EVALUATION OF A SOIL ALUMINIUM SATURATION INDEX FOR USE IN THE SOUTH AFRICAN SUGAR BELT

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Abstract

Although in the past much attention has been directed towards the amelioration of acid soil conditions, the criteria currently used in determining lime requirement needed reconsideration in light of a changed perception of estimating acidity. Data from a number of trials conducted in the South African sugar belt were used to evaluate soil aluminium saturation for indicating lime requirement and to rate some of the common Midlands varieties according to their apparent tolerance to soil acidity. The use of the aluminium saturation index (ASI) in conjunction with the aluminium to sulphur ratio (Al:S) is proposed as the basis for future lime recommendations. Varieties N12 and N16 appear to be more tolerant to aluminium than NCo376. There is some evidence that the apparent tolerance to aluminium in these two varieties is associated with a negative interaction at high rates of lime application. An aluminium saturation index value of 20% is proposed as the threshold for all varieties except N12, above which a response to lime is likely. A tentative threshold value of 40% is suggested for variety N12.

Introduction

Over the years various indices have been used for calculating lime requirement. Originally much emphasis was placed on soil pH for this purpose (Shoemaker *et al.*, 1961). However, it was recognised that aluminium toxicity, rather than acidity *per se*, was the primary limiting factor in acid soils (Kamprath, 1970). Despite the fact that this has been documented extensively, liming to near neutral conditions persists in some countries (McLean and Brown, 1984). The use of exchangeable aluminium as the basis for lime requirement was established in the early 1970s in Natal (Reeve and Sumner, 1970) and was introduced shortly therafter into the sugar industry (Moberly and Meyer, 1975). The Natal maize industry, however, adopted the approach suggested by Evans and Kamprath (1970) and based their lime requirement on percent acid saturation, according to which $Al^3+ +H^+$ is calculated as a percentage of the effective cation exchange capacity (Farina *et al.*, 1980). Despite the apparent agreement of utilising exchangeable aluminium for calculating lime requirement, the divergent viewpoints of exchangeable aluminium *per se* versus acid saturation had persisted over the past two decades. Therefore, whereas recommendations made by the Fertiliser Advisory Service (FAS) of the SA Sugar Association Experiment Station (SASEX) for lime application have been based on an exchangeable aluminium index (extracted in 0,2 $N\,NH^4Cl$) threshold value of 3,5 me/100 g clay (Moberly and Meyer, 1975), the maize industry has used an exchangeable acid saturation threshold value of 20% for this purpose (Farina and Channon, 1991).

In addition to the above, in some circumstances the use of Al *per se* (in the form of the EAI) may be overestimating the amount of lime required for sugarcane. This has already become apparent in sugar belt soils adequately supplied with sulphur and/or containing relatively high levels of organic matter. The use of the aluminium to sulphur ratio (Al:S) to modify lime requirement for soils containing >5% organic matter has been introduced (Schroeder *et al.*, 1993). More recently there have also been indications that some of the latest sugarcane varieties released by SASEX are more tolerant to aluminium than the traditional NCo376 variety (Anonymous, 1993). Further savings on lime application may therefore be possible.

In order to provide the sugar industry with the best possible advice regarding lime application, the criteria used for liming needed reconsideration. The objectives of this paper are to:

- evaluate the use of the soil aluminium saturation index for indicating lime requirement for sugar industry soils,
- rate some of the common Midlands varieties according to their apparent tolerance to soil acidity.

Procedure

Data were obtained from a number of field trials conducted at various times over a 25-year period in the KwaZulu-Natal Midlands. Trials were sited on a range of soils with widely differing chemical and physical properties, and included the cane varieties shown in Table 1. As the primary objective of each experiment was to establish or refine the lime requirement for cane grown under acid conditions, various rates of commonly used ameliorants were tested. These rates varied from 2-20 tons/ha dolomitic lime, 2,5-7 tons/ha gypsum and 2,5-20 tons/ha silicate slag. All nutrients were applied according to FAS recommendations.

