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# Fertilizer and soil P uptake by paddy rice, as affected by soil P level, source and date of application

BY G. L. TERMAN AND S. E. ALLEN

*National Fertilizer Development Centre,*
*Tennessee Valley Authority Muscle Shoals, Alabama, U.S.A.*

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## SUMMARY

A greenhouse pot experiment was conducted with paddy rice (*Oryza sativa* L. var. 'Nato') grown on Mountview silt loam at its initial low P level and on this soil receiving preplant unlabelled P applications (medium and high soil P levels). Labelled granular CSP (concentrated superphosphate) alone, a 2/1 mixture of CSP and DCP (dicalcium phosphate) and a 1/2 CSP-DCP mixture were evaluated.

Dry-matter yields and tillering increased markedly with amount of applied P on the low P soil, and slightly on the medium P soil; there was no response on the high P soil. Response decreased with decrease in water solubility of the applied P at the low and medium soil P levels. Total uptake of P by rice showed similar trends, except that uptake increased significantly with amount of P applied at the medium soil P level.

Percentages of plant P from the labelled fertilizer and uptake of fertilizer P increased in all situations with amount of applied P, decreased with decrease in water solubility of the applied P, and decreased with increase in soil P level. Uptake of soil P increased markedly with increase in soil P level. Soil labelling was much less satisfactory than fertilizer labelling for evaluating the effectiveness of P in different fertilizers.

A solution of labelled CSP was applied in a second experiment at time of transplanting and 3 or 6 weeks later. On the low P soil, yields, P uptake and tillering increased with rate of applied P but decreased with later date of application. On the medium P soil, yields, tillering and uptake of P by the grain were rather similar among treatments. Uptake of P in the foliage and mature straw, however, increased with later date of application. These results indicate that late-applied P is readily absorbed by rice but is not effective for increasing yields.

## INTRODUCTION

In a previous study (Terman & Allen, 1969) rather high levels of soil P were found essential for rapid early growth of maize (*Zea mays* L.), even though rather high applications of soluble P were made at planting. On low P soil with marked yield response to applied P, yield of dry forage, total uptake of P or uptake of fertilizer P were equally satisfactory for evaluating various labelled P sources. At medium to high soil P levels with little or no yield response to applied P, only uptake of fertilizer P was a suitable criterion for source evaluation. Granular water-soluble P sources provided the most available P for maize at both low and high soil P levels.

Satisfactory evaluation of unlabelled P sources for paddy rice was found possible (Terman, Allen & Engelstad, 1970) only on soil very low in acid-soluble P. In this study granular P sources high in water solubility were most effective for increasing tillering and yields of rice. Maximum yields were obtained at much lower rates of applied P than is true for most upland crops. Because of the lower response to P by paddy rice on most rice soils, very little data have been reported which are satisfactory for evaluating P sources for rice. Sources varying widely in availability for upland crops may all supply adequate P for rice under conditions of low response to applied P.

Satisfactory labelling of some P fertilizers is difficult, if not impossible. Fried (1954) evaluated natural rock phosphates in terms of 'A' values based on application of a $^{32}$P-labelled standard source to the soil. Another method that has been used to evaluate unlabelled P sources, especially under conditions of low yield response to applied P, is to attempt to label the soil P by addition of carrier-free $^{32}$P (Hall & Baker, 1967). Results with these

indirect methods of measuring uptake of P from various P sources might be in error if the P sources or limited crop capacity to absorb P caused variation in the utilization of soil P. Crop utilization of soil P usually varies with levels of applied and soil P. No results of direct comparison of fertilizer and soil labelling were found in the literature.

Some doubt seems to exist as to whether all of the P fertilizer for rice should be applied before planting. The best time might depend on soil P level, P content of the transplants, amount of applied P and other factors.

Objectives of the present experiments were: (1) to evaluate granular P fertilizers for paddy rice on soil varying widely in level of soluble P, (2) to compare fertilizer and soil labelling with $^{32}P$, and (3) to determine if fertilizer P applied after transplanting is effective for rice production.

