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SULPHUR NUTRITION OF THE GRASS COMPONENT ON A TUSSOCK
GRASSLAND SOIL.

A thesis submitted in partial requirement
for the Degree of Master of Agricultural Science with
Honours in Field Husbandry.

Canterbury Agricultural College,
University of Canterbury,
1960.

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SULPHUR NUTRITION OF THE GRASS COMPONENT ON A TUSSOCK GRASSLAND SOIL.

INTRODUCTION.

The tussock grassland area of the South Island comprises some thirteen million acres. This area has been classified by L. Cockayne 1927 on a species and altitudinal basis into the following regions:

- 0 - 1000 ft lowland tussock grassland
- 1000 - 3000 ft montane tussock grassland
- 3000 - 5000 ft sub-alpine tall tussock grassland
- 5000 ft and above alpine vegetation

The study undertaken was carried out in the montane tussock grassland region which in the South Island comprises some six million acres.

Almost fully occupied by 1880, the area has been utilized for fine wool production. Overgrazing, burning and rabbits to name a few of the factors responsible led to widespread deterioration of the vegetation and subsequent accelerated erosion of the soil. A considerable volume of work has been done on ways and means of arresting this development and improving the already deteriorated areas. Earlier work followed the lines of spelling and possible plant introduction, only limited success being obtained with these methods. More recently with the recognition of nutrient deficiencies, particularly sulphur, phosphorus and molybdenum and their relation to the nitrogen status of the association; successful means of clover over-sowing and an enlightened management policy, the picture has vastly changed.

Improvement through such practices was an important factor in the 10% increase in sheep numbers from 1950-56 (13) so that Garrett 1956 whilst forecasting little prospect of output increases from the highest country, predicted an increase of 22% total sheep numbers on the lower country.

That the position has been aided by better financial returns in recent years cannot be doubted, but this has operated through the improvement of the grazing condition of the runs and has entailed rabbit eradication, oversowing, manuring and appropriate managerial adjustments and control.
In the unimproved state, the vegetation is denoted by grass dominance with a virtual absence of legumes, the grass being unproductive due to the low nitrogen status of the association.

Plant-soil relationships indicate that despite adequate levels of nitrogen and sulphur in the organic matter (Walker et al. 1954 (b)) the factor limiting their availability to the plant is the slow mineralization rate (Ahmad 1960; Ross 1958). Thus, only small amounts of sulphur and nitrogen are available from this source. Anderson and Spencer 1950 and Walker et al. 1956 (a) have shown the importance of sulphur for adequate nitrogen fixation by clover. With sulphur a limiting factor, grass taken up 95% of the little that is available (Walker et al. 1958) the result being that legumes must depend for their sulphur on other sources, mainly atmospheric. Since Walker et al. 1956 (a) have shown that such sources tend to be very low in these areas, the association lacks legumes and is consequently of low vigour because of the slow turn-over of nitrogen.

Walker 1957 suggests that the aim in these circumstances should be to provide maximum grass production, concomitant with maximum nitrogen fixation by the clovers. Sulphur availability will be an important component of the system.

This study attempts to elucidate some of the factors connected with the sulphur nutrition of grasses in such a situation. Previous work had emphasised the clover component.

For the particular trial area, it was hoped to determine

1. Whether the response of the grass to nitrogen is governed by the sulphur level available.
2. A determination of what level of nitrogen was likely to be provided by clover fixation and transferred to the grass component under improved grassland conditions in the area.
3. What the optimum level of sulphur for the association is, allowing adequate sulphur for maximum possible nitrogen fixation as well as for utilization by the grass of the nitrogen transferred.
4. The effects of nitrogen and sulphur on plant chemical composition and any possible relationships between plant and soil as influenced by these factors.
REVIEW OF LITERATURE

Since their occupation in 1860, the condition of the tussock grasslands has generally deteriorated. This was realised as being a problem of great concern by 1910.

Various reports such as those of Cockayne 1918, Zotov 1942 and Gibbs and Basside 1945 adequately cover the situation. From reports such as these, recommendations were made and there generally followed two lines of approach, namely spelling and plant introduction.

1. SPELLING EFFECTS

For long an advocated policy, particular attention was given to spelling by Cockayne 1918 and Malcolm 1925 in earlier years and in more recent times by Sewell 1947, Dick 1956 and Moffat 1956.

These studies cover a wide ecological and climatic range, but all reached similar conclusions in that, although less bare ground was observed in spelled areas, there was no appearance of new plants and thus the practice was ineffectual unless native grasses were already in existence.

2. PLANT INTRODUCTION

Concurrent with spelling were attempts at plant introduction, noteworthy experimental work being carried out by Macpherson 1910 in Central Otago and the Mackenzie Country and Cockayne 1918 and Calder 1935 in Central Otago.

Cockayne 1918 considered that the inherently fertile mica schist country of Central Otago had a greater potential production from higher producing plants (presumably such species as cocksfoot, lucerne and clovers) than from the native vegetation and he considered that it should be only after failure to establish better plants, that a restoration of the primitive covering should be aimed at. Some success was obtained particularly with better soils on dark and semi dark faces, provided rabbits and sheep were excluded.
Zotov 1943 in later years however was less optimistic about introduced species and, basing his conclusions on ecological grounds, considered the source of suitable species to be amongst the native vegetation itself. Given relief from deterioration processes and reasonable help in establishment, these should then be able to reassert themselves.

This early introduction work, although generally disappointing in results obtained, indicated useful species in tall oat grass, cockfoot, Bromus inermis, Yorkshire fog, crested wheat grass, subterranean clover, white clover and lucerne amongst others. An important factor was protection from grazing pressure and the rabbit was a bar to this.

3. **Modern Outlook on the Problem**

Three events have been of great significance. Firstly, the eradication of the rabbit with such outstanding results as reported by Saxby 1957; secondly, the discovery of sulphur and molybdenum deficiencies in the South Island Lobb 1953, Davies et al 1951 and subsequent confirmation of these on tussock grassland areas by Walker et al 1954(b) along with an increased appreciation of other limiting factors; and thirdly the application of aerial oversowing methods.

The key to their improvement lies in the oversowing of clover and the correction of limiting factors, both mineral and those connected with cultural practice e.g. inoculation. Originally stimulated by successful overdrilling in the Mackenzie Country (Sievwright 1956), the emphasis has now moved to aerial oversowing (Lobb and Bennett 1958). At the moment, successful development practices would appear to be dependent on aerial methods.

Such work has comprised the initial improvement stage and the more difficult problem of grass introduction now follows. Difficulties in establishment have been demonstrated by Simpson and Moore 1955 and Dunbar 1950 on depleted country in the more difficult climatic situations, but a noteworthy point is the observation that heavy litter
definitely aided grass seedling establishment (Simpson and Moore 1955). Sievwright 1956 reports from the Holbrook trials that the introduction of grass species, with the possible exception of cocksfoot and tall oat grass, was difficult to achieve in the initial seeding, even when the seed was drilled. Similarly, Maclean 1957 at Broken River, Canterbury noted that grass species were difficult to establish by sod-seeding or by oversowing.

However, considerable success has been attained in Central Otago with lucerne-cocksfoot overdrilling (Schofield 1957) while Hooken 1959 advocates the inclusion of grasses along with aerial-sown clovers in the Mackenzie country. More recently, on depleted tussock land in the Hakatere Valley, success has been obtained with the establishment of ryegrass, cocksfoot and clovers up to 3,400 ft. (Darwin 1959).

To obtain the fullest benefit from clover introduction, it is desirable that use should be made of the higher fertility grasses and hence the second stage of the improvement plan, inclusion of these grasses in the association.

SULPHUR IN RELATION TO TUSSOCK GRASSLAND IMPROVEMENT

Lobb 1953 indicated the importance of sulphur by showing this to be the basis of clover response to super-phosphate on the Waiareka complex soils of North Otago, these soils being high in 'available' phosphorus. Earlier New Zealand work (McConnell 1913, 1914; Doak 1929) had indicated a possible sulphur deficiency of swedes, rape, pasture and lucerne. A possible sulphur deficiency of pasture was also shown in trials at Palmerston North reported by Sears 1953. These showed a growth response to superphosphate only in a grass-clover mixture receiving no manurial returns whereas cloverless mixtures or those receiving normal returns did not respond.

However, it was with Lobb's work 1950, 1954, 1958 that the full impact of the importance of sulphur was felt. This work was doubtless stimulated by prior and concurrent Australian findings Anderson and Spencer 1950, Anderson and Arnott 1953, Anderson 1952, Donald and Williams...
1954, McLachlan 1952. These showed a masked S - P response and interaction. Use of superphosphate had thus masked any sulphur deficiency.

Recognition of the importance of sulphur as a limiting factor on tussock grasslands was extended by Walker et al. in a trial on the effects of sulphur and phosphorus on a rape crop grown in the Canterbury foothills 1954(b). These workers in one trial obtained a significant yield response to gypsum in the presence of mono-calcium phosphate.

Sulphur studies were further expanded by the same team on a wide range of tussock grassland soil types Walker 1954(a). The general picture obtained was that sulphur was a more important factor than phosphorus in limiting clover growth in these situations and that molybdenum had no significant effects.

Concurrent improvement work was carried out in the Mackenzie Basin by Siewwright 1956 who obtained extraordinary legume growth by overdriiling with superphosphate at 2 cwt/acre.

Extensive work by Walker et al. on various aspects of sulphur has been reported briefly 1957, all this work being undertaken in the Rakaia Gorge area. Here they obtained a marked clover and grass response, a three-fold increase in dry matter and a four-fold increase in nitrogen yield with calcium sulphate. A high proportion of the sulphur was recovered at rates of up to 50 lb. CaSO₄/acre 1956(a) but recovery was less at higher rates. Further studies of the residual effects of calcium sulphate over four years showed that with rates varying from 25 - 200 lbs. gypsum/acre, recoveries were of the order of 80 - 30% 1958(b). Latest work, Walker 1959, has sought to discover the mechanism of this retention.

Along with this work of a fundamental nature has proceeded the extension work carried out notably by Lobb and Bennett in the Rakaia Gorge area 1958. Latest work reported by Lobb 1959 on rates of sulphur and phosphorus has shown at 22 lbs / acre of phosphorus an increasing plant growth response with increased sulphur rates from
10 lbs. is obtained in contrast to no response by increasing
the phosphate rate at a standard sulphur rate. General practice
from this work is now the use of fortified superphosphate containing
400 lbs. of added S/ton, 1 cwt of this supplying 30 lbs. of S/acre.

5. NITROGEN AND SULPHUR RELATIONSHIPS IN THE GRASS SWARD

Basic factors concerning the relationship of sulphur to the
individual components, grass and clover, were studied by Anderson and
Spencer 1950. They showed that sulphur was needed by non-legumes
for protein formation from the absorbed nitrogen. Nitrogen deficient
non-legumes responded little in colour or growth to sulphur and the
S - N yield interaction was positive.

Clover with a molybdenum supply inadequate for symbiotic nitrogen
fixation reacted in the same way to nitrogen and sulphur as did non-
legumes. On the other hand, with clover provided with molybdenum and
dependent on symbiotic nitrogen fixation for the nitrogen supply,
sulphur deficiency decreased percentage total N as well as yield
indicating a link between the sulphur status of the host and nitrogen
fixation. The results of this work showed that sulphur was needed
for nitrogen metabolism, promoting protein formation and that there
was a marked increase in symbiotic clover fixation on nitrogen
deficient soils provided the molybdenum status was adequate.

Walker et al. 1956(a) later studied the effects of gypsum on the
grass-clover association. Their results showed an eighteen-fold
increase in clover yield and a doubled grass yield. The grass responded
significantly to sulphur and this suggested either a direct sulphur
response or alternatively indirect through nitrogen by increased
clover fixation and subsequent underground transfer of nitrogen. A
larger fraction of the applied sulphur was taken up by grass than clover
under the deficiency conditions of control and at small applications.
Consideration of this led to a study of competition for sulphur in
ground clover associations by the same workers 1958(a). Applied
nitrogen was found to suppress the clover at control and the lower
sulphur level, but had little effect at the higher sulphur level which apparently supplied adequate sulphur for the grass to grow to the level determined by the applied nitrogen and still leave sufficient sulphur for the clover.

A paucity of legumes is a feature of tussock grasslands in their unimproved state. Hilder 1954, noting the highly gramineous nature of New England native pastures suggests that this may be an expression of sulphur deficiency as the low nitrogen content of many of these soils suggests satisfactory conditions for legume competition.

Walker et al. 1956(a) noted the low sulphur status of similar tussock grassland soils and obtained markedly increased dry matter yields with sulphur rates as low as 5 lbs/acre.

Most of the soils nitrogen and sulphur is in the organic matter. Donald and Williams 1954 showed a close relationship between total sulphur and total nitrogen on a podsolic soil. A linear relationship between total S, N and C was found by Williams and Steinbergs 1958 in Eastern Australia. Soils not conforming to this relationship contained large amounts of water soluble sulphate. Similarly, Walker et al. 1954(b) and White 1959 on a range of Canterbury hill and plain soils found C/N, C/S and N/S correlations.

In a comprehensive review of the situation, Walker 1957(b), 1955 suggests that if the sulphur and phosphorus supply is limiting, nitrogen fixation by clovers will be less than optimum. The grasses utilise almost all the mineral nitrogen and sulphur from the organic matter 1956(c), 1958(a) and the clovers are thus dependent on outside sources of sulphur in order to fix nitrogen symbiotically. Until an equilibrium point is reached; most of the legume-fixed nitrogen accumulates in the organic matter along with carbon, organic sulphur and organic phosphorus. Similar conclusions were reached by Williams and Donald 1957. In a similar vein, but on a sandy West Australian soil, Hingston 1959 found a similar organic matter build-up, but the
increase per cwt of superphosphate was less than that found by Donald and Williams 1954 due probably to lower phosphorus and sulphur retention by these soils.

The sulphur available to the association is thus dependent on

(a) mineralization of organic matter  (b) atmospheric return  
(c) fertilization.

(a) MINERALIZATION

White 1959 suggests that in soils with normal N/S ratios, relative rates of mineralization appear similar, producing mineral N and S\(_4\) -S in the proportion of 10 : 1. Under climatically favourable conditions, a mineralization level of 1.25\% for nitrogen undetermined by Walker et al. 1954(c). On a moderately to strongly acid Tekou soil from Beasley, Ross 1958 found a low nitrifying potential and also noted the irregular distribution of nitrifying organisms in the tussock grassland soils studied. Ahmad 1959 on a recent loessial Rakaia Gorge soil found that inoculation with Thiopeum thioxidans and incubation, rendered sulphur more available but, although these bacteria were present in the soil studied, owing to their small number and the lack of available sulphur, these were not active.

(b) ATMOSPHERIC RETURNS

Atmospheric returns of sulphur in the tussock grasslands are considered to be low and Walker et al. report a response to as low as 5 lbs S/acre in the Rakaia Gorge area. Little response would be expected to this low rate if other sources of sulphur such as atmospheric were available.

(c) RESPONSE TO APPLIED SULPHUR

A wide and varied literature discusses the response of pasture plants to sulphur. The initial response is generally through the clover component followed by an increase in grass production.

Work by Sears et al. 1953 emphasises the importance of
clovers and animal returns for maximum productivity, the latter factor speeding up the turn-over of nitrogen fixed by clover. Many workers have studied factors concerned with nitrogen fixation and transfer, Walker et al. 1954(a) comprehensively surveying these aspects.

Willoughby 1954 studied factors affecting grass clover relationships under low phosphorus status conditions. He found that until superphosphate through clover response had raised the soils nitrogen status and until there was excess phosphorus above the clover requirements, sufficient for the grass to make use of the available nitrogen, ryegrass would survive only as unproductive nitrogen deficient plants.

He further suggests that as the nitrogen status rises and the proportion of grass increases, the quantity of nitrogen fixed will decrease. Thus, the trend will be towards an equilibrium between grass growth and clover fixation governed primarily by the phosphorus level available to the association.

The same considerations should apply to sulphur as a limiting factor. Walker 1958(a) has suggested that photosynthesis may be restricted in grass if the content of protein nitrogen remains below 1% where this is caused by sulphur deficiency. Correction of this might influence photosynthesis and be reflected in higher dry matter yields.

Sulphur studies have been carried out for many years in the U.S.A. Amongst more recent references, legume responses to sulphur are reported by Conrad et al. 1947. Continuation of this work with natural range non-legumes in years subsequent to the application of fertilizer, showed that increased yields were obtained compared with unfertilized trials.

Bentley and Green 1954 also noted stimulation of native annual clovers on foothill range and a striking increase in grass production following increased clover production.
In Canada, the report of the Alberta Advisory Fertilizer Commission (quoted by Jordan and Ensminger 1958) notes that, whilst sulphur fertilization had little immediate effect on cereals or grasses, the benefits were large when these followed sulphur fertilised legumes.

