Nutrient Cycling in Agroecosystems **47**: 93–98, 1997.

Evaluating the efficacy of various phosphate fertiliser sources for oil palm seedlings

A.R. Zaharah[1], H. Zulkifli[2] & H.A.H. Sharifuddin[1]
[1]*Department of Soil Science, Universiti Pertanian Malaysia, 43400 UPM, Serdang, Selangor, Malaysia;* [2]*Palm Oil Research Institute of Malaysia (PORIM), Persiaran Institusi, 43650 Bandar Baru Bangi, Selangor, Malaysia*

Received 25 July 1996; accepted in revised form 31 October 1996

Key words: L value, oil palm, phosphate rock, P uptake, ^{32}P isotope dilution

Abstract

Isotope dilution techniques were used in a glasshouse experiment to compare seven P sources for oil palm seedlings grown on Rengam series soil (Typic Paleudult). The P sources were triple superphosphate (TSP) and six phosphate rocks from North Carolina, USA (NCPR), Tunisia (Gafsa PR), Jordan (JPR), Morocco (MPR), Christmas Island (CIPR) and China (CPR). The percent P derived from fertilisers (%PdfF) in the 3, 6, 9 and 12 months of growth ranged from 81% to 99%, indicating the poor P supplying power of the soil used. TSP was far superior than PR in supplying the required P at all times of measurement. Total amount of P taken up during the 12 months growing period was equivalent to 15.0% of the added P as TSP, it was 5.2% from NCPR, 4.2% from JPR, 4.1% from MPR, 3.2% from GPR, 4% from CIPR and 2.2% from CPR. The PR effectiveness based on the amounts of fertilizer P taken up by the oil palm seedlings at 12 months of growth was in the sequence of triple superphosphate > North Carolina PR > Gafsa PR ≥ Jordan PR ≥ Morocco PR ≥ Christmas Island PR > China PR. This was due to the reactivity of these P sources when applied into the soil, triple superphosphate being water soluble is immediately available. PR sources reacted with the soil solution with time, making P slowly available. PR solubilised by neutral ammonium citrate (NAC) expressed as percentage of rock was shown to correlate better than 2% citric acid and 2% formic acid with plant P uptake. Thus this method of extracting P from PR can be used as a basis for comparing PR effectiveness to oil palm seedlings.

Introduction

Oil palms in Malaysia that are planted on highly weathered soils, such as Ultisols and Oxisols, are largely dependent on inorganic fertiliser applications to maximise and sustain high yield (Ng, 1986). Direct application of phosphate rocks (PR) to supply the P demand of the oil palm crop has been a standard practice since the 1930s. Since Malaysia does not have indigenous phosphate rock deposits, all the requirements are imported from various PR producing countries in the world. For the past five decades, the major source of supply has been from Christmas Island, but since the closure of the phosphate rock mine on Christmas Island in the late 1980's, phosphate rocks from other countries like Jordan, Morocco, Tunisia, China and United States of America have been imported to compete in the local market. These PRs differ in their mineralogical properties, thus their solubility and availability will also differ (Lehr and McClellan, 1972; Smyth and Sanchez, 1982). Various P fertilisers have been evaluated for oil palm under nursery and field conditions (Foster et al., 1988; Ng, 1986; Goh, 1994; Foong, 1993). Biological characteristics evaluated were plant growth, dry matter yield and P uptake. These characteristics are unable to differentiate between the P derived from soil and the P derived from fertiliser and contradictory results were reported concerning comparative measurement of agronomic efficiency of various P fertilisers under field conditions (Bolland and Gilkes, 1987; Ghosh and Gilkes, 1987; Stephen and Condron, 1986). Thus this experiment was carried out to evaluate the contribution of triple super phosphate and PRs from USA (North Carolina), Morocco, Tunisia, Jordan, Christmas Island

Table 1. Some chemical and physical properties of TSP and phosphate rocks used in the experiment

