SULPHUR RESPONSES ON PASTURES

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The recognition of sulphur deficiency during the last few years over large areas of the South Island may be said to have originated in trials by Lobb (1953, 1954). The implications of earlier work by Doak (1929) and others had not been fully appreciated. After seeing some of the responses obtained by Lobb in North Otago, we at Lincoln decided to examine the nature of sulphur responses in Canterbury. After some initial experiments on rape (Walker, Adams, and Orchiston, 1954), where sulphur was shown to be of slight importance, emphasis was shifted to the tussock country in the Canterbury foothills (Walker, Adams, and Orchiston, 1955 and unpublished data). This paper will summarise most of our work.

1. Geographical Distribution of Sulphur Responses

Responses to sulphur have been obtained on the east side of the South Island from Southland to Marlborough and from near the coast to the main divide. We have obtained no definite responses on Banks Peninsula nor on lucerne at Ashley Dene, but residual effects of earlier topdressing with superphosphate may be a factor in the latter case. Further inland, responses have been obtained on all soil types tested, as shown in Table I. These particular areas are devoid of effective legumes and clover growth was taken as the yardstick of response, actual yields being measured or visual scores made. For simplicity, only the scores are presented, the best treatment being given 10 points.

Table I-Response of Clover to Sulphur and Phosphorus on various Soils.

Soil Series	Kowai	Oxford	Pukaki	Hurunui	Associate of Hurunui	Mean
Treatment						
0	1	2	1	1	0	1
S*	9	5	3	2½	5	5
P†	2	5	5	6	2	4
S + P	10	10	10	10	10	10

Soil Series	Amuri	Hui-Hui	Kaikoura	Spenser	Evans (Banks Pen.)	Mean
Treatment						
0	3	4	0	1	6	3
P	4	5	4	6	9	6
S + P	10	10	10	10	10	10

* S = 100lb. of gypsum per acre.
† P = 100lb. of triple superphosphate per acre.

It is clear from these results that over much of Canterbury the natural resources of sulphur are inadequate for optimum nitrogen fixation by legumes, and we believe the primary cause is low atmospheric returns of sulphur. The reason for this belief is briefly as follows: Many Canterbury soils have been analysed in 7in. horizons to a depth of 21 in. (Walker and Adams, 1958a). There is an extremely high correlation between nitrogen and sulphur contents, both between soils and down the profile, as shown by the following regression equation:

$$N = 7.643 + 0.007 \quad (r = 0.97^{+++}).$$

The line of best fit passes on extrapolation almost through the origin, suggesting that as with nitrogen, most of the sulphur is in organic forms. Any sulphur minerals from the parent material appear to have been oxidised and leached or used by organisms and converted to organic forms. The organic nitrogen and sulphur become available to plants again only after mineralisation by soil organisms, and evidence has been presented (Walker and Adams, 1958b) which suggests that grasses will utilise 95 per cent. or more of the nitrogen and sulphur made available from this source. Thus legumes which need 1lb. of sulphur to fix 10 to 15lb. of nitrogen are dependent almost entirely on sources of sulphur other than the soil. The need for sulphur therefore in topdressing practice should arise primarily in grass-legume associations and will depend on (a) how much sulphur is returned from the atmosphere and (b) the amount of nitrogen that can be fixed by legumes under given climatic conditions and management. Where virtually no sulphur is returned from the atmosphere, and this is probably true of much of the inland areas of the South Island, it must be applied as fertiliser if legumes are to fix any nitrogen at all. In areas where, say, 10lb. of sulphur per acre may be obtained from the atmosphere, fertiliser sulphur will be needed only where legumes can fix more than about 100 to 1 SO lb. of nitrogen per acre.

2. Rates of Application

The need for sulphur having been established in an area, the obvious practical problem is to decide the quantities needed. It is essential, of course, to correct all deficiencies other than sulphur and we have concentrated all our subsequent efforts on young soils (Kowai series) which are naturally rich in phosphorus and potassium, have not responded significantly to molybdenum, and, as far as we know, are adequately supplied with other nutrients. Calcium sulphate has been the main form of sulphur used, as this is the form in which it is supplied in superphosphate. Trials have now been put down in each of the last three years from which it is possible to reach certain tentative conclusions about initial rates of application in the Canterbury foothills. The annual yields of grass and clover (cutting trials) for various rates of gypsum are shown in Table 2.

