Disciplinarum Scientia. Série: Naturais e Tecnológicas, Santa Maria, v. 24, n. 3, p. 153-169, 2023.
Recebido em: 07.11.2023. Aprovado em: 15.12.2023.
ISSN 2176-462X
DOI: 10.37779/nt.v24i2.4731

USE OF SEWAGE SLUDGE IN THE PRODUCTION AND QUALITY OF *Jacaranda mimosifolia* D. DON SEEDLINGS

UTILIZAÇÃO DE LODO DE ESGOTO NA PRODUÇÃO E QUALIDADE DE MUDAS DE Jacaranda mimosifolia D. DON

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ABSTRACT

The substrate has great importance for the development of seedlings, and many materials can be used for its composition. Thus, the aim of this study was to evaluate the quality of *Jacaranda mimosifolia* D. Don seedlings on different substrates with sewage sludge (SS). The substrates were combined as follows: T1 (50% commercial substrate Plantmax® + 50% organic compost from horse bedding (organic compost - OC); T2 (20% SS + 80% OC); T3 (40% SS + 60% OC); T4 (60% SS + 40% OC). At 180 days after sowing, the following biometric characteristics were measured: aerial part height and root system length; stem diameter; number of leaves; fresh and dry mass of the aerial part and root; and total mass. The Dickson Quality Index (DQI) was calculated, and the content of macro and micronutrients in the root and aerial parts was quantified. The accumulation of macronutrients in the root system was in the order K>N>Mg>P>Ca>S and in the aerial part, N>Ca>K>P>Mg>S. Sulfur was less concentrated in the two vegetative structures. For the micronutrients, the accumulation in the root system was in the order Fe>Mn>Zn>Cu>B, and in the aerial part, it was Fe>Mn>Zn>B>Cu. In general, the Fe and Mn content were more concentrated in the two vegetative structures studied. The recommended substrate formulated according to our results was 60% SS + 40% OC, presenting the highest mean values of growth and biomass. Thus, the use of SS can be considered a viable substrate for the production of healthy seedlings of *J. mimosifolia* for planting in the field.

Keywords: mineral nutrients, substrates, morphological characters.

RESUMO

O substrato tem grande importância para o desenvolvimento das mudas, e vários são os materiais que podem ser utilizados na sua composição. Assim, o objetivo desse estudo foi avaliar a qualidade de mudas de Jacaranda mimosifolia D. Don em diferentes substratos compostos de lodo de esgoto (LE). Os substratos

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foram combinados da seguinte forma: T1 (50% substrato comercial Plantmax® + 50% de cama de cavalo (composto orgânico - CO); T2 (20% LE + 80% CO); T3 (40% LE + 60% CO); T4 (60 % LE + 40% CO). Aos 180 dias após a semeadura, foram mensuradas as seguintes características biométricas: comprimento da parte aérea e do sistema radicular, diâmetro do colo, número de folhas, massa fresca e seca da parte aérea e raiz, e massa total. Foi calculado o Índice de Qualidade de Dickson (IQD), e quantificado o teor de macro e micronutrientes da raiz e da parte aérea. O acúmulo dos macronutrientes no sistema radicular seguiu a ordem de K>N>Mg>P>Ca>S, e na parte aérea N>Ca>K>P>Mg>S. Nas duas estruturas vegetativas o enxofre esteve menos concentrado. Para os micronutrientes, o acúmulo no sistema radicular se deu com Fe>Mn>Zn>Cu>B, e na parte aérea foi Fe>Mn>Zn>B>Cu. Em geral, nas duas estruturas vegetativas o teor de Fe e Mn foram mais concentrados. O substrato recomendado, formulado de acordo com os nossos resultados foi de 60% LE + 40% CO, apresentando as maiores médias das características de crescimento e biomassa. Assim, o uso de LE pode ser considerado um substrato viável para a produção de mudas saudáveis de J. mimosifolia para o plantio em campo

Palavras-chave: *nutrientes minerais, substratos, características morfológicas.*

INTRODUCTION

Jacaranda mimosifolia D. Don, considered native to Brazil and also known as jacaranda, blue jacaranda, and black poui, is a forest species of the Bignoniaceae. The species occurs mainly in semi-deciduous broad leaf forests and has natural distributions in the states of Rio Grande do Sul, Paraná, Mato Grosso, Mato Grosso do Sul, São Paulo, Minas Gerais, and Goiás (FARIAS-SINGER, 2022). The species has the potential to be used in reforestation projects and commercially in carpentry (SERRANO, 2017). In addition, it has been widely distributed in tropical and subtropical regions of the world due to its easy adaptability (CAVALCANTI *et al*., 2021). Furthermore, *J. mimosifolia* is frequently used in urban reforestation and as an ornamental plant (MISSIO *et al*., 2016; SILVEIRA *et al*., 2018).

In Brazil, environmental awareness among the population has stimulated the demand for native seedlings for reforestation and restoration of deforested areas, allowing efficient restoration of vegetation cover, which is essential for restoring ecological balance (GONÇALVES *et al*., 2015; FREITAS *et al*., 2017; SOARES *et al*., 2017). Moreover, the demand for forestry products is increasing in Brazil, resulting in higher consumption of fertilizers in the production of seedlings and in planting (MORALES *et al*., 2013; PEREIRA; COSTA; ALMEIDA, 2018; SILVA *et al.,* 2023). In this context, the use of organic components such as sewage sludge (SS), carbonized rice husks, coconut fiber, cattle manure, chicken litter, and quail droppings can help reduce the use of mineral fertilizers (GONDIM *et al*., 2019; MOTA *et al*., 2021; COSTA *et al*., 2023). It is worth noting that the physical and chemical quality of substrates affects the seed germination process, especially root development (MORALES *et al*., 2013; COSTA *et al*., 2023). Cavalcanti *et al*. (2021) emphasized that the use of waste as substrate for seedling production is an alternative to reduce costs since it is available and easy to obtain.

