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Original Article

Proportions of sewage sludge in the production and quality of *Malpighia emarginata* DC. seedlings

Proporções de lodo de esgoto na produção e qualidade de mudas de *Malpighia emarginata* DC.

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Abstract

Sewage sludge (SS) has nutritional contents and has been implemented in the cultivation of seedlings. This study aimed to evaluate the quality of *Malpighia emarginata* DC. seedlings produced in different substrates with SS. Treatments were implemented with the addition of SS, and after 180 days seedling the characteristics were measured: aerial part and root system length, stem base diameter, number of leaves, fresh and dry mass of aerial part and root, and total biomass. The Dickson Quality Index (DQI) was calculated and the macro and micronutrient content of the aerial part and root. The accumulation of macronutrients in the root system followed the order of N>K>P>Ca>Mg>S, and aerial part of N>Ca>K>P>Mg>S, in the two vegetative structures N and S were in lower concentration. For micronutrients, the accumulation in the root system occurred with Fe>Zn>Mn>Cu>B, and aerial part with Fe>Mn>Zn>B>Cu. It was noted that in the two vegetative structures the Fe content was more concentrated. The use of SS in the substrate formulation proved effective in obtaining viable seedlings for field planting, being recommended the treatment with 60% SS + 40% organic compost.

Keywords: biosolids, mineral nutrition, propagation of seedlings, acerola.

Resumo

O lodo de esgoto (LE) possui teor nutricional e tem sido aplicado no cultivo de mudas. Assim, o objetivo deste estudo foi avaliar a qualidade de mudas de *Malpighia emarginata* DC. produzidas em diferentes substratos com LE. Os tratamentos foram implantados com adição de LE, e após 180 dias de semeadura as seguintes características das mudas foram avaliadas: comprimento da parte aérea e do sistema radicular, diâmetro da base do caule, número de folhas, massa fresca e seca da parte aérea e da raiz, biomassa total. O Índice de Qualidade de Dickson (IQD) foi calculado junto aos teores de macro e micronutrientes da parte aérea e da raiz. O acúmulo de macronutrientes no sistema radicular seguiu a ordem de N>K>P>Ca>Mg>S, e parte aérea N>Ca>K>P>Mg>S, nas duas estruturas vegetativas N e S estiveram em menor concentração. Para os micronutrientes, o acúmulo no sistema radicular ocorreu Fe>Zn>Mn>Cu>B, e na parte aérea Fe>Mn>Zn>B>Cu. Observou-se que nas duas estruturas vegetativas o teor de Fe foi mais concentrado. A utilização de LE na formulação do substrato mostrou-se eficaz na obtenção de mudas viáveis para o plantio em campo, sendo recomendado o tratamento com 60% de LE + 40% de composto orgânico.

Palavras-chave: biossólidos, nutrição mineral, propagação de mudas, acerola.

1. Introduction

Malpighia emarginata DC. (Malpighiaceae), popularly known as 'acerola' in Brazil, is a shrubby plant native to Central America that produces fruit all year round in tropical climates. The fruit is small and stone-like, with an edible pulp rich in vitamin C (Santos and Lima, 2020). Its cultivation is well adapted to the Brazilian climatic conditions (Vieira et al., 2020), and it demonstrates adaptability to a wide variety of soil types, including sandy and clay soils (Santos and Lima, 2020).

Currently, substrate management is one of the major challenges in establishing orchards for fruit species. This challenge arises from the need to adapt nurseries to the emerging paradigm of replacing soil with organic substrates for the commercial production of seedlings (Rabelo et al., 2019; Mota et al., 2023). The production of high-quality seedlings is crucial in fruit cultivation, as it enhances their resistance to prevailing abiotic conditions upon transplantation in the field, thereby directly influencing

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the success of their propagation (Dionísio et al., 2019; Vieira et al., 2020).

Seedling production requires the use of substrates that have optimal conditions for proper seedling development (Silva et al., 2018). Key characteristics of a suitable substrate include good texture and aeration, absence of pathogens, affordability, and efficient water supply of the root system (Almeida et al., 2019; Silva et al., 2023). When choosing a substrate, chemical and physical properties must be considered, especially regarding the nutrient requirements of the target species (Silva et al., 2020; Mota et al., 2023). Additionally, economic aspects such as low cost, supply availability, and profitability also need to be considered (Santos and Lima, 2020).

