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Original Article

Silviculture

Growth and Quality of *Leucochloron incuriale* Seedlings Subjected to Liming and Phosphorus

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ABSTRACT

Leucochloron incuriale can be used in projects to restore degraded areas and for logging purpose. Soil has been used in nurseries to produce seedlings; however, most soil types in Brazil have low nutrient availability and high acidity level. The aim of the current study is to assess the effect of liming and phosphate fertilization on the growth and quality of *Leucochloron incuriale* seedlings. Treatments were arranged in factorial design with five base saturation levels – 3.5 (original), 25, 40, 55 and 70% – and six P levels – 0, 120, 240, 360, 480 and 600 mg dm^{-3} – in completely randomized blocks with four repetitions. The morphological features and their relations were assessed 82 days after planting. Phosphorus levels had significant effect on most of the assessed traits. The recommended P dose was 475 mg dm^{-3}.

Keywords: base saturation, phosphate fertilization, seedling production.

1. INTRODUCTION

In recent years, agricultural expansion and logging activities have increased the pressure on native forest remnants, which has resulted in high deforestation rates in Brazil. According to IBGE (2015), 85.5% and 49.1% of the Atlantic Forest and Cerrado biome areas are deforested, respectively. Environmental degradation causes forest fragmentation and leads to fauna and flora species losses, even to their extinction (Barbosa, 2000).

Revegetation through native species planting is recommended for the recovery of degraded areas and for water source protection because it helps taking the ecological conditions back to the similar level of the original ones (Furtini et al., 1999).

Leucochloron incuriale (Vellozo) Barneby and Grimes, popularly known as angico-rajado, is native of Brazil. The species belongs to family Fabaceae and to sub-family Mimosoideae. It is distributed in Bahia, Minas Gerais, Pará, Paraná, Rio de Janeiro and São Paulo states, in Cerrado and Atlantic Forest biomes (Carvalho, 2008). According to the aforementioned author, besides being recommended for eroded land and fluvial or riparian environment recovery, *Leucochloron incuriale* timber can be used in luxury furniture, interior decoration, civil construction sites, as well as in power, pulp and paper production.

Seedling production is one of the most important stages in environmental or commercial forestry projects. According to Carneiro (1995), seedlings must present features that correlate with their growth and survival after planting, because they reduce the need of replanting and the frequency of culture and management treatments. Phenotypic (morphological) or internal (physiological) aspects of seedlings are usually used to set their quality (Gomes et al., 2002). Morphological features, such as height, collar diameter and dry matter, have been widely used in studies on the quality of seedlings given the practicality of their use in nurseries and their good correlation to growth and survival in the field after planting.

Soil is one of the substrates most often used to produce seedlings of native tree species. However, different Brazilian soil types have limitations for plant growth and development because of their high acidity and low nutrient availability. The acidic character of Brazilian soils results from their high aluminum and manganese content and, in some cases, from their low calcium and magnesium levels (Van Raij, 1991).

The goal of using liming is to reduce the toxic Al and Mn concentrations in order to provide favorable conditions for the development of microorganisms involved in organic matter decomposition, as well as of nitrification agents and nitrogen fixers, and to increase P and Mo availability, and Ca and Mg supply (Malavolta, 1980). The amount of corrective required to adjust soil acidity to the desired condition depends on the crop to be implanted and on soil features (Sousa et al., 2007).

The Base Saturation Method stands out in Minas Gerais state among all methods adopted to calculate the amount of corrective to be applied in the soil. This method takes into account the pH/base saturation (BS) relation and it is applied to reach suitable BS values for the crop (Alvarez & Ribeiro, 1999).

In addition to soil acidity correction, liming increases phosphorus availability in the soil, since this nutrient records low availability in Brazilian soils due to its high adsorption/fixation power (Novais & Smyth, 1999). The low P availability is one of the main limitations of agricultural production under humid, tropical and subtropical conditions (Hinsinger, 2001).