## MATERIALS AND METHODS

### *Experiment* 1

Mountview silt loam, an acid (pH 5·0) infertile upland soil (Lawrence County, Tennessee), was used for the experiments. To each 5 kg lot of soil/pot the following were added 6 weeks before flooding and transplanting rice seedlings: *low P soil* (initial P level)—4·0 g of a 2 to 1 mixture of $CaCO_3$ and $MgCO_3$, 100 mg of N as $NH_4NO_3$, 300 mg of K as KCl, and adequate micronutrients. *Medium P soil*—the same as for the low P soil plus 200 mg of P as a 1 to 1 mixture of fine concentrated superphosphate (CSP) and dicalcium phosphate (DCP). *High P soil*—the same as for the low P soil plus 1000 mg of P as the CSP–CDP mixture. After mixing, the soils were allowed to react in a moist state in the greenhouse. Then 400 g of N as $(NH_4)_2SO_4$ and 400 mg of N as urea were mixed/pot. Rates of P of 0, 50, 100 and 200 mg as follows were also mixed per pot:

*Series* 1, *labelled P sources*. Granular CSP and DCP were labelled and the following lots prepared: CSP alone, a 2 to 1 CSP–DCP mixture and a 1 to 2 CSP–DCP mixture. These sources contained 91, 64 and 30% of the total P in water-soluble form, respectively. Each was pressed into tablets, crushed and −6+9 mesh granules sieved out. Each lot had a specific activity of 0·34 mCi/g of P at time of transplanting rice.

*Series* 2, *labelled soil*. A 1750 g lot of soil was labelled with 12·5 mCi of $^{32}P$ by wetting, mixing and drying. Ten g lots of the labelled soil, together with unlabelled −6+9 mesh granules of CSP alone, 2 to 1 CSP–DCP, and 1 to 2 CSP–DCP, were mixed with 5 kg lots of soil. The labelled soil activity was equal to that in 200 mg of labelled P applied in series 1.

The soil was then placed in pots and flooded. Nato rice plants grown in sand without applied P for 3 weeks were transplanted the following day (21 March 1969). The plants were placed in four hills of three plants each.

The crop was grown under continuous flooding and harvested 9 May at the early heading stage of development. After drying, weighing and grinding, 2·0 g samples of the top growth from each pot were briquetted under 20000 p.s.i. and activity counts made in a gas-flow beta counter. Total P content of the plant samples was then determined by a vanadate photometric method.

For the fertilizer-labelled series, the percentage of plant P absorbed from the fertilizer was determined as the ratio of the specific activity of plant briquettes to that of the P fertilizer standards. For the latter, aliquots of fertilizer solution were dried with plant material grown without applied P. 'A' values were calculated according to Fried & Dean (1952). For the soil-labelled series, the specific activities of plant material grown without applied P at each soil P level were used as the standards.

### *Experiment* 2

'Low' and 'medium' P Mountview soil prepared as above was used, and 0, 50 and 100 mg rates of labelled P per pot were compared. On 7 July 1969 the soil was flooded and Nato rice seedlings were transplanted as for Exp. 1. For one set of treatments a solution of $^{32}P$-labelled CSP (specific activity of 0·45 mCi/g of P) was injected by means of a hypodermic needle into each pot as follows: (*a*) into the soil at each hill or (*b*) into the flood water. These $^{32}P$ applications were repeated for other sets of treatments 3 and 6 weeks after transplanting.

A first harvest was made on 10 September (9 weeks after transplanting) at the early heading stage. These foliage samples were dried, weighed, ground, $^{32}P$ activity assayed, and total P content determined, as for Exp. 1. A final harvest of mature grain and straw was made on 29 October, 16 weeks after transplanting. Yields of dry matter and content of total P were determined, but $^{32}P$ was not determined because of low activity at this time.