Sewage sludge (SS) is among the organic compounds that may be used in the substrate formulations for seedling production. Fruit species native to Neotropical America, such as *Eugenia uniflora* L. and *Psidium cattleianum* Sabine var. *cattleianum* (both Myrtaceae), have demonstrated successful production of high-quality seedlings using SS as substrate (Santos et al., 2019; Gonçalves et al., 2020). Considering the increasing production of this waste due to high population concentration and urbanization implies an increase in the volume of its disposal in landfills (Muter et al., 2022; Silva et al., 2023). However, its use in agriculture could provide an ecological alternative, as it can serve as a soil conditioner or fertilizer (Guimarães, 2018; Siqueira et al., 2020).

Therefore, studies seeking alternative solutions for the use of suitable substrates for the production of *M. emarginata* seedlings are of great importance, given the cultivation's potential. Currently, the limited availability of high-quality seedlings poses a major obstacle to the expansion of acreage for this fruit species, mainly due to the lack of studies on nutrient uptake and nutrient requirements specific to this species (Silva et al., 2016; Ferreira et al., 2019).

Hence, this study aimed to evaluate the effect of different compositions of substrates with sewage sludge on the production and quality of *Malpighia emarginata* DC. seedlings.

2. Material and Methods

2.1. Experiment location

The study was carried out at the Universidade Federal do Pampa - Campus São Gabriel (-30º20'11" S and -54º19'11" W, 114 m altitude), located in São Gabriel, Rio Grande do Sul, South of Brazil. The experiment was conducted in a greenhouse covered with low-density polyethylene (PeBD) of 100 µm and 50% shade.

2.2. Seeds and substrate

The fruits of *M. emarginata* were obtained from a home orchard in same city, underwent manual pulping, followed by maceration and washing in a sieve under running water to separate the seeds from the fruits. The seeds were dried in a shaded area on filter paper, ensuring the elimination of immature, spoiled, or damaged seeds (Faustino et al., 2005; Freitas et al., 2015).

The SS used in our study was obtained from Estação de Tratamento de Esgoto São Gabriel Saneamento, located within the same city. Before its usage, the SS underwent a disinfection process by solarization for 40 days. This procedure resulted in the production of a biosolid with an improved sanitary profile and reduced limitations for agricultural use (Faustino et al., 2005; Caldeira et al., 2014).

2.3. Implementation of treatments

We employed three organic materials to compose the treatments: commercial substrate known as Plantmax® (CS), semi-composted horse bedding (HB), and sewage sludge (SS). The substrates were combined as follows: T1 (50% CS + 50% HB), designated organic compost (OC); T2 (20% SS + 80% OC); T3 (40% SS + 60% OC); and T4 (60% SS + 40% OC). Substrate T1, which was free of SS, served as a control treatment. Prior to the seed planting, the contents of nitrogen (N), calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), zinc (Zn), copper (Cu), sulfur (S), boron (B), iron (Fe), manganese (Mn), and sodium (Na) were evaluated. These analyzes were performed at the Soil Laboratory of the Universidade Federal de Santa Maria (UFSM), located in Santa Maria, Rio Grande do Sul, Brazil (Table 1).

The experiment followed a completely randomized design, consisting of six replicates (dishes) per treatment, with 50 cells per dish. Each seed was sown individually in polyethylene tubes of 200 cm^3. These tubes were placed on metal benches 100 cm above the ground. To ensure optimal moisture levels for germination and subsequent seedling emergence, daily irrigation was provided using an automatic sprinkler system.

Table 1. Nutrient content of substrates used for planting *Malpighia emarginata* DC.

