THE AMELIORATION OF ACID SOILS IN THE SOUTH AFRICAN SUGAR INDUSTRY

P K MOBERLY & J H MEYER, South African Sugar Association Experiment Station, Mount Edgecombe

Abstract

A review is given of recent research into acid soils of the South African Sugar Industry. The results of a considerable number of glasshouse and field experiments, using various soil ameliorants at different levels, are presented, and the measured responses are related to certain soil characteristics. The current criteria for advice on soil amelioration for optimum sugarcane growth are described, and a tentative threshold value based on exchangeable aluminium per 100 g clay is suggested for improving the prediction of limestone requirements. Phosphorus and zinc availability in the presence of limestone are discussed, and comparisons are made of silicious materials and limestone. Methods of limestone application are briefly discussed, and the long-term effects of limestone on some soil characteristics are illustrated.

Introduction

Traditionally in the South African Sugar Industry the use of limestone has been relatively small because of the base-saturated nature of most of the soils in the old Natal sugar belt. Recommendations to cane growers of lime requirement have invariably been based on the results of standard soil pH and exchangeable Ca and Mg measurements. In the early sixties however, the industry expanded into the more highly leached soils of the Natal midlands. In parts of this new area sugarcane growth was relatively poor. While the limitation of the cooler climate on cane growth was widely appreciated, investigations conducted during 1968 to determine the reasons for the stimulating effects of wattle brushwood ash on cane growth, emphasised the extent of the nutritional limitations of a number of soils in a large part of this region.

Recent advances dealing with the chemistry of South African soils have indicated that exchangeable aluminium rather than adsorbed H^+ constitutes the main source of acidity and that the traditional Shoemaker, McClean & Pratt (1961) (SMP) buffer method of determining lime requirement is not always suitable for many of our soils (Le Roux & De Villiers, Reeve & Sumner (1970)). Our experience supports these findings and in view of the significant occurrence of Al toxicity in the Natal midlands soils, as indicated by the results of an industry-wide nutrient survey, a system based on the rapid measurement of exchangeable aluminium has been used to supplement the usual criteria for routine advisory purposes (Meyer, Wood & Du Preez, 1971; Meyer, 1974).

The objective of this paper is to review some of the more recent investigations into the need for acid soil amelioration, the responses obtained in both glasshouse and field experiments, the methods of ameliorant application, the forms of ameliorants and quantities required, and the criteria which may be used to determine the need for ameliorating soils for optimum sugarcane production.

Wattle brush ash investigation

Sugarcane planted in fields where wattle trees have previously been grown frequently exhibit a very marked 'tramline effect'. The superior growth of cane along these lines is associated with the windrows of wattle brush which are burnt prior to land preparation. The reasons for this effect were investigated by Meyer (1970) in a field survey and through glasshouse experimentation. Analyses of soils containing wattle ash showed highly significant reductions in acidity and labile Al, and increases in the amounts of exchangeable Ca, Mg, P, Si and K. Examination of the associated sugarcane third leaf analytical data showed similar increases in nutrient levels, particularly in regard to P and K. The data in Tables 1 and 2 illustrate these effects at a site that was sampled in the Eston area.

TABLE 1 Analysis of NOMANCI soil series sampled from areas with and without wattle ash near Eston in the midlands of Natal

Soil property	With wattle ash	Without wattle ash	Difference*
% Clay	22	19	NS
% Organic matter	5,5	5,6	NS
pH (water)	5,5	4,54	S
S-value (meq %)	5,90	2,30	S
CEC (meq %)	7,4	7,4	NS
% Base saturation	74	31	S
P (ppm)	22	18	NS
Al (ppm)	22	230	S

*NS = not significant at 5% level
S = significant at 5% level

TABLE 2 Analysis of cane from areas with and without wattle ash

Plant composition	Eston		
	With ash	Without ash	Difference
% N	2,30	2,26	NS
% P	0,18	0,12	S
% K	1,63	1,21	S
% Ca	0,33	0,54	S
% Mg	0,55	0,70	S
Fe (ppm)	230	350	NS
Al (ppm)	220	280	NS
Mn (ppm)	66	80	NS
An (ppm)	18	21	NS

TABLE 3 Cane yield in relation to selected treatments

Soil	Selected treatments	Code	Yield tops + stalk g	% Diff, relative to C	Root yield g
BALGOWAN (B)	Control (N & K)	A	8,1	– 36	1,7
	Supers (single)	C	12,8	0	2,5
	Sterilisation	D	8,2	– 36	1,2
	Ash	I	19,2	+ 48	4,2
	Lime	H	15,2	+ 19	2,9
	Aluminium	O	4,2	– 66	0,4
	Al & Ash	M	11,5	– 10	1,2
	Silicon	L	15,0	+ 17	3,1
	LSD (P =9,05)		1,06	–	1,30

Results of pot experiments using soil of the Balgowan series showed that the greatest responses in cane growth were obtained from the addition of wattle ash or lime as shown by the data in Table 3. A heavy application of aluminium salts caused a marked depression in yield and induced severe phosphorus deficiency symptoms. This negative response was more marked in the Balgowan soil series which inherently contains large amounts of exchangeable aluminium.

The main reason for yield improvement following application of either wattle brush ash or lime appears to have been due to a reduction in the amount of exchangeable aluminium, and to the improved utilisation of phosphorus at the higher soil pH values induced by such treatments.

Further investigations on soils from fields under wattle, and from adjoining areas not under wattle, indicated that continued wattle production has an acidifying effect on the soil. This effect, under certain conditions, can raise the exchangeable aluminium index from a level considered to be well below the critical value for sugarcane to levels which are dangerously high. The implication is that growers who plan to establish sugarcane on old wattle lands should anticipate an aluminium toxicity problem.