Anderson 1952 gives an early account of sulphur studies in Australia. On a basaltic soil of adequate P status, MacLachlan 1952 reported a marked sulphur response with subterranean clover. Hilder and Spencer 1954 obtained a very large yield increase on a natural Medicago denticulae pasture with sulphur. There was a slight grass response at lower rates, but legume competition was more restrictive with higher rates.

In New Zealand, a pilot trial at Grasslands Division Palmerston North 1954 showed that on a mown pasture where herbage was removed and no fertilizer applied, yields steadily declined, although there was no evidence from soil on herbage levels, of phosphorus deficiency. A similar treatment with superphosphate at 5 cwt/acre maintained a constant yield of 11,000 lbs dry matter/acre with an apparent sulphur response, judged from considerably increased white clover vigour.

Further work, already mentioned, was carried out by Walker et al. 1956(a). The latest report on this trial studying residual effects of CaSO₄ shows that the highly significant grass response is being maintained even in the fourth year of the trial, but clover response has diminished 1958(b).

6. NITROGEN AND SULPHUR IN RELATION TO PLANT CHEMICAL COMPOSITION

Sulphur occurs in the amino acids cystine, cysteine, homocysteine and methionine as well as in the vitamins biotin and thiamine. Sheldon et al. 1951 report that amino acids, presumably devoid of sulphur, amides, ammonia and acid hydrolysable carbohydrates accumulate in mustard when sulphur supplies are low.
Nightingale et al. 1932 showed that sulphur deficient tomato plants were not low in % total organic sulphur, but much of it was water soluble whereas the organic sulphur of the complete nutrient plants was mainly in a complex protein form.

In lucerne, total N was found by Tisdale et al. 1950 to be higher at lower levels of sulphur decreasing as the concentration of sulphur increased. This was probably due to large dry matter differences between the two extremes. The percentage of methionine and cystine increased with increasing concentration of sulphur, but there was a tendency for these percentages of amino acids to level off at higher concentrations. Based on cystine and methionine levels, the quantity or quality of the protein was lowest when total nitrogen was highest and this occurred at low sulphur levels. It thus appears that the sulphur containing amino acids increased as a proportion of total amino acids with increasing sulphur.

Mertz (quoted by Needham and Haage 1952) found however, that sulphur-containing amino acids in lucerne decreased no more than other amino acids where sulphur was deficient.

Bemner et al. 1953 studying wheat and barley showed that increases in % protein are associated with some decrease in quality as measured by % contribution of essential amino acids and this decrease in quality is less marked where sulphur-containing fertilizers are applied. Wheat after legumes compared with fallow - wheat had a greater range of cystine and methionine and thus suggested that the difference was due to the larger amounts of nitrogen and sulphur available, as cystine significantly correlated with sulphur and methionine with both nitrogen and sulphur.

Dealing specifically with the single components legumes and non-legumes, Anderson and Spencer 1950 showed that non-legumes deficient in S or N contained a lower percentage protein N than normal plants. Whereas nitrogen deficiency decreased percentages of non-protein nitrogen and total nitrogen, sulphur deficiency increased percentages of non-protein nitrogen and total nitrogen. This would be due to low dry matter production. Nitrate accumulation was shown in these sulphur
deficient plants and thus sulphur was needed by non-legumes for protein formation.

Sulphur-deficient clover was found by the same authors to contain a low percentage of protein N and an increased percentage of N.P.N. Under these conditions, there was a decreased demand for nitrogen and a decreased number of nodules in contrast to nitrogen and molybdenum deficiencies.

Spencer 1959 found an increased percentage of protein N and total N in white clover as the sulphur supply increased, protein N forming a greater proportion of the total N at higher sulphur levels. Protein S however formed the bulk of total S in deficient plants, and as the sulphur supply approached an adequate level for growth, there was a marked increase in non-protein organic sulphur and a smaller increase in inorganic sulphur. In this respect, white clover differs from non-legumes which accumulate sulphur mainly as sulphate.

Bardsley and Jordan 1957 showed that clover without sulphur was lower in sulphur and nitrogen yield, N/S ratios were wider and contents of cystine and methionine in the dry matter lower.

Aitken 1924 showed a constant percentage of organic sulphur in pasture grasses, variations in total S being due to variation in inorganic sulphur, and Evans 1931 found that a heavy dressing of inorganic sulphate increased organic S, but no correlation was found between organic S and protein content, suggesting that part of the organic sulphur was present as non-protein sulphur. No distinct correlation between organic sulphur and nitrogen of grass as influenced by ammonium sulphate was found by Askew and Bishop 1932. They also observed a marked increase in inorganic sulphur, but only a small increase in organic sulphur of pasture grass with topdressing. The inorganic sulphur content of ryegrass was 75% of total S and for white clover 50-60%.

Wood and Barien 1939 studied the effects of nitrogen and sulphur on Phalaris tuberosa and Lolium multiflorum. They found that an increase in ammonium N increased the content of cystine and protein S as well as amino N and protein N and decreased sulphate sulphur. An increase
in sulphate sulphur did not increase cystine or protein $\text{S}$. They thus concluded that nitrogen was the limiting factor under the conditions studied and there was no response to sulphur unless the nitrogen level was increased. In a further trial with Sudan grass they found that an increased nitrogen supply at the same sulphur level, caused an increase in protein $\text{S}$. They also noted that the ratio of protein N to protein $\text{S}$ was higher, the higher the nitrogen treatment. They suggest that this increase in value could be, that with increased nitrogen treatment, one or more proteins relatively rich in sulphur increase in amount, but at the same time are diluted with one or more proteins containing relatively little sulphur.

Further discussing sulphur metabolism of plants, Wood 1942 suggests that more than one protein exists in leaves and the change is generally in the direction that protein rich plants are sulphur rich. He quotes Heiserick as finding the $\text{SO}_4^-$ content much greater in plants receiving $\text{NO}_3^-$ than in those receiving $\text{NH}_4^+$ salts and the latter plants contained more protein $\text{- S}$. This would appear to be an ionic uptake effect.

Andrew et al. 1952 noted that in *Raspalum scrobiculatum*, the proportion of protein N to total N was depressed by nitrate treatment and raised by sulphate treatment.

A photosynthetic restriction if the content of protein N remains much below 1% is suggested by Walker et al. 1958(a). Correction of sulphur deficiency is thus reflected in increased dry matter yields through photosynthesis and not so much in higher protein content.

Increases in the yield of protein N are consequently a reflection of increased yields of dry matter rather than increased contents of protein N.

The same workers earlier found Walker et al. 1954(b) most of the extra sulphur taken up by grasses on their treated plots remained in the inorganic form, presumably because nitrogen was more of a limiting factor. Luxury consumption of sulphate by grasses is suggested, as
these in the above trial without any apparent yield increase took up more of the added sulphur than the clovers, despite the extra 1,000 lbs of clover dry matter produced per acre.

Their later trials on pasture 1958(b) showed a marked increase in the nitrogen contents of grass and clover. Increase in % N was almost entirely in protein N as non-protein nitrogen remained steady at 0.5% in grass and 1% in clover. Grass N/S ratios were 4 - 6 in the first year due to luxury consumption of S and increased to 12 - 18 in the fourth year.

The overall picture appears to be an increase in methionine and cystine as the sulphur level is raised in conjunction with nitrogen. From the nitrogen aspect, the need of sulphur for protein formation in legumes and non-legumes has been ably demonstrated. Other work dealing more with sulphur aspects indicates a build-up of non-protein organic sulphur with clovers and inorganic S with grasses where sulphur is at luxury levels. Grass accumulation of SO₄ → S appears to be due to nitrogen being more the limiting factor. Results obtained with grasses indicate that the relative importance of the various chemical fractions would appear to be largely dependent on the nitrogen level. Clover response does not depend so much on the nitrogen level as sulphur plays an important part in nitrogen fixation.

An important factor would appear to be the ionic form in which each element is taken up, this operating through competition in uptake between anions.

7. NITROGEN - SULPHUR INTERACTION

Experiments with flax, oats, linseed and Paspalum dilatatum by Anderson and Spencer 1950 showed that sulphur and nitrogen were needed together for protein formation and normal growth and there was a positive N - S interaction for protein and dry matter. Sulphur increased % protein N at the expense of N.P.N. but did not increase percentage total N.
Andrew et al. 1952 also showed that the addition of nitrogen and sulphur to *Paspalum serobiculatum* gave a substantial plant growth response, associated with an even greater increase in protein production.

Coastal Bermudagrass was shown by Bardsley and Jordan 1958 to respond to sulphur, provided the grass was heavily fertilized with nitrogen.

Cormack et al. 1951 showed that cereal crops following sulphur-fertilized legumes show marked yield increases and higher total N and S levels. Similar results were obtained by Jordan and Baker 1959 with winter wheat following lucerne.

In a more direct fashion, Rost et al. 1958 report that when accompanied by nitrogen fertilizer, sulphur significantly increased grain yield on five and straw yield on seven of fifteen fields, above those obtained with nitrogen alone.

With reference to tussock grasslands, O'Connor 1959 has shown the interaction of N, S and P on oversown tussock grassland at Enys Flat and an N - S interaction with resident vegetation at Broken River. A dry matter response was obtained with cocksfoot, using levels of added nitrogen up to 200 lbs N/acre along with adequate S, P and K. Further work indicated a position N - S interaction with sparse planted grasses in uncultivated turf at Broken River.

Harrison 1958 reports the response of *Festuca nova-zealandiae* on Tukua soil type to N, P, K and S under glasshouse conditions.

8. NITROGEN AND SULPHUR IN RELATION TO CULTURAL RELEASE FROM THE SOIL

A suggested release of sulphur to plants by mineralization is indicated by Anderson 1952 who showed that calcium and magnesium carbonates improved the colour and growth of plants as did sulphur on sulphur deficient soils provided with nitrogen.

Bilder 1954 suggests that the occasional lack of a definite response to superphosphate in the first year may be due to cultivation releasing sulphur.
The factor of increased availability through cultivation of elements that are normally relatively poorly available in the undisturbed soil is mentioned by Hilder and Spencer 1954 in relation to the soils studied. These are productive under cultivation, but not so under natural pasture.

Barrow 1957 found that renovation by ploughing increased phalaris yields due to the greater availability of nitrogen and sulphur. Nitrogen and ploughing increased sulphur yields and the effects of nitrogen could be due to increased breakdown of organic matter, improved grass nutrition, or to a decrease of the sulphur content of the plant roots. Increased availability of nitrogen however, was not linked with increased availability of sulphur as shown by the lessened effect of ploughing at high N levels and it was suggested that organic matter low in sulphur could decompose with little sulphur release at first.

Frenay and Spencer 1960 followed soil sulphate changes in the presence and absence of growing plants. Initial and final extractable soil sulphate (water soluble and adsorbed) and sulphur taken up by Phalaris tuberosa were measured. Where plants were grown, mobilization of the organic S occurred at the nil, 4 ppm 12 ppm and 36 ppm levels of sulphur addition and added sulphate was immobilized at 108 ppm level. In the absence of plants, no net mineralization of organic S occurred following additions of sulphate. They state that the results of the above work indicate that decomposition is greater under plant cover and the main factor in the build up of nutrients in a fallowed soil is the absence of plant uptake.

Further work of a fundamental nature by Barrow 1958 indicated that the formation of ammonia was delayed when the C/N ratio was wider than 5:1 and marked where there was at least one part of sulphur to 100 parts of carbon. When the proportion of sulphur in the organic matter was reduced, ammonia formed more rapidly. Utilization of nitrogen appeared to be limited by the sulphur supply and nitrogen in excess of microbial needs was mineralized. Conversely, when
the proportion of nitrogen in the organic matter was reduced, the
production of sulphate tended to be more rapid, though the effect
was not as marked as reducing the proportion of S on the production
of ammonia.

A later report of this work by Barrow 1960 studied the effect
of varying the N S and P content of organic matter on its decomposition.
The marked effect of low S on N mineralization indicated that adequate
S was necessary for proper N metabolism. Concurrent with this work
the same author showed that when organic materials of high N content
are allowed to decompose in the soil, the accumulation of ammonia
caused high pH values. This high pH facilitated increased production
of \( \text{CO}_2 \), sulphate and mineral nitrogen from the soil organic matter.

Hesse 1957 reports that the addition of \( \text{CaCO}_3 \) nitrates and non-
sulphur-containing amino acids had no effect on subsequent sulphate
production, but incubation with sulphur-containing amino acids or
calcium sulphate resulted in an increased rate of soil sulphur oxidation.

Earlier work by Shedd 1928 also found that where no sulphur was
added, lime had little influence on the oxidation to sulphate of the
combined S in the soil.

MacIntyre et al. 1961 in lysimeter trials report that mineralization
of organic matter and oxidation of elemental sulphur was stimulated
and \( \text{SO}_4 \) loss accelerated by moderate liming.

Retention of sulphate in soils is related to colloidal properties
by Emsberger 1958 who states that sub-surface layers contain more
sulphate and are capable of adsorbing more sulphate than surface layers.
Texture is an important factor and light textured soils show no adsorbing
capacity. He later suggests (1954) that the fact that phosphate will
release sulphate and decrease the soils capacity to adsorb sulphate
indicates that the sulphate is held by some of the same compounds
that fix phosphorus. Liming was also found to decrease the soils
capacity to adsorb sulphate.
A relationship between mineralization of sulphur and sulphate content was found by Halversen and Bollen 1923. Application of inoculated sulphur stimulated sulphur mineralization. Fife 1926 likewise, comparing the action of sulphur on sterilized and unsterilized soils found that crop yield due to sulphur was greatest on the unsterilized soil.

From a different aspect, Koser and Olson 1953 determined the effect of soil moisture on the oxidation of applied elemental sulphur and found that the maximum amount of S was oxidized at moisture tensions rather than field capacity.
Montane Tussock Grassland

Mt Somers

Mid Canterbury
EXPERIMENTAL WORK

METHODS

Mt. Somers Field Trials.

An early geological and botanical account of the Ashburton River Gorge area is given by Iaing, Speight and Cockayne 1910.

1. LOWER SITE

A field trial was established in the lower Ashburton River Gorge on 'Inverary' Mt. Somers at an altitude of 2300 ft. The site chosen was at the foot of a terrace with an easterly aspect. The vegetation consisted of Festuca novae-zelandiae, Holcus lanatus, Acrostis tenuis, Anthoxanthum odoratum, Dactyloctenium aegyptium, along with lesser components such as Leucopogon fraseri, Poa colensoi, Poa caespitosa, Agropyron scabrum, Lunula campestris, Vahlenbergia albo-marginata, Mascaria townsonii and Trifolium dubium. There was a small percentage of red and white clover, more evident on topdressing, which originated from adjacent aerial over-sowing.

SOIL ANALYSIS

The soil is classified as belonging to the Kakahi series. Analysis of the 0-3" layer by standard methods indicated:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rating</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>B.E.C.</td>
<td>20 me%</td>
<td>medium</td>
</tr>
<tr>
<td>T.E.E.</td>
<td>10 me%</td>
<td>&quot;</td>
</tr>
<tr>
<td>Total N</td>
<td>0.46%</td>
<td>&quot;</td>
</tr>
<tr>
<td>Org C</td>
<td>3.42%</td>
<td>low</td>
</tr>
<tr>
<td>Total S</td>
<td>0.094%</td>
<td></td>
</tr>
<tr>
<td>Exch Ca</td>
<td>7.75 me%</td>
<td>medium</td>
</tr>
<tr>
<td>Exch Mg</td>
<td>2.79 me%</td>
<td>&quot;</td>
</tr>
<tr>
<td>Exch K</td>
<td>1.20 me%</td>
<td>high</td>
</tr>
<tr>
<td>Trog P</td>
<td>.016 - .018 % P₂O₅</td>
<td></td>
</tr>
<tr>
<td>Total P</td>
<td>2010 ppm</td>
<td></td>
</tr>
<tr>
<td>Inorg P</td>
<td>743 ppm</td>
<td></td>
</tr>
<tr>
<td>Org P</td>
<td>1267 ppm</td>
<td></td>
</tr>
<tr>
<td>Heat Sol S</td>
<td>(negligible) (Williams and Steinbergs 1959)</td>
<td></td>
</tr>
</tbody>
</table>
Design

Commenced on 12th January 1959, the trial was designed to study nitrogen-sulphur interaction on native and introduced grass components. A factorial design was used with four replications in randomized block pattern. Plot size was 20 x 25 links (1/200th acre).

Treatments

Nitrogen - applied as nitrolime at a N equivalent of 0, 40 and 200 lbs N/acre respectively.

