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Phosphorus sources: effects on mahogany nursery trees. Fontes de fósforo: efeitos sobre plantas jovens de mogno

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Abstract

Questions persist regarding the best phosphorus (P) sources for tropical soils, especially for forest species. We evaluated the effects of four different P sources (single superphosphate - SSP; triple superphosphate - TSP; Arad reactive rock phosphate - ARP and Yoorin thermophosphate - YT) on nutrients accumulation, phosphorus use efficiency and growth on mahogany (*Swietenia macrophylla* King.) Mahogany is responsive to P fertilizer, however the high water soluble (TSP and SSP) and citric acid (YT) phosphorus sources had a similar effect on mahogany growth. It suggests that the seedlings producer can use any of them but should avoid the use of the ARP source in this stage of plant growth.
Keywords: fertilizers; nutritional efficiency; plant nutrition; *Swietenia macrophylla* King

Resumo

Persistem dúvidas sobre as melhores fontes de fósforo (P) para solos tropicais, especialmente para espécies florestais. Avaliamos os efeitos de quatro fontes de P (superfosfato simples - SSP, superfosfato triplo - TSP, fosfato natural reativo de Arad - ARP e Thermophosphate Yoorin - YT) sobre o acúmulo de nutrientes, eficiência no uso de P e crescimento do mogno (*Swietenia macrophylla* King.). O mogno é responsivo ao fornecimento de P, no entanto, as fontes de P alta solubilidade em água (TSP e SSP) e em ácido cítrico (YT) apresentam efeito similar sobre o crescimento do mogno. Isto sugere que o produtor de mudas pode usar qualquer uma delas, mas deve evitar a fonte ARP neste estágio de crescimento das plantas.
Palavras-chave: fertilizantes; eficiência nutricional; nutrição de plantas, fertilidade do solo; *Swietenia macrophyll*a King

Introduction

The mahogany (*Swietenia macrophylla* King., Meliaceae) wood has a high value due its resistance, softness, workability, being used to furniture-making, veneers, among others (LANGBOUR *et al.*, 2011). Its naturally occur from southern Mexico to Amazon (SONO; SNOOK, 2006), being the Brazilian Amazon, the main center of its occurrence and it is regarded by conservationist in endangered of extinction (MARTINELLI; MORAES, 2013). These regions usually had naturally low fertility soil, with low phosphorus (P) concentration, low basis saturation and pH, and high exchangeable Al^{3+} concentration (HEINEMAN; TURNER; DALLING, 2016). Besides the low P availability on Amazonian soils, they are able to adsorb 900 mg P kg^{-1} of soil (FALCÃO; SILVA, 2004), and less than 1% of these adsorbed P returns to soil solution.

The use of well-nourished nursery trees is a limiting factor to implement a successful forest system. It is important to plants initial growth, increasing the survival rate of nursery trees in the field, and ensuring higher wood yield of adult plants. There are few studies that approach the effect of P in mahogany growht, however these show positive effects on growth and quality of seedlings. Santos et al. (2008) assessing the effect of diferente levels of P (0 to 100 mg de P dm^{-3} of soil) in mahogany seedlings grown in very clayey Yellow Latosol, noted positve and linear effect in plant nutritional status and growth. Visual symptoms of deficiency in old leaves and reductions in both dry matter and nutrientes uptake were observed in mahogany seedlings cultivated in nutritive solution, when the P was omitted (WALLAU et al., 2008 and VIEGAS et al., 2012). Even though of ocurrence of this species in soil with low available P, these results indicate that the growht of this species can be improved with supply of by means of phosphate fertilizers.

On the high lands of Amazon rain forest, the use of water-soluble P (WSP) sources as the triple superphosphates (TSP) and single superphosphate (SSP) provide a ready P release, increasing the P adsorption and precipitation with Fe and Al, consequently decreasing its availability (FINK et al., 2016). Alternatively, the low water-soluble P (LWSP) sources such as Arad and Gafsa can increase the P availability to the plants, especially to those with low rate of growth such as mahogany.