Treat.	N	Ca	Mg	K	P	Zn	Cu	S	B	Fe	Mn	Na
	%	$cmol_c$ L^{-1}				mg L^{-1}						
T1	1.003	10.649	7.482	628	383.5	24.49	0.34	79.0	0.1	2907.5	10.87	88
T2	1.195	12.617	7.810	564	309.0	43.72	3.61	82.2	0.1	6343.7	19.05	72
T3	1.371	8.406	4.678	360	309.0	61.11	17.48	94.9	0.2	8697.5	18.91	44
T4	1.463	7.712	3.867	312	309.0	61.30	22.13	87.3	0.1	10792.4	22.18	36

Note: Treat. (Treatment); T1 (50% commercial Plantmax® substrate + 50% horse bedding (organic compost)); T2 (20% sewage sludge + 80% organic compost); T3 (40% sewage sludge + 60% organic compost); T4 (60% sewage sludge + 40% organic compost); N (nitrogen); Ca (calcium); Mg (magnesium); K (potassium); P (phosphorus); Zn (zinc); Cu (copper); S (sulfur); B (boron); Fe (iron); Mn (manganese); and Na (sodium).

2.4. Survival and biometric characteristics of seedlings

We evaluated the percentage of surviving seedlings (emergence) 180 days after sowing by the following formula: emergence (%) = Ns/Ni × 100, where Ns = number of seeds sown and Ni = number of seedlings that emerged (Labouriau and Valadares, 1976).

The following biometric characteristics of the seedlings were evaluated: aerial part height (H - in cm plant^{-1}) using a graduated ruler; root system length (RSL - in cm plant^{-1}) using a graduated ruler; stem base diameter (SBD - in mm) using a digital caliper; number of leaves (NL) counted in units. Furthermore, we measured the fresh and dry mass of the aerial part (FMAP - DMAP), the fresh and dry mass of the root system (FMRS - DMRS), and the total fresh and dry mass (MFT - DMT) using a digital scale (g plant^{-1}). To obtain these measurements, the seedlings were washed in running water and dried in a greenhouse with air circulation at 60 °C for 72 hours. Subsequently, the dried material was triturated using a Willey mill equipped with a 1.70 mm mesh sieve for the weighing process, and the Dickson Quality Index (DQI) was calculated (Dickson et al., 1960).

2.5. Nutritional content

The contents of macro and micronutrients were determined: N, P, K, Ca, Mg, S, Cu, Zn, Fe, Mn, and B in both the root system and the aerial part (leaves and stem) of the samples grown under the four treatments conditions (Tedesco et al., 1995; Miyazawa et al., 1999). The nutrient analyzes were performed at the Soil Laboratory of the Universidade Federal do Rio Grande do Sul (UFRGS), located in Porto Alegre, Rio Grande do Sul, Brazil.

2.6. Data analysis

The data were submitted to an Analysis of Variance (ANOVA), in cases of significance, the F test was applied. The mean values were compared by the Tukey test at 1% significance level using the statistical software ESTAT version 2 (UNESP, 1994).

3. Results

The addition of SS promoted a diverse nutrient composition of macro and micronutrients. A summary of the pre-experiment substrate analyzes is presented in Table 1. The addition of SS positively influenced the fertility properties of the substrate, especially in relation to macronutrient content, with a significant effect observed only on N content. Conversely, the content of other macronutrients (Ca, Mg, Na, and K) decreased as the proportion of SS increased. The addition of SS did not result in significant changes in P content. Notably, the treatments with SS exhibited higher values for the analyzed micronutrients (Table 1).

The morphological characteristics and seedling quality indices evaluated in our study showed different responses. Analysis of variance and Tukey's test at 1% probability revealed significant differences between the means of the studied substrates for all analyzed variables (Table 2).

The combined use of different proportions of SS affected the growth of *M. emarginata* seedlings. Treatments with SS, especially T4, exhibited significantly higher levels in comparison to the other treatments. Four treatments were analyzed for the biometric characteristics of the seedlings (number of leaves, stem base diameter, aerial part height, and height/stem base diameter). The addition of SS to the substrates yielded better results for all characteristics, except for the root system length and emergence, which did not show significant differences across the treatments.

The treatments T1, T2, and T3 displayed lower mean values for three biometric characteristics. However, aerial part height exhibited more pronounced effects in the treatments with SS (T2, T3, and T4) compared to T1. Moreover, treatments with SS showed higher mean values for SBD of *M. emarginata* seedlings compared to T1. Among the treatments, seedlings grown in substrate T4 showed the highest SBD values, followed by treatments T3 and T2. Notably, none of the tested treatments showed a significant difference in terms of root system length (Table 2).

