# A COMPARISON OF PHOSPHATIC FERTILISERS

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## Summary

A trial was laid down in February 1951 at Invermay Research Station to investigate pasture responses from several forms of phosphatic fertilisers in the presence and absence of lime.

The phosphatic fertilisers used were superphosphate, serpentine superphosphate, Thermophos, and North African and Nauru ground-rock phosphates. Lime treatments were: nil, 10 cwt, and 20 cwt annually.

Over a five-year period, Thermophos and serpentine superphosphate gave similar yields to superphosphate when compared on the basis of equivalent amounts of $P_2O_5$ per acre.

North African phosphate proved comparable to superphosphate in the absence of lime, but inferior in the presence of lime. Nauru rock phosphate proved inferior to the other treatments.

Lime increased yields slightly in the superphosphate, serpentine superphosphate, and Thermophos plots, but depressed yields in the North African and Nauru rock-phosphate treatments.


## INTRODUCTION

About the end of 1950 a world-wide sulphur shortage developed as a result of greatly increased consumption combined with exhaustion of some of the main sulphur deposits in America.

As New Zealand is dependent on overseas supplies of sulphur for the manufacture of sulphuric acid used in the preparation of superphosphate, a shortage of sulphur could seriously disrupt the fertiliser industry. A search for non-sulphurous alternatives to superphosphate thus became a matter of national importance, and trials were laid down over a wide range of soil types. These trials included North African and Nauru ground-rock phosphates, basic slag, serpentine and lime-reverted superphosphates, and several calcium-magnesium fused phosphates recently developed in America.

One of these, Thermophos, had previously shown promise in preliminary trials in New Zealand (Lynch 1951).

## EXPERIMENTAL

### *Details of Fertilisers Used*

*Serpentine superphosphate* is made by combining three parts of superphosphate with one part of serpentine rock. The resultant dicalcic phosphate is a non-acid fertiliser of excellent physical texture (Holford 1943; Grimmett and Elliott 1951). Elliott (1944) found over a wide range of soils that serpentine superphosphate was comparable to superphosphate on an equivalent-weight basis. More recent results from mowing trials, however, suggest that serpentine superphosphate is comparable to superphosphate only on a basis of equivalent $P_2O_5$ content (Lynch 1951; Van der Elst and Karlovsky 1953). Trials in England showed serpentine superphosphate to be equal or in some cases superior to superphosphate for reseeding pasture on acid hill soils (Cook 1956). However, serpentine superphosphate generally proved inferior under Australian conditions (Grimmett and Elliott 1951).

*Thermophos* is one of a group of fused calcium-magnesium phosphates manufactured by melting a magnesium silicate such as olivine or serpentine with phosphate rock in an electric-arc furnace and rapidly cooling the melt in high-pressure streams of water. The process was developed by the Tennessee Valley Authority in America (Walthall and Bridger 1943) and has since been used commercially in both America and Japan (Kusugai *et al.* 1949; Huang 1953; Bridger 1951). "Thermophos" is the trade name for a fused phosphate formerly manufactured by the Permante Metals Corporation in California, U.S.A., from serpentine and Idaho rock phosphate.

Calcium magnesium phosphate is a granular greenish material with grains about the size of coarse sand (Hill *et al.* 1948). When finely pulverised it is highly soluble in 2% citric acid, though insoluble in water. Its total $P_2O_5$ content is about 23%.

As calcium magnesium phosphate is non-corrosive and free-running, and does not cake or absorb water, it is ideal for bulk handling and aerial distribution.

It is a basic phosphate which is most suited to acid and neutral soils, its effectiveness being reduced in alkaline areas (Huang 1953). Results from three pot trials conducted in Norway showed Thermophos to be superior to monocalcic phosphate on acid soils of pH 4.5–5.5 but not on limed soils with a pH from 6.2–6.8 (Cook 1956).

Results in New Zealand have indicated that Thermophos is equivalent or slightly superior to superphosphate when applied at equivalent $P_2O_5$ content on slightly acid soils. (Lynch 1951; Van der Elst and Karlovsky 1953; Karlovsky 1957). Calcium magnesium phosphate has an important liming value, one ton of the material supplying the equivalent of about three-quarters of a ton of lime.