Phosphorus is part of most metabolic processes such as photosynthesis, respiration, energy storage and transfer. It is a constituent of nucleic acids, phospholipids, proteins, phosphate esters and adenosine triphosphate (ATP) (Dechen & Nachtigall, 2007). This nutrient stimulates root system growth and is needed for the juvenile stage of plants (Grant et al., 2001; Schumacher et al., 2004). Due to the lack of information about the nutritional requirements of native forest species, there is necessary to conduct experiments to gather information capable of enabling the production of better quality seedlings (Cruz et al., 2004) to financially and environmentally optimize the use of inputs.

Accordingly, the aim of the present study was to investigate the effect of liming, based on the base saturation of the substrate, and of phosphate fertilization on the growth and quality of *Leucochloron incuriale* seedlings.

2. MATERIAL AND METHODS

The collection of *Leucochloron incuriale* seeds was carried out in the municipality of Patrocínio, Minas Gerais state. The region is located in an area covered by the Cerrado biome. According to Köppen's classification, the climate in the region is Cwa, and the rainfall rate reaches 1,400 mm per year, on average. The best *Leucochloron incuriale* matrices were collected in the field, based on features such as diameter, height and quantity of produced seeds. The minimum distance of 150 m between matrices was stablished in order to reduce the possibility of collecting seeds from half-sister trees and, consequently, to get greater genetic variability.

After collection, the seeds were mixed in equal proportions per matrix and stored in cold room in the Forest Seeds Laboratory of the Forest Engineering Department of the Federal University of Viçosa.

The experiment was conducted in the Research Nursery of the Forest Engineering Department of Federal University of Viçosa, Viçosa, Minas Gerais state. According to Köppen's classification, the climate in the region is Cwb, which is characterized by hot and humid summers, and cold and dry winters. Mean annual rainfall and temperature are 1,221 mm and 19.4 °C, respectively (DNMET, 1992).

The treatments consisted of five levels of base saturation of the substrate – 3.5 (original), 25, 40, 55 and 70% – and six phosphorus doses – 0, 120, 240, 360, 480 and 600 mg dm^{-3} – combined in factorial arrangement. The experiment followed the completely randomized block design with four repetitions. Each experimental plot consisted of one 2 dm^3 pot.

Dystrophic Red-Yellow Latosol collected from the 20-50 cm deep layer was the substrate used in the experiments. The collected soil was sieved (4 mm diameter mesh) and air dried. It was chemically (Table 1) and physically (clay = 570 g kg^{-1}, silt = 110 g kg^{-1}, coarse sand = 190 g kg^{-1}, fine sand = 130 g kg^{-1}) characterized based on the methodology by Donagema (2011).

Liming was calculated according to the base saturation method (Alvarez & Ribeiro 1999) (Equation 1):

$$LR = \left[\left(BS2 - BS1 \right) \times CEC \right] \div 100 \tag{1}$$

wherein, LR = lime requirement (t ha^{-1}); BS2 = desired base saturation (25, 40, 55 and 70%); BS1 = current base saturation, according to the chemical analysis (equal at 3.5%); CEC = Cation Exchange Capacity at pH 7.

Soil acidity corrective consisted of a $CaCO_3$ and $MgCO_3$ mixture, at ratio 4:1, based on Alvarez & Ribeiro (1999). Five soil portions were separated and the incorporation of corrective in each portion was made according to the desired base saturation level. Next, the soil was incubated for 30 days and kept humid throughout this period.

Sodium Phosphate Monobasic Monohydrate ($NaH_2PO_4.H_2O$) – in its totality – was the P source in the initial fertilization. Supplementary fertilization counted on 240 mg dm^{-3} of N divided in 4 applications, and on 100 mg dm^{-3} of K divided into 3 applications. Fertilizer application was conducted in 20-day intervals after germination. A solution with micronutrients was applied in the first fertilization according to the following dosage and sources: 0.81 mg dm^{-3} of B (H_3BO_3), 1.33 mg dm^{-3} of Cu ($CuSO_4.5H_2O$), 3.66 mg dm^{-3} of Mn ($MnCl_2.H_2O$), 4.00 mg dm^{-3} of Zn ($ZnSO_4.7H_2O$), and 0.15 mg dm^{-3} of Mo ($(NH_4)_6 Mo_7O_{24}.4H_2O$), based on Alvarez et al. (2006).

