SOIL ACIDIFICATION: OCCURRENCE AND EFFECTS IN THE SOUTH AFRICAN SUGAR INDUSTRY

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Abstract

Soil acidity is often of major concern in crop production due to possible adverse effects on plant growth. The general causes and effects of soil acidification were reviewed and the occurrence of acidification in the South African sugar industry was investigated. Data from field experiments and commercial cane fields indicated increased acidity with continuous cropping. Although acidification is often associated with sandy soils, decreases in pH and exchangeable basic cation concentrations and increases in exchangeable aluminium index values were not confined to lighter textured soils. A mechanistic soil profile acidification model, developed in Australia, was used to predict rates of pH decline of soils under cane. The predicted acidification rates were reasonably well correlated with measured decreases in pH. The occurrence of soil acidification should be seen as part of the chemical and physical degradation of soils in the South African sugar industry. Further work on this topic is warranted.

Introduction

Soil acidity is a factor which may adversely influence plant growth, particularly in terms of the detrimental effects of toxic levels of exchangeable aluminium at low soil pH. As with other crops in Natal, much attention has been devoted to the identification and amelioration of aluminium toxicity in soils of the South African sugar belt (Meyer *et al.*, 1991; Moberly and Meyer, 1975; Schroeder *et al.*, 1993; Sumner, 1970). As a result, amelioration of toxic aluminium is primarily based on the application of lime, the rates of which are determined by means of exchangeable soil aluminium index (EAI) and clay percentage values for soils with pH (water) values less than 5,3. Above this value, the solubility of Al^{3+} rapidly decreases as aluminium in the form of $Al(OH)^{2+}$ or $Al(OH)_2^+$ (Jenny, 1961) is adsorbed by clay minerals.

Although many investigations have been also directed towards understanding the behaviour of soil nutrients, such as P and Zn, in acid soil environments (Meyer and Dicks, 1979), little attention has previously been given to identifying rates of acidification and the extent to which the soils of the sugar industry are affected. The purpose of this paper is to:

- review the general causes and effects of soil acidification
- investigate the occurrence of acidification in South African sugar belt soils

Causes of soil acidification

Acidification is becoming a major problem in South Africa, and in Natal it has been described as probably the most important factor limiting yield (Scotney and Dijkhuis, 1990). Accelerated acidification of soils under cultivation is most often the result of (i) increased mineralisation of organic matter, (ii) oxidation of ammoniacal fertilisers to nitric acid and (iii) removal of the basic cations during harvesting (Fey *et al.*, 1990).

However, in terms of (i) and (iii), certain qualifications are necessary. Mineralisation of organic matter only leads to acidification if nitrogen is mineralised and then leached as nitrate (NO_3^-), and the removal of basic cations must be in combination with organic anions such as acetate and succinate, to result in acidification (Helyar and Porter, 1989). It has also been noted that the loss of NO_3^- from the soil system by plant uptake may neutralise some of the acidity (Helyar, 1976).

The existence of long term maize and pasture fertiliser trials in Natal has enabled the effect of continuous cultivation on acidificationto be investigated. Decreases of up to 0,65 pH units were noted in clay loam soils of the Avalon form, after 16 years of cropping with maize and annual applications of 180 kg/ha nitrogen in the form of limestone ammonium nitrate (Fey *et al.*, 1990). Acidification also occurs after the application of other N carriers (Table 1).

Table 1

Variation in soil chemical properties (0-100 mm) with fertiliser sources following the application of 360 kg/ha in split dressings to irrigated Italian ryegrass over ten months (after Miles, 1991)

	Zero N	Urea	LAN*	AS**
Exchangeable Ca (ppm)	872	749	758	569
Exchangeable Mg (ppm)	164	118	151	83
Exchangeable Al + H (meq %)	0,48	0,85	0,80	1,94
Acid saturation (%)	7,1	14,2	12,8	34,1
pH (KCl)	4,45	4,28	4,37	4,03

* Limestone ammonium nitrate
** Ammonium sulphate

Effects of soil acidification

Apart from the presence and increased availability of toxic aluminium associated with acidifying soils, nutrient availability is often linked to soil pH values. Macro-nutrient availability generally decreases with increasing acidity (Figure 1). In addition, nutrient uptake by plants may be detrimentally affected by high H^+ concentrations in soil (Mengel and Kirkby, 1978). This is often due to damage of the biological membranes of root surfaces (Bennet *et al.*, 1985). Increasing acidity often negatively affects the important microbial and faunal activity in soils. While different microbial balances exist in acid and near-neutral soil conditions (Lynch, 1993), soil fauna has limited abilities to adapt to a low pH environment (Lavelle, 1993).