Since these fused phosphates contain a high percentage of readily available magnesium they are likely to be of particular benefit on magnesium-deficient areas.

*North African Rock Phosphate* (*Gafsa*) has been used in high-rainfall districts in New Zealand for many years, mainly on acid hill soils where it has compared favourably with superphosphate. Results have been poor, however, on limed soils and in drier districts (Lynch 1951).

In English trials Cook (1956) found ground North African rock phosphate to be less effective than superphosphate for establishing pasture and on established grassland even under acid conditions.

*Nauru Rock Phosphate* is a high-grade rock containing about 36% total $P_2O_5$ of which up to 8% is citric soluble. Ground Nauru rock phosphate has been included in a number of trials in New Zealand, but results generally have been poor, Nauru being inferior to superphosphate and even North African rock phosphate in most trials (Lynch 1951; Cottier 1952; Cullen 1954). Mixtures of Nauru rock with superphosphate have also been tried but have not given encouraging results (Cottier 1952).

*Design of Trial*

A replicated mowing trial was laid down at Invermay Research Station in March 1951 incorporating the following treatments:

1. Control—no phosphate
2. Superphosphate 3 cwt per acre per annum
3. North African phosphate (Gafsa) 3 cwt per annum
4. Ground Nauru rock phosphate 3 cwt per annum
5. Ground Nauru rock phosphate 10 cwt initially and 3 cwt per annum subsequently
6. Thermophos } equivalent $P_2O_5$ content to 3 cwt
7. Serpentine superphosphate } superphosphate per annum

*Lime* (pure carbonate basis), (a) Nil, (B) 10 cwt per annum, (C) 20 cwt per annum.

A basal dressing of 1 cwt muriate of potash was applied over the whole trial at laying down.

A split-plot latin-square design was chosen with the lime treatments as the main plots and the phosphatic fertilisers as the sub-plots. Plot size was 30 x 6 ft. This allowed for two 2-ft cuts to be taken from each plot. The technique adopted was "mowing and clippings returned" (Lynch 1947). This technique is suitable for fertiliser trials as no transference of fertility can occur between plots while a good measure of the relative production is obtained.

The trial was laid down on a three-year-old sward in which ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) were the dominant species and cocksfoot (*Dactylis glomerata*), Montgomery red clover (*Trifolium pratense*), and weed grasses subdominants. The clovers were rather pale and unthrifty. This was subsequently shown to be due to molybdenum deficiency.

After spectacular molybdenum responses were obtained at the Station in 1951 (Holmes *et al.* 1951), a basal dressing of 1¼ oz/acre of sodium molybdate was applied to the trial in September 1951.

*Soil Tests*

Soil samples were drawn from all treatments in 1954, 1955, and 1956 and tested for pH levels and for available phosphate by the method of Truog (1930).

*Soils*

The trial area is located on a level site in the lower foothills at Invermay Research Station at an altitude of approximately 300 ft.

The soil is a silt loam overlying clay similar to the Warepa series of yellow-grey earths which occur throughout South Otago. The parent material is mainly phonolitic volcanic rock which has been covered in most places by loess soils deposited to varying depths.

The texture of the soil is inclined to be heavy, leading to impeded drainage and cultivation difficulties.

In its natural state the nutrient status is low, the soil being deficient in calcium, phosphorus, and molybdenum. No marked sulphur deficiency has been demonstrated.

The trial site had received some lime and phosphatic fertiliser prior to 1951, but despite these dressings the calcium and phosphorus levels were low and the area was considered suitable for investigating phosphate and lime responses and interactions.

*Climate*

The annual rainfall average for the district is approximately 27 in. Although distribution is fairly even throughout the year, droughts are experienced periodically during the summer months. Growth normally commences during September, reaches its peak about the end of November, and falls off during January and February. A slight autumn flush may occur during March and April, but growth has usually ceased by May except for short-rotation ryegrass and other winter-growing species.

The normal pattern of growth results in grasses dominating during the spring and clovers in the summer. Phosphatic fertiliser applied during the late summer and autumn months has been shown to result in improved winter and early spring growth (Cullen 1954), and the fertiliser applications were made in March for this reason.

