USE OF AGROMINERAL AS SUBSTRATE FOR GROWTH OF EUCALYPTUS SEEDLINGS

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Resumo

Uso de agromineral como substrato para o crescimento de mudas de eucalipto. O sucesso na produção de mudas de eucalipto afeta diretamente o desenvolvimento das plantas a campo. Vários fatores influenciam no crescimento inicial dentre estes, destaca-se o substrato. Este estudo tem como objetivo avaliar o crescimento de mudas de *Eucalyptus globulus* e as características químicas e físicas do substrato com uso de agromineral silicático (AS) em diferentes proporções (substrato: AS; v/v): T0 – 100:00%, T1 – 90:10%, T2 – 80:20%, T3 – 50:50%. Os tratamentos foram avaliados por meio de delineamento inteiramente casualizado. Medidas de altura (H), diâmetro do coleto (DC) e a relação H/DC das plantas foram tomadas a cada 3 semanas, totalizando 4 medições. Ao término do experimento (12 semanas), amostras dos substratos foram analisadas quanto a fertilidade, granulometria (areia, silte e argila) e composição química total. Em função da composição química e mineralógica do AS, o seu uso no substrato, em maior proporção (T3), promoveu o aumento dos teores trocáveis de K, Ca e Si, elevando a soma de bases e a capacidade de troca catiônica. Os teores de P assimilável e dos micronutrientes Fe, Cu, Zn e Mn também foram maiores neste tratamento. O aumento das proporções de AS na composição do substrato também favoreceu o incremento da fração areia e redução da fração argila. Quanto ao crescimento das mudas, os resultados não foram significativos para H e DC em função das doses de AS, levando a constatar que o a solubilização e liberação lenta de nutrientes pelo AS não influenciou no crescimento das plantas.
Palavras-chaves: rochagem, remineralizador, reflorestamento, viveiros florestais, silvicultura.

Abstract

Success in the production of eucalyptus seedlings directly affects the development of plants in the field. Several factors influence their initial growth, especially the substrate. This study aimed to evaluate the growth of *Eucalyptus globulus* seedlings and characteristics of the substrate using silicate agromineral (SA) in different proportions (substrate:SA; v/v): T0 – 100:00%, T1 – 90:10%, T2 – 80:20%, and T3 – 50:50%. The treatments were evaluated using a completely randomized design. Measurements of height (H), stem diameter (SD) and calculation of the H/SD ratio of the plants were performed every 3 weeks, totaling 4 measurements. At the end of the experiment (12 weeks), soil fertility analyses, granulometric analysis (sand, silt and clay) and total chemical analysis were carried out. Due to the chemical and mineralogical composition of SA, its use in substrate in a greater proportion (T3) promoted the increase of exchangeable K, Ca and Si contents, which influenced the increase in the sum of bases and cation exchange capacity. The levels of assimilable P and micronutrients Fe, Cu, Zn and Mn were also higher in this treatment. The increase in SA proportions in the substrate composition also favored increase in the sand fraction and reduction in the clay fraction. As for the growth of seedlings, the results were not significant for H and SD as a function of SA doses, leading to the conclusion that the solubilization and slow release of nutrients by SA did not influence the growth of the plants.
Keywords: rock powder, remineralizer agrominerals, reforestation, forest nurseries, silviculture.

INTRODUCTION

The production of quality forest seedlings is one of the most important steps in the establishment of planted forests (EHLERS; ARRUDA, 2014; KNAPIK; ANGELO, 2007; PRATES *et al*., 2012; REIS *et al*., 2008; WELTER *et al*., 2011), since the quality of the seedling directly influences the survival and initial growth of plants after planting, impacting the productivity of reforestation (EHLERS; ARRUDA, 2014; PRATES *et al*., 2012; WOLSCHICK *et al*., 2016).

For the production of quality seedlings it is important that the substrates have characteristics such as biological sterility to avoid contamination by pathogens, good cation exchange capacity associated with good fertility levels, thus providing the nutritional supply for seedling growth, besides having adequate values of pH, electrical conductivity and C/N ratio. In relation to physical aspects, the substrate must be stable and promote an adequate water/air ratio, associated with a level of total porosity that favors both water retention and drainage (ALVES; FREIRE, 2017; EHLERS; ARRUDA, 2014). As these characteristics are hardly found in a single material, sometimes it is necessary to mix more than one component to obtain a desirable combination for the species to be grown. This favors the use of unconventional inputs, even to reduce costs in the production of the substrate, since the availability of a certain component is directly related to its region of occurrence (ALVES; FREIRE, 2017; EHLERS; ARRUDA, 2014).

