FERTILIZATION EFFECTS ON *EUCALYPTUS PELLITA* F. MUELL PRODUCTIVITY IN THE COLOMBIAN ORINOCO REGION[1]

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ABSTRACT – The Orinoco region, is the one with the largest area for forest development. Nonetheless, some of its soils are acid and characterized by low fertility levels, which has considerably limited plantation productivity. Therefore, this study aimed at assessing the effects of soil fertilizing and liming by using phosphorus and potassium on 34-month-old *Eucalyptus pellita* productivity. Tests have been carried out at: Villanueva, Casanare; Puerto Lopez, Meta and La Primavera, Vichada, under a random block design with a factor arrangement of 3x3x3, equivalent to: 0, 1 and 3 Mg ha^{-1} of dolomitic lime (LIME); 30, 75 and 120 kg ha^{-1} of P (P_2O_5) as well as 60, 120 and 180 kg ha^{-1} of K (K_2O). Timber productivity volume was assessed 34 months after planting, obtaining significant differences. In Puerto Lopez, LIME effect on *E. pellita* growth followed a simple linear model, whereas a logarithmic behavior was observed in La Primavera and Villanueva. P_2O_5 effect ($p<0.01$) on timber volume was observed only in La Primavera, following a square-root model. K_2O did not have a significant effect ($p>0.05$) on *E. pellita* growth. The results obtained indicate the positive effect on *E. pellita* growth in the three areas of study by using doses of approximately 1 Mg ha^{-1} of lime; and 120 kg ha^{-1} of P_2O_5 in La Primavera.

Keywords: *Lime, Phosphorus, Potassium.*

EFEITO DA ADUBAÇÃO NA PRODUTIVIDADE DO EUCALYPTUS PELLITA F. MUELL NA REGIÃO DA ORINOQUIA COLOMBIANA

RESUMO – A Orinoquia, é a região da Colômbia com maior área potencial para o desenvolvimento florestal; porém, apresenta solos com alta acidez e baixa fertilidade natural, o qual tem sido limitante para a produtividade dos plantios. Assim, o estudo teve como objetivo avaliar os efeitos da calagem e da adubação com aplicação de fósforo e potássio, no crecimento de Eucalyptus pellita *aos 34 meses de idade, procurando melhorar sua produtividade. Foram estabelecidos ensaios em: Villanueva, Casanare; Puerto López, Meta e La Primavera, Vichada, num desenho em blocos casualizados com três repetições, em esquema fatorial 3x3x3, correspondentes a: 0, 1 e 3 Mg ha^{-1} de calcário dolomítico (CAL); 30, 75 e 120 kg ha^{-1} de P (P_2O_5) e 60, 120 e 180 kg ha^{-1} de K (K_2O). Aos 34 meses foi avaliada a produção em volume de madeira, obtendo como resultado diferenças significativas ($p<0,01$), por efeito das doses de CAL aplicadas, com ajuste linear simples em Puerto López e logarítmico em La Primavera e Villanueva. Houve efeito raiz quadrático ($p<0,01$) do P_2O_5 no volume de madeira, apenas na Primavera. As doses de K avaliadas não apresentaram efeito significativo ($p>0,05$) sob o crescimento de* E. pellita*, nos locais de estudo. Os resultados obtidos indicam o efeito positivo sob a produtividade de* E. pellita*, nas áreas de estudio, com aplicação de doses próximas a 1 Mg ha^{-1} de calcário e 120 kg ha^{-1} de P_2O_5 em La Primavera.*

Palavras-Chave: Calagem; Fósforo; Potássio.

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1.INTRODUCTION

There are approximately 24.8 Mha suitable for commercial plantations, which is equivalent to 21.8% of the national territory (UPRA, 2014). Nonetheless, although the forest potential is considerably high, the country has not achieved to increase its production capacity. During this last years, furniture and timber sectors are showing negative trade balances with generalized export decrease and import increase trends (Colombia, 2016).

The Colombian Orinoco region is the one with the largest areas for forest development, including Meta and Vichada states, with more than 2.5 Mha suitable for forestry activities each. However, edaphic restrictions like high acidity and low natural fertility rates are common (UPRA, 2014). On top of that, the region is characterized by high rain levels that cause a very active lixiviation process implying nutrients loss and biological activity reduction, limiting forest plantations development and productivity (Zavala et al., 2005).