In relation to the use of alternative substrates such as SS, seedlings of *Jacaranda cuspidifolia* Mart. and *Jacaranda micrantha* Cham. already showed promising results in terms of macro and micronutrient values at early growth stages (BANDEIRA *et al*., 2018). According to this premise, SS has excellent potential as an additive in substrates for the production of high-quality forest seedlings. SS is an organic biosolid used in agriculture as an additive for soil fertilization (CAMARGO *et al*., 2013). Due to its macro- and micronutrient composition and its increasing production, mainly related to the urbanization process (CASTRO; RODRIGUES; SCALIZE, 2015; COSTA *et al*., 2023), SS has specific regulations for its use in agriculture (CONAMA, 2006).

However, one of the main problems in making plans for reforestation is the quality of seedlings (LIMA FILHO *et al*., 2019). Quality seedlings are crucial for the development of forest populations, as they are more resistant to biotic and abiotic conditions (DIONÍSIO *et al*., 2019). As main chemical characteristics, the SS presents levels of N, P, K, Ca, Mg, Na, Cu, Fe, Mn, and Zn, for example, which act in cellular composition, enzyme and protein synthesis, perform structural function, and are involved in virtually all processes of plant growth and reproduction (GONDIM *et al*., 2019; KLAFE *et al*., 2022). The available values of these nutrients in SS vary, as does the demand of each forest species, but both macro and micronutrients are vital for developing quality seedlings (BANDEIRA *et al*., 2018). It is important to note that in plant tissues, the absorption process occurs by the root directly arranged in the substrate, and that by active or passive transport, they will be distributed internally in tissues according to the plant's needs (TRAZZI *et al*., 2013). Deficiency of these nutrients can cause necrosis, early leaf abscission, deformations such as thickening or thinning of the stem, and even toppling after planting in the field (PEREIRA; COSTA; ALMEIDA, 2018).

Considering the above, the use of organic material in the composition of substrates is an excellent alternative to the use of waste as well as a source of plant nutrients that can reduce the high costs to the minimum necessary for the production of forest seedlings. Therefore, the aim of this study was to evaluate the effects of different substrates with SS on the production and quality of seedlings of *Jacaranda mimosifolia* D. Don.

MATERIAL AND METHODS

The experiment was conducted in a greenhouse with 256 m^2 area (8 m width x 32 m length x 4 m height), covered with 100 μm low density polyethylene (PeBD). The fruits of *Jacaranda mimosifolia* were obtained in the city of São Gabriel, Rio Grande do Sul state, Brazil, collected in summer 2021. Subsequently, the seeds were processed and distinguished into viable, spoiled, or damaged seeds (FREITAS *et al*., 2005). Only viable seeds were used in this study.

The sewage sludge (SS) used was obtained from the Estação de Tratamento de Esgoto São Gabriel Saneamento in São Gabriel, Rio Grande do Sul state, and previously disinfected by solarization for 40 days. The process resulted in the production of a biosolid with a better sanitary profile, the promotion of prior disinfection and disinfestation of pathogens, and fewer restrictions on agricultural use (CALDEIRA *et al*., 2014).

Three materials were used for the composition of the treatments: commercial substrate Plantmax® (CS) composed of pine bark, fine and superfine grained vermiculite, and humus; organic compost from horse bedding (HB); and SS. The substrates were combined as follows: T1 (50% commercial substrate Plantmax® + 50% organic compost from 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). The substrate T1 free of SS was used as a control treatment. Before seeding, the treatments were evaluated for nutrient levels: 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). The analyses were carried out in the Soil Laboratory at Universidade Federal de Santa Maria (UFSM), Santa Maria, Rio Grande do Sul State, Brazil (Table 1).

Table 1 - Nutrient content of substrates used for sowing *Jacaranda mimosifolia* D. Don.

Treat.	N	Ca	Mg	K	P	Zn	Cu	S	B	Fe	Mn	Na
	%	cmol L^{-1}				mg L^{-1}						
T1	1.003	10.649	7.482	628	383.5	24.29	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 substrate Plantmax® + 50% organic compost from 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). Nitrogen (N), calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), zinc (Zn), copper (Cu), sulfur (S), boron (B), iron (Fe), manganese (Mn), and sodium (Na).
Source: Authors (2022).

Seeds were sown in polyethylene plugs of 200 cm^3, with one seed per plug, placed on metal benches 100 cm above the ground. Irrigation was done three times daily by an automatic sprinkler irrigation system with an estimated intensity of 2.5 mm/h to maintain the humidity of the substrates. The experiment was performed in a completely randomized experimental design consisting of four treatments (T1, T2, T3, and T4) with six replicates (trays) for each treatment and 50 cells per tray. Data were submitted to analysis of variance ANOVA, and when the F test was significant, means were compared with the Tukey test at 1% probability level using the statistical software ESTAT version 2 (ESTAT, 1994).

After 180 days of the seeding period, all seedlings from the treatments were evaluated for the following parameters: the seedling emergence percentage was measured according to Labouriau and Valadares (1976), where emergence rate (% = Ns/Ne x 100 was calculated, representing Ns = number of seeds sown and Ne = number of emerged seedlings. The following biometric characteristics of the seedlings were measured: aerial part height (H - in cm $plant^{-1}$) with a ruler; root system length (RSL - in cm $plant^{-1}$) with a ruler; stem diameter (SD - in mm) with a digital caliper; number of leaves (NL - in units) calculated manually; fresh mass of the aerial part (FMAP), fresh mass of the root system

(FMRS), and total fresh mass (TFM) measured on a digital scale (g $plant^{-1}$); and their respective dry masses (DMAP, DMRS, and TDM) measured with a digital scale (g $plant^{-1}$). After drying in an oven with air circulation at 60 ºC, until reaching a constant dry mass, which was verified after approximately 72 hours, they were ground in a Willey type mill with a 1.70 mm sieve mesh.

In addition to the aforementioned characteristics, the Dickson Quality Index (DQI) was calculated according to the proposal of Dickson, Leaf and Hosner (1960).