The seedlings of *M. emarginata* from all treatments reached higher values of the DQI, considering the minimum value of 0.20 (Dickson et al., 1960). This indicates their suitability for field planting. Treatment T4 exhibited the most favorable results for this variable, and it displayed a statistically significant difference when compared to all other treatments (Table 2).

The substrate composition using SS had significant effects on the levels of seedling biomass. There was an increase in fresh, dry, and total biomass of *M. emarginata* (Table 3).

The fresh and dry mass of aerial part showed a gradual and significant increase with the addition of SS

Table 2. Means (± standard deviations) for the variables: emergence (E %), number of leaves (NL), stem base diameter (SBD), aerial part height (H), root system length (RSL), height/stem base diameter (H/SBD), and Dickson Quality Index (DQI) of *Malpighia emarginata* DC. seedlings on different substrates.

Treat.	E (%)	NL	SBD (mm)	H (cm)	RSL (cm)	H/SBD	DQI
T1	100 ± 0.00 a	12.57 ± 0.12 c	1.62 ± 0.35 d	12.50 ± 0.11 d	16.14 ± 0.13 a	7.71 ± 0.52 b	3.53 c
T2	99 ± 0.35 a	18.43 ± 0.27 b	3.15 ± 0.08 c	24.16 ± 0.69 c	18.18 ± 0.09 a	7.67 ± 0.47 b	9.73 b
T3	98 ± 0.82 a	24.09 ± 0.67 b	3.73 ± 0.46 b	36.20 ± 0.54 b	19.68 ± 0.22 a	9.70 ± 0.33 a	9.35 b
T4	100 ± 0.00 a	32.02 ± 0.91 a	4.37 ± 0.10 a	49.15 ± 0.45 a	19.32 ± 0.74 a	9.87 ± 0.36 a	12.62 a

Note: Treat. (Treatment); T1 (50% commercial Plantmax® substrate + 50% horse bedding (organic compost)); T2 (20% sewage sludge + 80% organic compost); T3 (40% sewage sludge + 60% organic compost); and T4 (60% sewage sludge + 40% organic compost). Means followed by the same letters in the columns do not differ significantly by the Tukey's test at 1% probability.

to the substrates. The average values varied from 31.22 to 152.68 g for fresh mass and 10.58 to 48.31 g for dry mass, with the most significant values observed in treatment T4. Conversely, treatment T1 exhibited the lowest average value for both fresh and dry mass (Table 3).

In terms of the fresh and dry mass of the root system, the average values ranged from 35.56 to 225.94 g for fresh mass and 18.67 to 83.54 g for dry mass. Treatment T4 demonstrated the highest values, while treatment T1 exhibited the lowest average values for the aerial part (Table 3). Additionally, treatment T4 showed superior results for the secondary development of the roots. This outcome can likely be attributed to the favorable conditions provided by the substrate, promoting the growth of lateral roots and resulting in a satisfactory development and greater biomass accumulation. It is important to note that the values of the main root length did not show statistically significant differences among the treatments (Tables 2 and 3).

Consequently, the seedlings showed a considerable increase in the accumulation of macro and micronutrients in both in the aerial part and roots. Regarding the macronutrients evaluated in the aerial part, the order of concentration was N>Ca>K>P>Mg>S. In the root system, the order of concentration was N>K>P>Ca>Mg>S. Notably, the highest concentration of nutrients was observed for N in both the aerial part and the root system, while S showed the lowest concentration (Table 4).

The gradual addition of SS led to a decrease in the concentration of P, K, and Ca macronutrients. However, there were no significant changes in Mg content among the different treatments. In the root system, on the other hand, the content of N, P, K, and S exhibited a significant increase with the addition of SS to the organic compost, with the highest concentrations observed in treatment T4. Nevertheless, the content of Ca and Mg did not show significant changes compared to treatment T1 (Table 4).

The addition of the different proportions of SS resulted in a significant increase in the contents of all analyzed micronutrients, except for B, in both the aerial part and root system. The contents of Cu, Zn, Fe, and Mn exhibited a gradual increase with the addition of SS, while the B content showed the reverse effect, decreasing with the gradual increase in the addition of this residue. The concentration of micronutrient content in the aerial part was Fe>Mn>Zn>B>Cu, in the root system was Fe>Zn>Mn>Cu>B. It is worth noting that there was an increase in the content of Fe and Mn, as well as low Cu content, in both vegetative structures evaluated (Table 5).

