PHOSPHATE FERTILIZATION OF *ACACIA MANGIUM*: RESIDUAL OF VARIOUS P-FERTILIZERS AND EFFECT ON UPTAKE OF OTHER ELEMENTS

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WAN RASIDAH ABDUL KADIR, AHMAD SAHALI MARDI & KHAIRUDDIN ABDUL RAHIM. 1993. Phosphate fertilization of *Acacia mangium* : residual of various p-fertilizers and effect on uptake of other elements. An isotope dilution technique, based on the uptake of labelled phosphorus (^{32}P), was used to measure the effectiveness of different P sources after incorporation into the soil under *Acacia mangium* plantation. The phosphate (P) sources tested were Christmas Island rock phosphate (CIRP), Moroccan rock phosphate (MRP), Jordanian rock phosphate (JRP) and triple superphosphate (TSP). Measurements were carried out at 6, 15 and 20 months after fertilizer application. Significant increment in foliage dry matter and P yield was obtained with JRP treated trees at 6 - and 15 - *mth* sampling. As for the whole tree, the contribution of dry matter weight initially comes mostly from foliage, but at later stages other parts contribute equally or higher. Application of P fertilizer increases the uptake of other nutrients, particularly N and K. The fraction of P taken up by the trees which was derived from fertilization with JRP and TSP decreased gradually with time. On the other hand, CIRP had a longer residual value. All fertilizers showed relatively comparable P availability for every equivalent unit of material after 20 months of application.

Key words: Phosphate fertilizers - residual - isotope technique - ^{32}P - *Acacia mangium*

WAN RASIDAH ABDUL KADIR, AHMAD SAHALI MARDI & KHAIRUDDIN ABDUL RAHIM. 1993. Pembajaan fosfat *Acacia mangium*: lebihan berbagai baja P dan kesan pengambilan elemen-elemen yang lain. Teknik isotop yang berasaskan kepada pengambilan fosforus berlabel ^{32}P, digunakan untuk mengukur keberkesanan beberapa baja P selepas dicampurkan dengan tanah di ladang *A. mangium.* Baja P yang dikaji adalah CIRP, MRP, JRP dan TSP. Data-data biojisim dan pengambilan P dianalisa pada 6, 15 dan 20 bulan selepas pembajaan. Terdapat peningkatan dalam berat kering daun dan pengambilan P pada 6 dan 15 bulan persampelan bagi pokok-pokok yang menerima baja JRP. Bagi keseluruhan pokok, berat kering pada awalnya paling tinggi dalam daun tetapi di peringkat akhir eksperimen, secara relatifnya berat untuk bahagian lain meningkat. Pembajaan P meningkat pengambilan nutrien lain terutamanya N dan K. Kadar pengambilan P oleh pokok yang diberi baja-baja JRP dan TSP berkurangan mengikut masa. Sebaliknya, CIRP mempunyai nilai lebihan yang panjang. Selepas 20 bulan pembajaan, kesemua baja memberikan nilai kesediaan P yang hampir sama bagi setiap unit bahan.

Introduction

Physiologically, P uptake by plants is governed by several factors such as uptake kinetics, root morphology and type of mycorrhizae present (Gardiner & Christiansen 1990). The major soil factor is the concentration of P in soil solution. The aluminium and iron oxide rich soils, particularly those Ultisols and Oxisols of the tropics, are well known for their low P availability due to high P-fixation (Easterwood & Sartain 1990).

With some changes in forest management towards agroforestry, it is undeniable that fertilization will constitute one of the major inputs for silviculture in the future. However, forest plantations usually require a cheap, low-input fertilizer strategy involving, for example, nitrogen fixing trees for N supply and perhaps slow release phosphate rock to supply P. There are many types of rock phosphates available commercially and those commonly used in Peninsular Malaysia include Christmas Island rock phosphate (CIRP), Jordanian rock phosphate (JRP) and Morrocan rock phosphate (MRP) (Chew 1990). Their efficiency in releasing P at different time intervals under forest plantation is the particular interest of this study. A comparison was made with the fast release acid soluble fertilizer, triple superphosphate (TSP).