Among the components used in the substrates for the production of forest seedlings are vermiculite, organic compost, bovine manure, earthworm humus, peats, charcoal fines, subsoil, sawdust, sugarcane bagasse, Pine needle, carbonized rice husk among others (ALVES; FREIRE, 2017). Silicate agrominerals (SAs) have also been indicated as potential components in the formulation of substrates for seedlings (EHLERS; ARRUDA, 2014; KNAPIK; ANGELO, 2007; PRATES *et al*.; 2010; 2012; SILVA *et al*., 2012a). SAs consist of mineral materials that have been subjected to physical processes of grinding and sieving and their use aims to improve the chemical, physical and/or biological properties of soils, favoring the performance of cultivated plants (BRASIL, 2013). SAs have as premise the use of by-products from the mining industry aiming at reducing the use of synthetic fertilizers as well as reducing the risk of them becoming an environmental liability (TOSCANI; CAMPOS, 2017).

In general, SAs are considered multielement, that is, they can provide more than one nutrient, including phosphorus, potassium, calcium and/or magnesium, in addition to a series of micronutrients (Fe, Cu, Mn and Zn). Other benefits of the use of this input are the increase in pH and CEC values (SILVA *et al*., 2012b; SILVA *et al*., 2017; TOSCANI; CAMPOS, 2017). The quantity and elements to be supplied depend, among other factors, on the size of the particles and on the mineralogical and chemical composition of the rock of origin (RAMOS *et al*., 2015).

Thus, the use of SAs as a substrate component can promote the release of nutrients to the seedlings, favor aeration and drainage, facilitate the reduction of production costs and also contribute to minimizing negative environmental impacts resulting from the accumulation of the by-product in mining companies. Studies on the effect of SAs on soil microbiota reveal the potential of this input for use in soils (SUGUINO *et al*., 2011; SILVA *et al*., 2012a), while Silva *et al*. (2012a) state that SA is an alternative as substrate for seedling production, raising the pH and contents of exchangeable cations, including Ca, Mg and Si, in substrates for cultivation of *Eucalyptus benthamii* seedlings.

In Brazil, most forest plantations for industrial purposes are concentrated in the South and Southeast regions, and one of the most important species is *Eucalyptus globulus*, given its tolerance to growth at low temperatures and because it is one of the species of greatest economic interest for the paper industry, due to the best yields for cellulose production, since the lower lignin contents in the wood result in a lower demand for chemicals during the bleaching process (CARDOSO *et al.*, 2011). Based on the hypothesis that the use of SA may favor the chemical and physical properties of the substrate, ultimately influencing the initial growth of seedlings, the present study aimed to characterize the properties of a SA and evaluate how its addition to the substrate, at different doses, can influence the chemical and physical characteristics of the substrate and the growth of *Eucalyptus globulus* Labill. seedlings.

MATERIALS AND METHODS

The experiment was set up and conducted in a commercial seedling nursery located in the municipality of Piracicaba-SP, Brazil (coordinates -22.735926 S; -47.528435 W). The climate of the region is Aw type (tropical with dry winter), according to Köppen's classification and determined by Alvares *et al.* (2013). According to the climatological data series of the Campus of the "Luiz de Queiroz" College of Agriculture (ESALQ/USP) of Piracicaba, SP, obtained for the period from 2000 to 2014, the average relative humidity of the region is 76%, with maximum, minimum and mean temperatures of 28.9, 16.0 and 22.5 ºC, respectively, and average annual rainfall of 1260 mm.

The substrate used was produced from the homogeneous mixture of soil (taken from the B horizon of a *Latossolo Vermelho Distrófico* - Oxisol) and aged bovine manure, in a 4:1 ratio (v/v), both passed through a 2-mm-mesh sieve. A sample of this substrate (soil+manure) was collected before transplanting the seedlings and used for chemical and physical characterization. The SA used was obtained from a quarry that commercially exploits a sill located in the municipality of Limeira-SP. The sill has rocks with different chemical compositions, from quartz-monzodiorite to basalt. A sample of SA was also collected for physical, chemical and mineralogical characterization.

Four treatments with different proportions of SA added to the substrate (v/v) were evaluated: T0 = 0% SA and 100% substrate; T1 = 10% SA and 90% substrate; T2 = 20% SA and 80% substrate; T3 = 50% SA and 50% substrate. Each treatment was composed of 16 replicates, one plant per replicate, distributed in a completely randomized design.

Polyethylene bags, with approximately 5 L, were filled with the treatments and received the transplanted clonal seedlings of *Eucalyptus globulus* produced in tubes and acquired with an initial size of approximately 25 cm and four to five pairs of leaves. According to the routine management of the nursery, a MAP solution (approximate composition of 11% N and 80% P) was applied in all seedlings, irrigation was performed manually every day and the seedlings were grown in full sun.