Table 3. Means (± standard deviations) for the variables: fresh mass aerial part (FMAP), fresh mass system root (FMSR), fresh mass total (FMT), dry mass aerial part (DMAP), dry mass system root (DMSR), dry mass total (DMT) of *Malpighia emarginata* DC. seedlings on different substrates.

Treat.	FMAP	FMSR	FMT	DMAP	DMSR	DMT
	g plant $^{-1}$					
T1	31.22 ± 3.59 d	35.56 ± 4.85 d	66.78 ± 3.28 d	10.58 ± 4.32 d	18.67 ± 6.86 d	29.25 ± 4.24 d
T2	104.79 ± 7.25 c	149.09 ± 10.65 c	253.88 ± 4.16 c	32.86 ± 5.94 c	48.36 ± 9.35 c	81.22 ± 5.05 c
T3	121.49 ± 5.57 b	212.02 ± 6.46 b	333.51 ± 7.33 b	37.28 ± 9.12 b	59.32 ± 6.32 b	96.60 ± 7.19 b
T4	152.68 ± 6.66 a	225.94 ± 8.60 a	378.62 ± 8.08 a	48.31 ± 5.08 a	83.54 ± 5.65 a	131.85 ± 8.96 a

Note: Treat. (Treatment); T1 (50% commercial Plantmax® substrate + 50% horse bedding (organic compost)); T2 (20% sewage sludge + 80% organic compost); T3 (40% sewage sludge + 60% organic compost); and T4 (60% sewage sludge + 40% organic compost). Means followed by the same letters in the columns do not differ significantly by the Tukey's test at 1% probability.

Table 4. Macronutrient content in the aerial part and system root of *Malpighia emarginata* DC. seedlings grown on different substrates formulated with sewage sludge.

Organ	Treat.	N	P	K	Ca	Mg	S
		g kg^{-1}					
Aerial part	**T1**	6.5 ± 0.02 c	3.8 ± 0.07 a	6.3 ± 0.01 a	9.5 ± 0.08 a	2.3 ± 0.01 a	1.0 ± 0.05 b
	T2	7.6 ± 0.09 b	3.2 ± 0.03 ab	6.4 ± 0.03 a	8.3 ± 0.05 b	2.3 ± 0.09 a	1.3 ± 0.03 ab
	T3	10.5 ± 0.06 a	3.1 ± 0.02 ab	5.4 ± 0.04 b	8.6 ± 0.04 b	2.4 ± 0.07 a	1.6 ± 0.06 a
	T4	11.5 ± 0.05 a	2.6 ± 0.04 b	4.3 ± 0.04 c	8.0 ± 0.02 b	2.5 ± 0.02 a	1.8 ± 0.02 a
Root system	**T1**	8.7 ± 0.01 b	3.3 ± 0.00 b	8.5 ± 0.05 b	3.3 ± 0.03 a	3.0 ± 0.06 a	0.8 ± 0.01 b
	T2	9.1 ± 0.03 b	3.6 ± 0.03 b	9.7 ± 0.07 a	3.2 ± 0.01 a	3.1 ± 0.02 a	1.2 ± 0.00 b
	T3	10.4 ± 0.02 a	4.4 ± 0.05 a	9.6 ± 0.02 a	3.1 ± 0.00 a	2.9 ± 0.01 a	1.3 ± 0.00 a
	T4	12.0 ± 0.04 a	4.9 ± 0.04 a	9.7 ± 0.03 a	2.9 ± 0.00 a	2.8 ± 0.02 a	1.4 ± 0.02 a

Note: Treat. (Treatment); T1 (50% commercial Plantmax® substrate + 50% horse bedding (organic compost)); T2 (20% sewage sludge + 80% organic compost); T3 (40% sewage sludge + 60% organic compost); and T4 (60% sewage sludge + 40% organic compost). Means followed by the same letters in the columns do not differ significantly by the Tukey's test at 1% probability.

Table 5. Micronutrient content in the aerial part and system root of *Malpighia emarginata* DC. seedlings grown on different substrates formulated with sewage sludge.

