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EUCALYPTUS RESPONSE TO THE APPLICATION OF LIMESTONE, GYPSUM, AND LIME MUD IN HUMIC CAMBISOL

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Resumo

Resposta de eucalipto à aplicação de calcário, gesso e lama de cal em Cambissolo Húmico. O trabalho objetivou avaliar o desenvolvimento de *Eucalyptus dunnii* Maiden em Cambissolo Húmico no Planalto Sul Catarinense tratado com doses e formas de aplicação de calcário dolomítico, gesso e lama de cal. O experimento foi conduzido a campo, testando-se os tratamentos: T1 – controle; T2 – 3,5 t ha^{-1} de calcário em área total; T3 – 1,75 t ha^{-1} de calcário na faixa de plantio; T4 – 3,5 t ha^{-1} de calcário na faixa de plantio; T5 – 3,5 t ha^{-1} de lama de cal na faixa de plantio; T6 – 3,5 t ha^{-1} de calcário + 2,75 t ha^{-1} de gesso na faixa de plantio; T7 – 1,75 t ha^{-1} de calcário no sulco; T8 – 1,75 t ha^{-1} de calcário + 1,38 t ha^{-1} de gesso no sulco; T9 – 1,38 t ha^{-1} de gesso no sulco. Os tratamentos foram aplicados em abril de 2016, seis meses após o plantio das mudas. Foram realizados quatro inventários florestais, com medições de altura e diâmetro das plantas, nos anos de 2019 a 2022. Amostras de solo até a profundidade de 0,40 metros foram coletados aos 31 e 56 meses após aplicação dos tratamentos, determinando-se as relações Ca/Mg e Mg/K. Nenhuma variável, medida ou calculada, das plantas foi significativamente alterada em função dos tratamentos. A relação Ca/Mg foi maior com aplicação de lama de cal e gesso, enquanto a relação Mg/K foi maior nos tratamentos que receberam calcário dolomítico.
Palavras-chave: Fontes de cálcio, Gessagem e Cultivo de Eucalyptus.

Abstract

Eucalyptus response to limestone, gypsum, and lime mud application in Humic Cambisol. This study aimed to evaluate the development of *Eucalyptus dunnii* Maiden in Humic Cambisol in the Santa Catarina. Individuals were treated with doses and application forms of dolomitic limestone, gypsum, and lime mud. The experiment was conducted in the field, testing the following treatments: T1 – control; T2 – 3.5 t ha^{-1} of limestone in total area; T3 – 1.75 t ha^{-1} of limestone in the planting strip; T4 – 3.5 t ha^{-1} of limestone in the planting strip; T5 – 3.5 t ha^{-1} of lime mud in the planting strip; T6 – 3.5 t ha^{-1} of limestone + 2.75 t ha^{-1} of gypsum in the planting strip; T7 – 1.75 t ha^{-1} of limestone in the furrow; T8 – 1.75 t ha^{-1} of limestone + 1.38 t ha^{-1} of gypsum in the furrow; T9 – 1.38 t ha^{-1} of gypsum in the furrow. The treatments were applied in April 2016, six months after the seedlings were planted. In total, four forest inventories were carried out, measuring plant height and diameter, from 2019 to 2022. Soil samples up to a depth of 0.40 meters were collected at 31 and 56 months after application of treatments, determining the relationships Ca/Mg and Mg/K. None of the variables, measured or calculated, of the plants were significantly altered as a function of the treatments. Ca/Mg ratios were higher under lime mud and gypsum, whereas Mg/K ones, under treatments with dolomitic limestone.
Keywords: Sources of calcium, gypsum and Eucalyptus cultivation.

INTRODUCTION

Forest plantations occupied about 9.55 million hectares in Brazil in 2020, mainly spanning the states of Minas Gerais, São Paulo, Mato Grosso do Sul, Paraná, Santa Catarina, and Rio Grande do Sul, of which 7.47 million hectares consist solely of *Eucalyptus*, 78% of its total area (IBÁ, 2021). A 2019 study found that Santa Catarina has 828,900 hectares of planted forest and that *Eucalyptus* occupies about 33% (275,300 hectares) of this area. Reports also suggest that Pinus and Eucalyptus plantations in the state are concentrated mainly in the mountainous region, especially in the Santa Cecilia, Lages, and Otacílio Costa municipalities, spanning about 90,000 hectares of mostly *Pinus* individuals (ACR, 2019).

Cultivation for commercial exploitation of wood in southern Brazil has occupied areas with soils of low agricultural suitability, both due to inadequate topographic conditions for mechanized planting and low soil fertility, mainly characterized by low calcium (Ca), magnesium (Mg), potassium (K) and phosphorus (P), in addition to an acidic pH. This, associated with the intensification of rotations, can cause a decrease in forest productivity, if soil fertility management measures are not adopted. (MAEDA *et al.*, 2015).

The Ca is the nutrient required and exported in greater quantities in commercial forestry crops. Since, under productivity conditions close to 50 m3 ha-1 year-1, around 416 kg ha-1 of Ca are exported for the shoot, until the seventh year (RODRIGUES *et al.*, 2016). The supply of Ca and Mg in forest plantations is normally carried out through the application of limestone. However, alternative products, such as gypsum and ash, can also be used as a source of Ca and/or Mg in forest plantations, but for both ash and gypsum, the Mg concentration must be corrected so that there is no deficiency of this element (ROCHA *et al.*, 2019). The pulp and paper industry generates a residue known as lime slurry, with an alkaline reaction and which qualifies as a possible substitute for limestone in the contribution of Ca (SIMONETE *et al.*, 2013). Another way to alter the availability of Ca and Mg to plants in acid soils is the variation in the calcium/magnesium (Ca/Mg) ratio in acidity correctives (MEDEIROS *et al.*, 2008).

