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ORIGINAL ARTICLE – Silviculture

Gypsum and Phosphorus Influence the Initial Growth of *Schinus Terebinthifolius* Raddi

Natália Hilgert de Souza Carnevali[1] 0000-0003-0242-7043
Marlene Estevão Marchetti[2] 0000-0001-6295-0720
Thiago de Oliveira Carnevali[3] 0000-0002-2577-6601
Maria do Carmo Vieira[2] 0000-0001-7047-3848
William de Andrade Silva[4] 0000-0003-2077-9448

Abstract

Because of the lack of agronomic information regarding cultivation of the pink pepper (*Schinus terebinthifolius*), this study aimed to verify the effect of gypsum and phosphorus on the initial growth and how they affect soil fertility. The treatments consisted of four levels of agricultural gypsum (0; 750; 1,500, and 2,250 mg kg^{-1}) and P_2O_5 (0; 41.7; 83.4, and 125.1 mg kg^{-1}), with a 4 × 4 factorial arrangement, in a completely randomized design with four replications. Morphological variables and nutritional content taken at 165 days after transplant were shown to be adequate to assess the initial growth and to show their nutritional requirements, indicating that plants are responsive to phosphorus. The association of higher gypsum and P_2O_5 levels promoted higher plant vigor and their application to the soil increased the availability of calcium, phosphorus, and base saturation.

Keywords: Brazilian pepper tree, nutritional requirements, dystrophic red latosol, leaching column.

1. INTRODUCTION AND OBJECTIVES

The nutritional requirements of native species are different from undemanding species to others, on which growth is totally limited in the absence of nutrients. Such factors hinder the choice of foresters to invest in planting native species, because the agronomic information, especially the nutritional ones, are still not accurate. Therefore, studies aiming to clarify these information are essential for increasing the diversity of native tree species implanted in forestry.

The Brazilian pepper tree (*Schinus terebinthifolius* Raddi, Anacardiaceae), naturally found in Brazil, presents high ecological plasticity (Dawkins & Esiobu, 2016). The hybrid form of the Brazilian pepper tree, found in the United States, presents growth and longevity even larger than the native trees found in South America (Geiger et al., 2011). It is important for both ecological and economic purposes. Worldwide, the species is also known as pink pepper or baies roses because its fruit has a very appreciated flavor in the market. Besides its food properties, the Brazilian pepper tree also has medicinal properties (Johann et al., 2010). It is indicated in reforestation programs, serving as shader of late secondary and climax species; moreover, its fruit also serves as food for birds (Andrade & Boaretto, 2012).

In Brazilian soils, acidity and high levels of aluminum content are common, both on the surface and on the deeper layers of the soil. With low cation exchange capacity and nutrient availability in these highly weathered soils (Eberhardt et al., 2008), 1:1 clay minerals with high phosphorus adsorption capacity predominate, such as kaolinite, iron (Fe), and Al oxides (Carnevali et al., 2016). The use of agricultural gypsum is recommended to improve the root environment in many cases, reducing the toxicity of Al^{3+} to the plants and providing cations in depth (Rampim et al., 2011; Ramos et al., 2013).

[1] Universidade Federal do Sul e Sudeste do Pará (Unifesspa), São Félix do Xingu, PA, Brasil
[2] Universidade Federal da Grande Dourados (UFGD), Dourados, MS, Brasil
[3] Universidade Federal do Pará (UFPA), Altamira, PA, Brasil
[4] Universidade Estadual do Mato Grosso do Sul (UEMS), Dourados, MS, Brasil

However, because of the lack of studies with native species, there are still doubts about the conditions on which favorable effects of gypsum can be expected and how to recommend the product, which is only used as a complement to fertilization as in the study performed by Alves & Souza (2008).

Information about the nutritional requirements of the Brazilian pepper tree is still limited, complicating recommendations for its cultivation. Therefore, our study aimed to verify the effect of agricultural gypsum and phosphorus in the initial development of the Brazilian pepper tree and its effects on soil fertility.

2. MATERIALS AND METHODS

This study was performed in a protected environment from August 2011 to January 2012, in Dourados (Mato Grosso do Sul State), which has the following geographical coordinates: 22° 11' 53.52" South and 54° 56' 2.25" West, and altitude of 461 m. The climate is tropical with dry winter (Aw), according to the Köppen climate classification, while the average temperature is 23.6 °C.

