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PHOSPHORUS SOURCES: EFFECT ON THE TROPICAL CEDAR NUTRITION AND GROWTH

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PEREIRA BFF, TUCCI CAF, SANTOS JZL & SILVA TAF. 2014. Phosphorus sources: effects on the tropical cedar nutrition and growth. Many questions remain unanswered regarding the effects of different phosphorus (P) sources and liming on forest species in tropical ecosystems. We investigated: (1) the influence of different P fertilisers and lime on the growth and nutrition of the tropical cedar (*Cedrela fissilis*) in a highly weathered Amazon rainforest soil, and (2) the economic viability of the tropical phosphate rock. The four P sources used were single superphosphate (SSP), triple superphosphate (TSP), Arad phosphate rock (APR) and Yoorin thermophosphate (YT). Results show that soil liming has no effect on cedar growth. Arad phosphate rock increases nutrient status and growth of cedar when compared with SSP, TSP and YT. The Phosphate Rock Decision Support System shows that APR has relative agronomical effectiveness 100% as good as TSP besides being a more economical P source on Amazon rainforest soil.

Keywords: Soil fertility, tropical soil, phosphate rock, Amazon rainforest

INTRODUCTION

The availability time of phosphate rock reserves was estimated at between 100 and 400 years (Dawson & Hilton 2011). Phosphorus (P) is also a limiting nutrient in the tropical rainforest soils. About 80 to 100% of soils from the state of Amazonas, Brazil, had less than 5 mg P dm^{-3} (Moreira & Fageria 2009). Studies are necessary to increase P-fertiliser efficiency to save fertilisation costs and P reserves. The Brazilian Amazon rainforest holds about 100 billion tonnes of carbon, equivalent to more than 10 years of global fuel emissions (Davidson et al. 2012). Thus, the best management practices of P fertilisers are essential to increase the soil fertility for nursery tree production and reforestation projects in the Amazon rainforest.

Most scientific studies have reported the effects of P fertilisers on agronomic species (Fageria et al. 1995, Fernandez et al. 2000, Muraoka et al. 2002, Szilas et al. 2007, Costa 2011). However, many questions remain on the effects of P sources and liming on nutrition and growth of forest species in tropical ecosystem (Silva et al. 2011). Studies regarding P fertilisation were carried out on non-tropical forest species (Dallatea & Jokela 1994, Turner et al. 2002, Trichet et al. 2009, Crous et al. 2011). After 50 years of fertilisation trials on *Pinus pinaster,* only plants fertilised with P displayed productivity improvement (Trichet et al. 2009).

The most used P fertilisers in Brazil are water-soluble phosphates (WSP) [e.g. triple superphosphate TSP and single superphosphate SSP, thermophosphates (e.g. Yoorin thermophosphate YT) and phosphate rocks (e.g. Arad phosphate rock (APR)] (Moreira et al. 2002, Muraoka et al. 2002). The water-soluble sources are more expensive and susceptible to P adsorption, retention, fixation and precipitation especially in tropical acid soils. Studies with crop plants frequently show that lime mitigates these negative effects increasing P availability for plants cultivated in acid soils. However, lime had only a slight effect on plant nutrition and growth of an Amazon wild species (*Swietenia macrophylla*) (Silva et al. 2011). Even for agronomic crops the effects of P sources and lime are different for species. Rice and wheat had slight response to liming because of their tolerance to soil acidity (Fageria et al. 1995). Natural reactive phosphate

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had a similar effect to TSP to increase soybean yield (Olibone & Rosolem 2010).

The advantages of phosphate rocks have been highlighted (Zapata & Roy 2004). However, this still has some limitations such as lack of knowledge on main factors affecting the agronomic effectiveness of phosphate rocks. The most important factors for phosphate rocks use are (1) solubility of P source, (2) soil properties, (3) crop species, (4) management practices and (5) agro-climatic conditions (Smalberger et al. 2006).

Besides the effects of P sources on soil-plant system, the economic viability of P sources must be considered. The International Fertilizer Development Center and the Food and Agriculture Organization/International Atomic Energy Agency developed the Phosphate Rock Decision Support System (PRDSS). With the PRDSS, it is possible to decide between WSP and phosphate rocks, in addition to determining if the use of phosphate rock is more economical (Chien et al. 2010, 2011).

