QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES

DIVISION OF PLANT INDUSTRY BULLETIN No. 410

CORRECTION OF SULPHUR DEFICIENCY IN LUCERNE IN THE WARWICK DISTRICT, QUEENSLAND

By J. W. LITTLER, B.Agr.Sc., and M. J. PRICE, B.Sc., Dip.Ind.Chem., Dip.Sug.Chem.

SUMMARY

Yield responses were obtained to applications of sulphur as elemental sulphur, gypsum and superphosphate.

An index of lucerne sulphur status was derived from the data, using the ratio of crude protein to total sulphur, a value less than 90 for $\frac{\text{crude protein}}{\text{total sulphur}}$ indicating sulphur sufficiency.

I. INTRODUCTION

To investigate the response of lucerne to sulphur in the Warwick district in south-eastern Queensland, a field trial was initiated at Glengallan in 1960. Treatment responses were not significant and a second trial was set down at Gladfield on flat land adjacent to Glengallan Creek. The results obtained from this experiment are recorded in this paper.

II. MATERIALS AND METHODS

The site of the experiment was a 5-year-old lucerne paddock situated on a creek flat, cultivated for the first time some 60 years ago. The soil was a dark brown clay, a general analysis of which provided the following information—

pH	7·2
Avail. P_2O_5 (p.p.m.)	>400
K as percentage of total replaceable bases ..	0·52

The trial was of a 17 x 3 randomized block design. Individual plots were 31·1 ft long and 7 ft wide; the central 3-ft strip only (0·002 ac) was harvested for yield determination and chemical analyses.

The treatments included three sources of sulphur, three rates of application and two times of application. In addition, one treatment consisted of the 2-yearly application of gypsum at 300 lb/ac. Details of treatments are given in Table 1.

On October 12, 1961, the site was mown and raked, the plots pegged out and the requisite fertilizer treatments applied. The second annual application of fertilizer was made on September 27, 1962. Harvesting was undertaken on each occasion when flowering had commenced. The oven-dried harvested samples were weighed and analysed for crude protein, total sulphur, phosphoric acid (P_2O_5) and crude fibre.

TABLE 1

DETAILS OF TREATMENTS

Treatment No.	Treatment	Designation
1	Control	Control
2	Control	Control
3	Control	Control
4	Control	Control
5	Gypsum 100 lb/ac annually	1/15S
6	Superphosphate 125 lb/ac annually ..	1/15S
7	Sulphur 15 lb/ac annually	1/15S
8	Gypsum 150 lb/ac annually	1/22S
9	Superphosphate 187 lb/ac annually ..	1/22S
10	Sulphur 22 lb/ac annually	1/22S
11	Gypsum 100 lb/ac 2-yearly	2/15S
12	Superphosphate 125 lb/ac 2-yearly ..	2/15S
13	Sulphur 15 lb/ac 2-yearly	2/15S
14	Gypsum 150 lb/ac 2-yearly	2/22S
15	Superphosphate 187 lb/ac 2-yearly ..	2/22S
16	Sulphur 22 lb/ac 2-yearly	2/22S
17	Gypsum 300 lb/ac 2-yearly	2/45S

The dates of cutting were as follows: First year: November 1, 1961; December 22, 1961; February 9, 1962; May 1, 1962; September 4, 1962. Second year: November 1, 1962; January 31, 1963; April 26, 1963; February 4, 1964.

The methods of the Association of Official Agricultural Chemists (1960) were used for determining crude fibre and crude protein, except that for crude protein determination the HgO catalyst was replaced by $CuSO_4$. For the determination of phosphoric acid (P_2O_5), sample preparation was as given by the Association of Official Agricultural Chemists (1960); this was followed by evaporation of the required aliquot to dryness before completing the analysis by the Lorenz method (Anon. 1930). Total sulphur was estimated by a method involving oxygen flask combustion followed by absorptiometry. The method is to be reported elsewhere.

Monthly rainfall records for the course of the experiment are given in Figure 1.

