



Dendrometric Analysis of Early Development of *Eucalyptus urophylla* x *Eucalyptus grandis* with Gypsum use Under Subtropical Conditions

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ABSTRACT

Gypsum can be used as a source for calcium (Ca) and sulphurum (S) for plants, as well as an acid, that is, a natural soil conditioner. Aiming to determine the influence of gypsum on the development of *Eucalyptus urograndis* in Brazil, an experiment was conducted at two locations in Paraná State. Experiments were conducted with rates of 0, 0.3, 0.6, 1.2, 2.4, 4.8 and 9.6 Mg ha⁻¹ to verify the method of broadcast planting in a randomized block design with four repetitions. Diameter and height of plants were measured every six months and volume was determined after 36 months. There was a difference in *Eucalyptus* growth between the two areas, possibly related to differences in planting season and climate. Gypsum did not influence on the dendrometric growth of *Eucalyptus* trees. The lack of a response to gypsum, as a source of Ca, S and soil conditioner, was discussed based on soil type, *Eucalyptus* tolerance to soil acidity, and climatic conditions in the period evaluated.

Keywords: soil conditioner, *Eucalyptus* forest, dystrophic oxisol.

1. INTRODUCTION

Gypsum is a known source of calcium (Ca) and sulphurum (S) for plants, and from 200 to 300 kg ha⁻¹ is sufficient to meet annual requirements of most agricultural crops (Sousa et al., 2007). Gypsum can increase Ca and sulphate (SO₄⁻²) availabilities within surface and subsurface soil layers when applied at high rates (Rentería-Villalobos et al., 2010) and it could be noted that gypsum has also diminished aluminium (Al) toxicity in these soil layers without changing soil pH (Araújo et al., 2016; Nascimento et al., 2017). Thus, gypsum can be considered a good source of Ca and S, and also able to alleviate aluminium (Al) toxicity in soils.

Soil chemical characteristics can influence the effectiveness of gypsum applications. Low soil availability of Ca and S nutrients can enhance plant responses to gypsum (Rocha et al., 2008; Marques et al., 2016). High toxic levels of Al and low levels of available Ca in subsurface soil layers are major factors regarding gypsum recommendations (Costa & Crusciol, 2016; Amaral et al., 2017). However, issues concerning these soil conditions, the crop yield responses to gypsum application varies from large (Wulff-Zottele et al., 2014; Marques et al., 2016) to small (Pauletti et al., 2014), or has no change (Gelain et al.; 2011; Moda et al., 2013).

Weather conditions during crop growth, especially in relation to soil water availability, can influence response to gypsum applications (Zandoná et al., 2015). Provided that gypsum can enhance root growth in subsurface soil layers, by decreasing Al toxicity and increasing Ca availability, Water Absorption Capacity (WAC) may be expanded (Carducci et al., 2015; Freitas et al., 2015). For this reason, positive growth response to gypsum applications may occur under drought conditions (Pauletti et al., 2014; Vitti et al., 2015).

Determining the ideal gypsum rate that optimizes yield and addresses Ca and S nutritional imbalance has been the focus of previous research (Moda et al., 2013). While the application of 12 Mg Ca ha⁻¹ decreased growth of soybeans displaying symptoms of Mg deficiency (Pauletti et al., 2014), several other studies reported no decreases in productivity using similar or higher rates (Ernani et al., 2001; Gelain et al., 2011). Under greenhouse conditions, Jackson et al. (2000) reported increased growth of *E. marginata* D. Don ex

Sm seedlings by using gypsum in nutrient solution. Gypsum applied with B has also been shown to stimulate growth of *E. citriodora* Hook seedlings, when this species grows in a container (Christo & Santos, 1990); however, the opposite was reported by Gabriel et al. (2018) when testing five rates of gypsum on *Eucalyptus* seedlings cultivated in pots. Under field conditions, Rodrigues et al. (2016) observed a large increase in *Eucalyptus* trunk size with applications of limestone and gypsum (1 Mg ha⁻¹) alone, or in combination of these nutrients. Macana (2017) reported that gypsum (1.2 Mg ha⁻¹) did not change *E. urophylla* S. T. Blake tree volume measurements, but increased timber (biomass) as a result of enhanced tissue density at 38 months.