In this context we evaluated (1) the influence of different P fertilisers and lime on the tropical cedar (*Cedrela fissilis*) growth and nutrition in a highly weathered soil from the Amazon rainforest and (2) the economic viability of APR comparing with TSP.

MATERIALS AND METHODS

Soil sampling and chemical–physical properties

This study was conducted under greenhouse conditions in Manaus, Amazonas, Brazil (3° 06' S; 59° 28' W, 75 m above sea level). A 20–40 cm layer of Typic Hapludox was collected (03° 06' S; 59° 58' W, at 77 m). Air-dried soils were ground to < 2 mm particle size prior to chemical analyses according to EMBRAPA (1999). Soil active acidity (pH_{H_2O}) was determined in water at 1:2.5 soil:solution ratio. Calcium, Mg^{2+} and Al^{3+} were extracted with KCl, 1 mol L^{-1}. Soil total acidity (H + Al) was determined using a pH 7.0 SMP buffer solution. Phosphorus and K were extracted using a Mehlich-1 solution. Cation exchange capacity (CEC), base saturation (V%) and aluminium saturation (m%) were calculated as follows:

$$\text{Cation exchange capacity (CEC)} = K^+ + Ca^{2+} + Mg^{2+} + (H + Al);\ \ (cmol_c\ dm^{-3})$$

$$\text{Base saturation (V\%)} = (K^+ + Ca^{2+} + Mg^{2+}) / CEC \times 100;\ \ (\%)$$

$$\text{Al saturation (m\%)} = Al^{3+} / (K^+ + Ca^{2+} + Mg^{2+} + Al^{3+}) \times 100;\ \ (\%)$$

Untreated soil displayed the following chemical–physical properties (EMBRAPA 1999): soil active acidity (pH_{H_2O}) = 4.54; extractable P = 2 mg kg^{-1}; exchangeable K^+, Ca^{2+}, Mg^{2+} = 0.35, 4.0 and 2.0 $mmol_c\ dm^{-3}$ respectively; H + Al = 42.8 $mmol_c\ dm^{-3}$; m = 55.94 %; CEC at pH 7.0 = 56.9 $mmol_c\ dm^{-3}$; V = 12.8%; organic matter = 9 g dm^{-3}. Soil granulometric fractions were of 11.5, 1.7, 86.8% for sand, silt and clay respectively.

Experimental design and soil fertilisation

The experiment was factorial 4 × 2 completely randomised in four replications (four P sources; with and without liming). The four P sources were SSP, TSP, APR and YT (Table 1). The experiment totalled 32 pots and each pot of 3 dm^{-3} was considered an experimental plot. One half of the plots were treated with $CaCO_3$ and $MgCO_3$ at the ratio of 4:1 of Ca:Mg, applied at the rate of 500 mg dm^{-3}. After liming, distilled water was used to fill 70% of the total pores and complete the soil incubation during 30 days.

Table 1 Chemical contents (%) of single superphosphate (SSP), triple superphosphate (TSP), Arad phosphate rock (APR) and Yoorin thermophosphate (YT)

P source	Total P_2O_5	Water soluble P_2O_5	Citric acid soluble P_2O_5	Available P_2O_5	Ca	Mg	S
SSP	20	18	2	20	20	0	1
TSP	46	41	5	46	14	0	1
APR	33	0	10	10	37	0	1
YT	17	0	13	13	20	7	6

Phosphorus rates were equivalent to 300 kg of water-soluble P_2O_5 ha^{-1} for SSP and TSP, and 300 kg of citric acid-soluble P_2O_5 for APR and YT.

All soil samples were fertilised with 100 kg N ha^{-1} as urea and 300 kg K_2O ha^{-1} as KCl. Fifty percent of urea was applied at transplanting and 50% 30 days after transplanting. Micronutrients were applied to all soil samples using MIB-3^{TM} commercial fertiliser as source at the rate of 50 kg ha^{-1}. Boron, Cu, Fe, Mn, Mo and Zn concentrations in MIB-3^{TM} were 18, 8, 30, 20, 1 and 90 g kg^{-1} respectively.

Nursery trees production and transplantation

Seeds of the tropical cedar (*C. fissilis*) were soaked in NaOCl (1%) for 2 min and rinsed in tap water for 5 min. Seeds were dried on filter paper and sowed in washed sand at room temperature. After germination, seedlings of 4–7 cm height were selected and transplanted to plastic pots of 3 dm^{-3} filled with soil.

