# MODIFYING LIME REQUIREMENT FOR SANDY, TO SANDY CLAY LOAM SOILS IN THE NATAL MIDLANDS

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## Abstract

Data from a number of field and pot trials established on humic sandy to sandy clay loams (15-35% clay) indicated non-significant responses to applied lime, despite exchangeable aluminium index (EAI) values well above the accepted threshold value of 54 ppm Al. The use of the Al:S soil ratio was investigated as a means of modifying lime requirement as the sulphate ion is thought to participate in the complexing of aluminium, and organic matter is known to release considerable amounts of sulphur by mineralisation. An Al:S ratio of 2 is proposed as the threshold above which a response to lime is likely. Modified lime recommendations for humic and sulphate-rich sandy loam/sandy clay loam soils are suggested.


## Introduction

Recommendations made by the Fertilizer Advisory Service (FAS) of the SA Sugar Association Experiment Station for lime application at planting, are based on the exchangeable aluminium index (EAI) and texture. Following investigations by Meyer (1974) and Moberly and Meyer (1975) it was recognised that a positive relationship existed between yield response data and EAI values expressed on the basis of 100 g of clay. Lime recommendations have since been made for soils with pH values less than 5,3 according to EAI threshold values (Table 1), which were established for each of three soil textural categories (less than 15% clay, 15-35% clay and greater than 35% clay).

**Table 1**

**Lime recommendations based on EAI values (after Moberly and Meyer, 1975)**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| EAI | meq% | <0,3 | 0,6 | 0,9 | 1,2 | >1,2 | |
| | ppm | <27 | 54 | 81 | 108 | >108 | |
| Pure lime | | Nil | 1,5 | 2,5 | 3,5 | 4,0 | <15% clay |
| Calcitic/dolomitic limestone (t/ha) | | Nil | 3 | 5 | 7 | 8 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| EAI | meq% | <0,6 | 0,9 | 1,2 | 1,5 | 1,8 | 2,1 | >2,1 | |
| | ppm | <54 | 81 | 108 | 135 | 162 | 189 | >189 | |
| Pure lime | | Nil | 1,5 | 2,5 | 3,5 | 4,5 | 5,5 | 7,0 | 15-35% clay |
| Calcitic/dolomitic limestone (t/ha) | | Nil | 3 | 5 | 7 | 8 | 11 | 14 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| EAI | meq% | <0,9 | 1,2 | 1,4 | 1,7 | 2,0 | 2,3 | >2,3 | |
| | ppm | <81 | 108 | 127 | 154 | 181 | 208 | >208 | |
| Pure lime | | Nil | 1,5 | 2,5 | 3,5 | 4,5 | 5,5 | 7,0 | >35% clay |
| Calcitic/dolomitic limestone (t/ha) | | Nil | 3 | 5 | 7 | 8 | 11 | 14 | |

The detrimental effects of toxic levels of exchangeable aluminium on plant growth are well documented for sugarcane and other crops grown in Natal (Sumner, 1970; Sumner and Meyer, 1971; Meyer and Wood, 1976; Mendes *et al.*, 1984; Noble, *et al.*, 1986). Much attention has been given to amelioration of toxic aluminium levels with various materials such as dolomitic lime, silicate slag and gypsum/phosphogypsum (Reeve and Sumner, 1970; Moberly, 1974; Moberly and Meyer, 1975; Buyeye *et al.*, 1985; Fey, 1986; Sumner *et al.*, 1986; Farina and Channon, 1988; Meyer *et al.*, 1991). Investigations of possible mechanisms involved in the chemical reactions following gypsum application to soil, were prompted after substantial yield responses to surface applied gypsum were reported for crops such as maize and soya beans (Hammel *et al.*, 1985; Noble *et al.*, 1986; Alva and Sumner, 1989; Shainberg *et al.*, 1989). To date no significant responses to gypsum have been obtained in sugarcane (Meyer, *et al.*, 1991). The suggested mechanisms involved in the detoxification of Al (Sumner, 1990) are nonetheless considered important, particularly as they might explain anomalous situations where cane does not respond to lime. The mechanisms indicate that Al is probably detoxified by gypsum due to adsorption and/or precipitation reactions involving the sulphate anion ($SO_4^{2-}$). Despite this, it appears that the concentration of $SO_4^{2-}$ in soil has not yet been used as an index for determining or adjusting lime requirement. It is thought that a parameter such as the Al:S soil ratio might be useful in this regard. Also, it is not unrealistic to hypothesise that other sources of 'free' sulphate ions originating from fertiliser applications and/or mineralisation of soil organic matter may help to reduce the toxic effect of exchangeable aluminium.