Soil samples (0-200 mm) were taken before planting and after harvest of each ratoon crop. In ratoon cane, soil samples were taken from the row and interrow, using the standard ratio of 1:7 (row to interrow). Prior to chemical analysis, soils were dried overnight at 50°C and ground to pass a 2 mm sieve. K, Ca and Mg values were determined by atomic absorption spectroscopy after extraction in 1 N ammonium acetate solution, using a soil to solution ratio of 1:10 and a shaking time of 20 min. The pH values were determined in a 2:1 water to soil slurry, and exchangeable aluminium indices (EAIs) were obtained after extraction with 0,2 $N\,NH_4Cl$ (Meyer, 1970). The organic matter contents were determined using the method of Walkley and Black (1934). Soil sulphur values were estimated from the organic matter percentage values according to the function

$$S = 8{,}5(OM) + 12{,}8$$

as derived by Schroeder *et al.* (1993), where S represents the estimated exchangeable sulphur (as sulphate) and OM represents the soil organic matter percentage. ASI values were calculated by expressing the EAI values (me%) as a percentage of the sum of the extractable cations (K, Ca, Mg and EAI expressed as me%). To compare the diagnostic values of EAI and ASI, relative yields were calculated for each crop (yield at each rate of amelioration expressed as a percentage of the yield at the optimum rate) and related to the appropriate index. In order to assess apparent varietal differences in response to acidity, data sets pertaining to individual varieties were examined separately. The ASI values were com-

Table 1
Details of various liming field trials conducted over a 25-year period in the KwaZulu-Natal Midlands

Site	Soil Form	Variety	Clay (%)	pH water	Organic matter (%)	EAI (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Al:S	ASI (%)
Sevenoaks	Clovelly	CB36/14	52	4,2	3,5	234	155	139	36	5,5	65,2
Sevenoaks	Clovelly	NCo376	45	4,6	6,7	174	164	350	80	3,6	40,5
Dalton	Griffin	CB36/14 NCo376	20	4,6	8,5	100	91	16	12	1,2	73,5
Dalton	Griffin	N12 N16	64	4,7	6,8	153	214	276	81	2,2	39,6
Eston	Inanda	NCo376	27	4,8	4,2	150	95	116	27	3,1	61,5
Eston	Inanda	N12 N16	30	5,1	5,5	96	138	134	34	1,6	45,1
Eston	Inanda	NCo293	16	4,5	8,0	118	106	45	13	1,5	68,5
Eston	Inanda	NCo376	27	4,7	9,9	60	91	180	69	0,6	28,2
Townhill	Magwa	NCo293	53	4,8	9,4	177	138	70	38	1,4	65,9
Paddock	Nomanci	NCo376 N12 N16	24	4,4	8,1	185	111	98	16	2,2	69,4

pared with acid saturation values used as the basis for lime requirement of maize in KwaZulu-Natal. This saturation index is determined by expressing titratable acidity (exchangeable Al^{3+} + H^+ using 1 *N* KCl) as a percentage of exchangeable K^+ + Ca^{2+} + Mg^{2+} + Al^{3+} + H^+ (me%) as described by Farina and Channon (1991).

Results

The relative yield data based on tons cane produced per hectare (tc/ha) from all sites plotted as a function of ASI and EAI (Figures 1 and 2 respectively) showed that, although poor relationships existed, the regression obtained for relative yield against ASI was slightly better than that for EAI *per se*. The fact that relative yield based on tons sucrose produced per hectare also resulted in similarly poor relationships, indicated that a single threshold value for determining lime requirement based on either EAI or ASI is not adequate for sugarcane. This fact was partially recognised by Moberly and Meyer (1975) when they introduced the threshold value of 3,5 me/100 g clay. The linear correlation coefficient (r) applicable in this case was 0,48. Although the subsequent introduction of the Al:S ratio for modifying lime requirement for sandy to sandy clay loam soils improved this regression to 0,70 (Schroeder *et al.*, 1993), the predictive value of EAI remained ineffectual in some cases.