After transplanting, commercial micronutrients fertiliser Chelamix^{TM} was sprayed on the soil six times each 15 days. The total amounts of B, Cu, Fe, Mn, Mo and Zn applied were respectively 0.15, 0.06, 0.09, 0.06, 0.1, 0.72 mg kg^{-1}. Soil moisture was monitored by weighing pots daily and using distilled water to keep 70% total pores filled with water. Plants were harvested 115 days after transplanting.

Plant nutrition and growth evaluation

The dependent variables analysed on plants were shoot length, stem diameter, shoot dry weight, root dry weight, total dry weight, shoot and root ratio, nutrient concentration and nutrient accumulation. Shoot length was measured with a ruler (cm) from soil surface to the top of the plant. Stem diameter was measured using a digital calliper rule (mm) 1 cm above the soil surface.

Plants were harvested at 0.5 cm above the soil surface using garden scissor. Roots were separated from soil using a 2-mm mesh sieve and tap water, and dried at 65 °C until constant weight (root dry weight). Shoots were firstly rinsed in tap water, then in distilled water, and dried at 65 °C until constant weight (shoot dry weight). Total dry weight was determined adding root dry weight and shoot dry weight. Dry shoots were separately ground in a Wiley mill.

For determination of shoot nutrient concentration, a sample of 0.5-g oven-dried tissue was accurately weighed and digested using 5-mL HNO_3 and HCl at 2:1 ratio on a block digester. For nitrogen determination a 0.1 g dry sample was digested using 3 mL of H_2SO_4 (98%) and H_2O_2 (30%). Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S) concentrations in the shoot tissue were determined according to EMBRAPA (1999).

Data analysis

Plant growth was evaluated considering the following dependent variables: shoot length, stem diameter, shoot dry weight, root dry weight, total dry weight, shoot and root ratio. Nutritional status in plants was evaluated using nutrient concentration and nutrient accumulation as dependent variables. Data normality was tested using Shapiro-Wilk test ($p > 0.05$) prior to statistical analysis of dependent variables. Then Tukey's test ($p < 0.05$) was used to compare the effects of different P sources and liming treatment. Only the significantly affected dependent variables were discussed. All statistical analyses were calculated using SAS program version 9.1.2.

The PRDSS (Smalberger et al. 2006) compared the relative agronomic effectiveness and economic viability of APR with TSP. According to the local conditions, the following attributes were used as PRDSS data input: rhizosphere effect, -0.8; P fixation effect, 1.0; soil organic carbon, 0.5%; soil pH_{H_2O}, 4.5; sand, 11.5%; clay, 86.8%; Al saturation; 55.94%; available P, 2 mg kg^{-1}; cation exchange capacity, 4.92 $cmol_c$ kg^{-1}; P rock attribute, 10% of P_2O_5 soluble at 2% citric acid; rainfall, 2000 mm per growing season; growing season length, 200 days; number of wet days, 200; APR sales local price, USD46.80 per 50 kg; TSP sales local price, USD60.25 per 50 kg.

RESULTS

All studied variables were considered normal according to the Shapiro-Wilk test ($p > 0.05$). Phosphorus sources influenced ($p < 0.05$) almost all variables used to evaluate plant nutrition and plant growth. Liming treatment had slight influence on Ca and Mg concentrations in shoots, and Mg accumulations in plants, thus the results were focused on means of unlimed soil.

Influence of P sources on the tropical cedar nutrition

The P sources influenced differently the nutrient concentration in the tropical cedar shoots. Plants treated with TSP had the highest N concentration ($p = 0.001$) in the shoots (17.4 g kg^{-1}) and those treated with APR showed the highest P ($p = 0.02$) and Ca ($p < 0.001$) concentrations in the shoots (Figure 1). Yoorin thermophosphate increased Mg ($p < 0.001$) concentration in the shoots. Treatments had no effect on K ($p = 0.215$) and S ($p = 0.187$) concentrations of the shoots (Figure 1).

Plants treated with APR showed the highest N, P, K, Ca, Mg and S accumulations in the shoots (Figure 2). Following APR, SSP and YT had similar effects both increasing nutrient accumulation in the shoots (Figure 2). Plants treated with TSP had the lowest P, K, Ca and Mg accumulations.