Table 2-Yields of Dry Matter in First Year of Separate Trials. (lb. per acre.)

Trial	Trial 1			Trial 2			Trial 3		
Year	1954-55			1955-56			1956-57		
Rainfall	18.8 in.			17.2 in.			40.0 in.		
Gypsum (lb. per acre)	Clover	Grass	Total	Clover	Grass	Total	Clover	Grass	Total
0	40	810	850	30	1640	1670	640	3560	4200
25	200	920	1120	710	1750	2460	1500	3760	5260
50	610	1230	1840	—	—	—	1790	4210	6000
75	—	—	—	640	1790	2430	—	—	—
100	670	1410	2080	—	—	—	2420	3830	6250
200	710	1590	2300	—	—	—	2130	4140	6270
400	—	—	—	—	—	—	2560	3740	6300

These trials were all on different pastures on the same farm near the Rakaia Gorge. The pastures were composed of inferior grass species and before oversowing with clovers, only the pasture in Trial 3 contained any appreciable quantity of white clover. The rainfall figures are from the beginning of September to the date of the last cut, usually in April; rainfall was exceptionally low for Trials I and 2. Although total yields increased in Trial 1 up to the heaviest dressing of gypsum applied, there was a marked flattening of the response curve above the 50 lb. dressing (equivalent approximately to Icwt. of superphosphate). In the drier season following, 75lb. of gypsum gave a yield no higher than the 25lb. dressing. Even under the very favourable growing conditions of 1956-57, total yields were near the maximum from a 50lb. dressing of gypsum. These results apply to swards in which clovers were introduced by surface broadcasting of seed and responses may have been better had the seed been introduced into the soil with a sod-seeder or sown on a prepared seed-bed. Clearly, dressings of gypsum exceeding 100lb. per acre could not be justified in this area in the first year of improvement by the methods employed, and even 50lb. would give responses not much less than 100lb. It should be noted that the major responses are given by the clover, but grass growth also increased in all cases, particularly in Trial 1. This increase in grass growth (and yields of nitrogen) is believed by Walker, Adams, and Orchiston (I 956) to be due to underground transfer of nitrogen from clover to grass.

3. Forms of Sulphur

Sulphur may be applied to the soil in many forms, including salts very soluble in water such as potassium or ammonium sulphates, a moderately soluble salt such as gypsum, and elemental sulphur and iron pyrites in which the sulphur must first be oxidised to sulphate before it becomes available to plants. The latter forms may be slower acting than the sulphates, but may have bigger residual effects. A long-term trial (Trial 3) to study the effects of forms of sulphur, rates, and times of application was put down in 1956 and full details will not be available for three or four years. Some comparisons of the various forms of sulphur can be made from the first year of this trial and others. As the primary effect of the correction of sulphur deficiency is on clover growth and nitrogen fixation, only the clover yields are presented in Table 3.

Table 3-Effects of Various Forms of Sulpbur on Yields of Clover. (lb. dry matter per acre.)

TRIAL	TRIAL 2		Residual Effects		TRIAL 3		
Year	1955-56		in 1956-57		1956-57		
Pounds of Sulphur per acre as	Gypsum	Elemental S	Gypsum	Elemental S	Gypsum	Elemental S	Potassium Sulphate
0	30	30	210	210	640	640	640
5	—	—	—	—	1500	810	1360
15	640	440	2270	740	—		
20	—	—	—	—	2420	1490	1940
80			—		2560	2230	2750

In Trial 2 (Table 3) finely ground flowers of sulphur at 15lb. per acre was compared with gypsum also supplying 15lb. of sulphur per acre. In the dry season of 1955-56, which was the first year of the trial, elemental sulphur was definitely inferior to gypsum, although lime had been applied to correct any possible effect of the sulphur on soil acidity. This trial was carried on into 1956-57 to measure residual effects. These were very large for gypsum, but very small for elemental sulphur. We can as yet offer no satisfactory explanation for this very poor response and residual effect from elemental sulphur. In Trial 3 (Table 3) in the much wetter season of 1956-57, the low rate of 5lb. of elemental sulphur gave a much smaller response than gypsum or potassium sulphate supplying 5lb. of sulphur. At heavier rates, however, responses from elemental sulphur increased and at 80lb. per acre were not very much lower than from the other forms. The logical conclusion is that the rate of oxidation of the elemental sulphur to sulphate is slow, and the greater the amount applied, the greater the amount oxidised, but considerably more elemental sulphur is needed to give the same response as the soluble sulphates. Unless elemental sulphur has a greater residual effect, and this is not supported by the data from Trial 2, it is clearly inferior to the sulphates. There appears to be no significant difference between calcium and potassium sulphates in the first year. Trial 3 has been designed to compare not only forms and rates of sulphur, but also, for example, the effects of 20lb. of sulphur in various forms applied each year for 4 years, with 80lb. applied in the first year.

