EFFECT OF PHOSPHORUS FERTILIZERS ON BIOMASS, PHOSPHORUS AND CALCIUM UPTAKE BY EUCALYPTS

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Abstract: We investigated phosphorus and calcium uptake and their effect on the yield of Eucalyptus grandis L., in response to natural and concentrated phosphate sources at Carbonita and Bom Despacho in the State of Minas Gerais of Brazil. Application of the natural phosphate rock (Araxa – PA) was at the rates of 500, 1000, 2000 and 4000kg/ha; Patos of Minas (24% P2O5 and 25% Ca) at 500, 1000, 2000 and 4000kg/ha and the concentrated phosphate rock (Arafertil – CA) was at 1000kg/ha. Triple superphosphate (ST) was also applied at 250, 500, 1000 and 2000kg/ha. ST contributes more to the phosphorous content in the biomass than does PA and PP. Its contribution was 1,76% and 9,39% higher than that PA and PP, respectively. On the two sites, ST contributes more to P while the natural phosphates (PA and PP)both contributes more to Ca in the trees. Comparisons among fertilizers revealed that, the recovery efficiency in ST and PA were similar at Carbonita. Increasing fertilizer rates and the P supply, reduced the recovery percentages for all of the sources tested in the two localities. The recovery of P was higher at Bom Despacho when compared with Carbonita. The recovery of Ca. was always superior to that of P.

[Awodun, M. A., Barros, N. F., Novais, R.F. and Dantas, S. V. **EFFECT OF PHOSPHORUS FERTILIZERS ON BIOMASS, PHOSPHORUS AND CALCIUM UPTAKE BY EUCALYPTS.** New York Science Journal 2012;5(1):67-70]. (ISSN: 1554-0200). http://www.sciencepub.net/newyork.

Keywords: Phosphatic rock, P and Ca recovery; fertilizer effectiveness; natural and concentrated.

Introduction.

Mineral nutrient deficiencies constitute one of the major limitations for plant growth on agricultural soils around the world. Specifically, soils of the tropical regions generally are highly weathered; and those with high clay content and acidic present high P fixation. Therefore, the use of P fertilizers is critically needed to improve soil fertility for sustainable crop production in large areas of developing countries. Phosphorus deficiency limits crop yield on more than 30% of the world's arable land. According to some estimates, world resources of inexpensive P may be depleted between 2040 and 2060 (Hans, et al., 2006).

Balanced supply of essential nutrients is one of the most important factors in increasing crop yields. In soils of the tropics, there is a close relationship between food production and fertilizer use (Mokwunye and Hammond, 1992). However, high cost and limited access to mineral P fertilizers limit their use by resource-poor farmers in these countries. Chien and Menon (1995) reported that, phosphate rock (PR) for direct application has been tested in tropical acid soils as a potential alternative to conventional water-soluble P fertilizers like single superphosphate (SSP) and triple superphosphate (TSP). The use of indigenous rock phosphate sources, coupled with the quantification of residual effects of broadcast and banded phosphate applications provided long –term ways to alleviate phosphorous deficiency in soils with high phosphorous fixation capacity (Souza and Lobato, 1988; Agyin-Birikorang, et al., 2007 and Resende , et al., 2007). Finely ground rock phosphate is an effective (and often the least costly) P fertilizer source for very acid rain-fed lowland and upland soils (pH < 4.5). The effectiveness of rock phosphates in tropical environments, however, depends on the extent to which the required P uptake rate of the crop plant can be maintained by the dissolution of rock phosphate P in the soil. Rock phosphate also contains Ca, which may help to alleviate soil acidity and Ca deficiency in highly weathered tropical soils (Dobermann and Fairhurst, 2000).