The morphological parameters chosen to evaluate seedling growth were shoot height (H), stem diameter (SD) and height/diameter ratio (H/SD), for being easy and non-destructive measurements, besides being universally accepted to predict the development potential of seedlings after planting (IVETIĆ *et al*., 2016). H was measured from the substrate level to the tip of the last leaf using graduated ruler, and SD was measured with a caliper, at the substrate level. These evaluations were performed every three weeks, totaling 4 measurements. At the end of the plant growth evaluation period (12 weeks), aiming at analyzing the changes in soil properties promoted by the use of SA, soil samples of the treatments were collected and sent to the soil analysis laboratory for fertility purposes (RAIJ *et al*., 2001), to determine the pH value, the exchangeable contents of Ca, Mg, K, P, Al, Na and Si, in addition to the contents of micronutrients (Fe, Cu, Zn and Mn). Potential acidity (H+Al) was determined by the Shoemaker, Mac Lean and Pratt buffer method (SMP) and the values of sum of bases (SB = Ca + Mg + K) and potential CEC (CEC = SB + H + Al) were calculated. Physical characterization of the substrate was performed by means of particle-size analysis using the hydrometer method (TEIXEIRA *et al*., 2017), to obtain the proportions of sand, silt and clay and quantify the degree of flocculation.

Samples of SA and soil of the treatments (after experiment) were subjected to total chemical analysis by the method of $LiBO_2/Li_2B_4O_7$ fusion at 1000 ºC, followed by acid dissolution in HNO_3 + HCl solution and extract analysis by Inductively Coupled Plasma - Atomic Emission Spectrometry (ICP-AES). Based on the obtained values, the difference between treatments with SA (T1, T2 and T3) and T0 was calculated, and the obtained value corresponded to the influence of SA on the chemical composition of the substrate.

The mineralogical characterization of SA was performed by X-ray diffraction (XRD), using a Rigaku Miniflex II benchtop diffractometer, with irradiation between 5 and 60º 2θ, CuKα radiation, 30kV and 15 mA, with the presence of Ni filter and NaI scintillator. The generated diffractogram was processed in Match! Software (V.3. Crystal Impact). Particle-size analysis of the SA was also performed by the hydrometer method.

The data obtained were subjected to statistical analyses to evaluate the homogeneity and normality of variances. After normality and homogeneity were confirmed, analyses of variance (ANOVA) and means comparison tests (Bonferroni test) at 10% probability level were performed using Sisvar software. The growth of the seedlings as a function of time was expressed using the regression method, with XLStat software.

RESULTS

The SA has in its chemical composition: 52.10% of SiO_2, 14.45% of Fe_2O_3, 11.90% of Al_2O_3, 6.94% of CaO, 3.45% of MgO, 3.06% of Na_2O, 1.59% of K_2O, 3.27% of TiO_2 and 0.75% of P_2O_5. The predominance of Si, Fe and Al is due to the mineralogical composition of the SA (Figure 1), whose main minerals are plagioclases and clinopyroxenes. This composition is typical of basic rocks (basalt/diabase), which are also characterized by having minerals such as ilmenite, magnetite (Fe sources), apatite (main source of P) and potassium feldspars (source of K) as accessory minerals. Other elements, considered micronutrients for plants, are also identified, especially Cu, Zn and Mn (27.3; 145.0; and 1680 mg kg^{-1}, respectively) and Co (28.7 mg kg^{-1}). The SA also has levels considered low of potentially toxic elements, such as Cd (0.14 mg kg^{-1}) and Pb (4.9 mg kg^{-1}), and whose limits are controlled for agricultural use (BRASIL, 2013).