DQI = TMD (g)/(H (cm)/SD(mm) + (DMAP(g)/DMRS)(g))

Wherein:

DMT = total mass dry; H = aerial part height; SD = stem diameter; DMAP dry mass of aerial part; DMRS = dry mass of root system.

Macro and micronutrient contents of N, P, K, Ca, Mg, S, Cu, Zn, Fe, Mn, and B were determined in the root system and aerial parts (leaves and stem) of samples grown in the four treatments according to Tedesco *et al*. (1995) and, Miyazawa, Pavan and Muraoka (1999). The analyses were performed in the Soil Laboratory at Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, Rio Grande do Sul state, Brazil.

RESULTS AND DISCUSSION

The results of macro and micronutrient analyses (N, Ca, Mg, K, P, Zn, Cu, S, B, Fe, Mn, and Na) of the substrate studied before installation of the experiment are shown in Table 1. It was observed that the addition of sewage sludge (SS) changed the nutrient composition of the studied substrates to varying degrees (Table 1).

The efficiency of a substrate for seedling production is related to its ability to provide aeration, water retention, and balanced nutrient availability. The first two are related to the physical properties, and the third to the chemical properties of the substrate (TAIZ; ZEIGER, 2017; ANDIVIA *et al*., 2021; TAIZ *et al*., 2021). Each time a new substrate is formulated, its chemical properties should be analyzed to verify that they are suitable for seedling growth and to know the conditions required for optimal growth of the species in question to support further studies (DALANHOL *et al*., 2017).

In general, the addition of SS had a positive effect on the fertility properties of the substrate, especially on the content of micronutrients. For macronutrients, there was only an effect on N, and for the other macronutrients (Ca, Mg, Na, and K) there was a decrease in the values when the proportion of SS increased. The changes in P were not significant and remained practically unchanged as a function of the amounts of SS (Table 1).

Regarding the analyzed micronutrients in the four treatments, it was found that the values were higher in the treatments with SS (Table 1). The results suggest that the presence of SS promoted a higher availability of Zn, Cu, Fe, and Mn in the soil solution, which certainly contributed to a higher content of these elements in seedlings. According to Klafe *et al.* (2022) and Areche *et al*. (2023), this result could be related to chelated compounds (organic substances that surround nutrients and prevent them from being bound to another element, which could lead to their immobilization), allowing them to enter the rhizosphere and be taken up by plant roots.

The morphological characteristics and indices of seedling quality evaluated in this study showed different responses among themselves. Analysis of variance and Tukey's test revealed significant differences among the means of the substrates studied for all variables analyzed, except for root growth and percent seedling emergence (Table 2). The combined use of different proportions of SS affected the growth of *J. mimosifolia* seedlings. The SS treatments, especially treatment T4 (60% SS + 40% OC), resulted in significantly more relevant values of the morphological parameters evaluated when compared to the other treatments and the control (Table 2).

Table 2 - Means (± standard deviations) for the variable's emergence (E %), number of leaves (NL), aerial part height (H), stem diameter (SD), root system length (RSL), height/stem base diameter (H/SBD), and Dickson Quality Index (DQI) of *Jacaranda mimosifolia* D. Don. on different substrates.

Treat.	E (%)	NL	H (cm)	SD (mm)	RSL (cm)	H/SD	DQI
T1	100±0.00a	15.97±0.10c	13.30±0.09d	1.82±0.32d	21.68±0.17a	7.30±0.23b	0.30±0.05d
T2	99±0.70a	22.43±0.25b	22.26±0.16c	3.05±0.28c	19.31±0.08a	7.29±0.18b	0.43±0.23c
T3	98±0.35a	25.09±0.37b	32.60±0.26b	3.93±0.13b	20.85±0.13a	8.30±0.40a	0.78±0.18b
T4	100±0.00a	36.02±0.17a	36.04±0.34a	4.47±0.08a	21.48±0.14a	8.06±0.22a	1.31±0.43a

Note = Treat. - Treatment. T1 (50% commercial substrate Plantmax® + 50% organic compost from 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). Means ± standard deviation followed by the same letters in columns do not differ significantly by Tukey test at 1% level of error probability.

Source: Authors (2022).

For the four biometric characteristics analyzed (number of leaves, stem diameter, height, and root length of the seedlings), except for the length of the root system, the addition of SS to the substrates showed significant values. The highest proportions containing SS such as those of 40 and 60% added to OC, showed favorable conditions for growth, especially in treatment T4 (Table 2). In relation to the significance of values for the biometric characters, they were found in crescent order in treatment T1 (OC), followed by T2 and T3. It was also found that seedling height was two and three times higher in the treatments with SS (T2, T3, and T4) compared to the control (Table 2).

The greater number of leaves is associated with the development of the plant because they are sites for photosynthesis, reserve centers, and sources of phytohormones (TAIZ; ZEIGER, 2017; TAIZ *et al*., 2021; WU *et al*., 2021). In this hypothesis, the parameters tested were more significant in the order of treatments T4, T3, T2, and control (Table 2). Similar results to the present study were obtained by Delarmelina *et al.* (2013) in the production of seedlings of *Sesbania virgata* (Cav.) Pers, Marques *et al.* (2018) in the production of seedlings of *Psidium cattleianum* Sabine var. *cattleianum*, and Santos *et al.* (2019) in the production of *Parapiptadenia rigida* (Benth.) Brenan. Thus, in the results in Table 2, it was simultaneously found that at the highest levels of SS, there was an increase in the number of leaves, stem diameter, and height of the seedlings increased in the combinations of 40%SS + 60%OC and 60%SS + 40%OC, the same treatments used in our analyses.