Sulphur - applied as gypsum at a S equivalent of 0, 10 and 50 lbs S/acre.

A basal dressing of 100 lbs double superphosphate per acre was also applied.

A row each of 20 short rotation ryegrass, cocksfoot and timothy seedlings was sown in each plot, the intention being to measure maturial response by means of these plants. These were planted by the technique of 'space planting' suggested by O'Connor 1959 whereby each plant was placed in a cut in the native sward, the intention being to provide as natural growth conditions as possible, with minimum disturbance. The resident vegetation in the line of each row was cut to facilitate planting and to lessen competition during establishment.

Weather conditions subsequent to planting proved to be too severe with a week of high temperatures and the majority of the seedlings failed to survive. Consequently it was decided to confine attention to the native (resident) vegetation and to study its response to nitrogen and sulphur in terms of dry matter production and botanical change.

On 10th March 1959, 9 quadrats of a total area of 1 sq. yd were cut from each plot to measure response prior to this date and the site was then mown with a cutter bar mower.

A further 1 sq. yd sample cut was made on April 20th to measure autumn growth response; the rest of the site was not mown on this
occasion.

On 4th October, the plots were again cut to measure winter growth using 1 sq. yd samples from each plot and the site was mown. A repeat measuring in the same quantities as initially was carried out as it was considered that the previous measuring would now be giving little response at the lower nitrogen level. Owing to an increase in the clover component due to the applied sulphur, one half of each plot was sprayed with a 1:5 mixture of the esters of 2,4-D and 2,4,5-T. The unsprayed half of each plot was oversown with a mixture of red and white clovers each at 2 lbs/acre, on the 20th October for a comparison of the effects of the manurnal treatment on a grass sward and on a mixed sward.

The fourth sample cut of the plots was made on 30th November, one square yard being cut as a sample from the sprayed and unsprayed portion of the plot respectively and the site was again mown.

The final sample cut of the trial was made in a like manner on 5th March 1960.

2. UPPER SITE

An identically designed trial was established on the same property at an altitude of 2600 ft with a north-westerly aspect. This site was of a wetter nature, with the chief tussock species Panthonia raculii; the other vegetational components were similar to those of the lower site, except for a greater native component, notably Coelmisia sp.

Soil Analysis

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>B.E.C.</td>
<td>20 me %</td>
<td>T.E.B.</td>
<td>6 me %</td>
<td>Total N</td>
</tr>
<tr>
<td>Org C</td>
<td>3.16 %</td>
<td>Total S</td>
<td>0.054 %</td>
<td>Exch Ca</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Exch Mg</td>
<td>1.66 me %</td>
<td>Exch K</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Truong P</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total P</td>
</tr>
</tbody>
</table>
Inorg P  830 ppm
Org P  114.0 ppm
pH ≤5.5

Spacing planting as for the lower site was carried out, but only the cocksfoot survived in sufficient numbers to allow recording. These plants were recorded on the basis of tiller numbers and total height, measured from the base of the plant to the tip of the tallest leaf. Determinations were made on March 1st, April 15th and 14th December 1959. The plants were cut to a height of two inches for a dry matter determination on the last date of observation. A final cut was made in March 1960.

ANALYTICAL METHODS

Treatment material from these trials was analysed for total N by the semi-micro Kjeldahl method; protein N by tri-chlor acetic acid treatment to precipitate the protein and determination of the protein N by semi-micro Kjeldahl (Wood and Sibly 1952); total S by magnesium nitrate oxidation and gravimetric determination (AOAC methods 1945); and inorganic S by the Johnson and Mishita method 1952 with modifications suggested by K. Spencer (pers. comm.). These consisted of using instead of the red phosphorus reducing mixture, a mixture of hypophosphorus acid, formic acid and hydriodic acid. Treatment prior to reduction aiming at reducing nitrate interference, was to place the plant material in the reducing tube, moisten with alcohol and heat for a few minutes on a boiling water bath to completely moisten the sample. 10 ml of 10% BaCl₂ were then added and digestion carried on for a further 10 minutes. The remaining liquid was then removed by Fregel filter stick and the residue reduced by Johnson and Mishita's method, leaving the filter stick in the reducing tube.

POT EXPERIMENTS

EXPERIMENT 1

This was a duplication of the Mt Somers trial with the intention of studying N-S interaction using single plants, under the relatively uniform conditions of the glasshouse. The trial comprised the
nine manorial treatments already given and had three replications.

Four inch diameter soil cores were obtained from Mt Somers using a cylindrical sampler. Soils cores were used, as previous work (White 1954) failed to show S response in the glasshouse; the cause suggested was release of soil sulphur through disturbance of the soil by sieving. The cores were shaped and placed in cardboard cartons. Surface vegetation was removed by cutting off below ground level and any further growth such as grass and small natives was removed during the trial.

Cocksfoot as single plants from seed, sweet vernal and Yorkshire fog as single tillers were used. The latter plants were separated, rooted in sand and selected for uniformity. A cut was made in the surface of each plot and a single tiller per plot planted. Cocksfoot and sweet vernal were sown on April 18th and Yorkshire fog on April 27th.

Growth was slow due to low winter temperatures. Tiller and height determinations were made at approximately monthly intervals and the first dry matter cut to a height of 1" was made on 11th July. The regrowth was cut on 1st September and the experiment terminated.

EXPERIMENT 2.

This trial with cocksfoot extended the nitrogen range. To ensure that sulphur was not limiting at the higher levels of nitrogen, the sulphur levels were also raised.

High variability of plant material was evident in the first experiment and so a clonal line of cocksfoot was used in an attempt to reduce this factor. Two plants per pot were planted using single tillers and one of these was later selected.

Nitrogen was applied as nitroline at rates of 0, 100, 200 and 300 lbs N/acre and sulphur as gypsum at 0, 25 and 75 lbs S/acre. Four replicates were used with a factorial design.

The plants were sown on 1st September 1959 and tiller counts and height measurements made regularly. A dry matter cut was made on 26th October and the regrowth cut on 30th November, the experiment then being terminated.
EXPERIMENT 3.

The surface of the pots from experiment two was cultivated and inoculated pedigree white clover sown. This was later thinned to four plants per pot.

The aim of this experiment was to study the effect of residual nitrogen and sulphur from the previous experiment and particularly to determine whether there was originally adequate S for the particular N level and vice versa as judged from clover growth utilizing residual sulphur. Excess N should likewise depress clover growth through lack of S if the condition of N-S interaction holds. Harvesting took place on 1st March 1960 and a dry matter determination was made. Total S and inorganic S were determined.

EXPERIMENT 4.

This experiment was designed to study the possible release of sulphur from the soil by cultural methods and its effect on the growth of cocksfoot.

The treatments were: soil disturbed by sieving and undisturbed; lime at 3 tons/acre and no lime; nitrogen as nitrolime at levels of 0, 40 and 200 lbs N/acre and sulphur at 0 and 10 lbs/acre as gypsum. A factorial design was used.

Single tillers from a cocksfoot clonal plant were established in each pot and later thinned to one plant per pot and the pots were manured on 6th October. The trial was cut for a dry matter determination on 15th December.

EXPERIMENT 5.

The aim of this experiment was to determine the optimum interaction level of sulphur, using as the nitrogen level an amount equivalent to that fixed and transferred by the clover component at Mt Somers.

The nitrogen level used was calculated according to theoretical considerations advanced by Walker et al., 1954(c). 11,000 lbs dry matter was taken as the optimum yield of a grass clover association under similar climatic conditions to Mt Somers. The ratio of grass/clover
was assumed as 60/40 and from Mt Somers field determination on a ryegrass - white clover pasture, the grass N percentage as 1.77% and clover 2.97%. The soil nitrogen contribution to the grass was taken at half the theoretical value as mineralization is considered to be low in these areas.

The trial then as planned, consisted of one nitrogen level at 80 lbs N and levels of S at 0, 15, 25, 40, 50 and 60 lbs S with five replications. Single tillers from a cocksfoot clonal plant were used. The experiment was managed on 1st March 1960.

To confirm the nitrogen level used, a cage was placed on a productive ryegrass - white clover pasture on the station flat at Mt Somers. Two cut of superphosphate/acre was applied on 4th October and the first cut made on 30th November. The final seasonal cut was made in March 1960 and nitrogen determined on the sample clover and grass dry matter.
TABLE 1.
Mt. Sneore Lower Site Dry Matter Production Ibs/acre.

<table>
<thead>
<tr>
<th>Out</th>
<th>F₀</th>
<th>F₁</th>
<th>F₂</th>
<th>F₀</th>
<th>F₁</th>
<th>F₂</th>
<th>F₀</th>
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<th>F₀</th>
<th>F₁</th>
<th>F₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer Prelim.</td>
<td>2635</td>
<td>2778</td>
<td>2535</td>
<td>2235</td>
<td>2568</td>
<td>2495</td>
<td>2423</td>
<td>3650</td>
<td>3838</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autumn Prelim.</td>
<td>773</td>
<td>505</td>
<td>743</td>
<td>1208</td>
<td>1233</td>
<td>1313</td>
<td>1655</td>
<td>2083</td>
<td>2160</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Cut</td>
<td>313</td>
<td>553</td>
<td>473</td>
<td>735</td>
<td>995</td>
<td>1063</td>
<td>1553</td>
<td>2583</td>
<td>2993</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Cut</td>
<td>1245</td>
<td>1238</td>
<td>693</td>
<td>1816</td>
<td>1743</td>
<td>2030</td>
<td>1873</td>
<td>4265</td>
<td>4372</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd Cut</td>
<td>1765</td>
<td>2558</td>
<td>2305</td>
<td>1980</td>
<td>2060</td>
<td>2693</td>
<td>1650</td>
<td>3203</td>
<td>3218</td>
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<td></td>
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</tr>
<tr>
<td>1 + 2 + 3</td>
<td>3343</td>
<td>4369</td>
<td>2671</td>
<td>4231</td>
<td>4798</td>
<td>5006</td>
<td>4976</td>
<td>10 058</td>
<td>10 146</td>
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</tbody>
</table>

Unsprayed 2nd Cut Total | 1180 | 1303 | 2120 | 1837 | 2383 | 2220 | 2870 | 3593 | 4797 |

2nd Cut Less clover | 759 | 728 | 1492 | 1533 | 1503 | 1744 | 2750 | 3593 | 4652 |

3rd Cut Total | 1417 | 2877 | 3137 | 1713 | 2507 | 2630 | 1737 | 2657 | 3843 |

3rd Cut less clover | 1242 | 2210 | 2073 | 1579 | 1910 | 2002 | 1660 | 2552 | 3043 |

TABLE 1(a)
Statistical Analysis of Table 1 (F values)

<table>
<thead>
<tr>
<th>Out</th>
<th>Summer Prelim.</th>
<th>Autumn Prelim.</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>1 + 2 + 3</th>
<th>2nd Unsprayed Prelim.</th>
<th>2nd Unsprayed</th>
<th>3rd Unsprayed Prelim.</th>
<th>3rd Unsprayed</th>
</tr>
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<tbody>
<tr>
<td>3%</td>
<td>5,4%</td>
<td>5,6%</td>
<td>2,8%</td>
<td>5,2%</td>
<td>7,6%</td>
<td>32%</td>
<td>3,0%</td>
<td>20,2%</td>
<td>3,1%</td>
<td>11,4%</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2,4%</td>
<td>4,2%</td>
<td>5,6%</td>
<td>2,8%</td>
<td>5,2%</td>
<td>7,6%</td>
<td>32%</td>
<td>3,0%</td>
<td>20,2%</td>
<td>3,1%</td>
<td>11,4%</td>
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<td></td>
</tr>
<tr>
<td>4,2%</td>
<td>7,6%</td>
<td>5,6%</td>
<td>2,8%</td>
<td>5,2%</td>
<td>7,6%</td>
<td>32%</td>
<td>3,0%</td>
<td>20,2%</td>
<td>3,1%</td>
<td>11,4%</td>
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<td></td>
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</tr>
<tr>
<td>Quad N</td>
<td>5,7%</td>
<td>6,8%</td>
<td>5,0%</td>
<td>6,8%</td>
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<td></td>
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</tr>
<tr>
<td>4,2%</td>
<td>7,6%</td>
<td>5,6%</td>
<td>2,8%</td>
<td>5,2%</td>
<td>7,6%</td>
<td>32%</td>
<td>3,0%</td>
<td>20,2%</td>
<td>3,1%</td>
<td>11,4%</td>
</tr>
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</tr>
<tr>
<td>Quad S</td>
<td>2,5%</td>
<td>15,7%</td>
<td>9,6%</td>
<td>10,6%</td>
<td>9,6%</td>
<td>10,6%</td>
<td>1,0%</td>
<td>1,23%</td>
<td>10,41%</td>
<td>10,41%</td>
</tr>
</tbody>
</table>
### Table 2.

#### Seasonal Analysis Dry Matter Mt Somers Lower Site 1ba/acre.

<table>
<thead>
<tr>
<th></th>
<th>$\overline{S_0}$</th>
<th>$\overline{S_1}$</th>
<th>$\overline{S_2}$</th>
<th>$\overline{N_0}$</th>
<th>$\overline{N_1}$</th>
<th>$\overline{N_2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fog</strong></td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Summer Prelim.</td>
<td>224.0</td>
<td>91.7</td>
<td>147.0</td>
<td>141.4</td>
<td>192.6</td>
<td>263.5</td>
</tr>
<tr>
<td>Autumn Prelim.</td>
<td>65.7</td>
<td>111.3</td>
<td>70.6</td>
<td>193.3</td>
<td>256.9</td>
<td>262.6</td>
</tr>
<tr>
<td>1st</td>
<td>26.6</td>
<td>60.0</td>
<td>44.9</td>
<td>117.3</td>
<td>204.0</td>
<td>212.6</td>
</tr>
<tr>
<td>2nd</td>
<td>361.1</td>
<td>234.6</td>
<td>174.1</td>
<td>453.4</td>
<td>528.1</td>
<td>738.0</td>
</tr>
<tr>
<td>3rd</td>
<td>303.5</td>
<td>319.8</td>
<td>656.9</td>
<td>445.5</td>
<td>607.7</td>
<td>523.5</td>
</tr>
<tr>
<td>$1 + 2 + 3$</td>
<td>691.2</td>
<td>688.4</td>
<td>875.9</td>
<td>1017.3</td>
<td>1069.8</td>
<td>1474.1</td>
</tr>
<tr>
<td><strong>S.V.</strong></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Summer Prelim.</td>
<td>131.8</td>
<td>250.0</td>
<td>132.1</td>
<td>231.2</td>
<td>482.8</td>
<td>474.1</td>
</tr>
<tr>
<td>Autumn Prelim.</td>
<td>87.3</td>
<td>172.0</td>
<td>113.7</td>
<td>314.9</td>
<td>300.7</td>
<td>246.8</td>
</tr>
<tr>
<td>1st</td>
<td>35.4</td>
<td>105.1</td>
<td>72.4</td>
<td>207.4</td>
<td>238.8</td>
<td>199.8</td>
</tr>
<tr>
<td>2nd</td>
<td>597.6</td>
<td>659.9</td>
<td>442.0</td>
<td>909.0</td>
<td>868.0</td>
<td>813.0</td>
</tr>
<tr>
<td>3rd</td>
<td>214.2</td>
<td>355.8</td>
<td>133.7</td>
<td>233.6</td>
<td>222.5</td>
<td>386.4</td>
</tr>
<tr>
<td>$1 + 2 + 3$</td>
<td>847.2</td>
<td>1130.6</td>
<td>688.1</td>
<td>1350.0</td>
<td>1329.3</td>
<td>1529.2</td>
</tr>
<tr>
<td><strong>O.G.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer Prelim.</td>
<td>126.4</td>
<td>364.7</td>
<td>400.5</td>
<td>377.2</td>
<td>255.8</td>
<td>237.0</td>
</tr>
<tr>
<td>Autumn Prelim.</td>
<td>180.4</td>
<td>134.4</td>
<td>133.7</td>
<td>202.9</td>
<td>179.2</td>
<td>255.5</td>
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<tr>
<td>1st</td>
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<td>96.8</td>
<td>85.4</td>
<td>123.1</td>
<td>142.3</td>
<td>287.0</td>
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<tr>
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<td>172.4</td>
<td>241.8</td>
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<td>145.5</td>
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<tr>
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<td>333.4</td>
<td>385.7</td>
<td>318.1</td>
<td>465.3</td>
<td>370.8</td>
<td>313.0</td>
</tr>
<tr>
<td>$1 + 2 + 3$</td>
<td>538.4</td>
<td>564.7</td>
<td>575.6</td>
<td>830.2</td>
<td>649.1</td>
<td>743.5</td>
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</tbody>
</table>

### Table 2(a)

#### Statistical Analysis of Table 2.

##### Seasonal Analysis Total of 1st 2nd and 3rd Cuts

<table>
<thead>
<tr>
<th>P Values</th>
<th>Fog</th>
<th>S.V.</th>
<th>O.G.</th>
<th>$%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>$596.11^{**}$</td>
<td>$81.69^{**}$</td>
<td>$82.59^{**}$</td>
<td>3.49</td>
</tr>
<tr>
<td>S</td>
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<td>$4.76^{*}$</td>
<td>$10.41^{**}$</td>
<td>5.61</td>
</tr>
<tr>
<td>N x S</td>
<td>$109.50^{**}$</td>
<td>$1.53$ E.S.</td>
<td>$7.05^{**}$</td>
<td>2.56</td>
</tr>
</tbody>
</table>

*Significance levels: **p < 0.01, *p < 0.05*
Mt Somers Lower Site
Summer pre-crop

lbs D.M./acre

- - - - - - - - - - - - - - - - - - - - -

S_1  S_2  S_0  S_3  S_4  S_5  S_6  S_7  S_8  S_9

N_0  N_4  N_1  N_2  N_3  N_5  N_6  N_7  N_8  N_9

Pog
S.V.
C.G.
RESULTS AND DISCUSSION

Mt Somers Lower Site Dry Matter

1. Summer Preliminary Cut.

Dry matter figures from the application of the annual treatment until the base cut on 10th March are shown as the summer preliminary cut. The weather over the period was dry, but a response to the higher nitrogen level was obtained at the two sulphur levels used. At all nitrogen levels, the response to sulphur was greater at the $S_1$ than at the $S_2$ level. The pH values of all plots were determined to see if this was an acidity effect, but similar values were obtained.