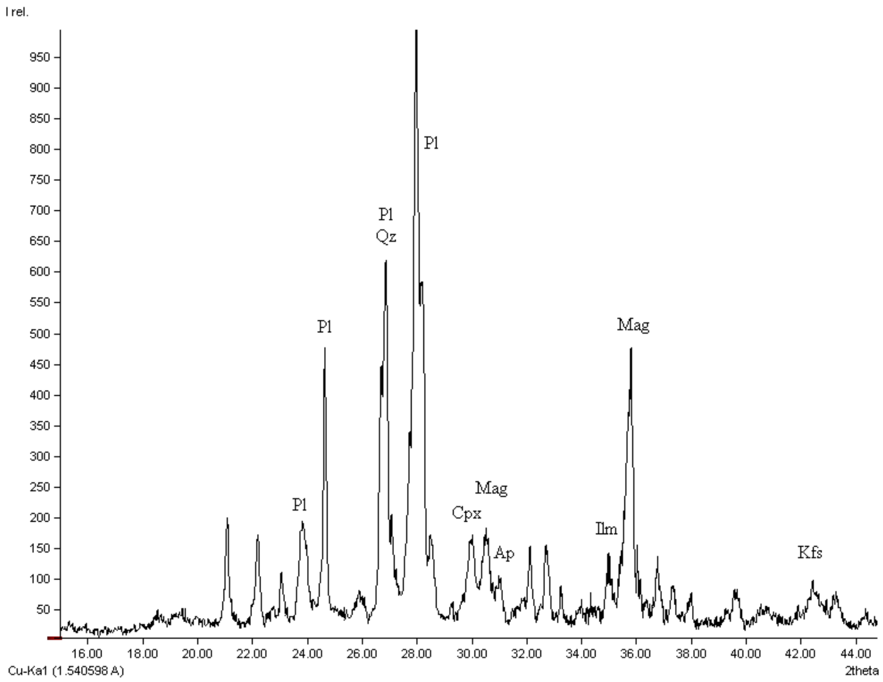

Figure 1. X-ray diffractogram of the remineralizer. Pl: plagioclase; Qz: quartz; Cpx: clinopyroxene; Mag: magnetite; Ilm: ilmenite; Kfs: K feldspar.

Figura 1. Difratograma de raio-X do agromineral silicático. Pl: plagioclásio; Qz: quartzo; Cpx: clinopiroxênio; Mag: magnetita; Ilm: ilmenita; Kfs: feldspato potássico.

The application of SA doses to the substrate resulted in changes in its chemical properties (Table 1). The substrates showed mild acidity, with pH values ranging from 5.5 to 6.0 and the contents of exchangeable aluminum, which is toxic to plants, remained equal to zero in all treatments. Potassium and magnesium contents were higher in T0 and T3 and lower in intermediate treatments, while calcium contents were higher in T3, followed by T2, which also resulted in the higher SB values. With regard to phosphorus and silicon, there was an increase in their contents as a function of the addition of SA in the highest proportion (T3). Sodium contents did not differ as a function of the treatments, but were noticeably higher when compared to the substrate sample analyzed before planting the seedlings.

Table 1. Mean[1] contents of exchangeable cations in the substrates before and after 12 weeks of development of *E. globulus* seedling and subjected to different doses of silicate agromineral (SA).

Tabela 1. Teores médios[1] de elementos do complexo sortivo dos substratos antes e após 12 semanas de desenvolvimento de mudas de *E. globulus* e submetidos a diferentes doses de agromineral silicático (AS).

Treatments[2]	pH	K	Ca	Mg	Al	H+Al	SB	CEC	P	Na	Si
		----------------- mmol$_c$ dm^{-3} -----------------							---- mg dm^{-3} ----		
Substrate[3]	5	1.1	15	6	0	28	22.1	50.1	2	17	10
T0	**6.0 a**	**4.5 a**	47 b	**14 a**	0 a	20.4b	65.4b	85.8b	180bc	253 a	17 c
T1	5.5 b	1.2 b	29 c	7 c	0 a	**24.6a**	37.0c	61.6c	128 c	288 a	15 bc
T2	5.6 b	2.1 b	55 b	8 bc	0 a	**23.1a**	60.2b	88.0b	228 b	273 a	19 ab
T3	5.6 b	**3.8 a**	**112 a**	10 b	0 a	20.8b	**126.4a**	147.3a	**459 a**	310 a	**21 a**
CV%	3.66	43.76	23.78	21.40	-	11.03	22.46	15.75	21.80	26.58	13.57

[1]Mean of 16 repetitions. Means followed by the same letter in the column do not differ from each other by the Bonferroni test at 10% significance level.
[2]Treatments: T0, substrate without SA; T1, substrate with 10% SA; T2, substrate with 20% SA; T3, substrate with 50% SA. [3]Substrate sample without SA analyzed before planting. CV%: Coefficient of Variation.

The application of SA in the highest proportion (T3; 50% SA) resulted in an increase in the contents of iron, copper, zinc and manganese (Table 2), with decrease in the contents as a function of the reduction in the proportion of SA in the substrate. Moreover, in all treatments, there was an increase in the contents of these elements compared to the substrate analyzed before planting.

Table 2. Mean[1] contents of micronutrients in substrates cultivated with *E. globulus* and subjected to different doses of silicate agromineral (SA).

Tabela 2. Teores médios[1] de micronutrientes nos substratos cultivados com *E. globulus* e submetidos a diferentes doses de agromineral silicático (AS).