The few studies that have evaluated the effects of gypsum on *Eucalyptus*, under field conditions, have only compared gypsum (compared to no gypsum) at rates below those used in grain crop tests. Thus, technical information on the effectiveness of using gypsum in *Eucalyptus* forest systems as a nutrient source and/or soil conditioner is limited. Furthermore, there are few existing studies that have been developed under tropical conditions with periods of water deficit. Our experiment was implemented in a subtropical environment with no dry season and evaluated the effects of a wide range of gypsum rates on growth parameters of *E. urograndis*.

2. MATERIAL AND METHODS

Eucalyptus urograndis is a hybrid of *E. urophylla* and *E. grandis*. Under subtropical conditions regarding Brazilian territory, *E. urograndis* was cultivated in Paraná State, in two municipalities (Jaguariaíva and Ventania) that are located in the second plateau of Paraná. The municipality of Jaguariaíva is situated at 24°15'04" S latitude, 49°42'21" W longitude, and has an elevation of 926m. The climate type Cfb (temperate, humid mesothermal with warm summer) was based on the Köppen classification system (Alvares et al., 2013). The Geographic Coordinate System (GCS) of Ventania is on 24°14'45" S latitude, 50°14'34" W longitude, has an elevation of 718 m, and climate is characterized by transition from Cfb to Cfa (humid subtropical climate), with hot summers (Alvares et al., 2013).

Air temperature and rainfall data were obtained from meteorological stations near the experimental areas. Meteorological monitoring occurred from

December 2013 to December 2016 at Jaguariaíva, and from April 2014 to April 2017 at Ventania (Figure 1). The cumulative rainfall for the first 36 months was 8,500 mm for Jaguariaíva, which precipitation was higher when compared to Ventania (6,000 mm).

The composition of native vegetation of the Jaguariaíva region was consisted of a variability of two biomes from Southern Brazil, savanna vegetation (a small fragment of Cerrado) and Mixed Ombrophilous Forest (MOF). The composition of native vegetation of Ventania was MOF. The two experimental areas had

previously been cultivated with *Pinus* spp. during a period of two cycles of 18 years each.

In this region, the geology could be characterized as sandstones, sedimentary rocks (Paleozoic period). Soils were classified as Dystrophic Oxisols with medium-textured soil (sandy loam). Prior to planting, soil samples were collected (0-0.20 m, 0.20-0.40 m, and 0.40-0.60 m depths) for initial characterization. Samples were air-dried, homogenized, and passed through a 2 mm screen mesh for analysis of pH, Ca²⁺, Mg²⁺, Al⁺³ (extracted with KCl 1 M), K⁺, and for measuring