Despite the natural occurrence of mahogany on soils with low P concentration, previous studies reported its positive response to P fertilization (SANTOS et al., 2008; SOUZA et al., 2010). However, many questions remain regarding to the best P management for forest species cultivated on tropical soils. Thus, we evaluated the effects of different P sources, WSP and LWSP, on mahogany nutrients accumulation and growth.

Material and methods

The experiment was carried out on greenhouse conditions, Manaus, AM, Brazil (03º 06' 04.1" S, 59º 58' 34" W; 75 m a.s.l.). A 20-40 cm layer of Xanthic Hapludox was collected (03º 06' 04.1" S, 59º 58' 34" W; 77 m a.s.l.). Soil subsurface horizon was chosen to avoid plants diseases and pests, and the influence of soil organic matter on plant nutrition. Air-dried soils were ground to < 2 mm particle size prior to chemical physical analyses: 36.2 dag kg^{-1}, 7.1 dag kg^{-1} and 56.7 dag kg^{-1} of sand, silt and clay, respectively, by "pipette method"; 60.7 g kg^{-1} of kaolinite; 12.2 g kg^{-1} of gibbsite; 2.32 g kg^{-1} of goethite; remaining P: 30 mg L^{-1}; 1 mg kg^{-1} of P; soil pH in water: 3.8; soil organic matter: 12 g kg^{-1}; 8 mg kg^{-1} of K; 0.1 $cmol_c$ kg^{-1} of Ca, 0.1 $cmol_c$ kg^{-1} of Mg; 1.4 $cmol_c$ kg^{-1} of Al; 8.0 $cmol_c$ kg^{-1} of H +

Al; 0.1 mg kg^{-1} of Zn; 220.3 mg kg^{-1} of Fe; 0.2 mg kg^{-1} of Mn; 0.2 mg kg^{-1} of Cu; 0.2 mg kg^{-1} of B and 59 mg kg^{-1} of S.

The experiment was completely randomized design with five treatments and three replications, a total of 15 plots. Each plot consisted of one pot with 3.6 kg^{-1} of soil and one plant. The P rate used were equivalent to 125 mg kg^{-1} of total P of each source. The treatments were: (1) Single superphosphate (SSP) [$Ca(H_2PO_4)_2{\bullet}H_2O + CaSO_4{\bullet}2H_2O$], 20% of total P_2O_5, 18% of P_2O_5 water soluble and 2% of P_2O_5 citric acid soluble, plus 20% of Ca and 12% of S; (2) Triple superphosphate (TSP) [$Ca(H_2PO_4)_2{\bullet}H_2O$], 46% of total P_2O_5, 41% of P_2O_5 water soluble and 5% of P_2O_5 citric acid soluble, plus 14% of Ca; (3) Arad rock phosphate (ARP) [$Ca_5(PO_5)_3F$], 33% of total P_2O_5, 10% of P_2O_5 citric acid soluble, plus 37% of Ca; (4) Yoorin thermophosphate (YT) [$Ca_{10-i-j}Na_iMg_j(PO_4)_{6-x}(CO_3)_xF_{2+4x}$], 17% of total P_2O_5, 15% of P_2O_5 citric acid soluble, plus 20% of Ca, 10% of Si and 7% of Mg; (5) Control treatment, without P fertilization.

Before the treatments application, each experimental plot received 2.0 g kg^{-1} of $CaCO_3$ and $MgCO_3$ at ratio of 4:1 ($CaCO_3$ + $MgCO_3$ $7H_2O$) and was incubated by 30 days with moisture kept at 70% of field capacity using distilled water. After soil liming incubation, treatments and a basic fertilization was applied with 300 mg kg^{-1} of N (urea + ammonium sulfate), 300 mg kg^{-1} of K (potassium chloride), 40 mg kg^{-1} of S (ammonium sulfate), 1.0 mg kg^{-1} of B, 1.5 mg kg^{-1} of Cu, 5.0 mg kg^{-1} of Fe, 5.0 kg^{-1} mg of Mn, 5.0 mg kg^{-1} of Zn and 0.15 mg kg^{-1} of Mo. The macronutrients were applied with pure reagents for analysis and the micronutents were supplyed with the commercial source MIB-3™. After treatments application and fertilization, the soil was incubated by 20 days to achieve a equilibrium between solubility of source, nutrients adsorption on soil particles and their availability to plants. The N and K fertilization was divided in three equal rates of 100 mg kg^{-1} each. The first, second and third rates were applied respectively at transplantation, after 30 and 60 days after transplantation.

