ISSN:
Malaysian Journal of Soil Science Vol. 1: 13-20 (1997) Malaysian Society of Soil Science

Assessment of the Availability of Phosphate to Corn (*Zea mays* L) Using ^{32}P Isotope Dilution Technique

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ABSTRACT

This study investigates the effectiveness of two phosphate rocks (PRs), an unreactive phosphate rock from China (CPR) and a reactive phosphate rock from North Carolina, USA (NCPR) compared to triple superphosphate (TSP), a highly water-soluble phosphate fertilizer. These fertilizers were tested using three crops of corn (*Zea mays* L) grown consecutively on a Serdang series soil (Typic Paleudult). ^{32}P isotope dilution technique was used to assess their P availability. The rate of P used was 100 kg P ha^{-1}, applied once at the beginning of the experiment. NCPR was as efficient as TSP in providing P to the first crop, while CPR showed the lowest percentage of utilization. In the second crop, NCPR was the superior source of P. However, in the third crop all three sources showed very poor percentages of utilization. The total amount of P taken up by the three crops of corn was 13.65, 18.04 and 8.56 kg P ha^{-1} from TSP, NCPR and CPR respectively. Thus this study suggests that NCPR is an effective source of P for corn and can be used as a substitute for the water-soluble phosphate fertilizers. CPR is not a suitable phosphate source.

Keywords: phosphate rock, isotope dilution, specific activity, relative availability

INTRODUCTION

Phosphate rocks (PRs) have been used almost exclusively as the P source for plantation crops in Malaysia, and have been found to be suitable in providing the P required by crops such as rubber and oil palm (Middelton and Pushparajah 1966; Chan 1981). The primary type used previously was Christmas Island phosphate rock. After the closure of the Christmas Island phosphate rock mine in 1987, Malaysia began importing PR from Jordan, Morocco, China and recently, North Carolina, USA. Many comparisons of the effectiveness of PRs versus water-soluble phosphates for short-term crops have shown that PR materials are not economic substitutes for water-soluble phosphates (Yeates and Allen 1987; Zaharah *et al.* 1989), though occasional reports to the contrary are also found (Sanchez and Uehara 1980). This paper reports the findings on P utilization from two PRs (NCPR and CRP) compared to TSP by three crops of sweet corn grown

successively on a Serdang series soil (Typic Paleudult) using the ^{32}P isotope dilution technique (Fried 1954; Kucey and Bole 1984).

MATERIALS AND METHODS

The field experiment was conducted on a Serdang series soil (clayey, kaolinitic, isohyperthermic Typic Paleudult) at Universiti Pertanian Malaysia farm. Some properties of the surface soil (20 cm) are: pH 5.25 (1:2.5 soil:water w/v), total nitrogen 0.09%, $NaHCO_3$ extractable P 13.55 mg kg^{-1}, and exchangeable K, Ca and Mg of 2.29, 0.39 and 1.26 cmol kg^{-1} soil respectively.

The phosphate fertilizers evaluated were triple superphosphate (TSP), North Carolina phosphate rock (NCPR) and China phosphate rock (CPR). Particle size of the PRs as determined by dry sieving showed distribution of 97.2% in the 0.1 - 0.5 mm size, 2.2% in the 0.5 - 2.0 mm size and 0.6% in the <0.1 mm size for NCPR; for CPR 95.2% was in the <0.2 mm size and 4.8% in the 0.2 to 1.0 mm size. The majority (98.34%) of the TSP particles were between 1.0 mm - 5.0 mm, with only 1.6% in <1.0 mm size. Total P of these fertilizers was determined by digesting 2-g samples with 30 ml 18% $HClO_4$ for 3 hours until white fumes appeared. The solution was transferred and made up to 250 ml with distilled water. P was determined by the ascorbic acid method. Total P content was 20.4% for TSP, 13.1% for NCPR and 14.7% for CPR.

Analytical grade KH_2PO_4 was used as the carrier for the ^{32}P isotope. The amount used as carrier was 2 g P with 7.4 Bg ^{32}P m^{-2}. This was applied in 2 litres of solution spread evenly in the centre 2 m^2 of each treatment plot of 5 m x 4 m. The ^{32}P-labelled area was allowed to equilibrate for one week, after which time the various P sources were applied at the rate of 10 g P m^{-2} in the planting row.

