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Relative efficiency of phosphatic fertilisers in pasture topdressing

III. Effects on a Rosedale silt loam

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Abstract Pastures grown on Rosedale silt loam, a central yellow-brown earth yielded 22–54% more dry matter (DM) after addition of "Ibex" mono-calcium phosphate (IMCP) and 12% more DM after gypsum addition over a 2.5 year period with regular mowing cuts. In a comparison of phosphatic fertiliser forms, fertilisers were placed in the following order of decreasing effectiveness in terms of DM yield, P concentration, and P uptake data: Thermophos > superphosphate > 1:3 mixture of calcined "C" grade Christmas Island phosphate rock (CCIP) and superphosphate > CCIP = Gafsa phosphate rock > Nauru phosphate rock. CCIP and Gafsa improved relatively to Thermophos and superphosphate in the third year of the trial. Annual application of Thermophos, CCIP-superphosphate, and CCIP increased levels of Al-P and Fe-P in the soil. Superphosphate increased Al-P but not Fe-P. These manufactured fertilisers led to little change or a decrease in occluded-P and Ca-P levels. In contrast there was a large accumulation of Ca-P in the Gafsa and Nauru treatments which showed no change or a decline in Al-P and Fe-P levels. A single heavy application of the manufactured fertilisers increased Al-P and Fe-P in the first year after application but values declined in the second and third years. Heavy applications of Gafsa and Nauru phosphate rocks could not maintain the initial levels of Al-P and Fe-P. These treatments resulted in large accumulations of Ca-P in the first year followed by decreases in the second and third years. Bray No. 1 and Olsen values for available P gave patterns of change similar to Al-P.

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

INTRODUCTION

This paper presents further results from a series of pasture topdressing trials with various forms of phosphatic fertilisers. Reasons for the trials have been discussed in Part I (Grigg 1980) and trials on a yellow-grey earth at Masterton are reported in Part II (Grigg & Crouchley 1980).

EXPERIMENTAL

The trials considered here were carried out on Rosedale silt loam, a central yellow-brown earth formed on moderately weathered Moutere gravels under a rainfall of 1150 mm (Chittenden et al. 1966; N.Z. Soil Bureau 1968). The site was on a gently rolling ridge at Rosedale near Motueka and consisted of an old and rather poor pasture of ryegrass, cocksfoot, and browntop with white and suckling clovers. Although the area had received 250 kg/ha/a of aerial superphosphate for the 3 years before laying down the trials, available phosphorus was low. The soil pH was 6.5 falling to 6.1 over 3 years. Phosphate retention was 21% (low).

Trial A comprised 4 replicates in randomised blocks of a 2P × 2S factorial design in order to assess the responsiveness of the site to P and S. P was applied annually at 31 kg/ha as "Ibex" brand MCP and S was applied annually at 37 kg/ha as gypsum.

Trial B comprised 4 replicates in randomised blocks of the fertiliser formulations listed in Table 1 applied in 2 ways. Mode 1 was an annual application at a total P equivalent of 31 kg/ha, and Mode 2 was at 93 kg/ha P equivalent applied only at laying down the trial. Additional gypsum was added as required to balance

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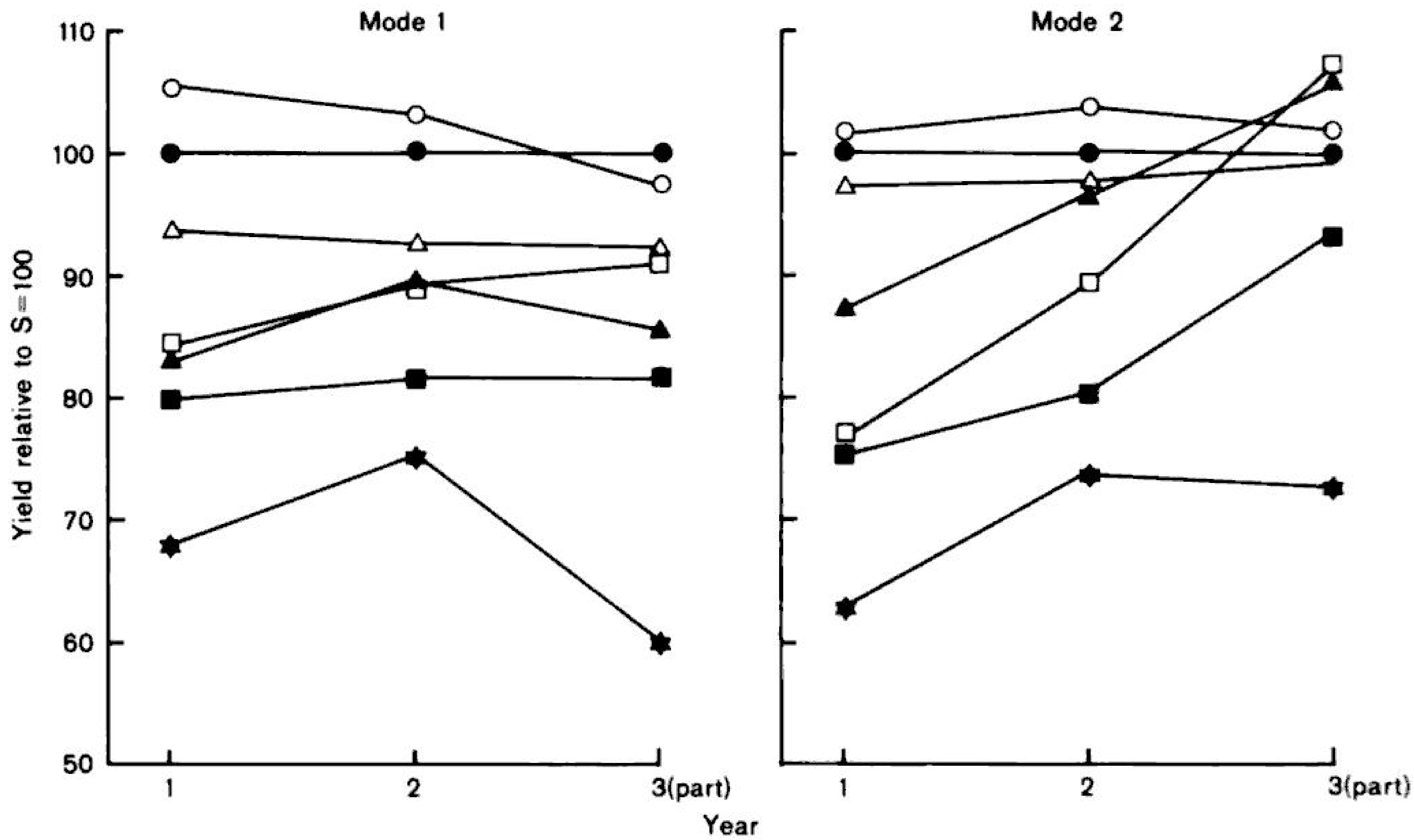

Fig. 1 Annual yields relative to superphosphate = 100 for each mode of application: ●——● S, Superphosphate; ○——○ T, Thermophos; ▲——▲ C, CCIP; △——△ C/S, CCIP-superphosphate, 1:3; ■——■ N, Nauru; □——□ G, Gafsa; *——* GP, Gypsum (Trial A).