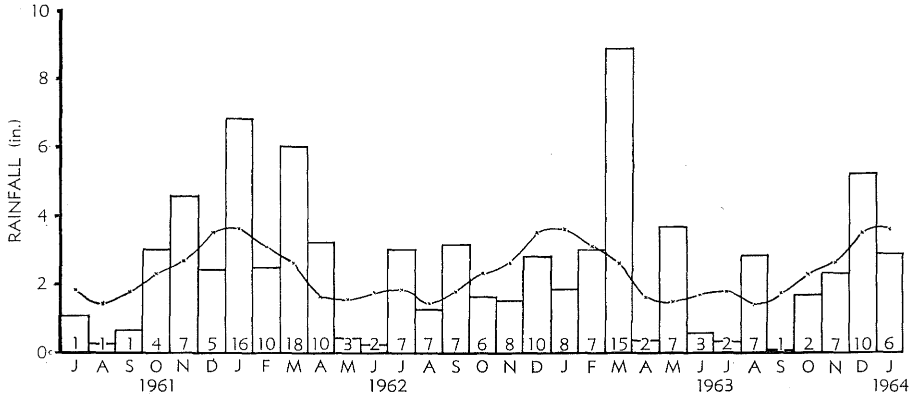

Fig. 1.—Monthly rainfall totals during trial period. The curve is the 90-year average rainfall at Warwick. Figures in the columns are number of wet days.

III. RESULTS

(a) Dry-matter Yields

Dry-matter yields are presented in Table 2. In the first year, results from the first cut indicate that all treatments except elemental sulphur at 15 lb/ac were significantly better (5% level) than control. The treatment superiority improved with the second, third and fourth cuts, in which all treatments were significantly better than control at the 1% level. At the fifth cut, only treatments involving 22 lb or more sulphur per acre, irrespective of source, were significantly better than control at the 1% level.

In examining the results from the second-year cuts, it is important to remember that certain plots (Table 1) received a second annual application of fertilizer 1 month prior to the first cut of the second year.

At the first cutting in the second year, gypsum at 300 lb was significantly better (1% level) than all other treatments.

Two of the 2-yearly treatments were superior to control plots at the second cut. These were the superphosphate treatment of 22 lb sulphur per acre (5% level) and the gypsum treatment of 45 lb sulphur per acre (1% level). Annual applications of superphosphate, gypsum and sulphur at the higher rates were significantly better than gypsum and sulphur at the lower rates at the second cut.

At the third cut, all annual applications of fertilizer except elemental sulphur at 15 lb/ac were better (5% level or less) than control, and the high levels of superphosphate and elemental sulphur at 2-yearly application were better (5% level) than control. Gypsum at 45 lb sulphur per acre was superior to control at 1% level.