P sources	Total P (%)	Total Ca (%)	←Solubility as percent of rock→ 2% Formic acid (FA)	2% Citric acid (CA)	Neutral Am. Citrate (NAC)
TSP	20.4 ± 0.3	11.6 ± 0.4	43.3 ± 0.6	41.9 ± 0.9	40.3 ± 0.7
NCPR	13.1 ± 0.3	31.0 ± 0.7	24.7 ±0.2	12.1 ± 0.2	5.8 ± 0.1
GPR	13.4 ± 0.3	31.8 ± 0.6	20.8 ± 0.2	11.7 ± 0.1	5.0 ± 0.1
JPR	14.1 ± 0.3	32.6 ± 0.6	20.4 ± 0.1	10.8 ± 0.3	4.5 ± 0.1
MPR	14.4 ± 0.4	33.4 ± 0.4	17.9 ± 0.4	10.6 ± 0.1	4.4 ± 0.1
CIPR	14.5 ± 0.4	24.2 ± 0.9	11.6 ±0.3	9.3 ± 0.1	3.6 ± 0.1
CPR	14.7 ± 0.5	29.2 ± 1.2	8.0 ± 0.2	7.5 ± 0.1	2.7 ± 0.1

Table 2. Dry matter weight of oil palm seedlings accumulated during 0-3, 3-6, 6-9 and 9-12 months of growth (g/plant)

P sources	0 - 3 months	3 - 6 months	6 - 9 months	9 - 12 months	Total 0-12 months
TSP	2.0	19.6	17.9	31.6	71.1
NCPR	2.6	19.1	9.6	40.8	72.1
GPR	2.1	18.9	11.1	38.4	70.5
JPR	2.3	18.1	14.1	30.9	65.4
MPR	1.6	21.5	10.9	29.0	63.0
CIPR	1.0	21.3	14.2	31.1	67.5
CPR	1.4	19.9	13.0	21.3	55.8
LSD P=0.05	1.84	10.66	12.80	10.32	-
	n.s	n.s	n.s	**	-

and China to P taken up by oil palm seedlings grown in the nursery during the first year prior to field planting, using ^{32}P isotope dilution technique (Zapata and Axmann, 1995).

Materials and methods

The top 30cm of a Rengam series soil (Typic Paleudult) was collected, air dried and prepared for nursery planting of oil palm seedlings. The soil had a pH (water) of 4.5, organic carbon 1.2%, Bray-2 extractable P 5.0 mg/kg, exchangeable K 1.5 cmol(+)/kg, exchangeable Ca 0.7 cmol(+)/kg, exchangeable Mg 0.2 cmol(+)/kg, and cation exchange capacity 7.4 cmol(+)/kg. Textural analysis showed a clay content of 53%, silt 9% and sand 38%. The phosphate fertilisers tested were triple super phosphate (TSP), North Carolina phosphate rock (NCPR), Moroccan phosphate rock (MPR), Gafsa phosphate rock from Tunisia (GPR), Jordan phosphate rock (JPR), Christmas Island phosphate rock (CIPR), and China phosphate rock (CPR). The total P content in the phosphate fertilizer was 20.4% for TSP and ranged from 13.1% to 14.7% for PR's (Table 1). Fifteen kg of the soil was weighed and placed in each polythene bag. A total of 128 bags were prepared. The first 32 bags were thoroughly wetted with 20% solution (by weight) containing 1.0 x 10^{10} Bq ^{32}P with 5 mg P as carrier. The soil was allowed to incubate for a week. Then these soils were mixed with 4 g P as TSP, NCPR, MPR, GPR, JPR, CIPR and CPR in four replicates. The remaining four bags were left without any addition of P to be used as controls and to reflect the P derived from the soil. Three-month old seedlings were planted into each bag. These seedlings averaged 9.9 g dry weight and 11.77 mg total P content. Nitrogen at 2.94 g/bag, K at 3 g/bag and Mg at 2.34 g/bag were applied as urea, muriate of potash and kieserite at the beginning of the experiment. The plants were allowed to grow for 3 months. Another three sets using the same procedure were made and planted with 3-months old oil palm seedlings to be harvested at 6, 9 and 12 months after planting. For the set of plants to be harvested at 6 months after planting, the ^{32}P solution with

