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Relative efficiency of phosphatic fertilisers in pasture topdressing

IV. Effects on a Takapau silt loam

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Abstract Trials with 7 phosphatic fertiliser formulations were carried out over a 3-year period on Takapau silt loam, a yellow-grey to yellow-brown earth intergrade. The pasture gave a large response to phosphate but only small responses to sulphate. Yields, P concentration, and uptake data all placed the fertilisers in the following order of decreasing effectiveness: Thermophos > Superphosphate > CCIP = CCIP-superphosphate > Gafsa > Nauru. Soil phosphate fractionation data and phosphate availability tests confirmed that Thermophos and superphosphate maintained higher levels of surface-bound P and available P than CCIP or CCIP-superphosphate mixture, and that the Nauru and Gafsa treatments were little higher than the gypsum-only control treatment. There were large increases in Ca-P levels under the phosphate rock treatments, indicating their slow rate of reaction with the soil.

Keywords Fertilisers; phosphorus; soil fertility; pastures; nutrient availability; nutrient content; nutrient uptake; topdressing

INTRODUCTION

This paper gives further results from a series of pasture topdressing trials with various phosphatic fertiliser formulations (Grigg 1980). Previous papers in the series have considered trials on a Kokotau silt loam (Grigg & Crouchley 1980) and a Rosedale silt loam (Grigg et al. 1982).

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EXPERIMENTAL

The trials considered here were laid down on Takapau silt loam at Takapau Field Research Area, Hawkes Bay. This soil is formed on alluvium derived from greywacke and volcanic ash (N.Z. Soil Bureau 1954) and is classified as a stony soil associated with central yellow-grey to yellow-brown earth intergrades (N.Z. Soil Bureau 1968).

The trials were laid down on 20 June 1967 on a flat area on a ryegrass-white clover pasture which had been sown in autumn 1967. The history of the area was: 1964, wheat; 1965, new pasture; 1966, pasture; and 1967, new pasture. Over this period the area received 100 kg/ha P as superphosphate or serpentine superphosphate and in 1965 it received 2500 kg/ha of limestone.

Before fertiliser applications, results of analyses of the topsoil (0-75 mm) were: pH 5.8, Bray No. 1 P 10 μg/ml, Olsen P 11μg/ml, and P retention (Saunders 1965) 46% (medium). Despite the regular topdressing the phosphate status by both soil tests was low.

There were 2 trials at the site, with their blocks intermingled so that direct comparisons between the trials were possible. Trial A was designed to assess the responsiveness of the site to P and S. It comprised 4 replicates in randomised blocks of a 2P × 2S factorial design with P applied annually at 0 and 42 kg/ha as "Ibex" brand monocalcium phosphate (MCP) and S applied annually at 0 and 50 kg/ha as gypsum.

Trial B comprised 4 replicates in randomised blocks of the 7 fertiliser combinations listed in Table 1 applied in 2 ways. Mode 1 was an annual fertiliser application at rates equivalent to a total P content of 42 kg/ha, whereas Mode 2 was at 126 kg/ha of fertiliser applied only at laying down. Additional gypsum was applied as necessary to balance treatments to the gypsum content of the superphosphate applications. For Nauru rock phosphate Treatments 7 and 14, the gypsum was replaced by an equivalent amount of elemental S. Analyses of the fertilisers used were given in Part II.

The trials were laid down on 20 June 1967 and re-topdressed (Trial A and Mode 1 of Trial B) on 1 June 1968 and 5 June 1969.

After a trimming cut on 24 August 1967, pasture yields were measured continuously by mowing cuts on 31 occasions until 26 May 1970, using the mowing and

Table 1 Trial B: annual dry matter production (kg/ha).

Treatment	Part year 1967/78	1968/69	1969/70	Whole period
Mode 1				
1 Superphosphate	7535	9910	10300	27745 (100)[2]
2 Nauru + gypsum	7060	8630	8835	24525 (88)
3 Gafsa + gypsum	7330	9035	9695	26060 (94)
4 CCIP + gypsum	7355	9650	10000	27005 (97)
5 CCIP superphosphate + gypsum	7255	9375	10315	26945 (97)
6 Thermophos + gypsum	8160	10210	10625	28995 (105)
7 Nauru + sulphur	6840	9015	9115	24970 (90)
Mode 2				
8 Superphosphate	8025	9685	10370	28080 (101)
9 Nauru + gypsum	7195	9135	9105	25435 (92)
10 Gafsa + gypsum	7230	9135	9430	25795 (93)
11 CCIP + gypsum	7580	9930	10010	27520 (99)
12 CCIP-superphosphate + gypsum	7790	9595	9855	27240 (98)
13 Thermophos + gypsum	8710	10470	10100	29280 (106)
14 Nauru + sulphur	6995	8555	8685	24235 (87)
LSD $P = 0.05$	452	566	893	—
$P = 0.01$	605	758	1195	—
Forms of fertiliser				
Superphosphate	7780	9798	10335	27913
Nauru + gypsum	7128	8883	8970	24980
Gafsa + gypsum	7280	9085	9563	25928
CCIP + gypsum	7468	9790	10005	27263
CCIP-superphosphate + gypsum	7523	9485	10085	27093
Thermophos + gypsum	8435	10340	10363	29138
Nauru + sulphur	6918	8785	8900	24603
LSD $P = 0.05$	318	401	632	—
$P = 0.01$	425	536	846	—
Modes of application				
1. 42 kg P/ha annually	7362	9404	9841	26606
2. 126 kg at laying down	7646	9501	9651	26798
LSD $P = 0.05$	172	215	338	—
$P = 0.01$	230	287	452·	—
Significance of interaction	NS	NS	NS	—
Coefficient of variation (%)	4.2	4.2	6.4	—

[1]Not statistically analysed [2]Relative to superphosphate mode 1 = 100

clipping return technique (Lynch 1960). Yields were oven-dried and analysed for P and S (Trial A) or P only (Trial B) by automated analytical techniques following digestion of the sample with a nitric-perchloric acid mixture.

Soil samples were taken from individual plots (0-75 mm depth) at laying down and on 21 May 1968, 20 May 1969, and 16 June 1970. They were analysed for Bray No. 1 and Olsen P on an individual plot basis and bulked into treatment samples for duplicate analyses for inorganic phosphate fractions (Williams et al. 1967).