Organ	Treat.	Cu	Zn	Fe	Mn	B
		mg kg^{-1}				
Aerial part part	**T1**	3.5 ± 0.02 d	27.5 ± 0.03 d	159 ± 0.06 d	130 ± 0.10 d	26.5 ± 0.10 a
	T2	5.0 ± 0.01 c	41.0 ± 0.05 c	175 ± 0.03 c	182 ± 0.08 c	24.5 ± 0.11 b
	T3	6.3 ± 0.00 b	63.0 ± 0.08 b	245.5 ± 0.09 b	257 ± 0.11 b	23.0 ± 0.13 bc
	T4	7.5 ± 0.00 a	106 ± 0.02 a	306 ± 0.10 a	296 ± 0.05 a	20.5 ± 0.09 c
Root system	**T1**	7.5 ± 0.02 c	72 ± 0.03 d	361 ± 0.06 d	134 ± 0.10 c	26.3 ± 0.03 a
	T2	21.5 ± 0.01 b	172.5 ± 0.05 c	858 ± 0.05 c	167 ± 0.08 b	20 ± 0.00 b
	T3	32.5 ± 0.04 a	230.1 ± 0.03 b	924 ± 0.08 b	223.5 ± 0.03 a	19 ± 0.01 b
	T4	34.0 ± 0.06 a	361.5 ± 0.01 a	1200 ± 0.10 a	225.5 ± 0.05 a	17.5 ± 0.02 b

Note: Treat. (Treatment); T1 (50% commercial Plantmax® substrate + 50% horse bedding (organic compost)); T2 (20% sewage sludge + 80% organic compost); T3 (40% sewage sludge + 60% organic compost); and T4 (60% sewage sludge + 40% organic compost). Means followed by the same letters in the columns do not differ significantly by the Tukey's test at 1% probability.

4. Discussion

The results of this study suggest that presence of SS increased the availability of Zn, Cu, Fe, and Mn in soil solution, resulting in higher levels of these elements in the seedlings. Substrates are evaluated based on their capacity for aeration, water retention, and nutrient availability (Silva et al., 2018). In this premise, we evaluated the macro and micronutrient content of SS to determine whether it was appropriate for seedling growth, once the chemical properties of the substrate are important in agriculture (Vieira et al., 2020). Thus, conditions are augmented for the best development of the species supporting further studies (Rabelo et al., 2019), as was shown in this study.

A positive correlation was found between leaves number and increased SS concentration. It is generally assumed that leaf number is linked to plant development since leaves are photosynthesis sites (Taiz et al., 2021). Additionally, Silva et al. (2016) in seedling production of *M. emarginata*, Marques et al. (2018) in seedling production and quality of *P. cattleianum* Sabine var. *cattleianum*, and Santos et al. (2019) in seedling production and quality of *Parapiptadenia rigida* (Benth.) Brenan, had similar results when using the same proportions of SS.

The SBD values found in the treatments analyzed demonstrated that seedlings could be planted in the field. According to Dionísio et al. (2019) quality of fruit tree seedlings for planting correlates with SBD once this factor is associated with survival in the field. Additionally, among the treatments analyzed, in relation to H values, T2, T3, and T4 showed values that are recommended as standards for seedling quality production. It is recommended a height limit between 20 and 35 cm for the quality of seedlings of forest species (Cordeiro et al., 2021). In this premise, *P. rigida, P. cattleianum* Sabine var. *cattleianum* and *H. dulcis* (Marques et al., 2018; Santos et al., 2019; Melo et al., 2021) also showed SBD and H values similar to our results in treatments with higher addition of SS.

As a result of the use of SS for *M. emarginata* seedlings, the average value of relation H/SBD was significant, and the best results were obtained with respect to the addition of SS in ascending order in treatments. Neither treatment showed a deviation from the average T1 treatment, but T3 and T4 are the most indicated. Generally, the relation H/SBD is used to evaluate the quality of forest seedlings and to determine the survivability rate in the field (Silva et al., 2018; Dionísio et al., 2019; Rabelo et al., 2019). However, the H/SBD and DQI are variable characteristics for each species (Trazzi et al., 2013; Silva et al., 2018; Dionísio et al., 2019; Rabelo et al., 2019). Management of seedlings in the nursery, the type and proportion of substrate, the volume of the container, and, above all, the age at which the seedling was evaluated, all these variables make comparisons with other species difficult (Santos and Lima, 2020; Vieira et al., 2020).