Treatments[2]	Fe	Cu	Zn	Mn
	mg dm^{-3}			
Substrate[3]	10	2.2	0.4	7
T0	15 d	**2.9 a**	2.6c	12 bc
T1	24 c	2.6 b	1.8c	11 c
T2	35 b	**2.9 a**	4.5b	14 b
T3	**61 a**	**3.1 a**	**8.1a**	**17 a**
CV%	23.66	10.00	25.04	18.02

[1]Mean of 16 repetitions. Means followed by the same letter in the column do not differ from each other by the Bonferroni test at 10% significance level.
[2]Treatments: T0, substrate without SA; T1, substrate with 10% SA; T2, substrate with 20% SA; T3, substrate with 50% SA. [3]Substrate sample without SA analyzed before planting. CV%: Coefficient of Variation.

The calculations performed based on the total chemical analysis show that SiO_2, CaO, MgO, Na_2O and K_2O had increments in their contents as a function of the increase in the proportions of SA. MnO and P_2O_5 also showed increments, but to a smaller extent, due to the lower concentrations of these elements in the composition of the SA (Figure 2). For Fe_2O_3 and Al_2O_3, the contents were lower in T3 than in T0, resulting in negative values, that is, there was loss of these elements in T3 or even a decrease in proportion compared to the other elements.

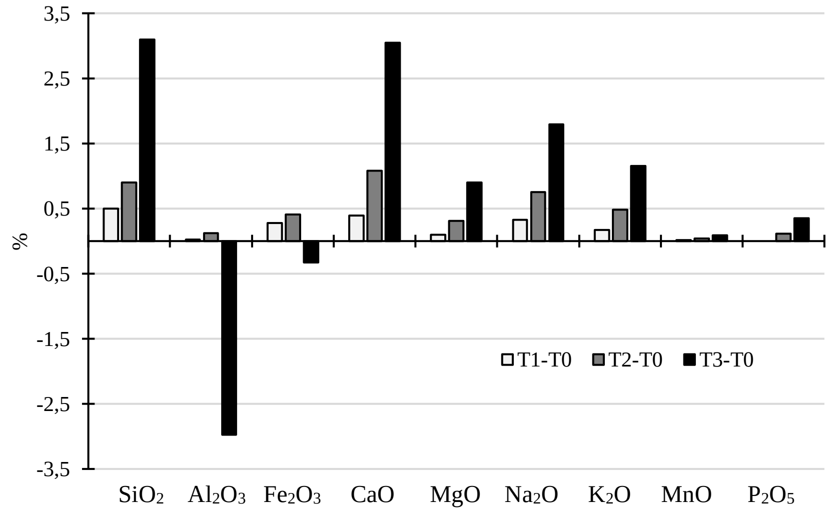

Figure 2. Difference in the total chemical composition of treatments with silicate agromineral (SA) (T1, substrate with 10% SA; T2, substrate with 20% SA; T3, substrate with 50% SA) as a function of T0 (substrate without SA).

Figura 2. Diferença na composição química total dos tratamentos com agromineral silicático (AS) (T1 substrato com 10% de AS; T2 substrato com 20% de AS; T3 substrato com 50% de AS) em função de T0 (substrato sem AS).

Regarding the distribution of particles in the substrates of the treatments (Table 3), it is possible to observe the increase of sand fraction as a function of the addition of SA, which influenced the contents from very coarse sand (VCS) to very fine sand (VFS), as well as the total sand (TS) contents. This pattern is due to the predominance of sand-sized particles in the SA (830 g kg^{-1} in TS), compared to the soil (320 g kg^{-1}). On the other hand, the increase of SA in the substrate did not alter the silt contents, although the SA contained about 40% more silt compared to the soil. For clay contents, there was a decrease in the proportion of this fraction as a function of the increase in the proportion of SA in the substrate, associated with the fact that the SA has low content of clay-sized minerals (15 g kg^{-1}), compared to the soil (592 g kg^{-1}). This reduction of clay contents in T2 and T3 also affected the percentage of flocculated clay, with decrease in these two treatments.

Table 3. Mean[1] values of particle-size fractions of substrates subjected to different doses of silicate agromineral (SA).

Tabela 3. Valores médios[1] das frações granulométricas dos substratos submetidos a diferentes doses do agromineral silicático (AS).

Treatments[2]	VCS	CS	MS	FS	VFS	TS	Silt	Clay	%DF
	g kg^{-1}								
SA	224	235	137	146	88	830	155	15	-
Substrate[3]	4	7	65	174	70	320	88	592	86
T0	18 b	11 d	67 d	159 c	70 b	325 d	82 a	**593 a**	**87 a**
T1	9 c	28 c	79 c	166 b	72 b	355 c	78 a	567 b	**86 a**
T2	17 b	63 b	105 b	170 b	74 b	429 b	79 a	492 c	83 b
T3	**30 a**	**124 a**	**150 a**	**182 a**	**85 a**	**571 a**	85 a	344 b	73 c
CV%	14.03	18.11	7.92	2.87	9.16	5.68	11.57	4.85	3.07

[1]Mean of 16 repetitions. Means followed by the same letter in the column do not differ from each other by the Bonferroni test at 10% significance level.
VFS: Very fine sand; FS: Fine sand; MS: Medium sand; CS: Coarse sand; VCS: Very coarse sand; %DF: Degree of flocculation.
[2]Treatments: T0, substrate without SA; T1, substrate with 10% SA; T2, substrate with 20% SA; T3, substrate with 50% SA. [3]Substrate sample without SA analyzed before planting. CV%: Coefficient of Variation.