TABLE 2

DRY-MATTER YIELD: 1ST AND 2ND YEARS

lb/ac

Treatment No.	Treatment	Designation	First Year Cuts 1	First Year Cuts 2	First Year Cuts 3	First Year Cuts 4	First Year Cuts 5	Second Year Cuts 1	Second Year Cuts 2	Second Year Cuts 3	Second Year Cuts 4	Trial Total
1–4	Control	..	488	1,452	1,181	889	108	335	268	476	249	5,446
5	Gypsum	1/15S	608	2,063	1,609	1,387	222	564	505	988	398	8,344
11	Gypsum	2/15S	608	2,063	1,609	1,387	222	402	285	607	322	7,505
6	Superphosphate ..	1/15S	635	2,117	1,699	1,413	246	464	543	1,155	380	8,652
12	Superphosphate ..	2/15S	635	2,117	1,699	1,413	246	487	355	683	287	7,922
7	Sulphur	1/15S	553	1,953	1,617	1,311	163	345	336	783	300	7,361
13	Sulphur	2/15S	553	1,953	1,617	1,311	163	461	268	508	264	7,098
8	Gypsum	1/22S	657	2,273	1,872	1,745	430	582	740	1,320	586	10,205
14	Gypsum	2/22S	657	2,273	1,872	1,745	430	591	314	763	253	8,898
9	Superphosphate ..	1/22S	635	2,316	1,876	1,694	493	667	696	974	538	9,889
15	Superphosphate ..	2/22S	635	2,316	1,876	1,694	493	556	426	947	388	9,331
10	Sulphur	1/22S	610	2,160	1,841	1,572	434	416	679	1,119	428	9,259
16	Sulphur	2/22S	610	2,160	1,841	1,572	434	478	389	898	255	8,637
17	Gypsum	2/45S	618	2,177	1,826	1,911	640	892	498	1,245	360	10,167
Necessary differences for significance		5%	99·2 (*a*)	218·8 (*a*)	314·2 (*a*)	270·0 (*a*)	193·0 (*a*)	126·0 (*a*)	136·4 (*a*)	374·8 (*a*)	111·0 (*a*)	
			76·8 (*b*)	169·5 (*b*)	243·4 (*b*)	209·1 (*b*)	149·5 (*b*)	159·5 (*e*)	172·5 (*e*)	474·0 (*e*)	140·4 (*e*)	
			108·6 (*c*)	239·7 (*c*)	344·2 (*c*)	295·7 (*c*)	211·4 (*c*)	122·7 (*d*)	122·9 (*d*)	335·2 (*d*)	99·3 (*d*)	
			88·7 (*d*)	195·7 (*d*)	281·0 (*d*)	241·5 (*d*)	172·6 (*d*)	..	..	..	..	
		1%	167·7 (*a*)	420·1 (*a*)	420·1 (*a*)	361·0 (*a*)	258·0 (*a*)	169·3 (*a*)	183·0 (*a*)	502·9 (*a*)	148·9 (*a*)	
			102·7 (*b*)	226·9 (*b*)	325·4 (*b*)	279·6 (*b*)	199·9 (*b*)	214·1 (*e*)	231·5 (*e*)	636·1 (*e*)	188·4 (*e*)	
			145·2 (*c*)	320·8 (*c*)	460·2 (*c*)	395·4 (*c*)	282·7 (*c*)	151·4 (*d*)	163·7 (*d*)	449·8 (*d*)	133·2 (*d*)	
			118·6 (*d*)	262·0 (*d*)	375·8 (*d*)	322·9 (*d*)	230·8 (*d*)	..	..	..	..	

(*a*) mean 12 *v*. 3; (*b*) mean 12 *v*. 6; (*c*) mean 3 *v*. 6; (*d*) mean 6 *v*. 6; (*e*) mean 3 *v*. 3.

* Treatment numbers correspond to numbers listed in Table 1.

In the fourth and final cut of the trial, all the annual treatments except elemental sulphur at 15 lb/ac were better (5% level) than control. Two of the 2-yearly treatments—superphosphate at 22 lb sulphur per acre and gypsum at 45 lb sulphur per acre—were superior to control at the 5% level. At this stage, gypsum and superphosphate applied annually at equivalent to 22 lb sulphur per acre were the outstanding treatments.

(b) Crude Protein Yield

Table 3 presents the protein yield for the first year of the trial. All treatments resulted in highly significant increases in protein yield over control. Gypsum at 45 lb sulphur per acre, gypsum at 22 lb sulphur per acre and superphosphate at 22 lb sulphur per acre were all significantly better (1% level) than the lower treatment levels of superphosphate, gypsum and sulphur. Elemental sulphur at 22 lb/ac was significantly better (1% level) than gypsum and sulphur at the lower application rate.

TABLE 3

CRUDE PROTEIN PER ACRE (LB), 1ST YEAR

Treatment	Means	N
Control	748	12
Gypsum 45 lb S/acre	1,394	3
Gypsum 15 lb S/acre	1,095	6
Superphosphate 15 lb S/acre ..	1,150	6
Sulphur 15 lb S/acre	1,041	6
Gypsum 22 lb S/acre	1,326	6
Superphosphate 22 lb S/acre ..	1,349	6
Sulphur 22 lb/acre	1,265	6

Necessary differences for significance	5%	121·9 (*a*) 136·3 (*b*) 149·3 (*c*) 105·6 (*d*)	1%	163·1 (*a*) 182·3 (*b*) 199·7 (*c*) 141·2 (*d*)

(*a*) Mean of 6 *v*. mean of 6.
(*b*) Mean of 3 *v*. mean of 12.
(*c*) Mean of 3 *v*. mean of 6.
(*d*) Mean of 12 *v*. mean of 6.