## RESULTS

Five seasons' results are now available from this trial. Excellent phosphate responses were obtained throughout the five years, superphosphate, Thermophos and serpentine superphosphate, proving superior to the rock phosphates. North African phosphate was almost as good as the more soluble phosphates in the absence of lime, but yields were inferior in the presence of lime. Nauru rock phosphate even at the 10 cwt initial application rate gave poor results generally, inferior to North African rock phosphate.

Lime at both rates increased yields slightly in the superphosphate, Thermophos and serpentine superphosphate plots, but depressed yields considerably in the rock-phosphate treatments.

During the first two years, samples taken for dry matter determination were bulked from the three replicas of each treatment and statistical analysis of the dry-matter yields was therefore not possible. Although the green weights have been subject to statistical analysis, these results are somewhat misleading because of differences in dry-matter percentages between treatments. The dry-matter percentage

TABLE 1. SUMMARY OF DRY MATTER YIELDS (lb/ac) RELATIVE TO NO PHOSPHATE NO LIME (100)

| Treatment | 51/52 | 52/53 | 53/54 | 54/55 | 55/56 | Total D.M. (lb/ac.) | Total D.M. (rel.) |
|---|---|---|---|---|---|---|---|
| *No Lime* | | | | | | | |
| No phos. | 100 | 100 | 100 | 100 | 100 | 24,270 | 100 |
| Super. | 133 | 160 | 202 | 157 | 135 | 38,240 | 158 |
| N. Afr. | 134 | 144 | 192 | 161 | 133 | 37,060 | 153 |
| Nauru 3 | 118 | 125 | 158 | 146 | 135 | 33,160 | 137 |
| Nauru 10 | 130 | 141 | 174 | 149 | 131 | 35,240 | 145 |
| Thermophos | 138 | 160 | 204 | 168 | 138 | 39,280 | 162 |
| Serp. super | 127 | 147 | 200 | 164 | 142 | 37,960 | 156 |
| *10 cwt Lime* | | | | | | | |
| No phos. | 103 | 101 | 130 | 123 | 117 | 27,820 | 115 |
| Super. | 133 | 175 | 219 | 178 | 148 | 41,630 | 172 |
| N. Afr. | 110 | 123 | 166 | 148 | 135 | 33,210 | 137 |
| Nauru 3 | 114 | 121 | 151 | 137 | 123 | 31,370 | 129 |
| Nauru 10 | 117 | 132 | 168 | 146 | 118 | 33,110 | 136 |
| Thermophos | 133 | 162 | 222 | 177 | 141 | 40,630 | 167 |
| Serp. super. | 129 | 153 | 214 | 170 | 133 | 39,270 | 162 |
| *20 cwt Lime* | | | | | | | |
| No phos. | 96 | 99 | 133 | 126 | 116 | 27,710 | 114 |
| Super. | 138 | 168 | 219 | 167 | 134 | 40,120 | 165 |
| N. Afr. | 111 | 119 | 174 | 146 | 136 | 33,220 | 137 |
| Nauru 3 | 104 | 106 | 146 | 128 | 128 | 29,690 | 122 |
| Nauru 10 | 114 | 128 | 178 | 151 | 132 | 34,200 | 141 |
| Thermophos | 135 | 163 | 224 | 175 | 131 | 40,240 | 166 |
| Serp. super. | 128 | 159 | 221 | 176 | 147 | 40,410 | 167 |
| Sig. dif. 5% | Not Available | | 16 | 12 | 13 | Not Available | |
| 1% | | | 21 | 16 | 18 | | |

of the control plots was normally much higher than that from the more efficient phosphate treatments.

Significant differences are quoted only for the years in which statistical analysis of dry weights was possible. The figures quoted are for comparisons between phosphate treatments with the same lime treatment.

*Response to the Various Fertilisers*

*Thermophos* proved as good as superphosphate in this trial both in the acid no-lime treatments and in the limed plots. At no time were marked differences apparent either in seasonal or yearly production between these two fertilisers.

*Serpentine superphosphate* also proved comparable to superphosphate over the five year period, being slightly inferior in the first two years but at least as good in the final years. However, it must be remembered that Thermophos and serpentine superphosphate were compared with superphosphate on an equivalent $P_2O_5$ basis, not on an equal-weight basis.

*North African phosphate* proved comparable to superphosphate only in the absence of lime, yields being depressed considerably by both rates of lime.