The objectives of the investigation were to:

(i) Evaluate the Al:S soil ratio as a means of predicting a yield response to applied lime on sandy to sandy clay loams (15-35% clay) containing appreciable amounts of organic matter and/or sulphate

(ii) Propose modified lime requirements for such soils.

## Procedure

The data obtained were from a number of field and pot trials originally established to investigate the effectiveness of lime or gypsum as ameliorants for toxic levels of exchangeable aluminium. The localities of the field trials and/or sites of bulk soil samples collected for the pot trials were all in the Natal midlands. Selection was based on soil EAI values generally in excess of the accepted threshold (Table 2). Although clay percentage values covered the range 15 to 70% clay, most soils were in the category 15-35% clay, i.e. sandy to sandy clay loams.

Indicator crops were either sugarcane or forage sorghum (babala) and fertiliser applications (N, P and K) were made according to FAS recommendations. Representative soil samples from the field and pot trials were taken before and

**Table 2**

**EAI and pH values of soils (0–200 mm depth) used in field and pot trials**

| Site No. | Locality | Soil form | Clay (%) | pH | EAI (ppm) | EAI TV (ppm) | Trial |
|---|---|---|---|---|---|---|---|
| 1 | Summerhill | Hutton | 46 | 4,50 | 400 | 81 | Glasshouse |
| 2 | Eston | Inanda | 29 | 4,60 | 120 | 54 | Glasshouse |
| 3 | Richmond | Nomanci | 27 | 4,90 | 62 | 54 | Glasshouse |
| 4 | Paddock | Glenrosa | 16 | 5,00 | 74 | 27 | Glasshouse |
| 5 | Paddock | Glenrosa | 15 | 5,20 | 45 | 27 | Glasshouse |
| 6 | Seven Oaks | Kranskop | 27 | 4,50 | 46 | 54 | Field |
| 7 | Eston | Nomanci | 49 | 4,95 | 113 | 81 | Field |
| 8 | Eston | Inanda | 28 | 4,75 | 120 | 54 | Field |
| 9 | Dalton | Hutton | 70 | 4,55 | 72 | 81 | Field |
| 10 | Townhill | Clovelly | 53 | 4,80 | 194 | 81 | Field |
| 11 | Mowbray | Griffin | 19 | 4,60 | 234 | 54 | Field |
| 12 | Eston | Inanda | 35 | 4,70 | 60 | 54 | Field |
| 13 | Townhill | Clovelly | 63 | 4,40 | 207 | 81 | Glasshouse |
| 14 | Eston | Cartref | 24 | 4,80 | 81 | 54 | Glasshouse |
| 15 | Mowbray | Griffin | 19 | 4,70 | 135 | 54 | Glasshouse |

**Table 3**

**Calculated indices and relative yield responses obtained to lime/gypsum applications**

| Site No. | Soil form | Clay % | EAI (ppm) | EAI (meq%) | S (ppm) | EAI/Clay (ppm/%) | Al:S ratio | % Response | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Lime | Gypsum |
| 1 | Hutton | 46 | 400 | 4,44 | 90 | 8,70 | 4,44 | 46 | 50 |
| 2 | Inanda | 29 | 120 | 1,33 | 49 | 4,14 | 2,45 | 21 | 36 |
| 3 | Nomanci | 27 | 62 | 0,69 | 20 | 2,30 | 3,10 | — | 56 |
| 4 | Glenrosa | 16 | 74 | 0,82 | 20 | 4,63 | 3,70 | 25 | 19 |
| 5 | Glenrosa | 15 | 45 | 0,50 | 24 | 3,00 | 1,88 | 27 | 30 |
| 6 | Kranskop | 27 | 46 | 0,51 | 54 | 1,70 | 0,85 | 0 | 0 |
| 7 | Nomanci | 49 | 113 | 1,26 | 99 | 2,31 | 1,14 | 0 | −2 |
| 8 | Inanda | 28 | 120 | 1,33 | 55 | 4,29 | 2,18 | 4 | 8 |
| 9 | Hutton | 70 | 72 | 0,80 | 105 | 1,03 | 0,69 | −2 | 7 |
| 10 | Clovelly | 53 | 194 | 2,16 | 113 | 3,66 | 1,72 | 27 | — |
| 11 | Griffin | 19 | 234 | 2,60 | 48 | 12,32 | 4,88 | 26 | — |
| 12 | Inanda | 35 | 60 | 0,67 | 27 | 1,71 | 2,22 | 1 | — |
| 13 | Clovelly | 63 | 207 | 2,30 | 113 | 3,29 | 1,83 | 19 | — |
| 14 | Cartref | 24 | 81 | 0,90 | 27 | 3,38 | 3,00 | 18 | — |
| 15 | Griffin | 19 | 135 | 1,50 | 48 | 7,11 | 2,81 | 59 | — |

