ESTABLISHMENT OF PASTURE ON YELLOW-BROWN LOAMS NEAR TE ANAU

VII. Comparison of forms of phosphatic fertiliser on young pasture

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ABSTRACT

Five forms of phosphate—superphosphate, lime-reverted superphosphate, serpentine superphosphate, basic slag, and fused calcium magnesium phosphate (Thermophos†)—were evaluated on Te Anau yellow-brown loam.

Thermophos, despite its lower phosphorus content, proved greatly superior to superphosphate when both were applied at 6 cwt per acre. Lime-reverted and serpentine superphosphate were inferior to superphosphate, but basic slag appeared slightly superior on an equivalent phosphorus basis. In further trials which included rates of superphosphate and Thermophos from 3 to 15 cwt/ac in the presence and absence of 2 tons lime, Thermophos again proved superior to superphosphate, especially in the absence of lime. In the superphosphate treatments lime either had little effect or aided response, but in the presence of Thermophos it generally depressed growth.

A high percentage of the phosphorus in Thermophos was recovered in the surface Al-P and Fe-P fractions, but the Ca-P fraction was higher in superphosphate. Addition of lime to Thermophos increased the Ca-P fraction.

The magnesium and trace elements in Thermophos were not considered to have been responsible for its superiority. The importance of silicon is not clear.

INTRODUCTION

Te Anau yellow-brown loam has been shown to have a high phosphate requirement, and initial applications of more than 6 cwt/ac superphosphate have been recommended (During *et al.* 1962; Cullen *et al.* 1966).

As claims have been made that reverted phosphates are less subject to fixation than water-soluble superphosphate, it was decided to compare

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† Formerly manufactured by Permanente Metals Corporation, U.S.A. The process, developed by T.V.A. in America, consists of fusing 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.

lime-reverted superphosphate and serpentine-reverted superphosphate with superphosphate, as well as with basic slag and Thermophos. Basic slag has given good results on high-phosphate-fixing soils in North Auckland, and Thermophos compared favourably with superphosphate in trials at Invermay Research Station (Cullen 1957) and Rukuhia Soil Research Station (Karlovsky 1957).

Because of the superiority of Thermophos in the initial investigation, two further trials were laid down to compare superphosphate with Thermophos over a range of application rates and in the presence and absence of lime.

Ground rock phosphates were not included in the trial, as these had been shown previously (During, pers. comm.) to give very poor results on Te Anau soil. Calcined Christmas Island phosphate also proved greatly inferior to superphosphate on this soil (Scott, pers. comm.).

EXPERIMENTAL

Trials 1 and 2 were on Te Anau yellow-brown loam in the experimental area approximately 6 miles north-east of Te Anau township. Trial 3 was on a Lynwood brown loam soil approximately 12 miles east of Te Anau.

Details of experiments

Trial 1:

This trial included seven treatments in a randomised-block design with six replicates.

Treatments were:

	cwt/ac	*P content lb/ac*
(1) Superphosphate	4½	50.9
(2) Superphosphate	6	67.9
(3) Superphosphate	7½	84.8
(4) Serpentine superphosphate	6	50.4
(5) Lime-reverted superphosphate	6	46.4
(6) Basic slag	6	51.7
(7) Thermophos	6	66.4

Treatments 6 and 7 had a basal treatment of 336 lb/ac gypsum, and treatments 1, 4, and 5 84 lb gypsum/ac. A basal treatment of 3 lb DDT and 5 oz sodium molybdate/ac was also applied at the time of sowing. The trial was sown on 4 October 1962 on a cultivated seedbed that had been sown the previous day with a pasture mixture containing 19 lb/ac grasses and 6 lb/ac clovers. The clover seed was inoculated. Plot size was 20 ft × 5 ft. On 30 August 1963 the fertiliser application was repeated on one half (chosen at random) of each plot.

Trials 2 and 3:

These included four rates each of superphosphate and Thermophos and two rates of lime in a split-plot factorial layout having four replications of the main plots, which consisted of 2 tons lime/ac and no lime.

The four rates of superphosphate and Thermophos made up eight sub-plot treatments:

	cwt/ac	*cwt/ac*	*P applied lb/ac*
(1) Superphosphate	3		30.2
(2) Superphosphate	7		70.6
(3) Superphosphate	11		110.9
(4) Superphosphate	15		151.2
(5) Thermophos	3	+ gypsum 1½	29.5
(6) Thermophos	7	+ gypsum 3½	68.7
(7) Thermophos	11	+ gypsum 5½	108.0
(8) Thermophos	15	+ gypsum 7½	147.3

