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Physical-Chemical characteristics of alternative substrates and fertilization on quality of *Spondias macrocarpa* seedlings

Oscar José Smiderle[1], Aline das Graças Souza[2]*, Nilmar Diogo dos Reis[3], Jaqueline Severino da Costa[3], Gabriel Souza Pereira[3]

[1]Brazilian Agricultural Research Corporation, Boa Vista, Brazil
[2]University Campus, of Ingá, Mandaguaçu, Brazil
[3]Federal University of Lavras, Lavras, Brazil
*Corresponding author, e-mail: alineufla@hotmail.com

Abstract

The objectives were to determine the physical and chemical characteristics of different substrates, and assess the influence of different substrates, with and without the addition of controlled-release fertilizer, on the growth and morphological quality of taperebá (*Spondias macrocarpa*) seedlings. The experimental design adopted was a 2 x 6 factorial scheme, with the presence and absence of 8.0 g L^{-1} of encapsulated controlled-release fertilizer and six substrates [Sub1= soil; Sub2= soil + carbonized rice husk (2:1 v/v); Sub3= soil + organic compos (2:1 v/v); Sub4= soil + carbonized rice husk + organic compost (1:1:1); Sub5= soil + carbonized rice husk + organic compost (2:1:1); Sub 6= soil + carbonized rice husk + organic compost (2:2:1)], with five replicates, composed of 10 seedlings (one in each container). Formulations of substrates containing soil + carbonized rice husk + organic compost (1:1:1) and soil + organic compost (2:1 v/v) had total porosity ranging from 0.88 to 0.91 m^3 m^{-3}, aeration space from 0.33 to 0.35 m^3 m^{-3} and available water from 0.27 to 0.29 m^3 m^{-3}, hence being suitable to obtain taperebá seedlings with superior quality. The substrate Cerrado soil (Sub1) is not viable for the production of taperebá seedlings, since it has acidic pH, an undesirable chemical characteristic for the cultivation of this species. Incorporation of controlled-release fertilizer into the substrates used in the present study led to better morphological characteristics, so it is indicated as an input for fertilization in the initial stage of growth of taperebá seedlings.

Keywords: Controlled-release fertilizer, organic compost, porosity, rice husk, taperebá

Introduction

The genus *Spondias*, belonging to the Anacardiaceae family, has some fruit species of good acceptance by consumers. In the Northern region of Brazil, yellow mombin (*Spondias mombin* L.) and taperebá (*Spondias macrocarpa* Engl.) are highly consumed in human diets (Novelli et al., 2017).

Additionally, in recent years there has been increased interest in and demand for seedlings of this species (Bastos et al., 2014) by producers and companies, due to the economic return and ecological awareness. However, for a successful implementation of commercial orchards and reforestation, it is necessary to use seedlings with fast growth and high quality during the nursery stage (Menegatti et al., 2020), and these attributes depend, among other factors, on a quality substrate.

Among the properties of a substrate, physical properties are the most important, since the others can be changed (Gayosso-Rodríguez et al., 2018). Therefore, it is essential that a substrate has good porosity and aeration space, favoring gas exchange and water holding capacity; in addition, part of this water should be available to plants, and the substrate must also have adequate density to facilitate the management of containers (Smiderle et al., 2017).

Thus, in order to optimize the initial stage of plant growth, that is, reduce the time between germination of seeds and obtaining of seedlings that are homogeneous and of commercial standard (Smiderle et al., 2021a), it is suggested that, in addition to cultivation in a protected environment, fertilizers should be incorporated into the substrate (Souza et al., 2020a).

In the production of native seedlings in the Northern region of Brazil, enriching the substrate with fertilizers is strongly recommended (Smiderle et al., 2020a; Smiderle et al., 2020b; Souza et al., 2018; Smiderle et al.,

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2021b), since the substrate alone does not usually have sufficient amount of nutrients for the complete growth of the plant (Smiderle et al., 2020b).

Among the available fertilizers, controlled-release fertilizers (CRF) stand out, characterized by promoting the slow release and absorption of the ideal amount of nutrients throughout the growth period of the seedlings, minimizing the risks of deficiencies (Menegatti et al., 2020) and allowing the formation of vigorous seedlings in shorter time, which consequently allows reduction in production costs, as they reduce the period of permanence of seedlings in the nursery (Souza et al., 2020b).

Therefore, this study aimed to determine physical and chemical characteristics of different substrates and also to assess the influence of these substrates, with and without addition of controlled-release fertilizer, on the growth and morphological quality of taperebá (*Spondias macrocarpa*) seedlings.