## RESULTS AND DISCUSSION

### *Experiment* 1

*Crop response to applied P*. Since rice yields and P uptake for corresponding treatments were similar with labelled P sources and with labelled soil, only results with the labelled P sources are reported in Figs. 1–3.

As shown in Fig. 1, dry-matter yields by rice increased markedly on the low P soil with amount of applied P and decreased with decrease in water solubility (increase in proportion of DCP in the granules). On the medium P soil these same trends were present but much less pronounced than at the

low soil P level. Treatment effects were not significantly different on the high P soil. Mean yields for all treatments increased with soil P level. Essentially the same trends occurred in numbers of viable plants plus tillers (Fig. 2) as for dry-matter yields. No tillering occurred on the low P soil without applied P.

Total uptake of P (Fig. 1) also showed about the same trends as were found for dry matter and tillering. On the medium P soil, however, uptake increased significantly with rate of applied P.

Percentages of the total plant P absorbed from the labelled P sources (Table 1) increased in all situations with amount of applied P, decreased with decrease in water solubility of the applied P, and decreased with increase in soil P level. The same trends

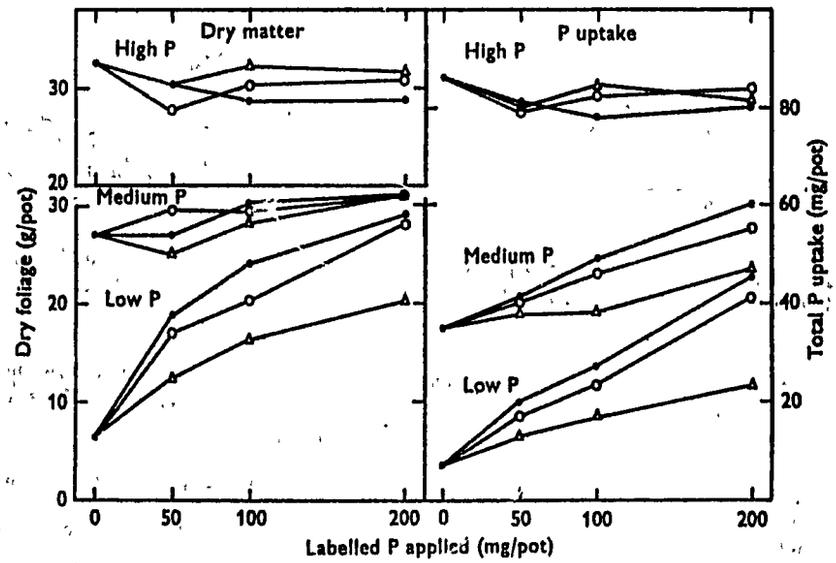


Fig. 1. Rice yields and total P uptake at the early heading stage, as affected by soil P level, rate and source of applied P (Exp. 1). ●—●, CSP; ○—○, 2/1 CSP-DCP mixture; △—△, 1/2 CSP-DCP mixture.