Studies evaluating the behavior of the development of modern eucalyptus clones to calcium sources, such as limestone, the alkaline residue, lime mud, thus like agricultural gypsum, as well as ways of applying these products, are necessary to expand the options for their use, adjusting them to the edaphoclimatic conditions of Serra Catarinense. Thus, this study sought to evaluate the long-term development of the plant, after the use of doses and forms of application of calcium sources, such as limestone, gypsum and lime mud, in the cultivation of *Eucalyptus dunnii* Maiden in a Humic Cambisol in the Santa Catarina Southern Plateau.

MATERIAL AND METHODS

The experimental area was located in the municipality of Bocaína do Sul, Santa Catarina, on the "Guarujá" farm (69º 36'70.0" S and 59º 99'80.0" W), which houses commercial eucalyptus plantations belonging to the company Klabin S /A. The climate of the region, according to the Köppen classification, is Cfb, subtropical without a dry season (ALVARES *et al.*, 2014), and the average altitude of the place is 860 m. The region's soil originates from basic volcanic rock that occupies most of the Catarinense Plateau (POTTER *et al.*, 2004), and was classified as a dystrophic Humic Cambisol with a clayey texture and wavy relief.

Previously to the implementation of the experiment, on average, layer 0 - 0.20 m had: clay content: 35%, MO: 4%, pH (water): 4.1, Al: 10.7 $cmol_c/dm^3$, Ca: 0.25 $cmol_c/dm^3$, Mg: 0.30 $cmol_c/dm^3$, P: 2.6 mg/dm^3, K: 75.5 mg/dm^3, S: 11 mg/dm^3, Zn: 0.45 mg/dm^3, Cu: 0.8 mg/dm^3, B: 0.45 mg/dm^3 and Mn: 5 mg/dm^3; and in layer 0.20 - 0.40 m clay: 38%, MO: 3.2%, pH (water): 4.2, Al: 10.8 $cmol_c/dm^3$, Ca: 0.15 $cmol_c/dm^3$, Mg: 0.15 $cmol_c/dm^3$, P: 1.1 mg/dm^3, K: 57.5 mg/dm^3, S: 14 mg/dm^3, Zn: 0.25 mg/dm^3, Cu: 0.8 mg/dm^3, B: 0.35 mg/dm^3 and Mn: 3.5 mg/dm^3.

According to the "Liming and Fertilization Manual for the States of Rio Grande do Sul and Santa Catarina" (CQFS, 2016) the need for lime application was determined. The standard dose, however, was defined based on the study by Almeida *et al.* (1999), aiming to raise the pH in water from the 0 – 10 cm layer to 5.2. According to the authors, for buffered soils in southern Brazil, raising the pH to 5.2 reduces soil acidity and may be sufficient to ensure adequate plant development. In addition, the low response to liming observed in forest species such as eucalyptus is reiterated (CQFS, 2016).

There was the application of 2.0 t ha^{-1} of limestone on the surface in the total area, this dose was subtracted from the stipulated dose of 5.5 t ha^{-1} of limestone. With this, the dose of 3.5 t ha^{-1} of limestone to be applied to reach the desired pH was established as a reference. The gypsum dose was calculated to provide an amount equivalent to half the amount of Ca added through this lime dose.

The following nine treatments were established for evaluation: T1 – control; T2 – 3.5 t ha^{-1} of surface limestone in total area; T3 – 1.75 t ha^{-1} of limestone on the surface in the planting range; T4 – 3.5 t ha^{-1} of limestone on the surface in the planting range; T5 – 3.5 t ha^{-1} of lime mud on the surface in the planting strip; T6 – 3.5 t ha^{-1} of limestone + 2.75 t ha^{-1} of gypsum on the surface in the planting strip; T7 – 1.75 t ha^{-1} of limestone incorporated in the planting furrow; T8 – 1.75 t ha^{-1} of limestone + 1.38 t ha^{-1} of gypsum incorporated in the planting furrow; T9 – 1.38 t ha^{-1} of gypsum incorporated in the planting furrow. The control treatment comprises the application of 2 t ha^{-1} of dolomitic limestone on the surface and on the total area before planting the seedlings, which covers the entire experimental area and was carried out six months before the application of the treatments. The seedlings were planted in October 2015. The treatments were applied in April 2016. The application in the seedling preparation strip was superficially, corresponding to one meter of strip, in the planting line. Application in the furrow was carried out after opening with a hoe to a depth of 0.20 m, with manual distribution of the products and closing the same by covering it with the soil that had been removed.

The sources of Ca used in the experiment were dolomitic limestone (PRNT: 56% and moisture: 1%), agricultural gypsum (33% of Ca) and lime mud (PRNT: 87% and moisture: 30.5%) (PFLEGER *et al.*, 2020). The materials gypsum, dolomitic limestone and lime mud used for the experiment were analyzed in an energy dispersion X-ray fluorescence spectrometer. For this analysis, 2g of each material were crushed with agate mortar and pistil of agate until reaching a granulometry of less than 0.25 mm. The results of the analysis indicated that for limestone, gypsum and lime mud, respectively in %, the contents were as follows: CaO: 50.83; 33.47 and 93.15; MgO: 22.38; 3.16 and 1.42; Al_2O_3: 4.55; 1.45 and 0.48 of the applied products.