Table 3. Total P uptake accumulated by oil palm seedlings at different harvest times (mg/plant)

P sources	0 - 3 months	3 - 6 months	6 - 9 months	9-12 months	Total 0-12 months
TSP	31.6	159.4	208.8	214.0	613.8
NCPR	13.0	56.5	21.4	128.1	217.5
GPR	10.3	57.8	13.0	81.9	163.0
JPR	11.0	50.9	21.1	87.4	179.1
MPR	10.0	59.4	3.3	91.8	177.2
CIPR	6.6	61.8	3.5	95.1	176.9
CPR	7.1	44.4	1.7	54.8	105.9
LSD P=0.05	4.7	27.5	45.0	45.2	35.5
	*	**	**	**	**

5 mg P as carrier was added to thoroughly wet the soil in the bag after the first set was harvested. For the set to be harvested at 9 months after planting, ^{32}P solution was added after the harvest at 6 months, and for the set to be harvested at 12 months, ^{32}P was added after the harvest at 9 months. This had to be done due to the short half-life of ^{32}P (14.3 days), and it is impossible to measure for the whole year with just one application of ^{32}P at the beginning of the experiment. Similar amounts of N, K and Mg were applied to all these plants. Destructive sampling of the oil palm seedlings were made at 3, 6, 9 and 12 months after planting. The samples were cut into pieces and dried at 70°C . The dry matter weight accumulated during the period of 0 to 3 months, 3 to 6 months, 6 to 9 months and 9 to 12 months were calculated by substracting the total dry matter weights obtained at harvest minus the average dry matter weight obtained during the previous harvest. Five g of the dried samples were ashed at 500°C. The ash was cooled and dissolved in 20 ml *1M* HCl and filtered. ^{32}P activity of the sample was measured by Cerenkov counting using a liquid scintillation counter. Inorganic P in the samples was analysed using the method of Scheel (1934).

L values were calculated using the formula of Larsen (1952) which was thought to be a measure of the available soil P. The formula used was: $L = Q[(R/Q)/(r/p) - 1]$, where, R is the initial radioactivity, Q is the amount of carrier, r is the radioactivity in the plant and p is the quantity of P in the plant. Phosphorus derived from fertilisers (PdfF) by the plant was calculated using the isotope dilution formula described by Zapata and Axmann (1995), where:

PdfF (%) = 100 [1 - (specific activity of plants with fertiliser)/ specific activity of plants without fertiliser)]

PdfF (mg) = [PdfF (%) × Total P yield]/100

Results and discussion

Dry matter yield:

All fertiliser P sources gave similar accumulated dry matter weights during the first 3 months after planting (Table 2). This indicates that during the initial growth period, very little response to P fertiliser sources occured, even though the P taken up was significantly different ($p \leq 0.05$) between the water soluble P source (TSP) and the PR (Table 3). At 6 months, there was a ten-fold increase in dry matter yield accumulated during the 3 to 6 months growing period as compared to the first 3 months of growth, but did not show any significant differences ($p \leq 0.05$) between these P sources. At 6 to 9 and 9 to 12 months growing periods, the dry matter accumulation were not significant ($p \leq 0.05$) between the P sources. Thus plant growth response did not differentiate the effects of water soluble P source (TSP) and the PRs. Total P accumulated from TSP at 3 to 6 months growth period was three times greater than P from the PR . At 6 to 9 months of growth, CIPR, MPR and CPR had the lowest P accumulation. NCPR and JPR gave only 10% of the amounts provided by TSP, while GPR provided only 6% of the amounts provided by TSP, MPR and CIPR provided about 1.6% and CPR only provided 0.8% . Over the 12 months growth period TSP provided 3 times as much P as the PR sources. Among the PR tested, NCPR provided the most P, giving 30% of the amounts provided by TSP. CPR provided the least P giving 17% of the amounts provided from TSP. This is due to the mineral structure of the PR. NCPR has

