is directly influenced by both substrate composition and pot size, as reported by Souza et al. (2022).

There was also a quadratic behavior for root length (Figure 1B), with no influence by the biosolid up to 40% proportion, so increments happened from 60% and 80% biosolid in the substrate. However, for other palm species, such as *Archontophoenix cunninghamiana* (Ferreira et al., 2021) and *Syagrus romanzoffiana* (Souza et al., 2022), there were no significant differences for this characteristic from biosolid use in substrate composition.

Regarding the collar diameter, the regression analysis indicated a negative linear behavior (Figure 1C). Silva et al. (2015) found similar results when cultivating *Euterpe* *edulis* palm seedlings in substrates combining biosolid and residual organic composts from the palm heart agroindustry. Also, Berilli et al. (2018) reported the same when using different proportions of dehydrated tannery sludge added to a commercial substrate to produce *Hyophorbe lagenicaulis* palm seedlings. However, Souza et al. (2022), when cultivating seedlings of *Syagrus romanzoffiana* palm, noted a quadratic behavior with a collar diameter increment up to 63.7% biosolid proportion in a dystrophic Red Latosol (Oxisol).

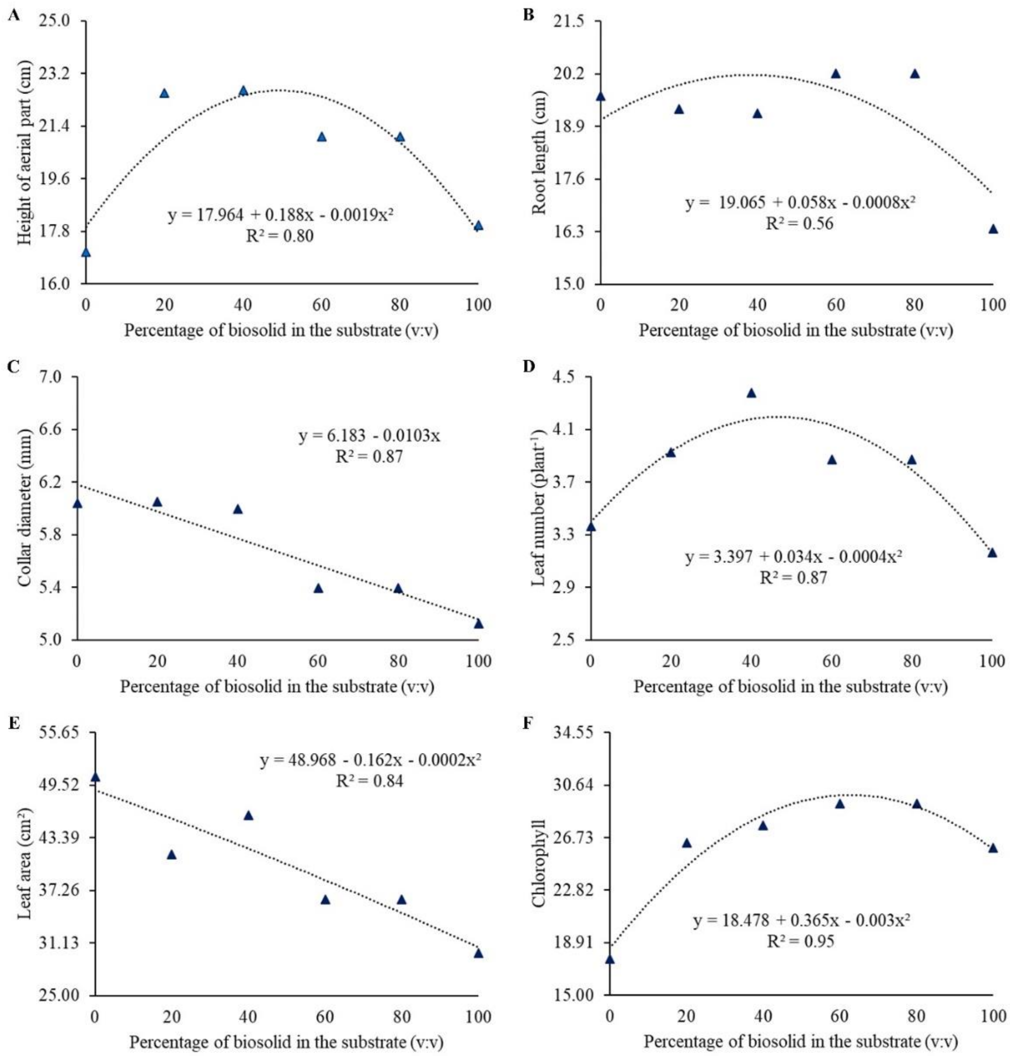

Figure 1. Height of aerial part (A), root length (B), collar diameter (C), leaf number (D), leaf area (E), and chlorophyll content (D) of *Euterpe edulis* seedlings cultivated in substrates composed of biosolid proportions. F test: significant at 5% probability.