TABLE 1—Clover Vigour and Percentage Cover Pointings Trial 1

Clover Vigour (Scale 0–10)						
	Original Application				Repeat Application	
Treatment No.	19 Mar. '63	29 Aug. '63	18 Dec. '63	16 Ap. '64	18 Dec. '63	16 Ap. '64
1.	4.2cB*	4.2cb	5.9bB	3.7dC	7.4ab	6.0dC
2.	5.1abAB	4.6bcB	6.2bB	4.4bcBC	7.6ab	7.2bB
3.	5.8aA	4.9bAB	6.2bB	4.8abAB	7.3ab	8.3aA
4.	4.8bcAB	4.7bcB	5.5bB	4.1cdBC	7.7ab	6.8bcBC
5.	3.8cB	4.2cB	5.8bB	3.8dC	6.8b	6.2cdBC
6.	4.1cB	4.7bcB	6.2bB	4.1cdBC	7.4ab	7.0bBC
7.	5.6abA	5.5aA	7.5aA	5.2aA	7.8a	8.9aA
C.V. %	15.3	9.5	9.5	11.2	9.6	8.7
	Clover Percentage Cover					
1.	12cBC	8cB	48dC	44dD	72bcAB	80dB
2.	18bcABC	12bcAB	62bcBC	61bcBC	73bcAB	88bcAB
3.	27aA	19aA	64abAB	69bAB	82abAB	95abA
4.	16bcABC	13abcAB	61cdBC	54cCD	76abcAB	83cdB
5.	11cC	8cB	57cdBC	57cBCD	69cB	79dB
6.	10cC	11cAB	63bcBC	58cBC	78abcAB	88bcAB
7.	23abAB	18abA	82aA	79aA	87aA	99aA
C.V. %	39.4	39.3	15.9	12.9	12.6	7.4

* Letters in this and subsequent tables are according to the multiple range test of Duncan (1955).

Trials 2 and 3 were laid down on 5 and 6 March 1965.

All plots received a basal application of 5 oz sodium molybdate/ac. and the clovers were inoculated. Plot size was 10 × 4 ft.

At both trial sites the seedbed was prepared with a rotary hoe and tine harrows and sown with a pasture mixture comprising (lb/ac) perennial ryegrass 15 lb, cocksfoot 5 lb, timothy 3 lb, N.Z. white clover 5 lb, and Montgomery red clover 3 lb. The lime and fertiliser treatments were broadcast on the ground surface after the seed was raked in. The native vegetation before cultivation at the site of Trials 1 and 2 consisted largely of stunted bracken fern (*Pteridium esculentum* (forst. F.) Diels), and at the site of Trial 3 red tussock (*Chionochloa rubra*).

In the three trials treatment effects were assessed by pointing for vigour on a 0–10 scale and by estimating the clover percentage cover of the sward. A yield cut was taken from Trial 3 in December 1965.

Soil samples were analysed for pH, Ca, K, and P, and soil phosphorus fractions were determined for Trials 2 and 3 using the modified Chang and Jackson (1957) method developed by Williams *et al.* (1967). Herbage phosphorus and magnesium levels were also determined. Yield data were recorded in Trial 3 only. The trials were not grazed, but were cut or trimmed off once or twice annually.

RESULTS

Clover establishment was good on all three trials, but grass growth was slow because of the low nitrogen status of the soil (Cullen and Arnold 1971). Clover vigour and percentage cover data for Trial 1 are shown in Table 1.

At all four pointings clover vigour in the Thermophos treatment was superior to that in the others. On 18 December 1963 Thermophos was significantly better ($P > 0.01$) than all other treatments including 7½ cwt/ac superphosphate. For clover percentage cover Thermophos was slightly lower than 7½ cwt/ac superphosphate at the first two pointings, but thereafter was slightly higher, i.e. the superiority of Thermophos over superphosphate increased with the passage of time.

Clover and grass vigour pointings taken in December 1965 for Trials 2 and 3 are shown in Table 2.

Clover and grass vigour in the Thermophos treatments was generally superior to that in the superphosphate plots, the mean clover vigour of the Thermophos treatments being significantly ($P > 0.01$) higher than that of the superphosphate treatments.

Lime had little effect on clover vigour in the superphosphate treatments, but tended to depress vigour in the Thermophos treatments. Lime generally aided grass vigour, especially in the superphosphate plots. Clover and grass percentage cover data for Trials 2 and 3 are shown in Fig. 1.

TABLE 2—Clover and Grass Vigour Pointings Trials 2 and 3 (0–10 scale) 1 December 1965