Nutrient survey

In 1969 a comprehensive nutrient survey was conducted throughout the sugar industry by Meyer (1970). This involved the systematic sampling of soils and third leaf laminae in some 470 sugarcane fields of the coast lowlands, midlands mistbelt, sub-humid midlands and the lowveld. One of the findings from this survey was that a relatively high percentage of the soils in the midland mistbelt physiographic region contained large amounts of exchangeable Al compared with the other regions. As an example, the frequency distributions of the exchangeable Al index (EAI) (Reeve & Sumner, 1970) in soils from the coast lowlands, the lowveld and the midlands are illustrated in Figure 1.

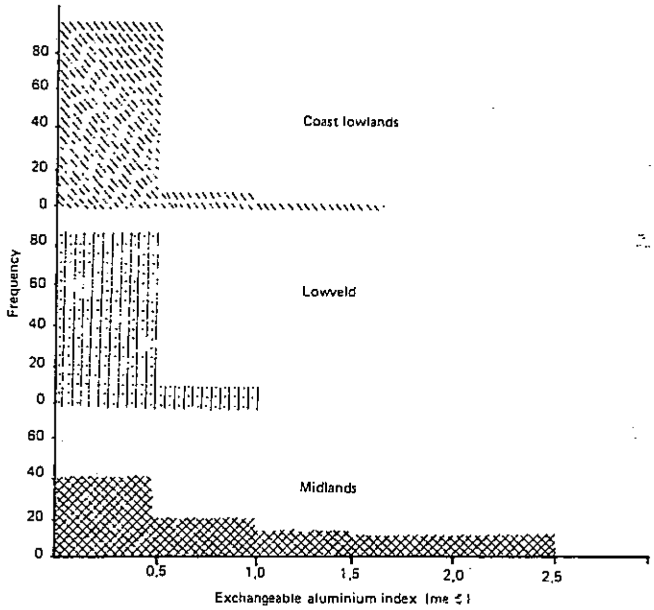

FIG 1 Frequency distribution of EAI in some Natal soils

Pot experiment programme

It has been found to be of great value to test proposed treatments for field experiments by means of glasshouse pot trials before embarking on long-term and expensive field experimentation. Rye grass is commonly used as an indicator plant and the results of the pot experiments are used as a guide in planning field experiments with sugarcane.

One of the pot experiments carried out for this purpose was designed to compare the relative efficiencies of limestone and calcium metasilicate on acid soils from the Natal

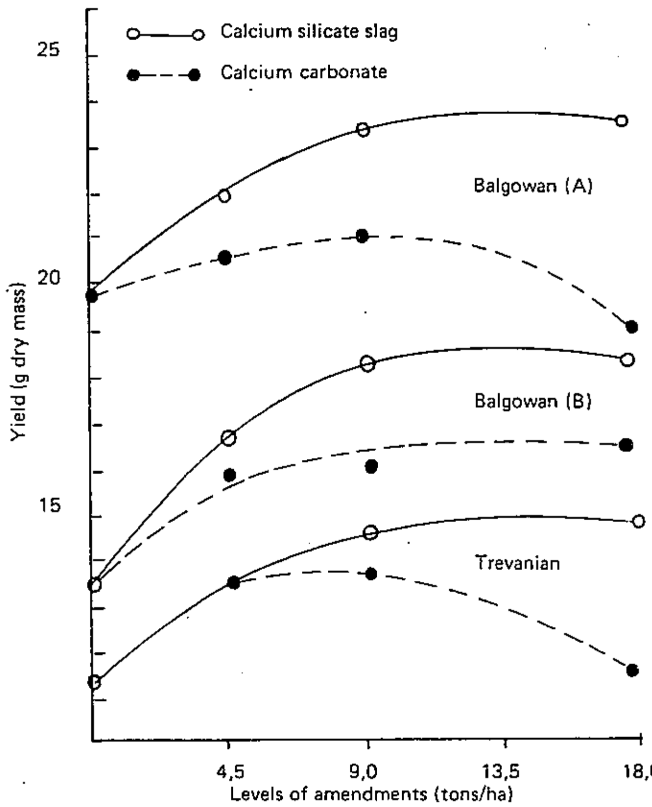

FIG 2 Yield in relation to levels of amendments

TABLE 4 Pot experiment responses to lime expressed as a percentage increase over control

Site No	Locality	Soil form	Clay %	Crop	Pre-treatment soil analysis (0–15 cm) pH H_2O	EAI me %	EAI/100 g clay	% Resp
1	Seven Oaks	Clovelly	71	Sugarcane	4,3	2,4	3,3	7
2	Hilton	Clovelly	63		4,4	2,3	3,6	19*
3	Eston	Cartref	24		4,8	0,9	3,7	18*
4	Mowbray	Griffin	19		4,7	1,5	6,0	59**
5	Darnall	Cartref	6		5,5	0,3	5,0	38**
6	Tongaat	Fernwood	6		5,0	0,4	6,6	33**
7	Bruyns Hill	Hutton	30	Ryegrass	4,6	1,4	4,6	21*
8	Melmoth	Kranskop	26		4,9	0,6	2,3	12
9	U Tongaat	Inanda	22		5,0	0,4	1,8	11
10	U Tongaat	Glenrosa	26		5,1	0,3	1,2	10
11	Glenside	Inanda	36		4,9	0,3	0,8	8
12	Margate	Clansthal	7		5,1	0,2	3,4	6
13	Bruyns Hill	Hutton	26		4,9	0,4	1,6	5
14	Seven Oaks	Clovelly	61		4,5	1,9	3,2	5
15	U Tongaat	Inanda	30		5,2	0,5	1,6	– 3
16	Renishaw	Fernwood	4		5,4	0,1	2,5	– 5
17	Balito	Fernwood	10		6,6	0,1	1,0	– 9
18	Tinley Manor	Fernwood	5		6,0	0,1	1,0	– 12
RANGE				High	6,6	2,4	6,6	59
				Low	4,3	0,1	0,8	– 12

midlands (Du Preez, 1970). Treatments containing silica proved to be superior to calcium carbonate treatments as shown by a comparison of the response curves given in Figure 2.