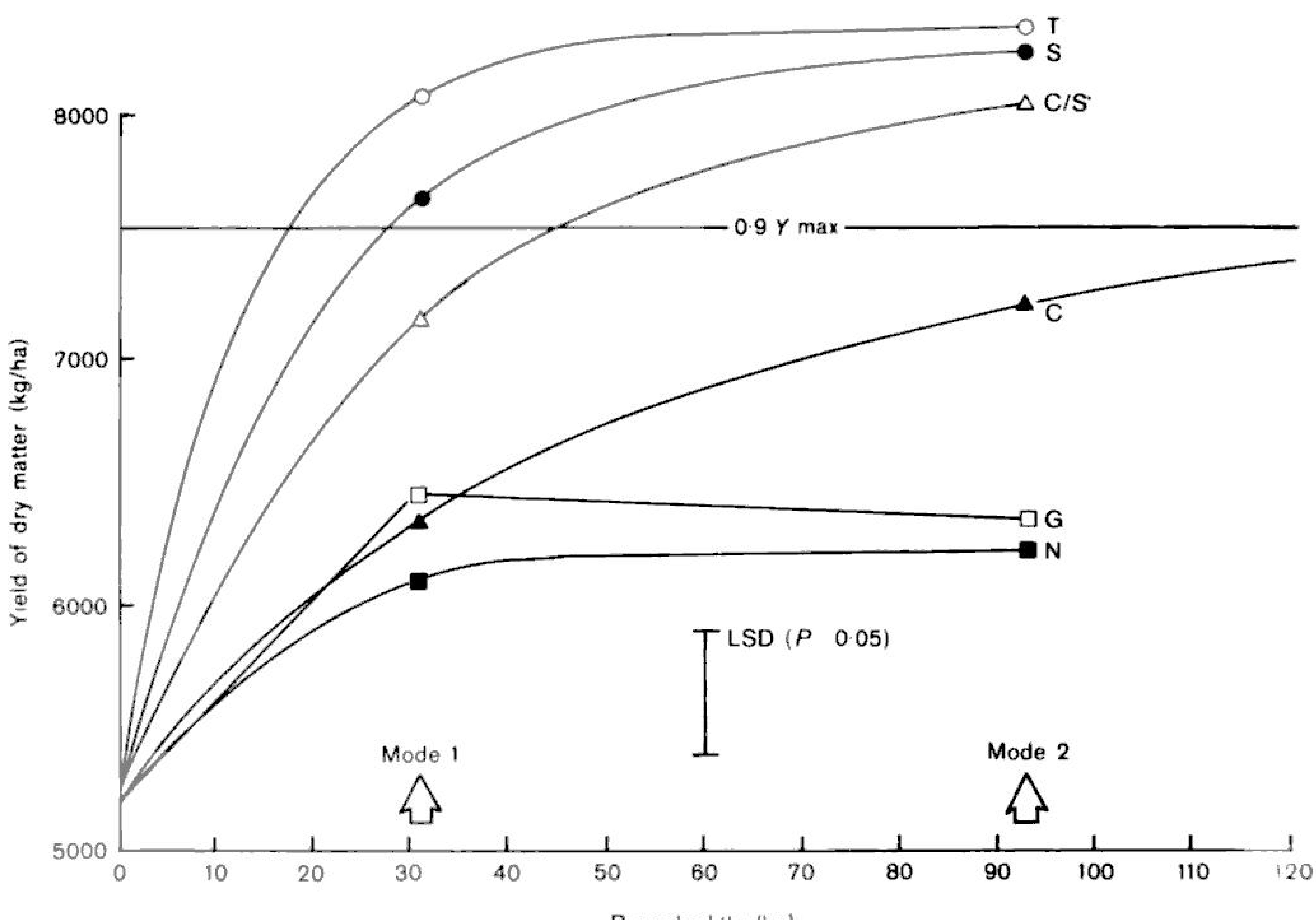

Fig. 2 Response curves for these rates of application, Year 1. Key as in Fig. 1.

the gypsum content of the superphosphate. For the Nauru + sulphur treatments, the gypsum was replaced by the equivalent amount of elemental S. Gypsum or S were applied to the Mode 2 treatments only at laying down.

The trials were commenced on 11 August 1966 and continued until 10 June 1970 with re-applications of fertilisers to Trial A and Mode 1 of Trial B on 3 August 1967 (Day 356) and 26 August 1968 (Day 746).

Herbage production was measured by continuous mowing cuts, using the mowing and return of clippings technique (Lynch 1960), until 18 December 1968 after which no further cuts were made because of drought conditions in the summer and autumn of 1969. However, visual assessments on the fertility index scale were carried out on 7 July 1969, 28 September 1969, and 10 June 1970 to follow the residual effects of the fertilisers.

Soil samples (0–75 mm) were collected at laying down (11 August 1966), and annually just before re-application of Mode 1 treatments on 3 August 1967, 26 August 1968, and finally on 18 June 1969. They were analysed for available phosphate by the Bray No. 1 and Olsen methods and for inorganic phosphate fractions by the procedure of Williams et al. (1967).

Herbage samples were analysed for P and S (Trial A) or P only (Trial B) using automated methods of analysis following digestion with nitric and perchloric acids.

RESULTS

P and S status of the site

For brevity, results from Trial A are not reported in detail. The main conclusions were:

1) There was a highly significant response to phosphate ($P<0.01$) at every cut, with responses being slightly greater in the presence of gypsum. The main effect of phosphate increased with time from a 22% response in Year 1 and 31% in Year 2 to a 54% response in part Year 3. Over the whole period the response was 28% in the absence of gypsum and 37% in its presence, a main effect of 33%.
2) Responses to gypsum were smaller, amounting to 9%, 14%, and 12% for the 3 years, an average of 12% over the whole period.
3) Herbage P concentrations declined with time from 0.34% to 0.22% in the no-phosphate treatments. Applications of MCP increased herbage P levels significantly ($P<0.01$) to values ranging from 0.35% to 0.55%, depending on season and time since topdressing.
4) Herbage S concentrations ranged from 0.2 to 0.3% in the no-sulphate treatments and from 0.3 to 0.6% in the gypsum treatments.
5) Soil phosphate tests (Olsen method) showed that the available soil phosphate fell from 11 to 8 μg/ml over the 3 years in the absence of applied phosphate, but increased to 14 μg/ml in the MCP treatments. Similar changes occurred in Bray No. 1 P test levels.

Yield data, Trial B (forms of phosphate)

Dry matter production

Annual yields and total yields from the trial are given in Table 1, and yields relative to superphosphate in each mode = 100 are shown in Fig. 1. The data for the Nauru + elemental S treatments were very similar to those for Nauru + gypsum and have been omitted from Fig. 1. Data for the gypsum-only treatment of Trial A are included to enable a comparison with zero phosphate application to be made.

In Mode 1, the fertiliser forms maintained their relative position over the trial period, although Gafsa tended to improve and Thermophos to decline relative to superphosphate in Year 3.

In Mode 2, yields from the more reactive fertilisers were significantly greater than from the rock phosphates in Years 1 and 2, but Gafsa, CCIP, and Nauru improved steadily relative to superphosphate over the period of the trials so that Gafsa and CCIP gave higher yields than superphosphate in Year 3.

Over the 3-year period, there was little difference in total dry matter production between modes of application of all fertiliser forms except CCIP and CCIP-superphosphate, which gave greater yields when applied in a single massive dose (Table 1). Over succeeding years, however, the yields from superphosphate, Thermophos, CCIP, and CCIP-superphosphate applied in Mode 2 decreased relative to Mode 1 applications. Yields in the 2 Gafsa treatments were almost equal in each year and in the Nauru treatments they were very similar in Years 1 and 2 but Mode 2 yields decreased relative to Mode 1 in part Year 3.