The proportion of up to 40% biosolid promoted an increase in leaf number (Figure 1D). For leaf area (Figure 1E), there was a negative linear behavior for all biosolid proportions. The 100% biosolid treatment was inferior than the others for both characteristics. Such results are indicators that great biosolid amounts may cause toxic effects in new leaf emission, what consequently influences leaf area reduction for plants of this species. Therefore, leaf area is an important variable to be considered as an indicator of seedling quality as it directly affects photosynthesis and transpiration being both important metabolic processes related to plant growth and development (Vieira, Gomes, Brown, Constantino, & Zanette, 2019).

For chlorophyll content (Figure 1F), all biosolid proportions in the substrate promoted positive results, so there was a quadratic behavior with an increment up to 80% biosolid. Similar results were obtained for palm seedlings of *Archontophoenix cunninghamiana* (Ferreira et al., 2021) and *Syagrus romanzoffiana* (Souza et al., 2022) with a significant chlorophyll increase according to the biosolid proportion rise. These results are indicators of a direct relation between chlorophyll content and nitrogen, which is present in greater concentration in the biosolid (CONAMA, 2006). Therefore, nitrogen promotes an increment in leaf chlorophyll content, increasing plant capacity to absorb light, resulting in major carbon fixation rate, thus rising carbohydrate production that acts as a source for energy and maintenance of plant growth rate (Bassi, Menossi, & Mattiello, 2018).

For height of aerial part/collar diameter rate, there was an increment according to increasing biosolid proportions in the substrate, with highest mean obtained from the 100% biosolid treatment (Figure 2A). Such relation comprises a non-destructive method to evaluate balance between seedling growth and quality (Grossnickle & Macdonald, 2018; Schwartz, Rocha, Almeida, Dionisio, & Corvera, 2022) so there is a need for an appropriate seedling development to decrease plant fall risks after plating in the field (Dionísio, Schwartz, Almeida, Rocha, & Corvera, 2021). Ferreira et al. (2021) verified greatest mean increment for this characteristic when palm seedlings of *Archontophoenix cunninghamiana* were cultivated in 55% biosolid proportion in the commercial substrate Carolina Soil®.

Treatments influenced the dry mass of aerial part (DMAP), so greatest accumulation was promoted by the 40% biosolid proportion (0.994 g plant^{-1}) (Figure 2B). For dry mass of roots (DMR), the regression analysis showed a negative linear behavior with a decrease from the control treatment (100% subsoil), reaching from this treatment the greatest mean accumulation of 0.445 g plant^{-1} (Figure 2C). For total dry mass (TDM), the greatest mean accumulation (1.415 g plant^{-1}) was promoted from the 40% biosolid proportion (Figure 2D). Therefore, proportions above 40% biosolid impaired dry mass accumulation in *Euterpe edulis* seedlings. Similar results were described by Ferreira et al. (2021) and Souza et al. (2022), as the addition in biosolid proportions in the substrate reduced dry mass accumulation for both *Archontophoenix cunninghamiana* and *Syagrus romanzoffiana* palms, respectively.

For *Euterpe oleracea* palm, the organic matter increment in the substrate promoted minor dry mass of roots but greater dry mass production of aerial part (Silva, Smiderle, Oliveira, & Silva, 2017). For the cultivation of *Euterpe precatoria* palm seedlings using agroindustry residue from fruit trees, Araújo et al. (2020) found that the substrate composed of Brazil nut shells + acerola stone (1:1 v/v) promoted the greatest dry mass accumulation, resulting in seedlings of better quality.

There was an increment for dry mass of aerial part/dry mass of roots rate (DMAP/DMR) according to the increasing biosolid proportions in the substrate, so 60% and 80% proportions promoted an equal value (2.6), superior to the others (Figure 2E). A similar result was described by Ferreira et al. (2021) when evaluating the seedling initial growth of *Archontophoenix cunninghamiana* cultivated in biosolid-based substrates combined with the commercial Carolina Soil®.