Acacia mangium was chosen as a test crop because it constitutes about 90 % of the trees planted under the Compensatory Forest Plantation Programme in Peninsular Malaysia. On some of the sites, 120 *g* CIRP had been applied in the planting hole during transplanting, followed by a mixture of 120 *g* CIRP and 60 *g* TSP for the second year (Johari & Chin 1986). Little is known about the amount of these fertilizers utilised by the trees and no data have been documented on the availability of P after certain periods of time. Therefore, this study included an evaluation of the residual effect of P fertilizer two years after application.

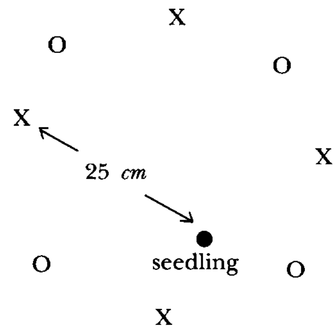
Materials and methods

Study area

Research was conducted in a 5-*mth*-old *A.mangium* plantation which had formerly been used to study the suitable P sources for the early growth of this species (Wan Rasidah *et al.* 1989). It is situated at Setul Forest Reserve in Negeri Sembilan. The annual rainfall distribution is between 2030 and 2290 *mm*. The area was formerly a natural forest which had received no artificial fertilization in the past. Site was prepared by clear felling followed by burning after the extraction of valuable logs. Soil was developed over granitic parent materials and is classified as Rengam series (Typic Paleudult).

Field experiment

The phosphate sources tested for this study were CIRP, MRP, JRP and TSP. They had been applied two weeks after transplanting at a rate of 200 *g* P per seedling, incorporated equally at four opposite spots (Figure 1). The distance was 25 *cm* from the seedling and depth 10 *cm* . Spacing was at 3.0 by 3.7 *m* distance, a normal planting density for this plantation. The experiment covered an area of 0.24 *ha.* To prevent termite attack, 30 *g* of heptachlor was broadcast around the bases of seedlings.



O ^{32}P - applied at 5, 14 and 18 months after planting

X P fertilizer - applied once after establishment

Figure 1. Fertilizer and radioactive P applications of one treated seedling

There were seven treatments for the present study (Table 1) and each plot consisted of one seedling. The design was completely randomised. Four replications were established for treatments T1 to T5 and six replications each for treatments T6 and T7. The latter two treatments were used to provide the tree biomass and nutrients concentration. Comparison was made with CIRP since it is the commonly used rock phosphate in the plantation. Two adjacent seedlings from each direction were used as guard rows.

Table 1. Phosphate application treatments with different sources

T1	T2	T3	T4	T5	T6	T7
^{32}P	^{32}P + CIRP	^{32}P + MRP	^{32}P + JRP	^{32}P + TSP	CIRP	UNFERT*

*UNFERT - Unfertilised plot.

To avoid tagging effect, ^{32}P was injected at four opposite spots, intermediate between P sources using the same distance and depth (Figure 1). An application of 0.75 *mCi* (2.78 x 10^7 *Bq*) ^{32}P per plant was given for the five-*mth*-old plantation. A second application of 1.25 *mCi* (4.73 x 10^7 *Bq*) ^{32}P per plant was made at 14 *mth* and an even higher activity, 5.00 *mCi* (1.85 x 10^8 *Bq*) ^{32}P per plant, was applied at 18 *mth* after planting. The radioactive used was carrier-free ^{32}P mixed with 1000 *ppm* potassium dihydrogen phosphate solution. The undergrowth was controlled manually by slashing each time before ^{32}P application.