Mineral fertilization with N, P and K (via ammonium nitrate, triple superphosphate and potassium chloride, respectively) was equally applied in all treatments, in three applications. In the first application, carried out 10 days after planting, 8, 52 and 12 g of N, P_2O_5 and K_2O were supplied per plant; in the second fertilization, 90 days after planting, 30, 0 and 60 g of N, P_2O_5 and K_2O were supplied per plant; in the third and last fertilization, 365 days after planting, 15, 7.5 and 45 g of N, P_2O_5 and K_2O were applied per plant, respectively, in coverage.

The experimental units (UE) consisted of 4 rows of 6 plants, with two row of two plant of border. Thus, the useful area of the UE corresponded to 8 plant (56 m2), with 4 plant from each of the 2 central lines. The experiment was conducted in complete randomized blocks with 4 replications, totaling 36 UE.

The planting used in the experiment was the second rotation and carried out with clonal seedlings of *Eucalyptus dunnii* Maiden (CL7003). The plant material originates from Australia and the seedlings are first generation, from a nursery in Rigesa, obtained by vegetative propagation. The seedlings were transplanted at a spacing of 3.5 m between rows by 2.0 m between plants in a second rotation area that received initial soil preparation by a crawler tractor and subsoiler, with a negative angle rod and 4 pairs of plow discs, up to 0.5 m deep, and formation of the planting strip with a width of 1 m.

Height and circumference at breast height (CBH) measurements were taken of all useful plants in each plot (8 plants, 4 plants per row, 2 central lines) with the aid of a hypsometer (vertex) and tape measure. The first measurement took place 40 months after planting the seedlings; approximately at 3 years planting (34 months after treatments application), on February 22, 2019. The second measurement took place at 51 months after planting the seedlings; approximately at 4 years planting (45 months after treatments application), on January 29, 2020. The third measurement took place at 63 months after planting the seedlings; approximately at 5 years planting (57 months after application of treatments), on January 7, 2021. And the fourth measurement took place at 77 months after planting the seedlings; approximately at6 years after planting (71 months after treatments application), on March 4, 2022.

Circumference at breast height (CBH) was then converted into diameter at breast height (DBH). Wood volume was estimated from height and diameter data. Volume is an important variable to analyze forest productivity, constituting basic information for production planning (AZEVEDO *et al.*, 2011). A form factor method was used to estimate volume (MIRANDA *et al.*, 2015) since this study assessed a developing forest and some individuals could not be cut for a volumetric model adjustment. The following equation was used:

$$V = \pi \frac{DBH^2}{4} h F$$

in which V = volume (m^3); π = pi; DBH = diameter at breast height (m); h = tree height (m); F = form factor.

A 0.48 form factor value was used, an average established according to the literature (MIRANDA *et al.*, 2015; AZEVEDO *et al.*, 2011). Since a 3.5×2.0 m (7 m^2) plant spacing was established by the company, a density of 1429 plants per hectare (10,000 m^2) was obtained. The volume of individuals was multiplied by plant density and the volume to be found per hectare in each treatment, estimated. It was later calculated the current annual increment — CAI (m^3 ha^{-1}) and mean annual increment — MAI (m^3 ha^{-1}) were calculated, in which CAI was estimated by subtracting the annual volume from the volume of the previous year and MAI, by dividing the annual volume by the age of plantations. CAI, in volume, expresses growth between the beginning and the end of growing season, in a period 12 month, that is, how much a tree grew in a year. The MAI expresses average total growth at a certain age of individuals, thus referring to the annual average growth for any age (ENCINAS *et al.*, 2005).

The soil was sampled twice; 31 and 56 months after treatment application. The first sampling was conducted in November 2018. Samples were composed of six subsamples for all treatments, collected from planting rows via a cut shovel and a Dutch auger. The layers between 0 and 0.05 and between 0.05 and 0.10 m were sampled via a cutting shovel, those between 0.10 and 0.20 and between 0.20 and 0.40 m, via a Dutch auger. The second soil collection was carried out in November 2020 from the space between rows, totaling seven subsamples, of which three were collected from the surface of the row and four, slightly away from the center (about 5 cm), two from either side to compose a soil sample at 0–0.05-m, 0.05–0.10-m, 0.10–0.20-m, and 0.20–0.40-m depths via a Dutch auger. Soil was prepared for analysis by drying it in an oven at 65 °C and then grinding and sieving it with a 2 mm-mesh. Exchangeable Ca and Mg values and available K levels were determined based on Tedesco *et al.* (1995). Based on these values, Ca/Mg and Mg/K ratios were calculated.

Collected data were initially tested for their normality by the Kolmogorov-Smirnov and Bartlett's variance homogeneity tests. If needed, they were normalized by the Box-Cox test. Data were then subjected to analysis of variance (ANOVA). If significant, they were compared by the Scott-Knott test under a 5% probability of error. Statistical analyses were performed via RStudio (RSTUDIO TEAM, 2021) and Sisvar, version 5.8 (FERREIRA, 2014).