For Year 1 it is possible to obtain an approximate appreciation of the relative efficiency of the fertilisers by comparing them at the 2 application rates and using the yield of the gypsum treatment of Trial A as the zero-phosphate point. Fig. 2 shows curves fitted for some treatments using the Mitscherlich equation. However, with only 3 application rates there is no possibility of assessing the goodness of fit and errors of estimate of these curves. No curve could be calculated for the Gafsa treatment. The maximum yield obtainable with phosphate was calculated as 8380 kg/ha for Thermophos. The horizontal line at 90% of this yield (7540 kg/ha) enables the fertiliser forms to be compared at the same level of production. Thus, in this first year 16 kg P as Thermophos was equivalent

Table 1 Dry matter production, Trial B, (kg/ha)[1].

Treatment	Part Year 1	Year 2	Part year 3	Whole trial[2]
Mode 1				
Superphosphate	7660	7260	5470	20390 (100)[3]
Nauru + gypsum	6110	5920	4470	16500 (81)
Gafsa + gypsum	6450	6490	4900	17930 (88)
CCIP + gypsum	6350	6480	4670	17500 (86)
CCIP-superphosphate + gypsum	7170	6720	5050	18940 (93)
Thermophos + gypsum	8080	7490	5330	20900 (103)
Nauru + sulphur	6170	6010	4500	16680 (82)
Mode 2				
Superphosphate	8270	7390	4510	20170 (99)
Nauru + gypsum	6220	5960	4230	16410 (80)
Gafsa + gypsum	6350	6610	4840	17800 (87)
CCIP + gypsum	7230	7140	4790	19160 (94)
CCIP-superphosphate + gyspum	8050	7210	4470	19730 (97)
Thermophos + gypsum	8380	7670	4600	20650 (101)
Nauru + sulphur	6450	6000	4020	16470 (81)
LSD, $P<0.05$	498	386	383	—
$P<0.01$	666	517	513	—
Forms of fertilisers				
Superphosphate	7965	7325	4990	20280
Nauru + gypsum	6165	5940	4350	16455
Gafsa + gypsum	6400	6550	4915	17865
CCIP + gypsum	6790	6810	4730	18330
CCIP-superphosphate + gypsum	7610	6965	4760	19335
Thermophos + gypsum	8230	7580	4965	20775
Nauru + sulphur	6310	6005	4260	16575
LSD, $P<0.05$	352	272	272	—
$P<0.01$	471	364	364	—
Mode of application				
1. Annual	6855	6625	4925	18405
2. Triennial	7065	6855	4495	18625
LSD, $P<0.05$	189	146	146	—
$P<0.01$	253	195	195	—
Significance of interaction	NS	NS	NS	—
Coefficient of variation (%)	5.0	4.0	5.7	—

[1] Yields from S-only treatment of Trial A were: Part year 1, 5192, Year 2, 5448; Part year 3, 3269, Whole trial 13909 kg/ha.
[2] Not statistically analysed
[3] Relative to superphosphate mode 1 = 100

approximately to 25 kg as superphosphate, 40 kg as the 1:3 CCIP-superphosphate mixture and by extrapolation, about 130 kg as CCIP although these assessments must be treated with caution. The 2 Nauru treatments yielded only slightly more at 93 kg/ha than at 31 kg/ha and the Gafsa treatment yielded less at the heavy rate. None of these rock phosphate treatments reached 90% of the maximum yield.

Comparisons such as this were not possible for Years 2 and 3 because of the complications introduced by interaction between the fresh Mode 1 applications and the residual effects of Mode 2.

After cutting was discontinued the residual effects of the fertilisers were assessed by fertility index pointing on 2 occasions in 1969 and one in 1970 (Table 2). In 1969 Thermophos and Nauru treatments were significantly better in Mode 1 than in Mode 2, but the other fertiliser forms showed no difference. In 1970 only Thermophos gave a significant difference between modes. Gafsa rock continued to improve relative to superphosphate and gave the highest pointing in 1970.

P concentration in herbage

Weighted mean annual concentrations are shown in Fig. 3. The Nauru + S treatment has been omitted for clarity and the gypsum-only treatment of Trial A has been included as a no-phosphate comparison. The mean data for seasons (not presented) showed a pronounced cyclic pattern, with higher P concentrations in the herbage in winter (which included the date of fertiliser application) when growth was least, and lowest in summer and autumn. The mean annual values for most forms in Mode 1 increased each year. Thermophos and superphosphate maintained highest P levels. CCIP-superphosphate gave values about 0.02% lower than these. CCIP and Gafsa gave significantly lower values ($P<0.01$) than CCIP-superphosphate. Concentrations were lowest in the Nauru treatments and did not increase with time.

In Mode 2, Thermophos, superphosphate, and CCIP-superphosphate treatments gave high P values initially. These declined throughout the 3 years with some seasonal fluctuations. CCIP and Gafsa gave