*Nauru rock phosphate* was inferior to North African rock phosphate at similar rates, and even at 10 cwt initially and 3 cwt subsequently proved no better than 3 cwt of North African rock phosphate. At some cuts the Nauru plots yielded little more than the controls.

On this soil type it is evident that Nauru rock phosphate even when applied at high initial rates is of limited value and offers little promise as a substitute for superphosphate.

*Results for Each of the Five Seasons*

*1951–52.* Phosphate yields were about 30% above control, Thermophos and superphosphate being slightly but significantly better than serpentine superphosphate (in green yields).

The rock-phosphate treatments compared favourly with Thermophos and superphosphate in the no-lime plots, but were significantly poorer in the presence of lime.

*1952-53.* Excellent responses were noted, especially in the superphosphate, Thermophos and serpentine superphosphate plots. The rock-phosphate treatments continued to yield well (though less than superphosphate) in the unlimed plots but poorly in both limed series. Serpentine superphosphate was again slightly inferior to superphosphate and Thermophos.

*1953-54.* The best treatments yielded more than double control, differences being greatest in the late autumn, winter, and early spring. In this season the limed control plots for the first time showed a significant increase in dry-matter yields compared with the unlimed controls. Dry-matter yields from the superphosphate, Thermophos, and serpentine superphosphate plots were comparable; a significant depression again occurred in the North African plots.

*1954-55.* Although the magnitude of response was less than the previous year, differences were still marked. The prevoius year's trends continued, with superphosphate, Thermophos, and serpentine superphosphate showing a response to lime, and North African and Nauru rock phosphates the usual decrease in the presence of lime. The limed controls again yielded significantly higher than those without lime.

*1955-56.* Dry conditions throughout the summer and autumn led to reduced yields and smaller phosphate responses. In the no-lime series, differences between the phosphate treatments were small. In the 10 cwt lime series, superphosphate gave the best response, being significantly better than serpentine superphosphate. However, in the 20 cwt lime series both superphosphate and Thermophos were significantly (5%) poorer than serpentine superphosphate, while superphosphate was significantly poorer in the 20 cwt than in the 10 cwt lime series. The reason for this is not clear.

TABLE 2. SEASONAL DRY-MATTER PRODUCTION. RELATIVE TO SUPERPHOSPHATE (100)

| Treatment | Spring | Summer | Autumn | Total D.M. (lb/ac.) | Total D.M. (rel.) |
|---|---|---|---|---|---|
| *No Lime* | | | | | |
| No phos. | 65 | 68 | 47 | 24,270 | 63 |
| Super. | 100 | 100 | 100 | 38,240 | 100 |
| N. Afr. | 96 | 100 | 91 | 37,060 | 97 |
| Nauru 3 | 88 | 90 | 71 | 33,160 | 87 |
| Nauru 10 | 92 | 96 | 81 | 35,240 | 92 |
| Thermophos | 102 | 104 | 101 | 39,280 | 103 |
| Serp. super. | 102 | 96 | 99 | 37,960 | 99 |
| *10 cwt Lime* | | | | | |
| No phos. | 71 | 69 | 45 | 27,820 | 67 |
| Super. | 100 | 100 | 100 | 41,630 | 100 |
| N. Afr. | 83 | 83 | 59 | 33,210 | 80 |
| Nauru 3 | 78 | 80 | 53 | 31,370 | 75 |
| Nauru 10 | 82 | 83 | 63 | 33,110 | 80 |
| Thermophos | 96 | 102 | 95 | 40,630 | 98 |
| Serp. super. | 93 | 94 | 92 | 39,270 | 94 |
| *20 cwt Lime* | | | | | |
| No phos. | 73 | 74 | 45 | 27,710 | 69 |
| Super. | 100 | 100 | 100 | 40,120 | 100 |
| N. Afr. | 86 | 86 | 65 | 33,220 | 83 |
| Nauru 3 | 79 | 78 | 49 | 29,690 | 74 |
| Nauru 10 | 88 | 89 | 66 | 34,200 | 84 |
| Thermophos | 97 | 108 | 95 | 40,240 | 100 |
| Serp. super. | 100 | 103 | 98 | 40,410 | 101 |



### *Seasonal Responses*

This table indicates that the response to serpentine superphosphate and Thermophos during the spring, summer and autumn was as good as or better than that from superphosphate.