RESULTS

The results of mean diameter at breast height (DBH) and mean height, in each treatment, with statistical evaluation of the data, are described in Table 1. There was no significant response from the treatments as a function of the management implemented, in the evaluations carried out, at 40, 51, 63 and 77 months after planting the seedlings. Mean DBH values, regardless of treatment, were 12.3, 13.8, 14.9, and 16.7 cm for assessments performed at 40, 51, 63, and 77 months after implantation, respectively. In the same sense, the average heights for the evaluations at 40, 51, 63 and 77 months after implantation were 15.2, 20.5, 21.2 and 23.7 m, respectively.

The mean values of diameter at breast height (DBH) varied, at 40 months with 11.85 to 12.78 cm with application of lime mud (T5) and with the lowest dose of limestone in the planting range (T3) , respectively; at 51 months with 13.16 to 14.45 cm; at 63 months with 14.28 to 15.46 cm; and at 77 months with 15.92 to 17.37 cm in the treatment with application of lime mud (T5) and with the application of the lowest dose of limestone plus the lowest dose of gypsum incorporated in the planting furrow (T8), respectively.

The tree height values varied, at 40 months with 14.26 to 15.60 m with the application of the lowest dose of lime incorporated in the planting furrow (T7) and with the application of lime mud (T5), respectively; at 51 months with 19.78 to 21.86 m; at 63 months with 20.68 to 21.98 m with the application of the lowest dose of lime incorporated in the sulcus (T7) and in the control treatment (T1), respectively; and at 77 months with 22.93 to 24.26 m with the application of the highest dose of limestone on the surface in the total area (T2) and with the application of the highest dose of limestone plus the highest dose of gypsum distributed in the planting range (T6), respectively.

Table 1. Plant height and average diameter at breast height (DBH) and wood volume (m^3) of *Eucalyptus dunnii* Maiden individuals 40, 51, 63, and 77 months after implantation in Humic Cambisol treated with limestone, gypsum, and lime sludge under several doses and nine treatments*.
Tabela 1. Altura de plantas e Diâmetro na altura do peito (DAP) médio e Volume de madeira (m^3) médio de *Eucalyptus dunnii* Maiden aos 40, 51, 63 e 77 meses após o plantio, nos nove tratamentos* estudados, em Cambissolo Húmico tratado com calcário, gesso e lama de cal sob doses e formas de aplicação.

Treatment	**DBH (cm)**				**Height (m)**			
	40 months	51 months	63 months	77 months	40 months	51 months	63 months	77 months
T1	12.41	13.82	15.00	16.85	15.52	21.86	21.98	24.03
T2	12.42	13.84	14.82	16.75	15.24	20.05	20.98	22.93
T3	12.78	14.24	15.41	17.27	15.27	20.22	21.04	23.37
T4	12.57	14.04	15.11	16.98	15.32	20.06	20.94	23.76
T5	11.85	13.16	14.28	15.92	15.60	20.59	21.26	23.53
T6	12.20	13.46	14.64	16.04	15.24	20.61	21.38	24.26
T7	12.26	13.54	14.72	16.44	14.26	19.78	20.68	23.61
T8	12.70	14.45	15.46	17.37	15.28	21.01	21.54	23.83
T9	11.88	13.42	14.50	16.41	15.27	20.04	20.82	24.24

Source: Elaborated by the author, 2022.
Non-significant in the absence of letters by the Scott-Knott test under a 5% probability of error. *T1 – control; T2 – 3.5 t ha^{-1} of limestone in total area; T3 – 1.75 t ha^{-1} of limestone in the planting strip; T4 – 3.5 t ha^{-1} of limestone in the planting strip; T5 – 3.5 t ha^{-1} of lime mud in the planting strip; T6 – 3.5 t ha^{-1} of limestone + 2.75 t ha^{-1} of gypsum in the planting strip; T7 – 1.75 t ha^{-1} of limestone in the furrow; T8 – 1.75 t ha^{-1} of limestone + 1.38 t ha^{-1} of gypsum in the furrow; T9 – 1.38 t ha^{-1} of gypsum in the furrow

Regarding plant productivity, the average volume of one individual per plot in m^3 was estimated. Analyzing the productivity per hectare, considering that single individuals per plot are not exploited, but a significant number of individuals, it was estimated, based on the average individual, the volume of Eucalyptus dunnii Maiden per hectare, in each treatment. The results of these two parameters are described in Table 2. There were no statistical differences between any of the treatments and between these and the control (T1), in the evaluations carried out at 40, 51, 63 and 77 months after planting the seedlings. For the volume of wood (m^3), the values ranged from 0.086 m^3 (T5) to 0.098 m^3 (T3 and T8) in the evaluation carried out 40 months after planting, with a general average of 0.09 m^3. In the evaluations carried out at 51 and 63 months after planting, the values varied between 0.14 and 0.17 (T5) to 0.18 and 0.22 m^3 (T8), with general averages of 0.16 and 0. 20 m^3, respectively. In the last evaluation carried out, 77 months after planting, the wood volume amplitudes were 0.25 (T5) and 0.31 m³ (T4), with an average value, among all treatments, of 0.29 m³.

Regarding the volume in m³ ha^{-1}, variations in their values were also observed, although there were no statistically significant differences. At 40 months after planting, values ranged from 123.6 (T5) to 139.5 m³ ha^{-1} (T3). In the two following evaluations, at 51 and 63 months after planting, the volume values ranged from 204.5 4 and 252 (T5) to 266.7 and 317.9 m³ ha^{-1} (T8), respectively. In the last evaluation period, at 77 months, amplitudes of 360.7 (T5) and 447.3 m³ ha^{-1} (T4) were observed, respectively. On average, the volume values were 132.6; 232.4; 284.3 and 416.1 m³ ha^{-1} in the evaluations carried out at 40, 51, 63 and 77 months after planting, respectively.