Further examination of the trial data showed that substantial differences in yield response to amelioration existed between varieties. For instance, the relative yield response curves for NCo376 (Figure 3) and NCo293 (Figure 4) resulted in correlation coefficient (r) values of 0,56 and 0,90 respectively. In both cases relative yield generally declined with increased aluminium saturation. In comparison, N12 showed the opposite trend (Figure 5). The fact that relative yield of N12 increased with increased ASI values indicated that this variety is more tolerant to aluminium than NCo376

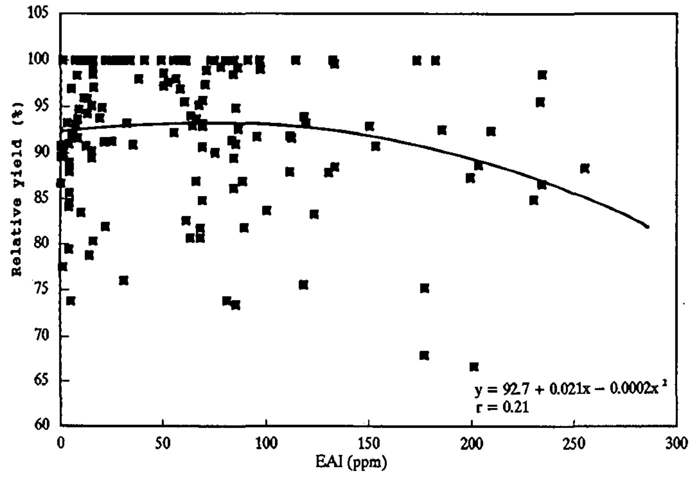

FIGURE 1 Relative yield (based on tc/ha) from all sites (Table 1) plotted as a function of ASI.

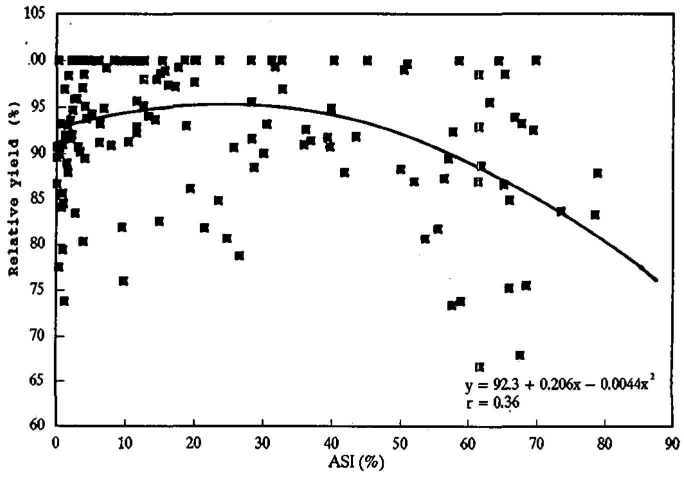

FIGURE 2 Relative yield (based on tc/ha) from all sites (Table 1) plotted as a function of EAI.

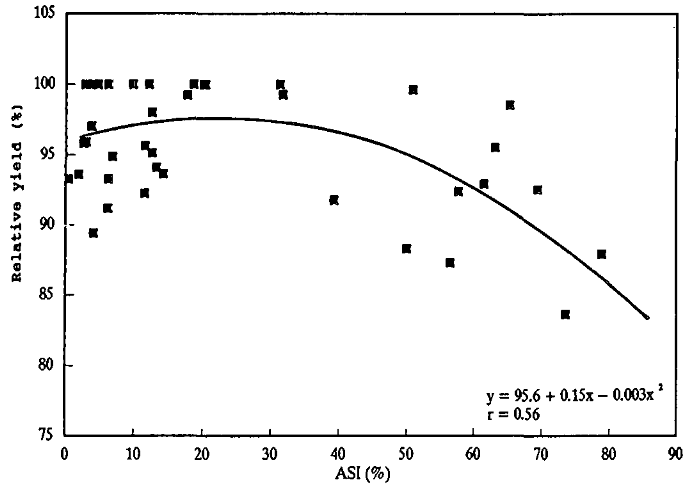

FIGURE 3 Relative yield of variety NCo376 as a function of ASI.