RESULTS

P and S status of the site

Results from Trial A are not presented in detail for reasons of brevity, but they can be summarised as follows:

1) MCP gave highly significant ($P<0.01$) responses for all cuts. The main effects of phosphate increased with time, being 13% in Year 1, 29% in Year 2, and 34% in Year 3.
2) There was only a small yield response to gypsum, amounting to 4% in Year 1 ($P<0.01$), nil in Year 2, and 5% in Year 3 ($P<0.05$).
3) P concentrations in the herbage were significantly higher in the MCP treatments than in the no-phosphate treatments for all cuts ($P<0.01$). In the control and gypsum treatments, weighted annual mean P concentrations declined from 0.33% in Year 1 to 0.25% in Year 3. In the MCP treatments, weighted annual mean concentrations were 0.38 to 0.41%.
4) S concentrations in the herbage were significantly higher in the gypsum than in the no-gypsum treatments. Weighted annual mean concentrations for the 3 years were 0.38, 0.32, and 0.24% in the

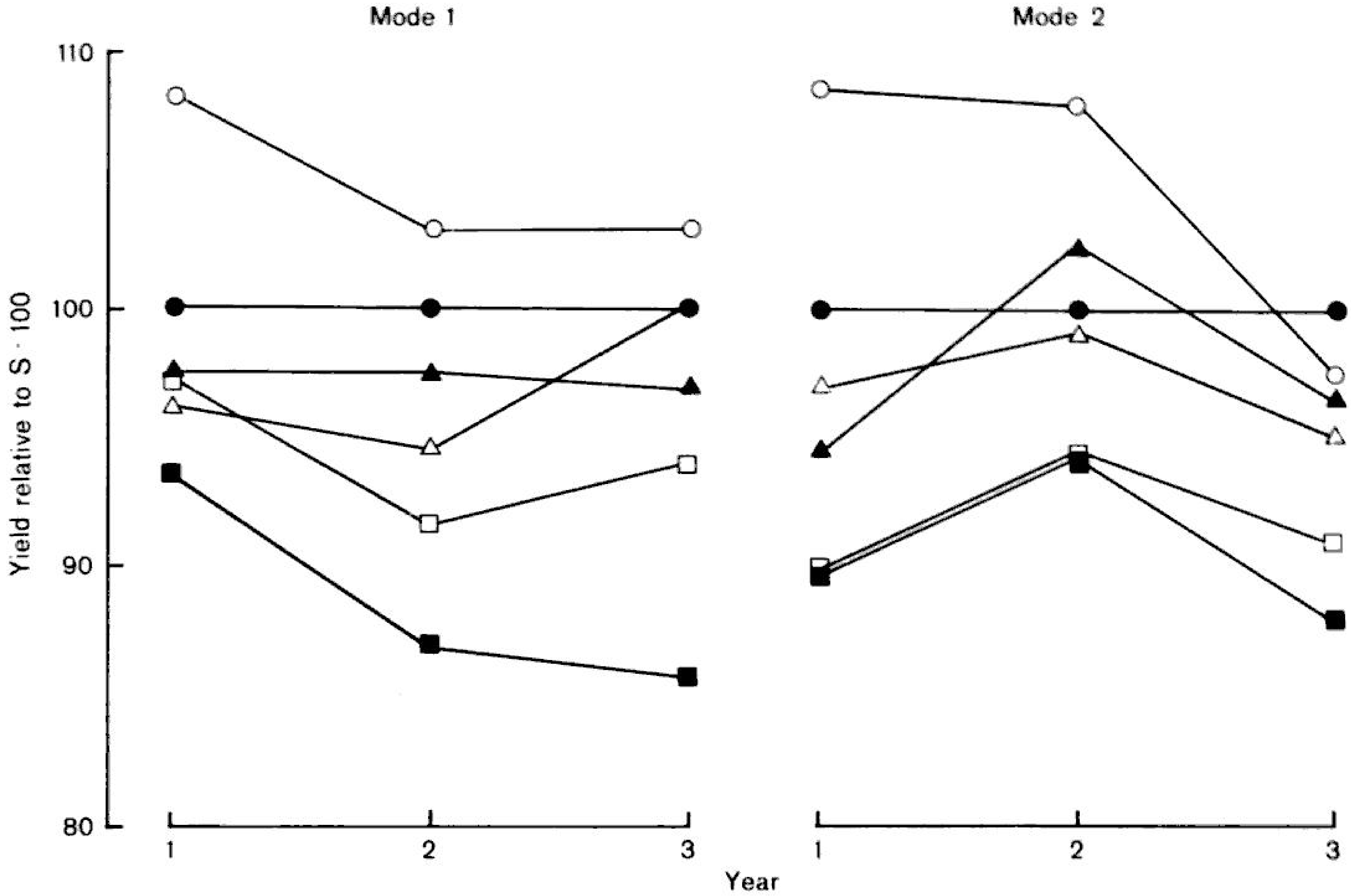

Fig. 1 Annual yields relative to superphosphate = 100 for each mode of application: ●——● S, Superphosphate; ○——○ T, Thermophos; ▲——▲ C, CCIP; △——△ C/S, CCIP - superphosphate; ■——■ N, Nauru; □——□ G, Gafsa; *——* GP, Gypsum (Trial A).

no-gypsum treatments compared with 0.42, 0.38, and 0.32% in the gypsum treatments.

5) The available P status of the soil, assessed by both the Bray No. 1 and Olsen methods was low (10 and 11 μg/ml respectively). Levels by both tests remained relatively constant over the 3 years in the no-phosphate treatment but increased steadily to about 15 μg/ml in the MCP treatments.

Yield data, Trial B (forms of phosphate)

Dry matter production

The yields of DM from individual cuts usually ranked the fertilisers in the same order of effectiveness, so only annual total yields are presented (Table 1). A clearer appreciation of the yields from each fertiliser form relative to superphosphate considered as the standard (= 100 for each mode of application) is obtained from Fig. 1.