	Clover				Grass			
	No Lime		Lime 2 tons		No Lime		Lime 2 tons	
Treatment No.	Trial 2	Trial 3	Trial 2	Trial 3	Trial 2	Trial 3	Trial 2	Trial 3
1.	2.8eD	2.4eD	2.4dD	2.2bC	3.9a	2.0dB	5.6a	3.5b
2.	4.8bcdBC	4.2cdBCD	3.8cdBCD	4.6aAB	2.6a	2.9cdAB	4.2a	4.0ab
3.	4.5cdBCD	4.0dCD	5.0bcABC	3.6aAB	3.0a	2.9cdAB	4.5a	3.8ab
4.	5.0bcdBC	4.8bcdBC	5.2abAB	5.9aA	3.0a	3.2bcdAB	4.2a	4.1ab
5.	3.9deCD	5.6abcABC	3.2dCD	3.1bBC	3.1a	3.5abcAB	4.5a	3.5b
6.	6.0abAB	5.5abcdABC	5.1bcABC	6.1aA	4.1a	4.2abA	4.2a	5.0a
7.	5.8bcABC	6.2abAB	6.6aA	4.7aAB	3.9a	4.6aA	5.2a	4.2ab
8.	7.2aA	6.9aA	6.6aA	6.0aA	4.2a	4.5abA	5.0a	4.5ab
C.V. %	19.1	20.7	19.1	20.7	24.2	21.6	24.2	21.6
Means								
No Lime	5.0a	4.9a			3.5bB	3.5a		
Lime 2 tons	4.8a	4.7a			4.7aA	4.1a		
Superphosphate	4.2bB	4.1bB			3.9a	3.3bB		
Thermophos	5.6aA	5.5aA			4.3a	4.3aA		

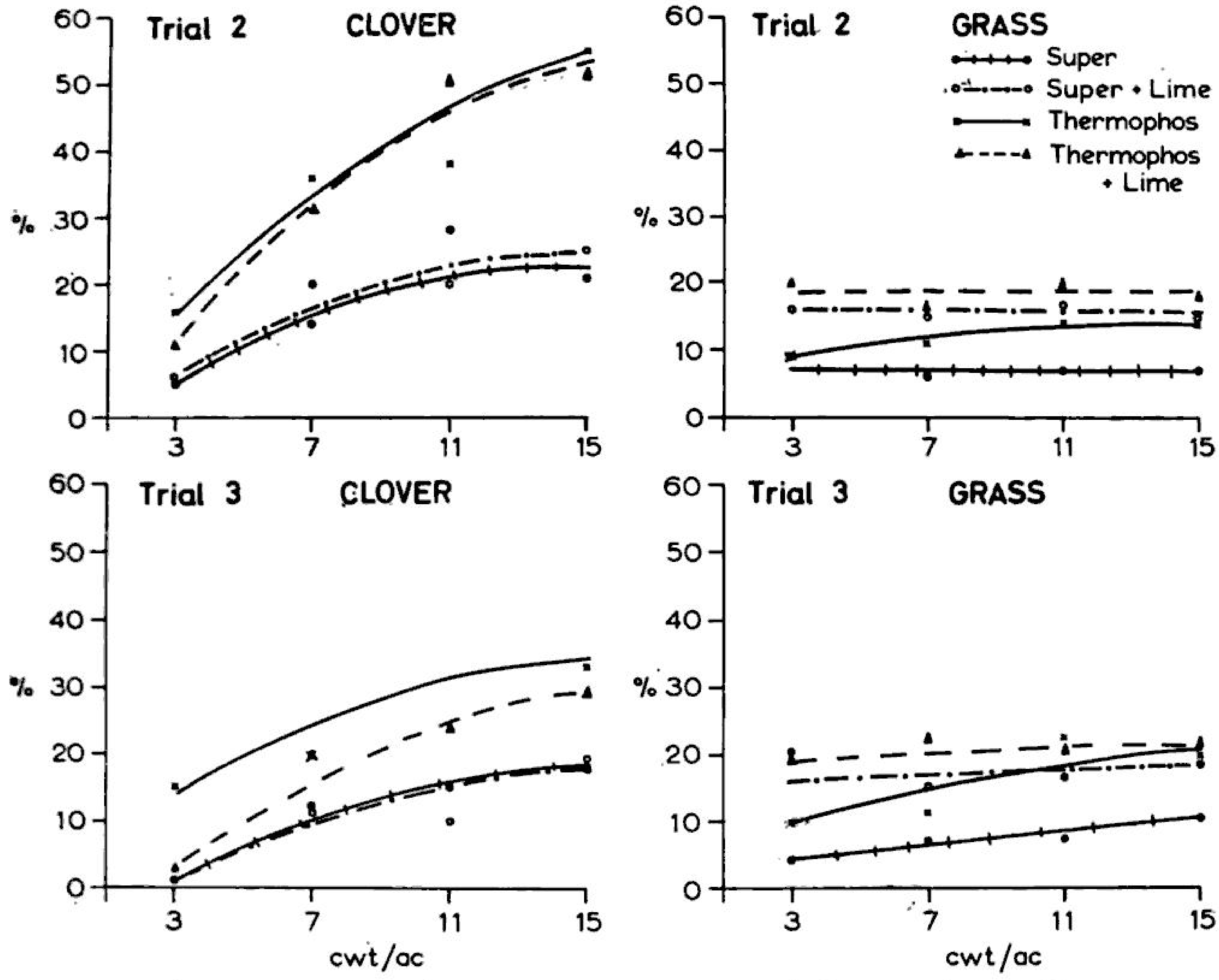

Fig. 1—Clover and grass percentages recorded December 1965.