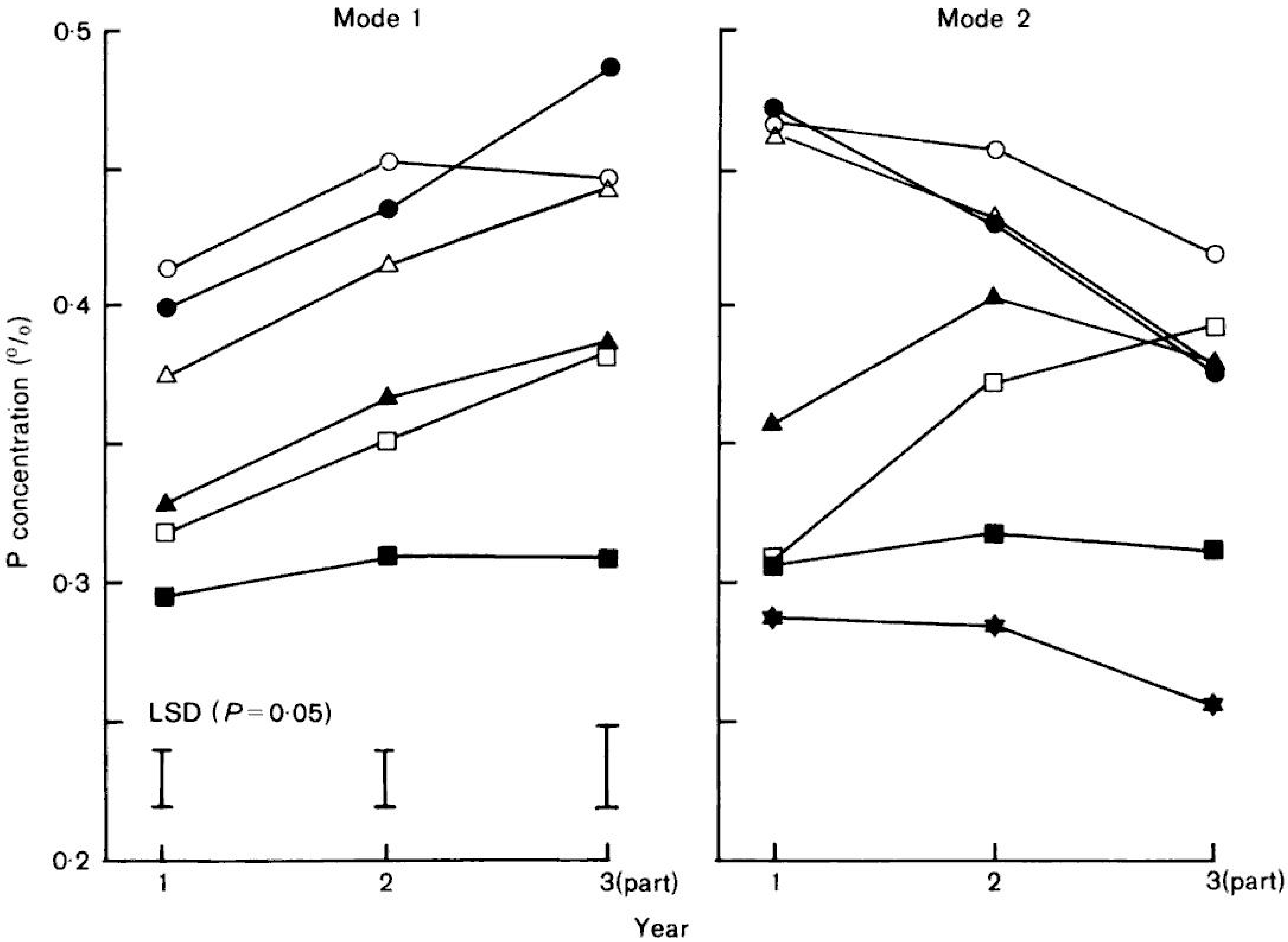

Fig. 3 Mean seasonal phosphorus concentrations in herbage. Key as in Fig. 1.

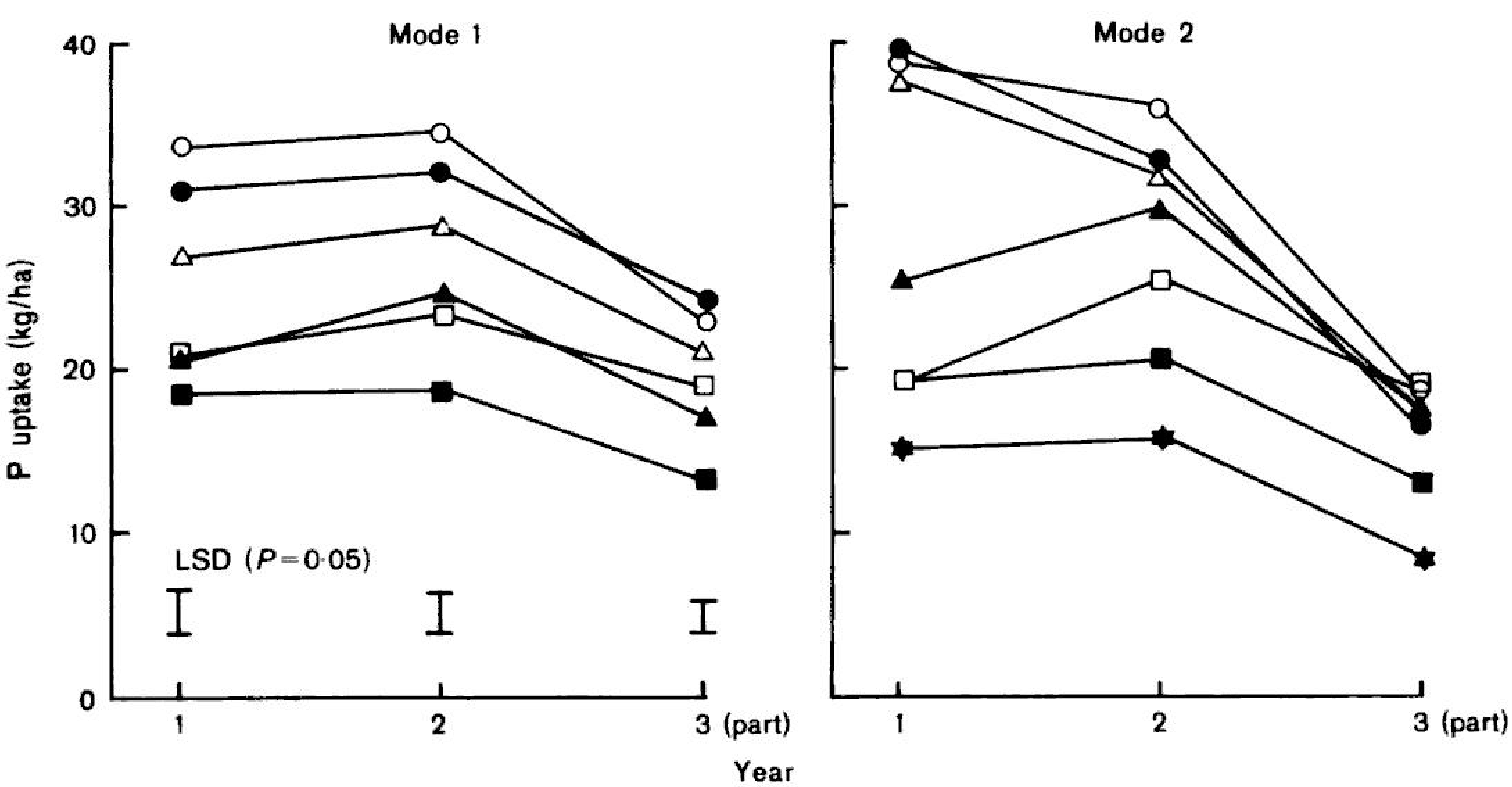

Fig. 4 Phosphorus uptake by herbage. Key as in Fig. 1.

Table 2 Fertility index assessment (0-20 scale).

Treatment	7 Sep 1969 and 28 Sep 1969 (Mean)	10 June 1970
Mode 1		
Superphosphate	11.9	10.5
Nauru + gypsum	10.7	9.7
Gafsa + gypsum	12.3	11.2
CCIP + gypsum	11.2	10.7
CCIP-superphosphate + gypsum	10.9	10.5
Thermophos + gypsum	12.7	11.2
Nauru + sulphur	11.1	9.7
Mode 2		
Superphosphate	10.9	10.7
Nauru + gypsum	9.4	10.3
Gafsa + gypsum	11.4	11.2
CCIP + gypsum	11.5	10.0
CCIP-superphosphate + gypsum	10.7	10.0
Thermophos + gypsum	10.9	10.0
Nauru + sulphur	9.6	9.2
LSD $P<0.05$	0.92	0.74
$P<0.01$	1.23	1.00
Forms of fertilisers		
Superphosphate	11.3	10.6
Nauru + gypsum	10.1	10.0
Gafsa + gypsum	11.8	11.2
CCIP + gypsum	11.4	10.4
CCIP-superphosphate + gypsum	10.8	10.3
Thermophos + gypsum	11.8	10.6
Nauru + sulphur	10.4	9.5
LSD $P<0.05$	0.66	0.51
$P<0.01$	0.88	0.69
Modes of application		
1. Annual	11.5	10.5
2. Triennial	10.6	10.2
LSD $P<0.05$	0.34	0.29
$P<0.01$	0.46	0.38
Significance of interaction	$P<0.05$	$P<0.05$
Coefficient of variation (%)	5.8	5.0

levels which were significantly lower than Thermophos, superphosphate, and CCIP-superphosphate in Years 1 and 2, but they were not significantly different from superphosphate and CCIP-superphosphate in part Year 3. The Nauru treatments gave low values with no significant differences between Mode 1 and Mode 2.