For Year 1 of the trial, response curves for 3 application rates were obtained by using the gypsum treatment of Trial A as the point for zero phosphate application (Fig. 2). Mitscherlich-type exponential curves were fitted for the Thermophos and superphosphate treatments. No fit could be obtained for the other treatments. It must be stressed that with only 3 values available to fit these curves no estimates could be made of goodness of fit or of error of estimate. Thus the comparisons given below have only general validity.

The calculated maximum yield for the best treatment (Thermophos) was 8787 kg/ha. The amounts of fertiliser required to give 90% of this maximum were 28 kg P/ha as thermophos, 97 kg/ha as superphosphate and, by extrapolation, about 145 kg/ha as CCIP-superphosphate. The other treatments failed to give 90% of the maximum. Although Thermophos was superior to superphosphate in the first year, herbage from this treatment had the same P concentration as superphosphate (Fig. 3).

It was not possible to make comparisons such as this in Years 2 and 3, because of the interaction between residual effects of Mode 2 applications and fresh Mode 1 applications. In Years 2 and 3 thermophos gave only a 3% increase over superphosphate in Mode 1 whereas in Mode 2 it gave an 8% higher yield in Year 2 and 3% lower yield in Year 3, so that over the whole trial period Thermophos

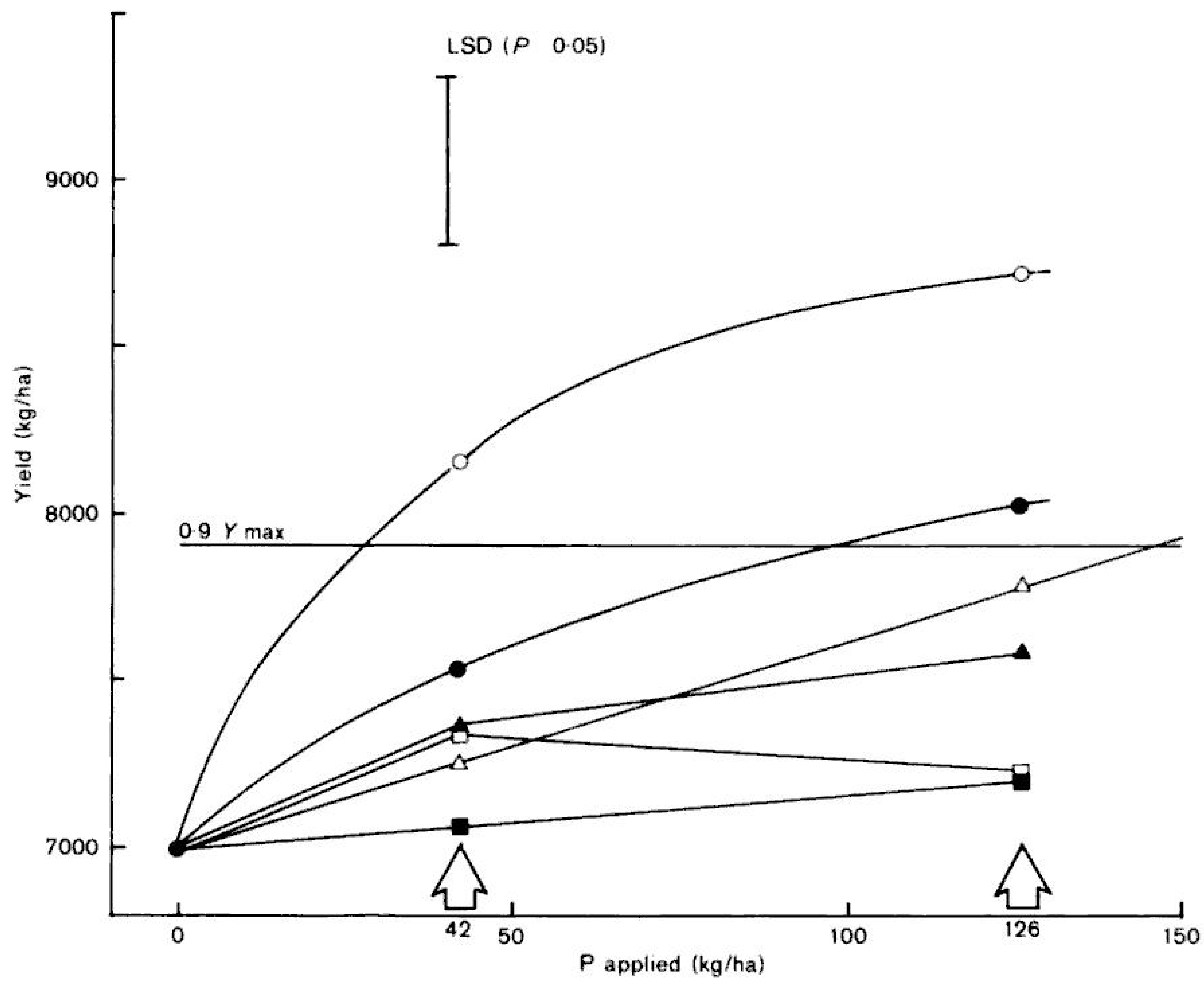

Fig. 2 Response curves for 3 rates of application, Year 1. Key as in Fig. 1.