All treatments caused a substantial reduction in exchangeable Al in the soil. The greater effectiveness of the silica treatments was associated with an increase in the silicon concentration in the plant. In an experiment with levels of superphosphate, the growth response to phosphorus in the presence of limestone was greater than the conventional method of analysis indicated it would be (Meyer, 1974). The marked interaction between the phosphorus and limestone treatments is illustrated graphically in Figure 3.

The maximum response to P was obtained only in the presence of limestone, which eliminates Al toxicity, a primary growth limiting factor.

A number of other experiments with limestone have since been conducted to investigate some growth failure areas in the sugarbelt. A summary of the mean response obtained to limestone in relation to soil texture and various soil acidity parameters such as pH and exchangeable aluminium index values, is given in Table 4.

Responses to lime varied widely from a highly significant response of + 59 per cent in the case of a Griffin soil to a depression in yield of 12 per cent in a Fernwood soil. The significance of the relationship between yield response and the various soil parameters will be considered later in the discussion.

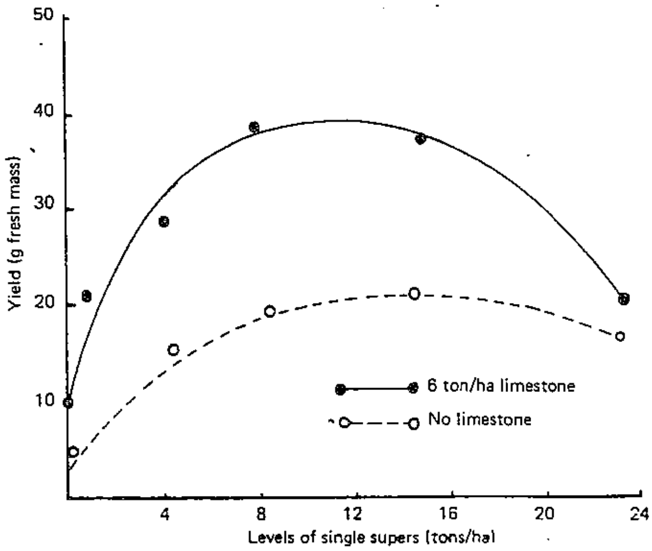

FIG 3 Yield in relation to levels of superphosphate and limestone

Field experiments

A number of field experiments were established, mainly in the new areas of the industry. Results of some of these experiments have been reported by Moberly (1974) and additional results have since become available.

Method and design

In most of the experiments the ameliorants were applied to the plots only a matter of days prior to planting. The plots were generally 12–14 m long and 8–10 m wide. Each plot therefore comprised at least six cane rows, including a minimum of two 'discard' rows.

Two metres of 'end effect' were removed from the end of each cane row prior to harvesting the net plots. The field layouts were generally randomised block or split-plot designs with six replications.

To ensure reasonably uniform application of ameliorants, each treated plot was subdivided into six approximately equal parts and a measured quantity of material was broadcast over each sub-division. With the exception of two sites where ameliorants were ploughed down to depth, disc harrows or rotary hoes were used to incorporate ameliorants to depths of 10–25 cm.

Materials

Apart from dolomitic and agricultural lime, other materials such as Slagsil, Hulsar lime, Amcor slag and Hawaiian calcium metasilicate were used in a umber of experiments. The chemical analyses of some of these materials and brief comments are given below:

(i) Amcor slag contained SiO_2 37%, Al_2O_3 18%, CaO 20%, MgO 20%. It is a coarse, steel furnace residue from Amcor, Newcastle.

(ii) Calcium metasilicate contained SiO_2 49%, Al_2O_3 2%, CaO 44%. It is a fine by-product of the cement industry, imported from Hawaii.

(iii) Slagsil contained SiO_2 35%, Al_2O_3 + Fe_2O_3 15%, CaO 41%. It is a fine material from the Slagment Co., believed to originate from Amcor.

(iv) Hulsar lime contained SiO_2 1,4%, $CaCO_3$ 82%, MgO 1,2%. It is a fine material from the Huletts Refinery and is known as 'filter cake'.

Agricultural lime, the lowest analysis of which contained 46% $CaCO_3$ and the highest 82% $CaCO_3$, with varying quantities of MgO.

Sugarcane yield responses

The yield responses obtained to agricultural limestone applied at various levels in eleven field experiments are shown in Table 5 together with some relevant soil analyses. The responses are expressed as the percentage increase in tc/ha over the yield obtained in the unameliorated control treatment.

