THE IMPACT OF LIME AND GYPSUM ON SUGARCANE YIELDS AND SOIL ACIDITY IN THE SOUTH AFRICAN SUGAR INDUSTRY

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Abstract

The yield responses of sugarcane to lime and gypsum at two sites in the KwaZulu-Natal Midlands of South Africa are presented and discussed. At Dalton, on a Magwa form soil with an initial aluminium saturation index (ASI) of >80%, over a plant and four ratoon crops variety N12 gave no significant response to dolomitic lime. By contrast, variety N16 gave consistent yield responses to lime at rates of up to 10 t/ha, and also to applications of 5 t/ha lime plus 5 t/ha gypsum, which gave the highest overall yield. At Paddock, on a Nomanci form soil with an initial ASI of about 80%, N16 gave consistent responses to dolomitic lime applied at 7 t/ha in the first to fifth ratoon crops, while N12 responded similarly from the third ratoon onwards. NCo376 gave yield responses to rates of 14 t/ha from the second ratoon onwards. The results confirmed the revised Fertiliser Advisory Service method of recommending lime to ensure that yields are not limited by soil acidity. In addition, there appears to be merit in applying gypsum as well as lime to acid soils. The implications for future research work on liming are discussed.

Keywords: sugarcane, lime, gypsum, aluminium saturation index

Introduction

The method of recommending lime currently used by the Fertiliser Advisory Service (FAS) at the South African Sugar Association Experiment Station (SASEX) is based on the aluminium saturation index (ASI; %) of the soil, which is defined as:

$$\mathrm{ASI} = \frac{\mathrm{EAI}}{\mathrm{EAI} + \mathrm{K} + \mathrm{Ca} + \mathrm{Mg}} \qquad (1)$$

Where EAI is the exchangeable aluminium index (me%), and K, Ca and Mg are the values of exchangeable potassium, calcium and magnesium (all in me%) respectively. The original method, based upon EAI and clay% was developed by Moberly and Meyer (1975), and subsequently modified by Schroeder *et al*. (1993) to use ASI as the basis for lime requirement. More recently, a recursive calculation was incorporated to take account of the effects of added lime and gypsum on final ASI (Schumann *et al*., 1999). As a result, predictions of lime requirement to achieve the target soil ASI of 20% (40% for N12) are more accurate, and generally represent a reduction in the amounts of lime being recommended.

Of the lime trials that have been conducted by SASEX, two are still current, sited at Dalton and Paddock in KwaZulu-Natal.

Results from the plant and early ratoon crops have been reported by Schumann *et al*. (1999). These experiments now provide further information allowing for assessment of the effects of lime and gypsum on sugarcane yields and soil conditions over a 7-10 year period.

Materials and Methods

Both trials were planted at 1 m row spacing on humic soils (Magwa and Nomanci forms) under dryland conditions at Dalton and Paddock. Details of the site conditions and treatments are given in Table 1. The lime and gypsum materials were surface-applied and incorporated to 0.2 m depth. N, P and K fertilisers were applied at FAS rates. Both trials were harvested on an approximate 18-month cycle. Cane and sucrose yields were determined by infield weighing and standard cane quality analysis respectively. Soil samples to 0.6 m depth were taken periodically at both sites using a dutch auger, which were analysed using standard FAS methods, including determination of EAI by the method of Reeve and Sumner (1970), allowing calculation of ASI (%). Routine third leaf samples were taken in each crop, and analysed using standard FAS methods.

Table 1. Site condition and treatments applied in two liming trials established at Dalton (1995) and Paddock (1992).

Location	Dalton	Paddock
Soil form	Magwa	Nomanci
Topsoil clay %	59	26
Soil organic matter (%)	6.8	8.8
Initial soil pH	4.2	4.4
Initial topsoil ASI (%)	84	80
Dolomitic lime rates (t/ha)	0, 5, 10	0, 7, 14
D. lime + gypsum rates (t/ha)	5 + 5	-
Gross (net) plot size (m)	10 x 6 (8 x 4)	8 x 6 (6 x 4)
Planting date (year)	1995	1992