In Table 4, the crude protein yield data for the second year of the trial are listed. All treatments except gypsum 100 lb 2-yearly, sulphur 15 lb annually and sulphur 15 lb 2-yearly gave significant yield increases over control. As in the first year, the yields obtained from the gypsum 300 lb 2-yearly, gypsum 150 lb annually, superphosphate 187 lb annually, and sulphur 22 lb annually were of greater significance.

TABLE 4

YIELD OF CRUDE PROTEIN PER ACRE (LB)

Treatment	Designation	Means		N
		2nd year	1st and 2nd years	
Control	..	264	1,014	12
Gypsum	2/45S	618	2,012	3
Gypsum	1/15S	500	1,666	3
Gypsum	2/15S	324	1,349	3
Superphosphate ..	1/15S	511	1,693	3
Superphosphate ..	2/15S	364	1,484	3
Sulphur	1/15S	376	1,398	3
Sulphur	2/15S	295	1,357	3
Gypsum	1/22S	666	2,082	3
Gypsum	2/22S	387	1,624	3
Superphosphate ..	1/22S	596	1,943	3
Superphosphate ..	2/22S	461	1,813	3
Sulphur	1/22S	543	1,815	3
Sulphur	2/22S	396	1,654	3

	5%	1%
2nd Year		
Necessary differences	152·9 (*a*)	205·3 (*a*)
	120·9 (*b*)	162·3 (*b*)

(*a*) Mean of 3 *v*. 3.
(*b*) Mean of 12 *v*. 3.

	5%	1%
1st and 2nd Years	298·6 (*a*)	401·0 (*a*)
	236·1 (*b*)	317·0 (*b*)

(*a*) Mean of 3 *v*. 3.
(*b*) Mean of 12 *v*. 3.

The statistical analysis of crude protein yield data for the full trial period is also presented in Table 4. Gypsum 300 lb 2-yearly, gypsum 150 lb annually, and superphosphate 187 lb annually were the superior treatments. It is interesting to note that at the completion of the trial one application of 45 lb sulphur per acre as gypsum gave almost as good a result as the best annual fertilizer application—gypsum at 22 lb sulphur per acre.

(c) Chemical Composition

Tables 5 and 6 contain the results of the chemical analyses of samples from the first and second year of the trial. All samples from both years of the trial were analysed for percentage crude protein. All of the first-year cuts were analysed for total sulphur. Crude fibre results were obtained for the first two cuts of the first year, and phosphoric acid (P_2O_5) analyses were made on all first-year samples and from samples of the first two cuts in the second year.

TABLE 5

CHEMICAL ANALYSES OF SAMPLES, 1ST YEAR
Moisture-free basis

Treatment	Designation	Cut 1				Cut 2			
		Crude Protein (%)	Total Sulphur (%)	P_2O_5 (%)	Crude Fibre (%)	Crude Protein (%)	Total Sulphur (%)	P_2O_5 (%)	Crude Fibre (%)
Control	..	23·8	0·23	0·95	19·3	16·1	0·14	1·03	30·5
Gypsum	15S	25·6	0·40	0·92	19·2	15·7	0·21	0·73	31·7
Superphosphate ..	15S	25·6	0·37	0·92	19·5	16·9	0·22	0·76	30·3
Sulphur	15S	24·9	0·27	0·94	19·2	16·8	0·18	0·79	30·1
Gypsum	22S	26·2	0·47	0·95	19·5	16·7	0·22	0·71	30·7
Superphosphate ..	22S	25·6	0·43	0·93	19·4	16·5	0·23	0·73	30·6
Sulphur	22S	25·2	0·29	0·92	19·4	16·7	0·21	0·75	33·9
Gypsum	45S	25·0	0·52	0·93	19·6	16·2	0·28	0·75	31·4