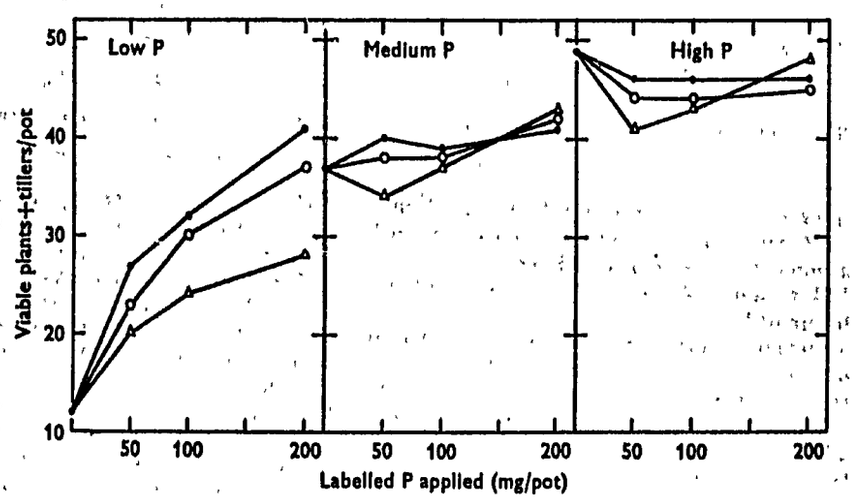


Fig. 2. Numbers of rice plants plus tillers, as affected by soil P level, rate and source of applied P (Exp. 1). ●—●, CSP; ○—○, 2/1 CSP-DCP mixture; △—△, 1/2 CSP-DCP mixture.

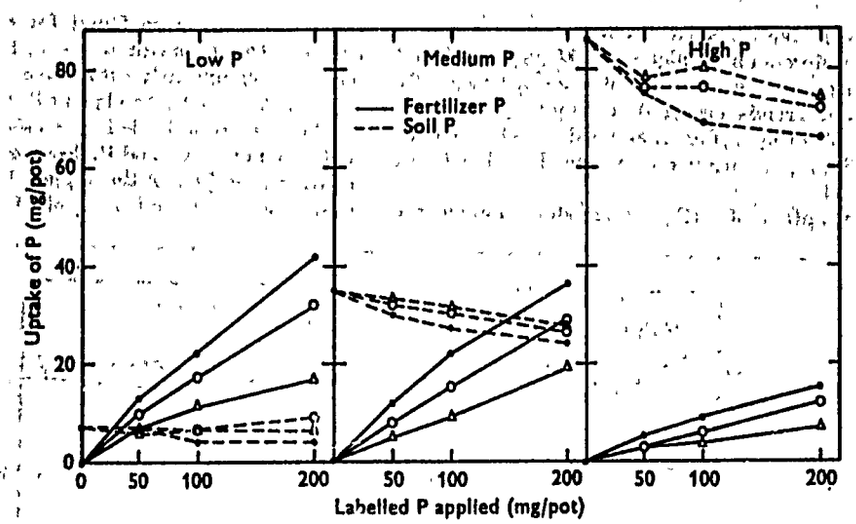


**Fig. 3.** Uptake of fertilizer and soil P by rice at the early heading stage, as affected by soil P level, rate and source of applied P (Exp. 1). ●, CSP; ○, 2/1 CSP–DCP mixture; △, 1/2 CSP–DCP mixture.

**Table 1.** *Percentages of plant P absorbed from the fertilizer and 'A' values, as affected by sources and rates of P applied to soil, low, medium, and high in soluble P (Exp. 1)*

| P applied at time of transplanting | Amount of P applied (mg/pot) | Plant P from fertilizer (%) | | | | | | 'A' values (mg P/pot)* | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Labelled fertilizer | | | Labelled soil | | | | | |
| | | Low | Med. | High | Low | Med. | High | Low | Med. | High |
| CSP alone | 50 | 68 | 27 | 6 | 57 | 11 | 7 | 24 | 135 | 783 |
| | 100 | 83 | 45 | 12 | 77 | 33 | 25 | 20 | 122 | 733 |
| | 200 | 92 | 60 | 18 | 81 | 45 | 31 | 17 | 133 | 911 |
| CSP–DCP, 2/1 | 50 | 59 | 20 | 4 | 51 | 8 | 18 | 35 | 200 | 1200 |
| | 100 | 74 | 34 | 8 | 61 | 13 | 19 | 35 | 194 | 1150 |
| | 200 | 78 | 53 | 14 | 76 | 30 | 30 | 56 | 177 | 1228 |
| CSP–DCP, 1/2 | 50 | 52 | 14 | 3 | 38 | −8 | 24 | 46 | 307 | 1617 |
| | 100 | 67 | 23 | 5 | 43 | −2 | 23 | 49 | 335 | 1900 |
| | 200 | 76 | 41 | 9 | 69 | −4 | 26 | 63 | 238 | 2020 |

* These values were determined from percentages of the plant P from the fertilizer in the fertilizer-labelled series.

occurred with uptake of fertilizer P (Fig. 3). Uptake of soil P increased markedly with increase in soil P level, and decreased slightly with increase in rate of applied P and with decrease in water solubility of the applied P.