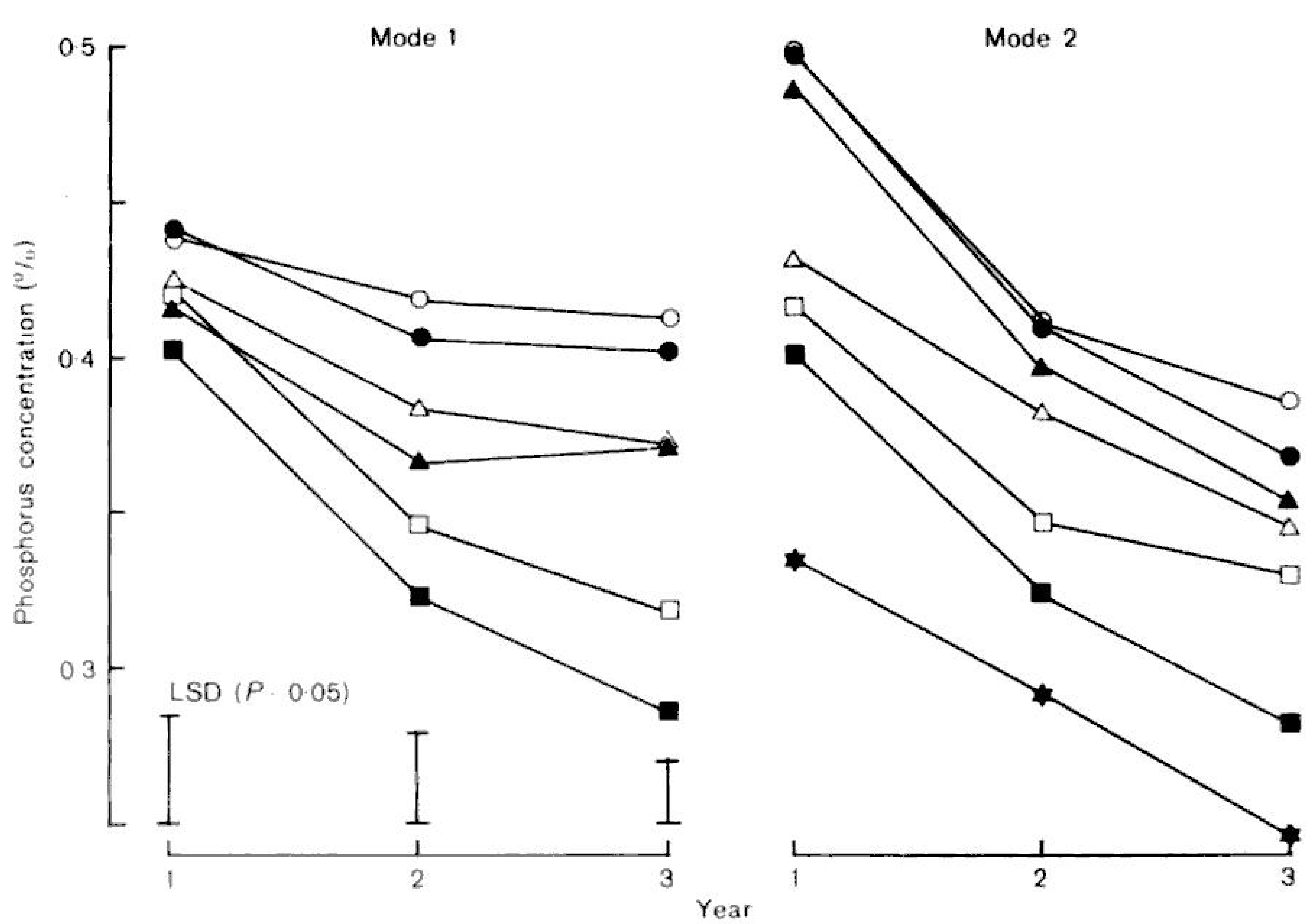

Fig. 3 Weighted annual mean phosphorus concentration in herbage. Key as in Fig. 1.

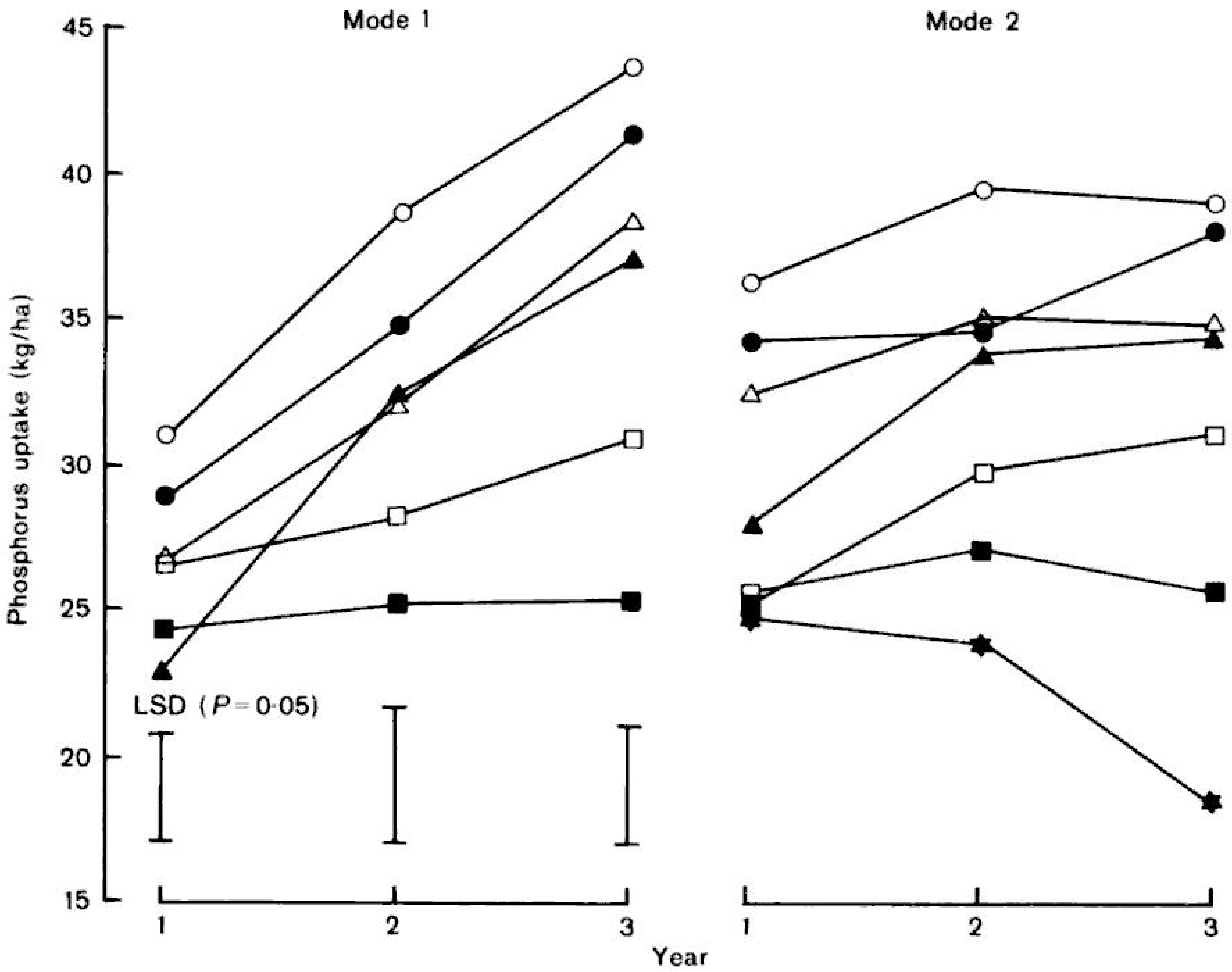

Fig. 4 Annual phosphorus uptake by herbage. Key as in Fig. 1.