Eucalyptus pellita F. Muell is native to North of Queensland, Australia and New Guinea, playing an important role in commercial reforestation in countries like Indonesia, Malaysia, the Philippines and Australia, among others. The species has good growth and coppicing properties, resistance to plagues, adaptability to a variety of environmental conditions and multipurpose timber (Clarke et al., 2009). In Colombia, it is one of the most adapted species to tropical rainforest conditions in the northeastern Orinoco region (Giraldo et al., 2014). Nonetheless, plantations with this species have shown low productivity mainly due to the lack of knowledge about the species nutrition requirements.

Among the practices to improve forest productivity in acidic soils are: soil preparation, liming and chemical fertilization (Rojas, 2015). Nonetheless, in order to achieve forest plantation sustainability during its development, it is necessary to balance nutrients on the short, long and medium term (Santana et al., 2002) by using the optimum dose adjusted to soil nutrients availability to achieve maximum site productivity (Rodríguez and Álvarez, 2010; Zapata, 2013).

Some species of the *Eucalyptus* genus are pretty tolerant to high aluminum, as well as to low nutrients concentrations (Barros and Novais, 1999). Nonetheless, in order to obtain high productivity rates, using fertilizers is necessary. Liming, is an agricultural practice that has been employed since very remote ages in order to improve acidic soil productivity, given its multiple effects on several soil chemical, physical and microbiological characteristics (Osorno, 2012).

Proper fertilization using phosphorus and potassium is essential for eucalypt plantations full development (Rocha et al., 2008). Usually, eucalypts require much P in planting and K in young and mature stages (Stahl et al., 2013). Bammanahali et al. (2011), for instance, improved young *E. pellita* productivity by using 100 kg ha^{-1} of P_2O_5 and 200 kg ha^{-1} of K_2O compared to the control treatment in Karnataka, south of India.

In eucalypt plantations, K and Ca, are among the nutrients with the highest accumulation rate in the trunk: between 312 and 455 kg ha^{-1} of Ca and between 148 and 192 kg ha^{-1} of K for 134 to 187 Mg ha^{-1} of trunk biomass at the age of 6.5 years (Santana et al., 2008). Several studies have demonstrated the high response to K, and this nutrient is one of the best indicators of eucalypt plantation sustainable productivity (Gonçalves et al., 2009).

In accordance with the above, this study had the purpose of assessing the effects of liming, phosphorus and potassium fertilization on 34-month-old *E. pellita* growth.

2.MATERIALAND METHODS

2.1. Studied areas

In October 2013, three experiments were established in three locations: Villanueva, Casanare (4°38’29.6”N; 72°53’26.2”W); Puerto Lopez, Meta (3°56’09.7”N; 72°38’53.3”W); and La Primavera, Vichada (5°35’28.5”N; 69°22’13.1”W), all belonging to the Colombian Orinoco Region, located in the eastern part of the country.

The studied areas are approximately 100 to 300 meters above sea level, plain relief, with temperatures of 25.8 to 27.5 ºC; average rainfall of 2,197 to 2,699 mm, yearly average potential evapotranspiration between 1,321 and 1,547 mm and relative humidity rates of 76.7% to 81%. According to the Köppen’s classification, the climate is (Am), tropical monsoonal with monomodal rain regime, the rainy season going from April to November and dry season from December to March. Minimum rainfall is recorded in January, where the water-deficit period begins and lasts until the first quarter of the year.

According to IGAC (1995), the area soils are classified as oxisols (in La Primavera and Puerto Lopez) and entisols (in Villanueva). These soils are typical of the region and are chemically characterized by low organic matter and interchangeable base contents, low fertility and sand content greater than 500 g kg^{-1} (Table 1).