Table 2. Average wood volume (m^3) and total volume (m^3 ha^{-1}) of *Eucalyptus dunnii* Maiden 40, 51, 63, and 77 months after implantation in Humic Cambisol and treated with limestone, gypsum, and lime sludge under several doses and nine treatments*.

Tabela 2. Volume de madeira (m^3) médio e Volume (m^3 ha^{-1}) de *Eucalyptus dunnii* Maiden aos 40, 51, 63 e 77 meses após o plantio, nos nove tratamentos* estudados, em Cambissolo Húmico tratado com calcário, gesso e lama de cal sob doses e formas de aplicação.

Treatment	**Volume (m³)**				**Volume (m³/ha)**			
	40 months	51 months	63 months	77 months	40 months	51 months	63 months	77 months
T1	0.097	0.183	0.218	0.309	138.3	260.9	311.1	441.9
T2	0.092	0.156	0.191	0.274	131.3	222.7	272.0	392.7
T3	0.098	0.166	0.205	0.292	139.5	236.8	292.7	417.4
T4	0.097	0.163	0.202	0.313	139.1	233.3	288.2	447.3
T5	0.086	0.143	0.177	0.252	123.6	204.5	252.4	360.7
T6	0.088	0.150	0.184	0.260	125.9	214.5	263.5	371.4
T7	0.088	0.161	0.202	0.307	126.3	230.0	288.6	438.2
T8	0.098	0.187	0.222	0.312	139.3	266.7	317.9	445.3
T9	0.091	0.155	0.191	0.301	130.1	221.9	272.3	430.3

Source: Elaborated by the author, 2022.
Non-significant in the absence of letters by the Scott-Knott test under a 5% probability of error. *T1 – control; T2 – 3.5 t ha^{-1} of limestone in total area; T3 – 1.75 t ha^{-1} of limestone in the planting strip; T4 – 3.5 t ha^{-1} of limestone in the planting strip; T5 – 3.5 t ha^{-1} of lime mud in the planting strip; T6 – 3.5 t ha^{-1} of limestone + 2.75 t ha^{-1} of gypsum in the planting strip; T7 – 1.75 t ha^{-1} of limestone in the furrow; T8 – 1.75 t ha^{-1} of limestone + 1.38 t ha^{-1} of gypsum in the furrow; T9 – 1.38 t ha^{-1} of gypsum in the furrow

The results of Current Annual Increment and Mean Annual Increment (m^3 ha^{-1}) are described in Table 3. There was no statistically significant difference between the treatments as a function of the management implemented, in the evaluations carried out at 40, 51, 63 and 77 months after planting of seedlings. Regarding the CAI values obtained at 40 months, ranges from 85.9 (T6) to 101.3 m³ ha $^{-1}$ (T8) were observed; at 51 months, the values ranged from 84.8 (T5) to 132.5 m³ ha $^{-1}$ (T8). In the third evaluation carried out, at 63 months, values of 53.2 (T5) to 70.7 m³ ha $^{-1}$ (T3) were observed, while in the last collection (77 months) 109.3 (T5) to 142.5 m³ ha $^{-1}$ (T9). On average, the CAI values were 95.2; 104.7; 61.3 and 130.9 m³ ha^{-1} in the evaluations carried out at 40, 51, 63 and 77 months after planting, respectively.

For the mean annual increment (MAI) m³ha^{-1}, variations were observed at 40 months from 41.2 (T5) to 46.5 m³ ha^{-1} (T3). In the second evaluation, carried out 51 months after planting, the values ranged from 51.1 (T5) to 66.7 m³ ha^{-1} (T8); in the third evaluation, 63 months after planting, amplitudes from 10.6 (T5) to 14.1 m³ha^{-1} (T3) were observed. In the last evaluation, at 77 months, the variations were between 18.2 (T5) and 23.7 m³ha^{-1} (T9). On average, the MAI values were 44.2; 58.1; 12.3 and 21.8 m³ ha^{-1} in the evaluations carried out at 40, 51, 63 and 77 months after planting, respectively.

Table 3. Current annual increment (CAI) and mean annual increment (MAI) in m^3 ha^{-1} of *Eucalyptus dunnii* Maiden at 40, 51, 63, and 77 months after implantation in Humic Cambisol and treated with limestone, gypsum and lime sludge in several doses and nine treatments*.

Tabela 3. Incremento Corrente Anual (ICA) e Incremento Médio Anual (IMA), em $m^3\ ha^{-1}$ de *Eucalyptus dunnii* Maiden aos 40, 51, 63 e 77 meses após o plantio, nos nove tratamentos* estudados, em Cambissolo Húmico tratado com calcário, gesso e lama de cal em diferentes doses e formas de aplicação.