This cut indicates the superiority of other grasses (here-after 0.6) at the $N_o$ level, an increase in sweet vernal (here-after S.V.) at the $N_1$ level and a corresponding decrease in O.C. with little change in Yorkshire fog (here-after fog). Fog asserts its superiority at the $N_2$ level in the presence of sulphur, but is inferior to the other species in the absence of sulphur.
Mt Somers Lower Site
Autumn pre-cut

lbs D.M./acre
2. Autumn Preliminary Cut.

The autumn preliminary cut measures production from March 10th - April 20th. Nitrogen gave a highly significant dry matter response and there was a slight though not significant response to sulphur at the two nitrogen levels. It is suggested that the lack of sulphur response was probably due to the dry season as a highly significant response was obtained in all future cuts. Despite the application of heavy levels of nitrogen, dry matter was only doubled at the heaviest nitrogen level.

Botanical analysis indicated that the higher producing species such as fog were not yet markedly dominant. O.G. is still dominant at the N₀ level, but S.V. has markedly increased its proportion. Fog is much increased at the N₁ level with the application of sulphur as is the case at the N₂ level, such that at N₁ and N₂ fog is now more markedly increased over S.V. than at the last cut. At N₂ S.p. production of fog is now above O.G. Thus, this cut indicates the increasing importance of fog with the application of higher nitrogen and sulphur levels and at lower nitrogen levels, an increasing superiority of S.V. over O.G. Despite the fact that S.V. is generally assumed to have a marked autumn flush, the magnitude of this in relation to the other species is not as marked as expected.
3. 1st Cut.

The first cut gives an indication of winter growth. Observations were also made on the effects of manural treatment on frost resistance and winter killing. High nitrogen gave pronounced frost resistance particularly with fog. The effect on S.V. was not as noticeable, but this could be due to the dominance of fog in the high nitrogen plots by this time. There did not appear to be any outstanding visual effect of sulphur in combination with the high nitrogen level on frost resistance. The lower nitrogen level showed no marked frost damage.

The site was only sampled cut at the autumn preliminary cut, without making a base cut and it would appear that the effects of this cut prior to winter were severe on the high nitrogen treatments and considerable winter killing of the fog occurred. S.V. which was the dominant on the lower nitrogen treatments was little affected and low nitrogen and nitrogen control treatments went through the winter with a good ground cover.

Clever by this stage were more evident in the award, but a surprising feature even on the low nitrogen, high sulphur plots was the small clover response despite the fact that up to 50 lbs of sulphur had been applied. This could have been due to the dry seasonal conditions in the previous autumn, as subsequent clover growth on over-sowing was prolific.

The figures for the first cut include those of the autumn preliminary cut (Note no base cut at the autumn preliminary cut). A comparison of the figures for the first cut and the preliminary cut, show that marked winter killing took place at the control and lower nitrogen level, the reduction in dry matter at these two levels being less with applied sulphur. There was an increase in production with the higher nitrogen level at the two sulphur levels. A highly significant response to nitrogen is shown by this cut and the effect of sulphur is now highly significant. The nitrogen-sulphur interaction closely approaches significance.
Botanically, the first cut presents the same picture as the autumn pre-cut, the major difference being the reduction in species dry matter at the $N_0$ and $N_1$ levels and increased values of fog at the $N_2$ level.
4. 2nd Cut.

Following the first cut, the plots were re-manured, half of each plot sprayed to remove clovers and the other half oversown with clovers. Samples from each half of the plot at the second cut, thus give in addition an indication of the adequacy of the sulphur level for the nitrogen level used as gauged by clover growth and also the suppressive effects of nitrogen on clover growth.

This second cut, which covers the period of the spring flush, shows a marked rise in production at the $N_0$ level compared with the two previous cuts. Production is increased at the $N_1$ level over $N_0$ and is three times greater than $N_0$ at the $N_2$ level. Sulphur shows a marked response at both nitrogen levels, there being little difference between $S_1$ and $S_2$ levels.

Botanically, at increasing nitrogen levels, fog increases such that it is now markedly dominant at the high nitrogen and sulphur levels S.V. has increased over the last cut, markedly so at the $N_0$ and $N_1$ levels, at which levels, it is still dominant over fog and to a greater extent than previously. This is probably an expression of spring growth on the nitrogen-control and low nitrogen plots as these did not carry as much growth coming out of the winter as did the high nitrogen plots where S.V. would be subject to heavy competition for light due to the resident fog. (Note only a quadrant was cut out of each plot before the winter and thus the complete plots did not exhibit the winter killing that occurred in the cut quadrates mentioned earlier). C.G. have now dropped below S.V. and fog; production has dropped compared with the last cut, doubtless due to competition of S.V. and fog.

The effects of sulphur, although now greater in magnitude are similar to the 20th April cut (autumn prelim.). The most marked change is at $N_2$, where S.V. is markedly dominant over fog. Over the $N_2$ level, fog responds markedly to sulphur and as a result of this superior competition ability, S.V. is markedly reduced with applied sulphur. At the $S_0$ level, over all nitrogen levels, fog shows little
change in production due to the superior competitive ability of S.V. at this level. O.C. is interesting in that it shows its only definite response to nitrogen and sulphur at the N₂ level with applied sulphur where apparently, some nitrogen is left by superior competition and some sulphur is available.

4(a) Unsprayed Flots (clover oversown) 2nd cut.

Total dry matter on the unsprayed plots at the second cut shows a doubled production from the use of nitrogen. Taking away the contribution to total dry matter made by the clovers, the production is trebled. Comparing the grass dry matter figures of the sprayed and unsprayed cuts, the sprayed cut i.e. (minus clovers) is greater at the N₀ and N₁ levels and less at the N₂ level than the unsprayed cut (clovers oversown). This suggests that any production differences are not due to nitrogen transfer, otherwise greater grass production would be expected at N₀ and N₁ with the unsprayed cut. The effect is probably due to physical clover/grass competition.

The clover yield at N₀ is five times the yield at N₂ indicating either the suppressive effects of nitrogen or the utilization of nitrogen and sulphur by the grass at the high nitrogen level. (Statistical analyses for these unsprayed determinations show a significant nitrogen-sulphur interaction both with total dry matter and dry matter minus clovers). Clover growth at the S₀ level is similar to that at the S₁ level over the aggregate of the whole nitrogen range, the only marked change being at the S₂ level. This appears to indicate that the only marked amount of sulphur available is at the S₂ level and this is confirmed by clover growth at the N₁ level, where clover production is doubled over control with high sulphur. At the N₂ level, production of clover at S₀ and S₁ is similar and slightly increased at S₂ indicating that the higher level of sulphur is providing some excess of sulphur.
5. **3rd Cut.**

Although responses were obtained to nitrogen and sulphur at the third cut, treatment differences were levelling out and production at N₁ was equivalent to production at the N₀ level, with a slightly greater production at N₂. Sulphur still shows a highly significant response with little difference between the two levels.

The response of fog to nitrogen is diminished at the N₁ and particularly the N₂ level, but fog is still dominant at the N₂ level. S.V. is appreciably diminished at all levels and O.G. has markedly risen. Whereas S.V. was the dominant at N₂ in the last cut, O.G. has now taken its place and shows a similar response to sulphur addition as S.V. did in the last cut. This downward trend with S.V. in the last cut at the N₂ level with sulphur addition appeared to be due to physical competition with fog. With O.G. in this cut, the trend would appear to be due to fertility effects. Whereas O.G. is dominant at the S₀ levels of N₁ and N₂, it falls with sulphur addition and either S.V. or fog depending on the nitrogen status rises in production. It would thus seem that the status of O.G. is dependent on nutrients not utilized by the fog and S.V. Whereas fog and S.V. show little change in production at the S₀ level with increasing nitrogen at this third cut, O.G. shows a marked rise. At the previous cut, S.V. showed a rise at S₀ whilst fog remained steady. Evidently then S.V. and O.G. show similar response patterns, S.V. being a better competitor for nitrogen than O.G. In this cut (3rd) O.G. is superior at the S₀ levels possibly due to S.V. being past its growth peak. Fog occupies the pre-eminent position with high nitrogen and added sulphur.

Consideration of the above factors seems to indicate that the N/S fertility rating of the three species is likely to be fog → S.V. → O.

5(a) **Unsprayed Plots (3rd cut)**

In the unsprayed analysis of the third cut, total dry matter yield at the N₂ level is only slightly above control. This is partly due to the large effect of the clover component at N₀, but even when
this is discounted, the gain is not large and there is no difference between control and the $N_1$ level. The clover again shows a marked decrease as the nitrogen level is raised and at each level of $N$ there is a clear cut sulphur response indicating that the $N_1$ level had not utilized all of the sulphur whilst the $N_2$ level had utilized most. It is surprising however, that clover production at $N_2S_2$ is greater than at $N_1S_2$. This could be a species effect as at this cut, fog which was giving the best response at this level had diminished and this seasonal drop in production would favour the clover. This also indicates that there was ample sulphur still available at the $N_2S_2$ level.
Mt Somers Lower Site
Total Seasonal Analysis

lbs D.M./acre

- Fog
- S. Vi.
- O. O.
Total Species Dry Matter Mt Somers lower site.

At the $N_0$ level, S.V. is superior in production to fog and O.G., in turn. S.V. and fog show a slight $S$ response but O.G. appears to be little affected. The superiority of S.V. could be due to its having the most marked spring growth response and carrying this advantage through the season.

Production of all species at the $N_1$ level is increased over that at the $N_0$ level. S.V. is again showing the best response to the $N_1$ level, but the gap is lessened with fog particularly as the sulphur level is raised. O.G. shows no response to sulphur and S.V. and fog are slightly raised in the case of the former and markedly in the case of the latter at the $S_2$ level.

At the $N_2$ level, S.V. shows a marked superiority over fog with $S_2$ application, but as the sulphur level is raised, fog asserts a marked superiority. The increase at the $S_2$ level over the $S_1$ level is not great. S.V. shows a slight increase to the $S_1$ level and drops at the $S_2$ level. O.G. increases with sulphur, but production at all levels of sulphur although above that of O.G. at $N_1$ is inferior to S.V. and fog at the $N_2$ level.

All three species show a slight increase in production as the nitrogen and sulphur levels are raised at $N_0$ and $N_1$. The most marked effect of sulphur occurs at the $N_2$ level with fog showing marked response to sulphur addition. The lack of response of S.V. at the $N_2$ level is probably indicative of the marked competitive effects of fog. O.G. shows increased response with $S$ at $N_2$, although production is at a lower level than S.V.

Comparing S.V. and O.G., their relative sulphur response at the $N_2$ level could be more indicative of the suppressive effect of fog on S.V. in the case of the former and for the latter, the response of O.G. later in the season when fog and S.V. were declining. Analysis of changes during the season supports this view.
Seasonal Change in Species Response.

The overall response picture shows that the main response at the first cut is with S.V. C.G. and fog are similar, but fog shows better response at the N_2 level. The second cut shows a marked rise in S.V. at the N_0 and N_1 levels and marked effects of fog at the N_2 level. C.G. is now below fog in production.

At the third cut, there is a marked rise in C.G. at all levels and a marked fall in S.V. particularly at the N_2 level. Fog holds its position over the last cut, but is much reduced at the N_2 level.

Effects of Sulphur on Seasonal Grass Dry Matter Production.

<table>
<thead>
<tr>
<th>Cut</th>
<th>N_0</th>
<th>N_1</th>
<th>N_2</th>
<th>N_0</th>
<th>N_1</th>
<th>N_2</th>
<th>N_0</th>
<th>N_1</th>
<th>N_2</th>
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<tr>
<td></td>
<td>S_0</td>
<td>S_1</td>
<td>S_2</td>
<td>S_0</td>
<td>S_1</td>
<td>S_2</td>
<td>S_0</td>
<td>S_1</td>
<td>S_2</td>
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<td>248</td>
<td>683</td>
<td>700</td>
<td>750</td>
<td>932</td>
<td>961</td>
<td>1299</td>
<td>1957</td>
<td>1962</td>
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<td>331</td>
<td>442</td>
<td>318</td>
<td>738</td>
<td>737</td>
<td>864</td>
<td>1147</td>
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<td>1709</td>
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<td>270</td>
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<td>448</td>
<td>585</td>
<td>629</td>
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<tr>
<td>2nd</td>
<td>1071</td>
<td>1039</td>
<td>769</td>
<td>1605</td>
<td>1262</td>
<td>1825</td>
<td>1748</td>
<td>3948</td>
<td>4150</td>
</tr>
<tr>
<td>3rd</td>
<td>871</td>
<td>1069</td>
<td>1109</td>
<td>1444</td>
<td>1201</td>
<td>1229</td>
<td>1163</td>
<td>2458</td>
<td>2153</td>
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<table>
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<th>S_2</th>
<th>S_0</th>
<th>S_1</th>
<th>S_2</th>
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<th>S_1</th>
<th>S_2</th>
<th>S_0</th>
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<th>S_2</th>
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<tbody>
<tr>
<td>N_1</td>
<td>N_2</td>
<td>N_0</td>
<td>N_1</td>
<td>N_2</td>
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<td>N_1</td>
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<tr>
<td>2nd</td>
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<tr>
<td>3rd</td>
<td>871</td>
<td>1144</td>
<td>1163</td>
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<td>1109</td>
<td>2458</td>
<td>2143</td>
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</table>

At the N_0 level, neither level of sulphur has had any consistent effect on dry matter yield.

With the addition of N_1, sulphur has had marked effects on yield with no marked difference between S_1 and S_2. The response to sulphur...
is levelling out by the third cut, probably due to a lack of nitrogen. Production dropped at the first cut due to the effect of winter and rose to a peak at the second cut, falling away to the third. This also happened at the N₂ level, but third cut values were on a par with 2nd cut.

Production increased markedly with sulphur at the N₂ level, there being a consistent rise with S₂ over S₁. A peak in production was reached at the second cut and then a fall. The rise and fall was very similar with both sulphur levels. This would appear to indicate that the fall was due to a fall in nitrogen available. If there had been a fall in sulphur with adequate nitrogen still available, the drop would have been greater if the conditions of an N/S interaction hold. This appears to be the case as nitrogen alone can have direct effects on grass dry matter production provided some sulphur is present, whereas sulphur has only marked effects in the presence of higher amounts of nitrogen. The same situation appears to hold also at the N₁ level.

Summarizing over the S₁ level, production at N₁S₁ falls by 61 lbs between cuts two and three, whilst at the S₂ level, production at N₁S₂ falls by 1490 lbs. Similarly at N₂S₁ production falls by 596 lbs compared with 2006 lbs at N₂S₂. The fall at the S₁ level expressed as a percentage of the 2nd cut is 5% for N₁ and 32% for N₂. At the S₂ level the fall is 38% for N₁ and 50% for N₂. If this had been a sulphur effect, the fall should have been greater at the S₁ than at the S₂ level. At the S₀ level, the decrease in production is greatest at N₂ and least at N₀.

A further possible explanation is that this could be a species effect as at the S₂ levels, there would be a marked drop in fog between the two cuts at N₁ and N₂ whilst at the S₁ level S.V. was not diminished so much. This could fit the picture of the above percentage falls between the cuts at the various nitrogen and sulphur levels.