The Brazilian pepper tree fruits, sampled in Dourados (22° 11' 43.30" S and 54° 56' 8.67" W), were manually macerated for seed removal and then seeded in polystyrene trays with Bioplant® agricultural substrate. The seedlings were maintained at 50% shading and irrigated daily until they were approximately 10 cm high.

Soil samples were collected from an Oxisol (Dystroferric Red Latosol), classified as a dystrophic Red Latosol (Oxisol) of clayey texture (Santos et al., 2013). They were collected at the Bw horizon and were chemically (Silva et al., 2009) and physically (Donagema et al., 2011) characterized. The soil had the following characteristics: pH_{water} = 4.5; pH ($CaCl_2$) = 4.2; Organic Matter (OM) = 8.0 g kg^{-1}; P = 1.1 $cmol_c$ dm^{-3} (Mehlich 1); K = 0.05 $cmol_c$ dm^{-3} (Mehlich 1); Ca = 0.4 $cmol_c$ dm^{-3}; Mg = 0.2 $cmol_c$ dm^{-3}; Al = 1.4 $cmol_c$ dm^{-3}; H+Al = 7.6 $cmol_c$ dm^{-3}; SB = 0.65 $cmol_c$ dm^{-3}; T = 8.2 $cmol_c$ dm^{-3}; V% = 7.9; Cu = 5.2 mg dm^{-3}; Mn = 3.6 mg dm^{-3}; Fe = 38.2 mg dm^{-3}; Zn = 0.7 mg dm^{-3}; Clay = 644 g kg^{-1}, silt = 203 g kg^{-1} and sand = 153 g kg^{-1}.

The treatments consisted of four doses of agricultural gypsum (0; 750; 1,500, and 2,250 mg kg^{-1}, corresponding to 0; 1,200; 2,400, and 3,600 kg ha^{-1}) and four doses of P_2O_5 (0; 41.7; 83.4, and 125.1 mg kg^{-1}, corresponding to 0; 100; 200, and 300 kg ha^{-1}, triple superphosphate source) with a 4 × 4 factorial arrangement in a completely randomized design with four replications. The study was performed in leach columns of 150 mm diameter × 60 cm height, divided into six 10 cm rings.

The columns were filled with soil samples sieved in a 4 mm mesh and compacted to reach density of 1.1 Mg m^{-3}. The compaction was performed only in the 20-60 cm layers, aiming to simulate soil density and tillage conditions in conventional crops. Liming, doses of gypsum and P_2O_5, as well as other nutrients, were applied and incorporated only in the 0-10 cm layer. To increase the base saturation to 60%, dolomitic limestone with 100% total neutralizing power was used, manually incorporated 30 days before transplantation. Additional fertilization was also performed with 62.5 mg kg^{-1} of N (urea source), divided into two applications, 25 mg kg^{-1} K_2O (source KCl) and 100 mg kg^{-1} of commercial FTE-BR12 micronutrient formulation, applied five days before transplantation. Each column was internally coated with a plastic bag to prevent loss of water and nutrients by drainage. Irrigation was performed every two days.

The experiment was performed for 165 days in a protected environment with transparent polyethylene cover and 50% shade side cloth. The following variables were analyzed at harvest: plant height (cm); stem diameter (mm); leaf area (cm^2), which was estimated using Windias image analyzer (Windias, Delta-T Devices, Cambrigde, UK); and dry weight (g) of the shoot and the root. From the morphological data, the leaf area ratio and the Dickson Quality Index (Dickson et al., 1960) were estimated.

Macronutrient contents in the shoot were quantified according to the method of Malavolta et al. (1997) and transformed into content by the product with shoot dry weight. The following aspects from the soil samples were assessed: pH_{water} and $CaCl_2$; P and K extracted by Mehlich one solution; Ca, Mg, and Al extracted with KCl (1.0 mol L^{-1}); S-SO_4^{2-}, extracted by phosphate ions dissolved in acetic acid (2.0 mol L^{-1}); H+Al; Sum of bases (SB); cation exchange capacity (CEC), and base saturation (V%), according to Silva et al. (2009).

The data were submitted to analysis of variance, and a regression and/or a Tukey test was performed at a 5% probability for the significant factors.

3. RESULTS AND DISCUSSION

3.1. Plant development and quality

There was a significant effect of gypsum and P_2O_5 interaction for all morphological parameters and relationships assessed. The highest doses of gypsum and P_2O_5 provided the highest height value (61.8 cm), while the largest diameter of the stem was obtained with the highest P_2O_5 dose (9.36 mm), as shown in Figures 1a and 1b, respectively.