Table 4. Specific activity of ^{32}P in plant tissue (Bq ^{32}P/μg P) and L value (mg P/kg soil) at different times of sampling

Time (months)	Treatments	specific activity (Bq/μP)	L value (mg P/kg)
3	Control	1.47 a	44.2 c
	TSP	0.06 c	1073 a
	NCPR	0.08 b	786 b
	GPR	0.10 b	779 b
	JPR	0.08 b	929 b
	MPR	0.11 b	636 b
	CIPR	0.10 b	670 b
	CPR	0.13 b	585 b
6	Control	1.47 a	66.7 c
	TSP	0.06 c	1358 a
	NCPR	0.16 b	467 b
	GPR	0.18 b	441 b
	JPR	0.20 b	367 b
	MPR	0.22 b	346 b
	CIPR	0.24 b	299 b
	CPR	0.28 b	227 b
9	Control	47.4 a	34.9 d
	TSP	0.05 c	3428 a
	NCPR	0.15 b	928 b
	GPR	0.15 b	935 b
	JPR	0.18 b	826 b
	MPR	0.23 b	674 bc
	CIPR	0.31 b	434 c
	CPR	0.47 b	394 c
9	Control	5.98 a	25 e
	TSP	0.06 c	2401 a
	NCPR	0.11 b	1238 b
	GPR	0.16 b	850 b
	JPR	0.19 b	726 b
	MPR	0.23 b	592 c
	CIPR	0.38 b	357 d
	CPR	0.27 b	491 cd

means in the same column followed by the same alphabet are not significantly different at $p \leq 0.05$

a higher carbonate substitution in its crystal structure, making the minerals less stable and easily reacted by the acids in the soil solution (Sale and Mokwunye, 1993; Chien and Menon, 1995; Chien, 1995). CPR is less reactive, and lower amounts of P are solubilised for plant uptake.

Labile P (L value) and Relative Agronomic Effectiveness

The L value of the untreated soil was 44 mg P/kg soil at 3 months, 66 mg P/kg soil at 6 months, 35 mg P/kg soil at 9 months and 22 mg P/kg soil at 12 months (Table 4). The L values decreased with time from 6 months to 12 months due to plant uptake of P by the oil palm seedlings. The addition of TSP increased the L value to almost 100 times the original soil L value at 9 months after TSP addition (Table 4). The availability of TSP

Table 5. P derived from fertilisers (percentage and mg/plant) in oil palm seedlings at different times of harvest

P sources	←——PdfF (%)			——→	←——PdfF (mg/plant)				——→
	3 months	6 months	9 months	12 months	3 months	6 months	9 months	12 months	Total
TSP	94.83	96.13	98.73	99.02	29.95	153.40	206.01	211.88	601.24
NCPR	93.14	89.17	96.34	98.22	12.10	50.53	20.58	125.82	209.03
GPR	92.34	87.67	96.39	97.41	9.48	50.44	12.57	79.84	152.33
JPR	93.05	86.64	95.63	96.90	10.20	43.86	20.50	84.79	167.46
MPR	91.16	84.83	94.44	96.26	9.06	50.13	3.71	88.36	163.09
CIPR	91.87	83.79	92.32	93.72	6.05	51.70	3.06	89.30	159.40
CPR	89.43	81.17	88.58	95.48	6.31	35.15	2.03	52.35	100.95
LSD P=0.05	24.98	35.01	16.69	16.46	4.62	24.61	42.02	43.78	35.46
	n.s	n.s	n.s	n.s	**	**	**	**	**