Results

Sucrose yields

At Dalton, N12 did not respond to lime during the first four crops, but did give a response ($P<0.05$) in the fourth ratoon (Table 2). Although N16 also did not respond in the plant and first ratoon crops, there was a yield benefit ($P<0.05$) to lime applied at 5 and 10 t/ha in the second, third and fourth ratoon crops. This resulted in a substantial cumulative (plant plus four ratoons) yield response to lime of 18 tons (or 33%) more sucrose per hectare where 10 t/ha lime was applied, as compared with the control treatment (Figure 1), representing about 1.7 tons sucrose per ton of lime applied. The use of 5 t/ha gypsum and 5 t/ha lime resulted in 9 t/ha more sucrose over the cycle compared with 5 t/ha lime alone, and this combination of ameliorants gave the highest cumulative sucrose yield for N16 (74 t/ha). By contrast, N12 did not respond to lime over the cycle, but the combination of lime plus gypsum resulted in a cumulative increase of 6 t/ha sucrose, compared with unlimed cane. Cane yields at this site were about 90-140 t/ha in the plant crop, 130-180 t/ha in the first ratoon and within the range 50-100 t/ha in subsequent ratoons. Sucrose content was not consistently related to the liming treatments.

Table 2. Yield (tons sucrose/ha) of the plant and four ratoon crops of varieties N12 and N16 in response to lime and gypsum application at Dalton.

Crop	Variety	Dolomitic lime (+ gypsum*) rates (t/ha)				
		0	**5**	**10**	**5 + 5***	**LSD (*P*=0.05)**
Plant	N12	11.2	12.2	12.4	12.7	1.35
	N16	13.2	14.3	14.4	15.8	
1R	N12	17.7	16.9	16.3	15.9	2.66
	N16	16.3	17.6	18.5	21.2	
2R	N12	10.9	11.0	10.9	12.8	1.72
	N16	9.4	13.2	14.7	14.5	
3R	N12	10.3	11.5	11.5	13.3	2.04
	N16	7.3	9.4	11.9	11.6	
4R	N12	8.7	10.5	10.5	10.4	1.49
	N16	7.4	10.8	11.7	11.4	

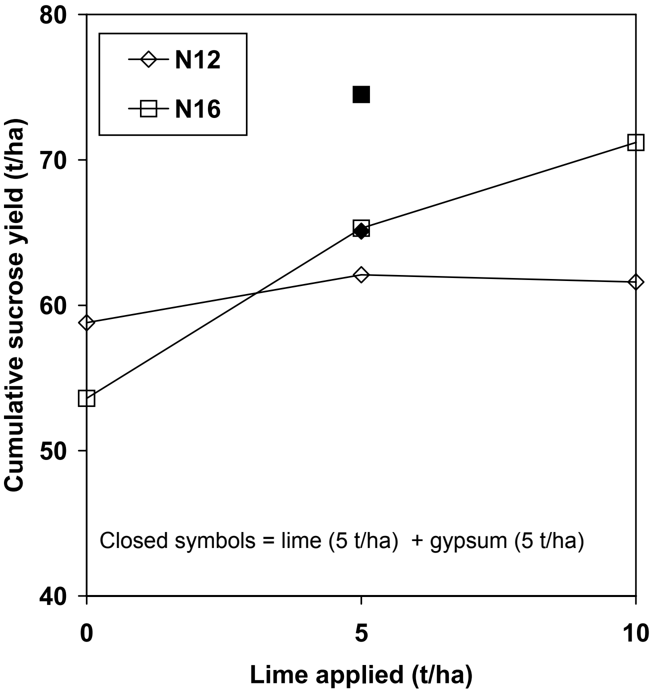

Figure 1. Cumulative sucrose yield (plant and four ratoon crops) of varieties N12 and N16 in response to liming at the Dalton site. The closed symbols are 5 t/ha lime + 5 t/ha gypsum.

At Paddock, none of the three varieties (NCo376, N12 and N16) responded to lime in the plant crop, and only N16 gave a significant ($P<0.05$) response to 14 t/ha lime in the first ratoon crop (Table 3). However in subsequent ratoons (2R-5R) all three varieties gave a yield response ($P<0.05$) to 7 t/ha lime, with only NCo376 showing any marked further response to lime applied at 14 t/ha in the later ratoons. Over the cycle (plant plus five ratoons), the cumulative sucrose yields of NCo376, N12 and N16 were increased by 15, 12 and 17 t/ha (or 24%, 19% and 30%) respectively when 7 t/ha lime was applied, with little further response at the higher lime rate (Figure 2). Cane yields in the plant (60-70 t/ha) and first ratoon (80-90 t/ha) crops at the site were lower than those at Dalton, but showed improvement in the later ratoons as the liming treatments became effective. Again, sucrose content was not affected by the liming treatments.