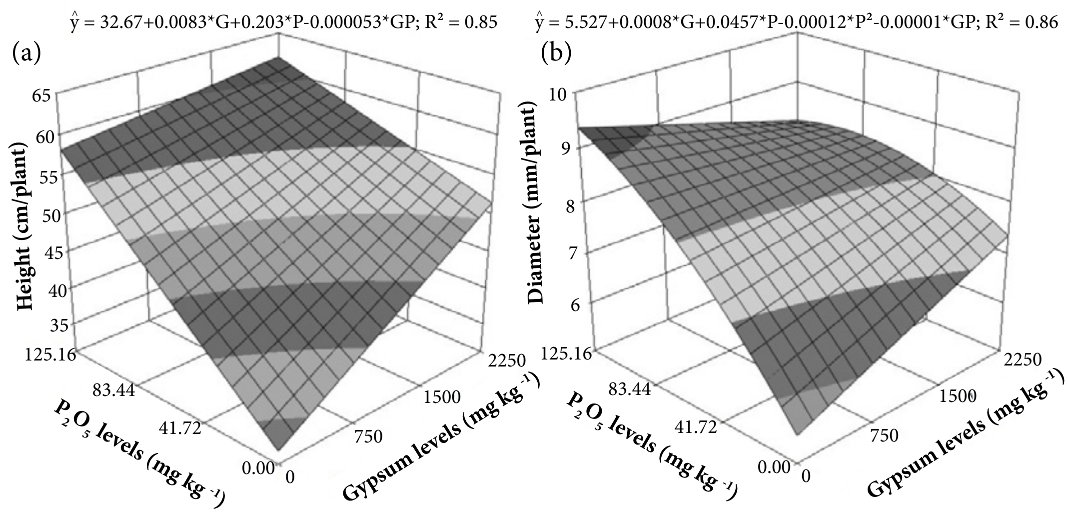

Figure 1. Plant height (a) and stem diameter (b) of Brazilian pepper tree at 165 days after transplantation by different gypsum and P_2O_5 levels. * Significant at 5% by t-test.

The benefits of the joint application of gypsum and P_2O_5 were evident in the Brazilian pepper tree growth. The high N and $S\text{-}SO_4^{2-}$ levels in the shoot, shown in Table 1, contributed to stimulate the vegetative growth, increasing leaf bud production. Andrade & Boaretto (2012) also observed high N and S levels in Brazilian pepper tree shoots, in which were observed 13 g kg^{-1} of N (572 mg/plant of N) and 1.95 g kg^{-1} of S (85.8 mg/plant of S) in complete nutrient solution.

The higher gypsum and P_2O_5 levels also provided a higher leaf area (1,023.7 cm^2). However, the leaf area ratio was lower (31.46 cm^2 g^{-1}) in the absence of gypsum and with the higher P_2O_5 dose, as shown in Figures 2a and 2b, respectively. This indicates that with higher phosphorus supply, the plant needs a smaller leaf area for biomass production.

The growth of leaf area determines the interception of light and is an important parameter to determine the plant yield (Koester et al., 2014). However, the relation between leaf area growth and mass growth will depend on how carbon is partitioned in increasing leaf area, total plant growth, reproduction, and respiration (Weraduwage et al., 2015). According to these authors, the use of the relationship between growth and leaf area is more appropriate at the beginning of the vegetative growth. Thus, in this study, the leaf area ratio was an important parameter to confirm that the Brazilian pepper tree has good responses to phosphorus in the initial growth stages.

The highest dry weights of shoot (18.2 g) and root (6.8 g) were obtained with the highest gypsum and P_2O_5 levels, according to Figure 3. The Brazilian pepper tree response to P (phosphorus) was high. The same result was also found for Santos et al. (2008), where 800 mg dm^{-3} of P were not enough to provide maximum biomass accumulation. At 90 days in this condition, the plants showed 51.9 g dry shoot weight, an increase of 250%, compared to the zero dose. It is worth mentioning that in this study the use of gypsum with phosphorus increased the dry weight gain in 13.2% for root and 13.6% for shoot.

Table 1. Macronutrients content (mg/plant) of Brazilian pepper tree shoot at 165 days after transplantation by different gypsum and P_2O_5 levels.

