OBSERVATIONS ON LEGUME ESTABLISHMENT AND GROWTH ON ACID SOILS

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THE PROBLEM of establishing plants and keeping them growing on acid soils has been present as long as agriculture has been practised, and the beneficial effect of liming materials of various kinds has been appreciated for almost as long. But while they have been appreciated, their precise mode of action has not been understood. Even with the considerable advances that have been made in understanding the "acidity complex" in recent years, the full solution of the complexities of plant growth on acid soils has still to be found.

Although this paper will deal only with legumes, this whole field of soil acidity and plant growth is a most interesting one, bristling with problems, and the aspects to be discussed here form a good example of the impact of modern research on an age-old traditional practice -that of liming the soil.

For some years workers at Lincoln College have been interested in the establishment of clovers on the acid soils in the tussock grasslands, partly because of the interesting problems involved, and partly because these areas might confidently be expected to make an important contribution towards the production increases necessary and aimed at for the future. In these areas the lack of readily available nitrogen is one of the major drawbacks to higher production, and if thriving legumes can be established there and kept thriving by the regular application of adequate amounts of the correct nutrients in the fertilizer programmes, a big advance towards the goal will have been achieved,

Originally, the nutrients sulphur and phosphorus were concentrated on but more recently the effects of broadcast lime, lime-pelleting and inoculation on legume growth have been studied. It is the results of these investigations both in field and pot trials that will be presented here, together with new problems that have arisen and the trials planned to help solve them.

When considering how lime assists the growth of plants on acid soils, mention must be made of the trace element molybdenum. Australian workers were the first to show that, if lime was used at traditional rates to raise the pH of the soil, the plants were then able to take up more molybdenum from the soil. It is now known, of course, that clovers will often grow quite well on acid soils, provided they are supplied with a few ounces of sodium molybdate per acre, even with no lime at all.

In some cases this does not work. Commonly, when this happens very few, if any, nodules are found on the clover roots; since it is really the bacteria in the nodules which need this molybdenum it is obviously pointless supplying molybdenum for bacteria that are not there.

This is where inoculation of the seed comes in, but if conditions before, at, or after sowing are unfavourable for the survival of the bacteria used for inoculation, this too may be unsuccessful. Small amounts of lime can often help, especially if put into close contact with the seed at sowing. Originally 2 cwt/acre of lime was drilled with the inoculated seed but later it was found that almost equally good results could be achieved by coating the seed with very fine limestone at the rate of 5 to 10 lb/acre. From this work arose the now familiar process of pelleting clover and lucerne seed.

The combination of these findings and their adoption in practice has meant that the cost of pasture establishment can often be appreciably reduced.

Trials

TRIAL A

In an early trial the effects were studied of lime, inoculation and lime-pelleting on the growth of subterranean clover, white clover and lucerne (grown separately) on a very acid soil, pH 4.9. The trial was of factorial design, with three replications. Superphosphate was applied to all pots as a basal dressing.

Tables **1** and 2 illustrate some of the recorded effects.

TABLE 1: EFFECTS OF INOCULATION AND LIME-PELLETING, WITHOUT LIME APPLICATION
(Weight in grams of D.M. from six pots)

	Subterranean Clover	*White Clover*	***Lucerne***
'No inoculation ; no pellet	1.5	0.7	
With inoculation ; no pellet	3.2	0.6	8.56
With inoculation ; with pellet	6.8	1.3	2.3

Table 1 shows that inoculation alone more than doubled the yield of subterranean clover but conferred no benefit on the other species. (Subterranean clover also responded very markedly to pelleting even without inoculation.) The use of a lime-pellet on the seed in conjunction with inoculation gave marked yield increases in all species.

In general, then, neither pelleting nor inoculation used alone did much good but the two together produced marked increases in yield.