Regarding the evaluation of morphological parameters, the means of both height and stem diameter of eucalyptus seedlings did not differ as a function of the treatments (Table 4). An increase in the value of H/SD ratio was observed only in T2, in the third measurement, but it becomes equal to the other treatments in the following measurement.

Table 4. Means[1] of height and diameter of *E. globulus* seedlings as a function of time and different doses of silicate agromineral (SA).

Tabela 4. Média[1] das alturas e diâmetro de mudas de *E. globulus* em função do tempo e diferentes doses de agromineral silicático (AS).

Treatments[2]	Height (H) of plants (cm)			
	1st measurement	2nd measurement	3rd measurement	4th measurement
T0	56.9 a	66.7 a	72.5 a	80.3 a
T1	61.3 a	73.9 a	79.2 a	84.8 a
T2	56.2 a	68.9 a	78.6 a	84.4 a
T3	57.3 a	71.4 a	78.6 a	83.6 a
CV%	15.23	11.50	2.83	2.78
	Stem diameter (SD) of plants (mm)			
T0	3.8 a	5.1 a	5.7 a	6.4 a
T1	3.8 a	5.4 a	5.9 a	6.7 a
T2	3.7 a	4.7 a	5.3 a	6.1 a
T3	4.0 a	5.3 a	5.9 a	6.5 a
CV%	18.84	17.24	8.82	8.78
	H/SD ratio			
T0	15 a	13 a	13 b	13 a
T1	17 a	14 a	14 ab	13 a
T2	15 a	15 a	**15 a**	14 a
T3	15 a	14 a	14 ab	13 a
CV%	19.72	16.67	2.67	3.28

[1]Mean of 16 repetitions. Means followed by the same letter in the column do not differ from each other by the Bonferroni test at 10% significance level.
[2]Treatments: T0, substrate without SA; T1, substrate with 10% SA; T2, substrate with 20% SA; T3, substrate with 50% SA. CV%: Coefficient of Variation.

The growth of seedlings was evaluated as a function of time in the different treatments (Figure 3) and, according to the results, it was similar in all treatments, for both height (Figure 3A) and stem diameter (Figure 3B). Regarding height, T0 maintained the lowest mean values and linear behavior, while the other treatments showed a logarithmic growth pattern. Also in the measurements of stem diameter, the predominant behavior of the treatments was logarithmic, except for T2, which was represented by a line, and with mean values lower than those found in the other treatments. For both parameters, T1 led to higher mean values over time, standing out for height in the 1st (approximately 7% higher than T0) and 2nd (approximately 11% higher than T0) evaluation.

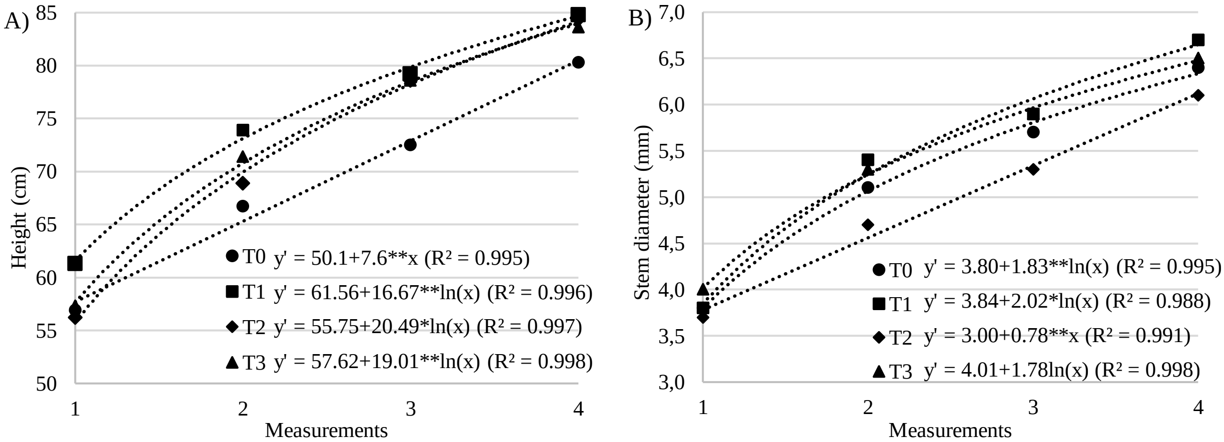

Figure 3. Variation of height (A) and stem diameter (B) of *E. globulus* seedlings as a function of time (4 measurements). Treatments: T0, substrate without silicate agromineral (SA); T1, substrate with 10% SA; T2, substrate with 20% SA; T3, substrate with 50% SA. **significant at 5%, *significant at 10% probability level.