P uptake by herbage

Annual P uptake data are shown in Fig. 4. In Mode 1, superphosphate, Thermophos, and CCIP-superphosphate gave significantly higher ($P<0.01$) uptakes than did CCIP and the rock phosphates. In Mode 2, CCIP and Gafsa treatments improved with time relative to the more reactive fertiliser forms and in Year 3, P uptakes were similar to those from superphosphate and Thermophos.

Phosphate fractions

Four fractions of inorganic soil phosphate were measured. Changes in the Al-P, Fe-P, and Ca-P fractions in annual soil samples from Trial B are shown in Fig. 5-7. Because occluded-P determinations were more variable than those of the other fractions and showed no clear pattern of changes, data for this fraction have not been presented. Values for the gypsum treatment of Trial A are included in Mode 2 of Fig. 5-7 to give a comparison with zero phosphate application.

Annual applications of superphosphate, Thermophos, CCIP, and CCIP-superphosphate gave steady increases in Al-P levels (Fig. 5). Al-P levels remained almost constant in the Gafsa treatment and declined steadily in the Nauru treatments.

For Mode 2 there were large increases in Al-P for the 4 most reactive fertilisers in the year after application. Levels then declined steadily in the following 2 years. The Nauru treatment gave a decrease in Al-P very similar to that for Mode 1 and for the no-phosphate treatment of Trial A. Gafsa gave a very small decrease in Al-P levels.

In Mode 1 Fe-P levels declined in Year 1 with all fertilisers, followed by increases in Years 2 and 3

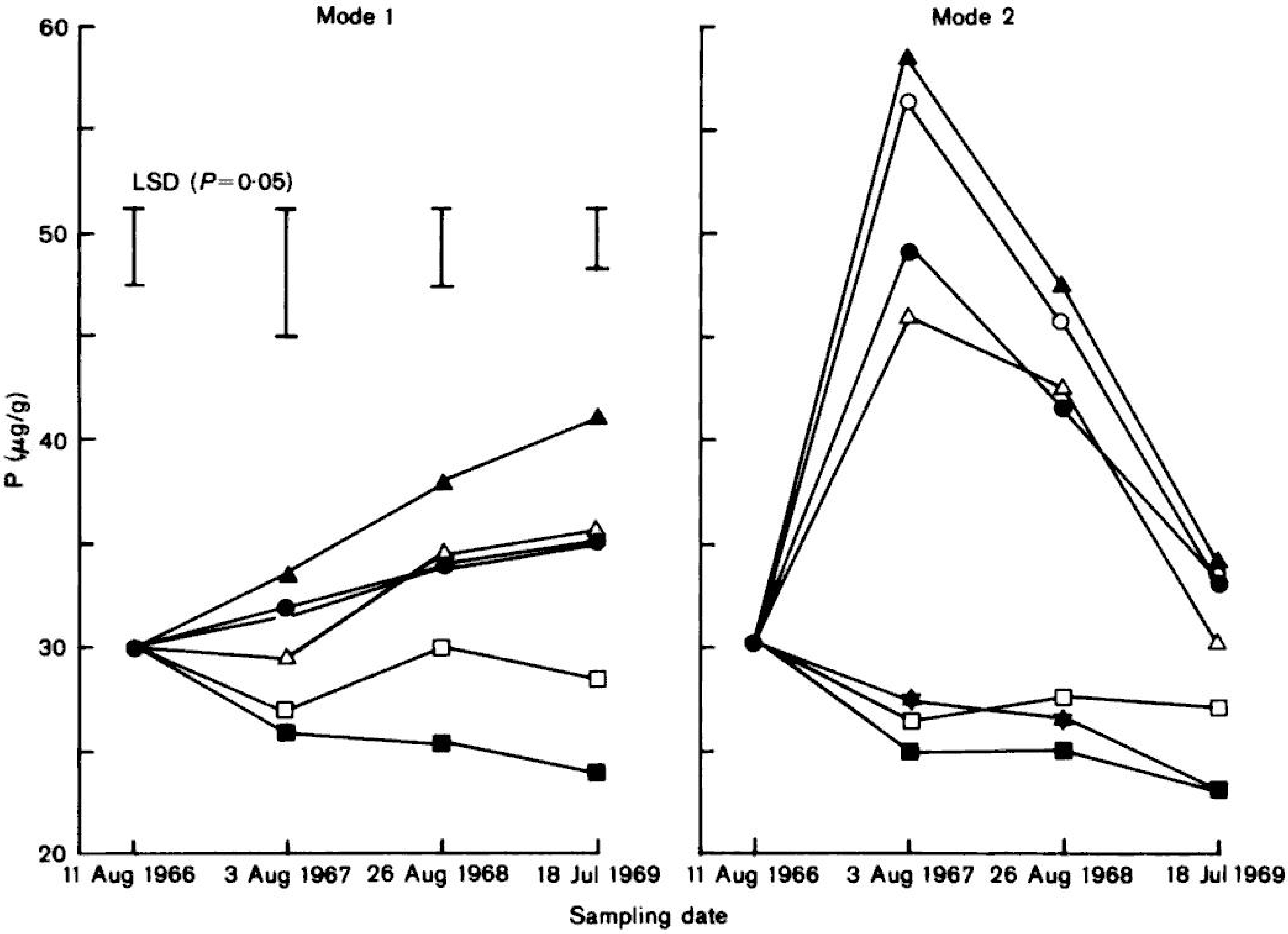

Fig. 5 Al-P phosphate fractions. Key as in Fig. 1.