Dry matter production

Yield data for Trial 3 are shown in Table 3. The pasture was cut at a hay stage of growth and the sward was dominated by red clover.

The dry matter yields confirmed the superiority of Thermophos indicated by the visual assessments. Over all phosphate rates there were no significant differences between no lime and lime treatments. There was, however, a highly significant interaction between lime and form of phosphate in yields of red clover, which was reflected in the total yields. Lime increased total yield in the superphosphate treatments, but depressed yields in the Thermophos treatments (Fig. 2). As a result, yields from the superphosphate plus lime treatments were comparable with those from Thermophos plus lime, but Thermophos alone was vastly superior to superphosphate alone and also to superphosphate with lime.

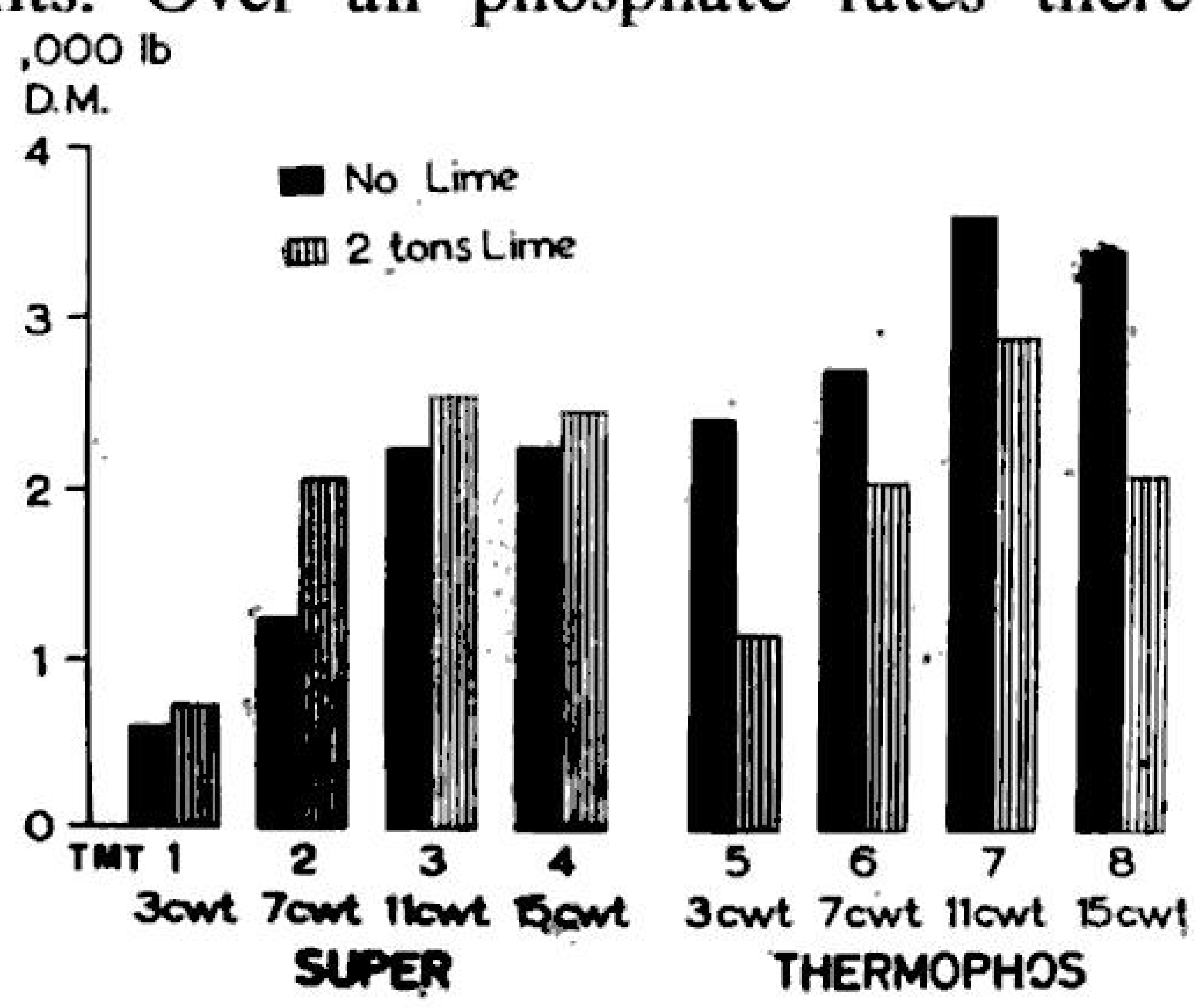

Fig. 2—Red clover yields Trial 3, 21 March 1966.