Table 3. Yield (tons sucrose/ha) of the plant and five ratoon crops of varieties NCo376, N12 and N16 in response to lime application at Paddock.

Crop	Variety	Dolomitic lime rates (t/ha)			
		0	7	14	LSD (P=0.05)
Plant	NCo376	8.6	9.2	8.7	1.32
	N12	7.4	7.3	7.2	
	N16	8.8	8.0	8.5	
1R	NCo376	12.5	13.1	10.8	2.59
	N12	15.3	13.9	12.9	
	N16	10.8	13.1	13.9	
2R	NCo376	8.4	10.5	11.5	1.54
	N12	8.7	10.4	11.0	
	N16	7.0	10.3	10.2	
3R	NCo376	11.2	15.7	17.4	2.50
	N12	10.9	15.8	15.3	
	N16	10.6	14.7	14.2	
4R	NCo376	8.4	11.2	12.0	N/A*
	N12	8.5	13.0	12.8	
	N16	7.5	12.2	12.0	
5R	NCo376	10.5	14.4	16.2	2.30
	N12	14.1	16.8	15.2	
	N16	13.6	17.3	18.3	

*LSD for fourth ratoon not available due to missing data

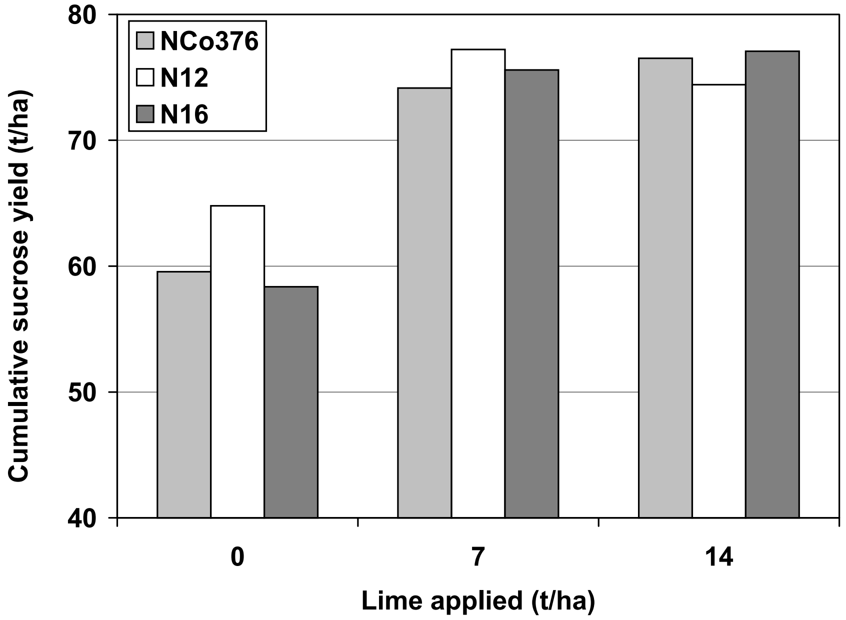

Figure 2. Cumulative sucrose yield (plant and five ratoon crops) of varieties NCo376, N12 and N16 in response to liming at the Paddock site.

Soil and leaf analyses

At Dalton, over a three-year period (1995-1998) ASI in the topsoil (0-0.3 m) was reduced 80% to 50% and 25% respectively where 5 and 10 t/ha lime had been applied (Figure 3a). The effect on ASI of the combination of 5 t/ha lime plus 5 t/ha gypsum was similar to that of 5 t/ha lime alone.

However within the subsoil ASI values were not markedly affected; 5/10 t/ha lime respectively reduced ASI to about 65/70% within the 0.3-0.6 m soil layer, with the lime plus gypsum treatment being about as effective as 10 t/ha lime (Figure 3b). The lime treatments resulted in modest increases in topsoil pH from 4.2 to between 4.5-4.8 following application.

At Paddock, topsoil (0-0.2 m) ASI was reduced to about 25% and 5% by 7 and 14 t/ha lime respectively, 1-2 years after application (Figure 4a). However five years after application ASI in the plots that received 14 t/ha had increased again to about 30%. There was evidence at this site, on a lighter textured soil, that lime had moved down the profile. Over the five-year period following application, ASI values within the 0.2-0.4 m soil layer were reduced to about 40% and 30% respectively by the application of 7 and 14 t/ha lime (Figure 4b), whilst in the 0.4-0.6 m layer the equivalent values were 65% and 50% (Figure 4c). Over the same period topsoil pH was increased from 4.4 to 4.9 and 5.1 by applications of 7 and 14 t/ha lime respectively.