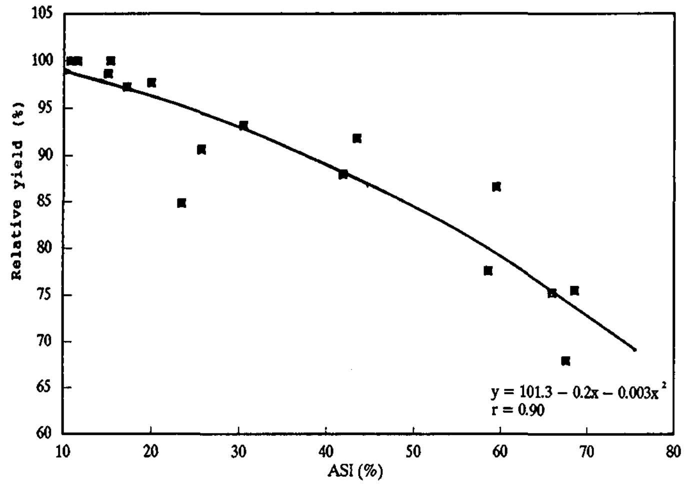

FIGURE 4 Relative yield of variety NCo293 as a function of ASI.

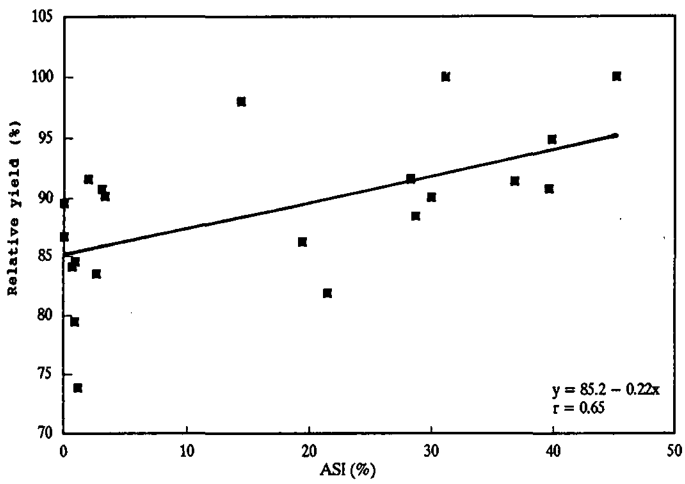

FIGURE 5 Relative yield of variety N12 as a function of ASI.

and NCo293. This trend is confirmed by initial yield data obtained from a trial at Paddock where NCo376, N12 and N16 were compared at the same site. Although there was no overall significant difference in yield between varieties, the data for N12 indicated a general decline in the plant crop yield with liming (61,1, 59,9 and 55,1 tc/ha at application rates of 0,7 and 14 t/ha dolomitic lime respectively). The corresponding soil test data indicated ASI values of 69,9%, 19,7% and 3,2%. However, the general paucity of yield data at the higher aluminium saturation values has disallowed the determination of the optimum ASI value for N12.

In order to establish a general ASI threshold value for the older varieties (NCo376, NCo293 and CB36/14) cognisance needed to be taken of the detoxifying effect of soil sulphur (Schroeder *et al.*, 1993). Data from trials where the initial Al:S values were less than 2 were therefore not considered. This gave rise to a composite curve (Figure 6) with a correlation coefficient (r) of 0,802 and indicated that the incidences of significant and non-significant responses could generally be separated by an ASI value of 20%. A similar regression involving EAI rather than ASI values yielded a correlation coefficient (r) of only 0,46. The ASI value of 20% compares favourably with the exchangeable aluminium percentage (EAP) value of 15% suggested by Meyer (1974). However, that author proposed expressing EAI as a percentage of the cation exchange capacity (CEC) at field pH, the determination of which is both cumbersome and time consuming.

The ASI values for various soils plotted against the traditionally quoted acid saturation figures (Figure 7) resulted in a correlation coefficient (r) of 0,93.