TABLE 5 The percentage increase in tons cane per hectare due to the application of agricultural lime in various field experiments

Site No	Locality	Soil form	Pre-treatment soil analysis (0–25 cm)				% change in yield		
			pH water	Ca ppm	EAI meq %	% Clay	Plant	1st ratoon	2nd ratoon
1	Townhill	Clovelly	4,8	104	2,15	53	+27**	+18**	+29**
2	Melmoth	Kranskop	5,7	225	0,19	63	+25**	+19*	+22*
3	Mowbray	Griffin	4,6	10	2,60	19	+26**	–	–
4	Mtunzini	Kroonstad	5,6	429	–	16	+14*	+ 5	Nil
5	Seven Oaks	Clovelly	4,2	120	2,57	61	+ 6	–	–
6	Seven Oaks	Clovelly	4,6	270	1,93	45	+ 4	– 5	–
7	Upper Tongaat	Inanda	5,3	295	0,17	30	+ 5	–	–
8	Eston	Inanda	4,7	130	0,66	35	+ 1	–16*	–
9	Upper Tongaat	Inanda	4,8	360	0,33	22	Nil	–	–
10	Umbumbulu	Inanda	5,5	435	0,75	23	Nil	Nil	Nil
11	Upper Tongaat	Glenrosa	4,6	249	0,30	26	Nil	– 5	– 4

** Statistically significant, $P < 0{,}01$

* Statistically significant, $P < 0{,}05$

In general, the response to ameliorants is seen to be greater where the exchangeable Al index (EAI) is high. There are, however, obvious exceptions where the predictions of a response to lime were not consistent with the levels of exchangeable Al, pH and exchangeable Ca criteria (ie pH less than 4,7, Ca less than 150 ppm).

(i) *Unpredicted positive responses*

In the first example the Kranskop series soil had recently been ploughed out of sour grassveld and the unpredicted response to lime could have been partially due to the acceleration in break-down of the veld grass, and to the effect of lime on the availability of phosphorus and nitrogen to the crop. In the virgin state the P status of the soil was only 2 ppm. To some extent this hypothesis is corroborated by the response obtained to lime in the presence of three different levels of nitrogen applied to the first ratoon crop. The levels used were 0, 66 and 132 kg N/ha, and the responses to lime in tons cane/hectare were respectively 12, 18 and 5 (SE ± 6,0). The results indicate that the response to lime on the Kroonstad series soil could also have been attributed, at least in part, to the effect of lime on nitrogen availability.

In the second example the large, unpredicted and short-term response to lime on the Kroonstad series soil is also attributed, in part, to the effect of lime on nutrient availability. Two levels of agricultural lime were used, 4,5 and 9 t/ha, with three levels of an NPK fertilizer mixture, viz nil, medium and high. The response to lime in the plant crop was greatest at the low and medium levels of fertilizer, and negligible at the high level. In the first ratoon crop the residual effect of lime was recorded only at the zero level of NPK fertilizer. This effect is illustrated diagrammatically in Figure 4.

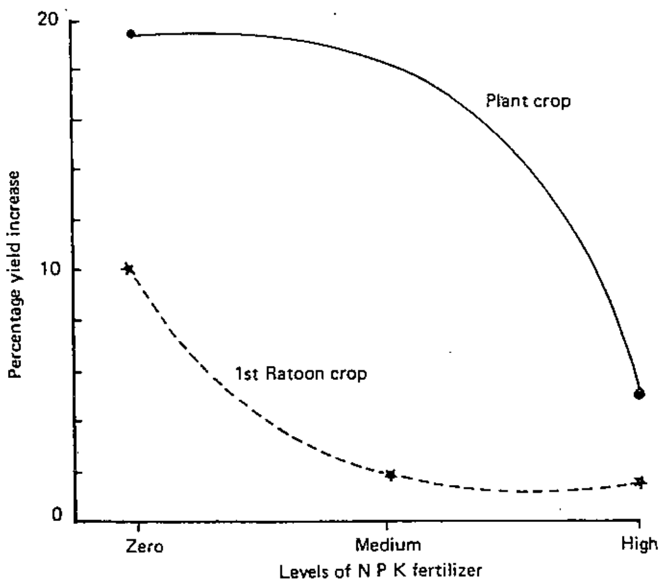

FIG 4 Response to lime as ± increase over unlimed control on a Kroonstad series soil

(ii) *Unpredicted negative response*

The yield depression (P > 0,05) measured in the first ratoon crop at site 8 on the Inanda series soil is cause for concern, as the two criteria for lime recommendations used in the past, ie pH and exchangeable Ca, are both marginal. Hence a slight response might have been expected, but the yield depression is difficult to explain. Rather limited third leaf analytical data indicate that a lime-induced zinc deficiency could have contributed to the yield depression. At three months of age, the mean Zn dry matter content of third leaf laminae samples from the limed and unlimed plots were respectively 14,8 and 13,2 (14 ppm is taken on the threshold value for 2 m). This antagonistic effect of lime on zinc uptake by the plant has been clearly demonstrated again in the recent experiments at sites 7 and 8 on the Inanda series soil, where zinc, applied @ 50 kg of zinc fertilizer material per hectare, was required to obviate a zinc deficiency where lime had been applied. These results are presented in Table 6.

TABLE 6 Zinc ppm in third leaf samples from cane on an Inanda series soil

	Site 7		Site 8	
Treatment	No zinc	Zinc	No zinc	Zinc
No lime	14,2	16,2	15,5	19,4
Lime	11,4	14,2	13,6	19,8

Effect of ameliorants on harvested crop characteristics

Where a yield response is obtained this is manifested in an increased stalk population and longer and heavier stalks. Varieties tend to respond in a similar manner.

Varietal sensitivity to soil amelioration

The imported Brazilian variety CB36/14 and the Natal variety NCo 376 were included in the recent experiments at sites 3 and 6. Results from the plant crops indicate that CB36/14 is slightly more sensitive than is NCo 376 to soil amelioration. These results are shown in Table 7.