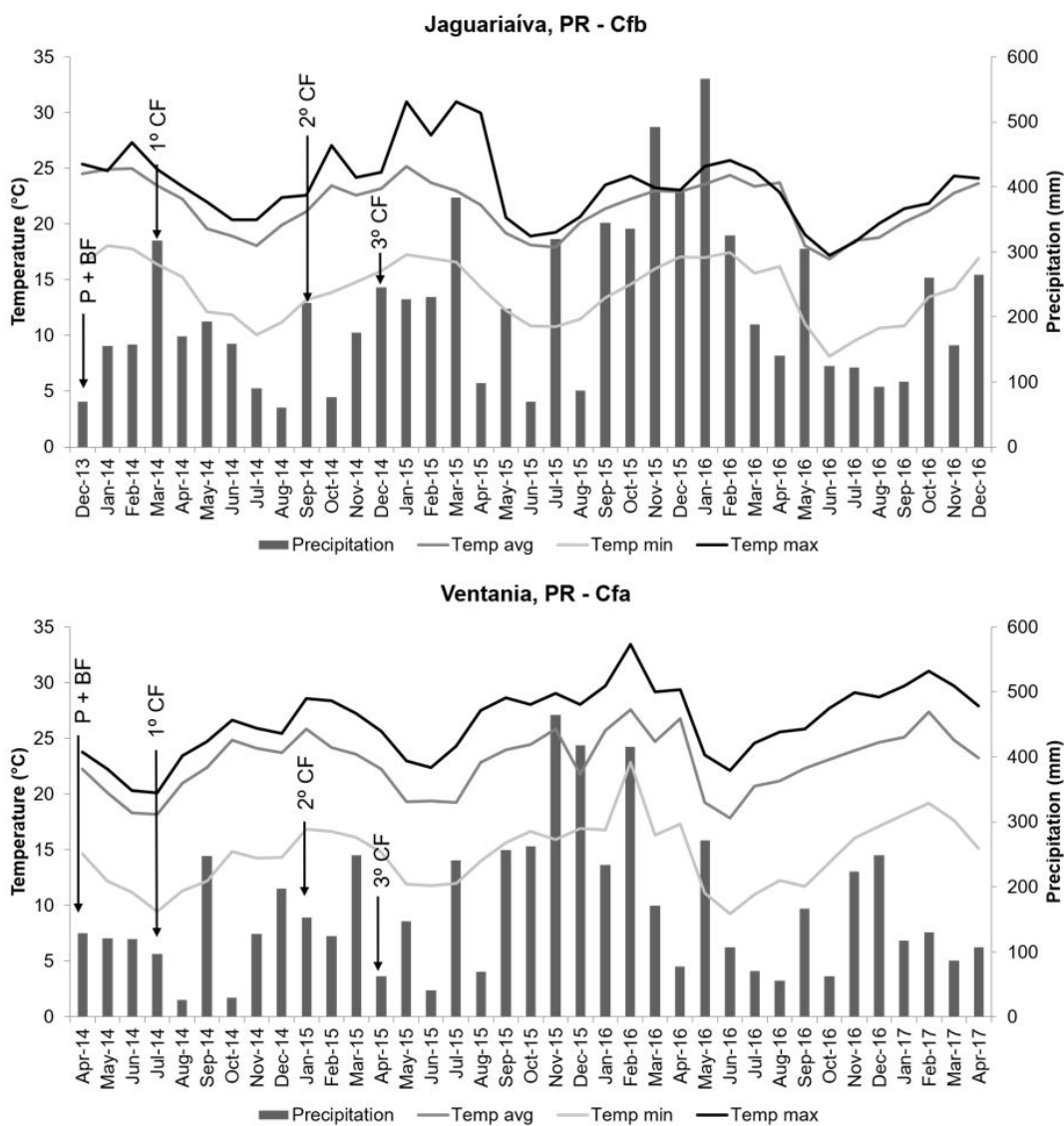


Figure 1. Minimum temperature (Temp min), average temperature (Temp avg), maximum temperature (Temp max), and precipitation over 36 months at Jaguariaíva and Ventania, Paraná State, Brazil. Planting (P); Base Fertilization (BF); 1°, 2°, and 3° side-dress fertilizations (CF).

extractable phosphorus (P) by P-Mehlich I. Table 1 shows soil chemical characteristics before performing experiments at both locations.

Seven gypsum rates were used as treatments (0, 0.3, 0.6, 1.2, 2.4, 4.8, and 9.6 Mg ha⁻¹). The experimental design was the Randomized Complete Block Design (RCBD) with four replications (28 total plots). Gypsum was obtained from phosphate fertilizer production with Ca content of 19.31% and S content of 15.83%. Gypsum broadcast on the soil surface took place when tree seedlings were being transplanted. The total experimental area was 16,128 m² and each treatment plot was 24 m x 24 m (576 m²). *Eucalyptus urograndis* (clone AEC 224) seedlings (~15-20 cm height) were transplanted at a spacing of 3 x 3 m (between plants and rows); there were a total of 64 plants per plot (8 x 8 plants).

Before transplanting, it was applied 2 Mg ha⁻¹ of dolomitic limestone (effective calcium carbonate equivalent = 82%) onto the soil surface. In addition, 200 kg ha⁻¹ of reactive natural phosphate (29% P₂O₅) was applied during subsoiling (45 cm depth). After transplanting, an initial application of Nitrogen/Phosphorus/Potassium (NPK) fertilizer added 8.5 kg ha⁻¹ of N, 51 kg ha⁻¹ of P₂O₅, and 17 kg ha⁻¹ of K₂O. After three, nine and 12 months of transplanting, side dressings (both sides of seedlings) were applied at rates of 24 kg N ha⁻¹, 8 kg P₂O₅ ha⁻¹, 48 kg K₂O ha⁻¹, and 0.8 kg B ha⁻¹. The compounds of the side dressing sources were urea (CH₄N₂O), triple superphosphate (TSP) (P₂O₅), potassium chloride (KCl) and boric acid (H₃BO₃).

