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Fertilization in *Eucalyptus dunnii* Maiden in Pampa biome - Brazil[1]

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Abstract: In silviculture, mineral fertilization is necessary to supply the nutritional demand, however, the recommendation of the quantities to be applied should aim at maintaining the productive capacity of the soil. The purpose of this study is to test whether increasing the recommended fertilizer dose improves soil fertility and increases the productivity of *Eucalyptus dunnii* in sites in the central region of the Pampa biome, Brazil. The doses of 150 g (T0), 225 g (T1) and 450 g (T2) of N-P_2O_5-K_2O were applied 24:00:24 per plant, after 14 months of planting. In all tested doses, the species productivity is considered satisfactory for the site. There was an improvement in soil fertility, especially in potassium contents, in addition to a higher individual volume of *Eucalyptus dunnii* trees after the application of the dose of 450 g plant^{-1} of N-P_2O_5-K_2O, 24:00:24 in coverage (T2).

Keywords: Silviculture; Soil fertility; Forest nutrition

Fertilização em *Eucalyptus dunnii* Maiden no bioma Pampa – Brasil

Resumo: Na silvicultura a fertilização mineral é necessária para suprir a demanda nutricional, no entanto, as recomendações das quantidades a serem aplicadas devem almejar à manutenção da capacidade produtiva do solo. O objetivo deste estudo é testar se o aumento da dose recomendada de fertilizante, melhora a fertilidade do solo e incrementa a produtividade de *Eucalyptus dunnii* em sítios da região central do bioma Pampa, Brasil. Foram aplicadas as doses de 150 g (T0), 225 g (T1) e 450 g (T2) de N-P_2O_5-K_2O 24:00:24 por planta, após 14 meses do plantio. Em todas as doses testadas, a produtividade da espécie é considerada satisfatória para o sítio. Houve melhoria da fertilidade do solo, especialmente nos teores de potássio, além de maior volume individual das árvores de *Eucalyptus dunnii* após a aplicação da dose de 450 g planta^{-1} de N-P_2O_5-K_2O 24:00:24 em cobertura (T2).

Palavras – chave: Silvicultura; Fertilidade do solo; Nutrição florestal

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Introduction

Optimizing the productivity of eucalyptus plantations is justified by the relevance that this culture has for Brazil, as it is the base that supplies raw materials for industries, e.g., cellulose, paper, charcoal, and steel (RESENDE et al., 2014). In this context, fertilization is essential, as silviculture is generally practiced in soils with low natural fertility and forest operations are still very intensive (BARROS et al., 2014).

The state of Rio Grande do Sul is characterized by wide pedological diversity, with fragile soils occurrence, susceptible to natural erosive processes. In Pampa biome region, the soil degradation is caused mainly by extensive livestock and mechanized agriculture, and natural factors additionally (STRECK et al., 2008; VERDUM et al., 2014). The silviculture practice in these sites requires careful planning about the fertilization, which must be combined with minimum cultivation practices and maintenance of forest residues (e.g. leaves, branches, stembark, stumps and roots) (GONÇALVES et al., 2004). To minimize leaching and depletion of soil nutrients, planning the silvicultural practices is essential. Annual fertilization excess, combined with intensive agricultural and forestry cultivation, cause eutrophication, environmental contamination, and 5 Gt of soil loss through erosion (FAO, 2015).

Knowledge about the effects of fertilization on soil productivity and nutrient stocks, especially in short-rotation stands, is essential to define conservation practices (LEITE et al., 2010). In long-term, soil sustainability and productive capacity reflect the soil organic matter maintenance and availability of nutrients via fertilizer, especially in sites with low natural fertility of the soil (BELDINI et al., 2009). Studies prove the importance of fertilization management in forest stands. Laclau et al. (2010) found an increase of up to 1/3 in stemwood volume in eucalyptus clones, when conserving soil organic matter. The organic matter resulting from the forest residues maintenance, and consequently, there was nutrient stock increase in sandy soils.

The silviculture effects on soil fertility, resulting from mineral fertilization, as well as the consequences of these changes on tree productivity and sustainability of eucalyptus cultivation, are little-known in Pampa biome. The aim of this study is to test whether increasing the fertilizer dose improves soil fertility and increases the *Eucalyptus dunnii* productivity, in central region of Pampa biome sites, Brazil.