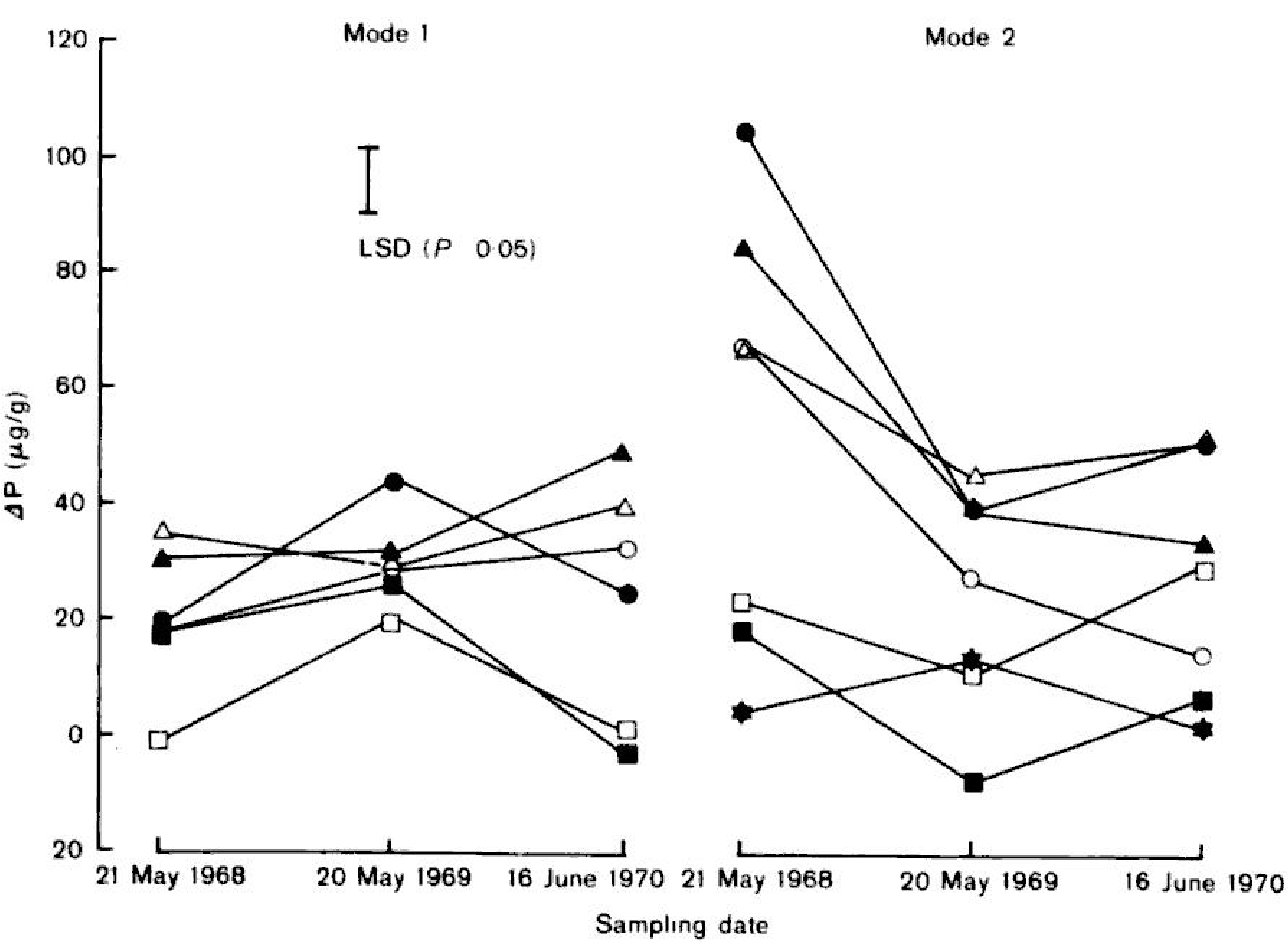

Fig. 5 Changes in surface-bound phosphate. Key as in Fig. 1.

yielded 5% more than superphosphate when applied annually and 6% when applied as one heavy dressing (Table 1).

P concentrations in herbage (Fig. 3)

P concentration values for individual cuts usually ranked the fertiliser forms in the same relative order. The results have therefore been condensed to weighted mean annual concentrations. As no analyses were available for the periods 6 December 1967—4 January 1968 and 13 November 1968—18 December 1968, data for Years 1 and 2 are slightly biased. Values for the gypsum treatment of Trial A are concluded in Mode 2 on Fig. 3 as a no-phosphate comparison.

Fig. 3 clearly shows that the rock phosphates could not maintain an adequate P supply in either mode of application and that Thermophos and superphosphate were superior to CCIP superphosphate and CCIP.

Phosphate uptake by herbage

Annual uptake of P is shown in Fig. 4. The data do not include amounts for the 2 periods mentioned above when samples were not analysed. Values for Years 1 and 2 may be underestimated by 2–4 kg/ha. Nevertheless they indicate clearly the relative uptake of the fertiliser forms.

In Mode 1, the uptake from all forms of phosphatic fertiliser except Nauru increased each year.

In Mode 2 the P uptake increased between Years 1 and 2 but tended to level off between Years 2 and 3. The relative order of P uptake was the same as for Mode 1.