TABLE 3—Trial 3 Dry Matter Yields (lb/ac) Cut 21 March 1966

Treatment No.	Sown Grasses	White Clover	Red Clover	Total*
No Lime				
1.	260a	110bA	600dC	1,060dE
2.	540a	650abA	1,230cdBC	2,610cD
3.	270a	670abA	2,240bcABC	3,240bcCD
4.	510a	650abA	2,230bcABC	3,610bBCD
5.	210a	340abA	2,420abcAB	3,120bcCD
6.	560a	630abA	2,700abAB	4,060abABC
7.	480a	870aA	3,610aA	5,020aA
8.	360a	910aA	3,420abA	4,780aAB
Lime 2 tons				
1.	500a	170cB	720cC	1,600dD
2.	390a	310cB	2,060abABC	2,910bcBC
3.	380a	510cB	2,530aAB	3,540abABC
4.	340a	780bcB	2,460aAB	3,790abAB
5.	710a	310cB	1,150bcBC	2,400cdCD
6.	660a	1,060abAB	2,040abABC	3,910aAB
7.	490a	640bcAB	2,900aA	4,190aAB
8.	810a	1,450aA	2,080abABC	4,490aA
Means				
No Lime	400a	600a	2.310a	3,440a
Lime 2 tons	530a	650a	1,990a	3,350a
Superphosphate	400a	480bB	1,760bB	2,790bB
Thermophos	530a	770aA	2,540aA	3,990aA
Interactions	N.S.	N.S.	1%	5%
C.V. %	67.7	66.9	37.6	18.9

Interaction Tables (Means)

	Red Clover		Total	
	No Lime	Lime	No Lime	Lime
Superphosphate	1,570bB	1,940a	2,630bB	2,960bB
Thermophos	3,040aA	2,040a	4,250aA	3,750aA

* Includes dead matter and species other than shown in table.

Herbage phosphorus and magnesium levels

Trial 1—Analyses of white clover samples taken in February 1964 showed significantly higher ($P > 0.01$) magnesium levels in the Thermophos treatment than in the other six treatments, although levels in the serpentine superphosphate treatment had also increased.

The % P concentrations in the Thermophos treatment were significantly greater ($P > 0.05$) than in treatments 1, 4, 5, and 6 for the original application, and, except for treatment 3, significantly greater ($P > 0.01$) than the others in the repeat application.

Trial 2—White clover samples were taken from the 7 cwt/ac superphosphate and Thermophos treatments for phosphorus analyses on 21 March 1966. Mean phosphorus levels are shown below. The data were not statistically analysed.

No Lime		Lime 2 tons	
Superphosphate	Thermophos	Superphosphate	Thermophos
0.128%	0.143%	0.110%	0.125%

Herbage phosphorus percentages were higher in the Thermophos treatments than in the superphosphate in both limed and unlimed plots. Lime depressed levels slightly. All phosphorus percentages were low.

Trial 3—Herbage samples were taken in March 1966 and analysed for % P. Results are shown in Table 4.

Phosphorus concentrations were significantly higher in the Thermophos than in the superphosphate treatments. Lime depressed phosphorus percentages in the grasses and white clover (almost significant 5%), but not in red clover.

Soil analysis

Trial 1—Soil analyses data for Trial 1 have not been tabulated, but samples taken in February 1964 indicated that basic slag and Thermophos increased the pH significantly compared with superphosphate; and that Thermophos, particularly in the repeat application, sharply increased the Truog P level. Thermophos effects were less marked in May 1965. The effect on soil phosphorus was confined almost entirely to the top inch for all treatments. More than 2½ years after the original application Truog phosphorus levels were still very low in the 1–2 in. levels in all treatments, indicating that downward movement had been negligible.

Soil analyses for Trials 2 and 3 are given in Table 5.

Lime raised the pH in both trials ($P > 0.01$), but the effect was greater in Trial 3. Thermophos also raised the pH slightly in both trials compared with superphosphate.

Truog phosphorus levels were significantly higher in the Thermophos treatments than in the superphosphate treatments in both trials. In Trial 3 lime raised the phosphorus concentration significantly ($P > 0.01$).

Calcium and potassium levels were not affected by the treatments.

Amounts and proportions of phosphorus present in different combinations are given in Tables 6 and 7 for Trials 2 and 3 respectively. The data are means of duplicate analyses of composite samples for each treatment.

Because of the high phosphorus retention capacity of these soils it was not possible to make the corrections for resorption of surface-bound Al-P during extraction as suggested by Williams *et al.* (1967) and by Smith (1965a). For this reason Al-P levels should be higher than reported and Fe-P levels lower. The fractions reported do not comprise the total soil phosphorus. Organic phosphorus and residual phosphorus not soluble in acids have not been determined, although an attempt was made to measure organic phosphorus by the ignition-extraction method of Saunders and Williams (1955). This method

TABLE 4—Herbage P % Trial 3 (21 March 1966)