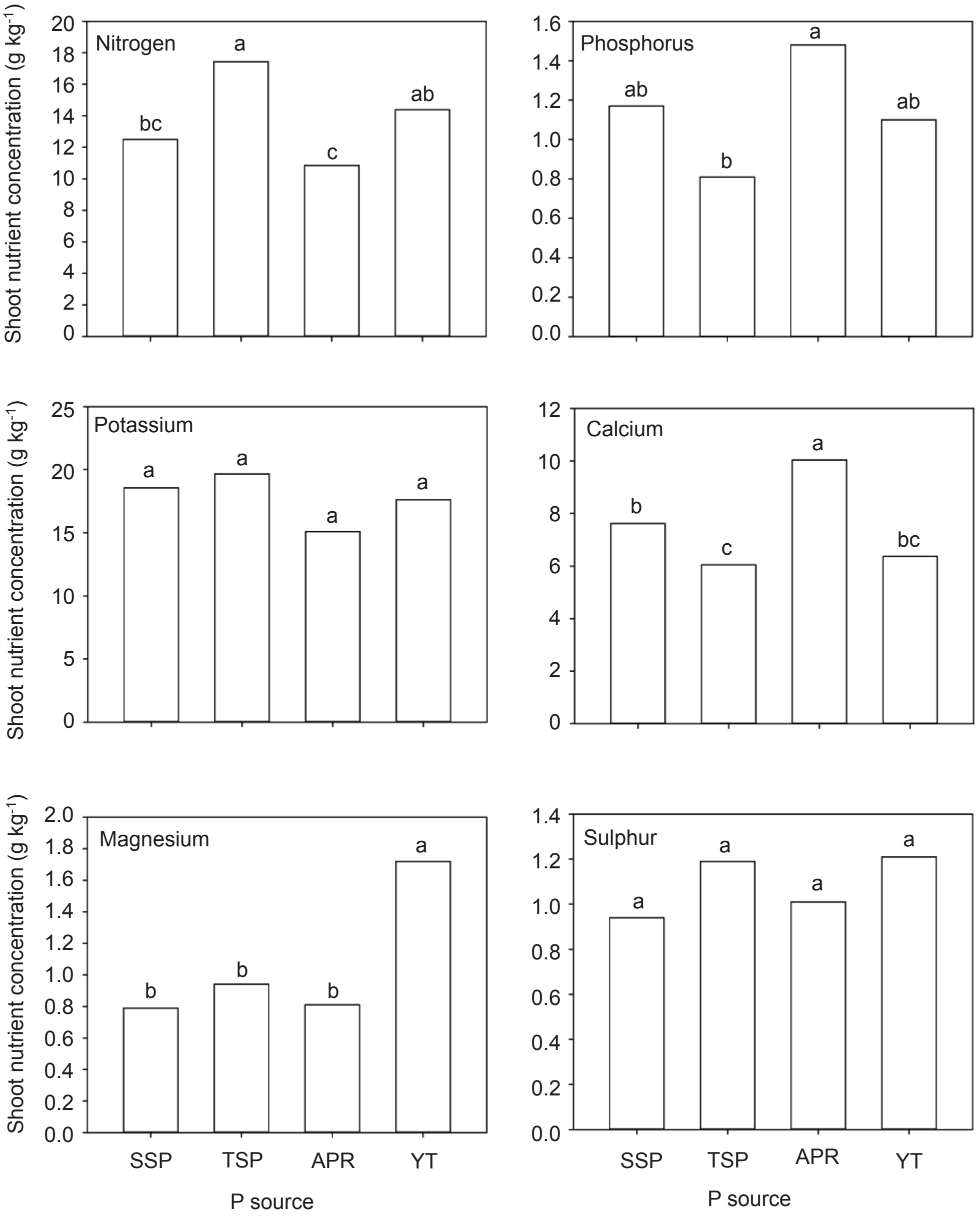

Figure 1 Effects of phosphate sources on nutrient concentration (g kg^{-1}) in the tropical cedar shoots (n = 4); SSP = single superphosphate, TSP = triple superphosphate, APR = Arad phosphate rock, YT = Yoorin thermophosphate; means of each nutrient concentration followed by the same letter(s) are not significantly different ($p < 0.05$) according to Tukey's test