Treatments	CAI (m³/ha)				MAI (m³/ha)			
	40 months	51 months	63 months	77 months	40 months	51 months	63 months	77 months
T1	98.5	121.3	57.5	139.3	46.1	65.2	11.5	23.2
T2	91.1	91.4	58.7	120.7	43.8	55.7	11.7	20.1
T3	100.9	98.6	70.7	129.7	46.5	59.2	14.1	21.6
T4	100.4	103.4	64.9	141.2	46.4	58.3	13.0	23.5
T5	88.3	84.8	53.2	109.3	41.2	51.1	10.6	18.2
T6	85.9	97.3	58.0	115.2	42.0	53.6	11.6	19.2
T7	97.4	107.9	56.1	140.6	42.1	57.5	11.2	23.4
T8	101.3	132.5	63.8	139.2	46.4	66.7	12.8	23.2
T9	93.4	105.2	69.2	142.5	43.4	55.5	13.8	23.7

Source: Elaborated by the author, 2022.
Non-significant in the absence of letters by the Scott-Knott test under a 5% probability of error. *T1 – control; T2 – 3.5 t ha^{-1} of limestone in total area; T3 – 1.75 t ha^{-1} of limestone in the planting strip; T4 – 3.5 t ha^{-1} of limestone in the planting strip; T5 – 3.5 t ha^{-1} of lime mud in the planting strip; T6 – 3.5 t ha^{-1} of limestone + 2.75 t ha^{-1} of gypsum in the planting strip; T7 – 1.75 t ha^{-1} of limestone in the furrow; T8 – 1.75 t ha^{-1} of limestone + 1.38 t ha^{-1} of gypsum in the furrow; T9 – 1.38 t ha^{-1} of gypsum in the furrow

In the soil, the Ca/Mg and Mg/K ratios had significant changes depending on the treatments, both at 31 months and at 56 months after application of the treatments, as shown in Figure 1. In the Ca/Mg ratio, in the evaluation of the 31 months after application of treatments, there was a significant change in all layers evaluated, Figure 1 (A), and in the evaluation at 56 months after application of treatments, significant change was observed only in layers of 0.05 – 0.10m and 0.10 – 0.20 m, Figure 1 (B). The Mg/K ratio in the evaluation at 31 months after application of the treatments showed significant changes up to a depth of 0.20 m, Figure 1 (C), and in the evaluation at 56 months after application of the treatments there were significant changes in the surface layer, 0-0.05m, and in the subsurface layer, from 0.20 - 0.40m, Figure 1 (D).

At 31 months after application of the treatments, the Ca/Mg ratio in the surface layer up to 0.05m was higher in the treatment with lime mud application (T5), reaching mean values of 8.45 $cmol_c\ dm^3$ (T5) and 0. 92 cmolc dm³ (T7); in all the other layers, the values of Ca/Mg were always higher in the treatment with the application of the lowest dose of gypsum incorporated in the planting furrow (T9), with the highest values observed being 32.4 $cmol_c\ dm^3$. In the second evaluation, at 56 months after application of the treatments, the Ca/Mg ratio in the layers of 0.05 – 0.10 and 0.10 – 0.20m was higher in the treatment with the application of the lowest dose of gypsum incorporated in the planting furrow (T9), where values reached 3.3 $cmol_c\ dm^3$.

The Mg/K ratio for the surface layer up to 0.05 m, in the evaluation 31 months after the treatments were applied, was higher in the treatments with the application of the highest dose of limestone on the surface in the planting range (T4) and with the application of the highest dose of limestone plus the highest dose of gypsum distributed in the planting range (T6). In these mentioned treatments, the values reached were 16.28 and 19.07 $cmol_c\ dm^3$, while in the other treatments the average value was 6.3 $cmol_c\ dm^3$. For the 0.05 - 0.10 m layer, the Mg/K ratio was higher in the treatments with the application of the lowest dose of limestone incorporated in the planting furrow (T7) and with the application of the lowest dose of limestone plus the lowest dose of gypsum incorporated in the planting furrow (T8), with values of 20.51 and 19.01 $cmol_c\ dm^3$ being observed. In the layer of 0.10 – 0.20 m, it was observed that with the application of the lowest dose of lime incorporated in the planting furrow (T7) there was a higher Mg/K ratio (value of 31.93 $cmol_c\ dm^3$).

In the second evaluation, at 56 months after application of the treatments, in the layer up to 0.05 m, the values in the Mg/K ratio were higher than the others in the treatments with the application of the lowest and highest dose of limestone on the surface in the planting range (T3 and T4), in the treatment with gypsum added (T6) and with the lowest dose of limestone and the lowest dose of limestone plus gypsum incorporated in the planting furrow (T7 and T8), with values reached of 17.5; 25; 23.4; 18.3 and 19.7 $cmol_c\ dm^3$, respectively. In the 0.20 - 0.40 m layer, the values in the Mg/K ratio were higher than the others in the treatments with the lowest doses of lime incorporated in the furrow, with or without the addition of gypsum (T7 and T8), with values of 22.8 and 24.1 $cmol_c\ dm^3$, respectively.