2.2. Experiment design

The experiment was designed in randomized blocks with three repetitions and a factorial arrangement of 3x3x3 corresponding to 3 doses of LIME (0, 1 and 3 Mg ha^{-1} of dolomitic lime); 3 doses of P (30, 75 and 120 kg ha^{-1} of P_2O_5) and 3 doses of K (60, 120 and 180 kg ha^{-1} of K_2O). Triple superphosphate with 43% of P_2O_5 was used as P source, potassium chloride with 60% of K_2O as K source and dolomitic lime with 32% of CaO and 17% of MgO as LIME. The sample unit was composed of 20 trees spaced in 3x3 meters, considering utile for assessment the six central trees.

2.3. Trial planting

The seedlings were produced at Reforestadora de la Costa's nursery with seed proceeded from Villanueva-Casanare. The seeds were sown on seedbeds and the seedlings transplanted to dibble tubes, being grown for 80 days. LIME was applied to the soil a month before planting and incorporated with a subsoiler. P was applied in a unique dose after planting, in lateral dibble holes 20 cm away from the seedling. K doses were applied in three moments: planting (lateral dibble holes 30 cm away from the seedling), seven months after planting and eight months after planting (in lateral dibble holes under the projection of tree canopy).

A base fertilization was applied to all trees, composed of 50 kg ha^{-1} of nitrogen and 57 kg ha^{-1} of sulfur, in the form of ammonium sulphate applied at planting and six months after, under tree canopy projection. Borax (11 kg ha^{-1}, with 15% of boron) and other micronutrients were also applied.

Table 1 – Chemical and physical properties of the soil at 0 to 20 cm of depth in experimental areas
Tabela 1 – *Propriedades químicas e físicas do solo a 0-20 cm de profundidade, nas áreas experimentais.*

		Villanueva	Puerto López	Primavera
pH H_2O	-	4.63	4.68	4.32
OM	g kg^{-1}	10.9	5.7	7.2
P	mg kg^{-1}	3	2.17	1.14
K	$cmol_c$ dm^{-3}	0.04	0.02	0.02
Ca	$cmol_c$ dm^{-3}	0.32	0.36	0.28
Mg	$cmol_c$ dm^{-3}	0.11	0.11	0.09
Al	$cmol_c$ dm^{-3}	0.72	0.2	0.97
H+Al	$cmol_c$ dm^{-3}	0.88	0.39	1.3
S	mg kg^{-1}	2.21	2.47	13.82
Fe	mg kg^{-1}	134	110	44.38
B	mg kg^{-1}	0.7	0.6	0.33
Cu	mg kg^{-1}	1.4	0.7	0.34
Mn	mg kg^{-1}	3.2	1.3	0.1
Zn	mg kg^{-1}	0.7	0.6	0.31
Sand	g kg^{-1}	710	820	540
Silt	g kg^{-1}	130	70	300
Clay	g kg^{-1}	160	100	160

pH soil:water relation 1:1; MO –Walkley-Back Method. Change Bases – Atomic Absorption, Extraction with Ammonium Acetate; Phosphor available, Bray II. Interchangeable Aluminum – Acid-base assessment, Yuang Method (KCl). Sulphur – Monobasic calcium phosphate. Boron - Colorimetric (Azomethine H), Monobasic calcium phosphate. Micronutrients - Atomic Absorption, Extraction with DTPA.

2.4. Statistical Analysis

At 34 months after planting, height (H) and diameter at 1.3 m above ground level (DBH) were measured using a VERTEX IV Haglof and a girth band, respectively. Data related to the six trees located in the center of each plot were used for analysis. The mean volume with bark (Vol) per tree was estimated from the formula adjusted for the species in the studied area (López, 2007): Eq-1

$$Vol\ (m^3) = 0.000114 * DBH(cm)^{1.227533} * H(m)^{1.371201}$$

Volume data obtained as a response to fertilization treatments were subjected to the Ryan-Joiner and Bartlett tests, for normality and homoscedasticity check, respectively. These tests showed that data was normal and homoscedastic ($p>0.05$) in the three locations. Subsequently, the ANOVA was carried out in order to determine treatment effect. The following regression models were assessed: simple linear, square root, exponential, hyperbolic and logarithmic. Analyses were carried out by means of the Sisvar and Minitab 18 statistical software.