Mahogany (*S. macrophylla*) seeds were obtained from the Centro de Sementes Nativas do Amazonas (CSNAM), Manaus, AM. For the disinfection of seeds against fungus, they were soaked in NaOCl (1%) for 2 min and rinsed in tap water for 5 min. Seeds were dried in filter paper and sowed in washed sand at room temperature. After germination, seedlings with 4-7 cm of height were selected and transplanted to plastic pots with 3.6 kg of soil after fertilization and treatments incubation. Soil moisture of pots were kept at 60% of total volume of pores, adding distilled water if necessary.

At 90 days after transplanting plants were harvested 2 cm above the soil surface. Shoot height and stem diameter were determined. Leaves, twigs and roots were separated and washed in tap and distilled water and dried at 70 ºC until achieve constant weight. Shoots dry matter (SDM), roots dry matter (RDM) and the ratio RDM: SDM were determined. The SDM was ground in a Wiley mill for nutrient analysis. For determination of P, K, Ca, Mg, Zn, Cu, Fe e Mn concentrations on SDM, a sample of 0.500 g oven dried tissue was accurately weighted and digested using 5 mL of HNO_3 and HCl at 2:1 ratio on a block digester (Tecnal, 040/25, Brazil). Calcium, K, Mg, Zn, Cu, Fe and Mn were determined by atomic absorption spectroscopy (AAS) (GBC, model Avanta Sigma, Australia). Phosphorus was determined by using $(NH_4^+)_6{\bullet}Mo_7O_{24}$ solution plus ascorbic acid at spectrophotometer (λ = 660 nm) (Thermo, model Helios Beta, Australia). For N analysis, a 0.100 g sample was digested using 2 ml de H_2SO_4 and 0.5 ml de H_2O_2 on a heater plate at 200 ºC. 2.5 ml of the digested sample was distilled on a micro-*Kjeldahl distiller* (Marconi, MA036, Brazil) and determined by titration with a H_2SO_4 0.02 M solution.

Nutrient accumulations were calculated multiplying the nutrient concentration by the SDM. Phosphorus use efficiency (PUE) was calculated dividing the SDM by the accumulated P. Phosphorus sources were considered as independent variables and height, stem diameter, SDM, RDM, ratio RDM: SDM, PUE and nutrients accumulations as dependent variables. Data normality was tested using Shapiro-Wilk test ($p \geq 0.05$) prior to statistical analysis of dependent variables. Data were analyzed using an analysis of variance ($p \leq 0.05$) and means comparison was carried out using Tukey test ($p \leq 0.05$), using Statistical Analyses System (SAS) software version 9.1.2.

Results

All studied dependent variables were considered parametric according to the Shapiro-Wilk test ($p \geq 0.05$). Lower nutrients accumulation and growth were observed on plants of control treatment as expected (Figure 1). The different P sources affected nutrients accumulation on mahogany. Phosphate sources with higher solubility TSP, SSP and YT increased nutrients accumulation on mahogany comparing with ARP, except for N (Figure 1A, 1B and 1C).