There are several plant anomalies that can be associated with low levels of Ca^{2+} , including poor root development, leaf necrosis and curling, blossom end rot, bitter pit, fruit cracking, poor fruit storage, and water soaking (Simon, 1978; White and Broadley, 2003 Burstrom, 2008). The myriad processes in which this ion participates is large, growing and involves nearly all aspects of plant development (Harper et al., 2004; Hetherington and Brownlee, 2004; Hirschi, 2004; Reddy and Reddy, 2004; Bothwell and Ng, 2005). Although, acid soil infertility is found worldwide, this limitation is more extensive in south America, where more than 50% of the soils present acidity problems both in surface and subsurface (Eswaran, et al., 1997). In Brazil, soils of the Cerrado area characterized by low pH; very high aluminum saturation; low and often undetectable levels of available phosphorous and often high phosphorous fixation (Gonçalves, et al., 1997; Resende, et al., 2007 and Martin, et al., 2008), Therefore, phosphorus application is necessary for improving and maintaining yields. The use of P soluble sources leads to a fast, conversion of P from soluble into less labile forms before significant plant P uptake (Gonçalves, et al., 1989 Novais and Smyth, 1999). Rock phosphate release P gradually through time and may represent a strategy to supply and enhance plant P uptake. (Novais and Smyth, 1999). Improvement of P acquisition and use by plants is critical for economic, humanitarian and environmental reasons. Barros and Novais (1990, 1995) and Gonçalves, et al., (1997) observed that, there is substantial productivity gain in response to mineral fertilizer for great majority of eucalypt plantations in Brazil. Response to phosphate fertilizer application seems to give highest eucalypts yield gains (Barros and Novais, 1995, Barros, et al., 2005), probably not only due to P but also due to the Ca in the fertilizer. The objective of this study was to evaluate the yield, phosphorous and calcium uptake by of eucalypts in response to phosphate fertilizer application to acidic and high P fixing capacity soils.

Materials and methods.

Two field experiments were conducted at two sites of the Cerrado (savannah type of vegetations) area in Brazil: Carbonita (Longitude $17^0 44^1$ W and Latitude 43^0 14^1S) and Bom Despacho (Longitude 19^0 35^1 W and Latitude 45^0 17^1E) with a rainfall of 1260 mm and 1476mm; mean temperature of 20^0C and 23.3^0C and the altitude of 726 m and 703 m, respectively. The soil in both sites were classified as an Oxisol (Table 1).

Three phosphatic rocks (Araxa rock -PA; Patos rock-PP and concentrated Arafertil - CAR) and triple super phosphate -ST were tested. Araxa rock and PR contain 24%P_2O_5 and 25% Ca, CAR 33% P_2O_5 and 35% Ca, and ST, 45% P_2O_5 and 13% Ca. The tested rates were 0, 500, 1000, 2000 and 4000 kg/ha for PA and PP, 0, 250,500,1000 and 2000 for ST, and 1000 for CAR. All the fertilizers were broadcast applied and incorporated into the 20cm of the soil surface layer by discing. Nitrogen and potassium were added as a 20-0-20 mixture at the rate of 150 kg/ha. The fertilizer treatments were replicated three times, and laid out in random blocks. Each experimental plot contained 100 trees and spaced 2 by 2m.

At both sites, soil samples were collected randomly at the 0- 20 cm depth, at five different points in each plot. The soil samples were placed into polythene bags and bulked for routine analysis. Physical characteristics were evaluated based on the equivalent particle size and moisture, in agreement with the methodology of Embrapa (1979) and field capacity was analyzed using transparent column method (Fernandes, 1967). The pH was determined in a ratio of 1:2.5 soil-water, with contact time of 60 minutes (Embrapa, 1979), potassium and phosphorus by Mehlish-1 (Vettori, 1969), extractable phosphorus by the method Bray-1 (Braga, 1980), and anions by exchange resin IRA-400 (Quaggio and Raij, 1983), exchangeable cations (Al^{3+}, Ca^{2+} and Mg^{2+}), as presented in the methodology Vettori (1969). Organic matter was determined using Walkley - Black potassium dichromate oxidation method (Embrapa, 1979). Remaining phosphorus in the solution was evaluated using the method describe by Neves, (1983). The composition of the clay mineralogy was determined by the method of allocation (Resende, et al., 1987).

Eucalyptus grandis L. seedlings, 30cm high were planted in holes of 20cm diameter and 20cm depth.

Biomass determination, tree diameter (DBH) and height were determined when the trees were 2.5years old. For these measurements a tree of mean DBH and height was felled per plot and its components (leaves, branches, stemwood, and stembark) weighed and sampled for dry matter determination (at 70^o C) and chemical analyses. Samples from the forest floor were also collected, weighed and chemically analyzed. The weight per treatment was then used to extrapolate the weight per hectare basis. Using this information and the nutrient content, the amount of P and Ca in tree biomass was calculated.

The efficiency of phosphorous recovery (R) by the plant was estimated using the formula (Prasad et al., 1984)

$R = (E_m - E_t) \times 100/E$

R = recovering percentage.

E_m = Amount of P in the fertilized trees.

E_t = Amount of P in the unfertilized trees.

E = Total amount of P applied as fertilizer.