Material and Methods

The study was conducted in the seedling nursery of the forestry sector of Embrapa Roraima. The species used in the present research was taperebá (*Spondias macrocarpa*), whose seeds, used for seedling formation, were collected from plants at the Embrapa Roraima headquarters, located in the municipality of Boa Vista - RR.

After preparation, samples were collected from the substrates for Chemical and physical characterization. The substrates were composed of soil (Sub1); soil + carbonized rice husk (2:1 v/v) (Sub2); soil + organic compost (2:1 v/v) (Sub3); soil + carbonized rice husk + organic compost (1:1:1) (Sub4); soil + carbonized rice husk + organic compost (2:1:1) (Sub5); and soil + carbonized rice husk + organic compost (2:2:1) (Sub6).

Dry density (DD) and wet density (WD) were determined using the graduated cylinder method described by Rober & Schaller (1985), with a 250-cm^3 graduated cylinder.

To obtain the dry weight, the samples were dried at 65 °C, until reaching constant weight. Particle density was determined by the volumetric flask method, according to the methodology described by Rowel (1994), using 30 cm^3 of substrate and 50 cm^3 of boiling water, subsequently completing the volume to 250 cm^3.

Samples of the substrates were put into rings with diameter and height of 40 and 50 mm, respectively. After saturation with distilled water for 24 h, the rings containing substrates were placed on funnels, with a porous plate close to the suction unit. Then, the rings were subjected to tensions of 1 and 10 kPa. At saturation, that is, at tension of 0 kPa, and at tensions of 1 and 10 kPa, the wet weight and dry weight of the set (ring + substrate) were determined on a semi-analytical scale.

The tensions of 0, 1 and 10 kPa were used to calculate total porosity (TP), available water (AW), remaining water (RW) and aeration space (AS) according to De Boodt & Verdonck (1974).

After the germination period, seedlings before producing one pair of leaves were selected and transplanted to 1.8-L polyethylene bags filled with each mixture. The plants were conveniently spaced and kept in a nursery with 50% shading, under sprinkler irrigation scheduled every four hours during the day and each irrigation event lasted five minutes.

The illuminance promoted by the 50% shade cover was determined by sampling, with measurement during the first three days of each month. The measurement was performed at six times during the day (8h00min; 10h00min; 12h00min; 14h00min; 16h00min; 18h00min).

The transparency promoted by the cover was characterized based on the average of the evaluations at the end of 240 days after transplanting the seedlings. The average temperature during the experimental period was 25 ± 5 °C and the relative humidity ranged from 60% to 70%.

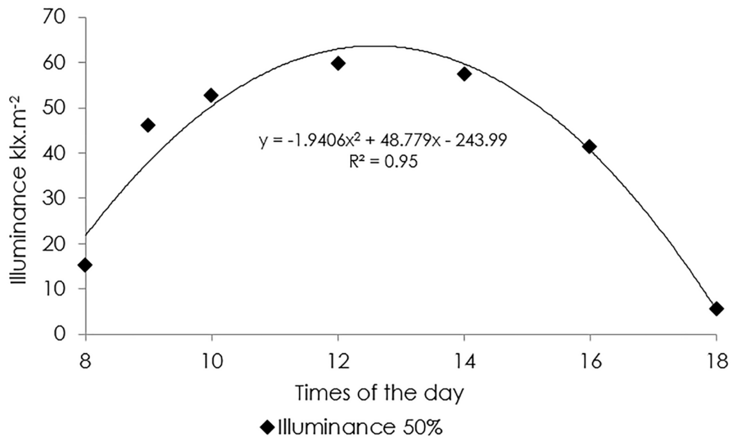

Figure 1. Illuminance recorded in the environment during the total period of production of taperebá (*Spondias macrocarpa*) seedlings.

The results of the chemical analysis Chemical and physical (Tables 1 and 2) of the substrates were obtained using the methodology described by the Official Network of Soil and Plant Tissue Analysis Laboratories of RS and SC - ROLAS (SBcS/cQFS, 2016).

Table 1. Chemical composition of the substrates formulated for the production of taperebá seedlings (Boa Vista, RR, 2021).