TABLE 5—continued

Treatment	Designation	Cut 3			Cut 4			Cut 5		
		Crude Protein (%)	Total Sulphur (%)	P_2O_5 (%)	Crude Protein (%)	Total Sulphur (%)	P_2O_5 (%)	Crude Protein (%)	Total Sulphur (%)	P_2O_5 (%)
Control ..	..	15·5	0·13	1·02	16·2	0·14	1·39	20·8	0·17	0·95
Gypsum ..	15S	16·1	0·17	0·83	17·1	0·17	1·08	21·8	0·20	0·77
Superphosphate	15S	15·6	0·17	0·81	16·8	0·16	1·09	22·0	0·20	0·80
Sulphur ..	15S	16·0	0·16	0·85	16·5	0·16	1·06	20·4	0·18	0·74
Gypsum ..	22S	15·5	0·20	0·80	17·3	0·18	0·94	22·7	0·21	0·76
Superphosphate	22S	16·5	0·20	0·78	17·9	0·19	0·99	21·6	0·20	0·74
Sulphur ..	22S	16·3	0·18	0·82	17·3	0·17	0·95	21·3	0·20	0·76
Gypsum ..	45S	16·5	0·26	0·79	17·6	0·22	0·90	24·9	0·28	0·79

Control results are mean of 12 replicate analyses. All other results are mean of 6 replicate analyses.

Crude protein.—At the first cut, all treatments were better than control (5% level). No significant differences were recorded for the second cut and at the third cut only one treatment (gypsum 300 lb 2-yearly) was superior to control (5% level). At the fourth cut, all the high levels of sulphur application were superior to control (5% level), while at the fifth cut, gypsum 300 lb 2-yearly was significantly better (1% level) than all other treatments. At the first cut of the second year, gypsum 300 lb 2-yearly, gypsum 100 lb annually, superphosphate 125 lb annually, and gypsum 150 lb annually were all superior (1% level) to control; however, by the fourth cut of the second year, no significant differences were observed.

TABLE 6

CHEMICAL ANALYSES OF SAMPLES, 2ND YEAR
Moisture-free basis

Treatment	Designation	Cut 1		Cut 2		Cut 3	Cut 4
		Crude Protein (%)	P_2O_5 (%)	Crude Protein (%)	P_2O_5 (%)	Crude Protein (%)	Crude Protein (%)
Control	..	20·1	1·11	17·9	0·86	18·9	16·1
Gypsum	1/15S	21·6	0·80	18·6	0·74	19·5	16·0
Gypsum	2/15S	19·9	0·96	18·0	0·78	20·2	15·7
Superphosphate ..	1/15S	21·5	0·85	19·0	0·76	18·2	16·6
Superphosphate ..	2/15S	20·3	0·91	18·4	0·81	19·2	15·8
Sulphur	1/15S	20·9	0·89	19·0	0·75	21·2	16·9
Sulphur	2/15S	19·8	0·91	18·1	0·79	18·5	15·8
Gypsum	1/22S	21·4	0·81	19·5	0·74	19·6	16·1
Gypsum	2/22S	20·4	0·81	18·9	0·83	18·7	15·6
Superphosphate ..	1/22S	20·7	0·79	19·7	0·73	19·6	16·6
Superphosphate ..	2/22S	19·5	0·85	18·5	0·80	19·3	16·0
Sulphur	1/22	21·0	0·82	19·2	0·74	19·9	16·4
Sulphur	2/22	19·9	0·89	18·5	0·80	18·0	16·0
Gypsum	2/45S	21·4	0·75	18·8	0·73	19·6	16·7

Control results are mean of 12 replicate analyses. All other results are mean of 3 replicate analyses.

Total sulphur.—The only values statistically analysed were those at the first cut first year, and in this cut all treatments were significantly better (1%) than control, and gypsum 300 lb 2-yearly was significantly better (1%) than all other treatments. In cuts 2, 3 and 4 (the high-yielding cuts), the sulphur percentage decreased markedly in all treatments.

Phosphoric acid (P_2O_5).— No significant differences were noted for the first cut first year samples, but at the second cut the control was significantly better (1% level) than all other treatments. This continued for the third, fourth and fifth cuts of the first year. In the fourth cut, gypsum 300 lb 2-yearly was inferior (1% level) to all low rates of sulphur application. In the first cut of the second year, the control was significantly higher (1% level) than all other treatments.