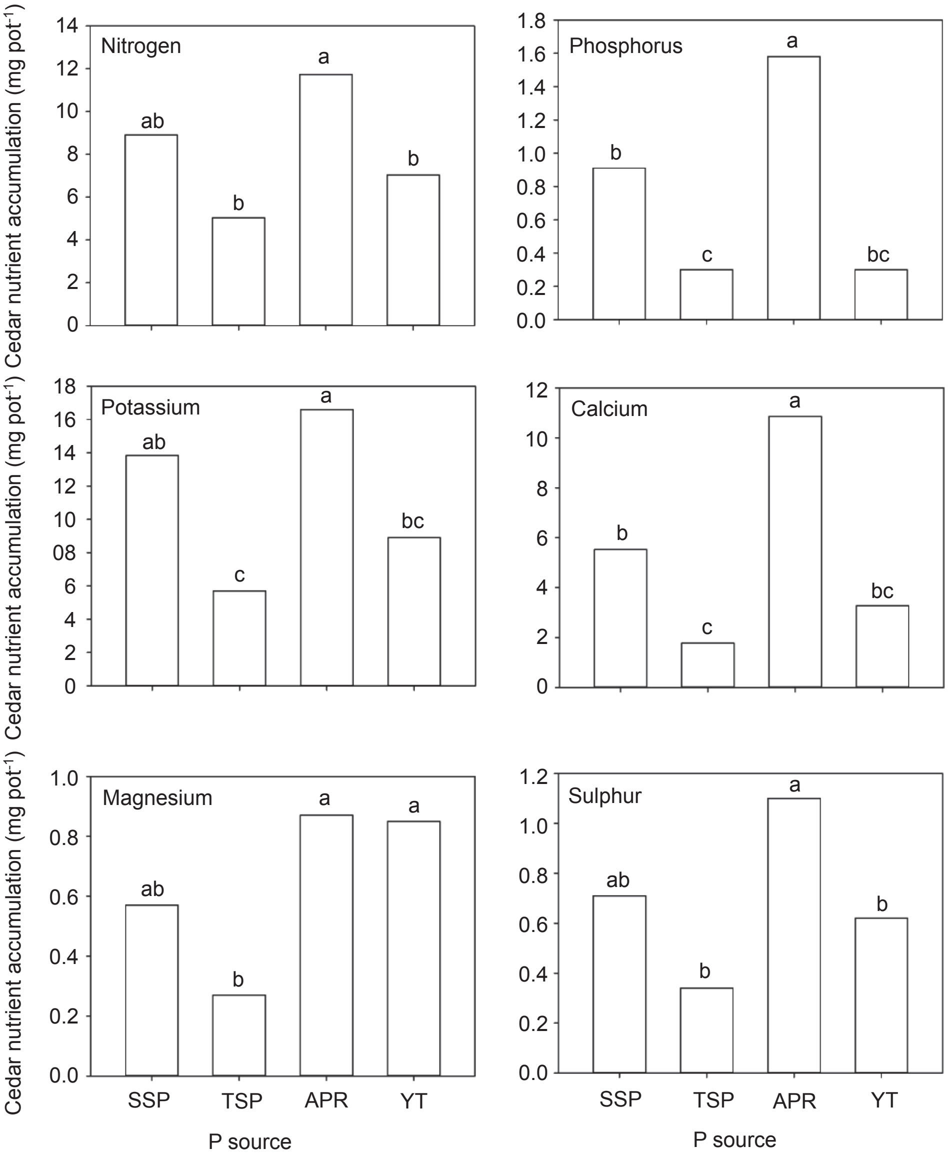

Figure 2 Effects of phosphate sources on nutrient accumulation (mg pot^{-1}) in the tropical cedar shoots (n = 4); SSP = single superphosphate, TSP = triple superphosphate, APR = Arad phosphate rock, YT = Yoorin thermophosphate; means of each nutrient accumulation followed by the same letter(s) are not significantly different ($p < 0.05$) according to Tukey's test

Influence of P sources on the tropical cedar growth

Treatments also influenced ($p < 0.05$) stem diameter, shoot dry weight, root dry weight and total dry weight of the tropical cedar (Figure 3). In general, APR and SSP sources increased all these variables compared with TSP and YTP. Plants fertilised with APR showed highest values of stem diameter, shoot dry weight, root dry weight and total dry weight followed by SSP. On the other hand, plants treated with TSP showed the lowest means of stem diameter, shoot dry weight, root dry weight and total dry weight compared with other sources. This result emphasises the positive influence of APR followed by SSP on the tropical cedar growth in highly weathered tropical soil. Treatments had no effects on shoot length ($p = 0.421$) and shoot root ratio ($p = 0.146$).