Four seeds were sown per pot. Seedlings were thinned 17 days after germination, only one plant was left per pot. Substrate moisture was daily monitored during the experimental period. Irrigation was manually performed with irrigator early in the morning and late in the afternoon in order to keep the substrate wet, but not soaked.

The experiment was assessed 82 days after sowing, when seedlings presented mean height and collar diameter within the range established by Gonçalves et al. (2005) for good quality seedlings. Height (H) and

Table 1. Chemical analysis of the Dystrophic Red-Yellow Latosol sample collected from the 20-50 cm deep layer.

pH	P	K	Al^{3+}	Ca^{2+}	Mg^{2+}	H+Al	SB	ECEC	TCEC	BS	m	OM
H_2O	--mg dm^{-3}--		---cmol$_c$ dm^{-3}---							------(%)-----		dag kg^{-1}
4.79	0.70	6.00	0.92	0.11	0.01	3.93	0.14	1.06	4.04	3.5	86.80	1.66

pH-H_2O (1: 2.5); P and K – Mehlich-1 Extraction; Ca^{2+}, Mg^{2+} and Al^{3+} – Extraction KCl 1 mol L^{-1}; H + Al – Extraction CaOAc 0.5 mol L^{-1}, pH 7.0; SB = Sum of bases; ECEC = Effective Cation Exchange Capacity; TCEC = Total Cation Exchange Capacity, pH 7.0; BS = Base Saturation; m = Aluminum Saturation; Organic Matter (OM) = C. org. × 1.724 – Walkley-Black Method.

collar diameter (D) data of all plants were collected by using a graduated ruler (in centimeters) and a digital caliper (0.01 mm accuracy), respectively. Subsequently, the seedlings were harvested, and the root was separated from the shoot. The parts were washed in running water and dried in forced air-circulation oven at approximately 70 °C until reaching constant weight. Shoot dry matter (SDM) and root dry matter (RDM) were measured on analytical balance (accuracy of 0.01 g). The total dry matter (TDM) was the sum of RDM and SDM. Seedling quality relations were calculated based on the SDM/RDM and Dickson Quality Index (DQI) (Equation 2):

$$DQI = TDM \div \left[(H \div D) + (SDM \div RDM)\right] \quad (2)$$

Variance and regression analyses were performed. Regression equations were adjusted and models were chosen based on regression significance, parameters, biological realism and coefficient of determination (R^2). The Pearson correlation coefficient was calculated to assess the correlation between the studied variables.

3. RESULTS AND DISCUSSION

All morphological features and their relation had significant response to the phosphorus doses (Table 2); the opposite was recorded for liming, only D and SDM/RDM showed significant response for it. SDM/RDM was the only variable presenting significant response to the interaction of factors BS and P.

The lack of response to liming by the species may have resulted from its ability to adapt to soils such as those found in the Cerrado biome, which presents high acidity level and low nutrient availability. The chemical limitations of the soil mean that the phytophysiognomy of this biome is featured by the presence of tolerant species, although these species face limited growth and development due to nutrient deficiency (Vieira & Weber, 2017). The aforementioned authors assessed the effects of liming on the growth and nutrition of *Tabebuia serratifolia* seedlings in an experiment using soil with 26.5% base saturation and found better growth in 70% BS. Although the species adapts to low pH soils, it can present better growth in corrected soils.

Similar to our study, the species *Anadenanthera colubrina* (Gomes et al., 2004), *Astronium fraxinifolium*, *Guazuma ulmifolia*, *Anadenanthera macrocarpa* and *Inga edulis* (Silva et al., 2011) did not respond to liming. Scheer et al. (2017) assessed the growth of *Schinus terebinthifolius*, *Gymnanthes klotzschiana*, *Luehea divaricata* and *Lafoensia pacari* seedlings based on two liming levels (250 and 500g cova^{-1} of dolomitic limestone with 75% RTNP – Relative Total Neutralizing Power). They observed that higher limestone doses had negative influence on plant growth. Such outcome was justified by a possible pH increase, which may have caused lower micronutrient availability and/or nutritional imbalance.