Treat	pH	K	P	Ca	Mg	Al	H+Al	CEC	SB	OM	Zn	Fe	Mn	Cu	B	S
		--------cmol/dm³-------								dag/kg	------------------mg/dm³-------------------					
Sub1*	4.6	0.28	0.80	10.4	0.5	0.0	1.0	12.18	11.18	2.6	26.7	40.4	139.0	1.1	0.6	18.8
Sub2	5.1	0.20	0.98	13.8	7.4	0.0	1.9	23.30	21.40	3.0	26.9	62.3	160.2	0.6	0.7	49.1
Sub3	5.8	0.30	1.42	10.2	5.0	0.0	1.7	17.20	15.50	4.2	24.4	13.5	90.9	0.6	0.8	50.7
Sub4	5.5	0.31	1.68	10.0	2.9	0.0	1.3	14.51	13.21	4.0	23.5	20.3	107.0	0.8	0.8	34.9
Sub5	6.2	0.24	0.92	9.9	1.6	0.0	1.2	11.74	11.74	3.8	24.3	27.9	111.2	1.0	0.7	25.9
Sub6	6.7	0.31	0.87	11.0	0.7	0.0	1.1	13.31	12.01	3.5	16.5	13.5	88.6	0.3	0.5	17.2

*(Sub1) soil; (Sub2) soil + carbonized rice husk (2:1 v/v); (Sub3) soil + organic compost (2:1 v/v); (Sub4) soil + carbonized rice husk + organic compost (1:1:1); (Sub5) soil + carbonized rice husk + organic compost (2:1:1); (Sub6) soil + carbonized rice husk + organic compost (2:2:1)

The experimental design adopted was a 2 x 6 factorial scheme, corresponding to the presence and absence of 8.0 g L^{-1} of encapsulated controlled-release fertilizer (Forth Coth®), in the NPK 18-05-09 formulation and six substrates [(Sub1) soil; (Sub2) soil + carbonized rice husk (2:1 v/v); (Sub3) soil + organic compost (2:1 v/v); (Sub4) soil + carbonized rice husk + organic compost (1:1:1); (Sub5) soil + carbonized rice husk + organic compost (2:1:1); (Sub6) soil + carbonized rice husk + organic compost (2:2:1)], with five replicates, each replicate consisting of 10 seedlings (one in each container).

Every 30 days, the taperebá seedlings were subjected to measurements of height (using millimeter ruler) and stem diameter (10 cm above the substrate with a digital caliper). At 210 DAT, taperebá seedlings were evaluated for root volume (Vroot, in cm^3), measured using the method described by Basso (1999). Then, the plants were divided into roots, stem and leaves, and dried in a forced air circulation oven, at a temperature of 65 °C ± 5, until reaching constant weight, for individual determination of the dry weight (g $plant^{-1}$) of the different parts of the plant: leaves (LDW), stem (StDW), root (RDW), and the sum of these parts, total dry weight (TDW). Dickson quality index was determined using the formula DQI=TDW/[(H/SD) + (SDW/RDW)], according to Dickson et al. (1960).

Possible differences between treatments were verified by analysis of variance (ANOVA). All variables were subjected to comparison of means by Tukey test, at 5% probability level, and quantitative variables were subjected to regression analysis in order to verify the growth response of the plants as a function of time. Data analysis was performed using the statistical package Sisvar (Ferreira, 2014). In order to obtain Pearson's correlation between the physical properties of the substrates, analyses were conducted using R software version 3.6.1 (R Core Team, 2019).

Results and Discussion

The analysis of variance revealed non-significant effects of the interaction between substrates (S), evaluation periods (P) and controlled-release fertilizer (F) on shoot height (H) and stem diameter (SD) (Table 3). It also showed a significant effect of the individually factors (S), (P) and (F) on stem diameter (SD) and shoot height (H), suggesting that substrates and evaluation periods (monthly) with fertilizer application (F) may exert direct influence on the biomass accumulation of taperebá seedlings.

Table 3. Summary of the variance analysis for growth variables: stem diameter (SD), shoot height (H) as a function of the sources of variation: Substrates (S), Evaluation periods (P), Fertilizer (F) and their interactions, until 210 days after transplantation.

		Mean square	
Sources of variation		SD (mm)	H (cm)
Substrate (S)	5	302.656**	27877.887**
Evaluation Period (P)	7	302.656**	41216.750**
Fertilizer (F)	1	262.902**	27489.585**
S x P	35	11.412**	1413.292**
S x F	5	51.344**	1112.952**
P x F	7	35.094**	2587.546**
S x P x F	35	2.090^{ns}	80.900^{ns}
Residual	768	2.547	95.196
Mean		5.98	35.81
CV (%)		11.39	12.98

At the end of the experiment (210 DAT), the substrate composed of soil + carbonized rice husk + organic compost (1:1:1) with the addition of controlled-release fertilizer (CRF) (Sub4) promoted higher means of height of taperebá seedlings, reaching 95.6 cm (Figure 2 A).

When the same substrate (Sub4) was used without the addition of controlled-release fertilizer in the cultivation of taperebá seedlings, there was a difference in height of 25% and with a delay of 90 days (Figure 2 A and B) in obtaining the seedlings suitable for the field, justifying the importance of the application of nutrients via controlled-release fertilizer for the production of taperebá seedlings.