TABLE 2: EFFECTS OF INOCULATION AND LIME-PELLETING, WITH LIME APPLICATION OF 3 TONS/ACRE
(Weight in grams of D.M. from six pots)

	Subterranean Clover	White Clover	Lucerne
No inoculation; no pellet	5.1	2.7	1.6
With inoculation; no pellet	7.8	2.5	6.0
With inoculation ; with pellet	5.2	1.7	5.4

Comparison of the figures in Table 2, where the equivalent of 3 tons of lime per acre was applied, with those in the top line (control) of Table 1 shows:

(1) Liming at the traditional liming rate (in this case 3 tons) has given good responses in all species. It is of interest to note that for subterranean clover a bigger yield still was obtained simply by inoculating and lime-pelleting the seed.

(2) Response of both subterranean clover and lucerne to inoculation and lack of response from white clover.

(3) Highest yields are obtained from a combination of liming and inoculation, *but that*

(4) Where pelleting is used also, yields are depressed.

TRIAL B

The next trial, a field trial, also studied the effects of lime at 0, 10 and 40 cwt/acre, lime-pelleting and inoculation on the establishment and growth of oversown legumes. The soil is strongly acid (pH 4.9) and is probably a Cass. Superphosphate at 4 cwt/acre (based on earlier findings) was sown throughout and a mixture of clovers sown, of which only white and alsike contributed significantly to the yield.

At 15 weeks the following effects were noted:

(1) Inoculation produced a highly significant increase in the percentage of plants nodulated.

(2) Inoculation produced a highly significant increase in nodules per plant.

(3) Lime produced a significant increase in nodules per plant

Statistical analyses of. the yield data from a cut at 7½ months revealed that the increases due to lime and inoculation were both significant at the 1% level. Over the whole trial, the depression from pelleting just fails to reach significance, but closer examination of the data reveals that this depression occurs most noticeably when lime at 40 cwt/acre is used in conjunction with the lime-pellet, and also that within this liming rate almost all the depression occurs on those plots sown with inoculated seed, as was also the case in Trial A.

TABLE 3: EFFECT OF LIME-PELLETING ON YIELD
(Mean D.M. yield in lb/acre; all plots included)

	No Pellet	With Pellet	% Depression
L_0	307	283	7.8
L_1	562	532	5.4
L_2	711	474	33.3

This yield depression at L_2 in Table 3 is highly significant and, since the effect is most evident on plots with inoculation, the implication is that it is an effect on the rhizobia, though effects on the host plant are not precluded.

TRIAL C

A further trial, laid down in August, 1963, was designed to study further this interesting finding. Six levels of lime up to 8 tons per acre were used in five replicates with unpelleted and pelleted seed, all inoculated. High variability, possibly due in part to a poor growing season, precluded any significant differences due to pelleting from being recorded at any one level of lime. (An interesting finding, which is somewhat outside the scope of this paper, was that yields from seed lime-pelleted using methyl cellulose were significantly lower than from unpelleted seed, while there was no difference in those pelleted using glue.)

Erratic results were recorded for the rates of lime used in conjunction with pelleting, but, with non-pelleted seed, yields increased up to the 10 cwt rate and decreased thereafter (Table 4). Significant differences occur only between 0 and 10 cwt and between 10 and 160 cwt, although the figures suggest a real effect at 2½ cwt also.

TABLE 4: EFFECT OF LIMING RATE ON YIELD

Liming Rate (cwt/acre)	*Yield of D.M. (lb/acre)*
0	222
2%	412
10	546
40	422
80	422
160	363

There was no effect of lime or pelleting on nodulation.

TRIAL D

The final results to be mentioned here concern trials with lucerne. Using inoculated seed, both lime-pelleting and liming to full lime requirement gave marked increases in yield, though the former was not significant. (A further trial showed a marked response in nodulation to pelleting.) Further significant increases resulted from the use of lime-pelleting and lime in conjunction (Table 5).

TABLE 5: EFFECTS OF LIME AND LIME-PELLETING ON YIELD OF LUCERNE
(Mean D.M. yield in lb/acre)

Control	*Pellet*	*Lime (at 30 cwt/acre)*	*Lime and Pellet*
110	500	1,650	2,740

SUMMARY OF TKIAL RESULTS

To summarize, the following effects have been recorded in these -trials.:- --

(1) *Effects of inoculation:*

A beneficial effect of inoculation of clovers on some soils.