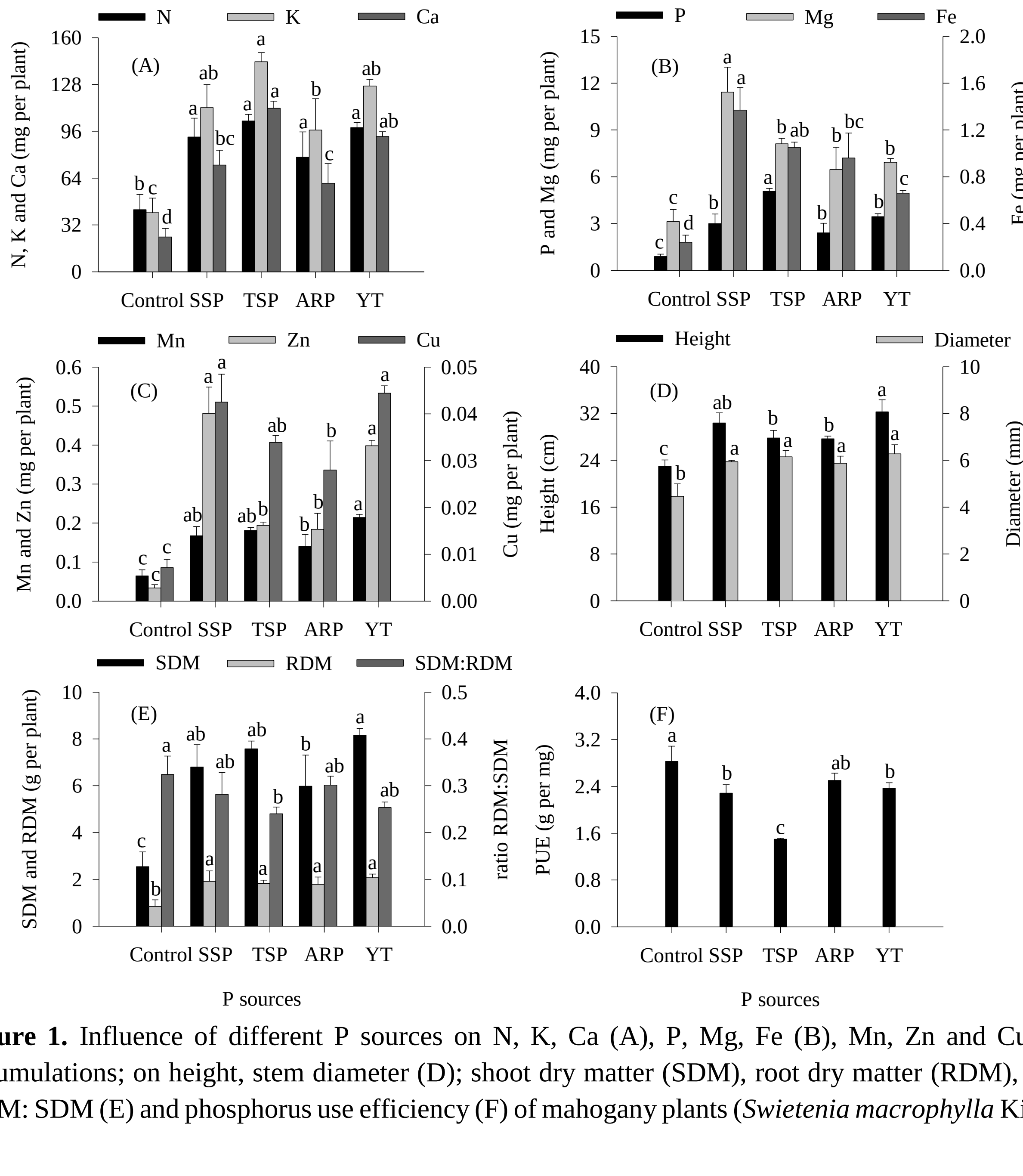

Figure 1. Influence of different P sources on N, K, Ca (A), P, Mg, Fe (B), Mn, Zn and Cu (C) accumulations; on height, stem diameter (D); shoot dry matter (SDM), root dry matter (RDM), ratio RDM: SDM (E) and phosphorus use efficiency (F) of mahogany plants (*Swietenia macrophylla* King.).

Control - without P fertilization, SSP - single superphosphate, TSP - triple superphosphate, ARP - Arad reactive rock phosphate, YT - Yoorin thermophosphate. Bars labelled by the same letter are not significantly different from each other by Tukey test ($p \geq 0.05$).