Chemical Composition at Sowem Lower Site.

**TABLE 3a:**

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<tr>
<th></th>
<th>Nitrogen</th>
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<td>Total N %</td>
<td>Prot. N %</td>
<td>N.P.N. %</td>
<td>Total N %</td>
<td>N yield</td>
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<tr>
<td>S₀</td>
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<td>S₂</td>
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<td>N₂</td>
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<td>1.37</td>
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<td>45.8</td>
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<tr>
<td></td>
<td>S₁</td>
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<td>0.93</td>
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<td>68.3</td>
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<tr>
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<td>S₂</td>
<td>2.20</td>
<td>1.32</td>
<td>0.88</td>
<td>66</td>
<td>69.5</td>
</tr>
</tbody>
</table>

Total N increases as the nitrogen level is raised. Sulphur has little effect at the lower nitrogen level, but causes a fall in total N % at the N₂ level. This is in accordance with dry matter production as sulphur had no marked effect at the N₀ and N₁ levels, but caused a marked increase in dry matter at the N₂ level, this being expressed as a 'dilution' effect on the total N %. S₁ has had similar effects to S₂ at the N₂ level. Protein N % shows no marked change with the addition of Nitrogen or sulphur at the N₀ and N₁ levels, but forms a higher percentage at the N₂ level. Likewise N.P.N. shows no marked change at the N₀ and N₁ levels, but decreases markedly with the addition of sulphur at the N₂ level. The protein N/total N ratio depicts the changes in N.P.N., there being little effect of sulphur at the N₀ and N₁ levels, but an increase in the ratio with sulphur addition at N₂, S₁ and S₂ levels being similar.

N yield increases with nitrogen addition. There is a slight increase with sulphur at the N₀ and N₁ levels and a marked increase at the N₂ level.
TABLE 4
Chemical Composition Sulphur

<table>
<thead>
<tr>
<th>(b) Sulphur</th>
<th>Total S %</th>
<th>Inorg. S %</th>
<th>Org. S %</th>
<th>Org. S %</th>
<th>Total S</th>
<th>Lbs S/acre/ft</th>
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</thead>
<tbody>
<tr>
<td>( N_0 )</td>
<td>( S_0 )</td>
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<td>.014</td>
<td>.376</td>
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<tr>
<td></td>
<td>( S_1 )</td>
<td>.432</td>
<td>.018</td>
<td>.414</td>
<td>96</td>
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<td></td>
<td>( S_2 )</td>
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<td>.034</td>
<td>.420</td>
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<td>5.83</td>
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<td>( S_0 )</td>
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<td>.007</td>
<td>.376</td>
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<td>7.75</td>
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<td>( S_2 )</td>
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<td>.044</td>
<td>.424</td>
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<td>( S_0 )</td>
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<td>.003</td>
<td>.275</td>
<td>59</td>
<td>4.74</td>
</tr>
<tr>
<td></td>
<td>( S_1 )</td>
<td>.308</td>
<td>.025</td>
<td>.283</td>
<td>54</td>
<td>12.05</td>
</tr>
<tr>
<td></td>
<td>( S_2 )</td>
<td>.445</td>
<td>.045</td>
<td>.400</td>
<td>89</td>
<td>15.80</td>
</tr>
</tbody>
</table>

Total S % shows no marked change with the addition of nitrogen at the \( N_0 \) and \( N_1 \) levels, but shows a slight drop at the \( N_2 \) level. Within each nitrogen level, total S % increases markedly with the addition of sulphur.

Inorganic S % is similar at the \( N_0 \) and \( N_1 \) levels, but increases at the \( N_2 \) level. Within each nitrogen level, inorganic S % increases as the sulphur level is raised. Between nitrogen levels, the most marked change is at the \( S_0 \) level, inorganic sulphur falling markedly as the nitrogen level is raised.

Organic sulphur % is similar at the \( N_0 \) and \( N_1 \) levels, and drops at the \( N_2 \) level. Within each nitrogen level, organic S % increases as the sulphur level is raised. Organic S forms a large percentage of total S at all nitrogen levels, emphasizing the low values of inorganic S obtained. The org. S / total S ratio shows only a slight increase as the nitrogen level is raised. Within nitrogen levels, there is a decrease in the ratio with sulphur additions more marked at the \( N_1 S_2 \) than the \( N_0 S_2 \) level. At the \( N_2 \) level, there is a drop at both the \( S_1 \) and \( S_2 \) levels indicating a greater uptake of inorganic S at the \( N_2 \) level.
Sulphur yield increases as nitrogen is applied and within each nitrogen level, increases with increased sulphur. The effect is greatest at the N₂ level.

**Nitrogen Yield and Recovery.**

**Table 5.**

<table>
<thead>
<tr>
<th>N</th>
<th>Yield and Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S₀</td>
</tr>
<tr>
<td>N₀</td>
<td></td>
</tr>
<tr>
<td>N₁</td>
<td></td>
</tr>
<tr>
<td>N₂</td>
<td></td>
</tr>
<tr>
<td>N₃</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>N. Yield lb/acre</th>
<th>43.4</th>
<th>65.1</th>
<th>54.2</th>
<th>66.0</th>
<th>67.1</th>
<th>79.5</th>
<th>126.6</th>
<th>208.0</th>
<th>207.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>% recovery</td>
<td>82.5</td>
<td>84.9</td>
<td>99.5</td>
<td>31.6</td>
<td>52.0</td>
<td>52.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The apparent recovery of nitrogen by the grass was very high for the N₁ treatments, slightly more being recovered at the S₂ level. The recovery at the N₂ level was less, an appreciably greater amount being recovered with the application of sulphur, but with little difference between S₁ and S₂. Dry matter figures for these two levels were also similar.

**Sulphur Yield and Recovery.**

**Table 6.**

<table>
<thead>
<tr>
<th>S</th>
<th>Yield and Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S₀</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>S₀</td>
<td>14.23</td>
</tr>
<tr>
<td>% recovery</td>
<td>97.16</td>
</tr>
</tbody>
</table>

Sulphur recovery was very high for the S₁ treatments and virtually all the sulphur was recovered at N₀. N₁ and N₂ recovered more sulphur than was applied, N₂ markedly so, indicating that the applied S₁ level was not sufficient for the nitrogen available.

Recovery at the S₂ level increased as the nitrogen level was raised, but was still relatively low, suggesting that there was ample sulphur available.
The increased recovery of sulphur at the $S_1$ level could be in accordance with the work of Frenzy and Spencer (1960) who suggest that in the presence of plants an application of sulphate to sulphur deficient soils may result in "sulphate bonus" from the organic matter equivalent to half the sulphur added. This appears to be the case at the $N_2 S_1$ level, as a "bonus" of 10 lbs sulphur gives an apparent recovery of 100% of the applied S.

N/S ratios

<table>
<thead>
<tr>
<th>N/S Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_0$</td>
</tr>
<tr>
<td>$S_0$</td>
</tr>
<tr>
<td>3.20</td>
</tr>
<tr>
<td>3.40</td>
</tr>
<tr>
<td>3.58</td>
</tr>
<tr>
<td>3.20</td>
</tr>
<tr>
<td>6.50</td>
</tr>
</tbody>
</table>

Ratios tend to fall at each nitrogen level as the sulphur level is raised and at each sulphur level, ratios increase with increased nitrogen. The increase is most marked at the $S_0$ level and thus indirectly gives an indication of N/S interaction evidenced by a lesser increase in the ratio with S addition as the N level is raised. The most marked increase is in the nitrogen yield, but more sulphur is taken up at each sulphur level as nitrogen is increased.
### TABLE 8(a)
**Effect of N on N Yield**

<table>
<thead>
<tr>
<th>Cut</th>
<th>$N_0$</th>
<th>$N_1$</th>
<th>$N_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer Prelim.</td>
<td>121.3</td>
<td>170.7</td>
<td>434.0</td>
</tr>
<tr>
<td>Autumn Prelim.</td>
<td>47.4</td>
<td>79.1</td>
<td>192.4</td>
</tr>
<tr>
<td>1st</td>
<td>17.7</td>
<td>33.5</td>
<td>112.1</td>
</tr>
<tr>
<td>2nd</td>
<td>48.5</td>
<td>93.2</td>
<td>289.6</td>
</tr>
<tr>
<td>3rd</td>
<td>96.5</td>
<td>85.9</td>
<td>140.7</td>
</tr>
</tbody>
</table>

### TABLE 8(b)
**Effect of S on N Yield**

<table>
<thead>
<tr>
<th>Cut</th>
<th>$S_0$</th>
<th>$S_1$</th>
<th>$S_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer Prelim.</td>
<td>196.0</td>
<td>286.8</td>
<td>243.2</td>
</tr>
<tr>
<td>Autumn Prelim.</td>
<td>96.7</td>
<td>110.3</td>
<td>111.3</td>
</tr>
<tr>
<td>1st</td>
<td>39.0</td>
<td>61.4</td>
<td>62.9</td>
</tr>
<tr>
<td>2nd</td>
<td>99.8</td>
<td>159.1</td>
<td>172.4</td>
</tr>
<tr>
<td>3rd</td>
<td>97.2</td>
<td>119.7</td>
<td>106.2</td>
</tr>
</tbody>
</table>

### TABLE 8(c)
**Effect of S on S Yield**

<table>
<thead>
<tr>
<th>Cut</th>
<th>$S_0$</th>
<th>$S_1$</th>
<th>$S_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>7.02</td>
<td>13.76</td>
<td>16.43</td>
</tr>
<tr>
<td>2nd</td>
<td>24.33</td>
<td>31.26</td>
<td>35.24</td>
</tr>
<tr>
<td>3rd</td>
<td>18.50</td>
<td>29.75</td>
<td>33.20</td>
</tr>
</tbody>
</table>

### TABLE 8(d)
**Effect of N on S Yield**

<table>
<thead>
<tr>
<th>Cut</th>
<th>$N_0$</th>
<th>$N_1$</th>
<th>$N_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>4.47</td>
<td>13.73</td>
<td>19.01</td>
</tr>
<tr>
<td>2nd</td>
<td>16.85</td>
<td>29.20</td>
<td>46.45</td>
</tr>
<tr>
<td>3rd</td>
<td>25.76</td>
<td>23.49</td>
<td>28.20</td>
</tr>
</tbody>
</table>
Effect of N on N yield

Summer  Autumn  1st  2nd  3rd  Cut

\[ N_0 \rightarrow N_1 \rightarrow N_2 \]

120 lbs N/acre x 3
Effects of Nitrogen on Nitrogen Yield

All cuts show an increase in nitrogen yield from \( N_1 \) to \( N_2 \), \( N_2 \) being markedly superior to \( N_1 \). Nitrogen yields are much reduced at the first cut and as this cut includes the autumn pre-cut (Note = no base cut at autumn pre-cut) it shows the effect of the winter period on species survival. The respective drop in production for the nitrogen levels has been \( N_0 \) 65%, \( N_1 \) 66% and \( N_2 \) 59%. The second cut at the \( N_0 \) and \( N_1 \) level is similar in yield to the autumn pre-cut. This is probably due to similar growth of S.V. at these levels. The \( N_2 \) level is markedly higher and is probably an expression of the spring growth of fog.

At the third cut the \( N_0 \) level is raised due to the rise in C.G. and \( N_2 \) is much diminished as fog was decreasing and the general growth appearance of the plots evening out by this stage.
Effect of S on N yield

300 Summer Autumn 1st 2nd 3rd Cut

150 N/acre X 3

260

220

180

140

100

60

20

→ S₀ S₁ S₂
EFFECTS OF SULPHUR ON NITROGEN YIELD.

Sulphur has increased nitrogen yield at all cuts with little difference between $S_1$ and $S_2$ levels. Production is down at the first cut, but sulphur has had no effect on the drop in production. The constancy of the $S_0$ level at the autumn pre-cut, second and third cuts probably indicates similar S.V. growth at the first two mentioned cuts and C.G. growth at the third. Yield is much reduced at the $S_1$ and $S_2$ level of the third cut probably due to a marked drop in fog.
Effects of Sulphur on Sulphur Yield.

Over the three cuts, sulphur has increased sulphur yield. The increase due to S₂ is most marked at the second cut probably due to the marked response of fog.

Sulphur yield is reduced at the third cut compared with the second, particularly at the S₂ level and this again is probably due to the drop in fog production.

Effects of Nitrogen on Sulphur Yield.

At the first cut, N₀ has had negligible effects on sulphur yield. N₁ and N₂ are markedly above N₀ with N₂ superior to N₀. All values are increased at the second cut, but N₂ is now markedly superior.

At the third cut N₁ and N₂ values are reduced, N₂ markedly so. No values reach their highest level, probably due to the increase in O₂ at this cut.
Mt Somers Top Site

(a) Dry Matter

**TABLE 9**

<table>
<thead>
<tr>
<th>Top Site</th>
<th>D.H.</th>
<th>N&lt;sub&gt;0&lt;/sub&gt;</th>
<th>N&lt;sub&gt;1&lt;/sub&gt;</th>
<th>N&lt;sub&gt;2&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>S&lt;sub&gt;1&lt;/sub&gt;</td>
<td>S&lt;sub&gt;2&lt;/sub&gt;</td>
<td>S&lt;sub&gt;1&lt;/sub&gt;</td>
</tr>
<tr>
<td>Fog</td>
<td>32</td>
<td>30</td>
<td>48</td>
<td>52</td>
</tr>
<tr>
<td>S.V.</td>
<td>464</td>
<td>239</td>
<td>311</td>
<td>1295</td>
</tr>
<tr>
<td>O.G.</td>
<td>688</td>
<td>517</td>
<td>670</td>
<td>673</td>
</tr>
<tr>
<td>Total</td>
<td>1164</td>
<td>836</td>
<td>1029</td>
<td>2020</td>
</tr>
</tbody>
</table>

**TABLE 9(a)**

Statistical Analysis of Table 9: F values

<table>
<thead>
<tr>
<th></th>
<th>Total D.H.</th>
<th>Fog</th>
<th>S.V.</th>
<th>O.G.</th>
<th>5%</th>
<th>1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>28.84**</td>
<td>30.67**</td>
<td>39.22**</td>
<td>11.00**</td>
<td>3.40</td>
<td>5.61</td>
</tr>
<tr>
<td>S</td>
<td>5.95**</td>
<td>11.22**</td>
<td>5.67**</td>
<td>44.00**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N x S</td>
<td>1.56 N.S.</td>
<td>11.22**</td>
<td>0.56 N.S.</td>
<td>24.00**</td>
<td>2.80</td>
<td>4.26</td>
</tr>
<tr>
<td>Lin N</td>
<td>54.80**</td>
<td>157.89**</td>
<td>57.33**</td>
<td></td>
<td>4.26</td>
<td>7.82</td>
</tr>
<tr>
<td>Lin S</td>
<td>10.36**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quad N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15.00**</td>
<td></td>
</tr>
<tr>
<td>Quad S</td>
<td></td>
<td>5.33*</td>
<td>11.22**</td>
<td>86.00**</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These plots were only sampled once for dry matter, this being in March 1960, so that the species yields may reflect their seasonal status at the time of the cut.

Total dry matter figures show trebled production due to nitrogen. Sulphur has also increased production.

Compared with the lower site, the soil of this site has a lower sulphur and nitrogen status. General conditions for growth were more inhospitable, the site tending to be rather exposed and due to the heavy nature of the soil was rather wet for long periods especially
in the winter. In these circumstances it is not surprising that dry matter production was only half of the lower site. This figure would be even further reduced if the space taken by the tall tussock was taken into account.

Although the increase in yield with nitrogen was not as great at the lower site, the effect was twice as great as the upper site. Sulphur also had about twice the effect at the lower site. The increase due to sulphur was less at the upper site.

Response to increased increments of nitrogen was similar to the lower site, but lower in magnitude. Lesser response was shown to sulphur at the upper site, possibly due to the lower levels of nitrogen. At both sites, dry matter production was increased to a similar amount with the higher sulphur level, the difference being in the magnitude of the level at which response took place.
(b) Species Analysis.

The production of fog is particularly low, sulphur levels also having little effect. There was a marked response by this species at the \( N_2 \) level and production was increased at both sulphur levels. At the \( N_2 \) level, fog does not show such marked superiority over S.V. as at the bottom site and the same applies to O.G.

The production of S.V. is below that of O.G. at the \( N_2 \) level. At the \( N_1 \) and \( N_2 \) levels, production is raised respectively at the \( S_0 \) levels. The \( S_2 \) levels in both cases are below the \( S_0 \) levels and the \( S_1 \) levels show a marked drop below that of both the \( S_0 \) and \( S_2 \) levels. It is suggested that the drop in production with the increase in sulphur level over all three nitrogen levels could be due to competitive effects in ion uptake, because as the nitrogen level is raised in each case, so is there an increase at each sulphur level over the previous nitrogen level. The gradient of depression at the \( N_2 \) level is also less marked than at the \( N_1 \) level.