Sampling and chemical analysis

Field sampling was carried out at 6, 15 and 20 *mth* after P fertilizer application, *i.e.* respectively one month, one month and two months after ^{32}P application. For the first two samplings, every fourth and fifth leaves were taken respectively for treatments T1 to T5. For the last sampling, foliar samples were collected from every fourth leaf out of every fourth branch. These samples were weighed and brought back to the laboratory for drying at 60° *C*, weighing, grinding, sub-sampling and dry ashing at 500° *C*. The aliquots from dry ashed samples were used to measure the P content using Scheel's method (Scheel 1936) and ^{32}P activity using liquid scintillation counter. Data for biomass and nutrients concentration of seedlings before transplanting were taken from an earlier study (Wan Rasidah *et al.* 1989).

For treatments T6 and T7, two trees were destructively sampled at each sampling and separated into different parts, *i.e.* leaves, branches and stems. Since the trees were large, sub-sampling was carried out both in the field (fresh) and in the laboratory (after grinding). The fresh and oven dry weights for each part were recorded. Roots were not taken due to the difficulty in sampling. Observation at 10 weeks after transplanting showed that roots constituted between 11.1 to 13.5 % of the total dry weight of the trees (Wan Rasidah *et al.* 1989). The above samples were subjected to nutrient analysis of N using Kjeldahl extraction and autoanalyser, P by dry ashing at 500° *C* and UV-spectrophotometer, and K, Ca and Mg by dry ashing, followed by atomic absorption spectrophotometer (Walinga *et al.* 1989). Analysis was carried out in triplicate.

Data analysis and calculation

Experimental data were statistically analysed using analysis of variance procedure and Duncan multiple range test. The data were also enumerated based on the equations of Zapata (1990), *i.e.*:

$$*\text{Pdf labelled source} = \frac{*\text{s. a. plant sample}}{\text{s. a. labelled P}}$$

where s. a. labelled source = s. a. labelled soil = s. a. plant in T1. Thus, Pdf labelled source = Pdf soil.

Since the trees were exposed to only two sources of P, *i.e.* soil and fertilizer, % Pdf unlabelled fertilizer was 100 minus % Pdf soil.

For relative comparison of the various phosphorus sources, the fractional utilisation relationship is used:

$$\frac{\%\ \text{Pdf unlabelled fertilizer}}{\text{Added amount of P fertilizer}} = \frac{\%\ \text{Pdf soil}}{X}$$

where X is the available amount of P in soil expressed as unlabelled fertilizer equivalent units.
(*Pdf - P derived from; s. a. - specific activity)

Results and discussion

Dry matter yield and P uptake

Foliage dry matter yield increased drastically after 15 months of fertilizer application and this was true for all treatments (Table 2). At every measurement period, the highest value was always recorded with JRP. The differences in the 6 - and 15 *-mth* sampling are statistically significant at p=0.05. The percentage increment for JRP was also very much higher at the above two samplings with the values of 124 and 106% respectively, compared to the 20-*mth* sampling which gave only 38 % increment. It is apparent that JRP fertilizer is effective in promoting foliage growth of *A.mangium.*

Similarly, the differences in P yield values are only significant for JRP treated trees, and at 6 - and 15 *-mth* sampling. The high uptake of P observed with this treatment could well be attributed to the higher solubility of this fertilizer compared to other rock phosphates used (Hammond & Day 1990). MRP and

Table 2. Dry matter yield and P concentration in the leaves of *Acacia mangium* as influenced by the residual of different sources of P

Time after application	Treatment	Dry matter yield (*g*)	Dry matter increment (%)	P yield (*mg* P/plant)
6 months	^{32}P	71.4 ab	-	314 a
	^{32}P + CIRP	68.2 a	-	307 a
	^{32}P + MRP	108.8 ab	52.3	406 ab
	^{32}P + JRP	159.7 b	123.6	846 b
	^{32}P + TSP	90.0 ab	26.1	810 ab
15 months	^{32}P	913 a	-	1136 a
	^{32}P + CIRP	1333 ab	46.0	1397 a
	^{32}P + MRP	1608 ab	30.1	2221 ab
	^{32}P + JRP	1878 b	105.7	2725 b
	^{32}P + TSP	1437 ab	57.4	1734 ab
20 months	^{32}P	5231 a	-	10216 a
	^{32}P + CIRP	5861 a	12.0	14917 a
	^{32}P + MRP	7008 a	34.0	15278 a
	^{32}P + JRP	7220 a	38.0	17506 a
	^{32}P + TSP	6729 a	28.6	17006 a

Means in the same column followed by the same letter are not significantly different at 5 % probability level.