Nitrogen was applied in the form of urea at the rate of 120 kg N ha^{-1} and potassium in the form of muriate of potash at the rate of 150 kg K ha^{-1}. Both fertilizers were applied in split application, one half at planting and the other half 30 days after planting. Corn seeds were planted in rows 75 cm apart at a distance of 25 cm within the row. Each treatment had four replications arranged in a randomized complete block design. All the plots were irrigated twice a day on non-rainy days. Harvesting was done 65 days after planting. The centre 5 plants of the labelled area were taken and separated into leaves, stem, flower and cobs, and weighed. These were oven dried at 65°C until constant weight was achieved, ground and analysed for ^{32}P activity and inorganic P content. Yield for each plot was taken from the 9 centre plants of the centre 5 rows.

RESULTS AND DISCUSSION

Dry Matter Yield

Due to the high initial extractable P in the soil and the application of 2 g P as KH_2PO_4 m^{-2} as carrier to the P-32 solution at the onset of the experiment, it was found that there was no significant difference in the total dry matter yield obtained in the treated and the control plots for all three crops (Table 1). The same observation was made on the fresh cob yield as well as the total P uptake by the corn crops (Tables 2 and 3). This was a desirable situation since it ensured that plants in the control plots were not restricted by their root growth from exploiting all the available P in the soil system.

TABLE 1
Dry matter yield of corn crops (kg ha^{-1}) for various treatments

P source	0 kg P ha^{-1}			100 kg P ha^{-1}		
	corn 1	corn 2	corn 3	corn 1	corn 2	corn 3
TSP	4311a	4561a	4972a	4417a	6373a	4802a
NCPR	4203a	6733a	4177a	4599a	6071a	4615a
CPR	3925a	4790a	3363a	4463a	7202a	4652a

Means in a column followed by the same letter are not significantly different at P=0.05

TABLE 2
Fresh cob yield (kg ha^{-1}) for various treatments

P source	0 kg P ha^{-1}			100 kg P ha^{-1}		
	Corn 1	Corn 2	Corn 3	Corn 1	Corn 2	Corn 3
TSP	7754a	7459a	6693a	7357a	7767a	6640a
NCPR	7052a	6781a	6010a	8824a	6685a	6742a
CPR	6939a	5618a	5347a	8139a	7152a	6728a

Means in a column followed by the same letter are not significantly different at P=0.05

TABLE 3
Total P taken up by corn (kg ha^{-1})

P source	0 kg P ha^{-1}			100 kg P ha^{-1}		
	Corn 1	Corn 2	Corn 3	Corn 1	Corn 2	Corn 3
TSP	14.19a	14.19a	15.64a	14.43a	19.22a	15.34a
NCPR	13.46a	27.95a	10.83a	15.11a	22.71a	16.27a
CPR	14.35a	16.26a	10.68a	13.27a	20.12a	16.16a

Means in the same column followed by the same letter are not significantly different at P=0.05

TABLE 4
^{32}P specific activity (dpm $5g^{-1}$ tissue) for various parts of corn plants

P source	0 kg P ha^{-1}				100 kg P ha^{-1}			
	Flower	Leaf	Stem	Cobs	Flower	Leaf	Stem	Cobs
CORN 1								
TSP	244	248	574	334	181	179	197	158
NCPR	216	219	312	360	210	194	195	235
CPR	209	228	288	241	231	231	255	234
CORN 2								
TSP	725	1236	1006	940	905	771	762	530
NCPR	779	1257	1014	559	462	433	587	416
CPR	914	838	1022	1325	625	993	527	629
CORN 3								
TSP	–	605	606	581	–	658	555	585
NCPR	–	751	552	747	–	711	775	770
CPR	–	775	820	786	–	783	849	723

^{32}P Specific Activity in the Corn Plants

Table 4 shows the specific activity values of ^{32}P in the various plant parts for the three corn crops. In crop 1, the specific activity in the corn fertilized with TSP was much lower than in the control plots, showing the dilution of the ^{32}P isotope with the P taken up from the applied TSP. The percentage of P in the plant derived from the fertilizer (%Pdff) was calculated using the equation:

$$\%Pdff = 1 - \frac{\text{specific activity (treated plots)}}{\text{specific activity (control plots)}} \times 100$$

The percentage of P derived from TSP was found to be concentrated mainly in the cobs (52.69%), stem (47.33%), leaf (27.82%) and flowers (25.82%). The P derived from NCPR was found to be highest in the stem (37.50%) followed by the cobs (34.7%), leaf (11.42%) and flowers (2.78%). P derived from CPR was found only in the stem (11.46%) and the cobs (2.9%).