IV. DISCUSSION

The results offer confirmation of the fact that lucerne requires considerable quantities of sulphur for efficient growth. The deficiency of sulphur in the control plots was effectively demonstrated by the poor colour and growth of the plants. This was in contrast to healthy plants in the treated plots. Response to sulphur was observed 15 days after the initial fertilizer applications.

Hilder (1954) showed that 30 lb sulphur per acre was responsible for a large growth increase of subterranean clover in the New England district of northern New South Wales. In the Warwick experiment, the results indicated that for applications less frequent than annual, rates higher than 22 lb sulphur per acre would be necessary. The only 2-yearly application to compare favourably with the higher rates of the annual treatments was gypsum 300 lb per acre, equivalent to 45 lb sulphur per acre.

Plant analyses for the first year showed that the uptake of sulphur had increased in all treated plots, the sulphur percentages for these being higher than for the control plots. The percentage total sulphur in the plant rose fairly sharply with increasing rates of sulphur application in the case of superphosphate and gypsum, but the application of elemental sulphur did not produce as rapid an increase (Figure 2). The uptake of sulphur from elemental sulphur is limited by the rate of solubilization, which in turn is partly dependent of particle size.

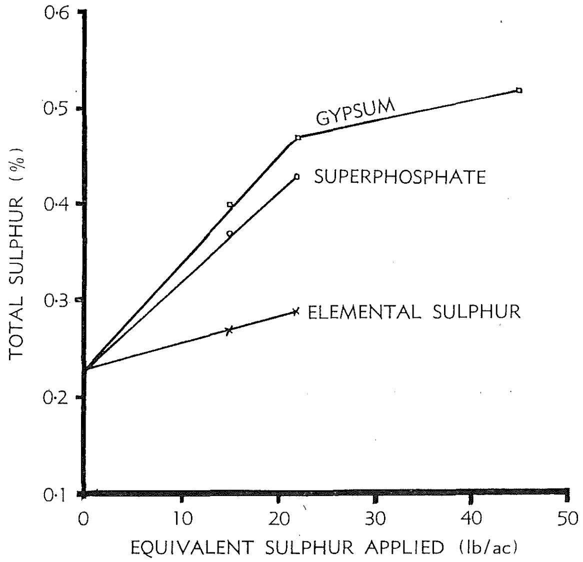

Fig. 2.—Total sulphur percentage in plant material *v*. amount of applied sulphur. First cut, first year.

In Figure 2, the curve for gypsum flattens off beyond the application of 25 lb sulphur per acre, the total sulphur percentage of the plant being approximately 0·5%. From field observations made on this trial it is evident that lucerne containing sulphur at this level has a very healthy appearance, with large, deep-green leaves.

Crude protein production was highest in those treatments having the highest yields of dry matter. This arose from the fact that protein percentages showed little variation between treatments, particularly during periods of maximum growth.

Figure 3 shows graphically total sulphur percentage in relation to crude protein percentage (first year cuts only). It is obvious that there is no correlation between total sulphur and crude protein that would apply throughout the duration of the trial. There does appear, however, to be some relationship on a growth rate basis, as the points on the graph fall into two distinct groups which correspond to periods of high and low growth rate. The lower group is composed of cuts 2, 3 and 4, which produced 80% of the first-year total crude protein, while the upper group is formed of cuts 1 and 5, which were made at approximately the same season of the year although almost a year apart. It would appear from these data that the total sulphur content of lucerne is influenced more by time of harvesting than by the sulphur content of the soil. This is in agreement with the findings of Evans and Greaves (1937).