(2) Effects of pelleting:

(a) Pelleting without inoculation. No increase in yield with lucerne, subterranean clover, white clover .... A.& B

(b) Pelleting with inoculated seed.

No *other lime used:*

Beneficial on the three species ...... A

No benefit to white and alsike ...... B

Beneficial (nodulation and growth) to lucerne .... D

With lime added to lime requirement:

Depressions in yield of subterranean clover, white clover and lucerne A & B

No effect C

Increased yield of lucerne .... D

(3) Effects of lime:

(a) Marked increase in yield — lucerne, subterranean clover, white clover (Trials A, B, C, D) — but in almost all cases note that there is no difference between liming at rates of ⅓ to ½ liming rate and liming to full liming rate . . . . A & B

(b) Tendency to depression with pelleting, especially with subterranean clover and white clover . . . . A & B

(c) Depression in yield of clovers in absence of pelleting C

This summary indicates that one does indeed meet many complications when trying to solve problems of acidity, especially with legumes.

Discussion

These complexities can be greatly simplified by concentrating on but a few aspects, and it is proposed to conclude this report by indicating the steps that will be taken to carry the investigations further.

Perhaps the most interesting aspect is that of the depressions in yield when lime-pelleting is used in conjunction with traditional rates of liming.

An important practical point is the success achieved by relatively low rates of application of lime, Possible functions of pelleting might first be considered. The success achieved by Anderson and Moye (1952) with 2 cwt/acre of lime drilled with inoculated seed was attributed by him to a localized pH effect creating a better environment for survival and multiplication of the rhizobia, rather than an effect of calcium. Since then, however, various workers — e.g., Turner (1955) — have achieved satisfactory results with other relatively inert pelleting substances, such as charcoal, and these results have highlighted the possibility of toxic secretions from the seed, although one has visions of beneficial exudates being similarly rendered ineffective. A further possibility is that of microbial antagonisms in the clover rhizosphere. In addition, the pellet undoubtedly exerts a strong protective influence on the rhizobia against the deleterious effects of desiccation during storage or while surface-sown seed is exposed on the ground, and against damage from contact with fertilizers. These are very important practical points, and it may be that this role of protection against numerous adverse environmental factors is the principal role of the pellet rather than the supply of a nutrient such as calcium or the actual change of pH in the vicinity of the seed.

It is difficult to see why the presence of additional lime near the pelleted seed should interfere with any of these functions except possibly in relation to pH conditions and associated nutritional factors. For example, when the lime-pelleted seed is surrounded on the ground by appreciable quantities of ground limestone, it is possible that the pH in its vicinity rises to quite high levels. Little seems to be known of the upper pH limit for rhizobial survival and the possibility exists that, in selecting for high-fixing strains adapted to slight to moderately acid soils, a strain which is sensitive to high pH has been produced. There is scope here for laboratory studies.

Associated with this are possible indirect effects on nutrient availability which might affect the rhizobia, the host plant, the nodulation process, or the symbiotic nitrogen-fixation process. Phosphorus is such a nutrient, and, following on a report that induced phosphate deficiency at high pH (due to liming) had caused poor legume growth (Dawson, M. D., pers. comm.), plants from **Trial B** were analysed for phosphorus content. These ranged from 0.20 to 0.25% and there appears to have been no reduction in phosphorus availability as a result of the simultaneous use of lime and the lime-pellet, However, in an endeavour to throw more light on some of these possibilities, a further pot trial is planned to check on the lime/lime-pellet depressions by including an inert pelleting substance as a further treatment to study its interaction with lime, the effect of different levels of phosphate and the response of different legume species to these treatments.

In addition, the possibility of trace element troubles has not been forgotten and a further possible pot trial envisages a soil perhaps with basal treatments of heavy lime, sulphate and molybdate ; other treatments to include pelleting,, levels of phosphate and a range of trace elements.

In this way it is believed that further progress will be made in understanding the problems of acid soils, an understanding which will be of value to the aim of increased pastoral production.

REFERENCES

Anderson, A. J. ; Moye, D. V., 1952 : *Aust. J. agric. Res.,* 3: 95-110.
Turner, E. R., 1955: *Ann. Bot., 19:* 149.