Nutrient	Regression equation	R^2	P levels	Gypsum levels	Maximum value
N	**$\hat{y}$ = 109.124** + 0.0322 * G + 1.602 * P – 0.006 * P^2	0.60	125.1	2,250	288.1
P	**$\hat{y}$ = 41.5102** + 0.0178 * G + 0.3231 * P	0.62	125.1	2,250	121.9
K	**$\hat{y}$ = 69.77** + 0.046 * G + 1.134 * P – 0.0035 * P^2 – 0.003 * GP	0.61	66.7	2,250	188.0
Ca	$\hat{y}$ = 37.504 + 0.0146 * G + 0.896 * P – 0.0039 * P^2	0.75	125.1	2,250	121.4
Mg	**$\hat{y}$ = 12.25** + 0.0043 * G + 0.113 * P	0.74	125.1	2,250	36
S	$\hat{y}$ = 63.68 + 0.054G + 3.09 * P – 0.0102P^2 – 0.00036GP	0.60	125.1	2,250	312.6

* Significant at 5% by t-test.

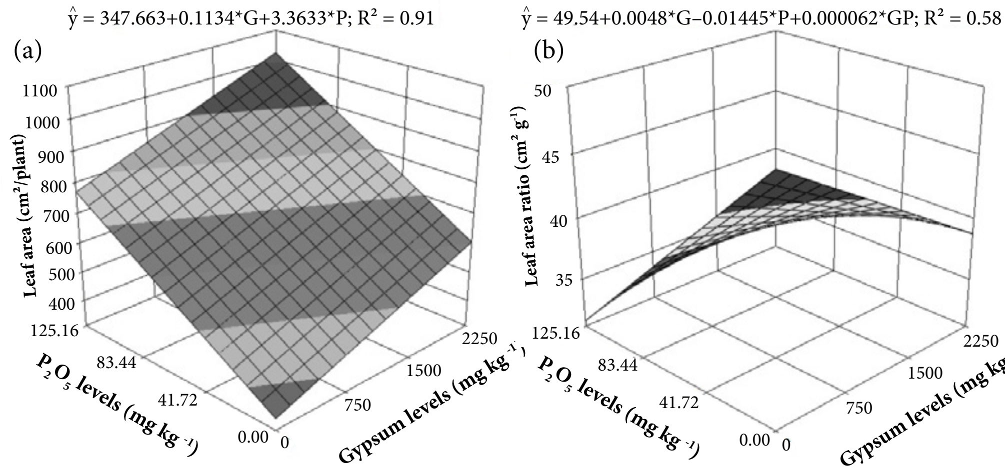

Figure 2. Leaf area (a) and leaf area ratio (b) of Brazilian pepper tree at 165 days after transplantation by different gypsum and P_2O_5 levels.

* Significant at 5% by t-test.

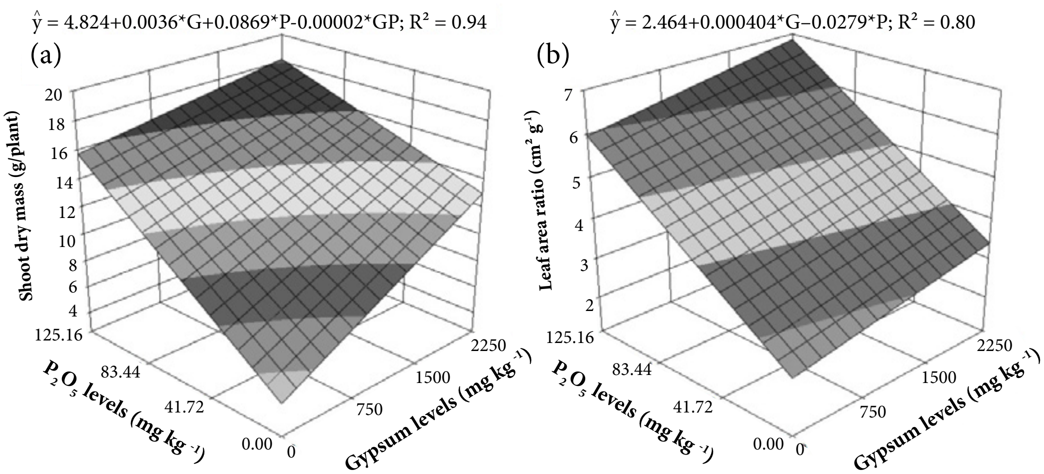

Figure 3. Shoot (a) and root (b) dry weight of Brazilian pepper tree at 165 days after transplantation by different gypsum and P_2O_5 levels.