4. Residual Effects of Gypsum

There are two trials from which some inferences can be drawn on residual effects. In Table 4 are shown the increases in yield of nitrogen (grass + clover) above the control yields from applications of gypsum for each of the 3 years of Trial 1 and the corresponding recoveries of sulphur in the herbage.

Table 4—Increases in Yield of Nitrogen and Recovery of Sulpbur from Applications of Gypsum Made in the First Year in Trial 1.

Increases in Yield of Nitrogen (lb. per acre)				
Year	1954-55	1955-56	1956-57	Total Increase
Gypsum (lb. per acre)				
25	9.1	5.3	10.6	25
50	27.3	12.1	23.6	63
100	35.9	29.4	28.8	94
200	40.0	56.3	42.0	138

Recovery of Sulphur (lb. per acre)

lb. per acre of sulphur applied as gypsum	1954-55	1955-56	1956-57	Total Recovery	% Recovery
5.2	2.23	0.35	0.60	3.2	62
10.S	5.61	0.69	1.69	8.0	76
20.9	6.47	1.72	1.94	10.1	48
41.8	6.30	3.95	2.91	13.2	32

There is clearly a marked residual effect from gypsum extending over at least two seasons and increases in yield of nitrogen have been maintained remarkably. Recoveries of sulphur were highest in the first year, due primarily to luxury consumption of sulphate by the grasses. It is worth noting that on the average for the 3 seasons about 8 to 10 lb. of nitrogen have been fixed for each pound of sulphur.

The corresponding data for the two seasons of Trial 2 are given in Table 5. The recovery of sulphur was rather poor in the first dry season, but was considerably higher in the second year of higher rainfall, and the total recovery was almost 100 per cent. for the low rate of gypsum. An important question to be answered is how sulphur is retained in the soil over the winter to give such marked residual effects. It may remain as undissolved particles of gypsum, although very finely powdered gypsum has been used in all trials. It may be dissolved, but not leached below root range; it may be absorbed (Ensminger, 1954), retained in the root systems, or immobilised by micro-organisms. This year, trials using ^{35}S have been put down to help solve this problem.

Table S-Increases in Yield of Nitrogen and Recovery of Sulphur from Applications of Gypsum Made in the First Year in Trial 2.

	Increases in Yield of Nitrogen (lb. per acre)			Recovery of Sulphur (lb. per acre)			
Year lb. per acre sulphur applied as gypsum	1955-56	1956-57	Total	1955-56	1956-57	Total	% Recovery
5	25	63	88	2.0	2.7	4.7	94
15	21	68	89	3.1	5.2	8.3	55

5. Competition for Sulphur in a Grass-Clover Association

It has been shown that grasses compete intensely with clovers for potassium by Blaser and Brady (1950) and for phosphorus by Trumble and Shapter (1937), and clovers in a pasture make little if any growth where these two elements are deficient. The same appears to hold for sulphur, and where herbage is entirely dependent on the mineralisation of soil organic nitrogen and sulphur, legumes make virtually no contribution to production. The suppression of clovers which normally follows the application of nitrogen fertilisers to a pasture is minimised if deficiencies of potassium and phosphorus are corrected. This is also true of sulphur, as shown in Table 6, and this trial has been more fully discussed by Walker and Adams (1958b).

Table C-Yields of Dry Matter (lb. per acre) for Three Levels of Fertilisei Nitrogen at Each of Three Levels of Sulphur.

	S_0			S_1			S_2		
Treatments	N_0	N_1	N_2	N_0	N_1	N_2	N_0	N_1	N_2
Grass	5740	5760	6070	5990	6110	7030	6220	6210	6800
Clover	240	80	80	2850	1640	1220	2910	3690	2670

S_0 = no sulphur. N_0 = no nitrogen.
S_1 = 5 lb. S per acre as gypsum. N_1 = 20 lb. N per acre as Nitrolime.
S_2 = 15 lb. S per acre as gypsum. N_2 = 60 lb. N per acre as Nitrolime.