remained high even at 12 months after TSP application. Among the PR tested, NCPR gave the highest L value followed closely by GPR. Thus these highly reactive PR provided available P upon contact with this acid soil. Phosphorus availability in NCPR treated soil was highest amongst all the PR tested at 12 months after PR application. This increase in soil available P due to the addition of NCPR and GPR is also shown in the specific activity of ^{32}P found in plant tissues (Table 4), where at all times of sampling, NCPR and GPR treated plants had lower counts than CPR, CIPR, MPR and JPR treated plants due to the dilution of the ^{32}P activity in the soil with the P released from solubilization of these two PRs. From the L values obtained at 12 months, the effectiveness of these PR sources in releasing P can be ranked as NCPR = GPR = JPR > MPR>CIPR>CPR. These results show that P was still available 12 months after PR and TSP application, which is contradictory to some studies which conclude that a significant fraction of added P becomes almost unexchangeable (Larsen, 1967; Barrow, 1974). The relative agronomic effectiveness of PR showed that there were no significant difference ($p \leq 0.05$) between these PR sources for the first 6 months of plant growth. At 9 months, NCPR, GPR and JPR were equally as effective. At 12 months NCPR was seen to be far superior than all the other PR tested, and it is still about 50% as effective as TSP.

Table 6. Correlation coefficient (r^2 values) of solubility tests with P uptake by oil palm seedlings grown for 12 months

Variable	r^2 value
2% formic acid (as % of rock)	0.88 *
2% citric acid (as % of rock)	0.90 *
Neutral ammonium citrate (as % of rock)	0.92**

*significant at $p \leq 0.10$
**significant at $p \leq 0.05$

Phosphorus derived from fertiliser (PdfF)

The P-32 specific activity present in the plant samples in the control and treated palms were used to calculate the%PdfF following the formulas described by Zapata and Axmann (1995). More than 90% of the total P present in the palms were derived from the fertilisers tested at all stages of growth (Table 4), showing the inadequate P supply present in the soil used. Soils in Malaysia are very deficient in P and plants cannot grow to maturity without P fertiliser application (Owen, 1953; Fuad, 1976). The total P in the palms at various stages of harvest was calculated and showed that TSP supplied the highest amount of P to the palms at 601.2 mg P for 12 months growth period (Table 5). This corresponded to 15.0% of the total amount of P added at the beginning of the experiment. Among the PR tested, NCPR had the highest PdfF at 208.4 mg P/palm followed by GPR at 160.5 mg/palm. JPR, MPR and CIPR had equivalent PdfF values, while CPR showed the lowest value of 86.1 mgP/palm. Fertiliser use efficiency of the PR ranged between 5.2% for NCPR to 2.2% for CPR.

Relationship between PR solubility to plant P uptake

The magnitude of PR solubility in 2% formic acid (FA), 2% citric acid (CA) and neutral ammonium citrate (NAC) expressed as percent of rock has been shown by Chien (1995) to be more related to chemical reactivity of PR than if the values obtained were expressed as percent of total P content. The latter expression gave misleading comparison especially for PR with low total P content (Chien and Hammond, 1978). Correlation coefficients obtained when the three methods of PR solubility tests were correlated to plant P taken up showed that neutral ammonium citrate gave the best r^2 value (Table 6). Chien and Hammond (1978) using bean as the indicator plant, obtained better r^2values when P uptake by bean was correlated with neutal ammonium citrate compared to 2% citric acid and 2% formic acid.

Conclusions

Dry matter yields obtained due to high P application did not indicate the effectiveness of a particular P fertiliser source on growth oil palm seedlings. The use of the isotope ^{32}P has made it possible to differentiate the P made available from the original soil and the fertiliser P sources. The effectiveness of these P sources used for oil palm planting was ranked in the order of NCPR $>$ GPR $\geq$ JR $\geq$ MPR $\geq$ CIPR $>$ CPR. This ranking is similar to the ranking made from the solubility of these PR by 2% formic acid, 2% citric acid or neutral ammonium citrate expressed as percentage of rock. Correlation coefficients obtained when these three solubility tests with plant P uptake showed that neutral ammonium citrate correlated better to plant P uptake than formic acid or citric acid.