Tree assessments included height, Diameter at the Tree Base (DTB), Diameter at Breast Height (DBH)

and tree volume. Initial tree height was measured using a standard graduated ruler. The height assessments employed after the initial one used the Hagl6f Electronic Clinometer (HEC); 36 centrally located trees (6 x 6) were measured at three, six, nine, 12, 24, 30, and 36 months after transplanting. The DTB was measured at three and six months at both locations. The DBH was measured using a standard flexible measuring tape in other months. At 36 months, an average size tree was cut (based on DBH) and volume was calculated using the Hohenald method. Diameters were measured at the trunk base and at points located at 25, 50, 75 and 100% of total trunk length. Using these measurements, the individual tree volume (m³) was determined using the shape function with an adjustment value of 0.33. For calculations of total volume (m³ ha⁻¹), the mortality rate was disregarded.

Results were submitted to analysis of variance (ANOVA). Averages were compared by regression analysis (Software ASSISTAT) and probability levels were 1% (p≤0.01) or 5% (p≤0.05).

3. RESULTS

Tree heights over the 36 month study period can be seen in Table 2. Gypsum affected tree height at Ventania area only at 30 months, with a linear increase [y (m) = 15.50 + 0.082x at Ventania]. However, this positive response was not observed at 36 months. There was a variation in tree heights at 36 months, in other words, 2.00 m variation (16.4 - 18.4 m) at Jaguariaíva area, and 1.40 m variation at Ventania area (18.1 - 19.5 m). At Jaguariaíva area, the average overall

Table 1. Soil chemical characteristics before initiation of studies at Jaguariaíva and Ventania, Paraná State, Brazil.

| Depth m | pH ¹ CaCl ₂ | pH ² SMP | Al ³⁺ | H+Al* | Ca ²⁺ | Mg ²⁺ | K ⁺ | BS ³ | CEC ⁴ | P | C _{org} | V ⁵ | m ⁶ |
|-------------|--------------------------------------|------------------------|------------------|-------|------------------|------------------|----------------|-----------------|------------------|-----|------------------|----------------|----------------|
| | | | | | | | | | pH 7.0 | | | | |
| Jaguariaíva | | | | | | | | | | | | | |
| 0.00 - 0.20 | 3.9 | 5.7 | 1.5 | 6.4 | 0.2 | 0.2 | 0.02 | 0.42 | 6.82 | 1.0 | 23.6 | 6.15 | 78.12 |
| 0.20 - 0.40 | 3.8 | 5.9 | 1.2 | 2.2 | 0.1 | 0.1 | 0.02 | 0.22 | 2.42 | 0.7 | 16.1 | 9.09 | 84.50 |
| 0.40 - 0.60 | 4.0 | 6.1 | 1.0 | 4.6 | 0.1 | 0.1 | 0.01 | 0.21 | 4.81 | 0.6 | 17.4 | 4.36 | 82.64 |
| Ventania | | | | | | | | | | | | | |
| 0.00 - 0.20 | 4.3 | 6.2 | 1.5 | 4.3 | 0.1 | 0.1 | 0.03 | 0.23 | 4.53 | 2.2 | 21.0 | 5.08 | 86.71 |
| 0.20 - 0.40 | 4.5 | 6.7 | 1.1 | 3.0 | 0.1 | 0.1 | 0.03 | 0.23 | 3.23 | 1.6 | 11.0 | 7.12 | 82.70 |
| 0.40 - 0.60 | 4.4 | 6.8 | 1.2 | 2.7 | 0.1 | 0.1 | 0.03 | 0.23 | 2.93 | 0.4 | 7.3 | 7.84 | 83.91 |

¹pH CaCl₂ = soil/CaCl₂ ratio 1: 2.5; ²pH_{SMP} = SMP buffer solution (Schumaker, Mc Lean and Pratney); ³BS = base sum (Ca+Mg+K); ⁴CEC = Cation Exchange Capacity; ⁵V = base saturation of CEC (Cation Exchange Capacity); ⁶m = saturation by aluminum; *H + Al extraction acetate Ca (0.5 mol L⁻¹); Al, Ca and Mg extraction KCl (1 mol L⁻¹) 1N; K and P extraction Mehlich I; C – organic carbon (volumetric method potassium dichromate).

height increase was 5.8, 6.7, and 4.9 m in the first, second, and third year, respectively, while respective values for Ventania were 7.5, 5.8, and 3.1 m.