Opposite results were recorded for *Tabebuia impetiginosa* (Cruz et al., 2004), *Anadenanthera macrocarpa* (Bernardino et al., 2005), *Azadirachta indica* (Caldeira et al., 2007) and *Ochroma lagopus* (Tucci et al., 2010). However, comparisons between responses to liming and fertilization are only possible under similar experimental conditions. Plant development phase can also influence the soil correction response.

Vargas & Marques (2017) assessed the effect of liming on *Anadanthera colubrina* (angico) and *Senna*

Table 2. Summary of the variance analysis applied to the assessed morphologic features and relations – shoot height (H), collar diameter (D), shoot dry matter (SDM), root dry matter (RDM), total dry matter (TDM), SDM and RDM relation, Dickson Quality Index (DQI) – in the production of *Leucochloron incuriale* seedlings in response to the base saturation (BS) of substrate and to phosphate fertilization (P) 82 days after sowing.

Source	df	p-value						
		H	D	SDM	RDM	TDM	SDM/RDM	DQI
Block	3	0.9505	0.7063	0.7211	0.5704	0.6302	0.8763	0.3846
BS	4	0.7125	0.0405	0.9791	0.3385	0.9603	0.0034	0.9869
P	5	0.0000	0.0000	0.0000	0.0013	0.0000	0.0000	0.0000
PxBS	20	0.7069	0.7854	0.4259	0.5135	0.5600	0.0008	0.4552
Error	87							
CV %		35.62	24.36	60.54	52.56	53.65	38.89	46.32

CV = coefficient of variation; df = degrees of freedom.

multijuga (canafístula) growth for 7 months in soil with 5% base saturation. The highest plant growth rate was recorded at 50% and 20% base saturation for angico and canafístula, respectively. Based on these results, the response to liming is mainly based on the genotype. According to Vale et al. (1996), the response to liming depends on characteristics of each species, mainly on tolerance to acidity, since some species can reduce Al absorption by increasing the pH value in the rhizosphere or even by excluding it from the root tissue.

Although D showed significant response to the base saturation of the substrate, it was not possible to fit a model to biologically explain the behavior of D based on BS. The estimated D was equal to the its mean (2.9 mm).

Phosphate fertilization had positive influence on all assessed features and relations (Figures 1 and 2). Several studies have confirmed the importance of P to the initial plant-growth phase, since phosphorus allows higher seedling survival rates in the field (Caione et al., 2012).