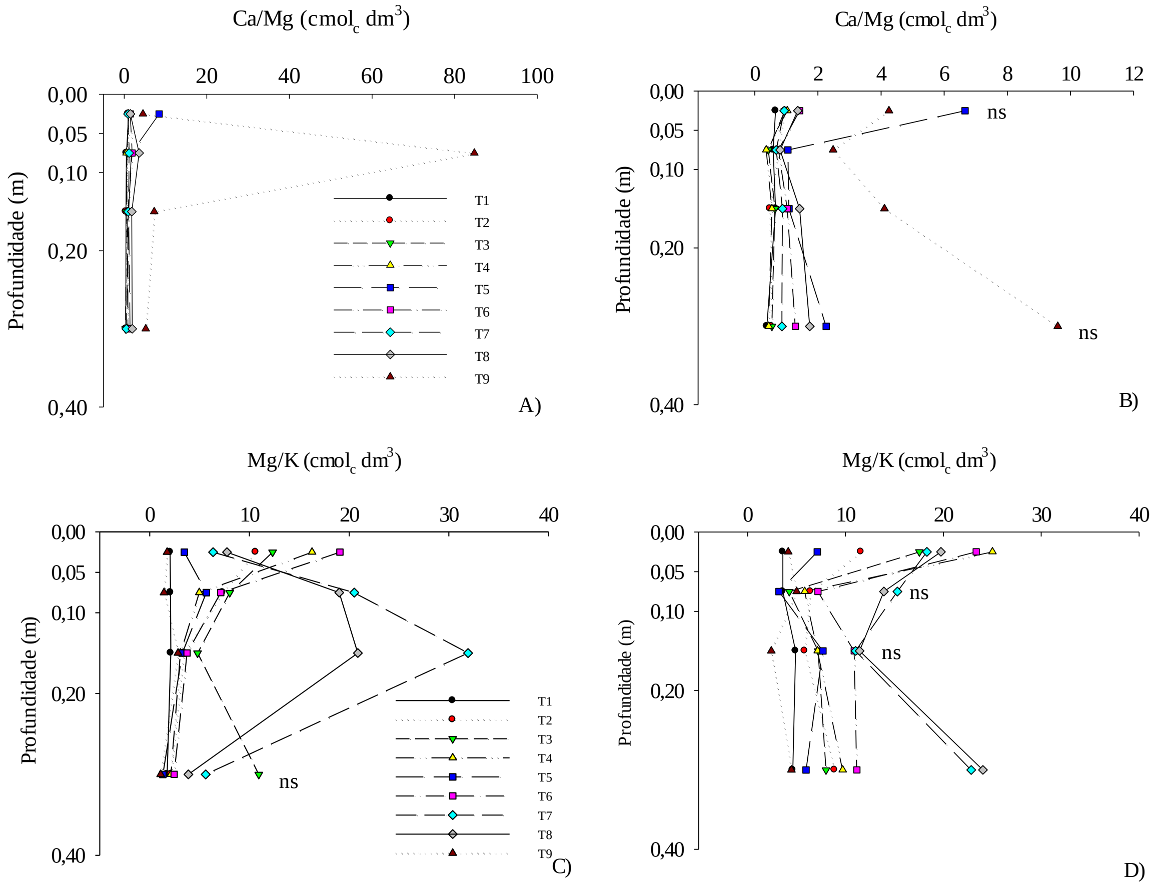

Figure 1. Ca/Mg and Mg/K ratios under nine treatments* with several doses and application of limestone, gypsum, and lime sludge to layers of Humic Cambisol of a *Eucalyptus dunnii* Maiden plantation up to a 0.40-m depth after 31 (A and C) and 56 months (B and D).

Figura 1. Relações de Ca/Mg e Mg/K nos nove tratamentos* estudados, com doses e modo de aplicação de calcário, gesso e lama de cal, em camadas de Cambissolo Húmico até a profundidade de 0,40 m após 31 meses (A e C) e 56 meses (B e D) da aplicação dos tratamentos, em plantio de *Eucalyptus dunnii* Maiden.

DISCUSSION

Plant development

None of the evaluations carried out on the eucalyptus plants showed a significant effect on their development depending on the treatments tested, so it is believed that this lack of responses is possibly due to the application of 2 t of limestone, previously applied to the treatments, which thus supplied possible deficiencies of Ca. In parallel, Gabriel *et al.* (2018), evaluated the initial growth of *Eucalyptus dunnii* Maiden and *Eucalyptus benthamii* Maiden et Cambage clonal seedlings in Humic Cambisol and found no influence of limestone and gypsum either by themselves or together on plant height and stem diameter. Ferreira *et al.* (2020) assessed the effects of a wide range of gypsum doses on *Eucalyptus* growth parameters in dystrophic Oxisol in the State of Paraná and found that these doses did not affect plant height 36 months after application.

On the other hand, there are works that found significant eucalyptus responses to soil correction. In a study carried out by Rodrigues *et al.* (2016), evaluating the productivity of eucalyptus, at 18 months of age, in response to the application of Ca, in a soil of medium texture, in the Cerrado region, the authors observed that the growth in height presented an average of 8.2, 9.5 and 10.0 m in height, for the treatments without limestone, with limestone and with limestone added with gypsum, respectively. And that the application of lime provided an increase in eucalyptus diameter, more expressive compared to vertical growth. Still in this study, the authors reported that there were increments in the stem, at 18 months of 56% with application of limestone on the surface in the planting strip reaching 23.2 m^3 ha^{-1}, and 99% with application of limestone in a total area with addition of gypsum in the planting range with productivity of 29.6 m^3 ha^{-1}. The authors also point out that the average gain of 58% in stem volume in the treatments that received limestone application alone in the planting range or total area, compared with non-application, makes evident the eucalyptus response to limestone application, especially to meet the demand for Ca and Mg.