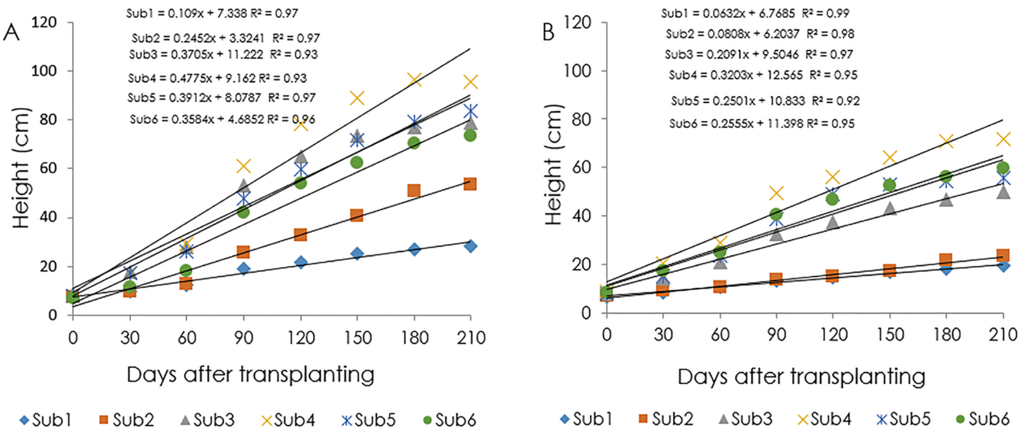

Figure 2. Average height of taperebá seedlings in six substrates (Sub1) soil; (Sub2) soil + carbonized rice husk (2:1 v/v); (Sub3) soil + organic compost (2:1 v/v); (Sub4) soil + carbonized rice husk + organic compost (1:1:1); (Sub5) soil + carbonized rice husk + organic compost (2:1:1); (Sub6) soil + carbonized rice husk + organic compost (2:2:1) with (A) and without (B) addition of controlled-release fertilizer until 210 DAT.

In the production of seedlings of native species in northern Brazil, as in the state of Roraima, it is interesting that the seedlings have rapid growth, both in height and in stem diameter thickness, because the latter variable is determinant for the seedling to be suitable for grafting, as well as for the field (Smiderle et al., 2021). According to Smiderle et al. (2020), stem diameter should be between 5.0 and 10 mm. The average stem diameter of the taperebá seedlings varied between 4.0 and 13.30 mm, with and without the addition of controlled-release fertilizer, respectively, in the different substrates (Figure 3 A and B). Similar to the results obtained for height, the lowest mean of stem diameter was observed in seedlings produced without the addition of controlled-release fertilizer (Figure 3 A and B). It is worth pointing out that, even with the addition of controlled-release fertilizer, the use of Sub1 (soil) as substrate led to the lowest stem diameter (6.5 mm) of taperebá seedlings, compared to the other substrates that received CRF (Figure 3 A). Similar behavior was recorded in taperebá seedlings cultivated without the addition of CRF in Sub1 (soil), followed by a 70% reduction for the best substrate (Sub4) with the addition of CRF.

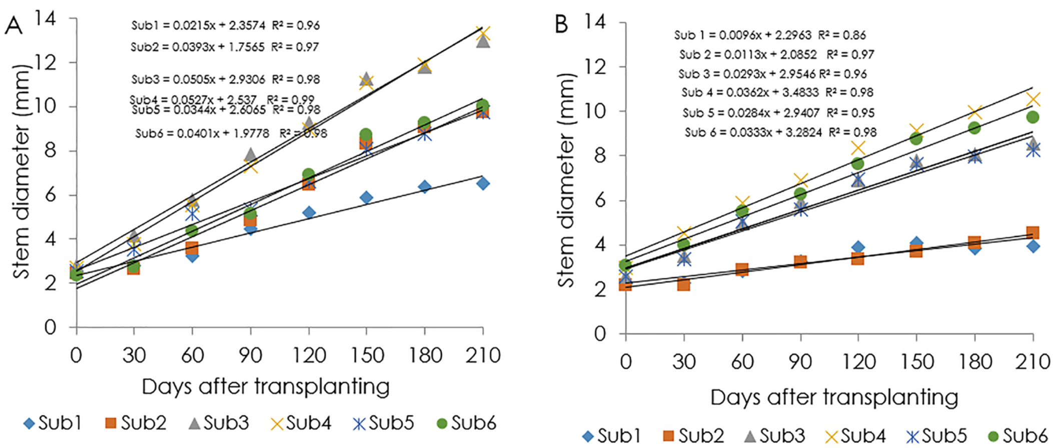

Figure 3. Average stem diameter of taperebá seedlings in substrates (Sub1) soil; (Sub2) soil + carbonized rice husk (2:1 v/v); (Sub3) soil + organic compost (2:1 v/v); (Sub4) soil + carbonized rice husk + organic compost (1:1:1); (Sub5) soil + carbonized rice husk + organic compost (2:1:1); (Sub6) soil + carbonized rice husk + organic compost (2:2:1) with (A) and without (B) addition of controlled-release fertilizer until 210 DAT.