Material and methods

Study site

This study was carried out in Pampa biome, São Gabriel, Rio Grande do Sul state, Brazil. The altitude is 114 m in relation to the average sea level and the relief varies from plain to undulating. The climate of the region, according Köppen classification, is a humid subtropical Cfa type, with average annual rainfall ranging from 1,600 to 1,900 mm year^{-1} (ALVARES et al., 2014). The soil of the site has low fertility (Table 1), classified as dystrophic Inceptisol (A-Bi-C horizons), with medium depth, medium texture (coarse sand = 70%; clay = 14%; fine sand = 9%; silt = 7%) and density ranging from 1.20 to 1.90 g cm^{-3}.

Table 1. Soil fertility in *Eucalyptus dunnii* stand before the mineral fertilization

Tabela 1. Fertilidade do solo em plantação de *Eucalyptus dunnii* antes da fertilização mineral.

Depth (cm)	SOM	N	pH	Al^{3+}	Ca^{2+}	Mg^{2+}	t	P*	K^{+}	V	m
	%	g kg^{-1}	(H_2O)	----------$cmol_c$ dm^{-3}----------				--mg dm^{-3}--		----%----	
0 - 20	1.40	1.40	4.50	0.80	0.40	0.13	1.60	32.80	63.90	43.10	54.20
20 - 40	1.10	1.10	4.70	0.90	0.32	0.06	1.40	7.40	56.20	37.10	63.00
40 - 60	1.00	1.00	4.70	0.80	0.32	0.06	1.30	4.80	59.50	40.80	59.40
60 - 80	0.80	0.80	4.70	1.10	0.34	0.05	1.60	2.20	47.90	31.90	68.50

Where: SOM = Soil Organic Matter; t = Effective CTC;* extracted by Melich1 method; Base saturation (V); Saturation by aluminum (m).

Experimental design

The experiment was carried out in *Eucalyptus dunnii* stand (central geographical coordinates of 30º30'12"S and 54º10'0.8"O). The stand is destined for cellulose production, cultivated in replacement site, where stumps and residues of branches, stembarks and leaves from the first harvest were kept on the soil.

For soil preparation, between the lines, subsoiling was performed at a depth of 50 cm. Pre-planting fertilization of 2 Mg ha^{-1} of dolomitic lime in total area, and 400 kg ha^{-1} of N-P_2O_5-K_2O, 10:27:10 applied in pit. Seminal seedlings were planted in May 2014, at 3.0 m x 1.7 m spacing.

Delimited in nine experimental units, with 20 m x 30 m each, the experiment was conducted in a completely randomized design. The use of this design was based on homogeneous conditions previously verified of soil fertility, soil depth and nutritional status of the trees, additionally the standardized pre-planting fertilization (DICK et al., 2016a).

For *Eucalyptus dunnii* cultivation in Pampa biome, in dystrophic soils, fertilization is essential and the recommended dose is 150 g $plant^{-1}$ N-P_2O_5-K_2O 24:00:24, indicated by the NUTRICALC platform®. The platform estimates the demand for nutrients to be applied via fertilization, by analyzing flows and stocks of nutrients, depending on the expected productivity and nutritional efficiency of the species (BARROS et al., 1995). The treatments, with three repetitions each, consisted of the application of this recommendation (control - T0) and additional amounts of fertilizer (Table 2). All treatments were applied on the same day, thrown on the soil in crown area projection, at 14 months after planting.

Table 2. Fertilization applied to *Eucalyptus dunnii* stand, São Gabriel, Rio Grande do Sul state, Brazil.
Tabela 2. Fertilizações aplicadas na plantação de *Eucalyptus dunnii*, São Gabriel, Rio Grande do Sul, Brasil.

Treatment	Dose
T0	150 g $plant^{-1}$
T1	225 g $plant^{-1}$
T2	450 g $plant^{-1}$

For evaluations of treatments effects on soil fertility and tree productivity, which were carried out at 36 months after planting (16 months after fertilization), double borders were considered in each experimental unit. This procedure was necessary to isolate possible interactions (root system and fertilizer distribution) and data interference (influence of treatments applied in neighboring plots).

Soil fertility analysis

Composed samples of soil were collected at depths of 0 to 20, 20 to 40, 40 to 60 and 60 to 80 cm, in trenches that were opened in center of each sample unit. The samples were air-dried and passed through a 2 mm mesh.