after treatment applications. These included subsoil samples at 200 mm intervals to a depth of 800 mm from the field trials taken six months and one year after treatment. Prior to chemical analysis, soils were dried at 50°C and ground to pass a 2 mm screen. The pH values were determined in a 2:1 water to soil slurry, and exchangeable aluminium indices and sulphur values, as sulphate, were obtained respectively after extraction with *0,2N* $NH_4Cl$ (Meyer, 1970) and 0,5N ammonium acetate (Bardsley and Lancaster, 1960). Al:S ratios were calculated using EAI and S values expressed as $\mu/g$ soil (ppm) together with EAI/clay values for each soil (Table 3). The organic matter contents of selected soils were determined using the method of Walkley and Black (1934). Yield response either to lime or gypsum was expressed as the percentage increase in dry matter production over the yield obtained in the control treatment (no lime or gypsum amelioration).

## Results

Yield data from the various field and pot trials (Table 3) indicated that significant responses to applied lime or gypsum did not always occur, despite EAI values above the accepted threshold values based on soil textures of 27, 54 and 81 ppm (Table 1). The regression of percentage yield response against EAI values resulted in a correlation coefficient (r) of only 0,48. However, use of the other calculated indices, namely EAI:clay and Al:S ratios resulted in somewhat better correlation coefficients (r) of 0,58 and 0,70 respectively. This implied that the use of the Al:S ratio in addition to extractable Al, as an index for determining lime requirement, would be substantially better than only the EAI value. Relative yield response to lime or gypsum, plotted as a function of the Al:S ratio, indicated that the incidence of significant and non-significant responses could generally be separated by an Al:S ratio of 2, which corresponded to a relative yield response of 20% (Figure 1).

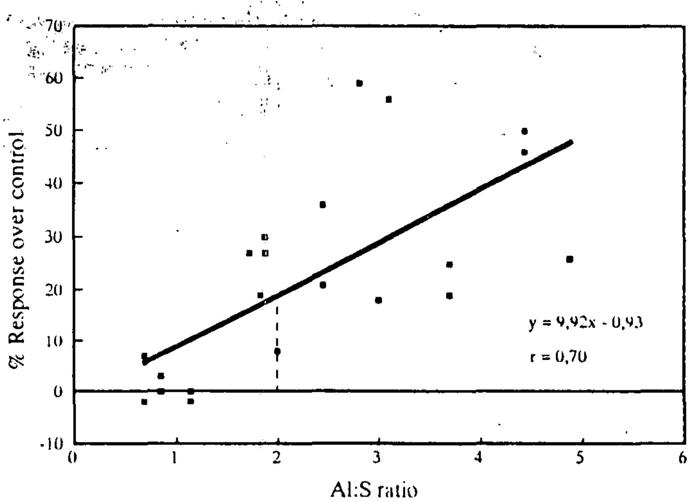


**FIGURE 1** Regression of relative yield to lime and/or gypsum vs A1:S ratio.

EAI and S values together with Al:S ratios from a number of the lime/gypsum field trials on Inanda form soils plotted as a function of depth, indicated that no response to lime or gypsum occurred despite initially high exchangeable aluminium values. For example, in a trial conducted at Eston (Site 8 in Tables 1 and 2), the EAI value was initially 120 ppm and sulphate was present at 55 ppm (Figure 2). The relatively high concentration of sulphate ions apparently contributed to the detoxification of aluminium. The 4 and 8% yield responses in this trial (Table 3) which were recorded after amelioration with seven tons of lime per hectare, and a combination of seven tons of lime and five tons of gypsum per hectare respectively, were consistent with the marginal conditions indicated by an Al:S ratio of 2,18. By contrast, in the pot trial conducted on a Hutton form soil (400 ppm Al, 90 ppm S and an Al:S ratio of 4,44) there were relative responses of 46% and 50% respectively to nine tons of lime and six tons of gypsum per hectare. The Al:S ratio declined to below 2 in both cases. Thus it appeared that soils containing relatively large amounts of sulphur in the form of sulphate ions, were less likely to show a response to applied lime despite EAI values above the accepted threshold.