In most years responses have followed a fairly consistent pattern. Greatest phosphate responses have been noted during the late autumn, winter, and early spring, when growth is at a minimum. At this time, production from the best treatments may be several times that of the control, e.g., a cut taken during June 1953 showed production from the superphosphate, Thermophos, and serpentine superphosphate treatments to be more than three times that from the control treatment. At the time of cutting it was observed that short-rotation ryegrass was contributing the bulk of the herbage in these plots.

During the spring months, when growth was at a maximum, responses to all phosphatic treatments were small. During October in 1954 and 1955 the phosphate response was less than 10%. At this time of the year grasses assume dominance and even the normally low-producing weed grasses provide a large bulk of herbage. The folly of relying entirely on results from one or two hay cuts taken at a time when differences are normally at a minimum, is apparent. During the summer, a response intermediate between that of the out-of-season cuts and the peak spring-growth period was normally recorded, the extent of the response being largely dependent on weather conditions. Under abnormal drought conditions, little if any response may be recorded. This would be expected where all herbage is dried off.

*Lime Responses*

No marked response to either rate of lime was noted in the first season, though a yield depression was apparent in the rock-phosphate treatments. In the second season there was a slight lime response in the superphosphate and serpentine superphosphate treatments, while the depression in yield continued in the rock-phosphate treatments.

In the third and fourth years, superphosphate and serpentine superphosphate responded considerably to lime, and Thermophos to a lesser degree. The control plots showed a marked lime response in the third, fourth, and fifth years.



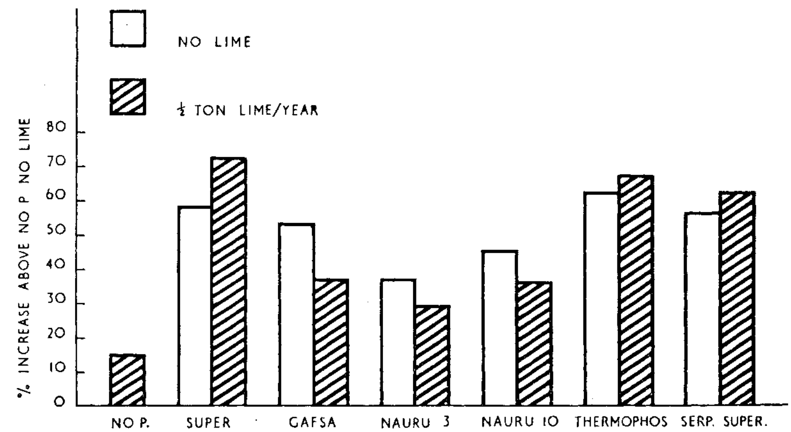


Fig. 1.—Effect of 10 cwt calcium carbonate on phosphate yields (1951–52 to 1955–56)

No differences have been noted between the two rates of lime. This is perhaps not surprising as the low rate was comparatively high (10 cwt/year), but in the later years at least it might have been expected that the high rate would have affected the rock phosphates more than the low rate. This did not prove to be the case.

Over the five-year period lime gave a 12% increase in the superphosphate plots, a 9% increase in the serpentine superphosphate plots, and a 5% increase in the Thermophos plots.

However, with North African phosphate, lime caused a 16% reduction; with Nauru 3 cwt, an 11% reduction; and with Nauru, 10 cwt initially and 3 cwt subsequently, a 6% reduction. Since North African rock phosphate without lime was the best of the rock phosphates, it had most to lose by liming. It can be seen from the above that this is exactly what happened.

*Botanical Composition and Sward Changes*

Despite continual mowing for five seasons, there was little deterioration of sward in the efficient phosphate treatments. The only evidence of deterioration was an increase in the percentage of Yorkshire fog (*Holcus lanatus*), but this would be expected as this species is favoured by mowing and spelling.

In the limed superphosphate, serpentine superphosphate, and Thermophos plots, white clover was the dominant legume while the control and poorer rock-phosphate treatments favoured red clover.

Similarly the percentage of ryegrass was higher in the more efficient phosphate treatments, while the percentage of weed grasses was higher on the controls. Percentage differences in composition in the seven treatments can be seen from herbage dissection analyses.