In laboratory, pH values in water, soil organic matter content (SOM), phosphorus (P), potassium (K), effective CTC (t), saturation by bases (V) and aluminum (m) were analyzed, according to Tedesco et al. (1995) methodology. Soil fertility was interpreted according the “Fertilization and Liming Manual for Rio Grande do Sul and Santa Catarina states", by Soil Chemistry and Fertility Commission (CQFS, 2016).

Dendrometric analysis

Diameter at breast height (DBH) data were measured at 1.30 m in relation to soil level with a diametric tape, in all the trees (approximately 80) of experimental units; height of 20% of the trees was obtained using a hypsometer (Vertex). To heights not measured were estimate regression models. The quadratic model $h = B_0 + B_1 * DBH + B_2 * DBH^2$ was the best adjustment (R^2aj. = 0.89; Syx% = 9.01), with B_0 = 13.36967, B_1 = -0.21415 and B_2 = 0.03304 regression coefficients.

For productivity estimate the stand basal area (G; $m^2\ ha^{-1}$) was calculated, and the average volume per hectare, with stembark, was obtained using the formula: $V = [(DBH/100)^2 * \pi/4] * h * f$ (PÉLLICO NETO; BRENA, 1997), where: V = total volume with stembark ($m^3\ ha^{-1}$), DBH = diameter at breast height (cm), h = total height (m) and f = 0.5 (form factor for *Eucalyptus dunnii*) (FINGER et al., 1995). To calculate individual volume (V'; $m^3\ trees^{-1}$), total volume (V) was divided by the number of trees per hectare (N).

Data analysis

After variances homogeneity normality of errors analysis, proven through the Bartlett and Shapiro-Wilk tests, respectively, for detection of differences between the means of soil fertility variables, for each soil depth compared between treatments, applied Tukey test, at 5% probability of error, in a completely randomized design. The same test was applied to differences analyze between the means of diameter at breast height, height and individual volume between treatments, in completely randomized design with different numbers of repetitions.

Results

Soil fertility

The T2 dose addition increased the potassium contents in topsoil (Table 3). The levels went from low to high, through fertilization with T1 and T2 doses; in soil fertilized with T0, at 0 to 60 cm depth, K levels are low and 60 to 80 cm are medium (CQFS, 2016).

Table 3. Effect of mineral fertilizer doses in soil fertility of *Eucalyptus dunnii* stand in Pampa biome, Rio Grande do Sul state, Brazil.
Tabela 3. Efeito de doses de fertilizante mineral na fertilidade do solo em povoamento de *Eucalyptus dunnii* no bioma Pampa, Rio Grande do Sul, Brasil.

	Depth	SOM	pH	t	[1/]P	K^+	V	m
	(cm)	%	H_2O	$cmol_c\ dm^{-3}$	------mg dm^{-3}------		---------%-------	
T0	0 - 20	[2/]1.1±0.2 a	4.5±0.1a	2.0±0.1a	42.0±3.8a	38.7±2.3b	57.5±5.2a	41.6±4.3a
	20 - 40	0.9±0.2a	4.2±0.0a	2.4±0.5a	19.8±3.2b	37.3±6.1b	14.5±0.3a	85.9±0.8a
	40 - 60	0.5±0.1a	4.3±0.1a	2.1±0.5a	16.3±2.4b	33.3±8.3b	15.1±6.0a	84.4±6.2a
	60 - 80	0.2±0.06c	4.4±0.1a	2.3±0.6a	14.9±9.5b	42.7±8.3a	24.4±13.0a	76.1±14.0a
T1	0 - 20	1.2±0.06a	4.2±0.2a	2.2±0.3a	46.3±3.9a	46.7±2.3b	34.9±5.2a	63.5±4.3a
	20 - 40	1.5±0.3a	4.2±0.2a	3.6±0.8a	23.7±9.5b	62.7±16.2a	14.8±2.2a	86.0±1.9a
	40 - 60	1.6±0.9a	4.2±0.1a	3.3±0.6a	14.3±10.0b	49.3±4.6ab	12.5±2.3a	86.8±2.3a
	60 - 80	0.8±0.06a	4.2±0.06a	3.6±0.5a	15.0±2.6b	54.7±10.1a	16.8±10.6a	83.9±10.5a
T2	0 - 20	1.2±0.1a	4.4±0.3a	2.2±0.2a	40.4±1.6a	57.3±2.3a	57.3±2.3a	43.1±21.5a
	20 - 40	1.4±0.4a	4.2±0.2a	3.3±1.1a	25.7±10.9ab	58.7±2.3ab	19.1±3.6a	81.0±4.7a
	40 - 60	0.8±0.06a	4.3±0.1a	2.7±0.5a	18.2±6.1b	72.0±16.0a	17.2±8.9a	83.4±8.3a
	60 - 80	0.4±0.1b	4.5±0.2a	2.4±0.4a	13.4±9.0b	60.0±10.6a	19.4±10.5a	79.4±10.3a