Plants treated with TSP showed highest P accumulations (Figure 1B), and plants treated with SSP had highest Mg accumulation (Figure 1B). Single superphosphate and ARP led to lower Ca accumulation on mahogany. Phosphorus was the nutrient most influenced by the P sources. Plants treated with TSP had 570% higher P accumulation comparing with control treatment (Figure 1B). Highest Fe accumulation was observed on SSP and TSP treated plants and higher Zn accumulation was observed on SSP and YT treated plants (Figure 1B and 1C). Plants treated with SSP, TSP and YT displayed highest Cu accumulation followed by ARP (Figure 1C). Plants treated with SSP, TSP and YT had highest Mn accumulation (Figure 1C). Arad rock phosphate led to lower K, Ca, Mg, Cu, Fe, Mn and Zn accumulations comparing the P sources, however, was higher than control treatment.

Phosphorous sources had small influence on mahogany plants growth. Plants treated with YT, SSP and TSP had similar behavior but were slightly higher than ARP (Figure 1D). Yoorin thermophosphate, SSP and TSP increased SDM comparing with ARP treated plants (Figure 1E). Phosphorous sources had no effect on plants diameter and RDM, however, all P sources displayed higher plant diameter and RDM comparing with control plants (Figure 1D and 1E). Plants treated with YT showed SDM and RDM, 3.2 and 2.4 folds higher, respectively, comparing with control plants. The RDM: SDM ratio was highest on control plants and TSP plants displayed lowest ratio (Figure 1E). Despites higher P accumulation on mahogany treated with TSP, these plants showed lowest PUE comparing with the P sources and control treatment (Figure 1F).

Discussion

The highest P accumulation observed on plants treated with TSP is probably related with its higher P availability on soil solution in a short time, comparing with other P sources (MODA et al., 2014). Higher N, K, Ca, Mg, Cu, Fe, Mn and Zn accumulations on plants treated with P fertilization is related with higher P uptake by mahogany comparing with control treatment. Nutrients uptake, especially N, demands high energy amount, hence more ATP, that is mainly compose by P, is necessary, resulting on synergy between phosphorus and nitrogen uptake (WEN et al., 2016). Santos et al. (2008) found higher P, K, Ca and Mg concentrations on mahogany plants cultivated on clay Oxisol fertilized with SSP under greenhouse conditions. However, these authors reported that higher P accumulation was associated with dry mass production. The same trend was not observed in our study. We observed higher SDM on plants treated with YT, SSP and TSP although higher P accumulation was found on TSP treated plants.

The higher Mg accumulation on SSP treated plant was because this source, differently of TSP and YT, had lower Ca^{2+} to compete with Mg^{2+} uptake. On the other hand, the higher Ca^{2+} amount released by TSP and YT, probably depressed Mg^{2+} uptake by the antagonist effect. However, no Mg deficiency symptoms were observed. The antagonism Ca^{2+} *vs* Mg^{2+} was previously described by Gransee and Führs (2013). The lower Zn accumulation on TSP treated plants, which had higher P accumulation, suggests an antagonistic effect of this micro-nutrient with P. This behavior is may related with the Zn precipitation with $H_2PO_4^-$, forming low-soluble Zn composts on the root surface (MARSCHNER, 2012). The suppression of Zn uptake by increased P rates of “andiroba” (*Carapa guianensis* Aubl., Meliacea), same family of mahogany, was previously observed by Neves et al.

(2004). These authors found deficiency symptoms of Zn on plants. Paiva et al. (2003) also reported lower P accumulation on cedar (*Cedrela fissilis* Vell., Meliacea), with increasing Zn rates on nutritive solution. These studies confirm our results of antagonism among P and Zn on mahogany uptake.

The antagonistic effect of P *vs* Zn, did not influenced mahogany growth. It was probably because the plants with lower Zn accumulation still had enough amount of this nutrient necessary to supply its demand. Silva et al. (2007) reported a low demand of mahogany by B, Fe, Mn and Zn cultivated in an Oxisol under greenhouse conditions. This result confirms that the lower Zn uptake, as consequence of higher P concentration, has low effect on mahogany growth.