	White Clover		Red Clover		Grasses	
Treatment No.	No Lime	Lime 2 tons	No Lime	Lime 2 tons	No Lime	Lime 2 tons
	%	%	%	%	%	%
1.	0.16cB	0.16cB	0.13cB	0.14bB	0.12dc	0.12cBC
2.	0.18bcB	0.16cB	0.13cB	0.14bB	0.14bcdBC	0.13bcABC
3.	0.18bcB	0.17bcB	0.14cB	0.15bB	0.13cdBC	0.13bcABC
4.	0.24aA	0.18bcB	0.16abAB	0.15bB	0.16abcAB	0.15abAB
5.	0.20bB	0.17bcB	0.15abcAB	0.15bB	0.16abcAB	0.11cC
6.	0.19bcB	0.17bcB	0.15bcAB	0.14bB	0.15bcBC	0.14bcABC
7.	0.24aA	0.20abAB	0.16abAB	0.16bB	0.16abAB	0.14bcABC
8.	0.25aA	0.23aA	0.17aA	0.19aA	0.18aA	0.17aA
C.V. %	12.0		8.6		12.6	
Means	No Lime	0.20a	No Lime	0.15a	No Lime	0.15a
	Lime	0.18a	Lime	0.15a	Lime	0.14a
	Super.	0.18bB	Super.	0.14bB	Super.	0.14bB
	Thermophos	0.21aA	Thermophos	0.16aA	Thermophos	0.15aA

TABLE 5—Soil pH and P Analyses Trials 2 and 3 (0–1½ in.)

Treatment No.	pH					
	Trial 2, 21 March 1966			Trial 3, 22 March 1966		
	No Lime	Lime	Mean	No Lime	Lime	Mean
1.	5.40abAB	5.80a	5.60bcAB	4.88a	5.80ab	5.34a
2.	5.22bB	5.80a	5.51cB	5.00a	5.70b	5.35a
3.	5.45abAB	5.80a	5.58cAB	4.90a	5.78ab	5.34a
4.	5.20bB	5.80a	5.50cB	4.93a	5.75ab	5.34a
5.	5.42abAB	5.82a	5.62abcAB	4.98a	5.83ab	5.40a
6.	5.52aA	5.92a	5.72abA	5.05a	6.03a	5.54a
7.	5.58aA	5.92a	5.75aA	5.13a	5.95ab	5.54a
8.	5.55aA	5.68a	5.61bcAB	5.13a	5.88ab	5.50a
Means						
Super.			5.45bB			5.34bB
Thermophos			5.68aA			5.49aA
No Lime			5.40bB			4.99bB
Lime			5.82aA			5.83aA
C.V. %	2.2			3.3		

Treatment No.	P					
	Trial 2, 21 March 1966			Trial 3, 22 March 1966		
	No Lime	Lime	Mean	No Lime	Lime	Mean
1.	1.8dC	2.2cdC	2.0bB	3.3dC	6.5cdD	4.9cdB
2.	2.5cdBC	2.8cdBC	2.6bB	3.5dC	7.5cdCD	5.5bcdB
3.	8.0abAB	4.4bcdABC	6.2aAB	7.3bcdACD	8.8cdCD	8.0bcB
4.	5.5bcdABC	8.8abAB	7.1aA	13.3aA	13.8bABC	13.5aA
5.	1.4dC	2.2cdC	1.8bB	3.5dC	5.5dD	4.5dB
6.	7.0abcABC	5.0bcdABC	6.0aAB	6.3cdBC	11.0bcBCD	8.6bB
7.	7.0abcABC	9.1abAB	8.1aA	11.3abAB	15.5abAB	13.4aA
8.	10.8aA	5.9abcdABC	8.3aA	10.8abcAB	19.5aA	15.1aA
Means						
Super.			4.5bA			7.9bB
Thermophos			6.0aA			10.4aA
No Lime			5.5a			7.4bB
Lime			5.0a			11.0aA
C.V. %	57.7			33.5		

failed because the liberated organic phosphorus was so strongly re-adsorbed.

Despite the high variability some general trends are apparent. 1. *Rate of application*—Surface-bound Al-P and Fe-P increased markedly, and reductant-soluble P slightly, with increasing rate of application. Calcium-P increased greatly on the superphosphate treatments, but only slightly on the Thermophos treatments. These effects were noticeable in both trials at both sampling dates. Occluded P did not change with rate of application. It comprised only a small proportion of the phosphorus present.