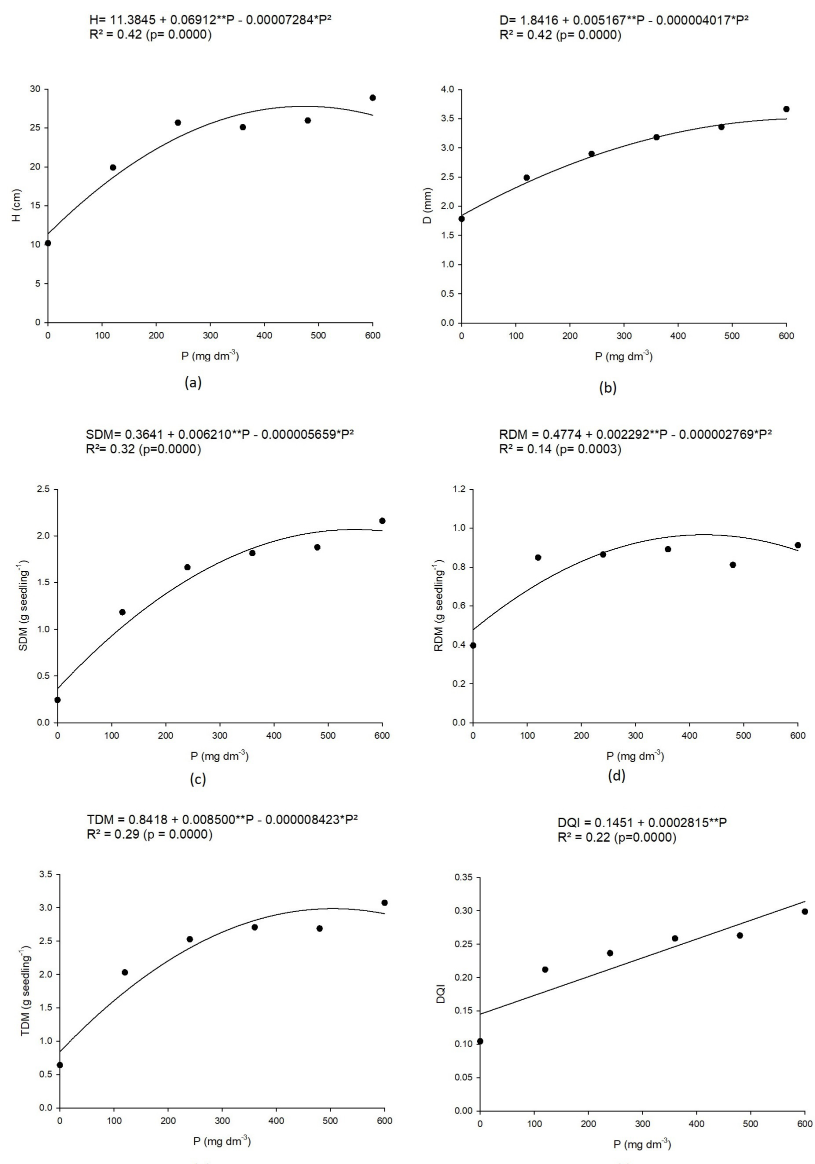

Figure 1. Shoot height (H) (a), collar diameter (D) (b), shoot dry matter (SDM) (c), root dry matter (RDM) (d), total dry matter (TDM) (e), and Dickson Quality Index (DQI) (f) of *Leucochloron incuriale* seedlings in response to phosphate fertilization (P) 82 days after sowing. Significant at (**) 1% and (*) 5% probability in the T test.

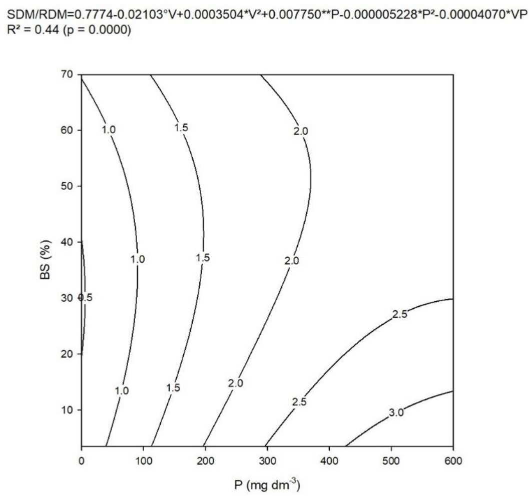

Figure 2. Answer surface of the shoot dry matter/root dry matter relation (SDM/RDM) in the production of *Leucochloron incuriale* seedlings in response to the base saturation of the substrate (BS) and to phosphate fertilization (P) 82 days after sowing. (**) significant at 1%, (*) 5% and (°) 10% probability in the T test.

The growth and quality of *Cordia goeldiana* (Fernandes et al., 2007), *Anadenanthera macrocarpa* (Gonçalves et al., 2008), *Apuleia leiocarpa* (Gomes et al., 2008), *Ilex paraguariensis* (Santin et al., 2008), *Lithraea molleoides*, *Schinus terebinthifolius*, *Sesbania virgata* (Santos et al., 2008), *Mimosa caesalpiniaefolia* (Gonçalves et al., 2010), *Senna macranthera* (Cruz et al., 2011), *Cassia grandis* (Freitas et al., 2017a), *Plathymenia foliolosa* (Freitas et al., 2017b) and *Enterolobium contortisiliquum* (Leite et al., 2017) seedlings were positively influenced by phosphate fertilization; this outcome corroborates the results in our study.

Seedling height in nursery is an easily obtainable feature that provides an estimate of initial growth in the field (Caione et al., 2012). The P dose 474.46 mg dm^{-3} generated the highest height (27.78 cm), which was within the limit established by Gonçalves et al. (2005) for good quality seedlings (20 to 35 cm height). Collar diameter is another feature reflecting seedling survival and initial growth in the field (Souza et al., 2006); however, the maximum diameter was recorded at P doses higher than 600 mg dm^{-3}.