For Dickson Quality Index (DQI), there was a negative linear behavior with a decrease from the control treatment (100% subsoil) (Figure 2F). DQI is considered a good indicator of seedling quality as it is a weighted morphological measurement that considers robustness and balance of seedling dry mass distribution (Abreu et al., 2019), so DQI values may vary according to the species, seedling age, and treatment applied (Araújo et al., 2020). Furthermore, seedling quality is affected by nutrient availability in the substrate (Silva, Marco, Welter, Viel, & Ros, 2020b).

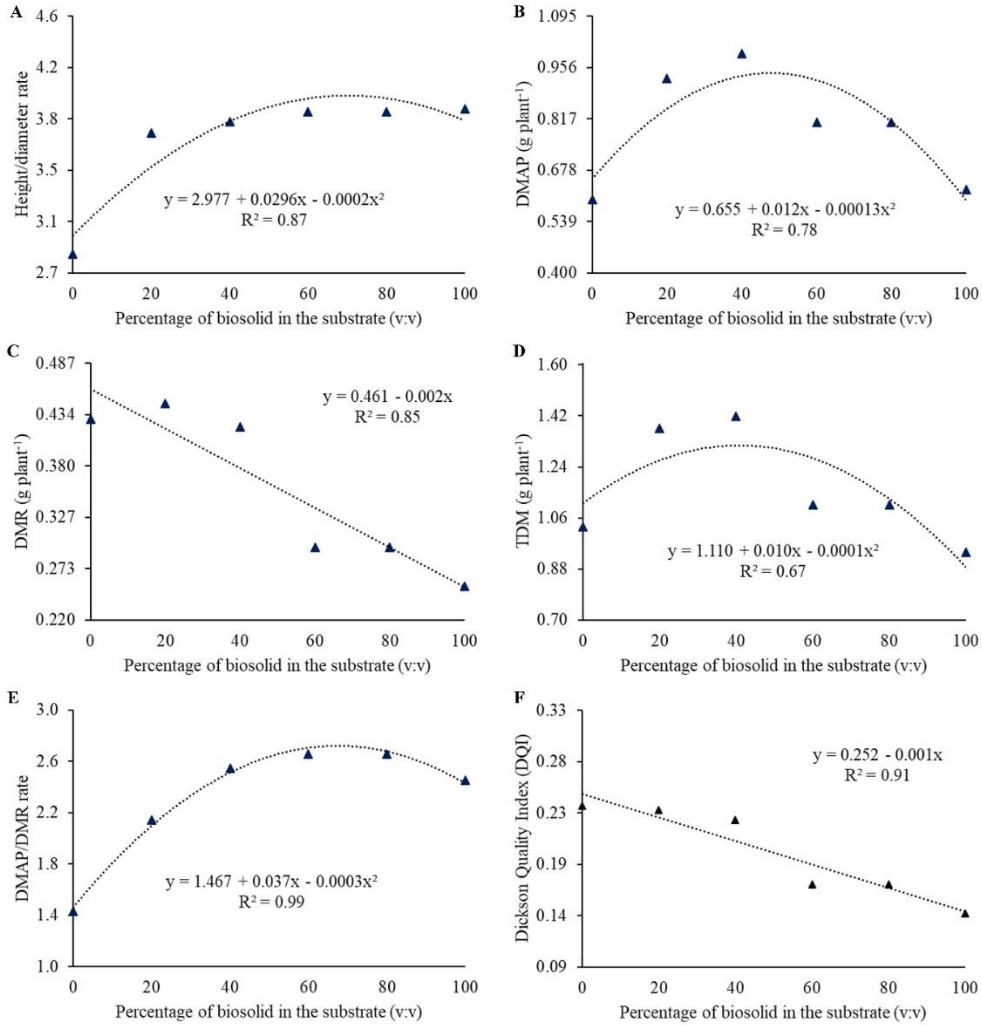

Figure 2. Height of aerial part/collar diameter rate (A), dry mass of aerial part – DMAP (B), dry mass of roots – DMR (C), total dry mass – TDM (D), dry mass of aerial part/dry mass of roots rate – DMAP/DMR (E), and Dickson Quality Index – DQI (F) of *Euterpe edulis* seedlings cultivated in substrates composed of biosolid proportions. F test: significant at 5% probability.

There are different DQI values for palm seedlings (Silva et al., 2015; Silva et al., 2017; Almeida et al., 2018; Oliveira, Carneiro, Pereira, Andrade, & Silva-Matos, 2019; Araújo et al., 2020; Bezerra, Andrade Neto, Lunz, Araújo, & Araújo, 2020; Ferreira et al., 2021; Souza et al., 2022), so there is no a determined mean value for such characteristic yet, what indicates the need for further studies so palm seedlings of high quality may be considered (Araújo et al., 2020; Souza et al., 2022).