Acknowledgements

The authors wish to thank the International Atomic Energy Agency for granting the Research Contract, Government of Malaysia for jointly financing this project under IRPA, and Universiti Pertanian Malaysia for all the facilities to carry out this research.

References

Barrow NJ (1974) The slow reaction between soil and anion: 1. Effect of time, temperature and water content of a soil on the decrease in effectiveness of phosphate for plant growth. Soil Sci 118: 380–386

Bolland MDA & Gilkes RJ (1987) How effective are Calciphos and Phosphal. Fert Res 12: 229–239

Chien SH (1995) Chemical, mineralogical and solubility characteristics of phosphate rocks for direct application. In: Dahanayake K et al. (eds) Proc Inter Workshop on Direct Application of Phosphate Rock and Appropriate Techology Fertilisers in Asia: What Hinders Acceptance and Growth, pp 49–58 Inst Fundamental Studies, Sri Lanka and Inter Fert Devt Centre, Muscle Shoal, Alabama, USA

Chien SH & Menon RG (1995) Factors affecting the agronomic effectiveness of phosphate rock for direct application. Fert Res 41: 227–234

Chien SH & Hammond LL (1978) A comparison of various laboratory methods for predicting the agronomic potential of phosphate rocks for direct application. Soil Sci Soc Amer J 42: 935–939

Foong SF (1993) Comparative efficacy of various rock phosphates on the growth of oil palm seedlings using radio-isotope and conventional techniques. 1993 PORIM International Palm Oil Congress, Kuala Lumpur: 625–638

Foster HL, Tarmizi AM, Tayeb MD & Zin ZZ (1988) Oil palm yield responses to P fertiliser in Peninsular Malaysia. PORIM Bull 17: 1–8

Fuad A (1976) Distribution of phosphate in six Malaysian soils. BSc Project Report. University of Malaya, Kuala Lumpur, Malaysia

Ghosh AK & Gilkes RJ (1987) The initial and residual agronomic effectiveness of some Indian, USA and Australian PR. Fert Res 12: 201–218

Goh KJ, Chew PS & Teo CB (1994) Maximising and maintaining oil palm yields on commercial scale in Malaysia. Proc Inter Planters Conf on Management for Enhanced Profitability in Plantations, 1994. Inc Soc Planters, Kuala Lumpur, Malaysia. pp 121–142

Larsen S (1967) Soil phosphorus. Adv Agron 19: 151–120

Larsen S (1952) The use of ^{32}P in studies on the uptake of phosphorus by plant. Plant and Soil 4: 1–10

Lehr JR & McClellan GH (1972) A revised reactivity scale for evaluating PR for direct application. Bull Y-43, TVA National Fertiliser Development, Muscle Shoals, Alabama, USA

Ng SK (1986) Phosphorus nutrition and fertilisation of oil palm. Oleagineux 41: 307–313

Owen G (1953) Determination of available nutrients in Malayan soils. J Rub Res Inst Malaya 14: 109–120

Sale PWG & Mokwunye AU (1993) Use of phosphate rocks in the tropics. Fert Res 35: 33–45

Scheel KC (1936) Calorimetric determination of phosphoric acid in fertilisers with the Pulfrich photometer. Zeitschrift für Analytische Chemie 105: 256–269

Smyth FJ & Sanchez A (1982) PR dissolution and availability in Cerrado soils as affected by phosphorus sorption capacity. Soil Sci Soc Am J 46: 339–345

Stephen RC & Condron LM (1986) An assessment of the agronomic efficiency of partially acidulated PR fertilisers. Fert Res 10: 269–282

Zapata F & Axmann H (1995) ^{32}P isotopic techniques for evaluating the agronomic effectiveness of rock phosphate materials. Fert Res 41: 189–195