Procedure

Data

The data were obtained from field trials and the records of the Fertiliser Advisory Service (FAS) laboratory of the South African Sugar Association Experiment Station (SASEX) (Table 2). Data sets relating to specific commercial

Table 2

Properties of soils and details of sites used in the investigation

Site	Parent material	Initial average soil test values				Other details	
		pH	Clay %	Ex bases (meq %)	Av CEC[1] (meq/100g soil)	Annual rainfall (mm)	N fertiliser applied (kg/ha/annum)
Eston	TMO[3]	5,42	28	3,1	6,4	905	?[2]
Paddock	TMO/TMM[4]	5,24	16	4,8	6,8	1146	
							130
	MES[5]	5,49	28	13,9	9,0		
Stanger	RSG[6]	5,88	20	20,9	3,6	1329	140
	DOL[7]	5,43	43	16,1	16,9		140
							140
Mtunzini	MES[5]	5,20	18	3,36	8,5	1300	
							140

[1] Beater (1959), except for the site at Eston
[2] According to rates indicated in Table 3.
[3] Table Mountain Sandstone (Ordinary)
[4] Table Mountain Sandstone (Ordinary) and Table Mountain Sandstone (Mistbelt)
[5] Middle Ecca Sediments
[6] Recent Sand Deposits (Grey)
[7] Dolerite

growers and miller-cum-planters were primarily selected according to the availability of analytical results from fields which had been regularly sampled over a number of years. In addition, data from a number of areas were chosen to cover a wide range of conditions and soil types where increasing soil acidity was thought possible.

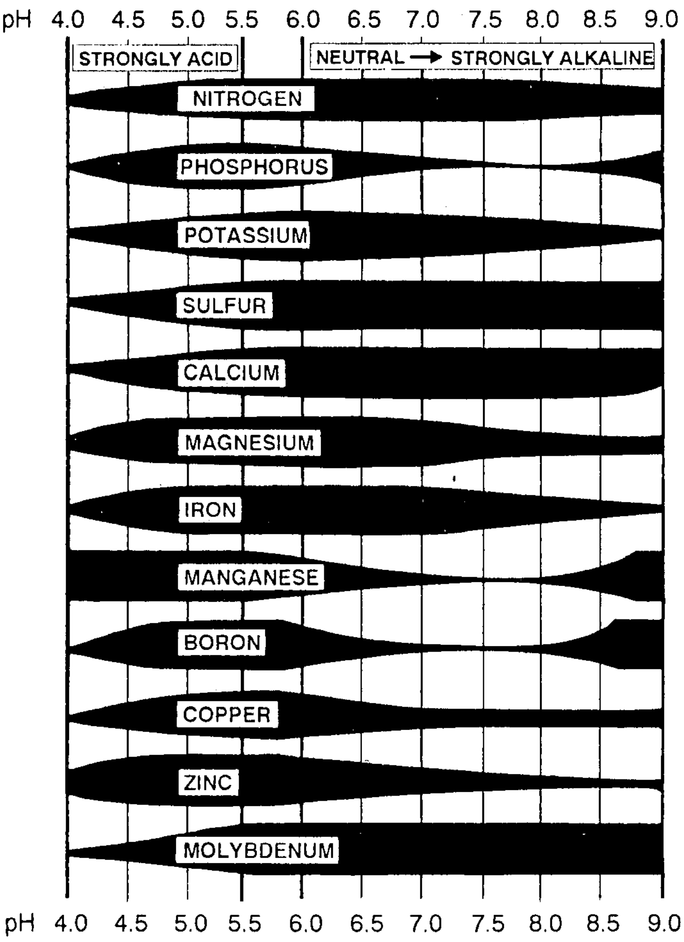

FIGURE 1 Influence of pH on the availability of plant nutrients; the widest parts of the shaded areas indicate maximum availability (after Lucas and Davis, 1961.).

Acidification of soils was investigated by calculating changes in soil pH (water), exchangeable base cation (K, Ca and Mg) concentrations and increases in exchangeable aluminium index (EAI) values. These data were all obtained using the analytical techniques routinely used in the FAS laboratory (Meyer *et al.*, 1989).

Geographic Information System (GIS)

Maps were produced using the data query facility of the GIS software, which is used by SASEX. Field boundaries were captured by a digitisation process into a computerised format. Analysis data were imported into the GIS and registered according to field numbers. Shaded maps were produced using the selected parameter class intervals.