Clover growth was very poor in the absence of sulphur and was further suppressed on the application of nitrogen; grass took up 98 per cent. of the total uptake of sulphur at N_0S_0. At S_1 and S_2 clover growth was greatly increased, but while nitrogen suppressed clover growth at S_1, it had little if any effect at S_2. Under these conditions, sulphate of ammonia stimulates both grass and clover growth as long as the usual precautions are taken to neutralise its effect on soil acidity, and it would be an ideal fertiliser on some of the soils naturally rich in phosphorus in these areas, 'as it is not much dearer per unit of sulphur than superphosphate.

6. Composition of Herbage

In all these experiments the grass and clover were analysed for total nitrogen and sulphur, and in many cases for protein nitrogen and sulphate sulphur. The stage of maturity of the herbage is important, but levels of total sulphur below about 0.2 per cent. in the dry matter generally denote a deficiency, and we have recorded levels of 0.1 per cent. In clover it is rare to find more than 5 per cent, of the sulphur in the form of sulphate, whereas in grass 25 per cent. or more of the sulphur is usually inorganic. The nitrogen : sulphur ratio has varied from 6 to 12 for grass and from 10 to 24 for clover, the higher ratios occurring under conditions of acute sulphur deficiency. Underwood and Moir (1956) have suggested that a level of 0. I per cent. sulphur in the ration can be considered adequate and that the nitrogen : sulphur ratio should not exceed 15. It is unlikely, therefore, that sulphur deficiency is a factor in animal health even in the most deficient areas. Sulphur deficiency is expressed mainly as a restriction of nitrogen fixation by legumes with consequent low pasture production and low carrying capacity. The phosphorus content of herbage has frequently been lowered by applications of gypsum.

7. The Sulphur Cycle in Grassland Soils

All the experiments described have been conducted in the absence of the grazing animal. This has been necessary because of the lack of research funds, but it is possible to extrapolate to grazing conditions and this has been attempted elsewhere (Walker, 195'7). Briefly there is an over-all similarity between the fate of ingested nitrogen and sulphur. The biggest fraction of both is excreted as low molecular compounds in the urine, as urea and sulphate respectively. Higher molecular compounds, probably more resistant to soil microbial activities, occur in the dung. It can generally be expected that less fertiliser sulphur will be needed when grazing compared with cutting for conservation because of animal returns; but much must depend on management.

Conclusion

Sulphur and phosphorus are main nutrients applied to New Zealand pastures. Soil analysis will select those soils responsive to phosphorus, but is useless for diagnosing sulphur deficiency. Without actually measuring cyclic returns of sulphur (and this is difficult), only field trials will pinpoint the responsive areas. To achieve maximum efficiency in the use of sulphur and phosphorus, both of which are imported, a series of fertilisers would be desirable, ranging from straight phosphorus fertilisers to straight sulphur fertilisers with one or two intermediate mixtures. Such a rational fertiliser policy is surely not beyond the bounds of possibility, and it is not too early to be thinking of the problem, even though all the questions cannot yet be answered.

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DISCUSSION

Dr Sears: Sulphur responses have been obtained on a mixed sward at Grasslands Division, Palmerston North. The white clover was more responsive than the red clover.

A. We used a mixture of red, white, alsiki and subterranean clover. The white clover was not the only clover to respond to sulphur, good responses were also seen with red clover.

Q. Would the sulphur return from the grazing animal reduce the need for fertiliser sulphur?

A. Yes, by an unknown amount.

Q. Have other forms of sulphur and elemental sulphur of different finenesses of grinding been tried'?

A. We have been disappointed with results from elemental sulphur, and cannot explain this.

Dr Davies: On a trial at Tauhara on pumice, a main effect from elemental sulphur of an increase in yield of 300 per cent. was secured at the most recent cut, Red clover was the main clover responding.

A. I suggest sulphur-oxidising bacteria may be deficient in the soils I have studied.

Q. Have the effects of sulphur on nodulation been studied?

A. Not in these trials.

Q. Might not large sulphur losses result from the patchy nature of urine return and localised areas of concentration?

A. I agree that losses or sulphur, nitrogen and potassium might be considerable for this season.