Assessments of DTB at three and six months showed no influence of gypsum treatments at both sites (Table 3); similarly, gypsum application had no effect

Table 2. Height of the *Eucalyptus* hybrid *E. urograndis* at 3, 6, 9, 12, 24, 30, and 36 months after gypsum applications (0, 0.3, 0.6, 1.2, 2.4, 4.8, and 9.6 Mg ha⁻¹) at Jaguariaíva (a) and Ventania (b), Paraná State, Brazil.

| Gypsum Rate Mg ha ⁻¹ | Age (months) | | | | | | |
|------------------------------------|-----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| | 3 | 6 | 9 | 12 | 24 | 30 | 36 |
| (a) | | | | | | | |
| 0 | 0.81 | 2.49 | 4.17 | 5.79 | 11.97 | 14.95 | 16.95 |
| 0.3 | 0.86 | 2.62 | 4.72 | 5.87 | 12.40 | 14.59 | 17.58 |
| 0.6 | 0.82 | 2.47 | 4.20 | 5.71 | 12.73 | 15.29 | 18.40 |
| 1.2 | 0.86 | 2.66 | 4.14 | 5.98 | 12.32 | 14.72 | 17.58 |
| 2.4 | 0.92 | 2.73 | 4.38 | 5.87 | 12.73 | 13.93 | 17.98 |
| 4.8 | 0.92 | 2.78 | 4.46 | 5.94 | 12.91 | 14.83 | 16.40 |
| 9.6 | 0.84 | 2.55 | 4.34 | 5.72 | 12.50 | 15.26 | 17.24 |
| C.V. (%) ¹ | 10.11 ^{n.s.} | 7.62 ^{n.s.} | 7.28 ^{n.s.} | 2.82 ^{n.s.} | 6.06 ^{n.s.} | 6.04 ^{n.s.} | 6.13 ^{n.s.} |
| (b) | | | | | | | |
| 0 | 0.62 | 3.44 | 6.02 | 7.63 | 13.16 | 14.91 | 19.38 |
| 0.3 | 0.64 | 3.44 | 6.04 | 7.26 | 13.27 | 15.73 | 18.12 |
| 0.6 | 0.55 | 3.46 | 6.18 | 7.38 | 13.33 | 15.27 | 18.80 |
| 1.2 | 0.58 | 3.68 | 6.01 | 7.08 | 12.68 | 15.48 | 18.98 |
| 2.4 | 0.59 | 3.43 | 6.16 | 7.81 | 12.58 | 16.24 | 19.54 |
| 4.8 | 0.58 | 3.40 | 6.06 | 7.58 | 14.11 | 16.69 | 18.22 |
| 9.6 | 0.55 | 3.42 | 5.85 | 7.60 | 13.52 | 15.81 | 19.03 |
| C.V. (%) [*] | 7.62 ^{n.s.} | 6.24 ^{n.s.} | 3.95 ^{n.s.} | 4.05 ^{n.s.} | 5.49 ^{n.s.} | 5.39 ^{**} | 3.87 ^{n.s.} |

*C.V = coefficient of variation; ** significant at the 5% probability level, regression test; ^{n.s.} indicates not significant. ¹ represents linear regression equations, respectively.