RESULTS AND DISCUSSION

Soils at both sites were acidic with low native nutrient content (Table 1). The soil at Carbonita was more acidic with pH of 3.9 as against 4.3 at Bom Despacho . However, both values were sufficiently low to promote the solubilization of the phosphate rocks (Novais and Smyth, 2000) and release P to the plants.

Table 1. Physical and chemical analyses of soil samples collected at the beginning of the experiment in Carbonita and Bom Despacho, Minas Gerais state, Brazil

Characteristics	Carbonita	Bom Despacho
pH	3.9	4.3
$Al3+$ (cmol /dm3)	1.00	1.4
$Ca2+$ (cmol /dm3)	0.00	0.07
$Mg2+$(cmol /dm3)	0.01	0.01
K (mg/dm^3)	13	52
P (mg/dm^3)	1	1.1
Organic matter (%)	4.35	2.68
Fe_2o_3(%)	16.1	9.8
AlO_3 (%)	4.35	23.78
SIO_2 (%)	11.7	20.49
TiO_2 (%)	29.26	0.89
P_2O_5 (%)	14.05	0.03

Table 2. Biomass and amount of Ca and P in eucalyptus trees 2 years old after planting at Carbonita and Bom Despacho as affected by sources and rates of phosphatic fertilizers.

Source	Dose	Carbonita		Bom Despacho	
		Ca	P	Ca	P
			Kg/ha		
ST	250	115.12	10.45	118.76	15.36
	500	118.29	11.97	112.89	17.77
	1000	169.19	19.48	149.75	20.85
	2000	184.89	19.83	180.14	25.98
PA	500	143.93	10.81	110.23	13.15
	1000	168.23	13.97	158.94	18.59
	2000	235.9	19.67	181.49	21.67
	4000	251.18	21.56	214.97	22.75
PP	500	119.79	9.18	115.46	16.04
	1000	130.79	10.45	118.87	13.67
	2000	184.00	13.09	127.70	14.35
	4000	252.76	18.70	166.94	15.63
CAR	1000	136.64	13.88	161.06	19.27
C	0	69.06	4.95	75.39	7.23

Increases in the amount of fertilizer applied does not show a corresponding increases in the values obtained in dry matter yield and the nutrient content values (Tables 2 and 3). This might be attributable to the fact that, crop response to fertilizer application depends not only on the level of available plant nutrients in the soil but also related to crop physiology and morphology (Baligar and Fageria,1997). Myungsu, et al., (2004) reported that levels of different pools of soil P have been affected not only by soil properties and climatic condition but also by rate and type of P applied. The values of dry matter unit in the canopy was 8,52% more in Carbonita than that of Bom Despacho. The value of nutrient units observed in the eucalyptus trunk was 1,02% more than that of Bom Despacho.

Table 3: Efficiency of P utilization for biomass production by eucalypt tree, 2. 5 years after planting as influenced by sources and rates of phosphatic fertilizers.

Treatment		Cover		Trunk	
PA	ST	Carbonita	Despacho	Carbonita	Despacho.
g/ha	g /hole	Unit of dry matter		Unit of Nutrient	
1000	0	1957	1222	5353	4260
1000	100	1450	1703	5194	5312
1000	200	1690	1374	4486	4953
1000	400	1158	1615	2992	5291
0	0	2425	1402	11232	8849

The highest biomass and calcium amount of the tree treated (Table 3) with PA were in the trend of 10,2% more than that of ST and 5,39% than PP at Carbonita, while treatment with ST gave the highest value for phosphorous content, 9% more than PA and 16,24% more than PP. At Bom Despacho, treatment with PA gave the highest value of calcium in the biomass while PP recorded the lowest values. The action organic chelates in solubilizing phosphates and phosphates minerals might attributes to formation of complexes with Ca, Fe, or Al thereby releasing the phosphate in water-soluble forms, hence more calcium being released (Stevenson and Cole,1999). ST contributes more to the phosphorous content in the biomass than does PA and PP. Its contribution was 1,76% and 9,39% higher than that PA and PP respectively. On the two sites, ST contributes more to the amount of P in the biomass while the natural phosphates (PA and PP) contribute to the higher amount of Ca. This may be attributable to the reactive nature of these P sources when applied into the soil; ST being water soluble is immediately available. PA and PP sources reacted with the soil solution with time, making P and Ca slowly available (Zaharah, et al.,1996). The content of calcium at Bom Despacho in the biomass was 0,71% less than that of Carbonita but the biomass content of phosphorous was 6,7% more at Bom Despacho after combined treatment of ST and PA were applied to eucalyptus (Table 4). Levels of different pools of soil P are affected not only by soil properties and climatic condition but also by rate and type of P applied (Myungsu, et al., 2004). This shows that phosphate dissolution was similar in both sites, but P fixation was higher at Carbonita.