Soil profile acidification model (SPAM)

A computer model developed by scientists from NSW Agriculture, Australia (Robinson *et al.*, 1993) was used to predict acidification of various sites using the oldest available soil data. Comparison of the predicted acidification with the youngest data from each site allowed for verification of the model under South African conditions. Generally the model is based on the fact that acid inputs into the soil system occur mainly from crop removal and nitrate leaching. Acidification from these two processes was calculated and, based on these figures, estimates of pH decline were computed.

Results

In investigating possible acidification of South African sugar belt soils, data from past trials were evaluated by changes of pH with cropping. The general absence of long term crop nutrition experiments seldom allowed the identification of substantial increases in acidity. However, indications of declining pH values were apparent in some of the nitrogen and lime trials, an example of which is the split rates of N trial at Eston (Table 3).

More extensive data, pertaining to commercial cane fields over relatively long periods, allowed for more meaningful investigation. The data set relating to a section of a miller-cum-planter at Paddock (Lower South Coast area of Natal) included soil test values for more than 200 soil samples taken over 12 years. These data, which were restricted to the Table

Table 3

Soil pH values associated with a timing of nitrogen application trial on a two year cropping cycle at Eston in the Natal Midlands

N Applied (kg/ha)	pH (water)	
	1989	1993
160 (single topdressing)	5,42	5,29
210 (split) (160 + 50 in autumn)	5,32	5,27
210 (split) (160 + 50 in next spring)	5,37	5,20
210 (single topdressing)	5,34	5,24
160 (split) (110 + 50 in next spring)	5,36	5,28
110 (split) (80 + 50 in next spring)	5,42	5,27
Mean	5,37	5,26

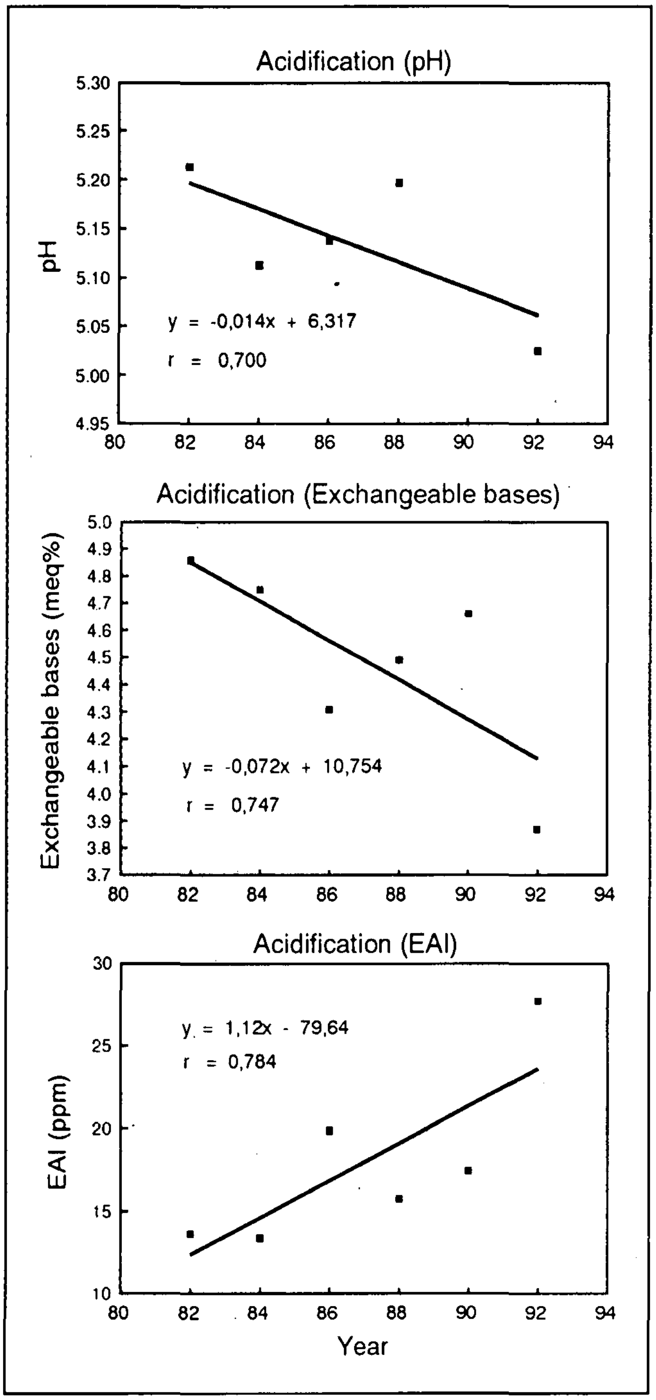

FIGURE 2 Acidification of soils in terms of pH, exchangeable base concentration and EAI values (Paddock).