Where: T0 = 150 g; T1 = 225 g; T2 = 450 g of $N-P_2O_5-K_2O$ 24:00:24 per plant; Soil Organic Matter (SOM); Effective CTC (t); [1/]P extracted by Melich1 method; Base saturation (V); Saturation by aluminum (m). [2/]Means (± standard deviation) of different treatments, for same layer, when followed by same letter in column, do not differ between treatments in Tukey test (α = 5%).

Due to prolonged action time of the fertilizer and availability of high levels of phosphorus, even after 36 months of 47 kg ha^{-1} application in pre-planting, it is not necessary to add the element in cover fertilization. In relation to the other attributes that characterize soil fertility, in all treatments and depths, soil organic matter contents are low and the pH of this dystrophic soil is acidic. The phosphorus content varied from very high to high in up to 60 cm from the soil and medium in depth from 60 to 80 cm (CQFS, 2016). In this soil there is also low saturation by bases (< 50%) and high saturation by aluminum.

Stand productivity

The addition of T2 dose resulted in a higher volume produced per tree (m^3 $trees^{-1}$). This result is a reflection of greater heights obtained in this treatment, as the DBH was not influenced by the different fertilizer doses (Table 4). After 36 months of planting, productivity of 36, 41 and 37 m³ ha^{-1} year^{-1} were reached for T0, T1 and T2, respectively. The greater volume produced per area (m³ ha^{-1}) in T1 is due to the greater number of trees (N) that received this treatment (lower mortality rate), however, individual volume (m³ trees^{-1}) obtained with T2 dose was 14.8% higher than that observed in T0.

Table 4. Effect of mineral fertilizer doses in *Eucalyptus dunnii* stand productivity in Pampa biome, Rio Grande do Sul state, Brazil.
Tabela 4. Efeito de doses de fertilizante mineral na produtividade de povoamento de *Eucalyptus dunnii* no bioma Pampa, Rio Grande do Sul, Brasil.

Treatment	N	DBH	h	G	V	V'
	tree ha^{-1}	cm	m	m² ha^{-1}	m³ ha^{-1}	m³ tree^{-1}
T0	1,183	12.1 ± 1.5 a[1/]	15.7 ± 0.9 b	13.67	107.07	0.0931 ± 0.02 b
T1	1,217	12.7 ± 1.9 a	15.8 ± 1.3 ab	15.52	123.45	0.1052 ± 0.03 ab
T2	1,067	12.8 ± 1.6 a	16.4 ± 1.4 a	13.58	111.16	0.1069 ± 0.03 a

Where: N = number of trees per hectare; DBH = diameter at breast height; h = total height; V = total volume; V' = individual volume; [1/] Means followed by same letter in column do not differ by the Tukey test, at 5% probability of error; Treatment T0 = 150 g; T1 = 225 g; T2 = 450 g of N-P_2O_5-K_2O 24:00:24 per plant;

Discussion

Soil fertility

As for the temporal dynamics of soil fertility (Table 3), the highest concentrations of potassium passed from superficial to subsurface layers, as there is rapid leaching and vertical mobility of this nutrient (NOVAIS; SMYTH; NUNES, 2007). The effect of mineral fertilizer doses is expressed only in potassium contents, as the variability in phosphorus contents is due to pre-planting fertilization, since there was no addition of this mineral. In the study area, the highest levels of phosphorus in soil superficial layers reflect the residual effect of pre-planting fertilization, which is three years or more (MALAVOLTA, 2006).

Due to resilience time and slower release, in operational silviculture of eucalyptus, higher amounts of phosphorus are commonly applied in pre-planting fertilization (SILVA et al., 2013; DIAS et al., 2014; FERNANDEZ et al., 2000). However, monitoring of soil fertility is essential, since less than 30% of phosphorus supplied is absorbed by plants, due to the formation of insoluble compounds, causing low mobility (MALAVOLTA, 2006). When phosphorus is applied via mineral source, in sandy soil, the availability of phosphorus is even greater, which is the case of dystrophic Inceptisol, where immobilization is less pronounced, due to the low levels of clay and oxides (MALUF et al., 2015).