3.RESULTS

3.1. La Primavera (Vichada)

There was a significant effect ($p<0.01$) of LIME and P doses on *E. pellita* growth. In Table 2, ANOVA related to the volume variable is presented, indicating that there was no interaction between P_2O_5 and LIME doses used in this experiment. The volume response to LIME was better adjusted to the logarithmic model, whereas for P doses the model with the best adjustment was the square-root one (Figure 1). Decreasing increments with LIME were observed, with stability beginning at 1 Mg ha[1] of LIME, approximately.

Eucalyptus pellita trees that received 1 and 3 Mg ha^{-1} of LIME, had a volume production of 0.046 and 0.049 m^3 respectively, a 34 and 39% increase compared with those that did not receive fertilization and had a mean volume of 0.033 m^3. The application of 75 and 120 kg ha^{-1} of P_2O_5 resulted in volume increase of 20 and 35% respectively, compared with the lowest dose (30 kg ha^{-1}) of P_2O_5. In La Primavera, K doses did not produce significant effects ($p>0.05$) on *E. pellita* tree volume.

3.2. Villanueva (Casanare)

LIME doses applied on soil before planting of *E. pellita* trees had a significant effect ($p<0.01$) on tree volume at 34 months after planting. No significant effect was observed ($p>0.05$) regarding P and K application and interactions (Table 2).

The mean volume per tree without LIME was 0.058 m^3, while a mean of 0.071 and 0.075 m^3 was obtained by applying 1 and 3 Mg ha^{-1}, a 23 and 27% increase on tree volume (Figure 2). The volume response to LIME adjusted better to the logarithmic model.

3.3 Puerto Lopez (Meta)

Variance analysis indicated that a significant effect was produced on 34-month-old *E. pellita* trees volume due to LIME application before planting (Table 2). Volume as a function of LIME doses followed a simple linear model (Figure 3). Tree volume reached 0.08 and 0.10 m^3, increasing by 8 and 24%, respectively, compared with those that did not receive LIME (Figure 3).

K and P application did not produce significant effects ($p>0.05$) on *E. pellita* tree volume in Puerto Lopez.

4.DISCUSSION

Productivity increases obtained by lime application have been observed in different eucalypt species (*E. pellita* included), in acidic soils with low base content, especially Ca and Mg. Giraldo and Parra (2012), evaluated the response of *E. pellita* with 14 months to the application of calcium and magnesium fertilizers in Villanueva – Casanare, evidencing a positive response to doses between 2 and 4 Mg ha^{-1}, in pH 4 soils with Ca levels of approximately 0.2 $cmol_c\ dm^{-3}$. In that case, height and DBH increases were between 76 and 160%, respectively, compared with trees that did not receive any fertilizer. Rodríguez et al. (2016), obtained significant volume increases by applying dolomitic lime in *E. grandis* plantations on a dystrophic Red-Yellow Latosol soil of medium texture, with a pH between 4.06 and 4.88 at 10 to 20-cm depth, and Ca and Mg levels lower than 0.01 $cmol_c\ dm^{-3}$, in the Cerrado region, Minas Gerais State, Brazil, increasing productivity by 58% 18 months after planting, compared with tress that received no fertilizer.