Mountain Sandstone soils (Beater, 1959), indicated a general decline in pH values across fields. This also corresponded to increased EAI values and decreased base cation concentration over the period of continuous cropping (Figure 2).

GIS generated maps of a particular section of a commercial grower operation at Stanger on the Natal North Coast (Figure 3) indicated that a decrease in pH values, as calculated over four to five years, generally occurred irrespective of soil type (based on parent material). However, the greatest increases in acidity (decreases of more than 0,7 pH units in some instances) were apparent on the Recent Sand deposits. In many cases this acidification was reflected also in a decrease in exchangeable base cation concentration. Despite decreases in base status being often greater than 40% in terms of the sands, this phenomenon was not restricted to this soil type only. The use of N mineralisation categories was found to be an unreliable indicator of soil acidification.

The soil profile acidification model was tested using data from a Zululand estate at Mtunzini (Table 4). In practice there was an increase in acidity with cane production from 1988 to 1993. The relevant soil properties from this site, which were needed for input into the model, are presented in Table 2.

Table 4

Selected chemical soil data for various fields on a Zululand estate (Mtunzini)

Date of sampling	1988/89			1992/93		
Field	pH	Ex Bases (meq %)	EAI (meq %)	pH	Ex Bases (meq %)	EAI1 (meq %)
6	5,10	1,85	0,19	4,55	4,03	0,40
16	5,65	3,38	0,01	4,95	3,28	0,11
30	5,30	2,00	0,06	5,20	1,23	0,11
32	5,00	3,09	0,18	4,70	0,89	0,20
36	5,30	3,37	0,07	4,40	1,29	1,03
44	5,00	3,09	0,09	4,90	2,87	0,28
59	5,25	6,78	0,09	5,00	5,07	0,13
62	5,30	4,50	0,06	4,75	5,28	0,27
66	4,95	3,36	0,14	4,85	2,38	0,26
74	5,45	4,12	0,01	4,70	1,02	0,42
80	5,05	2,48	0,20	4,65	0,21	0,52
86	5,05	2,29	0,07	4,90	1,70	0,34
Mean	5,20	3,36	0,10	4,79	2,38	0,34

Table 5

Annual pH decline for individual fields on a Zululand estate (Mtunzini)

Field	Actual pH decline	Predicted pH decline
6	0,11	0,13
16	0,18	0,15
30	0,03	0,11
32	0,08	0,16
36	0,22	0,00
44	0,03	0,13
59	0,06	0,16
62	0,14	0,13
66	0,03	0,15
74	0,19	0,10
80	0,10	0,11
86	0,04	0,12
Mean	0,10	0,125