Soil phosphate changes

Phosphate fractions

In contrast to the fractionation data reported for other trials in this series, changes in phosphate fractions in this trial are rather irregular. There was considerable variation between the plots at the time of laying down. Mean values and their ranges were Al-P 88.1 (78–98), Fe-P 98.5 (92–103), occluded P 79.1 (72–87), and Ca-P 29.9 (25–40) $\mu g/g$. Secondly Al-P, Fe-P, and occluded P values in the original soil are considerably higher than in the other trials so that differences caused by fertilisers are relatively smaller.

To overcome these difficulties, results are presented in Fig. 5 and 6 as changes in phosphate level (ΔP) from levels for the corresponding samples at laying down, and Al-P and Fe-P concentrations have been added together and are considered as surface-bound P.

In Fig. 5–8 the values for the least significant difference (LSD) at $P<0.05$ apply over all sampling dates. Fig. 5 shows differences in surface-P levels. In Mode 1, levels for superphosphate, Thermophos, CCIP, and CCIP-superphosphate increased by 20–35 mg/g after one year with slightly greater increases in the second and third years, except for superphosphate which decreased in Year 3. Nauru phosphate also increased in Years 1 and 2 but declined in Year 3, whereas Gafsa gave an increase over the original level in the second year only.

In Mode 2 there were large increases in surface-P after one year in superphosphate, CCIP, CCIP-superphosphate, and Thermophos treatments which decreased in the second year. Levels remained more or less constant from Year 2 to Year 3. Levels in the phosphate rock treatments did not differ very much from the original level, although there was an increase with Gafsa in Year 3.

Fig. 6 gives ΔP values for Ca-P. Annual applications of the Nauru rock phosphate gave a large continuing increase in Ca-P levels. Gafsa increased to a lesser extent. For superphosphate, levels remained 24–29 $\mu g/g$ higher than in the original soil, whereas for CCIP and CCIP-superphosphate they were only slightly higher than in the original soil, and for Thermophos slightly lower.

In Mode 2, there were large increases in Ca-P levels in the rock phosphate treatments in 1968 which decreased in the 2 succeeding years. Superphosphate gave a moderate increase which also declined with time. CCIP, CCIP-superphosphate, and Thermophos gave smaller increases, again with a downward trend whereas levels in the gypsum treatment were steady at 13 $\mu g/g$ less than in the original soil.

Changes in occluded-P are not shown. They were all less than $\pm$ 10 $\mu g/g$ with no very clear pattern except a slight decline in levels with time for Mode 1 applications and a slight increase for Mode 2.

Available phosphate, Bray No. 1 Test (Fig. 7)

In Mode 1, Bray P test values increased from 10 $\mu g/ml$ to about 15 $\mu g/ml$ in the superphosphate, Thermophos, and CCIP-superphosphate treatments in Year 1. Levels then fell to 12–13 $\mu g/ml$ during the following 2 years. Bray -P levels were lower in the CCIP treatment (12–13 $\mu g/ml$) and in the rock phosphate treatments levels decreased from 10 to 8 $\mu g/ml$, i.e., values were very similar to those in the gypsum-only no-phosphate treatment. In Mode 2 there were large increases in Bray values after one year for the more reactive fertiliser treatments, with Thermophos giving the highest values. Levels decreased in the following 2 years. Values for the rock phosphate treatments changed very little from those of the original soil.

Available phosphate, Olsen test (Fig. 8)

Changes in Olsen -P were smaller than for the Bray -P test, but showed a similar pattern, with Thermophos and superphosphate having slightly higher values than CCIP-superphosphate and CCIP except for 1970 samples when superphosphate (Mode