At the \( S_0 \) and \( S_2 \) levels over all nitrogen levels, O.G. shows similar production and as there was no marked effect of O.G. until the second season (mostly browntop) it is suggested that nitrogen was having no effect by this stage. The marked lift in production of O.G. at \( N_1 \) and \( N_2 \) corresponding to the marked drop in S.V. production at these points is a species effect due to some factors causing either a rise in O.G. or a depression in S.V. From the graph, the latter appears to be more probable.
Spaced Plant Analysis Top Site

<table>
<thead>
<tr>
<th>Date</th>
<th>S₀</th>
<th>S₁</th>
<th>S₂</th>
<th>S₀</th>
<th>S₁</th>
<th>S₂</th>
<th>S₀</th>
<th>S₁</th>
<th>S₂</th>
<th>S₀</th>
<th>S₁</th>
<th>S₂</th>
<th>S₀</th>
<th>S₁</th>
<th>S₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st March</td>
<td>3.72</td>
<td>3.59</td>
<td>4.37</td>
<td>4.44</td>
<td>5.00</td>
<td>4.51</td>
<td>5.40</td>
<td>7.17</td>
<td>7.37</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15th Apr.</td>
<td>3.32</td>
<td>3.68</td>
<td>4.19</td>
<td>4.39</td>
<td>4.91</td>
<td>4.83</td>
<td>6.61</td>
<td>10.55</td>
<td>8.81</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14th Dec.</td>
<td>5.05</td>
<td>6.24</td>
<td>7.84</td>
<td>6.03</td>
<td>7.25</td>
<td>7.29</td>
<td>10.68</td>
<td>16.11</td>
<td>15.70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Mar.</td>
<td>2.66</td>
<td>2.62</td>
<td>2.53</td>
<td>2.45</td>
<td>3.03</td>
<td>2.54</td>
<td>3.15</td>
<td>5.03</td>
<td>3.61</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15th Apr.</td>
<td>2.41</td>
<td>2.45</td>
<td>2.73</td>
<td>2.30</td>
<td>3.35</td>
<td>2.55</td>
<td>3.95</td>
<td>5.09</td>
<td>3.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14th Dec.</td>
<td>1.62</td>
<td>1.87</td>
<td>1.86</td>
<td>1.66</td>
<td>2.02</td>
<td>1.50</td>
<td>3.13</td>
<td>5.42</td>
<td>2.85</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE 10.

<table>
<thead>
<tr>
<th>Date</th>
<th>S₀</th>
<th>S₁</th>
<th>S₂</th>
<th>S₀</th>
<th>S₁</th>
<th>S₂</th>
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<th>S₀</th>
<th>S₁</th>
<th>S₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>14th Dec.</td>
<td>0.019</td>
<td>0.029</td>
<td>0.042</td>
<td>0.027</td>
<td>0.052</td>
<td>0.038</td>
<td>0.175</td>
<td>0.733</td>
<td>0.278</td>
<td>Dry Matter gms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The spaced plants show a response to nitrogen in terms of dry matter yield, height and tillering. The response at the N₂ level is markedly above that at the N₁ level and is probably a consequence of the high tillering rate at the N₂₁ level. The N₂₂ plots had a greater percentage of fog in them than the N₂₁ plots so that the superior performance of cocksfoot at N₂₁ was probably due to lesser light and nutrient competition. Further comparison indicates that this is the case for whereas there is a marked superiority in tillering comparing N₂₁ and N₂₂, such is not the case with height determination, indicating etiolation due to competition for light at the N₂₂ level.

Taking these factors into consideration, it is then suggested that the marked superiority of cocksfoot at N₂₁ is not a reflection of the direct manural effect on this species. Later pot trials with single cocksfoot plants under the same manural treatments tend to confirm this and indicate that the effects of S₁ and S₂ are similar.

As with nitrogen, sulphur is showing its greatest effect at the S₁ level due to the same factors. In these circumstances, it does not appear accurate to determine the effects of sulphur on height and tillering, from the data available.

On a manural basis, this trial appears to be unable to provide...
the data required, but has been useful for a study of factors affecting grass introduction in an established sward.

To offset the effects of the monumental treatment on the resident vegetation and to obtain an idea of these treatments on the indication plant, it would appear necessary to have established indicator plants at such a stage that they could respond differentially to treatment without the complicating factor of other species present at a different growth stage.

Winter survival was good with a slightly less mortality at the $N_2$ level. This was probably due to the shelter of dense fog and sweet vernal. There was very little protective growth on the $N_0$ and $N_1$ plots and survival in these cases was good.

Despite the fact that the plants survived, growth was not up to expectation in the following spring, tiller numbers remaining much the same as at the determination before the previous winter. The only marked change in the plants was in height, the change being greater with an increase in nitrogen and sulphur levels. This could be due to improved nutrition of the cocksfoot or to light competition effects as the native vegetation responded to the monumental treatment. Several of the high nitrogen plants flowered.

It was intended to make a further determination in the autumn, but resident grass growth was such at that stage, that the spaced plants were difficult to locate in the sward. There did not appear to have been much growth on the lower nitrogen treatments, but on the high nitrogen treatments, the plants were tillering well, although the vigour of growth was still not up to that of the resident vegetation.
### TABLE 11.

**Space Plants Chemical Composition**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(S₀)</td>
<td>1.31</td>
<td>1.11</td>
<td>0.20</td>
<td>85</td>
<td>0.78</td>
<td>0.07</td>
<td>0.712</td>
</tr>
<tr>
<td></td>
<td>(S₁)</td>
<td>1.27</td>
<td>1.02</td>
<td>0.25</td>
<td>80</td>
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<td>0.025</td>
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<tr>
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<td>(S₂)</td>
<td>1.27</td>
<td>0.86</td>
<td>0.41</td>
<td>68</td>
<td>0.51</td>
<td>0.005</td>
<td>0.507</td>
</tr>
<tr>
<td></td>
<td>(S₃)</td>
<td>1.50</td>
<td>0.90</td>
<td>0.60</td>
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<td>0.42</td>
<td>0.079</td>
<td>0.34</td>
</tr>
<tr>
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<td>(S₁)</td>
<td>1.23</td>
<td>0.94</td>
<td>0.29</td>
<td>76</td>
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<td>0.070</td>
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<tr>
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<td>(S₂)</td>
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<td>0.94</td>
<td>0.29</td>
<td>76</td>
<td>0.51</td>
<td>0.032</td>
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<tr>
<td></td>
<td>(S₃)</td>
<td>1.76</td>
<td>1.02</td>
<td>0.74</td>
<td>58</td>
<td>0.40</td>
<td>0.085</td>
<td>0.321</td>
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<tr>
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<td>(S₁)</td>
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<td>1.02</td>
<td>0.50</td>
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<td>0.374</td>
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<td>(S₂)</td>
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<td>0.28</td>
<td>78</td>
<td>0.97</td>
<td>0.063</td>
<td>0.909</td>
</tr>
</tbody>
</table>

Total N increases with nitrogen addition and decreases with the addition of sulphur. S₃ appears adequate for the nitrogen applied at the N₁ level, but there is a further response from S₂ at the N₂ level. Protein N again shows no marked change with nitrogen or sulphur. At the N₁ and N₂ levels, N.P.N drops markedly with the addition of sulphur. The protein N/total N ratio mirrors these changes. The ratio is higher at the N₀ level, but increases at the N₁ and N₂ levels with sulphur.

Total S increases with sulphur addition, markedly so at the N₂ level. Inorganic S is higher at the N₂ level and decreases with sulphur addition, indicating an N/S interaction and no marked luxury consumption of sulphur. There is an increase in the org S/total S ratio at the N₁ and N₂ levels, with applied sulphur. The change in ratio is similar at the N₁ and N₂ levels.
1st Pot Trial.

(a) Dry Matter

**TABLE 12.**

<table>
<thead>
<tr>
<th></th>
<th>N₀</th>
<th>N₁</th>
<th>N₂</th>
<th>N₃</th>
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<tbody>
<tr>
<td>S₀</td>
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<td>7</td>
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<td>S₁</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>14</td>
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<tr>
<td>S₂</td>
<td>32</td>
<td>32</td>
<td>32</td>
<td>40</td>
</tr>
<tr>
<td>D.M.</td>
<td>47</td>
<td>47</td>
<td>47</td>
<td>47</td>
</tr>
<tr>
<td>TILLERS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td>D.M.</td>
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<td>61</td>
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</tbody>
</table>

**TABLE 12(a)**

Statistical Analysis of Table 11 F values

<table>
<thead>
<tr>
<th></th>
<th>Cox</th>
<th>Fog</th>
<th>S.V.</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₁</td>
<td>N₂</td>
<td>N₁</td>
<td>N₂</td>
</tr>
<tr>
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<td>10</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>S₁</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>S₂</td>
<td>32</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>D.M.</td>
<td>61</td>
<td>61</td>
<td>61</td>
</tr>
<tr>
<td>TILLERS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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</tr>
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</tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

By using undisturbed soil samples and a planting technique with a minimum of disturbance, it was hoped in this trial to duplicate the field trial under more uniform conditions. The plants used were at a comparable stage of development, namely as single tillers. Dry matter figures show that over the total growth period, fog and S.V. were superior at the N₀ and N₁ levels, but at the N₂ level cocksfoot rises to the top position with added sulphur.

At the N₀ and N₁ levels, production of fog and S.V. is twice as great as cocksfoot, but this superiority is diminished at the N₂ level such that cocksfoot is slightly above fog and S.V. when sulphur is applied.
All three species showed tillering increases with nitrogen fog being the most marked than S.V. and cocksfoot.

A slight sulphur response with dry matter is shown, the greatest response being given in the order of cocksfoot, fog, S.V. Apart from S.V. the magnitude of the effect of sulphur on tillering is small.

Cocksfoot.

Total N % falls at the N₂ level and protein N shows no marked change with the addition of nitrogen or sulphur. In the presence of nitrogen, N.P.N. % falls with the addition of sulphur markedly so at the N₂ level. As a consequence protein N increases as a percentage of total N with the addition of sulphur. The most marked change in nitrogen yield per pot occurs at the N₂ level, where there is a marked increase with the addition of sulphur, S₁ and S₂ being similar.

Fog.

Fog shows an increase in % total N with the addition of sulphur at the N₀ and N₁ levels. As was the case with cocksfoot, the total N % is lower at the N₁ level. This could be a reflection of slightly increased dry matter at this level.

Protein N again shows no marked change, particularly within each nitrogen level. N.P.N is much increased at the N₂ level and there is a marked decrease with sulphur addition. At the N₀ and N₁ level, N.P.N is greater with cocksfoot than with fog, possibly indicating that fog utilizes nitrogen and sulphur at lower fertility levels. This appears to be confirmed by higher ratios of protein N as a percentage of total N at the N₀ and N₁ levels.

Nitrogen yield figures are higher at all nitrogen and sulphur levels for fog than for cocksfoot. At the N₂ level, fog does not show the marked increase in nitrogen yield with sulphur that cocksfoot does, and this is mirrored in the dry matter figures. It would thus
<table>
<thead>
<tr>
<th>Sample</th>
<th>Total N %</th>
<th>Prot. N %</th>
<th>N.P.N %</th>
<th>Prot. N/Total N %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cox</td>
<td>Fog</td>
<td>S.V.</td>
<td>Cox</td>
</tr>
<tr>
<td>S₀</td>
<td>1.50</td>
<td>1.38</td>
<td>1.49</td>
<td>0.99</td>
</tr>
<tr>
<td>S₁</td>
<td>1.40</td>
<td>1.56</td>
<td>1.45</td>
<td>1.03</td>
</tr>
<tr>
<td>S₂</td>
<td>1.62</td>
<td>1.54</td>
<td>1.62</td>
<td>1.16</td>
</tr>
<tr>
<td>S₀</td>
<td>1.03</td>
<td>1.22</td>
<td>1.76</td>
<td>0.84</td>
</tr>
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<td>S₁</td>
<td>1.00</td>
<td>1.27</td>
<td>1.81</td>
<td>0.79</td>
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<tr>
<td>S₂</td>
<td>1.16</td>
<td>1.32</td>
<td>1.59</td>
<td>1.00</td>
</tr>
<tr>
<td>S₀</td>
<td>1.56</td>
<td>1.73</td>
<td>1.95</td>
<td>0.99</td>
</tr>
<tr>
<td>S₁</td>
<td>1.22</td>
<td>1.59</td>
<td>1.27</td>
<td>0.99</td>
</tr>
<tr>
<td>S₂</td>
<td>1.22</td>
<td>1.48</td>
<td>1.40</td>
<td>1.01</td>
</tr>
</tbody>
</table>
appear that fog responds less to sulphur and nitrogen is a more important factor. This is apparently so, because whereas at the $N_2$ level, cocksfoot and fog have similar production at $S_1$ and $S_2$, production of fog at the $S_0$ level is far superior.

Sweet Vernal.

Sweet Vernal shows higher total N % values at all nitrogen levels than cocksfoot and fog. A fall in N % at the $N_1$ and $N_2$ levels as sulphur is raised, is indicated. Within each nitrogen level, there again appears to be no marked change in protein N % with sulphur addition. $N_2,N$ levels show little change at the $N_0$ and $N_1$ level, but fall markedly at the $N_2$ level with little difference between $S_1$ and $S_2$.

Protein N/total N ratio is similar at the $N_0$ and $N_1$ levels and increases with sulphur addition at the $N_2$ level with little difference between $S_1$ and $S_2$. Ratio figures at all levels are similar to those of fog which in turn is higher than cocksfoot.

Nitrogen yield is higher than fog at the $N_0$ and $N_1$ levels slightly so at the $N_0$ and markedly so at $N_1$. This is reflected in the respective dry matter figures.

Sulphur does not appear to have as marked an effect on S.V. nitrogen yield as it does with fog.

The overall picture of this trial seems to indicate that the fertility status of the species as judged by response to applied nitrogen and sulphur is S.V. > fog > cocksfoot. The response of S.V. and fog to $N_0$ is similar. S.V. is slightly superior at the $N_1$ level with both S.V. and fog above cocksfoot. Fog and S.V. are similar at the $N_2$ level, fog asserting its superiority over S.V. under higher sulphur conditions and cocksfoot is superior to both in the presence of sulphur, but inferior in its absence.
2nd Pot Trial

Cocksfoot

N_3  S_0  S_1  S_2
N_2
N_1
N_0
2nd Pot Trial

<table>
<thead>
<tr>
<th></th>
<th>N&lt;sub&gt;1&lt;/sub&gt;</th>
<th>N&lt;sub&gt;2&lt;/sub&gt;</th>
<th>N&lt;sub&gt;3&lt;/sub&gt;</th>
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</thead>
<tbody>
<tr>
<td>S&lt;sub&gt;0&lt;/sub&gt;</td>
<td>S&lt;sub&gt;1&lt;/sub&gt;</td>
<td>S&lt;sub&gt;2&lt;/sub&gt;</td>
<td>S&lt;sub&gt;0&lt;/sub&gt;</td>
</tr>
<tr>
<td>Tillers</td>
<td>35</td>
<td>42</td>
<td>45</td>
</tr>
<tr>
<td>D.M. gas</td>
<td>1.8</td>
<td>1.72</td>
<td>1.66</td>
</tr>
</tbody>
</table>

TABLE 14(a) Statistical Analysis of Table 13 F values

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<tr>
<th></th>
<th>Tillers</th>
<th>D.M.</th>
<th>5%</th>
<th>1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>47.17**</td>
<td>101.48**</td>
<td>2.90</td>
<td>4.46</td>
</tr>
<tr>
<td>S</td>
<td>21.49**</td>
<td>33.62**</td>
<td>3.30</td>
<td>5.34</td>
</tr>
<tr>
<td>N x S</td>
<td>3.18*</td>
<td>8.06**</td>
<td>2.40</td>
<td>3.42</td>
</tr>
</tbody>
</table>

(a) Dry Matter

This trial was designed to extend the range of nitrogen levels and thus determine a ceiling response to nitrogen for cocksfoot. Accordingly, the sulphur levels were raised so that sulphur would not be a limiting factor at the high nitrogen level.

Dry matter determinations showed a highly significant response to nitrogen. Under the conditions of this trial, response to nitrogen was not diminished at the N<sub>3</sub> level, indicating the ability of cocksfoot to respond to high levels of nitrogen. The rate of increase between N<sub>2</sub> and N<sub>3</sub> as compared with N<sub>1</sub> and N<sub>2</sub> was levelling out however.