The high saturation by aluminum in soil of the present study is conditioned by lower pH values, which favored the aluminum solubilization (FARIA et al., 2009). Aluminum can be toxic to plant nutrition, however, *Eucalyptus* species are tolerant of high levels of this element in the soil; at up to 88% saturation by aluminum there is no impairment in root development (NEVES: NOVAIS; BARROS, 1982).

Acidity and low nutrient availability are intrinsic characteristics of Pampa biome soils

(STRECK et al., 2008), however, silviculture can improve soil fertility in sites where it is implanted (DICK et al., 2016b; LEITE et al., 2010). The low natural fertility of Pampa biome soils is linked to several factors, among them the lowest levels of soil organic matter, type of vegetation cover and sand and silt fraction predominance granulometric composition, which are mostly sandy (granite, sandstone) (STRECK et al., 2008).

According Novais, Barros and Neves (1986) projections, who consider the stemwood volume expected as a function of nutrient contents contained in 20 cm of soil depth, to achieve the high productivity of eucalyptus (50 m³ ha^{-1} $year^{-1}$) only phosphorus contents are suitable; ideal potassium levels should be 90 mg dm^{-3}. Due to the fertility conditions of this dystrophic Inceptisol after mineral fertilizer doses application, the productivity projection of *Eucalyptus dunnii* stand is 30 to 40 m³ ha^{-1} $year^{-1}$.

Stand productivity

Higher heights in eucalyptus plants are generally associated with an adequate supply of potassium in the soil, since this nutrient is directly related to developmental functions of apical meristems (EPSTEIN; BLOOM, 2006). The effects of potassium on height of trees are reported in other species of eucalyptus, where the addition of higher doses of potassium promoted an increase in the height of young plants of *Eucalyptus grandis, Eucalyptus urophylla, Eucalyptus camaldulensis* and *Eucalyptus urograndis* (TEIXEIRA; GONÇALVES; JUNIOR, 2006).

It was expected that the effect mineral fertilizer doses would also be observed in DBH values of trees, however it is important to note that this stand was formed with seedlings. In this case, the dendrometric characteristics heterogeneity, which does not express significant effects of the treatments in DBH is attributed to progenies genetic variability (WARING; SCHLESINGER, 1985).

In addition to genetic factor, mineral fertilizer doses do not promote significant differences in dendrometric variables, especially DBH, since eucalyptus species are not very demanding on soil fertility, nor do they take advantage of all the fertilizer available in excess (PEREIRA; YAMAUTI; ALVES, 2012). Despite the increase in potassium supply in soil (Table 3), the application of 200% more fertilizer (T2) did not result in higher DBH values; same result was observed in eucalyptus clones, 2.8 years after cultivation in Leptosol (STAPE et al., 2010).

At 36 months after *Eucalyptus dunnii* planting, greater volume was obtained than that observed for same species, however at 60 months, where productivity was 24.8 m³ ha^{-1} $year^{-1}$ (DICK et al., 2016d). The referred stand (1,143 trees ha^{-1}) was also grown in dystrophic soil in Pampa biome, however, smaller amounts of fertilizer were applied (300 kg ha^{-1} of N-P_2O_5-K_2O 06-30- 06 pre-planting; 140 kg ha^{-1} of N-P_2O_5-K_2O 22-05-20 at 90 days and 22-00-18 at 270 days).

In addition to mineral sources influence, species, edaphic conditions, among other variables, the effect of fertilization on productivity is more pronounced when the stand is young (SILVA et al., 2013). There is efficiency of fertilization until the canopy closing of eucalyptus trees (SANTANA; FONTAN; OLIVEIRA, 2014), however, adding high doses will not always condition significant differences in productivity.

Although T2 treatment promotes greater individual volume, there is a need for analysis as to the cost/benefit ratio and environmental impacts after adding an additional 200% of fertilizer dose. The individual volume produced at this site, obtained with the recommended fertilization (T0), is 350% higher than that recorded for species grown in same region (DICK et al., 2016d).

Conclusion

For all mineral fertilizer doses, the *Eucalyptus dunnii* stand productivity is considered satisfactory for cultivation in Pampa biome. The dose of 450 g plant^{-1} of N-P_2O_5-K_2O, 24:00:24, promoted an improvement in soil fertility due to increase in potassium levels. With this fertilizer dose, there was also the greatest increase in height and individual volume of *Eucalyptus dunnii* trees.

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