In the experiment in question, however with assessments of DBH, height and estimated volume per hectare at 12, 15 and 24 months of cultivation age, Pfleger *et al.* (2020) observed that for DAP and volume, at 12 months, the limestone applied at a lower dose on the surface in the planting strip (T3) had an increase, in relation to the control treatment (T1). At 15 months, the application of limestone on the surface in the planting strip (T3), and limestone and gypsum on the surface in the planting strip (T6), the DBH and volume increased in relation to the gypsum incorporated in the planting furrow (T9). For height, at 12 months, the use of the lowest dose of limestone on the surface in the planting strip (T3) provided a higher average, when compared to limestone and gypsum incorporated in the planting furrow (T8), and gypsum incorporated in the planting furrow (T9). In the evaluation at 15 months, the use of lime mud (T5) resulted in greater height compared to the control treatment (T1). And at 24 months, there was no significant difference between treatments for DBH, height and volume. And in the evaluation of the ICA and the MAI, at 24 months after planting the seedlings, there was no influence of the evaluated treatments. Therefore, the present study had a significant response at the beginning of the cultivation cycle, for parameters such as DBH, height and estimated volume per hectare.

Paes *et al.* (2013) evaluated the impact of crop waste management, soil preparation, and different fertilizations, including industrial waste use, on soil fertility and *Eucalyptus* yield and found that maintaining all forest residues in the area after harvesting first-cycle wood increased volume in 36.6% (71.7 m^3 ha^{-1}) when compared to removing these residues after harvest. Residue removal greatly exports nutrients from plots, which, if uncorrected by fertilization, can compromise *Eucalyptus* productivity. It should be noted that in the present study with planting in second rotation, forest residues were left in the plot.

Ca/Mg and Mg/K ratios in soil

The isolated supply of Ca, through lime mud or agricultural gypsum, increased the content of this cation in relation to Mg and also to K (data not shown). In the same sense, the values of the Mg/K ratio were higher in the treatments with dolomitic limestone, a supplier of Mg, was applied. However, these alterations were not enough to influence the development of eucalyptus plants, as reported.

The unbalance between Ca and Mg can accentuate magnesium deficiency, especially when the Ca/Mg ratio becomes very high, thus inhibiting the absorption of Mg (and possibly also K) by plants (Medeiros *et al.*, 2008). In naturally poor soils, the continuous application of dolomitic limestone and/or lime mud, in the same way as using agricultural gypsum, can affect the Ca/Mg ratio, with negative repercussions on plant growth and nutrition (Simonete *et al.*, 2013).

The lack of Mg after lime mud or gypsum treatment leads us to an important question: the relation between these nutrients requires further investigation during treatment as a very high Ca/Mg ratio can impair Mg absorption. Simonete *et al.*, (2013) supplied Ca via lime mud to evaluate how it affected macronutrient availability and dry matter production in Eucalyptus, finding that continuously using lime mud in successive forest plantation rotations without adding Mg may exhaust it (especially in poor soils), thus requiring complementing residues containing this nutrient as its deficiency can limit the productivity of subsequent forest plantation cycles.

High K levels can inhibit the absorption of Ca and/or Mg, as well as high levels of these can also inhibit the absorption of K by plants. This fact is related to the antagonistic action between these cations confirmed by the increase in the K/Ca ratio, although not statistically significant (ROCHA *et al.*, 2008). In a study to evaluate the effect of different proportions between calcium and magnesium in acidity correctives on nutrient absorption, applied to a soil with high pH buffering, by Medeiros *et al.* (2008), they concluded that increasing proportions of Ca in relation to Mg, through the application of acidity correctives, increased the content and saturation of calcium in the cation exchange capacity (CEC) of the soil, reduced the levels of Mg and did not affect those of K.

The lack of response observed in the present study for the different treatments tested reinforces the low requirement of the Eucalyptus genus for acidity correction. Although plants have a high requirement for the element Ca, which is the nutrient extracted in greater quantities (Vieira *et al.*, 2015). However, the initial application of 2 ton ha^{-1} in the total area may have provided the amounts of Ca, as well as Mg, required by the plants to reach their full development. It is also worth mentioning that the application of small amounts of limestone, from 1 to 2 ton ha^{-1}, is already a common practice in areas cultivated with forest species in the mountainous region of Santa Catarina.

In addition to Ca supply being more important than completely neutralizing acidity, we should highlight two other factors: tolerance to Al^{3+} and the possible offer of forms of these nutrients which are usually less available to plants. Forest plants, such as *Eucalyptus*, seem to have a higher tolerance to Al^{3+}, better resisting its toxicity to their root systems (RAHMAN; UPADHYAYA, 2021). Another factor for discussion is the possible use of nutrients such as Ca, Mg, K, and P in less available forms as access to their forms of lower lability may adequately develop forest plants (Gatiboni *et al.*, 2020).

CONCLUSIONS

- Applications of doses of sources of calcium, limestone, lime mud and agricultural gypsum, on the surface whether in the total area or in the planting strip, or incorporated in the planting furrow, in addition to adding of 2 t ha-1 of limestone in surface area in total area, did not promote significant increments in height, diameter and productivity of Eucalyptus dunnii Maiden, determined at 40, 51, 63 and 77 months of age of trees cultivated in Humic Cambisol in the Santa Catarina southern plateau .
- The application of 2 t ha-1 of dolomitic limestone on surface in total area, may be sufficient for the development of Eucalyptus dunnii Maiden during its cycle, cultivated in Humic Cambisol in the Santa Catarina southern plateau.
- The Ca/Mg ratio is higher with the application of lime mud and agricultural gypsum than with the application of dolomitic limestone, due to the greater solubility of these products in the soil, while the Mg/K ratio, higher values are observed in areas corrected with dolomitic limestone.

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