Sulphur also gave a highly significant dry matter response and thus plays an important part in the response to nitrogen, a highly significant N/S interaction being obtained. Analyzing the effect of high sulphur on the plant response to nitrogen, it would appear that as the nitrogen level was raised, there was a response to sulphur. The greatest response lay between the N<sub>1</sub> and N<sub>2</sub> levels. A much
diminished response to increased nitrogen was shown at the $S_0$ level, but the greatest rate of increase was again between the $N_1$ and $N_2$ levels.

The lower level of sulphur appears to be adequate for the nitrogen levels used except at $N_2$ where an additional response was obtained from $S_2$.

(b) Tillers.

Tillering shows a highly significant response to nitrogen, but the increase in tillering due to additional nitrogen increments falls off. Within each sulphur level, total tiller numbers increase with increased nitrogen. The rate of tillering increase appears to be affected by the sulphur level. At $S_1$ the tillering increase peak is reached at the $N_1$ level and falls after this level. The $S_2$ peak is at the $N_2$ level.

Within nitrogen levels, sulphur increases tillering much to the same extent at each nitrogen level, but with tiller numbers being higher at higher nitrogen levels. The higher level of sulphur shows an increase in tillering over the lower sulphur level.
(c) Chemical Composition

TABLE 15.

Chemical Composition 2nd Pot Trial

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
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<td>.22</td>
<td>86</td>
<td>.432</td>
<td>.076</td>
<td>.376</td>
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</tr>
<tr>
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<td>87</td>
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<td>.076</td>
<td>.473</td>
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<td>N_1</td>
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<td>.085</td>
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<td>.275</td>
<td>.006</td>
<td>.269</td>
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<td>78</td>
<td>.374</td>
<td>.036</td>
<td>.338</td>
<td>91</td>
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<tr>
<td>N_1</td>
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<td>1.24</td>
<td>.28</td>
<td>82</td>
<td>.374</td>
<td>.069</td>
<td>.305</td>
<td>82</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>2.66</td>
<td>1.29</td>
<td>1.37</td>
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<td>77</td>
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<td>N_1</td>
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<td>.51</td>
<td>75</td>
<td>.463</td>
<td>.076</td>
<td>.387</td>
<td>84</td>
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</tr>
</tbody>
</table>

Total N values show little change with sulphur at the N_0 and N_1 levels. As in the first trial, values at the N_1 level are below those of the N_0 level possibly as a consequence of increased dry matter.

The N_2 and N_3 values show a fall in total N% with the addition of sulphur as a consequence of the increase in dry matter.

Apart from the N_3 and N_2 levels where protein is higher, there is no marked change in protein percentage with the addition of nitrogen or sulphur.

There is a marked fall in N.P.N at the N_2 and N_3 levels with the addition of sulphur. As a consequence, protein N forms an increased percentage of total N at these two nitrogen levels, the most marked change being with the addition of sulphur.

Total S decreases as the nitrogen level is raised but within each nitrogen level, total S increases as the sulphur level is raised. Likewise inorganic S decreases markedly as the nitrogen level is raised,
but increases with sulphur addition. Both sulphur levels are markedly reduced by nitrogen addition.

Although decreasing with nitrogen addition, organic S increases at each nitrogen level with the addition of sulphur. Organic S in this case, declined as a % of total S as the sulphur level was raised at the \( N_1 \), \( N_2 \) and \( N_3 \) levels. As protein N increased as a percentage of total N over the same range, this could indicate a lack of associative effects.

Sulphur Utilization Trial.

**TABLE 16.**

S utilization of trial 2 as shown by subsequent clover growth.

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<tr>
<th></th>
<th>( N_0 )</th>
<th>( N_1 )</th>
<th>( N_2 )</th>
<th>( N_3 )</th>
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<td>( S_0 )</td>
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<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>( S_2 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D.M. gms</td>
<td>2.77</td>
<td>3.84</td>
<td>2.37</td>
<td>2.73</td>
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</tbody>
</table>

**TABLE 16(a) F values**

<table>
<thead>
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<th></th>
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<th>( N )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.90</td>
<td>4.46</td>
</tr>
<tr>
<td>( N )</td>
<td>depression</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.30</td>
<td>5.34</td>
</tr>
<tr>
<td></td>
<td>( N \times S )</td>
<td>2.40</td>
</tr>
<tr>
<td></td>
<td>1.89 N.S.</td>
<td></td>
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</tbody>
</table>

The trend in clover dry matter production is towards a diminution with the increased nitrogen levels, indirectly indicating that sulphur utilization is greater at the higher nitrogen level. \( S_1 \) shows a decrease with increased nitrogen level indicating greater sulphur availability at lower nitrogen levels. There is evidently ample sulphur available for grass production at the \( N_0 \) and \( N_1 \) levels as judged by clover production. There is a marked drop in clover production at the \( N_2 \) and \( N_3 \) levels to values 55% of those at the \( N_0 \) and \( N_1 \) levels. This again indicates adequate sulphur for the nitrogen level supplied, but residual sulphur for the clover is less than at
the $N_0$ and $N_1$ levels.

Sulphur Mineralization Trial.

<table>
<thead>
<tr>
<th>TABLE 17.</th>
<th>S. Mineralization.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disturbed Soil</td>
<td></td>
</tr>
<tr>
<td>$N_0$</td>
<td>$N_1$</td>
</tr>
<tr>
<td>Dry Matter</td>
<td>$S_0$</td>
</tr>
<tr>
<td>Lime</td>
<td>.12</td>
</tr>
<tr>
<td>Control</td>
<td>.30</td>
</tr>
</tbody>
</table>

Dry matter production on the undisturbed soil was significantly higher than that of the disturbed. Lime had no marked effect on production on the undisturbed soil. There was a response to nitrogen, and sulphur also increased production at each nitrogen level.

On the limed disturbed soil, dry matter production was below that of the unlimed. Nitrogen and sulphur again increased production.

Consideration of the soil physical conditions of the experiment leads to the conclusion that this factor could have played a part in the reduced dry matter production with the disturbed soil.

Lime apparently had no effect on increasing the production of nitrogen and sulphur.

Sulphur Rates Trial.

The trial was designed to find the optimum sulphur level for a particular nitrogen level, assuming that the conditions of an N/S interaction held. Inconsistent results and the results of the other trials would tend to suggest that at the nitrogen level chosen, sulphur had little or no effect.

The only marked changes in plant composition were a slight increase in total S and organic S and a marked rise in the inorganic S level as the sulphur level was raised. The effect of this was to
cause a fall in the proportion of organic S to total S. This indicates adequate sulphur even at control, for the nitrogen level.

TABLE 17.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>S₀</td>
<td>1.55</td>
<td>.700</td>
<td>.018</td>
<td>.682</td>
<td>97</td>
</tr>
<tr>
<td>S₁</td>
<td>1.30</td>
<td>.803</td>
<td>.020</td>
<td>.783</td>
<td>97</td>
</tr>
<tr>
<td>S₂</td>
<td>1.37</td>
<td>.895</td>
<td>.046</td>
<td>.849</td>
<td>95</td>
</tr>
<tr>
<td>S₃</td>
<td>1.46</td>
<td>.778</td>
<td>.051</td>
<td>.727</td>
<td>92</td>
</tr>
<tr>
<td>S₄</td>
<td>1.36</td>
<td>.918</td>
<td>.052</td>
<td>.866</td>
<td>94</td>
</tr>
<tr>
<td>S₅</td>
<td>1.46</td>
<td>.900</td>
<td>.058</td>
<td>.842</td>
<td>93</td>
</tr>
</tbody>
</table>

D.M. production on station flat 15,500 lbs D.M./season.
DISCUSSION

The overall effect of applying nitrogen and sulphur to the vegetation at Mt Somers was to obtain highly significant responses to nitrogen, sulphur and an N/S interaction. Interaction analysis showed a highly significant linear N response and both linear and quadratic sulphur being highly significant, the quadratic value being slightly higher. This indicates sufficiency of the $S_1$ level for the nitrogen applied.

Highly significant responses to nitrogen were shown at the autumn preliminary, first and second cuts and a significant response at the third cut. The latter could have been due to the seasonal growth effect of fog on to a diminution in available nitrogen.

Sulphur had highly significant effects at the first, second and third cuts and evidently was present in sufficient amount over these cuts. There was apparently no marked sulphur response from the time of application until the autumn preliminary cut.

The N/S interaction was highly significant at the second cut; the period of spring growth and it just failed to reach significance at the first and third cuts. This would appear to be a reflection of fog response as this species showed the most marked change to nitrogen and sulphur addition.

The unsprayed analysis of the second cut indicates a highly significant response to nitrogen for the total cut (grass + clover) and for grass production alone. Clover depicted the opposite trend and was higher at the $N_0$ level. The change in clover with sulphur level was in the direction of similar production at $S_0$ and $S_1$ and an increased response at the $S_2$ level. The grass gave a highly significant response to sulphur as did the total dry matter (grass + clover) and this would appear to indicate that the clover status at this cut is not so much due to the level of sulphur available as to the level of physical competition with the grass at the higher $N$ levels. Nitrogen is having no significant effect at the third cut with total dry matter. Grass analysis however shows a significant effect.
This is a reflection of the markedly increased clover growth at the lower nitrogen levels compared with the last cut. Sulphur is still having highly significant effects with total dry matter and grass dry matter, but the N/S interaction is not significant as at the last cut. It would thus appear that although the effect of the applied fertilizers on the grass is not so marked as at the last cut, there is still ample sulphur available for the clover. The response of the clover to $S_4$ is now marked and is markedly increased at $S_2$ with all levels markedly above those of the last cut, indicating a lessened effect of the grass component on a competitive basis.

Clover production at the $S_0$ level fell with nitrogen addition, probably due to grass competition. There was a marked fall in clover production at the third cut at the $S_0$ level to values below that of the second cut whilst production at the $S_4$ and $S_2$ levels was increased over that at the second cut. A later pot trial (Utilisation of sulphur from pot trial 2) also showed good clover growth at $S_0$ levels whilst the prior grass crop showed a marked response to nitrogen.

Data such as this suggests that the sulphur status for the grass at the site is adequate for the nitrogen available, the main factor being a slow nitrogen turnover. Increased sulphur is needed with improved nitrogen turnover and markedly improved clover production can be obtained with increased sulphur.

O'Connor 1959 in a trial at Castle Hill Basin Canterbury suggested that the basal dressing (in this case $S$, $P$, $K$ and $N_0$) directly increased grass production by drawing on available soil nitrogen. Work at Mt Somers also indicates an increase in grass production at the $N_0$ level due to sulphur, although in each case, the $S_2$ level is less than $S_4$. The response to sulphur could be a direct grass response or indirectly linked with greater availability of soil nitrogen. Confirmation of the latter point was not gained by a subsequent pot trial (mineralization of sulphur) although Barrow's work (1960) suggests this is the case.
Walker et al. 1956 found a marked flattening of the response curve of grass + clover at 50 lbs of CaSO₄ / acre (10 lbs S equivalent). Comparing the soils of their trial and this trial, soils at Mt Somers were higher in total N, organic C and total S. The C/N ratio was markedly lower as were the C/S and N/S ratios. Thus, the soils were of a higher sulphur status than those in the Rakai Gorge.

Comparative production at the N₀ level for similar levels of sulphur was:

Rakai Gorge (Walker et al. 1956)

<table>
<thead>
<tr>
<th>S rate in S equiv, at N₀</th>
<th>0 lbs</th>
<th>10 lbs</th>
<th>40 lbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clover</td>
<td>0.40</td>
<td>6.08</td>
<td>7.08</td>
</tr>
<tr>
<td>Grass</td>
<td>8.13</td>
<td>12.31</td>
<td>15.94</td>
</tr>
<tr>
<td>Total</td>
<td>8.53</td>
<td>18.39</td>
<td>23.02</td>
</tr>
</tbody>
</table>

Mt Somers Trial

<table>
<thead>
<tr>
<th>S rate in S equiv, at N₀</th>
<th>0 lbs</th>
<th>10 lbs</th>
<th>50 lbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clover</td>
<td>0.89</td>
<td>12.42</td>
<td>16.92</td>
</tr>
<tr>
<td>Grass</td>
<td>20.01</td>
<td>29.38</td>
<td>35.65</td>
</tr>
<tr>
<td>Total</td>
<td>28.97</td>
<td>41.80</td>
<td>52.57</td>
</tr>
</tbody>
</table>

No botanical analysis is given for the Rakai Gorge site but personal observation would suggest that the growth of that site due to its more depleted cover and more adverse climatic situation would be less than that of Mt Somers. A factor in the markedly higher grass production at Mt Somers could also be the greater amount of fog present in the native sward. This in itself is an indication of higher fertility status. The response of clover on the Mt Somers site to sulphur addition was less marked as a percentage of production at control levels, than was the case at the Rakai Gorge.

Walker et al. 1956 found a 50% recovery of the applied sulphur at 10.5 lbs of S / acre and lesser recovery at higher levels. Over a four year period Walker and Adams 1958 recovery was 80% for 10.5 lbs S and 30% for 40 lbs of S. The recovery at Mt Somers was slightly
higher, but occurred in a much shorter time period probably due to the associated higher nitrogen levels used.

In the trial at Rakia Gorge, marked residual effects of the sulphur were obtained (Walker and Adams 1958) four years subsequent to the laying down of the trial. In that trial, by the fourth year, grass production was still increasing at all sulphur levels. Clover production had stabilized at the $S_0$ level, but was falling at the other sulphur levels. The only marked residual effects of sulphur at Mt Somers would be expected at the $S_2$ level.

A comparison of comparable manure levels between a trial of Walker and Adams 1957 and that at Mt Somers shows grass production to be lower at Mt Somers at the $N_0$ level, but would be equivalent at the $N_1$ level (40 lbs N at Mt Somers vs 50 lbs at Rakia Gorge). The grass showed a much greater response to nitrogen at Mt Somers. Sulphur had a much greater effect on grass production at Mt Somers than at the Rakia Gorge.

At both sites, clover production was depressed much to the same extent due to nitrogen. Clover production at the $S_0$ level was markedly higher at the Mt Somers site. Increases to sulphur were obtained at each site, but the increase was markedly greater at the Rakia Gorge.

<table>
<thead>
<tr>
<th></th>
<th>Mt Somers</th>
<th>Rakia Gorge (2nd and 3rd cuts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_0$</td>
<td>8,504</td>
<td>12,770</td>
</tr>
<tr>
<td>$N_1$</td>
<td>10,509</td>
<td>13,390</td>
</tr>
<tr>
<td>$S_0$</td>
<td>9,514</td>
<td>12,390</td>
</tr>
<tr>
<td>$S_1$</td>
<td>12,285</td>
<td>12,950</td>
</tr>
<tr>
<td>$N_0$</td>
<td>3,830</td>
<td>4,620</td>
</tr>
<tr>
<td>$N_1$</td>
<td>2,324</td>
<td>3,250</td>
</tr>
<tr>
<td>$S_0$</td>
<td>1,540</td>
<td>310</td>
</tr>
<tr>
<td>$S_1$</td>
<td>2,435</td>
<td>7,510</td>
</tr>
</tbody>
</table>
Nitrogen recovery at Mt Somers was high at both N levels, averaging 82% for $N_1$ and 45% for $N_2$.

Walker and Adams obtained only low recoveries of nitrogen and suggested that this could be due to the inferior species comprising the sward. The higher recovery at Mt Somers could be due to a greater proportion of fog in the sward, whereas there is no mention of fog in the Rakai Gorge trial.

**Botanical Change.**

The lower site trial at Mt Somers besides giving a measure of dry matter response to nitrogen and sulphur also gave a picture of differential species response according to the time of application and seasonal change as the species period of growth varied.

At the summer preliminary cut, O.G. was superior at the $N_0$ level, displaced by S.V. at the $N_1$ level and fog was showing the most marked response with sulphur at the $N_2$ level.

The autumn preliminary cut showed an increase in the proportion of sweet vernal and fog respectively at the $N_1$ and $N_2$ levels, fog such that it was now dominant over S.V. at the $N_2$ level.

The first cut followed the pattern of the autumn pre-cut but indicated the effect of winter conditions on dry matter production. This was reduced at the $N_0$ and $N_1$ levels and increased at the $N_2$ level. However, the trend was opposite if the plots were cut prior to the winter and a marked killing of fog took place. It would thus appear that fog had exhausted its reserves in its late autumn response. As the sward swung markedly to fog at high nitrogen levels, subsequent lack of regrowth after autumn grazing would leave a very open sward.