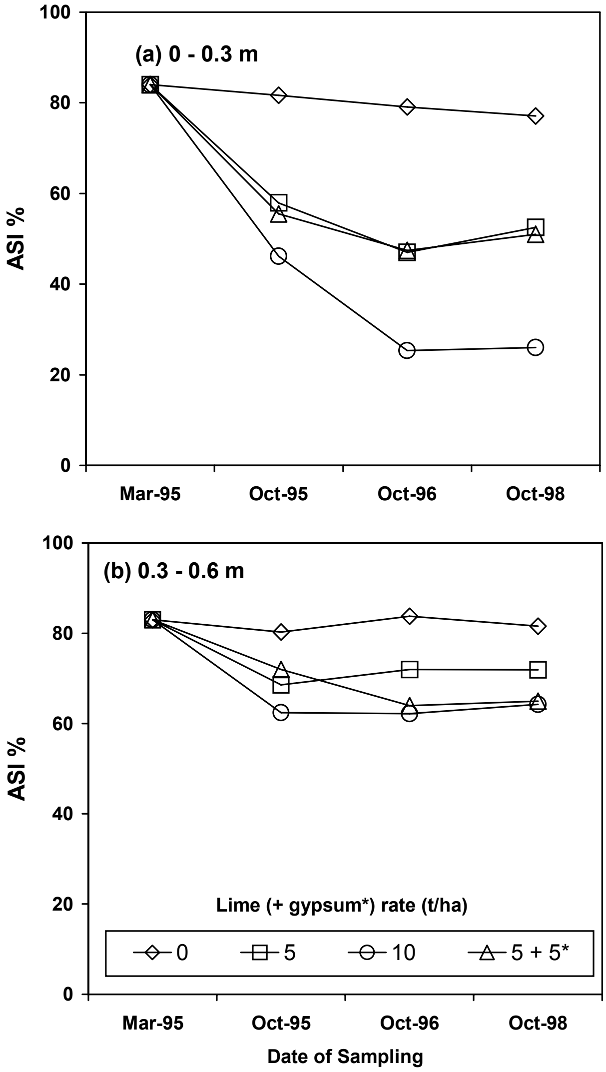

Figure 3. Aluminium saturation index (ASI%) values within the soil at the Dalton site following lime application in 1995.

At Dalton, leaf samples indicated calcium deficiency within the control plots in the plant and some ratoon crops. Schumann *et al.* (1999) related third leaf calcium levels to sugarcane yield, confirming the threshold level of 0.15%. The responses to lime at this site were therefore probably due in part to the alleviation of this calcium shortage. At Paddock, although soil calcium and magnesium levels in the control plots were below threshold, at no time were deficient levels of these two nutrients observed in the leaf analyses. However, in some crops DRIS indices indicated that magnesium levels may have been limiting, thereby possibly enhancing the observed responses to dolomitic lime. In future work it may be appropriate for the trial site to receive a uniform minimal application of dolomitic lime in order to prevent such deficiency problems occurring.