TSP treated trees also showed relatively high differences in dry matter increment and P yield, but they are not significantly different ($p = 0.05$). After six months of application, heavy rainfall could have probably leached out most of the P from the acid soluble fertilizer, TSP.

With the exception of roots, foliage constituted the main component for dry matter weight of the tree at 6 *-mth* sampling (Table 3). At 15 - and 20-*mth* sampling, however, foliage dry matter was found to be the lowest among the three parts measured. Wood formation increases the ratio for stem dry matter while heavy branching as a result of no prunning in this experiment increases the dry matter ratio of branches. Differences between treatments are obvious only at the 6 *-mth* sampling. At the later two samplings, yields are comparable.

Foliar nutrient concentrations

Results for the chemical analysis of foliage samples are shown in Figure 2. Each bar is the average of samples from two treated plots. Phosphate fertilization caused some tendency towards increasing nitrogen content in the leaves, branches and stems at six months after application (Figure 2a). This increment occurred as a consequence of a higher amount of nitrogen being taken up by the roots. This phenomenon has been shown by many researchers (Van Kessel & Roskoski 1983, Davis 1991, Sanginga *et al.* 1991). In this study, nitrogen supply could have come either from the soil or fixation or both.

Surprisingly, despite luxurious supply of P to the soil, P concentrations in the trees were rather low (Figure 2b). The high soil P sorption measured (Wan Rasidah 1991) and a small quantity of readily available P in CIRP perhaps obstructed an excessive P uptake. Nevertheless, additional P resulted in higher P content particularly at the 6-*mth* sampling.

Sufficient supply of P also increased the level of K in the foliage (Figure 2c). Similar observations were obtained with magnesium and calcium contents, but only at 6-*mth* sampling (Figures 2d & 2e).

Residual fertiliser utilisation

Calculated data from ^{32}P experiment are presented in Table 4. Calculations were based on the equations described earlier, and with the assumptions that there is no isotope effect, *i.e.* P uptake from the labelled and unlabelled materials is the same; the applied ^{32}P is not fixed to any large extent and reflects available soil P, and the activity in the leaves reflects what is happening in the trees.

The fraction of P derived from fertilizer showed no clear pattern with MRP and CIRP, but decreased with time for TSP and, to some extent, JRP (Table 4). When comparing among treatments, significant differences at 5% probability level were obtained with TSP and CIRP treated trees at the 6 - and 15 *-mth* samplings, while JRP and MRP differed significantly with CIRP only at the 15 - *mth* sampling.