Accordingly, with the addition of SS in the tested treatments, greater height-related values and significant differences among treatments with this biosolid were found (Table 2). Cordeiro *et al.* (2021) recommend that for forest species, the values can vary from 25 to 35 cm for field planting. According to these parameters, all treatments with SS in this study were within the recommended quality standard. Delarmelina *et al.* (2013) evaluated the use of SS and organic residues for the growth of *S. virgata* seedlings, and Faria *et al.* (2013) the growth of *Senna alata* (L.) Roxb., both reported that the treatments using SS together with organic compost resulted in the best average growth values in aerial part height. Delarmelina *et al.* (2013) and Faria *et al.* (2016) also noted the presence of acceptable nutrient content, such as N, P, K, Ca, and Mg, in addition to favorable characteristics such as density and porosity.

The treatments with SS showed higher mean values for stem diameter (SD) of seedlings compared to controls (Table 2). Morphologically, the stem diameter measurements on seedlings are used to indicate their quality. For example, the larger the diameter volume, the greater the chances of survival after field planting (ANDIVIA *et al*., 2021). On this premise, Mendoza *et al.* (2019) infer that for *J. mimosifolia* the optimal stem diameter for field planting ranges from 1.5 to 3 mm. In the present study, all SS treatments obtained results greater than 2 mm, and there was no significant difference in the treatments T3 and T2. For SS use, Faria *et al*. (2013) found the best results for stem diameter in *S. alata* seedlings in treatments with 60% and Melo *et al.* (2021) in *Hovenia dulcis* Thunb with 60%, corroborated with our data. Nevertheless, several studies in the literature indicate that SS has positive effects on seedling production of forest species (DELARMELINA *et al*., 2013; SANTOS; CALDEIRA; KUNZ, 2013; CALDEIRA *et al*., 2014; SANTOS *et al*., 2019; COSTA *et al*., 2023).

The value obtained by dividing the height of the seedling by the respective stem diameter expresses its growth equilibrium and relates these two important morphological characteristics into a single index, the robustness quotient (DICKSON; LEAF; HOSNER, 1960). The H/SD is used to evaluate the quality of forest seedlings and reflects the accumulation of reserves that provide greater strength and determine survivability in the field (FALSTER; DUURSMA; FITZJOHN, 2018). For *J. mimosifolia* seedlings produced in this study, all treatments stayed in the range considered appropriate for this ratio, 5.4 to 8.1 (CARNEIRO, 1995), with the best results obtained in substrates T3 and T4 (Table 2). In the study by Kratz, Wendling and Pires (2012) with the species *Eucalyptus benthamii* Maiden & Cambage and *E. dunnii* Maiden, the seedlings exhibited high vigor and were suitable for planting in the field, with H/SD values above the range considered appropriate. However, Trazzi *et al*. (2013) infer that treatments that were below the range mentioned by Carneiro (1995) should not be disregarded, since the main disadvantage of this method is that the root system is not evaluated.

The Dickson Quality Index (DQI) considers the seedling's morphological characteristics, and the higher its value, the better the quality standard of the seedlings. The minimum DQI value of 0.20 can be considered a parameter for forest seedlings (GOMES *et al*., 2013). Results with *J. mimosifolia* in all treatments reached higher values, indicating good quality for planting in the field, highlighting treatment T4 (Table 2). In this context, Marques *et al.* (2018) and Santos *et al.* (2019) evaluated this parameter in the production of seedlings of *P. cattleianum* var. *cattleianum* and *P. rigida*, respectively, and found higher values in substrates formulated with SS.

Several studies in the literature indicate that the relation between H/SD and the DQI has variable characteristics (KRATZ; WENDLING; PIRES, 2012; GOMES *et al*., 2013; SANTOS; CALDEIRA; KUNZ, 2013; TRAZZI *et al*., 2013; COSTA *et al*., 2023). It can be inferred that the characteristics in question may vary depending on the species, the management of the seedlings in the nursery, the type, and proportion of substrate, the volume of the container, and the age at which the seedling was evaluated (CALDEIRA *et al*., 2014). Since these are highly variable characteristics, it is often impossible to compare them with the results of other studies.

No significant differences were found in root system length among treatment means (Table 2). It is possible that the size and shape of the container used affected this response and limited the potential for root development. However, in terms of vegetative structure biomass, significant differences were found for both fresh and dry mass (Table 3). This discrepancy can be observed in the T2, T3, and T4 treatments with SS, which produced numerous secondary roots compared to the control treatment (T1).

In general, the use of SS in the composition of substrates had relevant effects on seedling biomass, with an increase in fresh, dry, and total biomass of *J. mimosifolia* seedlings (Table 3).

Table 3 - Means (± standard deviation) for the variables fresh mass of root system (FMRS), fresh mass of aerial part (FMAP), total fresh mass (TFM), dry mass of root system (DMRS), dry mass of aerial part (DMAP), and total dry mass (TDM) of *Jacaranda mimosifolia* D. Don. on different substrates.

Treat.	FMRS	FMAP	TFM	DMRS	DMAP	TDM
	g plant^{-1}					
T1	45.66±5.85d	33.42±2.89d	79.08±4.32d	22.77±5.89d	24.56±5.64d	47.33±5.34d
T2	159.00±11.65c	114.99±5.54c	273.99±6.08c	54.07±10.65c	82.33±6.94c	136.40±6.85c
T3	222.02±7.36b	141.69±3.87b	363.71±9.65b	78.46±7.64b	112.23±7.65b	190.69±6.79b
T4	235.94±9.70a	172.88±7.96a	408.82±5.87a	96.99±6.65a	128.71±4.96a	225.70±5.91a

Note = Treat. - Treatment. T1 (50% commercial substrate Plantmax® + 50% organic compost from 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). Means followed by the same letters in columns do not differ significantly by the Tukey test at 1% level of error probability.

Source: Authors (2022).

For the morphological characteristics, the same behavior was found in the biomass. The treatments that included SS in their composition had a higher mass of root and aerial parts. For both fresh and dry mass, the presence of SS in the formulation of the substrates led to a gradual increase in the biomass of *J. mimosifolia* seedlings. Another result observed for both root and aerial part biomass was that treatment T4 (60% SS) was the most satisfactory treatment (Table 3).