TABLE 6—Phosphorus Fractions Trial 2 (0–1½ in.)
(ppm P in oven-dry soil)

Means	Surface Al-P	Surface Fe-P	Reductant-soluble P	Occluded Al/Fe-P	Ca-P	Sum of fractions
21 March 1966						
Superphosphate	61(25.6)*	108(45.4)	26(10.9)	7(3.0)	36(15.1)	238
Thermophos	83(31.1)	129(48.3)	32(12.0)	9(3.4)	14(5.2)	267
Superphosphate + Lime	58(23.7)	99(40.4)	37(15.1)	10(4.1)	41(16.7)	245
Thermophos + Lime	77(29.4)	113(43.1)	39(14.9)	11(4.2)	22(8.4)	262
Superphosphate	60(24.8)	103(42.6)	32(13.2)	8(3.3)	39(16.1)	242
Thermophos	80(30.2)	121(45.6)	36(13.6)	10(3.8)	18(6.8)	265
No Lime	72(28.5)	119(47.0)	29(11.5)	8(3.1)	25(9.9)	253
Lime	68(26.9)	105(41.5)	38(15.0)	10(4.0)	32(12.6)	253
21 March 1967						
Superphosphate	64(21.0)	132(43.3)	36(11.8)	11(3.6)	62(20.3)	305
Thermophos	82(27.1)	149(49.2)	40(13.2)	11(3.6)	21(6.9)	303
Superphosphate + Lime	66(24.3)	104(38.2)	45(16.5)	12(4.4)	45(16.6)	272
Thermophos + Lime	94(30.9)	117(38.5)	50(16.4)	13(4.3)	30(9.9)	304
Superphosphate	65(22.5)	118(40.8)	41(14.2)	11(3.8)	54(18.7)	289
Thermophos	88(29.0)	133(43.7)	45(14.8)	12(3.9)	26(8.6)	304
No Lime	73(24.0)	141(46.4)	38(12.5)	11(3.6)	41(13.5)	304
Lime	80(27.7)	111(38.4)	48(16.6)	12(4.2)	38(13.1)	289

* Percentage of sum of fractions

2. *Superphosphate* v. *Thermophos*—Because of differences in the amounts of added phosphorus recovered, comparisons are best made on the basis of the proportions present in the different fractions. Surface Al-P and Fe-P were proportionally higher with Thermophos than with superphosphate in both trials and at both samplings, although differences for Trial 3 were very slight in 1967. Reductant-soluble P was also a slightly higher percentage on the Thermophos treatments. Ca-P was much higher on the superphosphate treatments, the differences being greater in 1967 than in 1966. However, less than 20% of the phosphorus in Trial 2 and 13% in Trial 3 was in the Ca-P fraction.

TABLE 7—Phosphorus Fractions Trial 3 (0–1½ in.)
(ppm P in oven-dry soil)

Means	Surface Al-P	Surface Fe-P	Reductant-soluble P	Occluded Al/Fe-P	Ca-P	Sum of Fractions
22 March 1966						
Superphosphate	43(16.3)*	117(44.3)	65(24.6)	19(7.2)	20(7.6)	264
Thermophos	44(17.5)	117(46.4)	65(25.8)	24(9.5)	2(0.8)	252
Superphosphate + Lime	59(19.5)	122(40.3)	61(20.1)	24(7.9)	37(12.2)	303
Thermophos + Lime	72(24.2)	123(41.3)	65(21.8)	24(8.0)	14(4.7)	298
Superphosphate	51(18.0)	120(42.3)	63(22.2)	22(7.7)	28(9.8)	284
Thermophos	58(21.2)	120(43.6)	65(23.6)	24(8.7)	8(2.9)	275
No Lime	44(17.0)	117(45.2)	65(25.1)	22(8.5)	11(4.2)	259
Lime	65(21.6)	123(40.9)	63(20.9)	24(8.0)	26(8.6)	301
21 March 1967						
Superphosphate	71(23.2)	112(36.6)	63(20.6)	22(7.2)	38(12.4)	306
Thermophos	71(24.2)	128(43.5)	64(21.8)	25(8.5)	6(2.0)	294
Superphosphate + Lime	67(21.9)	106(34.5)	70(22.8)	24(7.8)	40(13.0)	307
Thermophos + Lime	69(24.9)	104(37.6)	68(24.5)	25(9.0)	11(4.0)	277
Superphosphate	69(22.5)	109(35.6)	66(21.6)	23(7.5)	39(12.8)	306
Thermophos	70(24.6)	116(40.7)	66(23.1)	25(8.8)	8(2.8)	285
No Lime	71(23.7)	120(40.1)	63(21.1)	23(7.7)	22(7.4)	299
Lime	68(23.3)	105(36.0)	69(23.6)	24(8.2)	26(8.9)	292

* Percentage of sum of fractions

3. *Effect of liming*—In Trial 2 in 1966 surface Al-P was lower and surface Fe-P much lower on the limed than on the unlimed treatments, whereas reductant-soluble P and Ca-P were higher on the limed treatments. In 1967 differences in surface Al-P and Ca-P levels had practically disappeared, but surface Fe-P was still lower and reductant-soluble P higher in the limed treatments.

In Trial 3 differences between limed and unlimed treatments were smaller than in Trial 2, but the differences in the distribution of the fractions were similar.

4. *Time of sampling*—Comparing the results for the two years, it appeared that an equilibrium was being established slowly, with a shift of phosphorus from surface Al-P and Fe-P to the more insoluble reductant-soluble and Ca-P forms in Trial 2. In Trial 3 the overall changes were small between samplings.