In previous experiments with maize and wheat (*Triticum aestivum*), uptake of soil P usually increased with increase in amount of applied P whenever there was a yield response (Terman & Khasawneh, 1968). For unknown reasons, this did not occur in the present experiment. As in other labelled P experiments with maize (Terman & Allen, 1969), only the uptake of fertilizer P was satisfactory for evaluating P sources at high soil P levels.

*Soil* v. *P source labelling.* Table 1 shows a comparison of percentages of the plant P derived from the fertilizers, as determined with fertilizer labelling and with soil labelling with carrier-free $^{32}P$. Values obtained with the labelled fertilizers show the usual increase with amount of applied P, decrease with decrease in water solubility of the P, and decrease with increase in soil P level (Terman & Allen, 1969). On the low P soil the corresponding values obtained with soil labelling are lower, but relative differences are similar among sources. Values obtained with soil labelling are also lower for the medium P soil, but with the 1/2 CSP–DCP ratio, negative values for P from the fertilizer were obtained with soil labelling.

At the high soil P level, higher percentages were obtained with soil than with fertilizer labelling.

No conclusive explanation for these apparent discrepancies is obvious, but there may be varying effects at different soil P levels of the applied P on plant uptake of soil-labelled P. Varying degrees of isotopic exchange or equilibration between applied and soil P may also be involved. This is indicated by the calculated A values (obtained from the fertilizer-labelled series). The A values (Table 1) usually increase somewhat with amount of applied P and markedly with decrease in water solubility of the applied P. Although the A values are in terms of each P source, they do seem to indicate varying degrees of isotopic exchange, which result in unrealistic A values obtained with the less-soluble sources. Unrealistically high effectiveness values for phosphate rock estimated from soil labelling data were reported

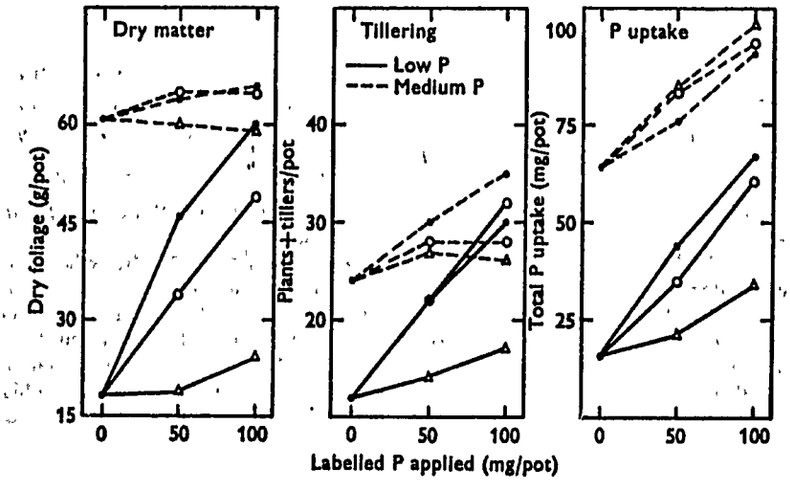


Fig. 4. Rice yields, tillering and total P uptake at the early heading stage, as affected by soil P level, rate, and time of applied P (Exp. 2). ●, At planting; ○, 3 weeks later; △, 6 weeks later.