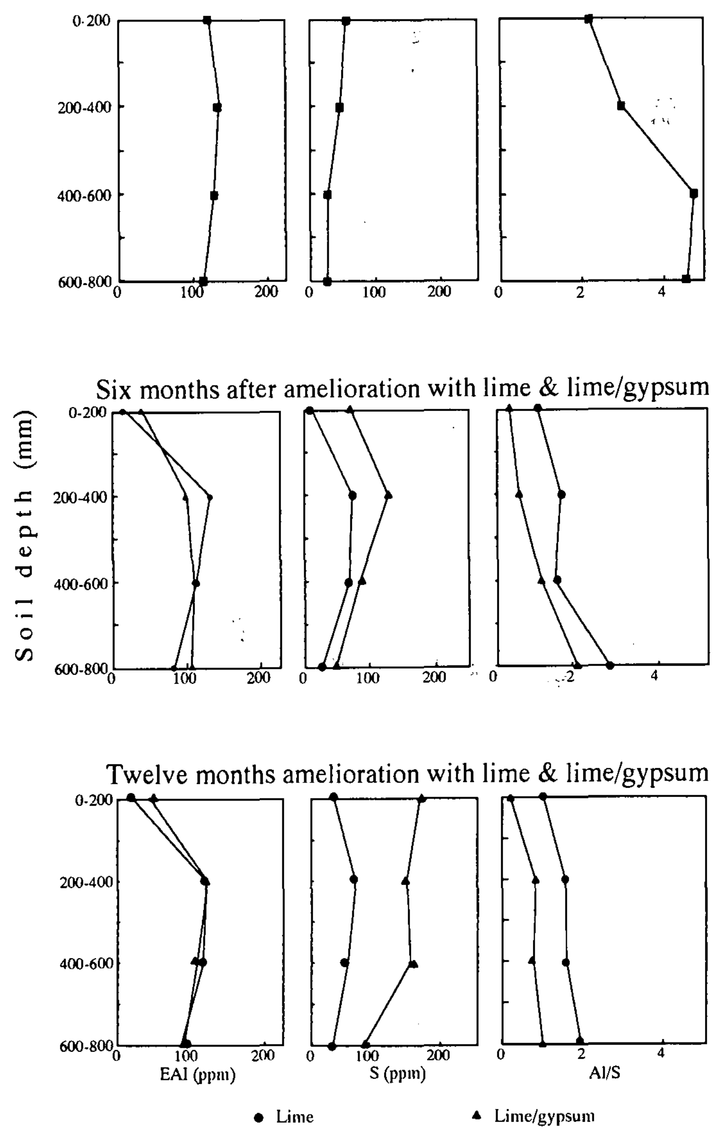


**FIGURE 2** EA1, S and A1:S ratio as a function of depth before amelioration and 6 and 12 months thereafter for an Inanda form soil (Site 8).

With regard to the analysis of soil samples taken to depth (Figure 2), it was found that EAI values declined to below 54 ppm (0-200 mm depth) after application of lime and lime/gypsum, while EAI values to depth were essentially unchanged after six and 12 months. As expected, the sulphate values increased substantially throughout the 0-800 mm profile after amelioration with lime/gypsum. The somewhat lower sulphate concentration in the topsoil six months after application of both lime and lime/gypsum, compared with that at the 200-400 mm soil depth, was probably due to aluminium-sulphate complexation reactions. Al:S values declined progressively with time after lime and lime/gypsum applications.

In this investigation, the origin of the extractable soil sulphur could either have been from the application of fertilisers or ameliorants such as single superphosphate and gypsum, and/or due to the mineralisation of soil organic matter, as a number of the non-responsive soils were humic in nature and found in the mist belt areas of the Natal midlands. Extractable soil sulphur plotted as a function of organic matter content for the humic soils (Figure 3) resulted in a correlation coefficient of r = 0,67. This confirmed that soils containing relatively large amounts of organic matter are able to supply substantial quantities of sulphur by the process of mineralisation (Meyer, 1985).