The analysis of variance revealed significant effects (p<0.01) of the interaction between substrate (S) and fertilizer (F) on stem diameter, shoot dry weight (SDW), root dry weight (RDW), total dry weight (TDW) and Dickson quality index (DQI) (Table 4), suggesting that the application of different combinations of S and F may exert direct influence on plant growth, as well as on biomass accumulation. There were significant effects of the individual factors S and F on all variables considered. It is worth mentioning that, at the end of the experiment (210 DAT) the survival rate of taperebá plants was 100% for all treatments.

Table 4. Summary of the analysis of variance for growth variables: stem diameter (SD, mm), height (H, cm), shoot dry weight (SDW, g/plant), root dry weight (RDW, g/plant), total dry weight (TDW, g/plant), root volume (Vroot) and Dickson quality index (DQI) of taperebá seedlings, as a function of the sources of variation: Substrates (S), Fertilizer (F) and their interactions at 210 days after transplantation.

		Mean square						
Sources of variation		SD	H	SDM	RDM	TDM	Vroot	DQI
Substrate (S)	5	123.691**	9189.383**	1579.069**	3123.080**	9072.31**	38073.984**	158.576**
Fertilizer (F)	1	210.757**	14231.067**	2712.714**	5012.433**	15100.052**	89916.796**	293.733**
S x F	5	12.682**	201.457^{ns}	200.331**	445.628**	977.636**	2147.109^{ns}	41.254**
Residual	96	3.908	115.437	57.967	105.254	254.600	1584.765	10.973
Mean		9.34	59.58	19.61	29.06	44.27	156.35	6.64
CV (%)		21.16	18.03	15.21	17.30	16.68	12.02	20.22

** and ^{ns}: significant and not significant respectively, at 1% probability level.

Regarding the parameters H and SD, taperebá seedlings at 210 DAT showed better results in sub3 and sub4, which had higher values of total porosity (Table 5), with means of 0.91 and 0.88 m^3 m^{-3}, respectively. According to Mejía et al. (2018), porosity is the volume of the substrate not occupied by the solid fraction. Thus, porosity is one of the most important characteristics of the substrate, as the pores serve for water storage, as well as gas exchange, hence being important for the development of plants and responsible for supplying water and oxygen to the root system.

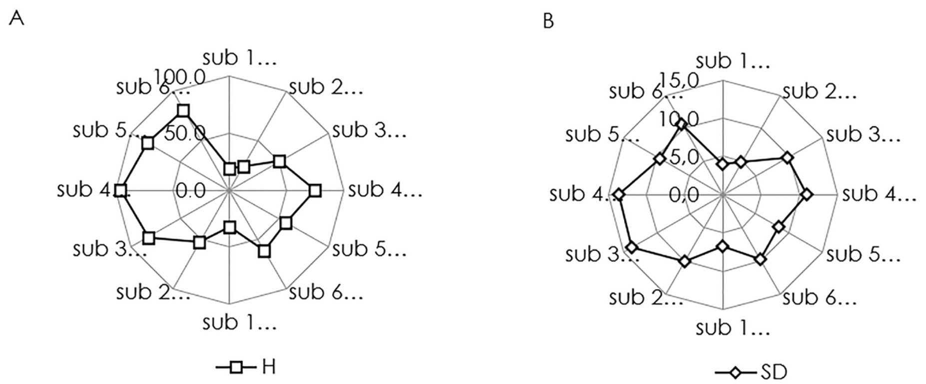

Figure 4. Average values of height and stem diameter of taperebá seedlings in six substrates (Sub1) soil; (Sub2) soil + carbonized rice husk (2:1 v/v); (Sub3) soil + organic compost (2:1 v/v); (Sub4) soil + carbonized rice husk + organic compost (1:1:1); (Sub5) soil + carbonized rice husk + organic compost (2:1:1); (Sub6) soil + carbonized rice husk + organic compost (2:2:1) with (A) and without (B) addition of controlled-release fertilizer at 210 DAT.