In the results of fresh and dry mass of the aerial part, the *J. mimosifolia* seedlings had average values ranging from 33.42 to 172.88 g for fresh mass and 24.56 to 128.71 g for dry mass, with the highest values obtained in treatment T4. The treatment that obtained the lowest average value was T1 (control) (Table 3).

Similar to the number of leaves, height of the aerial part, and stem diameter, more values of aerial dry mass were obtained in the treatments that had SS in the composition (Table 3). Also, Gomes *et al*. (2013) infer that the greater the dry mass of the aerial part, the greater the resistance of the seedlings. The results of the present study are consistent with the experiments of Santos *et al.* (2019) and Melo *et al.* (2021), who investigated the growth of *P. rigida* and *H. dulcis* seedlings in substrates with 60% SS and obtained better results. Delarmelina *et al.* (2013) also obtained the highest average values for the aerial part dry mass in their study in the treatments with SS 80 and 60%. Leal *et al.* (2016) reported that the results of this variable may be related to root biomass, which was also higher in the treatments with SS in this study (Table 3).

In the fresh and dry root mass results, the *J. mimosifolia* seedlings had average values ranging from 45.66 to 235.94 g for the fresh mass and 22.77 to 96.99 g for the dry mass. The highest values were recorded in treatment T4. The treatment that obtained the lowest average value was T1 (control). For root dry mass, the substrate with 60% SS + 40% OC provided better results in developing secondary roots and a larger absorption zone (Table 3). Thus, the better results in root dry mass observed in treatment T4 are probably related to the good conditions that the substrate provided for the growth of lateral roots. This point could be related to the satisfactory development of these roots and their higher biomass accumulation. Nevertheless, the values for the main root length were not statistically different from those of the other treatments (Tables 2 and 3).

In other studies with silvicultural species, root dry mass has been recognized as one of the best characteristics for evaluating the seedlings survival and initial growth in the field (CALDEIRA *et al*., 2014). The significant increase in root biomass in the SS-formulated treatments was due to the increased number of lateral roots in these treatments (TRAZZI *et al*., 2013). It is noteworthy that in treatment T4, there were also a greater number of leaves, the height of the aerial part, and the stem diameter. This confirms the higher biomass in this vegetative structure (Tables 2 and 3) and consequently, the seedlings responded with a considerable increase in macro and micronutrients accumulated in both the root and aerial parts (Tables 4 and 5).

Table 4 - Macronutrient content in the aerial part and root of seedlings of *Jacaranda mimosifolia* D. Don. on different substrates.

Organs	Treat.	N	P	K	Ca	Mg	S
		g kg^{-1}					
Aerial part	T1	5.5±0.08c	2.8±0.08a	3.8±0.00c	7.0±0.11a	2.6±0.10a	0.6±0.01c
	T2	8.5±0.10b	2.8±0.01ab	5.9±0.03b	7.8±0.10a	2.6±0.11a	1.2±0.00ab
	T3	14.0±0.08a	3.0±0.07a	7.0±0.01a	7.1±0.08a	2.3±0.08a	1.5±0.02ab
	T4	12.0±0.06a	3.0±0.06a	5.7±.05b	7.5±0.10a	2.3±0.21a	1.9±0.01a
Root part	T1	5.4±0.04c	2.5±0.01b	11.0±0.10ab	2.3±0.06a	3.2±0.08a	0.5±0.00b
	T2	7.4±0.01bc	2.9±0.06ab	14.0±0.13a	2.4±0.02a	3.5±0.07a	0.7±0.01b
	T3	10.0±0.05ab	3.2±0.02a	15.0±0.11a	2.4±0.01a	3.4±0.10a	1.0±0.01a
	T4	13.0±0.08a	3.0±0.00a	10.0±0.10b	2.3±0.01a	3.5±0.06a	1.1±0.03a

Note = Treat. - Treatment. T1 (50% commercial substrate Plantmax® + 50% organic compost from 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). Means ± standard deviation followed by the same letters in columns do not differ significantly by Tukey test at 1% level of error probability.
Source: Authors (2022).

In the root, N and S content increased significantly with the addition of SS to organic compost, while P and K content increased until treatment T3 and decreased when treated in T4. The contents of Mg and S did not change among treatments compared to the control treatment (Table 4). Similar behavior was observed in the aerial part, with N and S content increasing in the treatments with SS. For the N and S values, it is possible to infer better viability for field planting, since N and S are essential and structural nutrients (TAIZ; ZEIGER, 2017; WU *et al*., 2021; ARECHE *et al*., 2023). However, there were no significant changes in P, Ca, and Mg content, while K content increased up to treatment T3, followed by a decrease in treatment T4, as was observed for nutrient content in the root (Table 4).

The order of macronutrient content in the root was K>N>Mg>P>Ca>S and in the aerial part it was N>Ca>K>P>Mg>S. The S was found in lower concentrations in the aerial part and root (Table 4). Parallel in relation to S content, Melo *et al.* (2021) found in *H. edulis* the same concentrations of SS in the root (K>N>Mg>Ca>P> S) and in the aerial part (Ca>N>K>P>Mg>S), like Santos *et al.* (2019) with *P. rigida* in leaves (Ca>N>K>P>Mg>S) and in the root (N>K>Mg>Ca>P>S). Also, in the present result, K was more concentrated in the roots than in the aerial part (Table 4). Thus, it can be noted that in several studies, S was found in lower concentrations and that the order of some macronutrients may be different depending on the plant species analyzed, which is to be expected due to the needs of individual plants.

The contents of Cu, Zn, and Fe in the root and aerial parts increased significantly with the addition of the different proportions of SS. These nutrients are directly related to electron transfer and act actively in the processes of photosynthesis (TAIZ; ZEIGER, 2017; TAIZ *et al*., 2021; ARECHE *et al*., 2023). Thus, it is possible to infer that for seedlings with higher values, as in T4, the field planting would have a good photosynthetic performance. On the other hand, the Mn content increased significantly up to the T3 treatment, while it remained unchanged for B (Table 5).