Dry matter is one of the best variables used to predict the quality of seedlings, since it correlates with plant vigor and photosynthetic capacity (Cruz et al., 2011). However, dry matter determination may not be viable in some nurseries, because it is a destructive method that requires the use of greenhouses (Gomes & Paiva, 2012). TDM reflects the photosynthetic ability of plants; its maximum value (3 g plant^{-1}) was observed at P dose 504.57 mg dm^{-3}.

Shoot dry matter is essential to evaluate the quality of the seedling, since it is directly related to the photosynthetic area of the plant. The maximum shoot dry matter (2.07 g plant^{-1}) was generated at P dose 548.68 mg dm^{-3}. The maximum root dry matter value was recorded at lower P doses. RDM increased until P dose 426.02 mg dm^{-3} and started decreasing after it. According to Soares et al. (2007), plants assign greater root system growth potential under low P availability, otherwise plant should invest in shoot production. Based on Fernandes et al. (2000), higher P doses increased the SDM/RDM relation in *Schinus terenbinthifolius*, *Chorisia speciosa* and *Syzygium jambolanum* seedlings. Symptoms of phosphorus excess in plants in the field are uncommon. This result is different from deficiency, which is one of the main limiting factors of plant growth and development.

Despite the proven relation between seedling height and dry matter with its growth and survival in the field, it is important mentioning that the evaluation of these variables in isolate can lead to classification errors. According to Fonseca et al. (2002), *Trema micranta* seedlings developed during long shade periods recorded higher shoot height, as well as lower collar diameter values, root dry matter and DQI.

DQI is one of the best seedling quality indicators, since it takes into account the robustness and balance of the mass distribution in the seedling (Fonseca et al., 2002): the higher the index, the better the seedling quality. The DQI of *Leucochloron incuriale* seedlings increased linearly due to phosphorus dose increase. It was not possible to find the maximum DQI within the range of the assessed doses. The highest P dose provided DQI equal to 0.31, which means more than 107% increase in comparison to the treatment without this nutrient.

The SDM/RDM relation equal to 2 is ideal to good quality seedlings (Gomes & Paiva, 2012). A number of possible combinations between BS and doses P can be used to match this result: 196 mg dm^{-3} (BS = 3.5%), 295 mg dm^{-3} (BS = 25%), 350 mg dm^{-3} (BS = 40%), 367 mg dm^{-3} (BS = 55%) and 288 mg dm^{-3} (BS = 70%) (Figure 2).

Table 3. Pearson's correlation coefficient between variables: shoot height (H), collar diameter (D), shoot dry matter (SDM), root dry matter (RDM), total dry matter (TDM), SDM/RDM relation, Dickson Quality Index (DQI).

	H	D	SDM	RDM	TDM	SDM/RDM	DQI
H	1						
D	0.81	1					
SDM	0.90	0.85	1				
RDM	0.64	0.57	0.70	1			
TDM	0.88	0.82	0.97	0.84	1		
SDM/RDM	0.68	0.65	0.71	0.10	0.57	1	
DQI	0.67	0.81	0.85	0.87	0.92	0.39	1

Although all the assessed variables had positive effect on seedling growth, they presented different responses to phosphate fertilization; therefore, it was difficult to recommend a single P dose for the production of *Leucochloron incuriale* seedlings. These variables are correlated and can be inferred by each other. SDM was the feature best correlated to the other variables, since it showed significant correlation coefficient and higher than 0.70. The highest correlations were set with H and TDM (Table 3). Another important relation can be observed between seedling dry matter (SDM, RDM, TDM) and DQI.

Phosphate fertilization and liming can be recommended for the production of *Leucochloron incuriale* seedlings under the studied conditions based in results of shoot height, since it had high correlation with the other assessed variables and it was the easiest variable to be found in nursery.

4. CONCLUSIONS

Leucochloron incuriale did not respond to liming, but seedling growth and quality were positively influenced by phosphate fertilization under the assessed conditions.

The P dose 475 mg dm^{-3}, without liming, is recommended for seedling production.

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