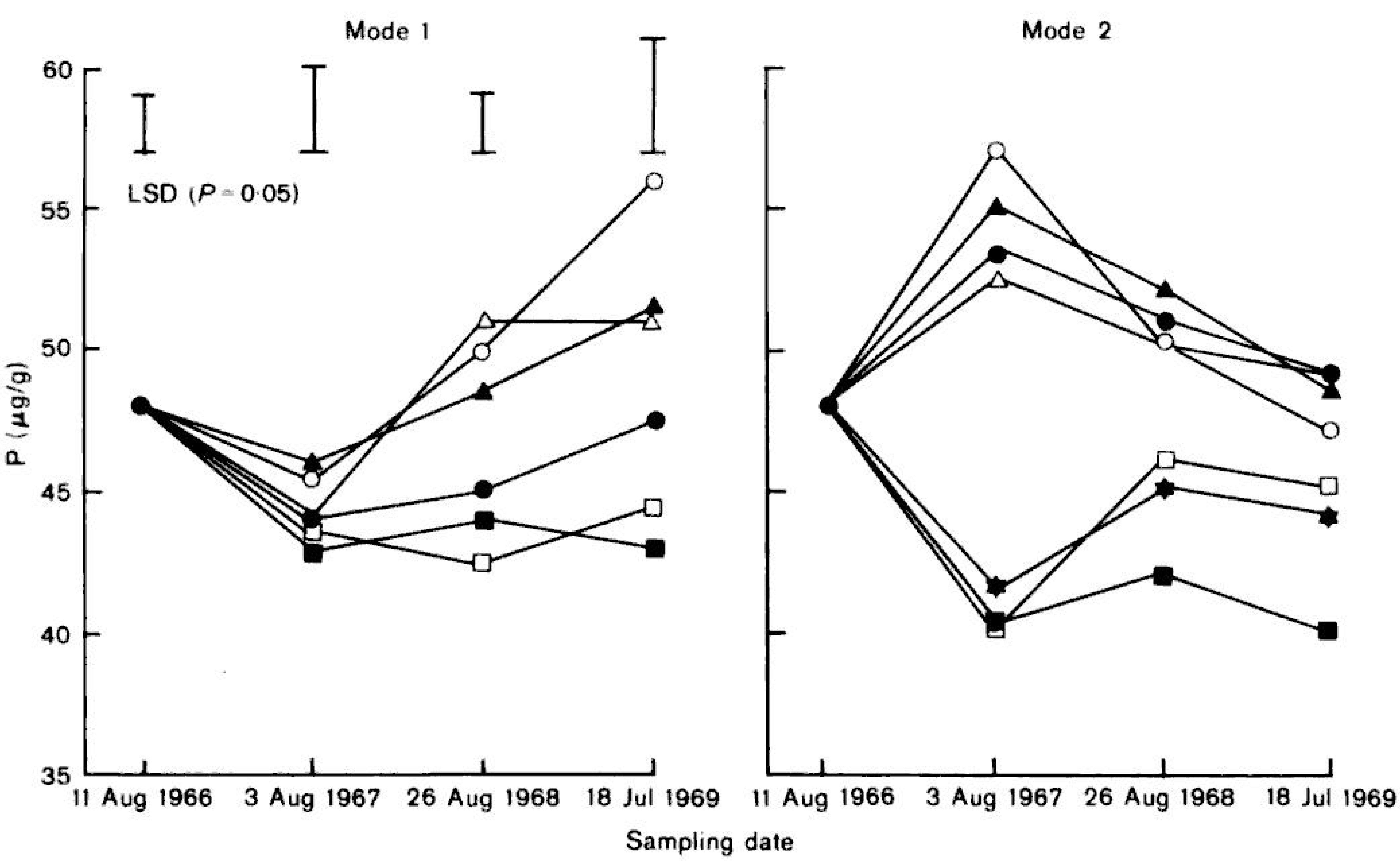

Fig. 6 Fe-P phosphate fractions. Key as in Fig. 1.

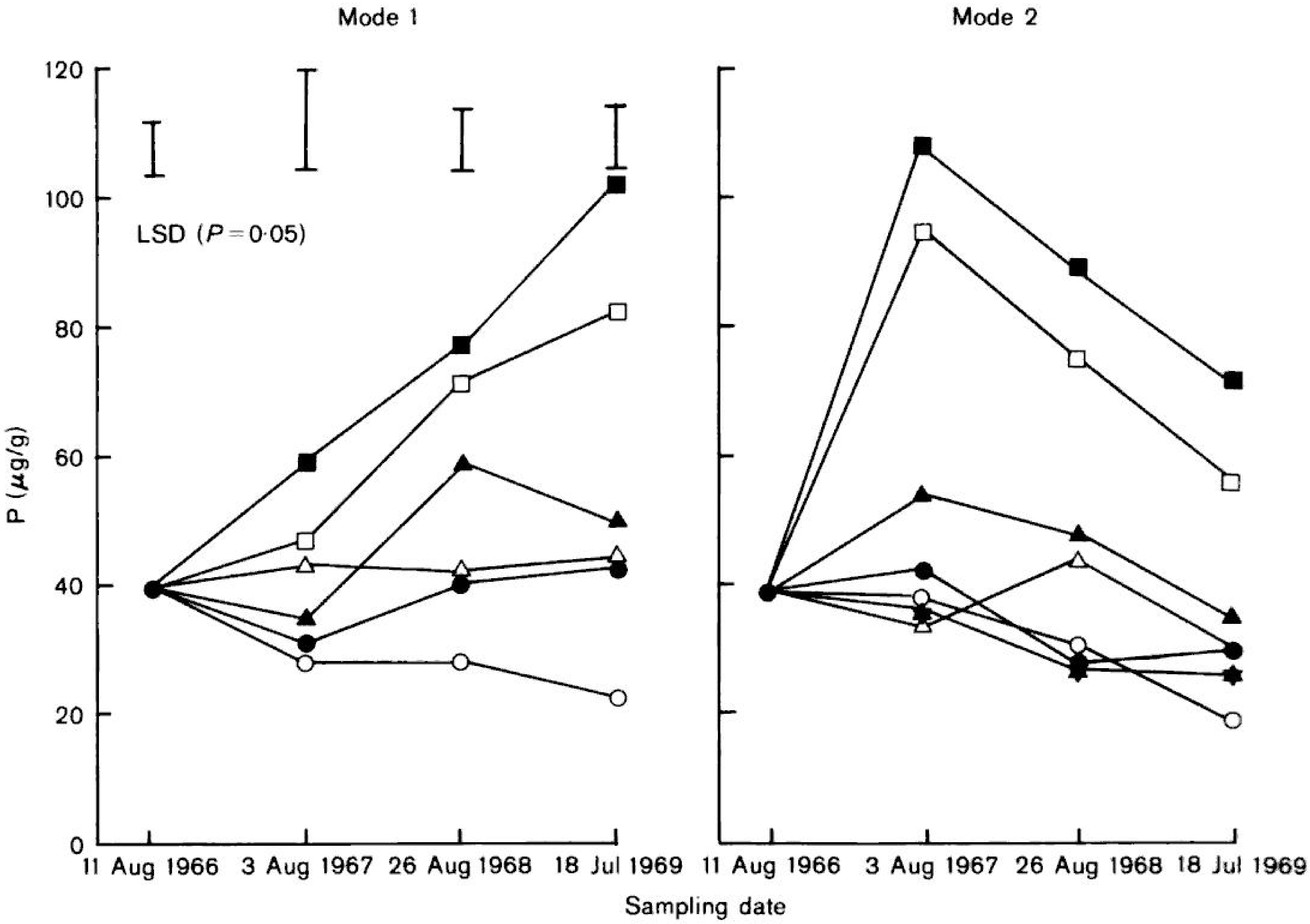

Fig. 7 Ca-P phosphate fractions. Key as in Fig. 1.

except for Gafsa and Nauru which were almost constant (Fig. 6). For Mode 2 the pattern of changes was similar to that for Al-P (Fig. 5).

Ca-P levels increased considerably with annual applications of Nauru and Gafsa rock phosphates (Fig. 7). CCIP gave a slight increase in Years 2 and 3 but levels in the superphosphate and CCIP-superphosphate treatments did not change, whereas in the Thermophos treatment they declined. In Mode 2 there were large increases in Ca-P after one year for the rock phosphates and a smaller increase for CCIP, followed by steady declines in Years 2 and 3. Superphosphate, Thermophos, and CCIP-superphosphate showed no build-up of Ca-P in Year 1 and values decreased steadily with time in these 3 treatments.

Available phosphate, Bray No. 1 test (Fig. 8)

Annual applications gave slight but non-significant increases in Bray-P test values with Thermophos and CCIP, but little change with superphosphate. Nauru failed to maintain the initial soil test level. For Gafsa the test level decreased in the first and second years but improved in the final year.

Applications in Mode 2 resulted in a very large increase in Bray-P test for Thermophos after one year, with smaller but highly significant increases for superphosphate, CCIP-superphosphate, and CCIP. Levels for these 4 fertilisers then decreased steadily in the second and third years to the initial soil test level. In the Nauru and Gafsa treatments, Bray-P levels fell below the initial value after 1 year and then remained steady.

Available phosphate, Olsen test (Fig. 9)

Because the results for this test are means of duplicate analyses of composite samples for each treatment, the LSD values are therefore rather high.