Table 5 - Micronutrient content in the aerial part and root of seedlings of *Jacaranda mimosifolia* D. Don. on different substrates.

Organs	Treat.	Cu	Zn	Fe	Mn	B
		mg kg^{-1}				
Aerial part	T1	5±0.01b	39±0.11d	204±0.10d	130±0.08d	20±0.10a
	T2	8±0.03ab	57±0.08c	235±0.08c	182±0.10c	22±0.11a
	T3	10±0.00a	87±0.10b	318±0.11b	257±0.06a	20±0.13a
	T4	12±0.01a	138±0.10a	434±0.10a	236±0.08b	20±0.09a
Root part	T1	8±0.12d	78±0.11d	351±0.12d	227±0.12d	16±0.01a
	T2	20±0.10c	162±0.10c	968±0.05b	269±0.10c	15±0.00a
	T3	32±0.08b	331±0.03b	914±0.08c	364±0.08a	18±0.02a
	T4	42±0.10a	560±0.05a	1200±0.10a	345±0.07b	15±0.01a

Note = Treat. - Treatment. T1 (50% commercial substrate Plantmax® + 50% organic compost from 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). Means ± standard deviation followed by the same letters in columns do not differ significantly by Tukey test at 1% level of error probability.
Source: Authors (2022).

The general order of micronutrient content evaluated in the root was Fe>Mn>Zn>Cu>B, and in the aerial part it was Fe>Mn>Zn>B>Cu (Table 5). It can be seen that the two vegetative structures analyzed had high contents of Fe and Mn and low contents of Cu for the root and B for the aerial part (Table 5). Fe, Mn, and Cu are linked mainly to redox processes, Zn to enzyme coupling, and B to reproductive structures, which are necessary for plant growth and development (TAIZ; ZEIGER, 2017). The studies of Toledo *et al.* (2013) and Melo *et al.* (2021), with the same SS concentrations in *H. dulcis* and *Eucalyptus urograndis* (*E. urophylla* S. T. Blake *X E. grandis* W. Hill ex Maiden), obtained the same result for the aerial part, with a difference only for the root, but the Fe had the highest concentrations. Thus, the results obtained in relation to these proportions can be considered viable for field planting.

According to Antunes *et al.* (2016) and Costa *et al.* (2023), the higher concentration of some micronutrients in the vegetative parts when SS is added may be due to the availability of these nutrients since these treatments have high concentrations. It is worth mentioning that contradictory results can be found in the literature regarding the dynamics of nutrient accumulation in plant tissues depending on the application of SS. However, it is necessary to consider the possibility of the effect of many factors, such as the chemical composition of SS, the time interval between soil application and tissue sampling for analysis, the characteristics of the studied plant species, and possible interactions with other factors. Nevertheless, it should be considered that SS is not a product with standardized chemical composition and properties, and that its properties may be influenced by the details of the composting process and the characteristics of the waste used (CALDEIRA *et al*., 2014).

Several researchers have tested SS in a wide variety of concentrations and with several native, exotic, and fruit tree species (DELARMELINA *et al*., 2013; MARQUES *et al*., 2018; SANTOS *et al*., 2019). It was found that SS has excellent results and shows beneficial effects when used as part of the composition of substrates, as shown in some works in the literature and this study.

The values of the addition of organic residues shown in this study infer stability for the main nutrients involved in plant growth and development. Organic fertilization is more interesting for the soil and the environment due to its environmental importance in nutrient cycling. Based on the results of this study, it can also be concluded that sewage sludge (SS) is an interesting raw material for the composition of substrates for the production of seedlings of forest species, especially *Jacaranda mimosifolia*.

CONCLUSION

The addition of sewage sludge to the substrate provided conditions for the growth and development of *Jacaranda mimosifolia* seedlings. In parameters height, stem base diameter, and seedlings biomass, as well as the content of macro and micronutrients in the plant tissues of this species these improvements were evident. The use of alternative substrates proves to be a viable option for cultivating this tree species. Based on the substrates analyzed in this study, a recommended mixture for the cultivation of *J. mimosifolia* consists of 60% sewage sludge and 40% organic compost (OC).

ACKNOWLEDGEMENTS

This study was financed in part by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

REFERENCES

ANDIVIA, E. *et al*. Climate and species stress resistance modulate the higher survival of large seedlings in forest restorations worldwide. **Ecological Applications**, v. 31, n. 6, e02394, 2021. https://doi.org/10.1002/eap.2394

ANTUNES, R. M. *et al*. Crescimento inicial de acácia-negra com vermicompostos de diferentes resíduos agroindustriais. **Ciência Florestal**, v. 26, n. 1, p. 1-9, 2016. https://doi.org/10.5902/1980509821060

ARECHE, F. O. *et al*. Recent and historical developments in chelated fertilizers as plant nutritional sources, their usage efficiency, and application methods. **Brazilian Journal of Biology**, v. 83, e271055, 2023. https://doi.org/10.1590/1519-6984.271055

BANDEIRA, S. B. *et al*. Qualidade de mudas de *Jacaranda cuspidifolia* produzidas em diferentes substratos. **Revista Brasileira de Agropecuária Sustentável**, v. 8, p. 79-84, 2018. https://doi.org/10.21206/rbas.v8i1.433

CALDEIRA, M. V. W. *et al*. Lodo de esgoto como componente de substrato para produção de mudas de *Acacia mangium* Wild. **Comunicata Scientiae**, v. 5, n. 1, p. 34-43, 2014.

CAMARGO, R. de *et al*. Diagnose foliar em mudas de pinhão-manso (*Jatropha curcas* L.) produzidas com biossólido. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 17, p. 283-290, 2013. https://doi.org/10.1590/S1415-43662013000300006

CARNEIRO, J. G. A. **Produção e controle de qualidade de mudas florestais**. Curitiba: UFPR/FUPEF, 1995. 451 p.