Table 4: Biomass content of Ca and P in eucalyptus, two and half years after planting at Carbonita and Bom Despacho, as affected by increased rates of ST combined with Araxa phosphate rock.

Treatment		Carbonita		Bom Despacho	
PA	ST	Ca	P	Ca	P
kg/ha	g/cover	g/ha			
1000	0	149.06	12.22	128.86	15.45
1000	100	191.84	17.44	194.82	21.67
1000	200	175.9	18.52	201.78	22.93
1000	400	250.58	27.62	199.89	22.14
0	0	60.62	4.37	90.9	9.21

Though, phosphate uptake is strongly influenced by the nutrient availability and Pi status of plants, the low affinity transport system appears to be expressed constitutively in plants, whereas the high affinity uptake system is regulated by the availability of Pi (Furihata,et al.,1992) . Recovery efficiency of Ca and P by Eucalyptus grandis, 2.5 years after planting as influenced by combined and separate phosphate fertilizer sources are presented in table 5 and table 6 respectively. The efficiency of added fertilizer (NPK) is very low in acids soils. Also, the efficiency of nutrient acquisition, transport, and utilization by plants grown in soil is controlled by(i) the capacity of the soil to supply the nutrients and{ii}the ability of plants to absorb, utilize and remobilize the nutrients(Baligar and Fageria, 1997).

Calcium and P recovery efficiency in Carbonita was higher (19.23% and 9.35%) than in Bom Despacho Tree Ca recovery values at Carbonita was highest with ST treatment , 31.48% and 47.2% higher than that of PA and PP respectively (Table 6).On the other hand, PA gave the highest P values (30.79) recovered when compared with ST and PP that, with values 29.53% and 20.48% higher respectively. The trend in nutrient recovered in trees growing in Carbonita was equally repeated in Bom Despacho .ST gave the highest values (63.53%) of calcium as against 21.24% and 15.21% recorded for PA and PP respectively. The differences in P values recovered by ST were 6.28% and 10.61% over that of PA and PP. Comparatively, 12.57% of Ca was recovered more at Carbonita than that of Bom Despacho, but, the situation was different with P recovery. P values recovered at Bom Despaho, was 12.96% more that of Carbonita. The rates of calcium recovery indicated that the solubilization of natural sources of phosphorus was higher in Carbonita. In short, the natural phosphates utilization, and particularly PA, in reforestation with eucalyptus in the cerrado soils leads to considerable gains of growth; raised the levels of soil phosphorus, calcium and increase the potential of these soils to keep forest productivity in subsequent cycles, according to the estimate of nutrient cycling .The percentages of recovery of phosphorus and calcium were established throughout the dry matter produced in the aerial part of the plant, including organic matter. Therefore, the non- inclusion of the estimates of the P portion that would have returned to the soil from the decomposition of the organic matter will not influence the results of the recovery estimates, because these values are not enough to be expressive over a period of two years, especially for the fact that, it was accomplished through cultural method. However, immobilization of nutrients in the root system is usually high. Ferreira (1984) observed immobilization of P up to 12.9% in the roots of Eucalyptus grandis at 26 months old at Bom Despacho and 39% for 21 months old eucalypts at Carbonita. Thus, the non-inclusion of the estimates of root system in the estimates could lead to phosphorous recovery values being underestimated. Relative to the effect of rates, with the increase in supply of phosphorus, there was a reduction in the percentages of recovery, for all sources tested in both localities. Leal (1988) observed decrease in rates of recovery when the supply of NPK was combining with 1000kg/ha of rock phosphate or when phosphate alone was used and the rates was increased from 1000 to 2000kg/ha. Ballard (1978) cited by Prasad, et al., (1984), observed low rates of recovery of phosphorus by Pinus radiata ,and attributed it to the high phosphorus-fixing capacity of soils and justification of the higher doses required by the plant. The recovery of calcium was always higher than that of phosphorus. Thus, increasing the rates provided decrease in rates of recovery of calcium in two localities, for all fertilizers. Among locals, except for treatments with CAR, there was a higher recovery in Carbonita for all rates tested and fertilizers.