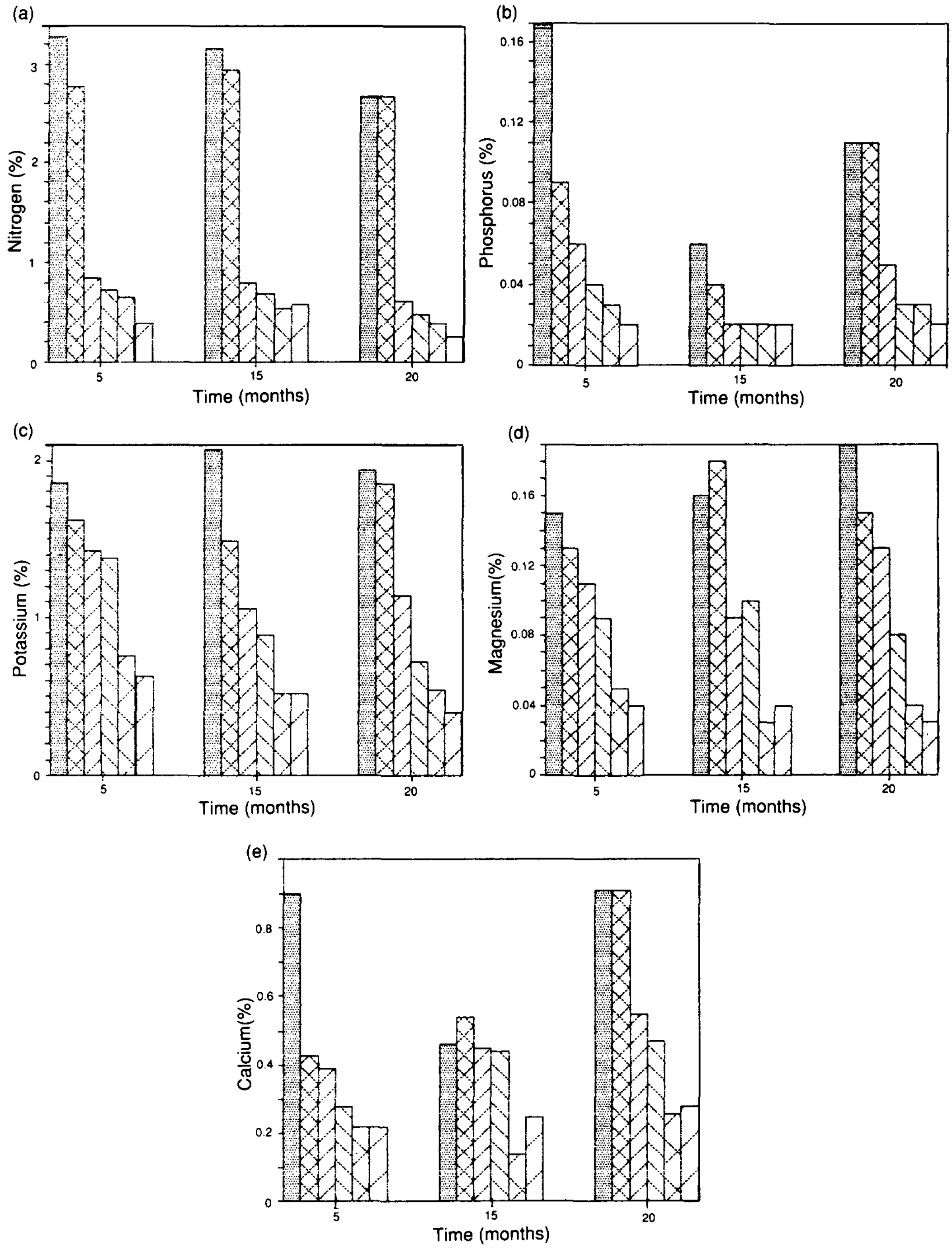


Figure 2. Elemental concentrations for different parts of the trees from P fertilized (T6) and non-fertilized (T7) plots

Leaf-T6 Leaf-T7 Branch-T6 Branch-T7
Stem-T6 Stem-T7

Table 3. Dry matter yield and P concentration in various parts of the tree of *Acacia mangium* as influenced by the residual of P fertilizer

Time after application	Treatment	Parts of tree	Dry matter weight (g)
6 months	T6 - CIRP	Leaves	312 ± 86.4
		Stem	279 ± 71.8
		Branches	164 ± 57.0
	T7 - control	Leaves	179 ± 48.8
		Stem	106 ± 27.7
		Branches	90 ± 32.6
15 months	T6 - CIRP	Leaves	1315 ± 196.0
		Stem	1509 ± 139.0
		Branches	1485 ± 182.5
	T7 - control	Leaves	1235 ± 104.5
		Stem	1380 ± 80.5
		Branches	1511 ± 193.0
20 months	T6 - CIRP	Leaves	7870 ± 275.5
		Stem	7666 ± 102.0
		Branches	8202 ± 293.0
	T7 - control	Leaves	6129 ± 202.5
		Stem	6334 ± 104.5
		Branches	7783 ± 344.5

Figures are means of two replications ± SE.