According to Smiderle et al. (2021), these values of stem diameter could be increased with top-dressing fertilization applied during the production of seedlings in nursery. Similarly, this fact occurred in the present study with the stem diameter of taperebá seedlings with the addition of the controlled-release fertilizer (Figure 4 B).

The average values of stem diameter at 210 DAT (Figure 4 A and B) were grouped into different classes, that is, Sub1 and Sub2 without the addition of CRF with the lowest values, from 4.0 to 4.5 mm, the second class encompassing intermediate values with the substrates sub3 (8.5 mm), Sub4 (10.5 mm), Sub5 (8.3 mm), Sub6 (9.7 mm) without addition of CRF and Sub2 (9.7 mm) and Sub5 (9.7 mm) with addition of CRF, and the third class comprising the substrates Sub3 (13.0 mm) and Sub4 (13.5 mm) with addition of CRF, which had the highest values (Figure 4 A).

All substrates included in the class of lowest values had in their composition the soil in Sub1 and soil + carbonized rice husk (2:1 v/v) in Sub 2 without the addition of CRF. The occurrence of lower values of stem diameter in substrates containing soil and/or soil + carbonized rice husk (2:1 v/v) may be associated with the increase in particle density (Table 5), Sub1 (1715.6 kg m^{-3}) and Sub2 (1080.1 kg m^{-3}).

According to Elsacker et al. (2019), when particle density increases, there is a restriction in the growth of the roots of cashew plants. This result was also observed in the root volume of taperebá seedlings (Figure 5).

Table 5. Particle density (PD), dry density (DD), wet density (WD), available water (AW), remaining water (RW), aeration space (AS) and total porosity (TP) in six substrates.

Substrate	PD	DD	WD	AW	RW	AS	TP
		kg m^{-3}			m^3 m^{-3}		
Sub 1*	1715.6 a	149.6 c	530.4 c	0.11 b	0.35 a	0.19 b	0.65 ab
Sub 2	1080.1 b	642.1 b	642.1 bc	0.10 b	0.17 b	0.22 b	0.49 b
Sub 3	438.2 d	532.6 b	1000.6 a	0.29 a	0.26 ab	0.33 a	0.88 a
Sub 4	571.2 d	558.6 b	1018.6 a	0.27 a	0.29 ab	0.35 a	0.91 a
Sub 5	658.0 cd	891.9 a	891.9 b	0.13 b	0.38 a	0.18 b	0.69 ab
Sub 6	830.4 c	206.6 c	490.2 c	0.16 b	0.35 a	0.17 b	0.68 ab
CV%	12.1	14.5	16.3	13.7	13.4	12.91	11.97

In the column, means followed by the same letter do not differ from each other by Tukey test (p≤1%). *(Sub1) soil; (Sub2) soil + carbonized rice husk (2:1 v/v); (Sub3) soil + organic compost (2:1 v/v); (Sub4) soil + carbonized rice husk + organic compost (1:1:1); (Sub5) soil + carbonized rice husk + organic compost (2:1:1); (Sub6) soil + carbonized rice husk + organic compost (2:2:1).

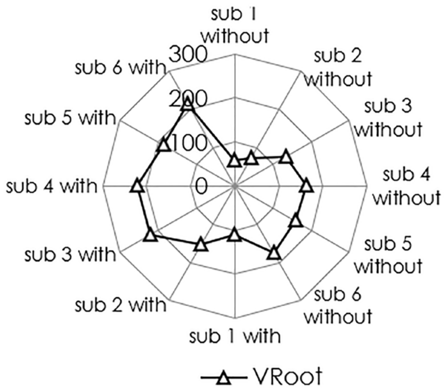

Figure 5. Average values of root volume of taperebá seedlings in different substrates (Sub1) soil; (Sub2) soil + carbonized rice husk (2:1 v/v); (Sub3) soil + organic compost (2:1 v/v); (Sub4) soil + carbonized rice husk + organic compost (1:1:1); (Sub5) soil + carbonized rice husk + organic compost (2:1:1); (Sub6) soil + carbonized rice husk + organic compost (2:2:1) with (A) and without (B) addition of controlled-release fertilizer to 210 DAT.

For substrates of fruit crops, the ideal aeration space (AS) proposed by Penningsfeld (1983) is 0.33 m^3 m^{-3}, a value similar to that found in the present study for taperebá seedlings in Sub3 and Sub4. The results obtained reinforce, once again, the importance of knowing the physical characteristics of substrates close to that indicated for certain plant species and that these properties vary depending on the composition, granulometry and compaction of the substrate (Elsacker et al., 2019).