As with the Bray-P test, annual applications resulted in only slight increases in Olsen-P for all forms except Nauru which decreased steadily over the 3 years.

For Mode 2, the Olsen test was highest for Thermophos, followed in order by superphosphate, CCIP-superphosphate, CCIP, Gafsa, and Nauru. Values increased markedly after one year and then decreased as with the Bray test and the Al-P and Fe-P fractions.

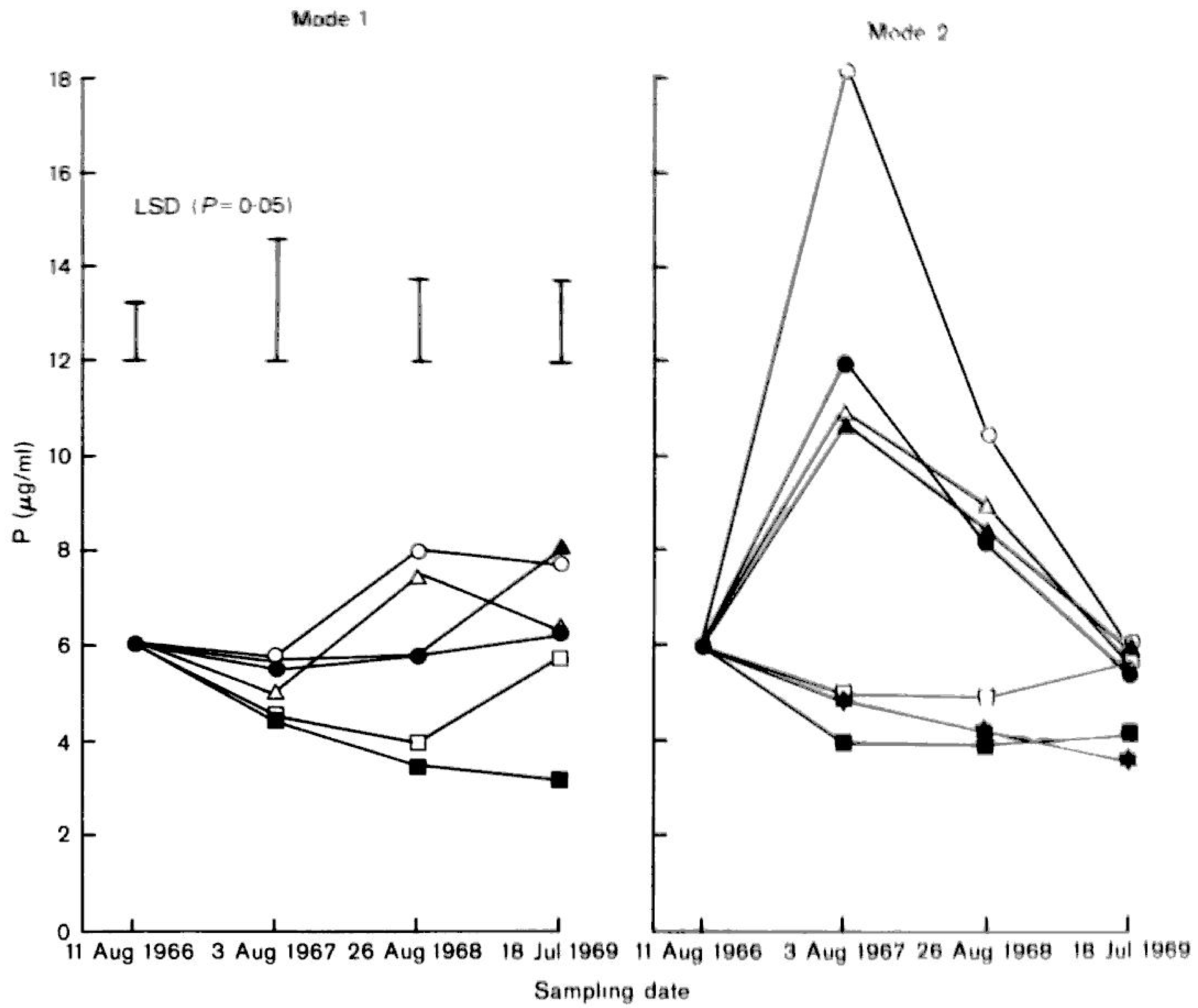

Fig. 8 Bray No. 1 P test values. Key as in Fig. 1.

Table 3 Correlation coefficients between DM yields and soil P tests.

Correlation	Bray test	Olsen test
Yield 11 Aug 1966–3 Aug 1967 v. mean 11 Aug 1966 and 3 Aug 1967 soil samples	0.793**	0.869**
Yield 4 Aug 1967–26 Aug 1968 v. mean 3 Aug 1967 and 26 Aug 1968 soil samples	0.888**	0.872**
Yield 27 Aug 1968–18 Dec 1968 (3½ months) v. mean 26 Aug 1968 and 18 July 1969 soil samples	0.631*	0.611*
Yield 4 Aug 1967–26 Aug 1968 v. soil tests 3 Aug 1967 (Mode 2 only)	0.832*	0.905**
Yield 27 Aug 1968–18 Dec 1968 (3½ months) v. soil tests 26 Aug 1968 (Mode 2 only)	0.496	0.543