TABLE 7 Varietal response to lime and slagsil as % increase over unlimed control on Griffin and Clovelly series soils

	Variety	Lime	Slagsil	Mean
Site 3	NCo 376	− 6	+ 2	− 2
	CB36/14	+ 9	+ 16	+ 13
Site 6	NCo 376	+ 13	−	+ 13
	CB36/14	+ 17	−	+ 17

The effect of ameliorants on sugarcane quality

The effects of soil ameliorants on estimated recoverable sugar (ers %) are inconsistent, but in general there is a slight depression. It is usual for an increase in tons cane/ha to be associated with a slight decline in ers per cent cane in respect of many treatments, but particularly in the case of nitrogenous fertilizer treatments. Although in some instances there has been no measurable effect, the situation here is confused because ers per cent cane has been reduced when the effect of treatment on tc/ha has been either positive or negative. In the first ratoon crop on the Inanda series soil at site 8, where lime depressed yield in terms of tc/ha, the ers per cent cane for 0, 4,5 and 9 t lime/ha was respectively 10,1 per cent, 9,7 per cent and 8,6 per cent. At site 3 on the Griffin series soil, where a statistically significant response to lime in tc/ha was measured, the ers per cent cane declined on average from 12,7 per cent to 11,5 per cent. Liming, in this instance, had increased considerably the nitrogen status of the crop as measured by the third leaf N content, which was 2,21 per cent and 2,53 per cent dry matter for the control and limed treatments respectively.

Lime x phosphorus interaction

The effect on sugarcane growth of ameliorants in the presence of moderate and high levels of single superphosphate (8,3 per cent P) have recently been tested on soils with high phosphate fixing characteristics. At site 3 on the Griffin series soil, where the phosphorus desorption index (PDI) was 0,26 and Truog P was 8 ppm, the response to 6,6 t/ha lime was measured in the presence of 0, 2,25, 4,50 and 6,75 t single superphosphate per hectare broadcast and disced into the soil prior to planting. In addition, all treatments received 0,6 t superphosphate per hectare in the planting furrow. Results of the plant crop are illustrated graphically in Figure 5.

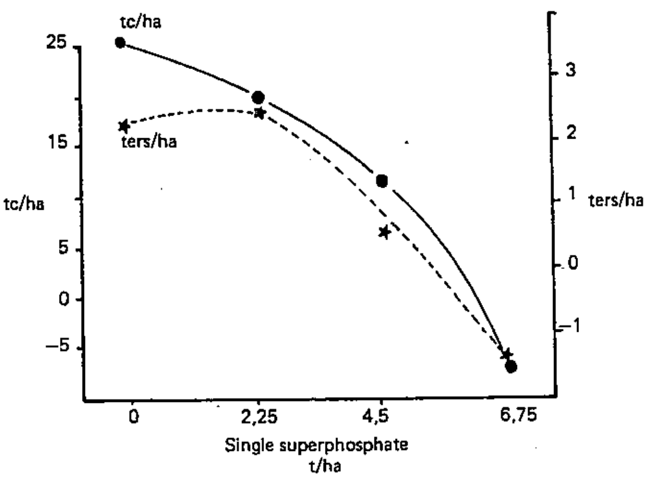

FIG 5 The response to lime in the presence of high levels of superphosphate

It is clear that the response to lime is greatest at the zero level of superphosphate for tc/ha, and at the 2,25 t/ha level in terms of t ers/ha. Superphosphate, at high levels will itself ameliorate the problem by precipitating toxic levels of aluminium.

A comparison of soil ameliorants

A number of different soil ameliorants were included in the three experiments on soils of the Clovelly form, and the comparative effectiveness of these materials is given in Tables 8 and 9.

Hulsar lime is clearly as effective as the commercially available agricultural lime, and both these materials were markedly superior to the Amcor slag. The slag was a coarse material and its relative ineffectiveness is therefore not surprising. The imported Hawaiian metasilicate material was as effective as the locally produced slagsil. Of particular interest is the comparison between lime and the silicate materials in the two Seven Oaks experiments on the Clovelly soil. In the one case, where the ameliorants were both applied to a depth of approximately 65 cm, Slagsil increased yield significantly (P > 0,01), whilst the response to lime did not attain a level of statistical significance. The superiority of Slagsil over lime was approximately 11 per cent. In the second experiment where the ameliorants were applied to a conventional depth of about 25 cm, responses were small but the trend was again in favour of Slagsil by approximately 5 per cent. There is no evidence of the siliceous materials being more active than limestone as a soil ameliorant, so there is some likelihood that Si was beneficial as a nutrient.

Methods of incorporating ameliorants

A disc harrow and rotary hoe were compared on a sandy loam soil to assess their effectiveness in incorporating lime. Subsequent soil sampling revealed that the rotary

TABLE 8 Effectiveness of various soil ameliorants — tc/ha : Clovelly

Crop stage	Control	Hulsar lime	Dolomitic lime	Amcor slag	SE treatment mean
Plant	78	101	104	96	± 4,23
1st Ratoon	67	82	82	78	± 3,48
2nd Ratoon	51	74	75	66	± 4,99

TABLE 9 Effectiveness of different ameliorants — tc/ha : Clovelly

	Control	Agric lime @ 5,6 t/ha	Hawaiian silicate @ 5,6 t/ha	Hawaiian silicate @ 11 t/ha	Slagsil @ 11 t/ha
Plant crop	91	95	98*	103*	102*

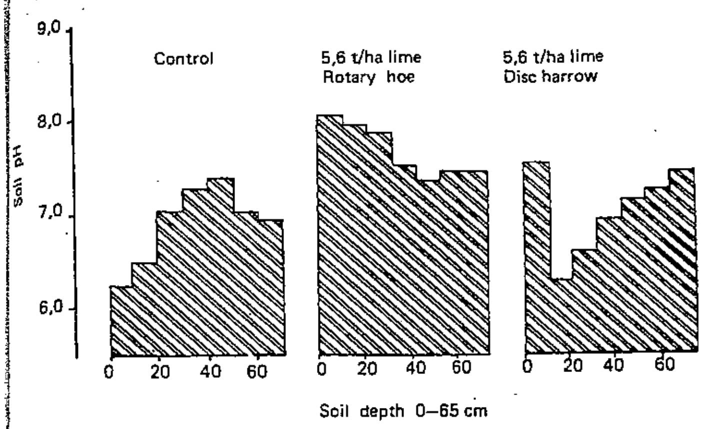

FIG 6 Methods of lime incorporation

hoe incorporated the lime more efficiently than did the disc harrow (Figure 6).