The second cut indicated the marked spring flush of S.V. at the $N_0$ and $N_1$ levels. S.V. also rose markedly at the $N_2$ level. Fog however, increased markedly with sulphur at the $N_2$ level. O.G. indicated its lack of competitive ability at this stage in that its only marked response was at the $N_2$ level where presumably some nitrogen and sulphur were available.
O'Connor 1959 found at Broken River an increase in Browntop in the presence of nitrogen and the absence of sulphur and suggested that this was a reflection of the superior competitive ability of this species for sulphur. The present work suggests that such is the case in this trial, but S.V. responds to nitrogen more markedly than browntop under the same conditions. Browntop responds to sulphur where there is nitrogen and sulphur available such as at the $N_2$ level, but the response is less than that of S.V. The response of browntop noted at Broken River could have been due to the greater amount of this species in the sward.

Treatment differences levelled out at the third cut and fog and S.V. were diminished in response. O.G. was much increased at lower $N$ levels at this cut but was still inferior to the other two species in the presence of sulphur.

Consideration of the data suggests that the status of O.G. is dependent more on nutrients not utilised by the fog and S.V. so that the $N/3$ fertility rating of the species is likely to be fog $\rightarrow$ S.V. $\rightarrow$ O.G.

**Total Species Dry Matter.**

Total species dry matter gives an indication of species response to nitrogen and sulphur without differential seasonal species response. S.V. is superior to fog and O.G. in turn at the $N_0$ level. The production of all species is increased at the $N_1$ level with fog more increased as the sulphur level is raised. At the $N_2$ level, S.V. is markedly above fog at $N_2S_0$, but fog attains a marked superiority as the sulphur level is raised. The response of S.V. to sulphur at the $N_2$ level is indicative of the marked competition of fog as the sulphur level is raised. O.G. shows some sulphur response, but below that of the other two species.

The species response is thus similar to the seasonal response except that the superiority of S.V. is more marked at the $N_2$ level.
Sulphur effects on dry matter production.

The $S_4$ level was adequate for the $N_3$ level, but at the $N_2$ level, $S_2$ gave additional effects. It is suggested that the fall in response to sulphur could have been due to a diminution in nitrogen in the third cut. Other determinations previously mentioned also suggest that adequate sulphur was still present at this cut. A further possibility was that on a species basis, there was a more marked drop of fog at the $S_2$ level than was the case with S.V. at the $S_4$ level and as fog gave a marked response to nitrogen and sulphur, this could have given the marked decrease in response to sulphur.

On a podsollic soil in New South Wales, Donald and Williams 1954 indicate the change in native pasture with superphosphate addition. The native vegetation comprised an open stand of perennial ryegrasses, mainly Daunthonia, Fannon and Chloris sp. with a varying degree of invasion by introduced annuals such as *Vulpia bromoides*, *Bromus hordeaceus*, *Aira carveryllae*, *Trifolium glemaratum*, *T. campostre*, *T. arvense*, *T. rubrum*. These invaders were obviously limited in their growth by the poor nutrient status.

The introduction of subterranean clover with superphosphate initiates a sere which finally results in a complete change in sward composition. As the density and vigour of the clover increases, the native species are eliminated and subterranean clover becomes dominant, and as the soil fertility status rises, grasses other than native perennials appear and the clover is reduced from full dominance. River and Crocher (J. Brit. Grass. Soc. 6, 29, 1951) give a more detailed botanical account of changes. A characteristic feature of the improved fertility is the relatively small number of different species and these are particularly sensitive to climatic fluctuation. This instability necessitates the introduction of a perennial such as *phalaris*. Similar changes take place under higher rainfall, but fog becomes a common constituent and it persists under relatively low fertility but responds markedly to improved fertility.
The trials at Mt Somers indicate that similar botanical changes to these take place with nitrogen and sulphur addition in the direction of the higher fertility demanding fog. The change is rapid due to the applied nitrogen and appears to be rapid in its downward trend due to low nitrogen residual effects. Undoubtedly trends would be different under grazing, but then seasonal effects in conjunction would be much greater e.g. winter killing of fog.

O'Connor 1959 suggested that full climatic potential was not achieved at Castle Hill Basin without the addition of fertilizer nitrogen. In the absence of this and without clover oversowing, Mt Somers trials suggest that the sulphur status is adequate for the nitrogen available and even with clover oversowing, the lower level of sulphur should be adequate for grass and clover production.

Considerably higher production could be obtained with nitrogen addition, but might require a slightly higher level of sulphur. The adequacy of the sulphur level is suggested by the sulphur rates pot trial where using nitrogen at 100 lbs N/acre, the level of sulphur used had very little effect on dry matter production.

Chemical Composition Mt Somers.

Total N increased with increased nitrogen and sulphur had its most marked effects at the N2 level, where it decreased nitrogen percentage, this being due to a dilution effect occasioned by increased dry matter.

Protein N % formed a higher percentage at the N2 level, but showed little change with sulphur addition. N.P.N however was markedly increased at the N2 level and decreased as sulphur was added. As total N fell at the N2 level with sulphur addition and protein N remained constant, the protein N/total N ratio increased.

Total S showed no marked change with N addition but increased slightly within each nitrogen level with sulphur addition. Inorganic S followed a similar pattern, but markedly increased with sulphur addition. Between nitrogen levels, the most marked change in inorganic S was at
the S₀ level, inorganic S falling markedly as the nitrogen level was raised.

Organic S dropped at the N₂ level and within each nitrogen level, increased as the sulphur level was raised. At each N level, organic S decreased as the sulphur level was raised. This is the opposite trend to protein N/total N ratios suggesting that the increase with N + S addition is mostly in protein N.

Results of Walker and Adams 1958 for grass were similar. As with their trial, the protein N/organic S ratios of the Mt Somers data remained steady whereas the total N/total S ratio was reduced by sulphur application. In this trial, protein N/organic S ratios were much higher at the N₂ than at lower N levels, as were total N/S ratios. This again appears to indicate more marked effects of nitrogen.

The main changes which appear to take place at the N₂ level with sulphur addition are:— Protein N remains steady as does Organic S. The N/S ratio decreases and this change is a consequence of the decrease in N.P.N and an increase in inorganic sulphur. The effect of this is to increase the absolute amount of protein as dry matter has increased whilst protein N values have remained constant. Luxury consumption of sulphur is apparent as inorganic sulphur increases markedly whilst N.P.N decreases.

Nutrient Yields.

Nitrogen increased nitrogen yield markedly. The drop in nitrogen yield due to winter conditions was N₀ 69%, N₁ 66% and N₂ 58%. Nitrogen yield figures mirror species seasonal changes.

Sulphur increased nitrogen yield with little difference between S₁ and S₂ levels, again indicating the adequacy of the lower sulphur level. The presence of fog had a marked influence on the effect of sulphur on nitrogen yield.

Sulphur increased sulphur yield, the most marked response being when fog markedly responded. Likewise nitrogen affected sulphur yield,
more markedly so as fog increased to dominance at high nitrogen and sulphur levels.

In Walker and Adams trial 1958, nitrogen did not increase grass nitrogen yield markedly except at the N_2 level (60 lbs N). Sulphur increased grass yield with little difference between S_1 and S_2 (5 - 15 lbs S). Their response pattern thus seems similar to that at Mt Somers.

Mt Somers Top Site.

The top site showed highly significant total dry matter and species response to nitrogen and sulphur and the N/S interaction was highly significant for fog and O.C. The nitrogen response was linear and the sulphur response quadratic, indicating again the effectiveness of the S_1 level. The soil at this site was lower in nitrogen and sulphur and dry matter yield with added fertiliser was only half that of the lower site. This would also have been affected by climatic conditions and physical soil conditions particularly in the winter.

Fog production was particularly low and only showed a marked response at the N_2 level with applied sulphur. The superiority over S.V. was not as marked as at the lower site.

S.V. was rather unusual in that although its production was increased with nitrogen at the N_1 and N_2 levels, production fell off with sulphur addition markedly so at the S_1 level. O.C. acted in the opposite fashion and responded markedly where S.V. was depressed in production.

Spaced Plants.

The spaced plants responded to nitrogen in terms of height tillering and dry matter yield and showed increased dry matter with nitrogen and sulphur addition. Response of other species in the plot precluded accurate determination of the effects of sulphur on height and tillering. Indications however were that sulphur had an effect on height, but no effect on tillering. Work by K.F. O'Connor
at Castle Hill Basin with space planted cocksfoot showed similar results (pers. comm.) Tilling was not markedly increased with 200 lbs N as nitrogen, but in the presence of 25 lbs S, there was a marked increase. Height changes were greater with nitrogen and increased with nitrogen and sulphur. Dry matter yields followed a similar trend. It is noted that competition by the resident vegetation as judged by dry matter yield would be much less at this site than at Mt Somers.

1st Pot Trial.

Cocksfoot fog and S.V. showed highly significant responses to nitrogen in tillinging and dry matter yield. Sulphur had a significant effect with fog dry matter yield and cocksfoot closely approached significance. There was little effect of sulphur on tillinging. Cocksfoot showed a highly significant N/S interaction with tillinging and a significant dry matter response.

In chemical composition, the species showed similar changes to applied nitrogen and sulphur as previously mentioned for the Mt Somers site. At the N_o and N_1 levels M.P.N was greater with cocksfoot than with fog possibly indicating that fog utilized nitrogen and sulphur at lower fertility levels. Values for S.V. were slightly above those of fog at the N_0 and N_1 levels, but fog had much lower values at N_2 indicating superior response of fog at this level.

Cocksfoot showed the lowest M.P.N. values with S_2 addition at the N_2 level followed by fog and then S.V. and total N.P.N values followed this trend.

Sufficient material was not available for sulphur analysis. The overall picture of the trial indicated that the fertility status of the species as judged by response to applied nitrogen and sulphur was S.V. > fog > cocksfoot. The response of S.V. and fog to N_0 was similar. S.V. was slightly superior at the N_1 level with both S.V. and fog above cocksfoot. Fog and S.V. were similar at the N_2 level, fog asserting its superiority under higher sulphur conditions and cocksfoot was
superior to both in the presence of sulphur, but inferior in its absence.

A similar pattern is shown by O'Connor with cocksfoot *Bromus inermis* and *Agropyron intermedium* on nitrogen and sulphur addition (pers. comm.). The latter two show superior dry matter response at the N₀ level. At the N₁ level the rating is *Bromus inermis*, *Agropyron intermedium* and cocksfoot, but with the application of sulphur, the rating changes to cocksfoot, *Bromus inermis*, *Agropyron intermedium*.

2nd Pot Trial.

The second pot trial showed highly significant nitrogen, sulphur and nitrogen - sulphur responses. Response to nitrogen was not diminished at the N₂ level indicating the ability of cocksfoot to respond to high levels of nitrogen, but the rate of increase was diminishing. The lower rate of sulphur (25 lbs S) appeared to be adequate for the nitrogen level used except at N₃ (300 lbs N) where an additional response was obtained from S₂ (50 lbs S).

S Utilization Trial.

As judged by clover growth, the sulphur utilization trial indicated greater sulphur availability at lower nitrogen levels. There was a drop in clover production at the N₂ and N₃ levels to values 55% of those at the N₀ and N₁ levels. This indicated adequate sulphur for the nitrogen level supplied, but residual sulphur for the clover was less than at the N₀ and N₁ levels.
CONCLUSIONS

1. The overall effect of applying nitrogen and sulphur to the vegetation on the lower site at Mt Somers was to obtain highly significant responses to nitrogen, sulphur and a nitrogen – sulphur interaction.

2. A marked change was affected in the swards botanical status. Analysis of cuts during the season gave an indication of differential species seasonal response.

3. The change was rapid in its upward and downward trends and production changes appeared to be due more to nitrogen status than to sulphur status.

4. Botanical change with nitrogen and sulphur addition suggests that the fertility rating of the species is fog → S.V. → O.G.

5. There appeared to be a slight grass response to sulphur at the N₀ level, although it is not known whether this was direct or through an effect on nitrogen mineralization.

6. Grass showed a greater response to nitrogen and sulphur at Mt Somers than at the Rakaia Gorge, probably due to the species present.

7. Nitrogen recovery was higher at Mt Somers than at the Rakaia Gorge.

8. Similar sulphur recovery figures were obtained, but those at the Rakaia Gorge were over a four year period and this may explain the low sulphur recovery. The sward at Mt Somers contained species more capable of rapid response such as fog.

9. High nitrogen gave pronounced frost resistance. There was marked winter killing at control and lower nitrogen levels, reduction in dry matter yield being less with sulphur addition.

10. However, the effects of the cut prior to winter were severe on high nitrogen treatments. Low nitrogen and control went through the winter with good ground cover.

11. On the unsprayed plots, good clover growth was obtained at S₀ levels suggesting that the sulphur status was higher than at the Rakaia Gorge. A lower response was obtained with sulphur addition.
12. Clover status appeared to be more affected by physical competition with grass than with sulphur status.

13. Sprayed cuts were greater in grass dry matter yield at N₀ and N₁ levels and less at N₂ than unsprayed. This suggests that production differences were not due to nitrogen transfer by the clover, otherwise greater grass production would be expected at N₀ and N₁ with the unsprayed cuts.

14. The main changes in chemical composition with nitrogen and sulphur addition were that protein N and org S remained steady. The N/S ratio decreased whilst the protein N/org S ratio was steady. There was a decrease in N.P.N and a rise in inorganic S. The overall effect was to increase protein yield as dry matter increased whilst protein N values remained constant.

15. Nitrogen and sulphur increased nitrogen yield. The drop in yield due to winter conditions was N₀ 65%, N₁ 66%, N₂ 53%. Sulphur and nitrogen increased sulphur yield mainly through fog response.

16. The top site showed significant dry matter and species response to nitrogen, sulphur and the combination. Production was below that of the lower site.

17. Space plants responded to nitrogen in tillering and dry matter production and showed an N/S dry matter response. Height and tillering increased with nitrogen in the presence of sulphur.

18. The spaced plant technique only appears to be suitable in a sward that is not too aggressive.

19. Survival of the space-planted cockfoot was good but growth in the following year was poor, probably due to lack of nutrients in lower fertility plots or to physical competition in higher.

20. The first pot trial showed that cockfoot, fog and S.V. responded to nitrogen; fog and cockfoot to sulphur and cockfoot to the combination. The fertility response status is thus indicated as being cockfoot → fog → S.V.
21. The second pot trial showed a nitrogen, sulphur and nitrogen - sulphur response. Response to nitrogen was not diminished at 300 lbs N level. The 25 lbs S rate was adequate for lower nitrogen levels but at 300 lbs N an additional response was obtained to 50 lbs S.

22. The sulphur utilization trial indicated adequate sulphur for all levels of nitrogen used. Residual sulphur was less at N₂ and N₃ levels than at N₀ and N₁.

23. Using undisturbed soil samples, sulphur responses were obtained in the glasshouse, whereas White (1954) failed to get a response with disturbed samples.

24. Soil disturbance in the mineralization trial compared with undisturbed soil appeared to affect the trial through water relationships, the disturbed soil pots being hard to water without water-logging the soil.

25. Lime had no effect in increasing the production of nitrogen and sulphur.

26. In the Mt Somers trials the S₁ level was adequate for the N₁ level, but at the N₂ level, S₂ gave additional effects.

27. The sulphate rates trial indicated that at 100 lbs N the sulphur level was not critical and 25 lbs S was adequate.

28. If dry matter production is to be increased, then the nitrogen status must be greatly increased. Higher fertility species will then be required and a suitable management policy for these to retain a modified sward such that it is not too subject to cover changes with grazing management changes. This is important as the higher fertility sward leads to a lesser species composition which normally has a balancing effect with changes in cover of the major component.

In the absence of applied nitrogen and without clover oversowing, the sulphur status is adequate for the nitrogen available and even with clover oversowing the lower level of sulphur should be adequate for grass and clover production. Considerably higher grass production could be obtained with nitrogen addition, but might require a slightly higher level of sulphur. It would appear that an adequate level of sulphur would be somewhere between 10 and 25 lbs S/acre. This amount of sulphur would be contained in 1 cwt of fortified superphosphate (20 lbs Ca₃P₀₄ + 10 lbs elemental S).
ACKNOWLEDGMENTS

Professor R.E.M. Lenger and Mr. A. Adams, Lincoln College for helpful guidance and criticism.

Messrs. A. Adams, C. Iversen and Dr. K.P. O'Connor for assistance in planning the experimental work.

Mr. R. Vartha and numerous others for technical assistance.

I would specially like to thank Mr. and Mrs. L.P. Chapman and staff of 'Inverary' Mt Somers for their hospitality and generous loan of station facilities.

The New Zealand Wool Board for financial assistance through an extended Wool Board Bursary.

To all these people I extend my grateful thanks.

Acknowledgement

Mrs. J. M. Wright, Dept Research, Division B.S.I.R. Lincoln for statistical guidance.
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