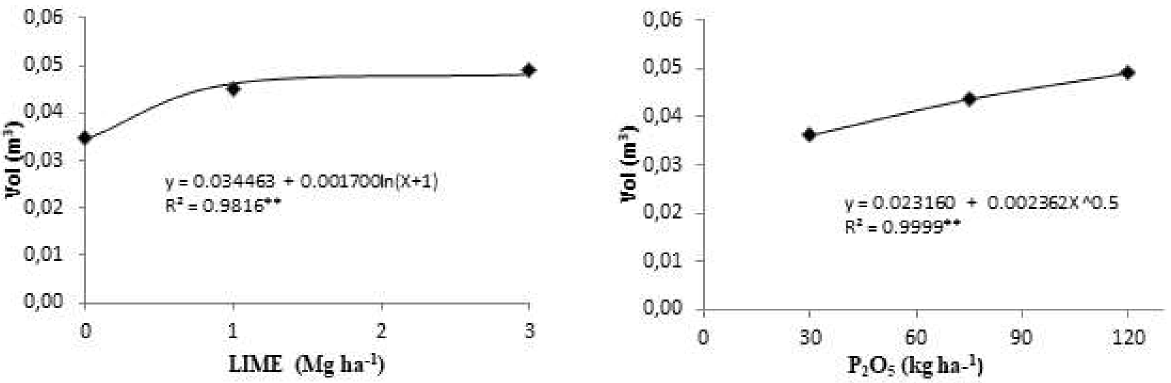

Figure 1 – Volume of *E. pellita* trees at 34 months in La Primavera, Vichada; as a response to LIME (Dolomitic lime in Mg ha^{-1}) and P (kg ha^{-1} of P_2O_5). **Significant ($\alpha = 0.01$).
Figura 1 – *Volume em árvores de E. pellita aos 34 meses de idade em La Primavera, Vichada; como resposta à aplicação de CAL (Calcário dolomítico em Mg ha^{-1}) e P (kg ha^{-1} de P_2O_5). Significativo ($\alpha = 0.01$).*

Table 2 – Analysis of variance of *E. pellita* volume (m^3) at 34 months, as a response to K (kg ha^{-1} of K_2O); LIME (Dolomitic Lime in Mg ha^{-1}) and P (kg ha^{-1} of P_2O_5) application. Significant** *(α = 0.01)*.
***Tabela 2** – Analises de variancia para o volume (m^3) de E. pellita aos 34 meses de idade como resposta à aplicação de K (kg ha^{-1} de K_2O); CAL (Calcário dolomítico em Mg ha^{-1}) e P (kg ha^{-1} de P_2O_5). Significativo** (α = 0.01).*

		La Primavera		Villanueva		Puerto Lopez	
Sources of Variation	DF	SS	P value	SS	P value	SS	P value
Block	2	0.000969	0.025	0.001559	0.000	0.003063	0.028
LIME	2	0.002994	0.000 **	0.004156	0.000 **	0.00526	0.003 **
P	2	0.002279	0.000 **	0.000215	0.286	0.002233	0.07
K	2	0.00038	0.22	0.000126	0.476	0.001147	0.247
LIME *P	4	0.000178	0.832	0.000209	0.648	0.000458	0.885
LIME *K	4	0.000262	0.708	0.000381	0.349	0.002425	0.21
P*K	4	0.000934	0.121	0.000167	0.736	0.001539	0.435
LIME *P*K	8	0.001248	0.273	0.000653	0.467	0.002531	0.611
Error	52	0.006324		0.004357		0.020735	
Total	80	0.015566		0.011824		0.03939	
Mean of treatment			0.0429	0.0685			0.0865
CV%			32	17.7			25.6

On the other hand, the lack of response of *E. pellita* to P and K doses in Puerto Lopez and Villanueva can be partly associated to a better assimilation of these nutrients due to LIME effects on soil. According to Rocha et al. (2008), increasing Ca supply from lime application increases soil pH, effective cationic exchange capacity, base saturation and interchangeable Ca and Mg, as well as P, K and S availability, allowing significant diameter and height increases.

After 34 months of growth, phosphate fertilization response on tree volume was observed only in La Primavera, where P soil levels were the lowest of the three testing sites: 1.14 mg kg^{-1}, compared with 2.17 and 3 mg kg^{-1} in Puerto López and Villanueva, respectively (Table 1). Soils with P levels between 0 and 2 mg kg^{-1} show high responses to phosphate application (Gonçalves, 2016).

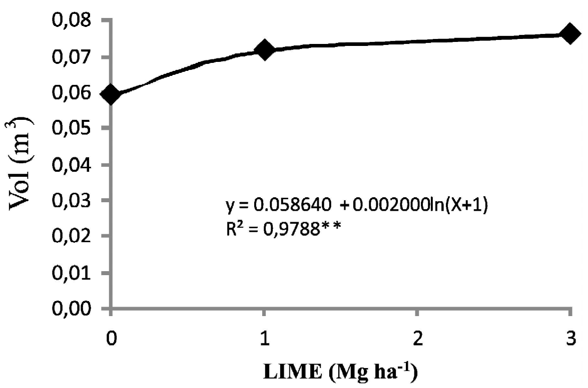

Figure 2 – Volume of *E. pellita* trees at 34 months in Villanueva, Casanare; as a response to LIME (Dolomitic lime in Mg ha^{-1}) and P (kg ha^{-1} of P_2O_5). Significant** (α= 0.01).
***Figura 2** – Volume de árvores de E. pellita aos 34 meses de idade em Villanueva, Casanare; como resposta à aplicação de CAL (Calcário dolomítico em Mg ha^{-1}). Significativo** (α = 0.01).*