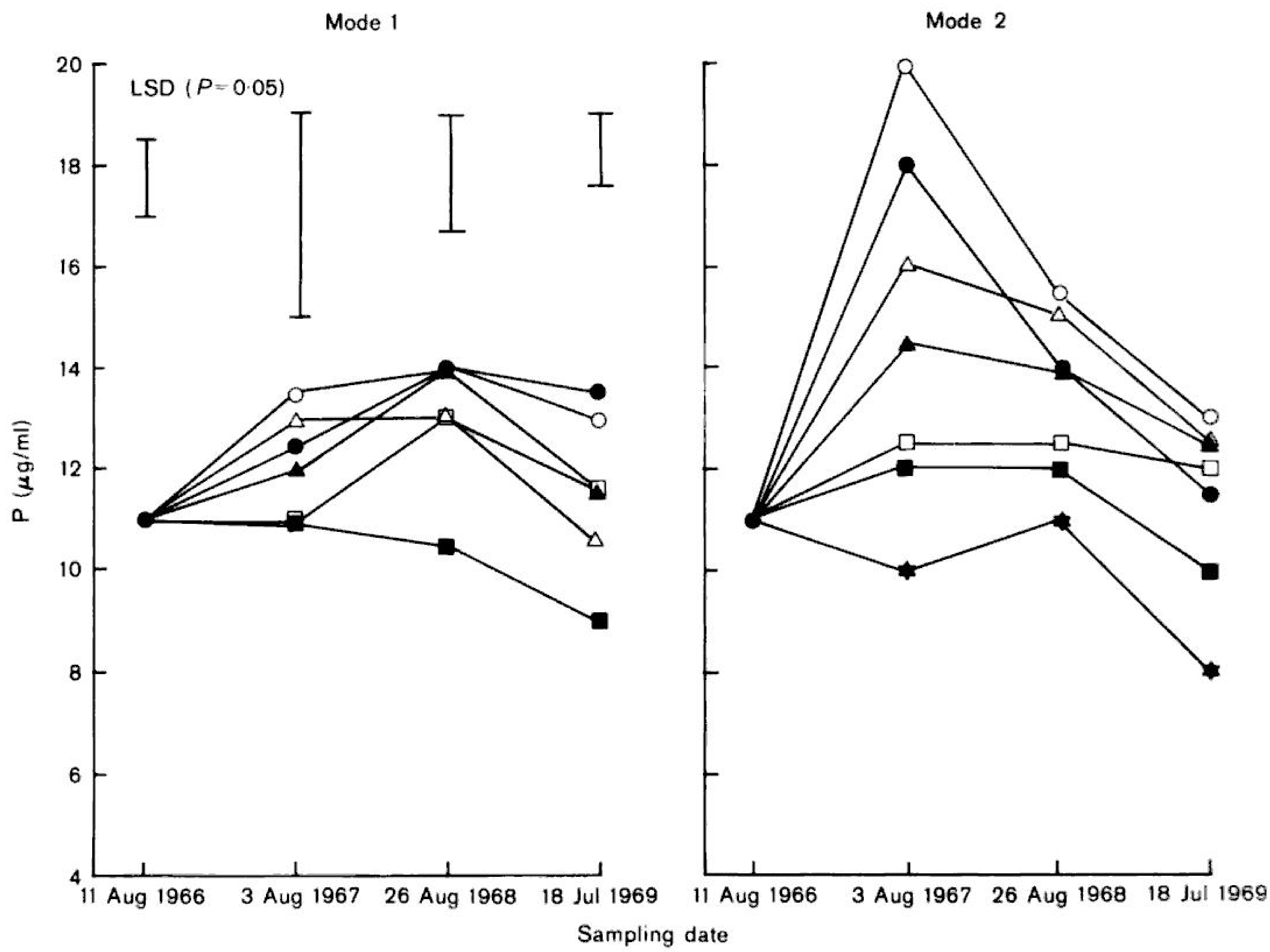

Fig. 9 Olsen P test values. Key as in Fig. 1.

Relations between yields and soil tests

If the Bray and Olsen P tests give true assessments of plant-available P irrespective of the form in which it is applied, there should be close relationships between yields and mean soil tests for each year, or, in the residual-P situation, the soil test at the start of the year. To test this, correlation coefficients were calculated as listed in Table 3. The yields used for these calculations were yields between soil sampling dates and not those shown in Table 1.

DISCUSSION

Dry matter production

The site soil responded well to phosphate addition (Trial A), DM yield increasing from 22 to 54% over the 2.5 years, and was therefore quite suitable for comparing the effects of the fertiliser forms. These gave annual yields ranging from 80 to 106% of the yield achieved with superphosphate when applied annually, and 75 to 108% when applied in one heavy dressing (Fig. 1).

The fertiliser forms could be ranked similarly for either mode of application. Over the whole trial period the order of relative efficiency was: Thermophos> superphosphate>CCIP-superphosphate> CCIP = Gafsa>Nauru. This ranking is very similar to that obtained in the trial on Kokotau silt loam reported in Part II (Grigg & Crouchley 1980).

However, in the present trial CCIP and Gafsa treatments applied in Mode 2 showed a relatively greater improvement with time, both in yield (Fig. 1) and in P concentration (Fig. 2) and uptake (Fig. 3), possibly because of (a) a lower initial phosphate status, (b) a greater phosphate retention capacity which would cause a decrease in response from the more reactive fertilisers and (c) moister soil conditions allowing more rapid solution of CCIP and Gafsa. However, because the soil pH levels were higher (6.5 falling to 6.1), rates of reactivity should have been slower than in the trial on Kokotau silt loam at pH 5.5.

If the errors associated with the curves in Fig. 2 are ignored, Thermophos would be rated in the first year as 1½ times as effective as superphosphate, CCIP-superphosphate ⅔ as effective, and CCIP only ⅓ as effective. Theoretically the CCIP-superphosphate mixture should have been at least 75% as efficient as superphosphate. The CCIP component of the mixture appears to have had a negative effect, no doubt because of chemical reversion of water-soluble phosphate in the superphosphate component by the CCIP. As shown in Part I, Table 3 (Grigg 1980), the superphosphate used had 75% of its phosphate in water-soluble form, whereas the ⅓ mixture contained only 45% water-soluble phosphate as against a calculated value of 56% if there was no interaction between the 2 components.

Herbage P concentration and uptake

A herbage P concentration of 0.35–0.40% is accepted as being adequate for growth of grasses and clovers (McNaught 1969). Mean annual concentrations were in or above this range at all times for superphosphate, Thermophos, and CCIP-superphosphate in both modes of application and for MCP in Trial A. Mean annual values for CCIP and Gafsa were below 0.35% in Year 1 but above this critical level in Years 2 and 3. Because of the seasonal cycle of P concentration mentioned above, the herbage on these 2 treatments would be regarded as slightly P-deficient in the summer and autumn of all 3 years for Mode 1 and in Year 1 for Mode 2. In the Nauru treatments, P concentration were below 0.35% at all seasons.

The increase in efficiency of the heavy application of CCIP and Gafsa with time is seen in both the P concentration data (Fig. 3) and the P uptake data (Fig. 4). In the third year of the trial, these 2 forms improved to give P uptake values equal to superphosphate, although over the whole trial period they gave only 71% and 83% of the uptake from superphosphate respectively.

Soil phosphate changes

The pattern of changes in soil phosphate fractions is similar to that found on Kokotau silt loam (Part II, Grigg & Crouchley 1980). As pointed out, the fractions measured do not necessarily represent products of reaction with the soil. The high Al-P levels with CCIP and Thermophos (Fig. 5) can result from direct solution of unreacted fertiliser by the NH_4F extractant. Likewise the high Ca-P values from Nauru and Gafsa treatments (Fig. 7) indicate that even after 3 years a portion of the fertilisers is still present as unreacted apatite, although the softer Gafsa rock has reacted more than the Nauru.

Superphosphate and Thermophos would react with the soil more rapidly. In Mode 1 Ca-P levels were practically constant for superphosphate (possibly because of a small amount of residual apatite in the superphosphate) and decreased with Thermophos. In Mode 2 they decreased with both fertilisers giving Ca-P levels very similar to the gypsum treatments of Trial A (Fig. 7).

The Bray and Olsen P tests support the ranking of the fertilisers given above, although the Bray No. 1 test seems to overrate the Thermophos and CCIP treatments relative to superphosphate. The correlations between annual yields and the P tests (Table 3) show that both methods are capable of assessing the relative availability of the fertiliser forms. Within time periods, there were no significant differences between the correlation coefficients for each soil test.

General comparison

The findings of this trial support the conclusions from the Kokotau silt loam trial (Grigg & Crouchley 1980) and confirm that CCIP alone is an inefficient fertiliser compared with superphosphate and that when used as an extender in a mixture 1:3 with superphosphate it has a deleterious effect by chemical reversion of the water-soluble phosphate.

As in the first trial, there was no significant difference between Nauru + Gypsum and Nauru + S, possibly because the phosphate was not intimately mixed with the S and the sulphuric acid formed by sulphur oxidation would be neutralised in the soil before it could react with the rock phosphate.

Thermophos gave higher yields than superphosphate when compared with modes of application, although the increases were statistically significant only for Mode 1 in Year 1. P concentrations were usually higher for Thermophos than for superphosphate, although in Mode 1 they were higher for superphosphate in the winter periods following topdressing. The superiority of Thermophos appeared to be associated with its ability to maintain higher available phosphate levels in the soil.

Although total DM production over the whole trial period was similar for both modes of application of the more reactive fertilisers, production was more uniform if the fertilisers were applied annually, and annual applications would be recommended.

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