There was an inverse relationship between the amount of fertilizer applied and the recovery efficiency (Table 5). This is similar to the result reported by Muniz (1983) who found an inverse relationship between P utilization by soybean plants and the dose of P fertilizer. Estimates of overall efficiency of applied fertilizer have been reported to be about or lower than 50% for N, less than 10% for P, and about 40% for K (Baligar et al.,2001) Efficient plants in the absorption and utilization of nutrients greatly enhance the efficiency of applied fertilizers, reducing cost of inputs, and preventing losses of nutrients to ecosystems. The use of legumes in acid soils may be a strategy to improve P recovery from humid forest agro ecosystems. (Oikeh, et al., 2008).

Table 5. Recovery efficiency of Ca and P by Eucalyptus grandis, two and half years after planting at Carbonita and Bom Despacho, as affected by the combination of soluble and low soluble P – source.

Treatment		Carbonita		Bom Despacho	
PA	ST	Ca	P	Ca	P
Kg/ ha	g/hole	%			
1000	0	35.38	7.50	15.18	5.96
1000	100	41.66	6.44	32.99	6.14
1000	200	30.34	4.70	29.18	4.56
1000	400	37.25	4.67	21.37	2.66
0	0	_	_	_	_

Comparisons among fertilizers revealed that, the recovery efficiency of ST and PA were similar at Carbonita . This, is in agreement with the work of Szilas, et al., (2006), who reported that, except for the first season, where Minjinju phosphate rock (MPR) was slightly inferior to Triple super phosphate (TSP), direct application of MPR gave the same yields as TSP indicating that MPR can replace TSP on acid, severely weathered tropical soils low to very low in available P and exchangeable Ca and with high to very high phosphate adsorption capacity. The recovery of P by eucalypts was higher at Bom Despacho when compared with Carbonita.. This may be attributable to the best distribution of rain in the first site (Leal,1988). High moisture content in the soil facilitates the diffusion, transport and absorption of P by plants (Ruiz,1986).

Table 6: Eucalypt P and Ca recovery efficiency as influenced by different phosphate source and rates, 2.5years after planting at Carbonita and Bom Despacho, Brazil.

Source	Dose	Carbonita		Bom Despacho.	
		Ca	P	Ca	P
	Kg /ha	%			
ST	250	141.75	11.19	133.44	16.55
	500	75.75	7.15	57.69	10.73
	1000	77.03	7.40	57.19	6.93
	2000	44.55	3.79	40.29	4.77
PA	500	59.9	11.19	27.97	11.29
	1000	39.67	8.61	33.42	10.84
	2000	33.37	7.03	21.22	6.89
	4000	18.21	3.96	13.96	3.70
PP	500	40.59	8.07	32.06	16.81
	1000	24.69	5.25	17.39	6.15
	2000	22.99	3.88	10.46	3.40
	4000	18.37	3.28	9.15	2.00
CAR	1000	19.31	6.20	24.48	8.36
C	0	_	_	_	_

According to Smyth and Sanchez (1982), Calcium is a product of the dissolution of rock phosphate which liberation to the soil solution occurs in quantities below the rates at which phosphorus is released. According to these authors, while phosphorus is adsorbed on the surface or reacts with iron and aluminum to form compounds of lower solubility in the rock phosphate, calcium remains in the soil predominantly as exchangeable cation. Therefore, recovery rates of calcium can be interpreted as an estimation of the rock solubilization . From this reasoning, it could be inferred that the condition for phosphate solubilization in Carbonita, are more favourable as indicated by the greater recovery of calcium in this locality. Similarly, it can be inferred that the PP was less soluble than the other natural sources in both locations (Table 6). These observations confirm the estimates of solubilization and the increase of exchangeable calcium in soil and nutrient content of the total biomass. Moreover, the relationship between calcium and phosphorus was always higher in Bom Despacho which confirms the evidences on the passage of more P-labile to non-labile form in Carbonita, which was also observed by Leal (1988).

Conclusion.

Soil acidity, Fe and Al oxides increased the solubilization of phosphatic rocks as indicated by soil Ca content but reduced the availability of P to eucalypt.

Phosphates sources from indigenous phosphate rocks under specific conditions may supplement/replace the expensive imported P fertilizers, and allow a saving of much needed foreign exchange. Phosphate rocks fertilizers can be made to be agronomically effective and economically competitive to improve soil fertility for sustainable crop production in large areas of developing countries.

Acknowledgement

The authors acknowledge the scholarships as Post-doctor (the first author) and Research Productivity given by TWAS and CNPq.

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12/12/2011