Deep application of lime

If the root development of a crop is restricted by the presence of toxic levels of aluminium in some soils, it would be reasonable to assume that the crop would benefit from deep amelioration of the soil profile, particularly in a dry season. This hypothesis was tested in the experiment on the Griffin soil. To incorporate lime to depth the following procedure was followed: half the required amount of lime was broadcast, mixed in with a rotary hoe and then the area was ploughed with a large trailed mouldboard plough to a depth of about 65 cm. The remainder of the lime was then applied, and the same operations were then repeated. This deep liming treatment was compared with conventional liming to a depth of 25 cm, deep ploughing twice to approximately 65 cm depth without lime, and conventional ploughing to about 25 cm depth without lime. The results of the plant crop are given in Table 10.

In a year of average rainfall the marked response was the same whether it was applied deep or shallow. It is noteworthy that this is one of the few soils where a response to deep ploughing has been recorded. The treatment effects will be followed through successive ratoon crops.

TABLE 10 Response to deep versus conventional lime application – tc/ha : Griffin

Conv plough	Conv plough + lime	Deep plough	Deep plough + lime
86	111	98	124

Percentage response to lime:

Conventional	29
Deep	27

The effects of ameliorants on some soil chemical properties

The long-term effects of liming on Inanda series soil are illustrated graphically in Figures 7 and 8. Although the variability of the soil pH is considerable, the trend is for a very slow decline in soil pH after treatment with lime, while the exchangeable Ca tends to remain static.

The extent to which soils can be ameliorated to depth by means of conventional equipment is illustrated in terms of soil analyses in Figures 9 and 10. The lack of movement of lime through the soil profile over a period of 12 years is shown in Figure 11.

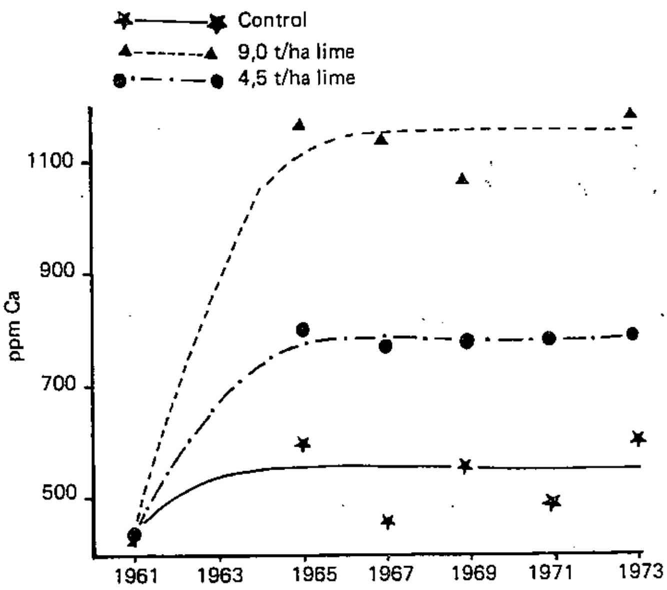

FIG 7 The long-term effects of lime on exchangeable Ca in an Inanda series soil

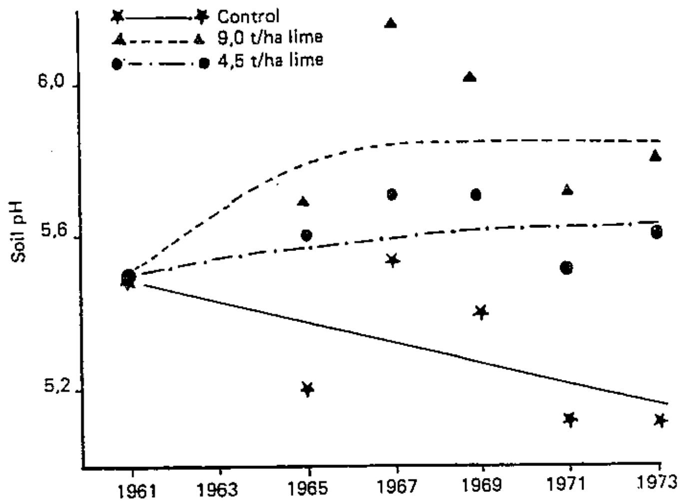

FIG 8 The long-term effects of lime on soil pH in an Inanda series soil

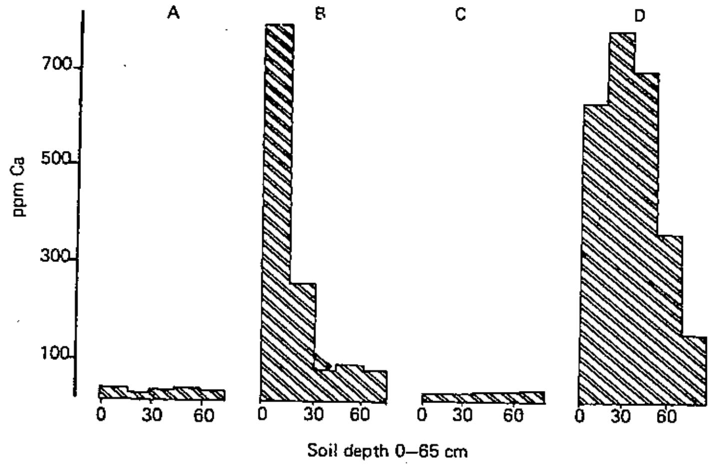

FIG 9 Exchangeable Ca (ppm) after deep amelioration : Griffin

A: No lime Conv plough C: No lime Deep plough
B: 6,6 t/ha lime Conv plough D: 20 t/ha lime Deep plough