The slight increasing on plants height and SDM fertilized with YT may is consequence of Si and Mg on this P source, besides its neutralizing capacity of soil acidity (FAGERIA; SANTOS, 2008). However, Mg accumulation on YT treated plants was lower than in SSP, thus, indicating that the major contribution can be associated with a possible neutralization of soil acidity for plants growth on YT. In addition, accordind to Khan & Roy (1964) the Si can increase the use of P applied to the soil, and sometimes perform some functions of P, even replacing it partially. Regardless to the P sources we found higher SDM comparing with the control plants. It’s suggests that, despites mahogany being a late successional secondary species, usually less responsive to P fertilization at short time (RESENDE et al. 1999), we found significant growth of mahogany for P sources comparing with the control. Hence, without P fertilization, mahogany growth will decrease. Wallau et al. (2008) showed that mahogany SDM decreased only when P was omitted in nutritive solution conditions. In our study, control treatment plants decreased 70% comparing with YT plants. Under greenhouse conditions Santos et al. (2008) and Souza et al. (2010) reported mahogany growth decreasing variables without P application.

Although YT led to a slight SDM and height, this did not differ significantly of high water soluble phosphorus sources (TSP and SSP). On the other hand, the low P rate applied (125 mg of P kg^{-1} of soil) and the low solubility of ARP probably contributed to a slight negative effect on mahogany growth. A Prochnow et al. (2006), low solubility P sources can be agronomically effective in soils with high P adsorption capacity. Moreira et al. (2014) reported that in tropical soils usually low in plant-available P and with high P-fixing capacity, the application of phosphate rocks can be an alternative for WSP fertilizers use. But this behavior was not observed in this study.

Higher SDM and RDM in response to the P fertilization are probably related with cells division and meristem development of plants (NIU et al., 2015). According to Silva et al. (1997), supplying the nutritional demand of plants allows to increase biomass production of forest species that has accentuated initial growth. Moreover, the SDM is the most influenced variable by the nutritional status. This behavior is related with the positive effect of P on the roots development that allows roots to explore a mayor area of soil (SHI et al., 2016). According to Haase (2007), the survival and development of forest nursery trees are sharply related with SDM, because water and nutrients reserves are necessary to the adaptation under adverse conditions in field.

Higher RDM: SDM ratio of control plants is explained by the fact that on soils under low nutrients availability, especially P, plants trends to increase RDM, decreasing SDM, building up RDM: SDM on plants with lower P availability (NIU et al., 2013). Thus, biomass reallocation is a possible plant response of its nutritional status. Besides, considering that the assimilated P can be incorporated in many organic compounds of roots cells, it is possible that under low P availability, roots will firstly supply its nutritional need. Phosphorus reallocation to shoots increases only after roots supply leading to the root growth comparing with shoots, under low P availability.

Triple superphosphate treated plants had lower PUE suggesting that SDM was not equivalent to the P accumulation on mahogany. These results suggest that, considering this source, the P rate used (125 mg kg^{-1}) was above to the metabolic need of mahogany. When P supply is limited, plants roots increases grow and P is relocated from old leaves, besides the P of vacuole is consumed (LIU et al., 2015). With these strategies plants increased PUE under low P availability, as observed in our results. Despite ARP provided lower nutrients accumulation, it provided the highest PUE considering all P sources. Although the soil used in the present study has a high clay content (56.7 dag kg^{-1}), it has a mean potential (remaining P = 30 mg $L\text{-}^{1}$) for adsorption of P (ALVAREZ et al., 2000; WADT and SILVA, 2011). In spite of that, it is probable that these characteristics contributed to adsorb part of the released P of the ARP source, consequently, reducing the availability of P in soil and forcing the mahogany plants to present a higher PUE. This result suggests that using LWSP, mahogany plants uses a metabolic strategy in order to optimize the lower P concentration available in soil solution.

Conclusions

Mahogany is responsive to P fertilizer, however the high water soluble (TSP and SSP) and citric acid (YT) phosphorus sources had a similar effect on mahogany growth. It suggests that the seedlings producer can use any of them but should avoid the use of the ARP source in this stage of growth.

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