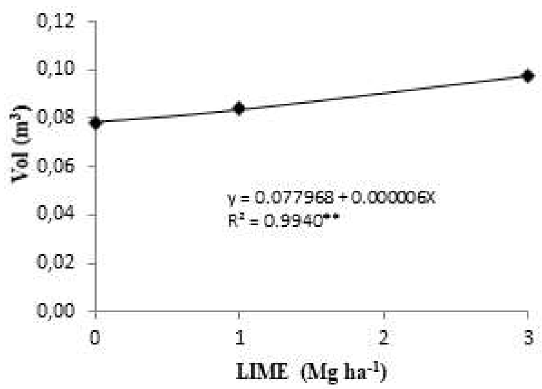

Figure 3 – Volume of *E. pellita* trees at 34 months in Puerto López, Meta; as a response to K (kg ha^{-1} of K_2O); CAL (Dolomitic Lime in Mg ha^{-1}) and P (kg ha^{-1} of P_2O_5). **Significant (α = 0.01).
***Figura 3** – Volume de árvores de E. pellita aos 34 meses de idade em Puerto Lopez, Meta; como resposta à aplicação de K (kg ha^{-1} de K_2O); CAL (Calcário dolomítico em Mg ha^{-1}) e P (kg ha^{-1} de P_2O_5). **Significativo (α = 0.01).*

Results with similar doses to those used in this study were obtained by Fernandez et al. (2000), who reported increase of 73% at 9.5 years with 112 kg ha^{-1} of P_2O_5, compared with trees that did not receive P in *E. camandulensis* clonal plantations located in Viçosa, Minas Gerais, Brazil. Likewise, Xu et al. (2005), using superphosphate as base fertilizer, significantly increased *E. urophylla* productivity at 54 months, in ultisols located in the south of China with P contents of 1.53 mg kg. The application of 20 kg ha^{-1} of P_2O_5 increased productivity to 21 m^3ha^{-1} per year, while 29.7 $m^3 ha^{-1}$per year were obtained with 200 kg ha^{-1} of P_2O_5.

Potassium is one of the most absorbed elements by the majority of forest species, nonetheless, only a small quantity is available in soils, resulting in high demands of this nutrient to satisfy tree nutrition requirements (Alvarado and Raigosa, 2007). Likewise, K is one of the most demanded nutrients by eucalypts, which usually respond to K fertilization and grow poorly when this element is lacking (Teixeira et al., 2006). However, in this study, no effect of K application was observed in *E. pellita* tree volume, regardless of the location, which can be attributed to the fact that the lowest dose (60 kg ha^{-1} de K_2O) used in this experiment was calculated to supply the species demand. Different studies report positive responses to K in soils with low K levels, similar to those of this study (0.02 to 0.04 $cmol_c$ dm^{-3}). Gazola (2014), for instance, obtained the maximum diameter of *E. urophylla* clones at 18 and 24 months after planting by employing 86 and 129 kg ha^{-1} of K_2O, respectively. The nutrient source employed that study was also KCl and the soil showed K level of 0.02 $cmol_c$ dm^{-3}. Melo et. al (2016), obtained 130% increase in tree volume by using 125 kg ha^{-1} of K_2O compared with trees that did not receive K, in soils with K level of 0.03 cmol dm^{-3}.

5.CONCLUSIONS

The results obtained indicate the positive effect on *E. pellita* growth in the areas of study by using doses of approximately 1 Mg ha^{-1} of lime, in soils with Ca lower levels than 0.3 $cmol_c$ dm^{-3}.

In La Primavera, which had 1.14 mg kg^{-1} of available P in the soil, more than 120 kg ha^{-1} of P_2O_5 might be required to achieve maximum productivity, and 30 kg ha^{-1} of P_2O_5 can be considered satisfactory for *E. pellita* in Puerto López and Villanueva.

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