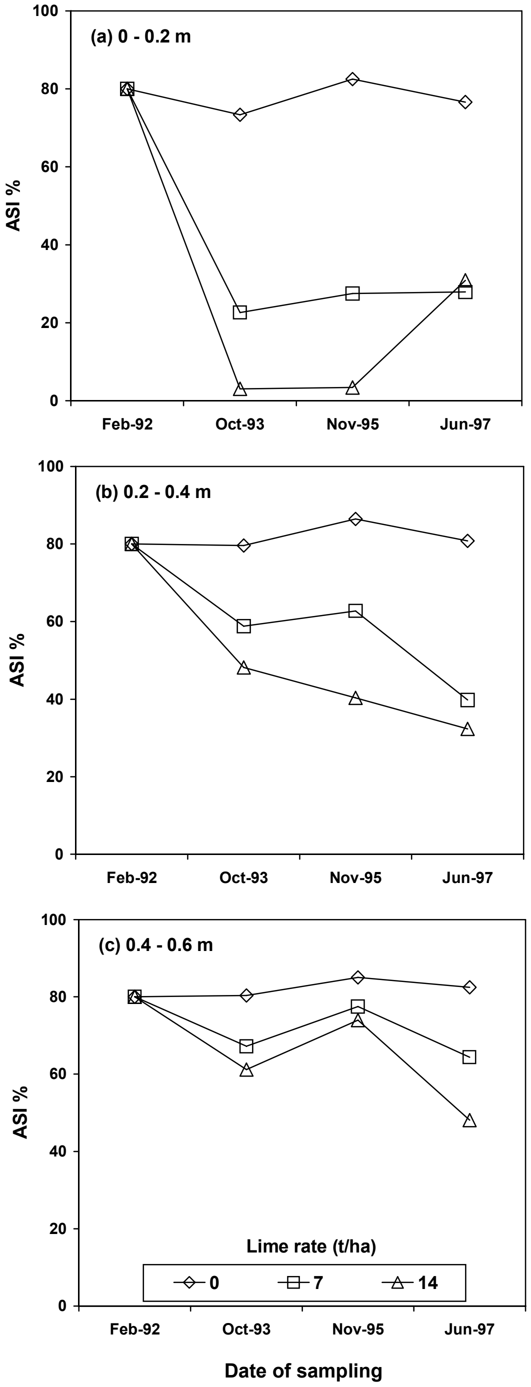

Figure 4. Aluminium saturation index (ASI%) values within the soil at the Paddock site following lime application in 1992.

Discussion

The trials clearly demonstrated the yield benefits that may be obtained by applying lime to acid humic soils in the KwaZulu-Natal (KZN) Midlands. Given the current cost of lime application, of approximately R300 per ton applied, the observed responses represent a substantial return. Based on a sucrose price of R1200 per ton, the net return (ignoring the associated additional production costs) where lime was applied at 5 and 10 t/ha to N16 at Dalton were R12 500/ha and R18 100/ha respectively (Table 3). At Paddock, the returns from lime applied to N16 at 7 and 14 t/ha were similar (R18 300 - R18 600/ha), representing a potential return of up to R2500 per ton of lime applied.

Table 4. Estimated return per ton of dolomitic lime or gypsum applied to variety N16 at the Dalton and Paddock trials, assuming a current sucrose price of R1200/t and the cost of lime or gypsum to be R300 per applied ton.

Site	Application rate (t/ha)	Estimated cost applied (R)	Gross return (R)	Net return (R)
Dalton	5	1500	14 000	12 500
Dalton	10	3000	21 100	18 100
Paddock	7	2100	20 700	18 600
Paddock	14	4200	22 500	18 300

Using the revised programme developed by Schumann *et al*. (1999), the FAS lime requirements would have been 12 t/ha at Dalton and 7 t/ha at Paddock. At Dalton, N16 gave an almost linear yield response to lime at rates of up to 10 t/ha, which resulted in the reduction of topsoil ASI to 25%, which is close to the target ASI of 20%. While the relative lack of response to lime in the more acid-tolerant variety N12 was perhaps expected, the observed yield increase of only 5-10% over the cycle at this site was surprising, given the initial ASI of 84%. At Paddock, 7 t/ha lime reduced the ASI to 20%, and it is encouraging that the cumulative yield response of all three varieties over the whole cycle was highest at this rate. The magnitude of the lime response of N12 at Paddock was greater than that at Dalton; indeed, N12 receiving 7 t/ha lime gave the highest cumulative sucrose yield over the plant and five ratoon crops (78 t/ha). Although NCo376 showed a significant response to lime applied at 14 t/ha in the later ratoons, over the cycle the higher liming rate only resulted in an additional 2.6 t/ha sucrose, compared with where 7 t/ha lime was applied. The results from these two trials therefore confirm the revised FAS method for calculating lime requirement on the basis of ASI. The results from Dalton also demonstrate the additional yield benefit that may be obtained from the application of lime with gypsum. Similar yield responses to this combination of ameliorants have been observed in trials at Eston (Schumann *et al*., 1999). The additional response may, in part, be due to the detoxifying effect of sulphur on soil aluminium, which has previously been reported by Sumner (1990).

Over the past 20 years, soil acidity levels have been carefully monitored in parts of the KZN sugar industry. In the southern Midlands the pH values of soil samples being analysed by the FAS laboratory (expressed as a three-year mean of at least 1000 samples per data point) have remained relatively constant at about 5.2, and ASI values within these soils has remained within the range 30-40% (Figure 5). By contrast, pH values in soils of the lower South Coast have declined from about 5.3 during the period 1980-85 to under 5 at present, with the proportion of samples with pH <5 having roughly doubled. Values of ASI have shown a concurrent increase, from 20-25% during the period 1980-88 to over 40% at present, with a consequent increase in the number of samples indicating a lime requirement. While much of the previous research work investigating the use of lime has concentrated on the traditionally acidic Midlands areas, there is justification for concentrating future emphasis on the coastal soils, where problems of acidity have been developing more rapidly than elsewhere.