* Significant at 5% by t-test.

The distribution of roots in deeper layers of the soil was favored by the increasing gypsum levels, which mitigated the differences between treatments that did not receive P_2O_5, as shown in Table 2. The best root growth in the presence of gypsum may be associated to the increase of Ca and $S\text{-}SO_4^{2-}$ content in the soil, as shown in Table 3.

Table 2. Root dry weight distribution of the Brazilian pepper tree at each depth, at 165 days after transplantation by the interaction between different doses of gypsum and P_2O_5.

Levels (G × P)	Depth (cm)					
	0-10	10-20	20-30	30-40	40-50	50-60
0 × 0	0.809 Ag	0.173 Bh	0.078 Bc	0.052 Bc	0.046 Ba	0.059 Ba
0 × 41.7	3.047 Ad	0.687 Bcde	0.401 Cab	0.269 DEabc	0.175 Da	0.092 Ea
0 × 83.4	3.127 Ad	0.435 Befgh	0.262 CDbc	0.202 Dabc	0.162 Da	0.113 DEa
0 × 125.1	3.787 Ab	0.725 Bbcd	0.403 Cab	0.230 CDabc	0.190 CDa	0.169 Da

Table 2. Continued...

Levels (G × P)	Depth (cm)					
	0-10	10-20	20-30	30-40	40-50	50-60
750 × 0	2.061 Af	0.253 Bh	0.182 Bbc	0.181 Babc	0.146 Ba	0.101 Ba
750 × 41.7	3.239 Acd	0.336 Bgh	0.258 Bbc	0.223 Babc	0.163 Ba	0.147 Ba
750 × 83.4	3.829 Ab	1.029 Ba	0.581 Ca	0.406 Cda	0.208 Da	0.145 Ea
750 × 125.1	4.324 Aa	0.975 Bab	0.666 Ca	0.340 Dab	0.231 Da	0.221 Da
1,500 × 0	1.905 Af	0.372 Bfgh	0.192 CDbc	0.154 CDbc	0.126 Da	0.112 Da
1,500 × 41.7	2.354 Ae	0.329 Bgh	0.242 Bbc	0.190 Babc	0.144 Ba	0.141 Ba
1,500 × 83.4	3.947 Ab	1.012 Ba	0.431 Cab	0.369 CDab	0.244 Ca	0.182 Da
1,500 × 125.1	3.494 Ac	0.950 Babc	0.607 Ca	0.363 Dab	0.243 Da	0.229 Da
2,250 × 0	2.619 Ae	0.352 Bfgh	0.228 Bbc	0.213 Babc	0.208 Ba	0.202 Ba
2,250 × 41.7	3.141 Ad	0.552 Bdefg	0.287 Cbc	0.218 Cabc	0.146 Ca	0.137 Ca
2,250 × 83.4	3.931 Ab	0.617 Bdef	0.445 BCab	0.314 CDabc	0.203 Da	0.168 Da
2,250 × 125.1	3.876 Ab	1.013 Ba	0.648 Ca	0.354 Dab	0.260 Da	0.242 Da

Means followed by the same letter, uppercase in the same row, and lowercase in the same column, do not differ by Tukey's test at a 5% probability level. Gypsum and P_2O_5 levels in mg kg^{-1}.

The highest value of the Dickson index (2.52) was obtained at higher gypsum and P_2O_5 levels, indicating higher plant quality, according to Figure 4. This index is an important parameter for the assessment of the Brazilian pepper tree quality, as it considers the balance of biomass distribution. The Brazilian pepper tree shows high growth response when fertilized with phosphorus; moreover, gypsum increases the availability of Ca and S and, therefore, it promotes improvements in absorption of nutrients.