Even with DQI wide use for seedling quality evaluation, it is essential to relate it to the others growth indicators with the aim to define more practical and precise procedures to evaluate quality of nursery seedlings (Avelino, Schilling,Dalmolin, Santos, & Mielke, 2021), once quality standards vary with species, and among species and cultivation locations, so such evaluation assumes specific parameters and definition criteria (Matos, Oliveira, Medeiros, & Novaes, 2022). In this sense, Silva et al. (2015) consider the variables height of aerial part and collar diameter the main characteristics used to determine seedling quality of *Euterpe edulis* palm. These are of easy measurement, what is an advantage, so there is no need for destructive analysis (Grossnickle & Macdonald, 2018; Silva et al., 2020a).

According to the Pearson correlation coefficient, there were few positive significant correlations among characteristics of growth, biomass allocation, and quality of *Euterpe edulis* seedlings (Figure 3). Height of aerial part and Dickson Quality Index were the characteristics that most positively correlated with the others. For height of aerial part, there was correlation with leaf number, chlorophyll content, dry mass of aerial part, height of aerial part/collar diameter rate, and dry mass of aerial part/dry mass of roots rate.

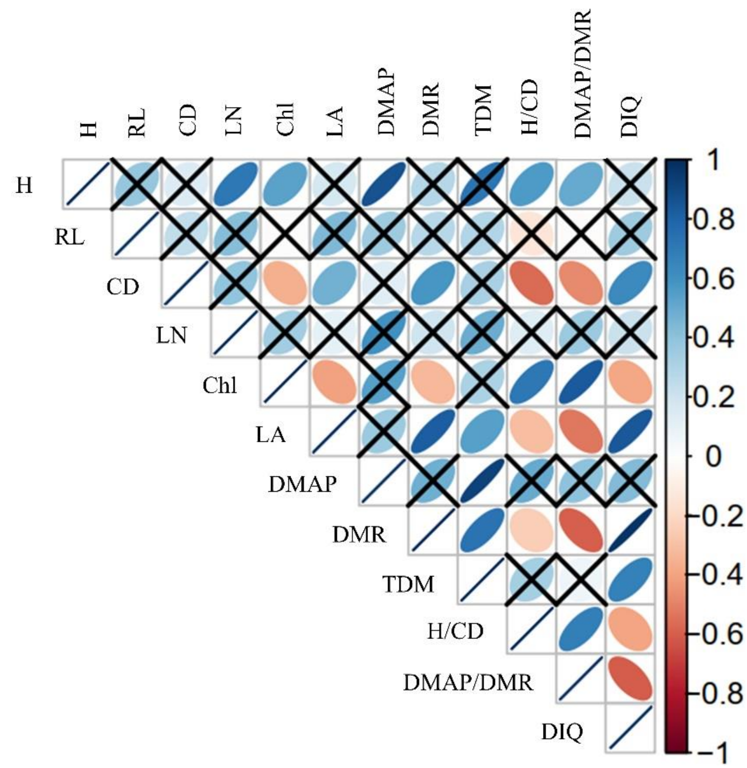

Figure 3. Heatmap showing Pearson correlations among the studied variables of *Euterpe edulis* seedlings cultivated in substrates composed of biosolid proportions. Significant at 5% probability. **X** over colors indicates there is no significant correlation between variables. Where: H = height of aerial part; RL = root length; CD = collar diameter; LN = leaf number; Chl = chlorophyll content; LA = leaf area; DMAP = dry mass of aerial part; DMR = dry mass of roots; TDM = total dry mass; H/CD = height of aerial part/collar diameter rate; DMAP/DMR = dry mass of aerial part/dry mass of roots rate; DQI = Dickson Quality Index.

For Dickson Quality Index, there was a positive correlation with collar diameter, leaf area, dry mass of roots, and total dry mass; on the other hand, there was a negative significant correlation with chlorophyll content, height of aerial part/collar diameter rate, and dry mass of aerial part/dry mass of roots rate. Avelino et al. (2021) report that a negative correlation between DMAP/DMR rate and DQI may be explained because such variable is a denominator of the DQI formula. Studies on the correlation among characteristics of seedling growth for palm species are still incipient, especially when a biosolid-based compost is used in substrate composition as highlighted by Souza et al. (2022) when working with seedling production of *Syagrus romanzoffiana* palm.

CONCLUSIONS

Biosolid at 20% and 40% proportions in the substrate composition was efficient for *Euterpe edulis* seedling production as it promoted best responses for most of characteristics related to morphological parameters and quality.

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