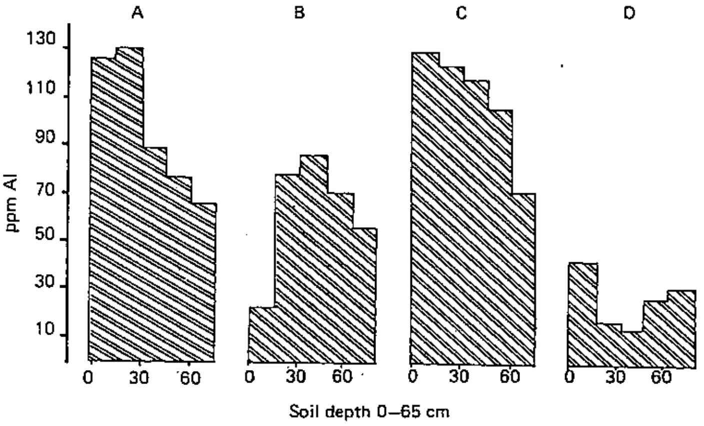

FIG 10 Exchangeable Al (ppm) after deep amelioration: Griffin

A: No lime Conv plough C: No lime Deep plough
B: 6,6 t/ha lime Conv plough D: 20 t/ha lime Deep plough

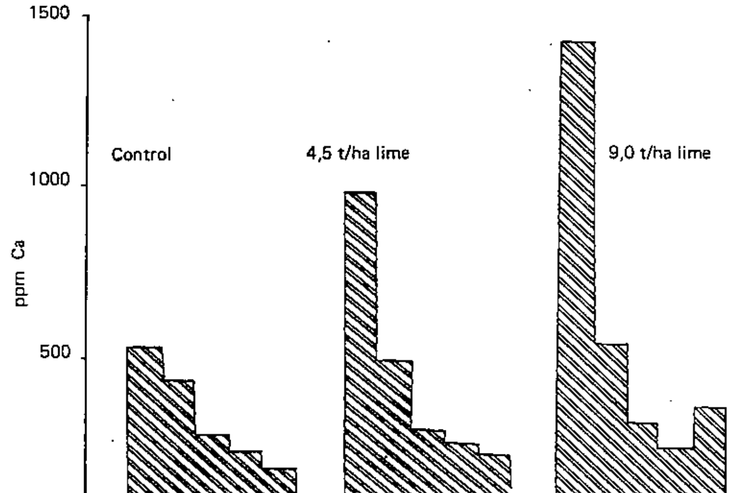

FIG 11 Movement of lime through soil profile in an Inanda series of soil, 1961 to 1971

Discussion

The development of suitable criteria for lime recommendations

An assessment of the pot and field experiment data shows that significant responses were obtained to limestone in six of the 18 pot experiments and in four of the eleven field experiments involving plant crops. Regression analysis of the responses to limestone and the main traditional criteria such as pH, exchangeable Ca and Mg indicated no significant trend. Likewise an interpretation of the data in terms of the exchangeable Al index values alone was not always consistent with the responses obtained to lime. For example, referring back to the pot experiment data in Table 4, responses to limestone occurred at both high and low values of EAI (compare the data from sites 2, 4 and 7 with those from sites 3, 5 and 6). Even where EAI levels were high (for example in soils from sites 1 and 14) no responses to limestone were measured. This inconsistent trend is corroborated to a large extent by the field experiment data shown in Table 5.

It has been shown by Evans (1975) and his associates and subsequently by Ayres (1965) that for sugarcane, expressing exchangeable Al levels in terms of the cation exchange capacity is a more reliable criterion to use than an interpretation based on exchangeable Al alone. This contention is supported by recent investigations by Meyer (1974) in respect of the determination of limestone and P requirements in some midlands soils. It was shown that by expressing the EAI value as a per cent of CEC measured at field pH (referred to as exchangeable aluminium per cent, or EAP), the response to limestone could reliably be predicted whenever the EAP value was in excess of 15. In the present investigation the merits of this criterion for advisory purposes could not be fully tested owing to the lack of adequate CEC data. However, an examination of the yield response data and associated EAI values, expressed on the basis of 100 g of clay, indicated a positive relationship between these two parameters as shown in Figure 12.

It is seen that responses in excess of 10 per cent are invariably associated with EAI/clay ratio values in excess of 3,5. By interpreting the experimental data in this way and by using a tentative ratio value of 3,5, it is possible to account for many of the anomalous results mentioned previously.

For example, the negative responses to limestone in the two heavy-textured, high-EAI soils from the Seven Oaks sites were found to have an EAI: clay ratio of below 3,5, indicating that a response to limestone was unlikely. Similarly, in the case of the two sandy soils (sites 5 and 6, Table 4) the positive response to limestone can be correctly predicted since the EAI: clay ratio values are well above the 3,5 threshold.