In the second corn crop, fertilizer P was still made available from the TSP, NCPR and CPR applied. This is seen from the specific activity values in the various plant parts that are lower than the specific activity values of the control plots. In crop 3, only 8.45% of the plant P was found to be derived from TSP, 1.78% from NCPR; no P was detected from CPR.

The total percentages of P derived from fertilizers (%PdfF) for the three crops are shown in *Fig. 1*. These values, when multiplied by the total P taken up by the crop, give the total amount of P taken up by the crop contributed by the fertilizers applied. The total amounts of fertilizer P used by the three corn crops were 13.65, 18.04 and 8.56 kg ha^{-1} for TSP, NCPR and CPR, respectively (*Fig. 2*).

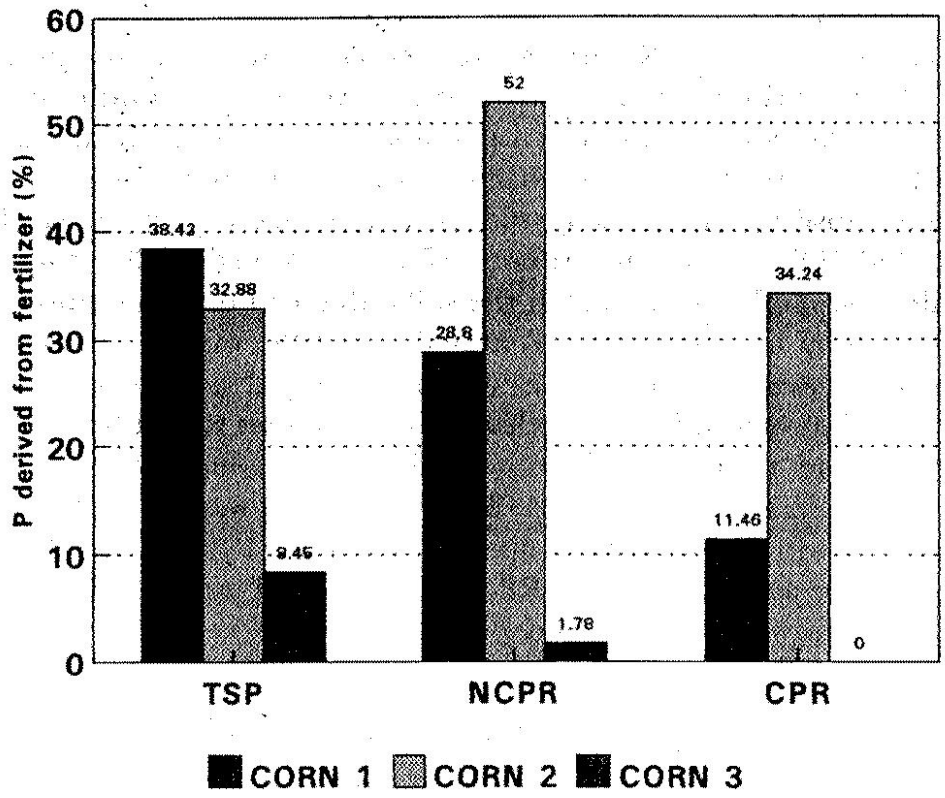

Fig. 1: Percentage of P derived from the P fertilizers tested

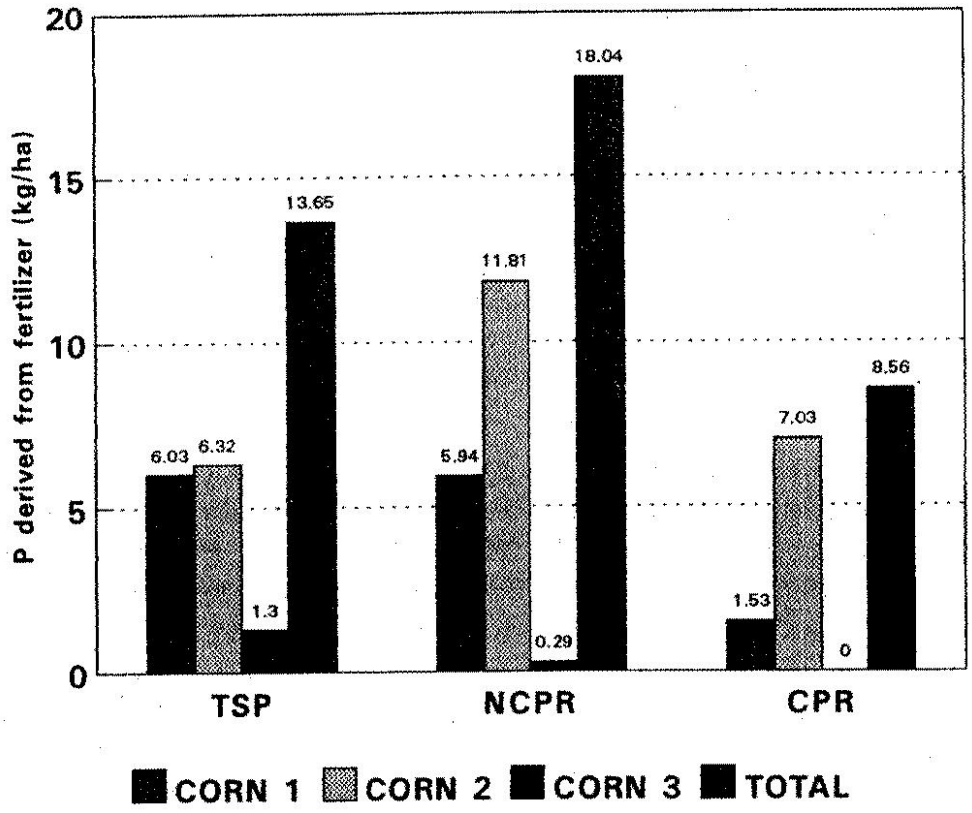

Fig. 2: P uptake (kg ha^{-1})

It was found that NCPR and TSP were equally effective in the first crop and NCPR was more effective than residual TSP in the second crop. CPR was an ineffective source of P for crops 1 and 3, and was as effective as TSP in crop 2. The effectiveness of NCPR can be attributed to the effect of carbonate substitution in its crystal structures (Anderson *et al.* 1985; MacKay *et al.* 1986; Yeates and Allen 1987). Even though NCPR contained little water-soluble P, the acidity in the soil enhanced the dissolution of its crystals, thereby increasing the P availability. CPR on the other hand, being a non-reactive fluoroapatite, was not as rapid in its dissolution as