Figura 3. Variação da altura (A) e do diâmetro do coleto (B) de mudas de *E. globulus* em função do tempo (4 medições). Tratamentos: Tratamentos: T0, substrato sem agromineral silicático (AS); T1 substrato com 10% de AS; T2 substrato com 20% de AS; T3 substrato com 50% de AS. **significativo a 5%, *significativo a 10% de probabilidade.

DISCUSSION

The main minerals of SA are plagioclases and clinopyroxenes, which are a source of nutrients such as Si, Ca, Mg and Na, in addition to Fe and Mn (RAMOS *et al*., 2015; SILVA *et al*., 2012; TOSCANI; CAMPOS, 2017) (Figure 1). Based on these properties, it was possible to observe changes in soil chemical composition after the 12 weeks (84 days) of seedling development, mainly for Ca, K and Mg contents, which in turn influenced the SB and CEC levels (Table 1). On the other hand, the increase in Cu and Zn contents in the soil was the result of the use of SA and is due to the isomorphic substitution that occurs in silicates and in ferromagnesian minerals, mainly pyroxenes (SILVA *et al*., 2012b).

Similar behavior for the increase in K contents with the application of SA in the substrate was identified by Silva *et al*. (2012a), who indicate that, despite the slow solubility, the element was released into the soil in adequate quantity. The authors also point out that slow and gradual availability of K may be favorable, as it reduces possible leaching losses and promotes the supply of the nutrient for a longer period. In addition, according to Silva *et al*. (2012a), an increase of up to 7 $mmol_c\ dm^{-3}$ of Ca was observed in the soil after incubation of SA for 100 days, which also contributed to changes in the values of SB. On the other hand, the increase in CEC, which was observed in T3, may be associated both with the increase in the release of bases, such as Ca, Mg, and K, by the SA, and with the neoformation of clay minerals, possibly amorphous mineral compounds of Fe and Al, as assumed by Silva *et al.* (2017). Despite the high levels of Fe and Al in the composition of SA, the formation of these amorphous compounds also justifies the low levels of exchangeable Fe and Al in the soil solution (Silva *et al.* 2017).

However, even with the increase in the contents of bases, the mean pH values were higher for T0, when compared to the other treatments, contradicting other studies that reported increase in soil pH as a function of the application and dissolution of SA (RIBEIRO *et al*., 2010; SILVA *et al*., 2012a; 2012b; SILVA *et al*., 2017; TOSCANI; CAMPOS, 2017). This effect may be associated with the evaluation time of the experiment, which was relatively short, compared to other studies that point to the release of nutrients from SA for more than one year (SILVA *et al*., 2017). Silva *et al.* (2012a), in an experiment with *Eucalyptus benthamii* seedlings, verified an increase in Si and Mg contents, in addition to an increase in soil pH, after 300 days of SA application.

Although the SA has low P content (about 0.3% of P), there was an increase of available P in T3, which may be associated with two hypotheses: i) competition of silicate anions for the same exchange sites of phosphate anions, so the high content of exchangeable Si in T3, resulting from the dissolution of silicate minerals contained in SA, may have favored the desorption of P that was previously retained to oxidic surfaces, and/or from the decrease of P applied, increasing its availability (SANDIM *et al*., 2014); and/or ii) as P is determined by colorimetry, high contents of Si and Fe (also released by SA; Tables 1 and 2) may interfere in the reaction between phosphates and ammonium molybdate, causing deviations in the reading (BLOMQVIST *et al*., 1993).

Regarding the contents of Na, there was no difference between treatments, but they were high when compared to the Na content obtained in the substrate before planting (Table 1). Its effect on the soil may be associated mainly with the use of MAP fertilizer, which may have contributed to the supply of Na as a contaminant. In addition, the SA contains Na in its composition and that explains the increase in the contents of this element in the total chemical composition (T3-T0). Nevertheless, Na is an easily leached element in the soil, which reduces the risk of salinity, not representing a risk to the development of eucalyptus seedlings.