Table 3. Diameters at the tree base (DTB) and breast height (DBH) for the *Eucalyptus* hybrid *E. urograndis* at 3, 6, 9, 12, 24, 30, and 36 months after gypsum applications (0, 0.3, 0.6, 1.2, 2.4, 4.8, and 9.6 Mg ha⁻¹) at Jaguariaíva (a) and Ventania (b), Paraná State, Brazil.

| Gypsum Rate Mg ha ⁻¹ | Age (months) | | | | | | |
|------------------------------------|----------------------|----------------------|-----------------------|----------------------|----------------------|----------------------|----------------------|
| | 3 | 6 | 9 | 12 | 24 | 30 | 36 |
| (a) | | | | | | | |
| | DTB | DTB | DBH | DBH | DBH | DBH | DBH |
| 0 | 1.41 | 4.59 | 4.44 | 6.96 | 12.99 | 14.40 | 15.90 |
| 0.3 | 1.53 | 4.89 | 3.90 | 6.37 | 13.11 | 14.05 | 15.00 |
| 0.6 | 1.42 | 4.64 | 4.38 | 7.34 | 13.57 | 14.76 | 15.87 |
| 1.2 | 1.49 | 4.96 | 4.43 | 7.36 | 13.09 | 14.02 | 15.33 |
| 2.4 | 1.67 | 4.95 | 4.70 | 7.30 | 13.21 | 14.17 | 15.21 |
| 4.8 | 1.68 | 4.92 | 4.77 | 7.44 | 14.17 | 14.40 | 15.68 |
| 9.6 | 1.41 | 4.66 | 4.45 | 7.19 | 13.53 | 14.80 | 15.60 |
| C.V. (%) ¹ | 4.56 ^{n.s.} | 6.96 ^{n.s.} | 11.96 ^{n.s.} | 9.83 ^{n.s.} | 5.43 ^{n.s.} | 3.74 ^{n.s.} | 4.25 ^{n.s.} |
| (b) | | | | | | | |
| | DTB | DTB | DBH | DBH | DBH | DBH | DBH |
| 0 | 1.04 | 2.94 | 6.27 | 8.28 | 12.79 | 13.57 | 15.47 |
| 0.3 | 1.07 | 2.84 | 5.96 | 8.36 | 12.75 | 13.66 | 15.32 |
| 0.6 | 0.89 | 2.96 | 6.11 | 8.01 | 12.71 | 13.54 | 15.53 |
| 1.2 | 0.96 | 2.86 | 6.05 | 8.40 | 12.89 | 13.62 | 15.64 |
| 2.4 | 0.93 | 2.93 | 6.22 | 8.46 | 13.13 | 14.04 | 15.65 |
| 4.8 | 0.98 | 2.84 | 6.09 | 8.56 | 12.88 | 13.65 | 15.51 |
| 9.6 | 0.87 | 2.87 | 6.01 | 8.61 | 13.01 | 13.82 | 15.96 |
| C.V. (%) [*] | 7.93 ^{n.s.} | 9.89 ^{n.s.} | 3.69 ^{n.s.} | 3.82 ^{n.s.} | 3.55 ^{n.s.} | 3.89 ^{**} | 3.39 ^{n.s.} |

*C.V = coefficient of variation; ** significant at the 5% probability level, regression test; ^{n.s.} indicates not significant. ¹ represents linear regression equations, respectively.

Table 4. Individual tree volume (m^3) and total tree volume ($\text{m}^3 \text{ha}^{-1}$) of *Eucalyptus* hybrid *E. urograndis* at 36 months after gypsum application [0, 0.3, 0.6, 1.2, 2.4, 4.8, and 9.6 Mg ha^{-1}] at Jaguariaíva and Ventania, Paraná State, Brazil.

| Gypsum Mg ha^{-1} | Individual tree volume | | Total tree volume | |
|-------------------------------|------------------------|----------------------|-----------------------------|----------------------|
| | m^3 | | $\text{m}^3 \text{ha}^{-1}$ | |
| | Jaguariaíva | Ventania | Jaguariaíva | Ventania |
| 0 | 0.11 | 0.12 | 124.22 | 133.90 |
| 0.3 | 0.10 | 0.11 | 114.03 | 122.56 |
| 0.6 | 0.12 | 0.12 | 134.07 | 130.44 |
| 1.2 | 0.11 | 0.12 | 118.88 | 134.12 |
| 2.4 | 0.11 | 0.12 | 120.05 | 137.92 |
| 4.8 | 0.10 | 0.11 | 116.09 | 126.75 |
| 9.6 | 0.11 | 0.13 | 121.41 | 139.74 |
| C.V. (%) ¹ | 10.86 ^{n.s.} | 8.96 ^{n.s.} | 10.86 ^{n.s.} | 8.96 ^{n.s.} |