DISCUSSION

Liming effect on the tropical cedar nutrition and growth

A previous study confirmed the benefits of lime on agronomic species such as corn, rice and pea

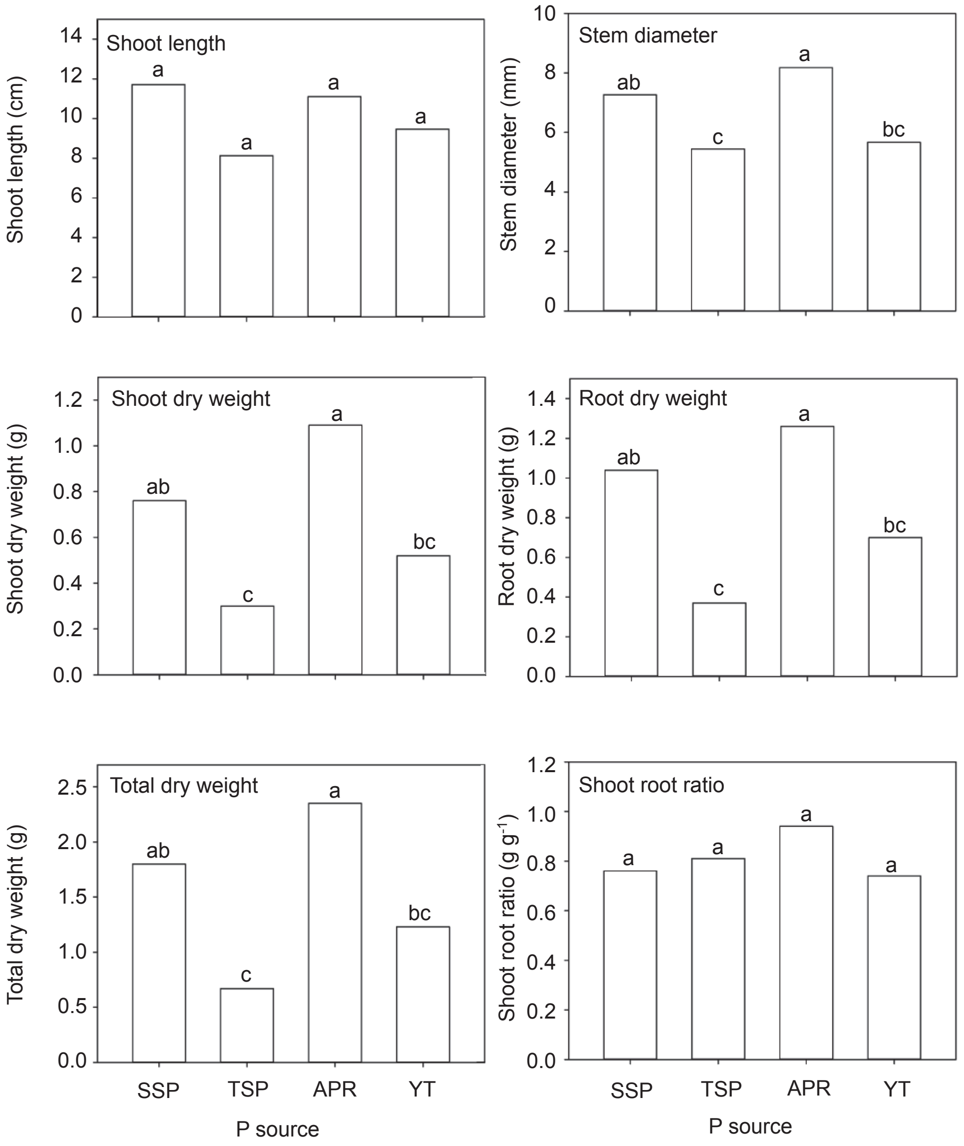

Figure 3 Effects of phosphate sources on the tropical cedar growth variables (n = 4); SSP = single superphosphate, TSP = triple superphosphate, APR = Arad phosphate rock, YT = Yoorin thermophosphate; means of each growth variables followed by the same letter(s) are not significantly different ($p < 0.05$) according to Tukey's test