$\hat{y} = 0.993+0.00016^{*}G-0.0175^{*}P-0.000065^{*}P^2; R^2 = 0.79$

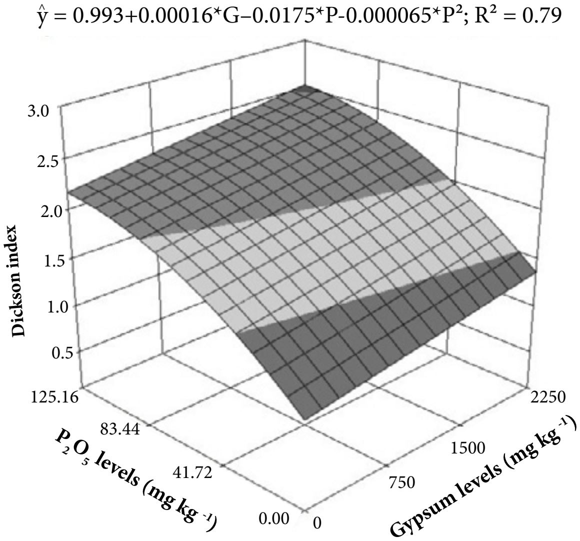

Figure 4. Dickson index of the Brazilian pepper tree at 165 days after transplantation by gypsum and P_2O_5 levels.

* Significant at 5% by t-test.

3.2. Soil chemical characteristics

The levels of P, Al^{3+}, H+Al, and pH_{water} were significantly altered by depth effect, as shown in Table 3. The Al^{3+} content showed the maximum point at 42.8 cm depth; at the same depth, the P content presented the minimum point (1.13 mg dm^{-3}). On the other hand, the potential acidity decreased in depth, from 13.9 cmol$_c$ dm^{-3} in the 0-10 cm layer to 13.4 cmol$_c$ dm^3 at 60 cm. At 37.6 cm depth, the soil pH_{water} had the minimum point of 4.59.

The vertical displacement of fine limestone particles, and consequently their chemical mobilization in subsurface, can reduce the effects of acidity, even in a short period (Amaral et al., 2004), which would explain the reduction in Al^{3+} and H+Al contents and the increase in pH and P levels at depths greater than 40 cm. At the same depths, where the acidity and the Al^{3+} contents are higher, P content was reduced, possibly because of adsorption reactions, which naturally occur with Fe oxides, such as goethite and hematite (Lü et al., 2017).

There was vertical displacement of soil particles, such as Ca, S, K, as well as base sum and base saturation, with few effects regarding gypsum and phosphorus. The direct effects of gypsum applications in depth were only observed for the Ca and S content, according to Table 3, in which there were minimum points for the Ca content (0.73 cmol$_c$ dm^{-3}) at 43.9 cm and for sulfur (14.1 cmol$_c$ dm^{-3}) at 37.5 cm. As gypsum is more soluble than limestone, it promotes a fast Ca availability in the soil, especially in the superficial layers (Soratto & Crusciol, 2008). On the other hand, the $S\text{-}SO_4^{-2}$

anion movement is favored by its cation binding capacity, forming null charge molecules that ease the descent into the soil profile (Cremon et al., 2009). However, the higher the gypsum amount applied to the soil, the greater the permanence of $S\text{-}SO_4^{-2}$ and Ca in the surface layers. It possibly happens because of high iron and oxides levels in the soil, which have high anion retention capacity, hindering the movement in the profile.

Table 3. Soil chemical attributes after 165 days of experiment by the depth effect and the interaction between depth and levels of gypsum and P_2O_5.

Element	Regression equation	R^2
	Depth	
Al^{3+}	$\hat{y} = -0.95 + 0.12 * D - 0.0014 * D^2$	0.92
P	$\hat{y} = 2.01 - 0.041 * D + 0.0005 * D^2$	0.83
H+Al	$\hat{y} = 13.9 - 0.0073 * D$	0.81
pH	$\hat{y} = 5.63 - 0.055 * D + 0.00073 * D^2$	0.90
	Depth and gypsum	
Ca	$\hat{y} = 6.78 - 0.29 * D + 0.0033 * D^2 + 0.00014 * G$	0.85
S	$\hat{y} = 14.56 - 0.03 * D + 0.0004 * D^2 + 0.0003 * G - 0.000007 * DG$	0.77
	Depth and P2O5	
K	$\hat{y} = 3.92 - 0.12 * D + 0.0013 * D^2 - 0.0076 * P + 0.00022 * DP$	0.70
S	$\hat{y} = 14.92 - 0.03 * D + 0.004 * D^2 + 0.0001P + 0.000005 * DP$	0.88
SB	$\hat{y} = 15.2 - 0.59 * D + 0.006 * D^2 - 0.007P + 0.0001DP$	0.84
V%	$\hat{y} = 57.9 - 1.93 * D + 0.02 * D^2 - 0.02 * P + 0.0005DP$	0.86
	Gypsum and P2O5	
P	$\hat{y} = 1.114 - 0.000007G + 0.00000004G^2 + 0.0034 * P - 0.0000008GP$	0.61
Ca	$\hat{y} = 1.97 - 0.0002G + 0.0000001G^2 - 0.004 * P + 0.000002 * GP$	0.59
V%	$\hat{y} = 25.04 - 0.002 * G + 0.000001 * G^2 - 0.02 * P + 0.00001 * GP$	0.53

* Significant at 5% by t-test. D: depth; G: gypsum; P: P_2O_5.