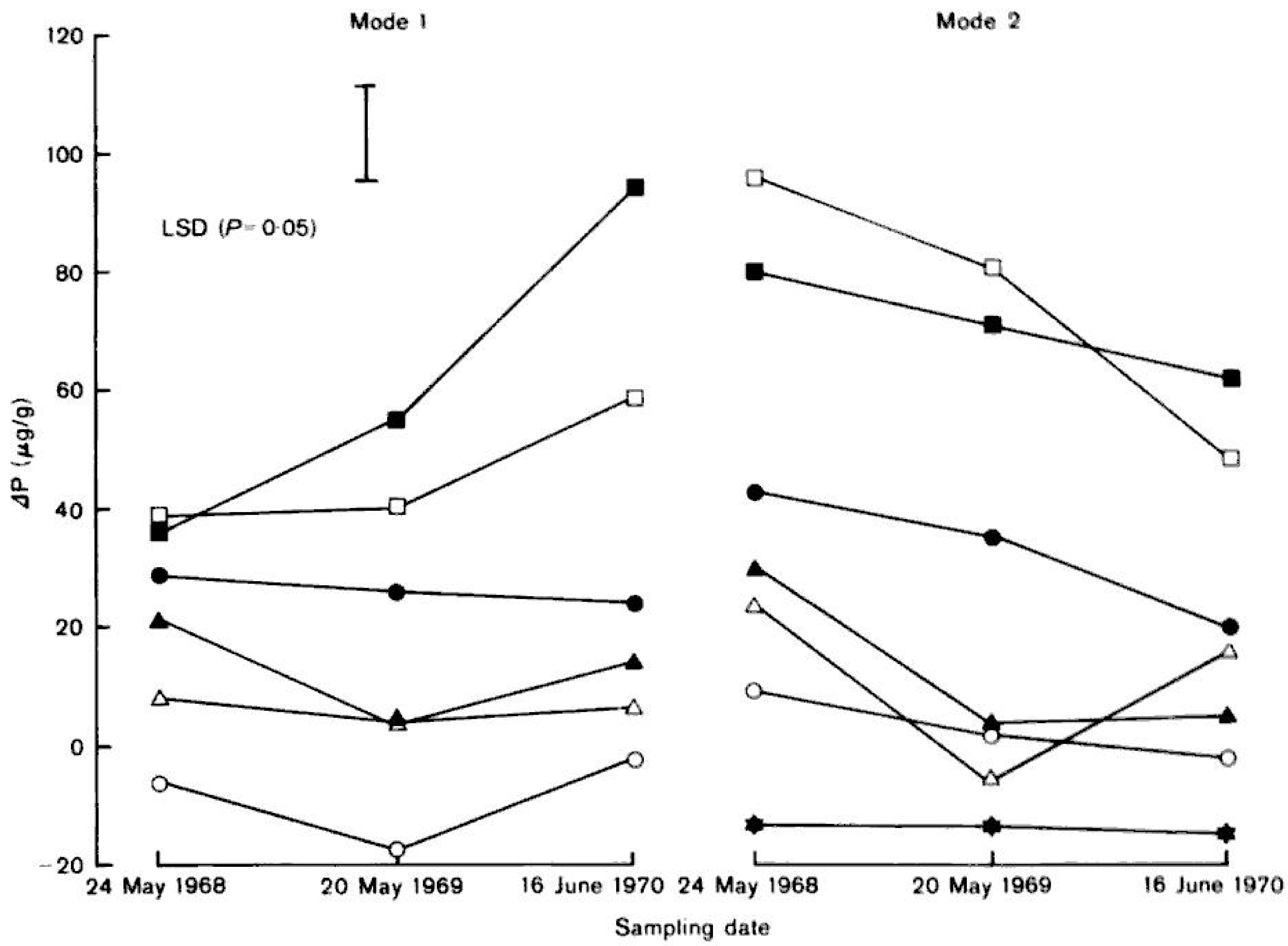

Fig. 6 Changes in calcium-bound phosphate. Key as in Fig. 1.

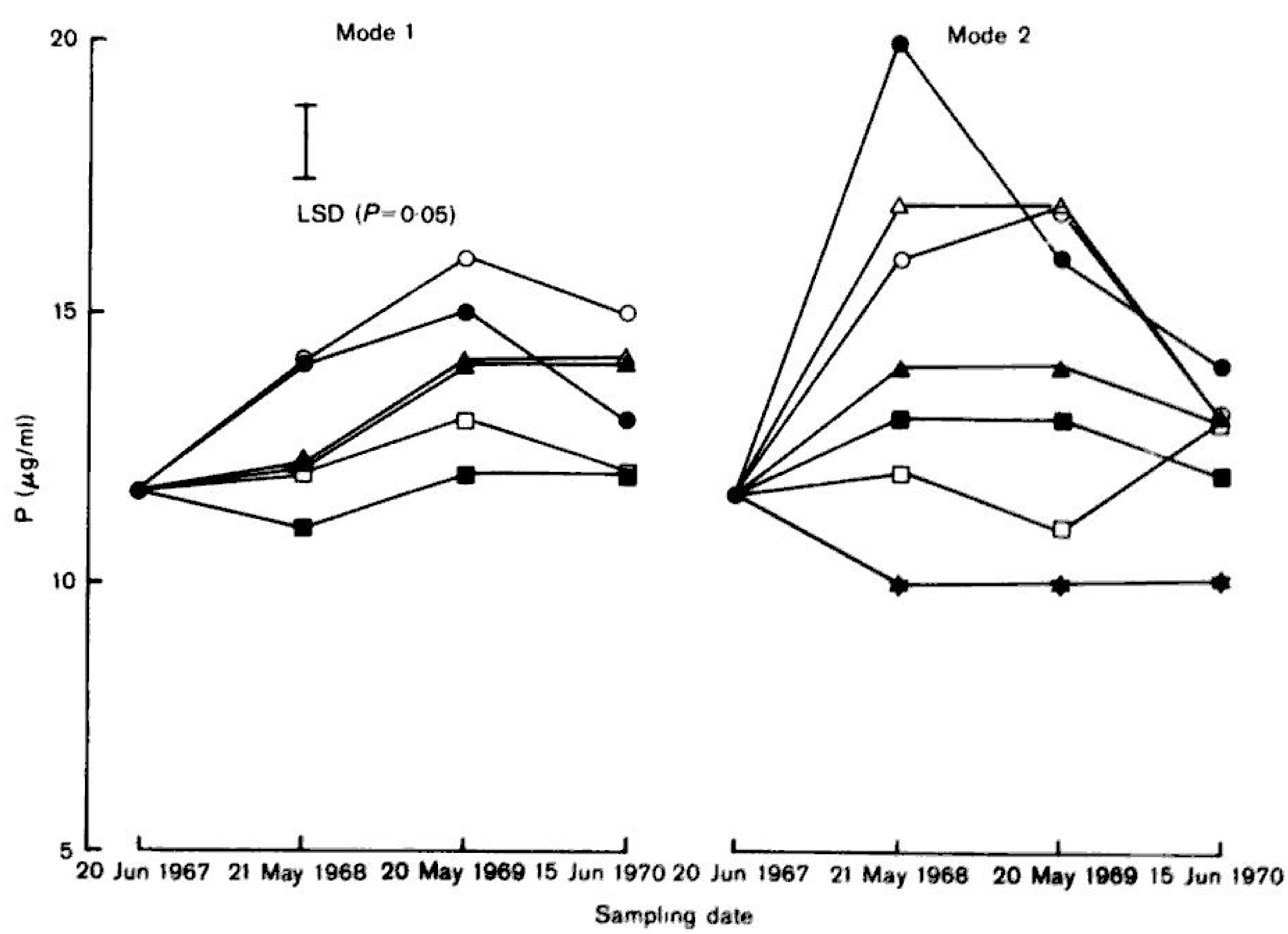

Fig. 7 Bray No. 1 P test values. Key as in Fig. 1.