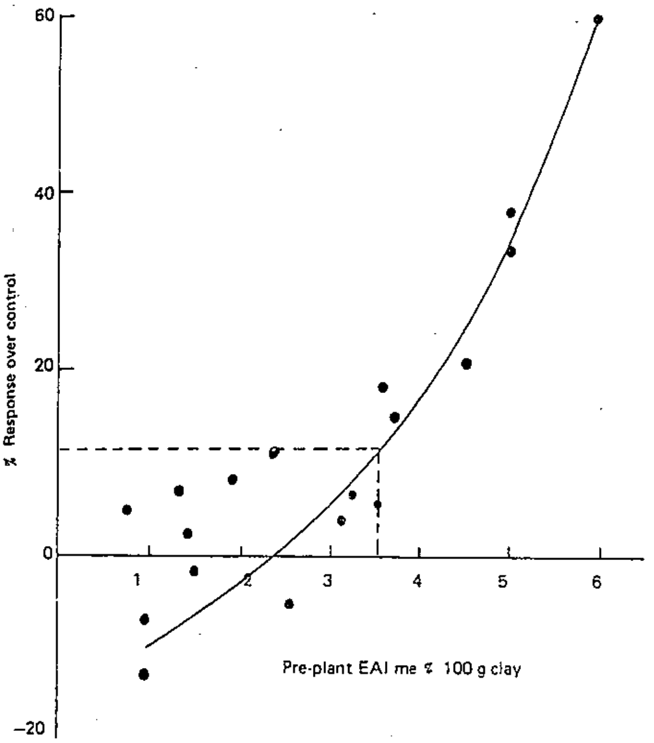

FIG 12 Yield response to limestone in relation to EAl/ 100g clay

As sugarcane is more tolerant of acid conditions than is rye grass it is possible that the tentative threshold value of 3,5 is too low.

This is confirmed by the fact that responses which are statistically non-significant, were obtained at sites with the ratios bordering on 4. For sugarcane, a value of 4 may be preferred and this has therefore been used as a basis for determining lime requirement.

Lime requirement calibration

In developing a suitable soil-testing programme, it is important not only to predict when a response to limestone is likely, but also to know the quantity needed to correct potential aluminium toxicity. On theoretical considerations and experimental evidence, it has been shown by Reeve & Sumner (1970) that, on average, 3 tons/ha limestone are needed to neutralise the effects of 1 ml per cent of exchangeable Al index. With only a few exceptions, this suggested rate of application is in good agreement with the rates at which optimum yields were obtained in the series of pot experiments described in this paper.

Table 11 shows the average limestone requirements for the three main soil textural classes, based on three different criteria: (1) the level of limestone coinciding with the optimum yield response, (2) the level of limestone required to neutralise a given concentration of exchangeable aluminium, and (3) the level required to raise soil pH values to 6,5.

TABLE 11 Lime requirement of soils based on different criteria (tons $CaCO_3$/ha)

Textural class (% clay)	Criteria: Average maximum yield	Average EAl	Average SMP
· 35%	6	6,6	17
15–35%	4	3,7	16
< 15%	1,5	1,3	6

In general, there is good agreement between the first two criteria, but the requirements based on the SMP buffer method are comparatively very high, and in some instances these levels actually caused yield depressions in the experiments.

The above information obtained on EAl:clay ratios and limestone/EAl relationships was used to compile a framework for routine and advisory purposes, and part of this has been reproduced in Table 12.

Safety margins in the vicinity of the threshold values have been built into the system in order to allow for unforeseen contingencies. This applies mainly to cases with EAl/ clay ratios lying between 3 and 4, where the possibility exists that the response to limestone will be small.

Supplementary levels of limestone are also recommended in the event of calcium (< 150 ppm) or magnesium deficiency (< 25 ppm) in soils.

TABLE 12 Basis of determining lime requirements in soils with pH values less than 5,2

TEXTURE		Less than 15% clay			15–35% clay			Greater than 35% clay			
Exchangeable aluminium index	meq %	Less 0,3	0,9	Over 1,2	Less 0,6	1,8	Over 2,4	Less 1,1	1,7	2,3	Over 2,9
Pure limestone (tons/ha/15cm)		Nil	2	4	Nil	3	7	Nil	2	4	8
Agricultural/dolomitic limestone		Nil	3	6	Nil	5	9	Nil	5	7	11

TABLE 13 Lime requirement in relation to soil calcium

Soil	ppm	> 150	100	50	< 50
calcium	kg/ha	> 350	225	110	< 110
Ca (needed)	kg/ha	Nil	125	240	350
Agricultural lime	t/ha	Nil	0,75	1–2	2–3
Dolomitic lime	t/ha	Nil	1	2	3
Gypsum	t/ha	Nil	0,6	1,2	1,8

The procedure used for example in correcting calcium deficiency is shown in Table 13.

Conclusions

The results obtained indicate the need for modification to the criteria used in determining the limestone requirement of sugarcane. The use of the value EAl/100 g clay, in addition to exchangeable Ca and Mg will improve predictions. When using Ryegrass, the responses obtained to amelioration indicate that the EAl/100 g clay threshold value is approximately 3,5, but for the more tolerant sugarcane crop a tentative figure of 4,0 is suggested. Third leaf nutrient analysis is currently considered of little value as a guide to problems of soil acidity.

In soils with high P fixation characteristics, the optimum level of superphosphate required can be reduced by limestone application. Where the level of zinc is inherently marginal, the application of limestone is likely to induce a zinc deficiency in sugarcane.

In both pot and field experiments amelioration with siliceous materials has, in some instances, resulted in higher yield than in the case of limestone amelioration. The differences in efficiency between these two materials can be considerable but the reasons for the differences are not fully understood.

The rather limited data that are available indicate that melioration of acid soil to depths greater than the conventional 20–25 cm, is not warranted, but the investigation continues.

The indications are that substantial areas in the midlands will benefit from amelioration with limestone particularly in areas formerly under wattle. Certain soils in the coastal areas of the sugar belt may also benefit from liming particularly where calcium and magnesium are needed as nutrients.

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