The results of the total chemical analysis (Figure 2) were consistent with those observed in the soil fertility analysis, although the former determines total contents of elements (exchangeable + non-exchangeable) and the latter determines only exchangeable contents of soil elements. These results show that the SA added to the substrate is indeed making nutrients available to plants. Toscani and Campos (2017), in a study evaluating soil geochemistry before and after the application of different SAs, also verified increases in the contents of K, P and S oxides in soils, which in turn positively affected soil fertility, increasing base saturation (V%), pH and available phosphorus (P).

Although the SA altered the chemical and physical composition of the substrate, increasing the proportion of sand (Table 3), this did not result in changes in the development of eucalyptus seedlings (Table 4 and Figure 3). Contrary to what was observed by Ehlers and Arruda (2014) and Knapik and Angelo (2007), who state that the use of SA, with predominance of the silt fraction in its composition, alters the soil density and consequently the porosity of the substrate, hence affecting the development of seedlings. For Welter *et al*. (2011), the particle-size of the SA used influenced the growth parameters in *Myrciaria dubia* seedlings, as better performance was obtained using SA with smaller particle size (0.05 mm in diameter).

Regarding plant growth, as the solubilization and release of nutrients by SA is slower than that of synthetic mineral fertilizers (TOSCANI; CAMPOS, 2017), the effect of SA on seedling development was supplanted by that of MAP fertilizer, which is faster to release phosphorus and ends up meeting plant demand, so that the nutrients supplied by soluble fertilizer were those that promoted greater responses in the morphological parameters of the plant (PRATES *et al*., 2012). Other studies point to varied effects of the use of SA mixed to the substrate for seedling production, demonstrating that there is a great variation in the effects of SA, as a function of either the type of substrate and/or of the species (EHLERS; ARRUDA, 2014; KNAPIK; ANGELO, 2007; PRATES *et al*., 2010; PRATES *et al*., 2012).

The growth pattern with logarithmic behavior is common in plant development, with accelerated growth rate at first until reaching a point of stabilization, being recurrent in forest stands for both economic purposes and environmental recovery purposes (LELES *et al*., 2014). In the last measurement, there was still an increasing logarithmic trend, indicating that the seedlings did not reach maximum growth and were not limited by the of experimental conditions.

An increase in the H/SD ratio was verified in T2, in the 3rd measurement, reaching a value of 15. Ehlers and Arruda (2014) identified for the H/SD ratio values ranging from 6 to 8, while Reis *et al*. (2008) identified slightly higher values, ranging from 8 to 10. However, it is worth mentioning that both studies were conducted with *Eucalyptus grandis* seedlings grown from seeds. Unlike the H and SD parameters, high values of the H/SD ratio are related to lower seedling quality, since the imbalance between height and diameter can reduce the robustness of the seedling and, consequently, compromise its performance in the field (EHLERS; ARRUDA, 2014; PRATES *et al*., 2012; REIS *et al*., 2008). The imbalance in the relationship between the measurements may be associated with SD, which for this treatment was about 9% lower compared to the others. Additionally, when analyzing the variation of SD as a function of time, besides having rectilinear behavior, lower means were observed in T2. According to Ehlers and Arruda (2014), stem diameter is a parameter that can indicate whether there is balance in growth. According to Gomes *et al*. (2002), the expression of morphological parameters is based on phenotypic and genotypic aspects, that is, on genetic load and on environmental management conditions and in the nursery, procedures of the production techniques, structures and equipment used.

The production of seedlings and initial growth of *E. globulus* are relatively rapid processes, in which no major chemical contribution by the effect of the dissolution of SA, slower than that of soluble fertilizers, is expected at first. Thus, the use of SAs would be interesting in three aspects: i) in the production of seedlings of species with slow growth and/or that require longer time of permanence in the nursery; ii) use of SAs in the field, directly in the soil; and iii) in the composition of substrates for urban afforestation. Additionally, it is necessary to understand that the amount and availability of nutrients by the SA is highly variable due to factors such as the nature of the material of origin (types of rock) and particle size (RAMOS *et al*., 2015; TOSCANI; CAMPOS, 2017). Therefore, it is necessary and important to evaluate the development of fast-growing seedlings, such as those of *Eucalyptus ssp.*, with different types of SAs to check the efficiency of nutrient release in a short period of time.

CONCLUSIONS

- Contents of exchangeable Ca, K, P and Si, as well as micronutrients (Fe, Mn and Zn), were higher in the T3 treatment due to the influence of the silicate agromineral.
- Contents of bases (SB) and CEC were proportional to the increase in the amount of silicate agromineral added to the substrate.
- Silicate agromineral contributed to increasing the sand fraction in the substrate.
- The use of silicate agromineral did not influence the morphological parameters (height and stem diameter) of *Eucalyptus globulus* seedlings.

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