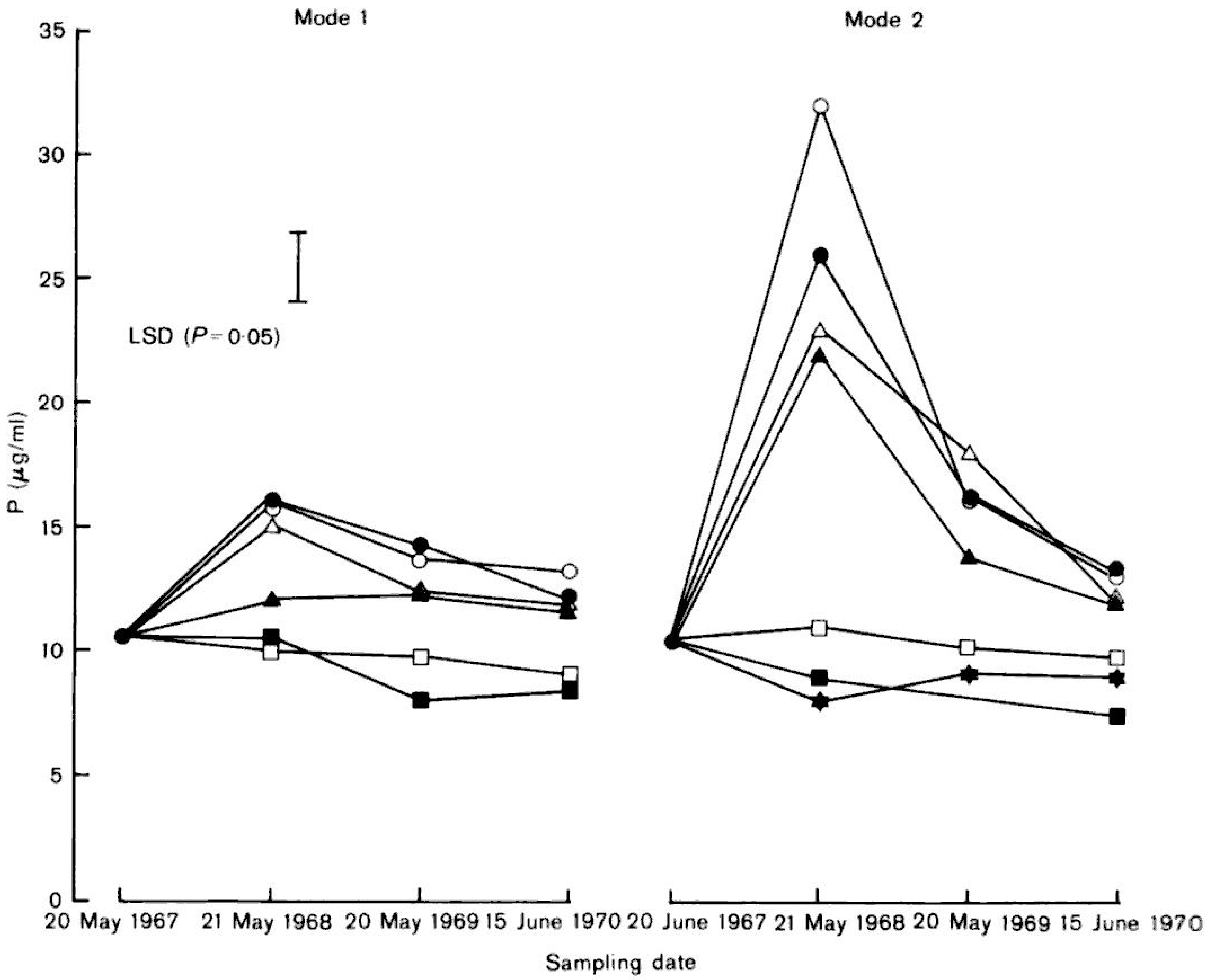

Fig. 8 Olsen P test values. Key as in Fig. 1.

1) was lower than these. For this test also, there was a small decrease in values for the gypsum treatment of Trial A in Year 1 after which there was no further decline.

Relations between yields and soil tests

Annual yields (to 31 May) were correlated with the mean Bray and Olssen P test levels for each year (Table 2). All correlations were highly significant, with the Bray test giving slightly higher correlations than the Olsen test in Years 1 and 2 and vice versa in Year 3.

Table 2 Correlations between annual yields of dry matter and mean Bray No. 1 P or Olsen P tests for each year.

Year	Bray P r	Olsen P r
1	0.838**	0.694**
2	0.754**	0.744**
3	0.791**	0.881**

DISCUSSION

The pasture gave responses to phosphate increasing from 13 to 34% over the 3 years. If annual superphosphate applications are taken as the standard against which to compare the other forms and modes of application, it can be seen from Table 1 and Fig. 1 that these gave yields ranging from 86 to 109% of the yields from superphosphate. The fertilisers can be placed qualitatively in the following order of decreasing effectiveness:

Thermophos > superphosphate > CCIP = CCIP-superphosphate > Gafsa > Nauru.

This order is similar to that found in the trials of Kokotau silt loam (Grigg & Crouchley 1980) and on Rosedale silt loam (Grigg et al. 1982). In this present

trial, however, the superiority of Thermophos over superphosphate is greater than in the other trials. One possible reason is that the phosphate dissolving from the superphosphate was absorbed more strongly in this soil with a phosphate retention of 46% than it was in the other soil types of lower retention, whereas the plants were able to draw phosphate directly from the fine Thermophos particles as they dissolved more slowly over a longer period of time.

Sinclair (1975) considered that the superiority of Thermophos over superphosphate on Te Anau brown loam (phosphate retention over 90%) reported by Cullen & Grigg (1971) resulted from movement of fine unreacted Thermophos particles deeper into this light textured soil, to depths where greater moisture availability permitted better growth. This mechanism could possibly be acting in this well-drained light-textured Takapau soil, with its inclusion of volcanic ash and stony subsoil.

P concentrations and uptake data support the rankings given by the yield data, and show quite clearly that the raw ground rock phosphates did not maintain a satisfactory phosphate status in the herbage even with annual applications. Changes in surface-bound P and Ca -P in the soil show patterns similar to those found in trials reported previously. These data partly reflect undissolved or unreacted fertilisers and partly forms of soil phosphate into which the fertilisers have been changed. The implications of these changes were discussed in Part 2 of this series.

The Bray No. 1 -P and Olsen -P test results show an unusual feature in that test levels in the gypsum-only treatment decreased slightly in Year 1 and then showed no further decrease with time. This may result from the phosphate returned to the soil in the clippings being reincorporated as inorganic P at a rate sufficiently rapid to maintain a steady low level supply of available P.

In the Nauru and Gafsa treatments Bray No. 1 -P and Olsen -P remained steady at a slightly higher level than gypsum in Mode 2, but increased very slightly in Mode 1. For the manufactured materials, Bray No. 1 and Olsen P tests increased to plateaus about 3–5 μg/ml higher than the controls. There were reasonably good correlations between annual yields and mean soil test values for each year by either method (Table 2), except that in Year 1 yields from Thermophos were higher than might have been expected from the Olsen test.

The results from this trial are compatible with results from the other trials in the series.

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