Table 3 shows that, although the percentage of total grasses and of total clover is not affected by treatment, there are large variations

TABLE 3. SUMMARY OF PASTURE DISSECTION RESULTS
(Average of 15 pasture dissections)

| Treatment | Ryegrass Species % | Other Grasses % | Total Grasses % | Ratio Rye/ Other Grasses | White Clover % | Red Clover % | Total Clover % | Ratio White to Red Clover |
|---|---|---|---|---|---|---|---|---|
| *No Lime* | | | | | | | | |
| No lime, no phosphate | 35 | 28 | 63 | 1.3 | 17 | 15 | 32 | 1.1 |
| Superphosphate | 42 | 19 | 61 | 2.1 | 29 | 8 | 37 | 3.9 |
| Nth. African rock phosphate | 40 | 20 | 60 | 2.0 | 27 | 12 | 39 | 2.4 |
| Nauru rock, 3 cwt | 35 | 26 | 61 | 1.4 | 27 | 10 | 37 | 2.8 |
| Nauru rock, 10 cwt | 37 | 21 | 58 | 1.8 | 28 | 11 | 39 | 2.6 |
| Thermophos | 44 | 17 | 61 | 2.6 | 28 | 9 | 37 | 3.1 |
| Serp. super. | 40 | 24 | 64 | 1.7 | 26 | 8 | 34 | 3.0 |
| *10 cwt Lime* | | | | | | | | |
| No phosphate | 35 | 22 | 57 | 1.6 | 17 | 20 | 37 | 0.9 |
| Superphosphate | 46 | 17 | 63 | 2.7 | 30 | 5 | 35 | 5.5 |
| Nth. African rock phosphate | 40 | 19 | 59 | 2.1 | 24 | 14 | 38 | 1.7 |
| Nauru rock, 3 cwt | 40 | 20 | 60 | 2.0 | 24 | 14 | 38 | 1.8 |
| Nauru rock, 10 cwt | 39 | 19 | 58 | 2.0 | 23 | 16 | 39 | 1.4 |
| Thermophos | 43 | 16 | 59 | 2.8 | 32 | 7 | 39 | 4.5 |
| Serp. super. | 42 | 16 | 58 | 2.6 | 29 | 9 | 38 | 3.1 |
| *20 cwt Lime* | | | | | | | | |
| No phosphate | 40 | 20 | 60 | 2.1 | 17 | 18 | 35 | 1.0 |
| Superphosphate | 44 | 18 | 62 | 2.5 | 29 | 8 | 37 | 3.4 |
| Nth African rock phosphate | 42 | 19 | 61 | 2.2 | 23 | 14 | 37 | 1.6 |
| Nauru, 3 cwt | 40 | 18 | 58 | 2.2 | 20 | 18 | 38 | 1.1 |
| Nauru, 10 cwt | 42 | 19 | 61 | 2.1 | 20 | 16 | 36 | 1.2 |
| Thermophos | 46 | 14 | 60 | 3.2 | 30 | 9 | 39 | 3.2 |
| Serp. super. | 45 | 17 | 62 | 2.7 | 27 | 9 | 36 | 3.0 |

in the ratio of ryegrass to other grasses and of white to red clover. These ratios increase as the yield or quality of pasture increases. Liming, however, has generally increased the ratio of ryegrass to other grasses, while the ratio of white to red clover is more sensitive to the available phosphate. On the No Lime treatments all phosphates have markedly increased the ratio of white to red clover. On the limed plots the rock phosphates have a much lower ratio of white to red clover than the other phosphates.

These herbage dissection figures indicate the major composition changes. However, herbage dissection is primarily a measure of production rather than of sward composition and hence those species in the sward which are highest producing are favoured. For example, a few ryegrass plants in a control plot may produce most of the herbage since the low-producing weeds and grasses may be largely below mower height and as a consequence contribute only a small fraction of the herbage.