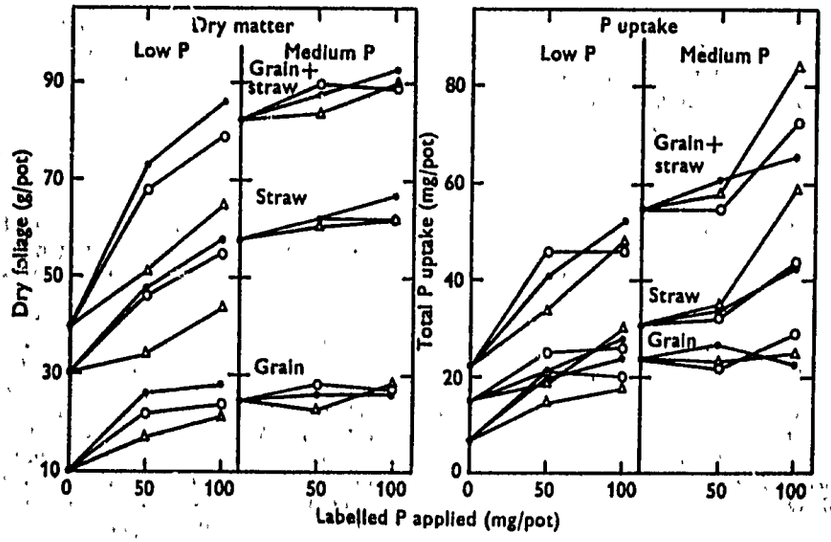


Fig. 5. Mature rice yields and total P uptake as affected by soil P level, rate, and time of applied P (Exp. 2). ●—●, At planting; ○—○, 3 weeks later; △—△, 6 weeks later.

Table 2. *Uptake of fertilizer and soil P by rice at the early heading stage, as affected by rate and time of application (Exp. 2)*

| Time of application | P applied (mg/pot) | Uptake of P (mg/pot) Low P Fert. | Low P Soil | Low P Total | Med. P Fert. | Med. P Soil | Med. P Total |
|---|---|---|---|---|---|---|---|
| At transplanting | 50 | 14 | 30 | 44 | 14 | 62 | 76 |
| | 100 | 39 | 28 | 67 | 33 | 60 | 93 |
| 3 weeks later | 50 | 14 | 21 | 35 | 20 | 63 | 83 |
| | 100 | 36 | 25 | 61 | 39 | 57 | 96 |
| 6 weeks later | 50 | 7 | 15 | 22 | 23 | 61 | 84 |
| | 100 | 19 | 15 | 34 | 37 | 64 | 101 |
| No P | 0 | — | 16 | 16 | — | 64 | 64 |
| L.S.D. 5% level | — | 5 | 5 | 7 | 3 | 6 | 7 |

by Mattingly & Widdowson (1956) for some soil-crop situations.

*Experiment 2*

During injection of $^{32}P$ solution into the soil it was found that, because the soil was already saturated by water, some of the solution flowed out of the soil into the flood water. Since the results with injection into the soil and into the water were similar, averages for the two placements are given in Figs. 4 and 5.

At the early heading stage on the low P soil, yields of dry foliage, tillering and total uptake of P (Fig. 4) all increased with rate of applied P but decreased with later date of application. On the medium soil, dry matter and tillering also decreased but total P uptake increased with later date of application.

Uptake of fertilizer P (Table 2) was essentially linear with amount of labelled P applied at both soil P levels. It was lower with later date of application on the low P soil but higher on the medium P soil. Uptake of soil P was much higher from the medium P soil.

Yields and P uptake by mature grain and straw (Fig. 5) also increased on the low P soil with rate of applied P and decreased with later application. Grain yields and P uptake in the grain on the medium P soil were not appreciably affected by rate or date of applied P. Straw yields were affected only slightly. Uptake of P in the mature straw increased with both rate of applied P and later date of application.

These results indicate that P applied 3 and 6 weeks after transplanting was readily absorbed by the crop but was not effective for increasing yields of grain and straw.

The $^{32}P$ labelled fertilizers for this study were prepared by G. A. Wieczorek, Tennessee Valley Authority, by methods described by Wieczorek & Breen (1964).

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