However, it is only by evaluating the initial growth of plants that one can infer whether the physical properties of different substrates are adequate or not. Also, in this aspect, it should be considered that it is difficult to obtain a substrate that meets all the ideal physical characteristics for a given plant species, and one should select the most important characteristics of each substrate and formulate a substrate that is capable of promoting better morphological and physiological characteristics for the growth of the plants under study.

It is worth pointing out that the substrates Sub3 and Sub4 used in the present study promoted adequate initial growth and greater gain in the biomass of taperebá seedlings, hence being promising substrates for the production of seedlings of this species.

The superiority of root dry weight in Sub3 and Sub4 suggests greater capacity of seedlings to absorb and transport water and nutrients from roots to shoots, as well as to withstand any limitations and adversities to which they may be subjected in post-planting, making this attribute essential in the recommendation of vigorous seedlings for a wide range of field conditions (Grossnickle & Macdonald, 2018).

By analyzing the averages of shoot dry weight, total dry weight and Dickson quality index, it is possible to observe that the best results were obtained in seedlings subjected to Sub3 and Sub4 with addition of CRF, while Sub1 led to the lowest average values (Figure 4 A, B, C and D). It is important to highlight that the Sub1 substrate is composed only of Cerrado soil, a naturally acidic soil (Table 1), which may explain the low growth and lower biomass of the plants obtained in this substrate.

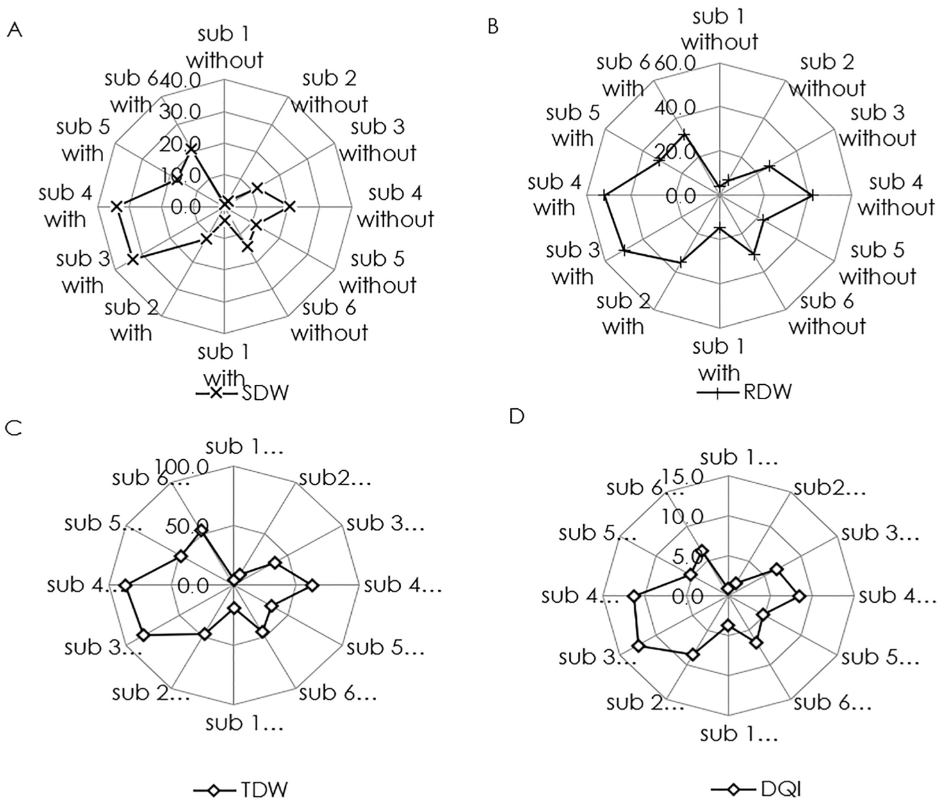

Figure 6: Average values (A) of shoot dry weight (SDW), (B) root dry weight (RDW), (C) total dry weight (TDW) and (D) Dickson quality index (DQI) of taperebá seedlings in different substrates (Sub1) soil ; (Sub2) soil + carbonized rice husk (2:1 v/v); (Sub3) soil + organic compost (2:1 v/v); (Sub4) soil + carbonized rice husk + organic compost (1:1:1); (Sub5) soil + carbonized rice husk + organic compost (2:1:1); (Sub6) soil + carbonized rice husk + organic compost (2:2:1) with and without addition of controlled-release fertilizer at 210 DAT.

In general, the plants grown in Sub3 and Sub4 showed satisfactory morphological characteristics, and it is assumed that this result is related to the chemical and physical composition of the substrates, with high levels of nutrients and base saturation, which possibly promoted adequate plant growth.