DISCUSSION

Forms of phosphorus

In Trial 1 Thermophos proved superior to the other forms, 6 cwt/ac being the equal of or superior to 7½ cwt/ac superphosphate. As the phosphorus content of the Thermophos was slightly less than that of superphosphate, the superiority would have been greater had equivalent rates of phosphorus been applied. Basic slag was similar to superphosphate when both were applied at 6 cwt/ac, but on an equivalent phosphorus basis the former was generallly superior. Lime-reverted superphosphate proved similar to 4½ cwt/ac superphosphate, suggesting there was no advantage in this reverted form. Serpentine superphosphate, however, was slightly superior to superphosphate at 4½ cwt/ac and to lime-reverted superphosphate, but the advantage was small and not comparable with the result from Thermophos.

Although not included in this experiment, ground Nauru rock phosphate and calcined C grade Christmas Island rock phosphate proved grossly inferior to superphosphate in a neighbouring trial.

Reasons for superiority of Thermophos

The marked superiority of Thermophos could be due to:

1. Its effect in raising soil pH;
2. Its magnesium and trace element content;
3. The forms in which the phosphorus is combined with the soil;
4. The presence of silicon.

The first of these can be ruled out from the results of Trials 2 and 3 where the addition of 2 tons/ac of lime to the superphosphate treatment failed to give results comparable with Thermophos without lime, despite the higher pH. Lime added to the Thermophos treatments depressed rather than enhanced the effects, despite the increase in pH.

The magnesium content of Thermophos was not considered to have been responsible for its superiority, as magnesium failed to show any responses in two other trials in this area (During *et al.* 1962; Cullen and

Arnold 1971). Also serpentine superphosphate proved inferior to Thermophos, although serpentine superphosphate contains magnesium and raised magnesium levels significantly in the herbage.

As molybdenum was applied as a basal dressing, and other trace elements (including copper, boron, zinc, manganese, iron, and cobalt) showed little if any response on this soil, trace elements present in Thermophos were considered unlikely to be responsible for its superiority. The form in which the phosphorus was present in the soil provides the most likely explanation of the superiority of Thermophos. The phosphorus in the Thermophos treatments was present to a greater extent in the surface-bound Al-P and Fe-P forms than in superphosphate treatments, where the Ca-P fraction was much higher. The amount present in the Ca-P form was increased by the addition of lime with both superphosphate and Thermophos, and this could account partly for the depressions when lime was added to the Thermophos, the Ca-P form apparently being less available than the other forms.

The response to lime in the superphosphate treatments appears to conflict with the above suggestion. A possible explanation is that a relatively high proportion of the P in the superphosphate treatments was in the Ca-P fraction even without lime, and the increase in this fraction thus had relatively little effect on P response. There could also be minor pH, nitrogen mineralisation, and other effects of lime which gave a small response, but in the Thermophos treatments these were overshadowed and obscured by the primary effect of the conversion of the phosphate into the Ca-P form.

Laverty and McLean (1961), McLachlan (1965), and Smith (1965b) considered that the aluminium forms were likely to be the most available source of phosphorus. Smith suggested that the aluminium phosphate changes slowly into the less soluble iron phosphate. He also noted that soils of high retention capacity fix more of the added phosphorus in the iron form. However, in the Te Anau trials the phosphate present in the iron form was not disproportionately high compared with the aluminium-bound form, despite the high fixing capacity of the soils. The percentage would be even lower if the correction factor could have been applied.

The apparently low availability of the calcium form is in agreement with the results from the work of Hanley (1962), who found on six soils that little phosphate was taken up from the calcium fraction by grasses and clovers.

The Ca-P form is possibly octocalcium phosphate, $Ca_4H(PO_4)_3.2.5H_2O$, which was shown by Bouldin *et al.* (1960) to form as concretionary deposits on calcite crystals when a mixture of monocalcium phosphate and calcium carbonate was incubated with an acid soil. Most of the phosphate so fixed remained at the granule site.

The high silicon content of Thermophos could be important. By occupying a proportion of the adsorption sites that otherwise would have been filled by phosphate ions from superphosphate, "fixation" may have been reduced. Silica has been shown to increase the assimilability of soil phosphate, increase the uptake of phosphorus and other nutrients, and increase yields (Comhaire 1966). In a subsidiary trial

the addition of soluble silica to monocalcium phosphate slightly increased clover vigour and yield, although the results from monocalcium phosphate + silica were inferior to those from comparable rates of Thermophos.

These results suggest that calcium phosphates of Thermophos type could prove very useful in high-fixing soils similar to Te Anau yellow-brown loam. By use of Thermophos supplemented by sulphur where necessary, lower rates of phosphates could be applied than those found necessary with superphosphate.

Basic slag was superior to superphosphate on an equivalent phosphorus content basis, although the results were inferior to those from Thermophos.

None of the reverted forms showed any superiority over superphosphate, and they are not recommended.

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