CASTRO, A. L. F. G. de; RODRIGUES, O.; SCALIZE, P. S. Cenário da disposição do lodo de esgoto: uma revisão das publicações ocorridas no Brasil de 2004 a 2014. **Multi-Science Journal**, v. 1, n. 2, p. 66-73, 2015. https://doi.org/10.33837/msj.v1i2.84

CAVALCANTI, H. S. *et al*. Decomposed babassu biomass: new substrate for the production of *Jacaranda mimosifolia* D. Don seedlings. **Floresta e Ambiente**, v. 28, n. 2, e20200045, 2021. https://doi.org/10.1590/2179-8087-FLORAM-2020-0045

CONAMA. Conselho Nacional do Meio Ambiente (CONAMA). **Resolução nº 375, de 29 de agosto de 2006**. Define critérios e procedimentos, para o uso agrícola de lodos de esgoto gerados em estações de tratamento de esgoto sanitário e seus produtos derivados, e dá outras providências. Disponível em: http://www.mma.gov.br/port/conama/res/res06/res37506.pdf. Acesso em: 24 set. 2023.

CORDEIRO, I. M. C. C. *et al*. Crescimento e sobrevivência de espécies nativas plantadas em florestas em diferentes estágios de sucessão após pastagem. **Natural Resources**, v. 11, n. 3, p. 20-32, 2021. https://doi.org/10.6008/CBPC2237-9290.2021.003.0004

COSTA, A. L. *et al.* Proportions of sewage sludge in the production and quality of *Malpighia emarginata* DC. seedlings. **Brazilian Journal of Biology**, v. 83, e274643, 2023. https://doi.org/10.1590/1519-6984.274643

DALANHOL, S. J. *et al.* Efeito de micorrizas e da fertilização no crescimento de mudas de *Campomanesia xanthocarpa* (Mart.) O. Berg., produzidas em diferentes substratos. **Ciência Florestal**, v. 27, n. 3, p. 931-945, 2017. https://doi.org/10.5902/1980509828665

DELARMELINA, W. M. *et al*. Uso de lodo de esgoto e resíduos orgânicos no crescimento de mudas de *Sesbania virgata* (Cav.) Pers. **Revista Agroambiente**, v. 7, n. 1, p. 184-192, 2013. https://doi.org/10.18227/1982-8470ragro.v7i2.888

DICKSON, A.; LEAF, A. L.; HOSNER, J. F. Quality appraisal of white spruce and white pine seedling stock in nurseries. **Forestry Chronicle**, v. 36, p. 10-13, 1960. https://doi.org/10.5558/tfc36010-1

DIONÍSIO, L. F. S. *et al*. Production of *Bertholletia excelsa* Humb. & Bonpl., (Lecythidaceae) seedlings in micro environments under different substrates. **Revista Brasileira de Ciências Agrárias**, v. 14, n. 3, 2019. https://doi.org/10.34117/bjdv6n6-414

ESTAT 2.0. **Sistema de análise estatística**. Pólo Computacional do Departamento de Ciências Exatas da UNESP, Jaboticabal. 1994.

FALSTER, D. S.; DUURSMA, R. A.; FITZJOHN, R. G. How functional traits influence plant growth and shade tolerance across the life cycle. **Proceedings of the National Academy of Sciences**, v. 115, n. 29, e6789-e6798, 2018. https://doi.org/10.1073/pnas.1714044115

FARIA, J. C. T. *et al*. Uso de resíduos orgânicos na produção de mudas de *Senna alata* (L.) Roxb. **Ecologia e Nutrição Florestal**, v. 1, n. 3, p. 133-146, 2013. https://doi.org/10.5902/2316980X14754

FARIA, J. C. T. *et al.* Substratos alternativos na produção de mudas de *Minosa setosa* Benth. **Ciência Florestal**, v. 26, n. 4, p. 1075-1086, 2016. https://doi.org/10.5902/1980509824996

FARIAS-SINGER, R. ***Jacaranda* in Flora e Fungi do Brasil.** Jardim Botânico do Rio de Janeiro. Disponível em: https://floradobrasil.jbrj.gov.br/FB623001. Acesso em: 13 set. 2023.

FREITAS, A. R. de *et al*. Emergência e crescimento de mudas de maracujá doce em função de lodo de esgoto e luz. C**omunicata Scientiae**, v. 4, n. 4, p. 342-351, 2005.

FREITAS, E. C. S. de *et al*. Efeito da fertilização de fosfato e saturação base de substrato no crescimento e qualidade de mudas de *Plathymenia foliolosa* Benth. **Revista Árvore**, v. 41, n. 1, 2017. https://doi.org/10.1590/1806-90882017000100011

GOMES, D. R. *et al*. Lodo de esgoto como substrato para produção de mudas de *Tectona grandis* L. **Cerne**, v. 19, p. 123-131, 2013. https://doi.org/10.1590/S0104-77602013000100015

GONÇALVES, E. P. *et al*. Umedecimento do substrato e temperatura na germinação de sementes de *Parkia platycephala* Benth. **Ciência Florestal**, v. 25, n. 3, p. 563-569, 2015. https://doi.org/10.5902/1980509819607

GONDIM, F. A. *et al*. Avaliação das características germinativas e de crescimento e de crescimento em mamoneira cultivada em diferentes resíduos orgânicos agroindustriais. **Holos**, v. 6, n. 35, 2019. https://doi.org/10.15628/holos.2019.7572

KLAFE, A. *et al*. Phytoremediation: mechanisms, plant selection and enhancement by natural and synthetic agents. **Environmental Advances**, v. 8, 2022. https:doi.org/10.1016/j.envadv.2022.100203

KRATZ, D.; WENDLING, I.; PIRES, P. P. Miniestaquia de *Eucalyptus benthamii* x *E. dunnii* em substratos a base de casca de arroz carbonizada. **Scientia Forestalis**, v. 40, p. 547-556, 2012.

LABOURIAU, L. F. G.; VALADARES, M. E. B. On the germination of seeds of *Calotropi sprocera*. **Anais da Academia Brasileira de Ciências**, v. 48, n. 2, p. 263-184, 1976.