The X value data were used to calculate the relative values for quantitative comparison between various P sources, and the figures are presented in Table 5.

About 10 *g* of CIRP or 4.9g of MRP or 2.3 *g* of JRP are required to obtain a similar P availability as 1 *g* TSP after six months of application (Table 5). This shows that among the rock phosphates used, JRP has the highest soluble P. This could probably be associated with higher reactivity of this fertilizer which is 41 % soluble in dilute citric acid (Table 6). Nevertheless, this solubility is far lower than that of TSP which is 85-87 % soluble in water whereas JRP is insoluble (Hammond & Day 1990).

At 15-*mth* sampling, more than 7 *g* of CIRP is required to arrive at similar P availability as 1 *g* of TSP, while JRP and MRP need less than 2 *g*. It is apparent that CIRP is the most unfavourable P source at this stage. In terms of solubility, both CIRP and MRP have almost comparable figures (Table 6). Thus, other fertilizer characteristics such as chemical and mineralogical properties of phosphate rocks also have a major influence on the P availability. The difference is less pronounced after 20 months of P fertilizer application. This finding could well support the statement of Hammond and Day (1990) relating to the possibility that almost all of the P in rock phosphate is actually available, but over a longer period of time.

Table 4. The percentage of P derived from soil and fertilizer and the P-fertilizer equivalent unit (X) calculated for various sources

Time after application	Treatment	Pdf soil (%)	Pdf unlabelled fertilizer (%)	X value
6 months	^{32}P + CIRP	54.52 b	45.48 a	240
	^{32}P + MRP	36.02 ab	63.98 ab	113
	^{32}P + JRP	21.09 ab	78.91 ab	54
	^{32}P + TSP	10.23 a	89.77 b	23
15 months	^{32}P + CIRP	71.19 b	28.81 a	494
	^{32}P + MRP	33.33 a	66.67 b	100
	^{32}P + JRP	39.79 a	60.21 b	132
	^{32}P + TSP	25.23 a	74.77 b	68
20 months	^{32}P + CIRP	41.14 a	58.86 a	140
	^{32}P + MRP	47.90 a	52.10 a	184
	^{32}P + JRP	41.90 a	58.10 a	144
	^{32}P + TSP	37.20 a	62.80 a	119

Means followed by the same letter are not significantly different at 5 % probability level.

Table 5. Relative values for amount of P sources required to obtain similar utilisation by the trees

Time after P application	Relative values			
	CIRP	MRP	JRP	TSP
6 *mth*	10.44	4.91	2.25	1
15 *mth*	7.26	1.47	1.94	1
20 *mth*	1.18	1.55	1.21	1

Table 6. The solubility of rock phosphates in various solvents (after Hammond & Day 1990)

Phosphate rocks	1*N* ammonium acetate (neutral)	2 % citric acid	2 % formic acid
		Total P_2O_5 (%)	
Christmas island	11.4	28.6	34.3
Morrocan	14.5	24.3	34.3
Jordanian	13.2	40.9	66.2

Conclusion

Rock phosphates appear to require more than a year to be effectively utilised by the trees. Comparing the differences between all parameters measured, it is concluded that JRP is more effective compared to TSP in increasing dry matter production of *Acacia mangium,* even though it requires a greater amount of fertilizer to arrive at the same P availability as TSP. On the other hand, there is a tendency towards greater prolonged residual effects from CIRP.

No attempt was made in this study to evaluate the cost of fertilization, but as some unacidulated phosphate rock has shown comparable performance with acid soluble sources in biomass production, management can go for the lowest cost option.

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