on a Typic Hapludult from the Amazon rainforest (Costa 2011). It was reported that liming reduced soil acidity and Al toxicity, improved the root system, nutrient uptake and crop yield. However, in our conditions using a wild forest species, the only influence of liming treatment was to increase Ca and Mg concentrations in the shoots because of $CaCO_3$ and $MgCO_3$ application at the rate of 4:1 in the soil. All other dependent variables of plant growth and plant nutrition were not affected by liming. This may be explained because the tropical cedar is a slow-growth species, growing wild in low fertility soils of the Amazon rainforest. Wild plants that are adapted to nutrient poor sites (Type I, slow growers) usually have small growth response of roots and shoots in nutrient-rich sites (Marschener 1995). Similar to our results, Fageria et al. (1995) concluded that since rice and wheat are tolerant to soil acidity, not too much improvement could be achieved by liming.

Phosphorus sources and the tropical cedar nutrition and growth

The P_2O_5 concentrations in all P sources used in this experiment (Table 1) were similar to those in previous studies: SSP was 18% P_2O_5 water-soluble (Fernandez et al. 2000); TSP was 41% P_2O_5 water-soluble (Muraoka et al. 2002); APR was 9.9% P_2O_5 citric acid soluble (Moreira et al. 2002) and YT was 17% P_2O_5 citric acid soluble (Muraoka et al. 2002).

In general we observed better effects of APR on the tropical cedar nutrition and growth compared with SSP, YT and TSP (Figures 1 and 2). This result was not expected because water-soluble P such as TSP usually display better effects on nutrition and growth of agronomic species (Fageria et al. 2011), compared with water-insoluble sources.

Chemical properties of the highly weathered tropical soil used in this study might have been favourable to APR treatment. Although TSP and SSP are readily soluble in soil, in the form of orthophosphate these water-soluble sources can be readily converted to water-insoluble P through Fe-Al-P on the surface of Fe-Al oxides (Chien et al. 2010). Moreover, according to these authors, P in soil solution can precipitate with cations as amorphous Fe-P and/or Al-P in acid soils such as the studied Oxisol. The positive effect of phosphate rock was found in previous studies with tropical soils. Phosphate rock replaced TSP as P fertiliser on a weathered tropical, pH KCl ~4, soil with low P concentration and high phosphate adsorption capacity (Szilas et al. 2007).

Higher efficiency of APR compared with other P sources may also be related to the following properties of the Amazon rainforest soils: (1) Soil pH of 4.5. Phosphate rock agronomic effectiveness is highly dependent of soil pH since it is on a logarithmic scale (Chien et al. 2011). These authors showed that soil pH alone explains 56% of variability of relative agronomic efficiency. The presence of H^+ is important to phosphate rock dissolution (Novais & Smyth 1999); (2) Low Ca concentration of the Amazon rainforest soils also favourable for phosphate rock dissolution. The low Ca soil concentration acts on mass action law (Chien et al. 2011); (3) High P-fixing capacity. Phosphate release from phosphate rocks increases with the P-fixing capacity of the soil (Chien et al. 2011); (4) Physiological mechanisms of the tropical cedar to increase P uptake similar to other plants. Rape (*Brassica napus*) was highly efficient in P uptake due to the exudation of malic acid and citric acid by roots and dissolution of phosphate rock (Habib et al. 1999). Tolerance to high Al concentration and efficiency to absorb and metabolise P coexist in roots of tropical crops such as cassava (*Manihot esculenta*) (Fageria et al. 1988, Marschener 1995). As discussed, the tropical cedar is a wild tree adapted to the Amazon rainforest soils. About 50% of Amazon rainforest soils have more than 50% of Al saturation (Moreira et al. 2009); (5) Liming effect of phosphate rock. Previous studies reported the liming effect of phosphate rocks (Sikora 2002) because of the PO_4^{3-}, CO_3^{2-} and F^- in the carbonate apatite structure of phosphate rock which consume soil H^+. This author estimated 59 to 62% of calcium carbonate equivalence of different phosphate rocks.

The favourable conditions for P uptake of APR discussed above explain the higher P concentration (Figure 1) and accumulation in the tropical cedar shoots (Figure 2). Arad phosphate rock also built up Ca concentration (Figure 1) and accumulation (Figure 2) in the tropical cedar shoots. This may be explained because APR has 37% Ca.