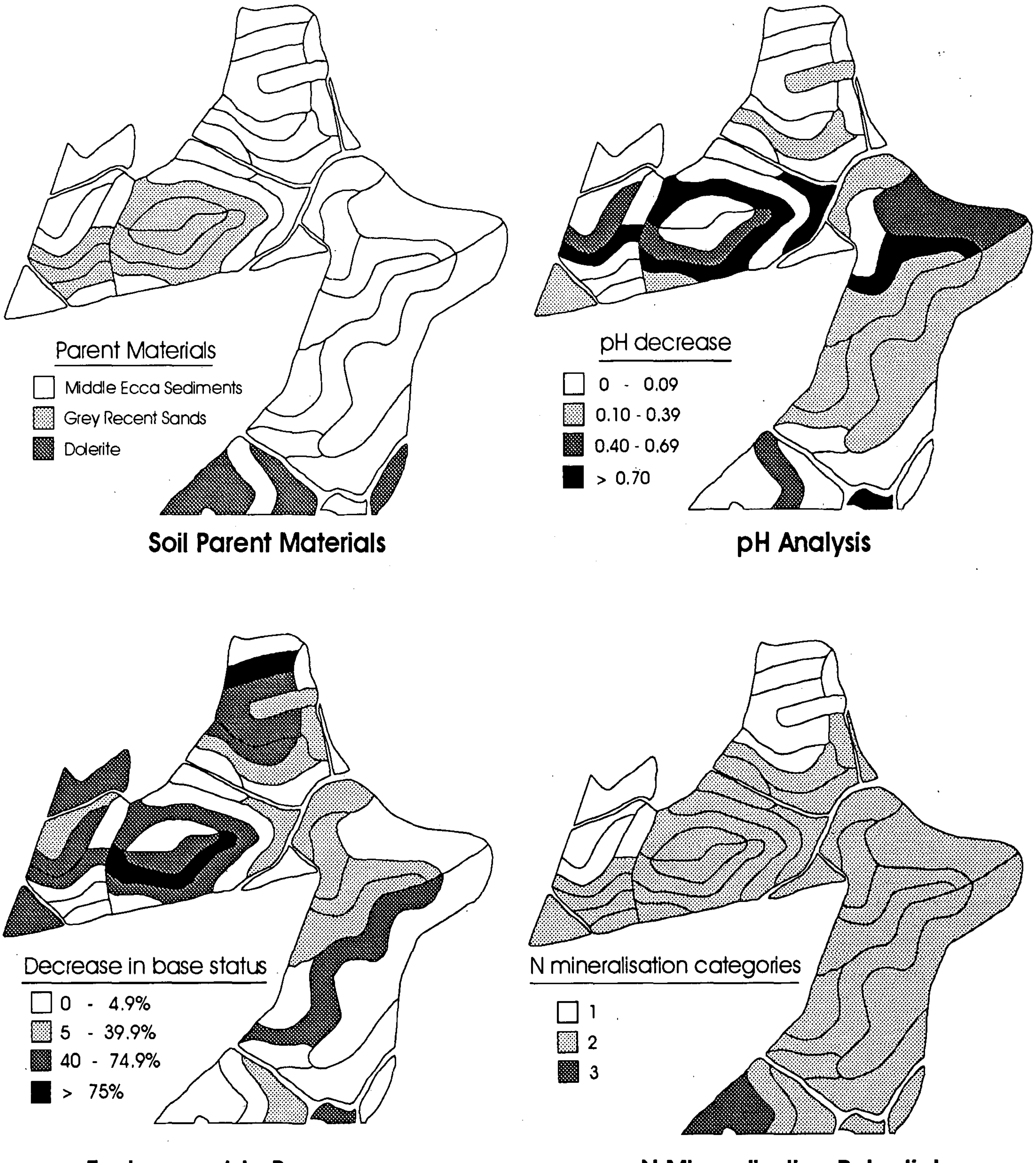

FIGURE 3 GIS representation of parent material, N mineralisation categorisation, pH decline and decrease in exchangeable base concentration (commercial sugar estate at Stanger).

The total acid input due to crop removal was calculated from the N, P, K, Ca and Mg figures for an adequately fertilised 12 month old rainfed crop (Bishop, 1967).

Nitrate leaching was estimated as 10% of the applied N. An estimate of pH decline (Table 5) was calculated by the model according to the acid input and the pH buffer capacity of the soil due to exchangeable cation changes. Below a soil pH of 5,5, the pH buffering due to Al^{3+} was also included. The regression of actual pH decline versus that predicted by SPAM gave a correlation coefficient (r) of 0,65.

Discussion

Acidification of soils is certainly a reason for concern, particularly with regard to the adverse effects related to low pH soils. This is despite certain sugarcane varieties appearing to be more tolerant of soil acidity than others (Turner *et al.*, 1992). Although the nutrient information retrieval system (NIRS) has indicated little build up of acidity in the various regions of the sugar belt (Meyer *et al.*, 1992), acidification of soils in the South African sugar industry is indeed occurring. Historical data should therefore be used more frequently, to identify nutrient/fertility trends in specific fields. The current global applications of NIRS may mask actual changes on individual estates. Although acidification is usually expected in sands, it certainly does not appear to be confined to the lighter textured soils. The reasonably good correlation obtained between the actual pH decline and that predicted by SPAM, indicates that increases in acidification due to crop removal of bases and leaching effects are real, and in line with similar processes noted elsewhere. It appears also that, as in the rest of South Africa (Scotney and Dijkhuis, 1990), insufficient lime is being applied to counteract the acidification of soils due to continuous cropping. Band placement of lime at relatively low rates has been recommended to alleviate a similar problem in the Western Transvaal maize areas (van Vuuren and Barnard, 1990). Similarly, regular liming by band or broadcast applications may be worth considering in the sugar industry.

Conclusions

That acidification of the sugar belt soils is occurring not only warrants further investigation into the extent of this problem, but indicates also the need for research into amelioration practices.

This initial investigation suggests that the soil profile acidification model developed in Australia is compatible with conditions in the SA sugar industry. Further work in this regard is necessary, particularly in linking the estimated acidification rates to fertiliser advice. Acidification should be seen as part of the chemical and physical degradation of soils and may be important in explaining, to some extent, the yield declines which are noted both locally and overseas.

In the long term, temperature increases associated with the expected global warming might result in further degradation/acidification due to increased losses of organic matter, increased erosion and decreased soil fertility levels. These issues need to be addressed through sustained research and modelling of soil degradation and cannot be achieved by short term trials only.

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