For this reason botanical changes have probably been greater than is evident from dissection data. However, dissection analyses indicate that the control plots contained more flatweeds, red clover, and weed grasses, such as browntop (*Agrostis tenuis*), sweet vernal (*Anthoxanthum*

TABLE 4. INFLUENCE OF LIMING ON TRUOG TEST FOR PHOSPHATE

| Treatments | Date of Sampling | | | | | |
|---|---|---|---|---|---|---|
| | 15/2/54 | | 28/2/55 | | 21/2/56 | |
| | pH | P | pH | P | pH | P |
| *No Lime* | | | | | | |
| No phos. | 5.7 | 4 | 5.6 | 4 | 5.5 | 3 |
| Super. | 5.5 | 7 | 5.5 | 6 | 5.5 | 6 |
| N. Afr. | 5.6 | 10 | 5.6 | 9 | 5.6 | 14 |
| Nauru 3 | 5.5 | 18 | 5.6 | 19 | 5.4 | 36 |
| Nauru 10 | 5.7 | 27 | 5.7 | 28 | 5.5 | 45 |
| Thermophos | 5.7 | 8 | 5.7 | 6 | 5.8 | 9 |
| Serp. super. | 5.5 | 6 | 5.5 | 5 | 5.5 | 7 |
| *10 cwt Lime* | | | | | | |
| No phos. | 6.5 | 5 | 6.4 | 5 | 6.5 | 5 |
| Super. | 6.4 | 8 | 6.2 | 7 | 6.5 | 9 |
| N. Afr. | 6.5 | 14 | 6.4 | 19 | 6.6 | 30 |
| Nauru 3 | 6.3 | 25 | 6.4 | 36 | 6.4 | 40 |
| Nauru 10 | 6.6 | 34 | 6.6 | 44 | 6.5 | 52 |
| Thermophos | 6.7 | 7 | 6.6 | 6 | 6.7 | 8 |
| Serp. Super. | 6.5 | 6 | 6.4 | 8 | 6.4 | 8 |
| *20 cwt Lime* | | | | | | |
| No phos. | 6.8 | 4 | 6.9 | 4 | 6.8 | 5 |
| Super. | 6.8 | 9 | 6.9 | 8 | 7.1 | 10 |
| N. Afr. | 6.9 | 17 | 7.0 | 20 | 7.1 | 40 |
| Nauru 3 | 6.8 | 26 | 7.0 | 28 | 7.1 | 45 |
| Nauru 10 | 6.9 | 38 | 6.9 | 45 | 6.8 | 58 |
| Thermophos | 7.1 | 9 | 6.9 | 10 | 6.9 | 10 |
| Serp. super. | 6.8 | 8 | 6.8 | 9 | 7.0 | 10 |

NOTE.—P = parts of available phosphate per 50,000,000 of soil extract.

*odoratum*), and Yorkshire fog (*Holcus lanatus*), than the higher-yielding phosphate treatments. These latter treatments also contained a high proportion of short-rotation ryegrass (*Lolium multiflorum* × *L. perenne*) which appeared to have increased as a result of the build up in fertility. The presence of short-rotation ryegrass may explain the relatively better yields of the efficient phosphate treatments in the winter and early spring.

*Summary of Soil Analysis Results*
*Comments on Table 4*

In spite of the annual applications of 10 cwt and 20 cwt lime per acre, the pH did not rise during the three years for which soil analyses are available.

The following are the average phosphate figures over the three years:

| | *Lime* | *P Value (Truog)* |
|---|---|---|
| Average of superphosphate serpentine superphosphate, and Thermophos | Nil | 6.7 |
| | 10 cwt | 7.6 |
| | 20 cwt | 9.2 |
| Average of Nauru and North African rock phosphates | Nil | 23 |
| | 10 cwt | 33 |
| | 20 cwt | 35 |

The rise in the phosphate figure due to liming is more marked in the rock-phosphate treatments. The change occurs largely between the no-lime and 10 cwt rates. This change corresponds to a lowering of efficiency of rock phosphates.

The phosphate figures have risen steadily in the rock-phosphate plots but not in the plots receiving the more soluble phosphates.

## DISCUSSION

In evaluating various forms of phosphates, care is necessary to see that results are not influenced by the presence of major or minor elements in the fertiliser.

Many claims for superiority of slag can be explained by its trace-element content. Recent research in New Zealand has indicated that the molybdenum, vanadium, and tungsten content may separately or in combination give marked responses (Davies and Stockdill 1956; During 1955). North African phosphate has a relatively high molybdenum content (4.0 p.p.m.), and this could be responsible for good responses with this fertiliser on molybdenum-deficient country.