The likely reasons for this acidification are:

- The continuous use of nitrogenous fertilisers, particularly those containing an ammonium component, which release acidity upon reaction within the soil.
- Long term monocropping, leading to mining of nutrient bases, mainly potassium, calcium and magnesium, by the crop.
- In coastal areas, the risk of damage by eldana has led to a shortening of harvest age to 12-15 months. However, the recommendations for nitrogen in these areas are still based on norms established for crops harvested at 18-24 months, resulting in an increase in the application of N per unit time.
- In recent years, mono-ammonium phosphate (MAP) and di-ammonium phosphate (DAP) have become popular as P carriers due to favourable price and N content. However, both these materials are strongly acidifying, being roughly equivalent to ammonium sulphate in this respect.

Given the acidifying nature of fertiliser materials, it may be necessary to initiate a system of lime amendment to counteract the application of nitrogen. For instance, 100 kg/ha nitrogen applied as ammonium sulphate theoretically requires about 700 kg/ha of $CaCO_3$ to neutralise the inherent acidity, and the figure for urea-N is about half this (Sanchez, 1976). It may be necessary to pay more attention to soil pH when making lime recommendations. Current lime requirement calculations, based on reduction of ASI, do not fully take into account acidity resulting from the reaction of nitrogen carriers, which generate H^+ ions within the soil. However, the lowering of soil pH leads to an increase in aluminium solubility, meaning that a good correlation exists between acid saturation and ASI (Schroeder *et al*., 1995). Nevertheless, it may be necessary to modify the system to allow for this by recommending lime to raise the soil pH to a certain threshold, and work is currently under way to investigate this issue. The observations made in this study of lime movement down the profile of lighter textured soils also provides the possibility of modifying future lime requirements to account for the amelioration of sub-soil acidity.

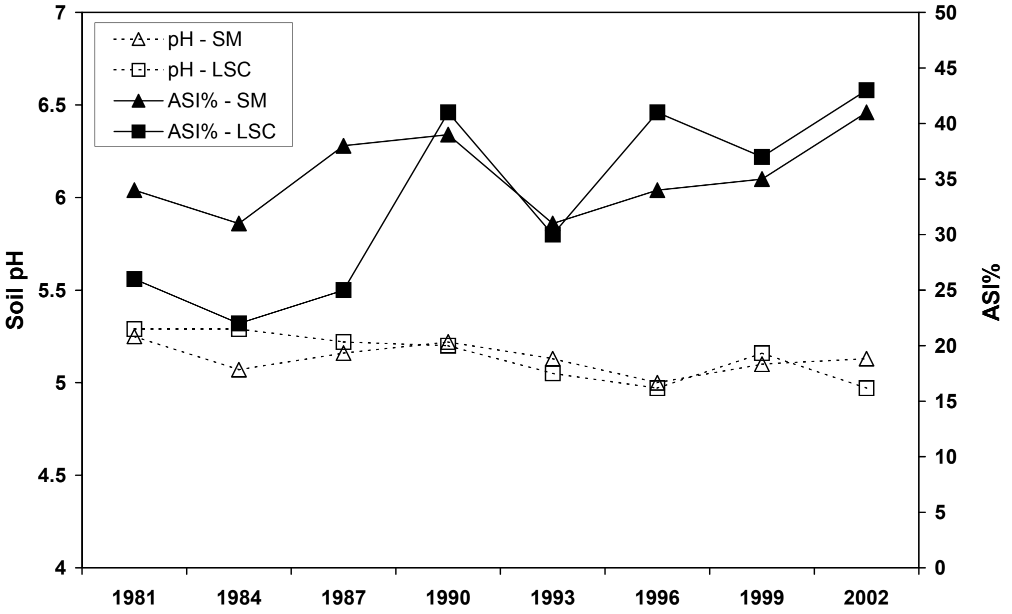

Figure 5. Rates of acidification in the southern Midlands (SM) and lower South Coast (LSC) regions of KZN in terms of soil pH and aluminium saturation index (ASI%) during the period 1980-2002, expressed as a three-year running mean.

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