In the interaction between phosphorus and depth, the K content had the minimum point (1.57 $cmol_c\ dm^{-3}$) at 40.7 cm, as shown in Table 3. From this point, the K content increases, reaching the maximum (2.45 $cmol_c\ dm^{-3}$) at 60 cm with the highest level of P_2O_5. The sum of base showed the same pattern in depth, reaching 2.35 $cmol_c\ dm^{-3}$ at 49 cm, according to Table 3. The fertilizers addition to soil affects the availability and permanence of other elements in the soil, even temporarily (Ernani et al., 2007), confirmed by the K content reduction with the increasing of phosphate fertilization in the superficial layers. Nonetheless, unlike Akinremi & Cho (1993) observed in their study, the phosphorus addition did not reduce the K percolation at deeper layers. On the contrary, the higher the level of phosphorus, the greater the K losses by leaching. The same was observed to the sum of bases. The Ca^{2+}, Mg^{2+}, and K^+ exchangeable cations of the soil have different retention energies to soil colloids, following the lyotropic series (Werle et al., 2008). K^+ has lower energy retention, because it is a monovalent cation. This results in higher leaching levels in well-drained soils, especially in soils with lower cation exchange capacity. This partly explains why the K and sum of base reduced until a certain depth level.

There was also a significant interaction between gypsum and P_2O_5 doses, for Ca and P contents as well as for base sum, as shown in Table 3. The highest doses promoted maximum Ca content in the soil (2.2 $cmol_c\ dm^{-3}$) and also increased P content in the soil. However, the P_2O_5 doses increase was more favorable than its application with gypsum, increasing from 1.1 to 1.5 mg dm^{-3} the P content in the soil. In the fraction clay of the Savanna Brazilian Oxisols (Latosols) there are oxides of iron and aluminum, which strongly adsorb the phosphorus. Under these conditions, high phosphate application fertilizer is required to increase plant availability. Santos et al. (2008) verified that the Brazilian pepper tree showed high phosphorus use efficiency, even in the absence of fertilization, which explains satisfactory growth even at low doses. These results indicate the species is adapted, because of its high plasticity to the low fertility conditions of the soil.

The sum of base and the $S\text{-}SO_4^{2-}$ showed similar behavior to the interaction between P_2O_5 doses and depth, with the minimum point between depths of 37.5 and 48.2 cm, respectively. Because of the high binding strength of the phosphates to the colloids, especially in clayey soils (Raij, 1991), it is expected that greater sulfate losses occur in depth. In this sense, it is necessary to consider the leaching of bases and sulfate when combining these inputs. The splitting of the recommended gypsum dose may be the solution to avoid nutrients loss under field conditions.

4. CONCLUSION

The use of morphological variables and their relationships are adequate to assess the initial growth of the Brazilian pepper tree and show its nutritional needs.

The gypsum is an important conditioner of the soil, and therefore, it can be indicated as a complement to the Brazilian pepper tree fertilization.

The association of gypsum and P_2O_5 is beneficial and favors higher quality of plants.

The Brazilian pepper tree is not demanding in phosphorus; however, it is very responsive to it.

An adequate management is crucial in order to produce Brazilian pepper tree with commercial purposes, as phosphate fertilization is essential to develop the vegetative characteristics that will later benefit fruit production.

The application of agricultural gypsum favored improvements in the chemical characteristics of the soil, increasing the availability of some nutrients.

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0000-0002-1402-3612

CORRESPONDENCE TO

Natália Hilgert de Souza Carnevali

Universidade Federal do Sul e Sudeste do Pará (Unifesspa), Rua Constantino Ferreira Viana, s/n, quadra 8, Centro, CEP 68380-000, São Félix do Xingu, PA, Brasil

e-mail: nataliahilgert@unifesspa.edu.br

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