Higher Mg concentration in cedar shoots of plants treated with YT was expected because this source has higher Mg concentration (7%) (Table 1). Considering the YT application rate of 2307 kg of YT ha^{-1}, this source provided nearly 161 kg of Mg ha^{-1} ($2307 \times 7\% = 161$).

Plants treated with TSP showed the highest N concentration compared with other P sources. This fact may be related to the lower dry mass production and the dilution effect on plants; however, this effect was not observed in other nutrients.

The Phosphate Rock Decision Support System (PRDSS)

We used the PRDSS to compare the relative agronomical efficiency of APR with TSP and its economic viability (Smalberger et al. 2006). According to these authors, the PRDSS shows the relative agronomic efficiency—an index to estimate the response of a crop to P application—and was used in comparing APR with TSP. The PRDSS indicates that the initial relative agronomic efficiency of APR is 100% as good as TSP. Moreover, the PRDSS economic validation shows that APR is more economical than TSP (Figure 4). Similar results comparing TSP with Gafsa phosphate rock was found

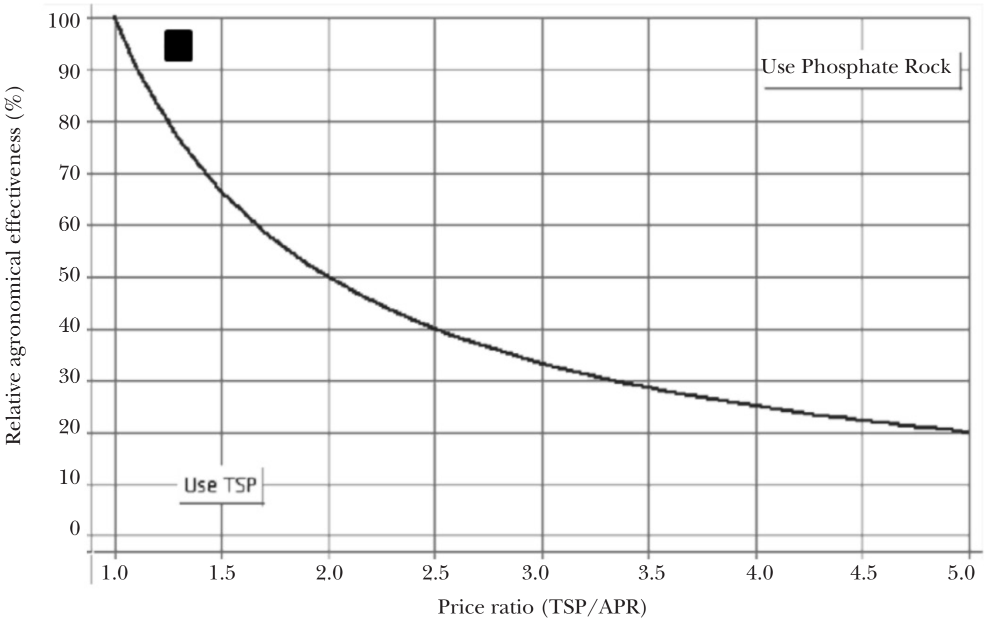

Figure 4 Economical validation of the Phosphate Rock Decision Support System; when the black square symbol coordinate (price ratio × relative agronomic efficiency) is above the black line, it is more economical to use Arad phosphate rock (APR) and when it is below the black line, water soluble P fertiliser (e.g. triple superphosphate TSP) is the better P source

(Chien et al. 2011). They reported that relative agronomic effectiveness of phosphate rock increased as soil pH dropped in 15 studied soils. Prochnow et al. (2006) also found higher relative agronomic efficiency of phosphate rock on Oxisol. These results—together with the low tropical cedar response to soil nutrients—confirm phosphate rock as the most appropriated P source for the tropical cedar. The economical and environmental advantages of using local phosphate rock over imported superphosphates have been highlighted (Szilas et al. 2008). Phosphate rock was economically competitive in acid soils specially because of the transportation costs (Szilas et al. 2007).

CONCLUSIONS

Soil liming has no effect on the tropical cedar growth. When compared with SSP, TSP and YT, APR increases the nutrient status and growth of the tropical cedar cultivated in the highly weathered Amazon rainforest soil. The PRDSS shows that APR has relative agronomical effectiveness 100% as good as triple superphosphate besides being a more economical P source.

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