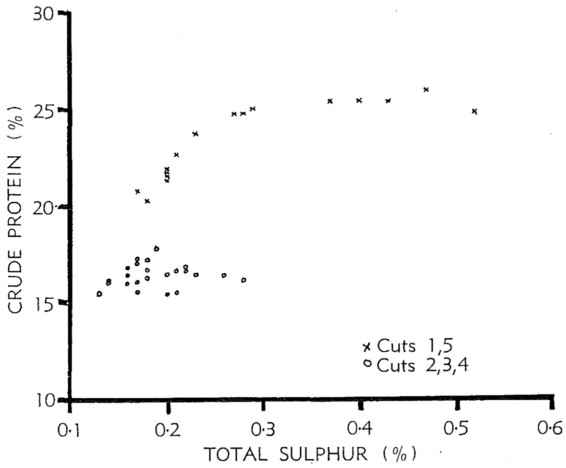

Fig. 3.—Crude protein percentage *v.* total sulphur percentage.

Figure 4, which shows the crude protein percentages and total sulphur percentages obtained from cuts 1 and 5, indicates that there is very little change in percentage crude protein of lucerne samples after the total sulphur content increases beyond 0·28%. It is reasonable to assume, therefore, that a level of 0·28% total sulphur in a lucerne plant of crude protein content of 25·3% is the minimum required for healthy growth. The crude protein: total sulphur ratio would be $\frac{25\cdot 3}{0\cdot 28} = 90\cdot 0$. If this ratio is used as a criterion of sulphur status of a plant, then values less than 90 would indicate excess sulphur storage while values greater than 90 would indicate possible sulphur deficiency.

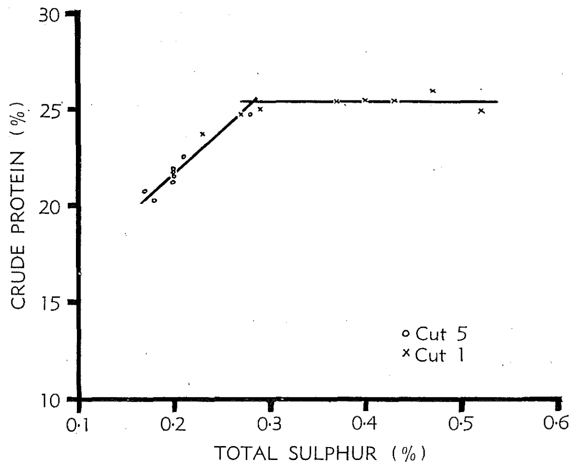

Fig. 4.—Crude protein percentage *v.* total sulphur percentage. First year, cuts 1 and 5.

Table 7 lists the ratios of crude protein:total sulphur at cuts 1-5 inclusive for gypsum treatments and control samples. From this table it is noted that increasing rate of gypsum application has the effect of keeping the ratio of crude protein: total sulphur below the derived value of 90 for progressively longer times. It would be reasonable to assume that gypsum 300 lb 2-yearly would allow the lucerne to be in such a state of sulphur sufficiency (ratio = 89 at the fifth cut) that the plants would be better able to take advantage of a favourable growth period than either of the other treatments listed in Table 7.

TABLE 7

CRUDE PROTEIN:TOTAL SULPHUR RATIO: 1ST YEAR CONTROL AND GYPSUM TREATMENTS

Treatment	Cut 1	Cut 2	Cut 3	Cut 4	Cut 5
	$\frac{\text{Crude Protein}}{\text{Total S.}}$	$\frac{\text{Crude Protein}}{\text{Total S.}}$	$\frac{\text{Crude Protein}}{\text{Total S.}}$	$\frac{\text{Crude Protein}}{\text{Total S.}}$	$\frac{\text{Crude Protein}}{\text{Total S.}}$
Control ..	103	115	119	116	122
Gypsum 15S ..	64	75	95	100	109
Gypsum 22S ..	56	76	78	96	108
Gypsum 45S ..	48	58	63	80	89

This is confirmed by the figures (Table 2) obtained for the first cut of the second year, in which the yield of dry matter from gypsum 300 lb 2-yearly is significantly higher (1% level) than all other treatments.

A second application of fertilizer was made to a number of plots (Table 1) 1 month prior to the first cut of the second year. While this had most effect on the dry-matter yield (Table 2) from plots receiving treatments 5, 8 and 9, it was not until good rain was received early in 1963 (Figure 1) that the full value of the second fertilizer application was realized. The inference is that by the end of the first year, sulphur availability was declining in the highest annual applications (22 lb sulphur). This has led to the idea that the most efficient application of sulphur to lucerne could be an initial heavy rate of 45 lb sulphur per acre, followed by annual applications of 22 lb.