¹C.V. = coefficient of variation; ^{n.s.} indicates not significant.

on DBH over time. Across all treatments, higher initial growth in terms of DTB was observed at Jaguariaíva area. At three months of age, DTB at Jaguariaíva area varied from 1.41 to 1.68 cm compared to 0.87 to 1.07 cm at Ventania area. Even after six months, Jaguariaíva presented larger values of DTB compared to Ventania. Differences in both areas were maintained at nine and 12 month assessments (Ventania presented larger DBH), but similar values of DBH were observed at 24, 30, and 36 months for both areas. In addition, small differences between treatments were observed at Ventania area at 30 months (first degree linear regression).

Results for individual tree volume and total volume ($\text{m}^3 \text{ha}^{-1}$) at 36 months are shown in Table 4. As could be observed in tree height and diameter assessments, gypsum application did not affect either individual tree or total volume.

4. DISCUSSION

Dendrometric measures in our study generally reflect those of other *Eucalyptus* studies of similar age. It could be noted that tree height increases of 5, 12, and 18 m were reported for the first, second, and third years in São Paulo State (Brazil) for *E. grandis* and *E. urograndis* (Almeida et al., 2010; Pinheiro et al., 2016). Tree heights in our study were similar with an overall average of 6, 13, and 17 m at Jaguariaíva and 8, 13, and 19 m at Ventania for three years of study period. At three and nine months, Freitas et al. (2009) by evaluating the effects of different managements of *Eucalyptus* seedlings, they could find an average

diameters from 2.0 to 4.5 cm, which were similar to diameters noted at Jaguariaíva; on the other hand, at nine months diameters were smaller than Ventania. At 18 months, Rodrigues et al. (2016) reported a DBH of ~8.0 cm for *E. urograndis*, closer to height parameters for Jaguariaíva area, but lower than Ventania area at 12 months. Despite these variations, tree diameters at both areas were within the range expected for this species.

In addition, mean yields of 40.3 $\text{m}^3 \text{ha}^{-1} \text{year}^{-1}$ at Jaguariaíva and 44.0 $\text{m}^3 \text{ha}^{-1} \text{year}^{-1}$ at Ventania were similar to the national mean (IBÁ, 2016). While their soils had somewhat similar characteristics, some edaphoclimatic characteristics can be highlighted as a variation factor: accumulated precipitation was higher at Jaguariaíva (+1,500 mm), while Ventania had slightly higher annual mean temperature ($\pm 1^\circ\text{C}$) and less annual frost. Measures of height, diameter, and yield confirmed that our study areas reflected normal productivity despite very low soil fertility under subtropical climatic conditions.

Due to the lack of a gypsum response, our findings suggest that soils were able to supply needed for Ca and S nutrients. The absence of a response may be related to isolated or combined effects of edaphic, management, and climate factors. *Eucalyptus* may have a high Ca demand and has been shown to exhibit high Ca extraction capacity, primarily due to arbuscular mycorrhizal fungi (AMF) and exploration of the radicular canal of soil depth (Pinheiro et al., 2016). This capacity can even occur under very low availability conditions as could be observed in our study of these soils. In

addition to this high capacity, it is important to note that 400 kg ha⁻¹ of Ca were added during limestone application prior to planting. Calcium was also added in smaller quantities at planting and during the three side dressings of TSP. Concerning a study on the same soil type in our region, Bizon (2005) evaluated sources of Ca nutrient in a *Pinus taeda* L. plantation and found that litter accumulations above 40 Mg ha⁻¹ were equivalent to 80 kg Ca ha⁻¹. Thus, litter from previous *Pinus* forest cycles was another potential Ca source that may have decreased the effect of gypsum application. A combination of the above factors (high Ca capacity, Ca from lime, fertilizer and litter) could have supplied sufficient Ca (350 to 450 kg ha⁻¹) for seven years of productivity at a rate of 50 m³ ha⁻¹ year⁻¹ (Benatti, 2013).