NCPR, such that very little P was released into solution to be utilized by the corn crop. The results obtained for CPR were consistent with those reported by Bolland (1985) and Bolland and Bowden (1986), which indicated the low effectiveness of apatites with low carbonate substitution.

The relative availability of NCRP and CRP to TSP was calculated using the following formula (Kucey and Bole 1984):

$$\text{relative availability} = \frac{\text{P derived from phosphate rock}}{\text{P derived from TSP}} \times 100$$

In the first crop, NCPR had a relative availability of 98.5% compared to 2.5% for CPR. The relative availability of NCPR and CPR increased by 187% and 111% respectively in the second crop. In the third crop, the values were 22.3% for NCPR and 0% for CPR. This shows that TSP, which consisted mainly of the water-soluble P, reacted with the soil constituents over time and became less available to plants, while NCPR and CPR were continuously dissolved by the soil acidity, making P available to the second crop. A similar observation was made by Zaharah and Sharifuddin (1990) with the residual values of various grades of Christmas Island phosphate rocks. But in the third crop, both the phosphate rocks were no more effective.

CONCLUSION

This study indicated that North Carolina phosphate rock dissolution in acid tropical soil was rapid and this phosphate rock was as effective as TSP in promoting corn growth for the first and second crops. China phosphate rock tended to be a poor source of P for short-term crops such as corn.

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