LEAL, C. C. P. *et al*. Emergência e desenvolvimento inicial de plântulas de *Cassia grandis* L. f. em função de diferentes substratos. **Ciência Florestal,** v. 26, n. 3, p. 727-734, 2016. https://doi.org/10.5902/1980509824196

LIMA FILHO, P. *et al*. Produção de mudas de *Ceiba speciosa* em diferentes volumes de tubetes utilizando o biossólido como substrato. **Ciência Florestal**, v. 29, n. 1, p. 27-39, 2019. https://doi.org/10.5902/1980509819340

MARQUES, A. R. F. *et al*. Produção e qualidade de mudas de *Psidium cattleianum* var. *cattleianum* Sabine (Myrtaceae) em diferentes substratos. **Acta Biológica Catarinense**, v. 5, n. 1, p. 5-13, 2018. https://doi.org/10.21726/abc.v5i1.283

MELO, H. S. *et al*. Uso de lodo de esgoto na produção e na qualidade de mudas e teores de nutrientes em *Hovenia dulcis* (Rhamnaceae). **Iheringia: Série Botânica**, v. 76, e2021020, 2021. https://doi.org/10.21826/2446 82312021v76e2021020

MENDOZA, Z. H. A. *et al.* Sobrevivencia, mortalidad y crecimiento de tres especies forestales plantadas en matorral andino en el sur del Ecuador. **Revista Cubana de Ciencias Forestales**, v. 7, n. 3, p. 325-340, 2019.

MISSIO, A. L. *et al.* Physical and mechanical properties of fast-growing wood subjected to freeze-heat treatments. **BioResources**, v. 11, n. 4, p. 10378-10390, 2016.

MIYAZAWA, M.; PAVAN, M. A.; MURAOKA, T. Análises químicas de tecido vegetal. *In*: **Manual de análises químicas de solo, plantas e fertilizantes**. SILVA, F. C. (Org). Embrapa Comunicação para Transferência de Tecnologia, Brasília, 1999. p. 171-224.

MORALES, D. A. *et al*. Utilização dos diferentes vermicompostos produzidos a partir de resíduos da estação de tratamento de efluentes como substrato para produção de mudas de alface. **Revista Ciência e Natura**, v. 35, n. 1, p. 055-063, 2013. https://doi.org/10.5902/2179460X9592

MOTA, M. V. S. *et al.* Chewing insects, pollinators, and predators on *Acacia auriculiformis* A. Cunn. ex Beth (Fabales: Fabaceae) plants fertilized with dehydrated sewage sludge. **Brazilian Journal of Biology**, v. 83, e248305, 2021. https://doi.org/10.1590/1519-6984.248305

PEREIRA, M. D. A.; COSTA, F. P.; ALMEIDA, R. G. de. Is the ‘‘F Word’’ an option for Brazilian farmers? The place of forestry in future integrated farming systems. **International Journal of Agricultural Management**, v. 6, n. 1029, p. 134-140, 2018. https://doi.org/10.22004/ag.econ.287298

SANTOS, F. E. V.; CALDEIRA, M. V. W.; KUNZ, S. H. Qualidade de mudas de *Parapiptadenia rigida* (Benth.) Brenan produzidas em diferentes substratos com lodo de esgoto e casca de arroz. **Ecologia e Nutrição Florestal**, v. 1, n. 2, p. 55-62, 2013.

SANTOS, R. P. dos *et al*. Efeito do lodo de esgoto na produção e nutrição de mudas de angico-vermelho (*Parapiptadenia rigida* (Benth.) Brenan). **Ecologia e Nutrição Florestal**, v. 7, 2019. https://doi.org/10.5902/2316980X36959

SERRANO, D. M. C. Sistema agroflorestal com espécies nativas de valor madeireiro, como alternativa sustentável para o uso da terra na Chapada Diamantina. **Cadernos Macambira**, v. 2, n. 2, p. 231-235, 2017.

SILVA, J. L. *et al*. Phytophagous insects and natural enemies on *Sapindus saponaria* L. (Sapindales: Sapindaceae) plants fertilized with or without dehydrated sewage sludge. **Brazilian Journal of Biology**, v. 83, e271509, 2023. https://doi.org/10.1590/1519-6984.271509

SILVEIRA, C. E. *et al*. A micropropagation protocol for the domestication of *Jacaranda ulei* (Bignoniaceae). **Phyton**, v. 58, 2-18, 2018. https://doi.org/10.12905/0380.phyton58(2)-2018-0165

SOARES, C. B. *et al*. Nitrogen sources and doses on growt and quality of seedlings of *Cassia grandis* and *Peltophorum dubium* L. **Revista Árvore**, v. 41, n. 2, 2017. https://doi.org/10.1590/1806-90882017000200014

TAIZ, L.; ZEIGER, E. **Fisiologia e desenvolvimento vegetal**. 6. ed. Porto Alegre: Artmed, 2017. 858 p.

TAIZ, L. *et al*. **Fundamentos de fisiologia vegetal**. Porto Alegre: Artmed, 2021. 558 p.

TEDESCO, M. J. *et al.* **Análise de solos, plantas e outros materiais.** Porto Alegre: UFRGS (Boletim Técnico), 1995. p. 174.

TOLEDO, F. H. S. F. de *et al*. Influência da qualidade química do substrato no teor de nutrientes em folhas de mudas de eucalipto. **Ecologia e Nutrição Florestal**, v. 1, n. 2, p. 89-96, 2013.

TRAZZI, P. A. *et al*. Substratos de origem orgânica para produção de mudas de teca (*Tectona grandis* Linn. F.). **Ciência Florestal**, v. 23, n. 3, p. 401-409, 2013.

WU, W. *et al.* The diverse roles of cytokinins in regulating leaf development. **Horticulture Research,** v. 8, n. 118, p. 1-13, 2021. https://doi.org/10.1038/s41438-021-00558-3