Since no S was applied by fertilization (except ~1% S from TSP) and no gypsum response was observed, it is probable that S requirements were met via the mineralization of organic S. On a dystrophic red-yellow (Oxisol) having 2% organic matter, Rodrigues et al. (2016) observed large yield increases that were attributable to S, in contrast to our study. Soil organic C levels had a concentration from medium to high at both areas (Jaguariaíva and Ventania) suggesting a S reserve. About 98% of S in tropical soils can be associated with organic matter (Aita & Giacomini, 2007). In *P. taeda* plantations, the annual contribution from litterfall decomposition could be 1.3 kg S ha⁻¹ (Viera & Schumacher, 2010). Thus, litter originated from antecedent *Pinus* cycles was a likely source of S in our study. Rocha et al. (2015) reported that S accumulated in soil and leaf litter (13 to 33 kg S ha⁻¹) on *Eucalyptus* plantations could meet tree requirements for cycles lasting from seven to nine years. In addition, the presence of paper cellulose factories in the Jaguariaíva region implies the possibility of atmospheric S contributions.

Similar to S, organic matter can also be a major nitrogen (N) soil reservoir. At the same locations (Bassaco et al., 2018), the absence of N response in *Eucalyptus* over three years suggested an adequate supply via Soil Organic Matter (SOM) and litter decay. In another Brazilian *Eucalyptus* study, adequate concentrations of N supplied by organic matter decomposition resulted in little or no response to applied N (Gazola et al., 2015).

Limiting characteristics of our soils (e.g., high soil acidity, toxic Al levels in deeper soil zones, low Ca

in deeper soil zones) favored the use of gypsum as a soil conditioner (Nietfeld & Prenzel, 2015). Several reasons could explain the lack of a gypsum response in our study. Firstly, the limestone application prior to study initiation may have limited soil conditioning properties of gypsum. While some researchers have reported a decreased response to gypsum when used to correct soil acidity (Rodrigues et al., 2016), others have reported that one limestone application increased *Eucalyptus* production (Rocha et al., 2008). Regarding the second reason, high and well distributed precipitation favored soil water availability and could have assisted the mechanism of Ca contact by mass flow. Oliva et al. (1989) observed Ca deficiency in *Eucalyptus* during dry periods, and the largest responses to gypsum observed by Pauletti et al. (2014) were under water deficit conditions. Third, *Eucalyptus* is recognized for a high tolerance to toxic Al levels (Rocha et al., 2008) via different mechanisms (Hartwig et al., 2007). In addition to immobilizing Al into cell walls, Echart & Molina (2001) proposed that these plants may tolerate Al by accumulating it in the symplast and excluding it from the root apex. Such mechanisms may play a role in explaining why applications of gypsum displayed little affect.

Differences in tree height between areas were observed at 12, 24, and 36 months with higher values observed at Ventania. Jaguariaíva trees were expected to be taller since they were planted four months earlier and this region had more total rainfall; however, taller heights at Jaguariaíva only persisted up to six months. Despite soil conditions similar to Jaguariaíva, *Eucalyptus* generally exhibited better growth at Ventania. This difference could be attributed to slightly higher air temperatures and lower altitude (± 208 m) at Ventania, since *Eucalyptus* has generally shown higher growth potential under more tropical conditions (Stape et al., 2010). Hybridization of *E. urophylla* may have resulted in the selection of factors more suitable for growth in this climate (Scanavaca & Garcia, 2003). However, further studies should be conducted to identify which features favor optimal growth in this region.

5. CONCLUSION

The absence of a response to gypsum as a source of Ca and S nutrients may be related to edaphic, management and climate factors. The application of

Ca via limestone, coupled with the high capacity of *Eucalyptus* to extract Ca, could help explaining a lack of response to gypsum. Further, high organic matter and leaf litter from preceding *Pinus* cycles likely provided sufficient S amounts for *Eucalyptus* growth. The lack of a response to high rates of gypsum, as a soil conditioner, could also be due to a combination of factors. Limestone application prior to study initiation may have hindered a response. Probably, the abundance of water from well distributed rainfall played a role since positive responses to gypsum applications have been more pronounced under water deficit conditions. Despite a focus of using gypsum as a soil conditioner to overcome high soil Al levels, *Eucalyptus* has inherent physiological mechanisms to resist Al toxicity. Findings indicated some variation in area conditions that favored *E. urograndis* growth at Ventania.

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