In terms of fresh mass of aerial part and root system, T4 treatment was significant. There were results in T4 regarding the dry mass similar, confirming the result of biomass in both vegetation structures. According to Silva et al. (2018), the dry mass of aerial part indicates the resistance of the seedlings, so the use of organic compost in the composition of substrate may also affect the resistance of *M. emarginata* seedlings. In our study, there was no significant difference in root system length among tested treatments, but there was a significant difference in lateral root density. Using SS as a substrate, Caldeira et al. (2014) obtained similar results with *Acacia mangium*, concluding that the most informative values related to root system dry matter were associated with lateral roots. The availability of nutrients in the substrate influences the growth of lateral roots (Trazzi et al., 2013; Neimog et al., 2022). Additionally, in other analyzes of treatments formulated with SS, lateral roots are more likely to occur when the SS content is higher (Santos et al., 2019; Gonçalves et al., 2020).

In our results, there were no significant differences in macronutrients between the aerial part and root system in relation to the use of SS. In both T3 and T4 treatments, only N contents showed better values, along with P contents in the root system. The increased nitrogen in the substrate stimulates growth, delays senescence, and alters plant morphology. Thus, nitrogen fertilization leads to a significant increase in chlorophylls in leaves, but this level varies in concentration depending of species (Kerbauy, 2019), favoring or not biometric characteristics (Faria et al., 2016). However, N and P contents determined in this study are within the range of values considered appropriate for *M. emarginata* seedlings grown for field cultivation (Silva et al., 2016; Yamamoto et al., 2017).

Treatments T3 and T4 have higher values of S in the aerial part and K and S in root system. There was also an oscillation of K and S in the aerial part of the plant, whereas they decreased in the root in the study of Gonçalves et al. (2020). Santos and Lima (2020) conclude that the content of N, P, K, and Ca in leaf structures is significant in seedlings grown in substrates with organic derivatives. In the production of *P. cattleianum* Sabine var. *cattleianum* seedlings, with the same SS content was found similar results for the content of N and S in the aerial part and root (Gonçalves et al., 2020). Similar to our study, S content was the lowest with other forest species using SS as substrate (Camargo et al., 2013; Santos et al., 2019; Melo et al., 2021).

There was a significant concentration of Fe in both the aerial part and root system for the micronutrients. Cu was the lowest element in the aerial part, while B was the lowest element in the root system. The study with *H. dulcis* with the same SS proportions showed similar results for the aerial part, with a difference in the order of elements Fe>Zn>Mn>B>Cu (Melo et al., 2021). Their study with *P. rigida*, Santos et al. (2019) reported an increase in Cu, Zn, Fe, and Mn contents in root system upon addition of SS, and in aerial part upon addition of Zn and Mn. According to Antunes et al. (2016), concentration of some micronutrients in the vegetative parts when SS is added may be due to the availability of these nutrients. SS is a variable chemical composition, which can be affected by the composting process and the waste used (Caldeira et al., 2014). Many researchers have tested SS with a variety of native, exotic, and also fruit tree species, in general, the SS has demonstrated results excellent (Faustino et al., 2005; Caldeira et al., 2012, 2014; Faria et al., 2013; Marques et al., 2018; Santos et al., 2019; Gonçalves et al., 2020; Melo et al., 2021; Silva et al., 2023).

Results of this study infer the use of sewage sludge (SS) as substrate was suitable for the production of quality seedlings of *M. emarginata*. In general, the gradual increase in the addition of SS by the morphometric measurements (height, stem base diameter, and fresh and dry biomass of seedlings) showed values already considered acceptable for the species in literature. Although some contents of macro and micronutrients evaluated in aerial part and system root of different treatments were reduced by the addition of SS, no visible signs of deficiency were observed in the seedlings. The treatment with 60% sewage sludge and 40% organic compost is recommended for seeding of this species. Thus, it can be concluded that SS is an interesting raw material for the composition of substrates in production of *M. emarginata* seedlings.

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