According to Smiderle et al. (2021), it is also important to highlight the pH of the substrate, which can influence both the availability of nutrients and the biology of microorganisms in the substrate. It is known that soil microbial biomass is more efficient as carbon loss decreases, being mainly influenced by the factors temperature, pH, luminosity, moisture, energy sources and the decomposition of organic residues, resulting in the rapid synthesis of new material that is indispensable for plant growth (Al-Taey et al., 2019).

As in the present study, Smiderle et al. (2020) reported that in substrates based on organic components the "ideal" pH range is on average 5.5 to 6.0 for native species of the Cerrado of Roraima, promoting greater nutrient availability.

According to a study conducted by Smiderle et al. (2020), the substrates used can be classified in relation to pH as follows: Sub1 and Sub2 (low) and Sub3 and Sub4 (optimal); Sub5 and Sub6 (slightly high). In addition to pH, cation exchange capacity (T) is directly related to the availability of cations and the reduction in leaching losses, since the higher it is, the higher the retention of absorbed cations, especially in crops where irrigation is frequent (Wang et al., 2019). In this context, values from 6 cmolc L^{-1} to 16 cmolc L^{-1} are recommended by Abul-Soud et al. (2015) for the cultivation of strawberry *(Fragaria* X *ananassa* Duch.).

This demonstrates once again that the cultivation of taperebá seedlings in Sub3 and Sub4 promotes multiple benefits due to their physical and chemical characteristics (Tables 1, 2 and 3), promoting better edaphic conditions and greater availability of nutrients for taperebá plants.

In general, the results obtained in this study suggest that taperebá plants grown in different substrates, especially Sub3 and Sub4, have better utilization of production resources such as nutrients, water, temperature, light, good porosity and aeration space, favoring gas exchange and water holding capacity; in addition, part of this water should be available to plants and the substrate must also have adequate density to facilitate the management of containers.

In addition, according to Menegatti et al. (2019), the use of CRF incorporated into the substrate, when combined with the appropriate and defined physical and chemical characteristics of the substrate, promotes better initial growth of seedlings of stone fruit (*Prunus persica*), making it possible to obtain seedlings with high vigor.

Regarding the dry density (DD) of the substrates, there was a correlation with wet density (WD) and available water (AW), showing positive and similar correlations (Table 6), hence pointing to the importance of density and its influence on solid, liquid and gaseous fractions of substrates.

The available water (AW) was influenced and correlated with RW, AS and TP, thus proving that pores have an influence on available water, especially pores of smaller diameters as shown by the negative correlation between AW and AS, since AS predominates in pores of larger diameters. Ruiz & Salas et al. (2019) also observed a relationship between AS and AW.

Table 6- Pearson's linear correlation matrix for the characteristics dry density (DD), wet density (WD), total porosity (TP), aeration space (AS), available water (AW) and remaining water (RW) in substrates used for the production of taperebá seedlings under nursery conditions, Bela Vista, RR.

	WD	AW	RW	AS	TP
DD	0.85*	0.85*	0.20ns	-0.50*	0.32*
WD	-	0.80*	0.40*	-0.40*	0.50*
AW	-	-	0.41*	-0.89*	0.39*
RW	-	-	-	-0.25ns	0.89*
AS	-	-	-	-	0.43*

** and ns: significant and not significant respectively, at 1% probability level.

The characterization of the genotype under study regarding the physical and chemical attributes of the substrates in the production of taperebá seedlings is a viable strategy, because it enables the rational use of fertilizers and shorter cultivation period, besides meeting future requirements by systems that recommend the rational use of correctives and fertilizers, factors that can make the maintenance and implementation of taperebá orchards attractive.

Conclusions

The substrate formulations proposed in Sub3 (soil+ organic compost) and Sub4 (soil + carbonized rice husk + organic compost) have great potential to be used in the production of taperebá (*Spondias macrocarpa*) seedlings with superior quality.

In the formulations of substrates containing soil + carbonized rice husk + organic compost (1:1:1) and soil + organic compost (2:1 v/v), the physical properties of the substrates comprise total porosity ranging from 0.88 to 0.91 m^3 m^{-3}, aeration space from 0.33 to 0.35 m^3 m^{-3} and available water from 0.27 to 0.29 m^3 m^{-3} to obtain taperebá seedlings with superior quality.

The Cerrado soil substrate (Sub1) is not suitable for the production of taperebá seedlings, since it has acidic pH, an undesirable chemical characteristic for the cultivation of the species.

Incorporation of controlled-release fertilizer into the substrates evaluated in the present study leads to better morphological characteristics, so it is recommended as an input for fertilization in the initial stage of growth of taperebá (*Spondias macrocarpa*) seedlings.

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