It is interesting to note that the fertilizer treatment of elemental sulphur at 15 lb/ac, which was the only treatment that was not significantly better than control at the 5% level (Table 2), was also the only treatment in which the crude protein: total sulphur ratio was greater than 90 at the first cut.

Table 8 gives a list of crude protein:total sulphur ratios of lucerne calculated from values of crude protein and total sulphur found in the literature; also included are relevant treatments and observations regarding plant growth. It would appear from the table that the derived value of 90 used as an index of sulphur status has reasonably wide application. In all cases where healthy crops were growing, the crude protein: total sulphur ratio is less than 90 and in cases where deficiency symptoms prompted the application of sulphur the control samples give a ratio in excess of 90.

TABLE 8

CRUDE PROTEIN:TOTAL SULPHUR RATIOS CALCULATED FROM DATA IN THE LITERATURE

Crude Protein / Total Sulphur	Treatment and Remarks	Authority
69	Control with full nutrient supply but no atmospheric SO_2	Setterstrom, Zimmerman, and Crocker (1938)
113	Control on sulphur deficient soil (low yield) ..	Rendig, Weir, and Inouye (1955)
65	400 lb gypsum on above soil	
59	No applied sulphur—1st cutting of a healthy crop	Kingsley (1955)
50	No applied sulphur—2nd cutting of same area ..	
111	Control on Loon River loam	Cairns and Carson (1961)
80	Gypsum at 30 lb S/acre on Loon River loam ..	

It was shown in this experiment that, of the three sources used, gypsum and superphosphate were superior to elemental sulphur. When applied to well-aerated, moist soils, elemental sulphur is attacked by soil micro-organisms to form sulphuric acid. This sulphuric acid in turn supplies the sulphate ion (SO_4) that is the nutrient element taken up by plants. The speed of conversion to sulphuric acid depends upon how finely the sulphur is ground, the temperature, the moisture content and the population of sulphur-oxidising bacteria in the soil. It is likely, therefore, that the lesser performance of elemental sulphur could be associated with any or all of the above factors.

Superphosphate showed up well in the 2-yearly application 22 lb sulphur per acre. This treatment was better than elemental sulphur at the same level applied annually. Where there is no deficiency of phosphorus in the soil the choice suggested by the experimental results is gypsum.

V. ACKNOWLEDGEMENTS

The authors wish to thank Messrs. V. Willatt and F. Brown for the use of land, field officers of the Department for field assistance, the staff of the Agricultural Chemical Laboratory for assistance in the analyses, and the Biometrics Branch for all statistical analyses.

REFERENCES

ANON. (1930).—*In* Report of the 20th Meeting of the Australian and New Zealand Association for the Advancement of Science, 1930.

ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS (1960).—"Official Methods of Analysis." 9th Ed. (Association of Official Agricultural Chemists: Washington.)

CAIRNS, R. R., and CARSON, R. B. (1961).—*Can. J. Pl. Sci.* 41:709.

EVANS, R. J., and GREAVES, J. E. (1937).—*Proc. Utah Acad. Sci.* 14:17.

HILDER, E. G. (1954).—*Aust. J. Agric. Res.* 5.39.

KINGSLEY, A. F. (1955).—*Bi-mon. Bull. N. Dak. Agric. Exp. Stn* 17:212.

RENDIG, W. V., WEIR, W. C., and INOUYE, T. S. (1955).—*Calif. Agric.* 9:9.

SETTERSTROM, C., ZIMMERMAN, P. W., and CROCKER, W. (1938).—*Contr. Boyce Thompson Inst. Pl. Res.* 9:179.

(Received for publication May 23, 1966)

J. W. Littler is an officer of the Agriculture Branch, Division of Plant Industry, Department of Primary Industries, and is stationed at Warwick. M. J. Price is an officer of the Agricultural Chemical Laboratory Branch, Division of Plant Industry, Department of Primary Industries, and is stationed at Brisbane.