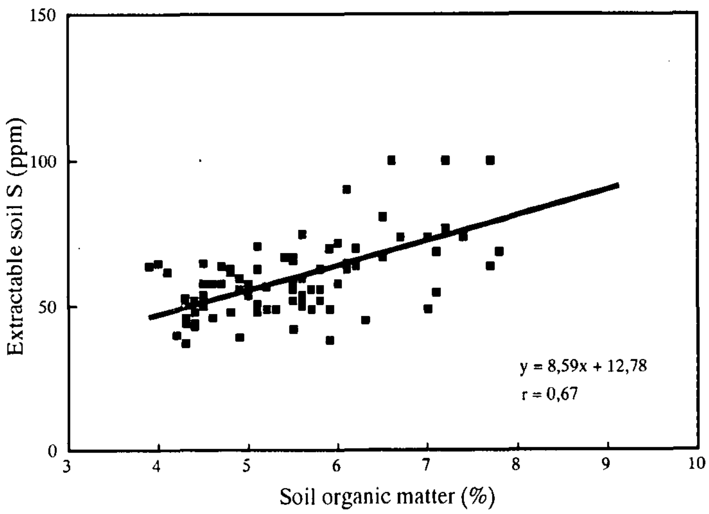


**FIGURE 3** Extractable soil sulphur as a function of organic matter content of selected humic soils.

## Discussion

Soils containing substantial amounts of S in the form of $SO_4^{2-}$ are not uncommon in the South African sugar industry. This is due not only to the use of sulphur based inorganic fertilisers such as single superphosphate and ammonium sulphate or ameliorants such as gypsum, but also to the mineralisation of organic matter, particularly in humic soils of the Natal midlands. The self liming and ion pair mechanisms involved in the detoxification of Al by the sulphate anion, respectively proposed by Reeve and Sumner (1972) and Pavan *et al.* (1982), are important in explaining the lack of response in cane yield on sulphur-rich soils.

The improved correlation between relative yield response and Al:S ratio compared with the use of EAI *per se*, appears to justify the use of the Al:S ratio in addition to extractable Al as an index for determining lime requirement. As this investigation was conducted primarily on sandy loams to sandy clay loams (15-35% clay), it is suggested that the Al:S ratio be used to modify the lime requirement for this textural group of soils only. In this respect a soil Al:S ratio of 2 is proposed as the threshold above which a response to lime is likely. Modifications to existing lime recommendations, using this threshold value, are given in Table 4.

**Table 4**

**Modified lime requirements for soils containing 15-35% clay based on an Al:S ratio of 2**

| Al:S | EAl (ppm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | <54 | 54 | 81 | 108 | 135 | 162 | 189 | >189 |
| | Calcitic/dolomitic lime (t/ha) | | | | | | | |
| <2,00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2,50 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3,00 | 0 | 1 | 3 | 3 | 3 | 3 | 3 | 3 |
| 3,50 | 0 | 1 | 3 | 5 | 5 | 5 | 5 | 5 |
| 4,00 | 0 | 1 | 3 | 5 | 7 | 7 | 7 | 7 |
| 4,50 | 0 | 1 | 3 | 5 | 7 | 8 | 8 | 8 |
| 5,00 | 0 | 1 | 3 | 5 | 7 | 8 | 11 | 11 |
| 5,50 | 0 | 1 | 3 | 5 | 7 | 8 | 11 | 14 |
| 6,00 | 0 | 1 | 3 | 5 | 7 | 8 | 11 | 14 |
| 6,50 | 0 | 1 | 3 | 5 | 7 | 8 | 11 | 14 |
| >7,00 | 0 | 1 | 3 | 5 | 7 | 8 | 11 | 14 |

The lighter textured soils (0-15% clay) were not considered as it was thought unlikely that they would contain substantial concentrations of sulphate. The heavier textured soils (greater than 35% clay) were also excluded as it is intended to investigate the possibility of a threshold value higher than 81 ppm aluminium for this category. The modifications suggested could bring about substantial reductions in lime requirement for soils which contain relatively high concentrations of sulphate. Apart from the economic implications there may also be some environmental benefit to humic soils. The application of lime to such soils is known to enhance the release of N and other nutrients due to microbial action (Wood, 1979). Over-application of lime may contribute to the premature degradation of such soils.

## Conclusions

- The investigation highlighted the fact that sulphur is an important secondary nutrient, and that the sulphate anion is a meaningful soil detoxifying agent. The latter property could possibly be considered in relation to other potentially problematic metals such as manganese.
- The use of the Al:S soil ratio appears to be effective in modifying lime requirement for humic and sulphate rich sandy loam/sandy clay loam soils. The larger the ratio the greater the probability of a response to lime.
- Although no significant responses to gypsum have yet occurred in field trials with sugarcane, the Al:S ratio may be used in future as an appropriate index.


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