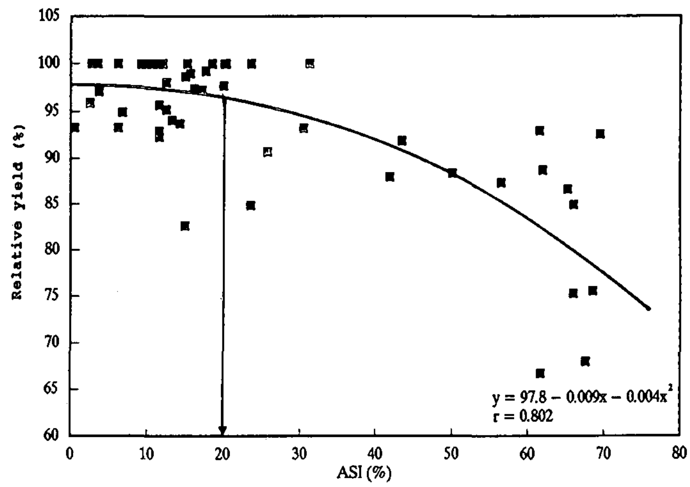

FIGURE 6 Relative yield of varieties NCo376, NCo293 and CB36/14 as a function of ASI for all trials where the Al:S ratio was greater than 2.

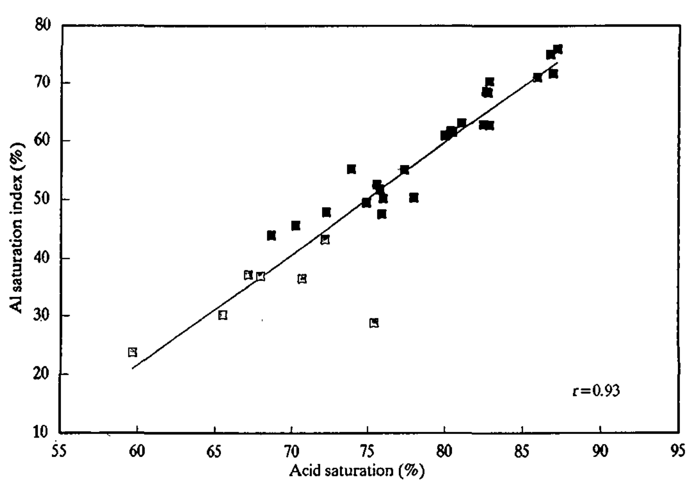

FIGURE 7 Regression of ASI vs acid saturation.

Discussion

An improved correlation between relative yield response and ASI (modified for soils containing substantial S levels) compared with EAI *per se*, indicates that lime requirement in the South African sugar industry in future should be based on aluminium saturation. An ASI value of 20% is therefore proposed as a threshold for all existing varieties except N12 and N16, above which a response to lime is likely. A tentative threshold value of 40% is suggested for variety N12, subject to modification when further data is available. Overliming of soils on which this variety is grown may be detrimental, as yield appears to be adversely affected at low ASI values (Figure 5). The reasons for this are not understood at present and possibilities that need to be investigated include lime induced micro-element deficiencies. The limited amount of data available for variety N16 at present contributed to the poor relationship between relative yield response and ASI. However, it appears that N16 may be somewhat more tolerant to Al than the NCo376/NCo293 group. Implementation of the proposed threshold values will reduce the amount of lime applied in some circumstances. Any reduction in the use of lime must however be seen in relation to the acidification of soils that is occurring due to continuous cropping within the sugar belt (Schroeder *et al.*, 1994). As this acidification is often related to both increased EAI and decreased base saturation values, an acidity index such as the ASI, which is based on a combination of these parameters, will be more sensitive to changes with time.

Conclusions

This investigation has indicated that future research into lime requirement for sugarcane should take varietal differences into consideration, particularly in a variety such as N12 which appears to show a negative response to high rates of lime application. Screening of new cane varieties for use in the non-irrigated areas is therefore essential. Use of the haematoxylin stain test for rapid assay of the relative aluminium tolerance (Bennet, 1995) may be useful in this regard.

The use of aluminium saturation in conjunction with the Al:S ratio, rather than Al *per se*, as the basis for calculating lime requirement is justified in terms of the improved correlation obtained with yield response. It also recognises that aluminium levels cannot be seen in isolation from other important soil solution constituents such as SO_4^{2-} which appears to be an meaningful detoxifying agent (Kinraide and Parker, 1987; Schroeder *et al.*, 1993) and the Ca^{2+}-ion to which crucial ameliorative properties are ascribed (Noble *et al.*, 1988).

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