Sulphur deficiency in New Zealand and interactions have been described by Walker *et al.* (1955) who suggest a new phosphate evaluation in the light of recent knowledge. In the experiment described however, Thermophos has compared favourably with superphosphate over a five-year period and it is unlikely that sulphur has influenced the trial results to date. Although one advantage claimed for serpentine superphosphate is that it has a high content of magnesium, this element does not appear to have been of benefit in this trial.

Both magnesium and sulphur are included in a neighbouring trial on the same soil type and have shown negligible responses in three years' yield measurements.

The rates of lime chosen may appear unduly high. This trial was planned at a time when the use of heavy lime applications was general in the district, little being known then of molybdenum deficiencies. It has since been shown that much of the benefit of heavy lime dressings is to make molybdenum available (Davies 1956).

With 20 cwt lime per acre, a pH of about 6.9–7.0 was reached in the third year after application. The pH tended to remain at this level despite further annual lime applications.

With 10 cwt lime the pH level also remained relatively stationary at about 6.4.

The increased lime response in the control treatments has already been mentioned. The extent of this response is surprising, being about 30% in the third season and over 20% in the fourth.

The reason for this increase is not clear. The most likely explanation is an increase in molybdenum availability together with a release of phosphate (there has been some evidence of the latter in the soil-test figures). A basal dressing of $1\frac{1}{4}$ oz sodium molybdate was applied in September 1951 and the increases were noted in the 1953-54 season—over two years later. Other work at Invermay Research Station (Cullen 1955) has indicated that responses from 1 oz sodium molybdate continue for approximately three years, and it is quite probable that this response from both rates of lime was largely an indirect molybdenum effect. The measurement of responses generally proved satisfactory and it is considered the technique adopted was suitable. Normally the plots were cut six to seven times each season when the herbage was three to five inches in height and capable of being cut by a Dennis motor mower.

At certain times hay cuts were necessary because of wet weather interfering with normal cutting but these were avoided whenever possible because of the possibility of sward upsets.

When the sward is left for a lengthy period in a long and rank state the control plots tend to continue growing relatively faster than the higher-producing treated plots. The latter may lodge and almost cease growth. If left unduly long prior to cutting the controls may even outyield the treated plots.

In such instances recovery following cutting may be much slower on the treated plots. This is especially so where the herbage in the control plots is short and dense and in the topdressed plots rank and open at the base. As the herbage is normally removed from the plots when they are hayed, the sward is left open and is liable to dry out. This occurred in the 1955 season when dry conditions resulted in very poor recovery following haying. As a result the control plots outyielded the treated ones at two subsequent cuts and the poorer treatments appeared in a very favourable light. It can be seen that false interpretation could be given to yield data obtained under such conditions.

Results from this trial have in the main confirmed work carried out in New Zealand and elsewhere. Superphosphate proved superior to the other phosphates in this trial, under acid and neutral soil conditions. Thermophos and serpentine superphospate proved equal to superphosphate on an equivalent $P_2O_5$ basis only. North African phosphate applied at equivalent weight was almost as good as superphosphate under acid soil conditions ($pH<6$) and could be used as an alternative on acid soils. Results from Nauru rock phosphate were generally poor, and it is doubtful if this phosphate is worthy of serious consideration as a substitute. The superiority of North African phosphate over Nauru is probably due to the former being a much softer rock. Both rock phosphates have a relatively low fluorine content. Although Thermophos compared favourably with superphosphate in the trial, it has the disadvantage of containing no sulphur. As sulphur deficiencies appear to be widespread in New Zealand, serious consideration would be necessary before recommending the use of phosphates without sulphur. The fused phosphates could possibly replace superphosphate on soils where sulphur was known to be in adequate supply.

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## CORRIGENDA

Volume 1, page 152, 4th para., *Experiment 1.*

The 3rd and 4th lines of this paragraph should read:

The only significant or nearly significant responses were to P or PN, and plant analytical levels for other nutrients showed no abnormalities.

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Volume 1, pages 301, 305, 329, 341:

In the bibliographical reference at the foot of each of these pages, for *N.Z. J. agric. Res. 3:* read *N.Z. J. agric. Res. 1:*