THE EFFECT OF SOIL ACIDITY ON SUGAR BEET GROWTH IN SOME NATAL SOILS

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Abstract

During the latter part of 1975 an investigation was conducted in the Natal Midlands to locate sites, representative of the main bioclimatic subregions, that would be suitable for sugar beet experiments. Soil acidity was identified as an important limiting factor in the majority of soils examined. A glasshouse study with sugar beet revealed a marked response to lime where soil pH values were less than 5,3, while deep incorporation was responsible for optimum development of the tap root. This effect is ascribed primarily to the elimination of toxic elements such as Al, with secondary benefits from improved P and N availability. In general the amount of lime required for optimum growth varied between 20 and 40% of the amount needed to raise the pH value to 7,0.

Introduction

In reviewing the prospects for sugar beet in Natal, Rose[11] considered that it would grow satisfactorily in such areas as Richmond, Howick, Nottingham Road, Rosetta, Mooi River and Seven Oaks despite the fact that conditions were so unlike those found in the traditional beet-growing areas situated in northern temperate regions. On the credit side the physical properties of the soils in the above areas appeared to fulfil four major requirements for successful beet production:

(i) good soil depth which is conducive to unimpeded tap root development;
(ii) non-plastic consistency of soils which, by minimising soil adherence to roots when wet, promotes more efficient mechanical harvesting and less spoil reaching factories;
(iii) general suitability of texture for good seedbed preparation;
(iv) freedom from stones.

With regard to the chemical aspects, however, the factor of greatest concern in the local environment was the strongly acid reaction which characterises these soils and the detrimental effect this would have on root growth. Certainly the wealth of literature on sugar beet nutrition leaves little doubt about the sensitivity of this crop to soil acidity which manifests itself mainly in irregular germination, stunted plant growth with chlorosis of the leaf and fibrous and fangy development of the tap root.

In order for the SASA Experiment Station to mount an experimental programme with sugar beet in time for planting in September 1975, and to ensure that soil acidity was corrected, the following priorities were recognized:

(i) to locate suitable sites for conducting the preliminary field trials;
(ii) to sample top and subsoils from these sites with the main object of determining pH and exchangeable Al levels in order to apply lime, where necessary, before the first sowing;
(iii) to conduct glasshouse experiments at the Station in order to test the effects of top and subsoil acidity on root development and to compare the efficacy of two different procedures for assessing lime requirement.

The above have been investigated and this paper reports on the progress achieved.

Phase I — Siting and sampling of field trials

Widely varying soil types and topography and fragmented distribution of land in the areas concerned made it necessary to visit a large number of prospective co-operators in order to locate suitable representative sites. This was accomplished by subdividing the test area into bioclimatic subregions, based on the system of classification developed by Professor Phillips.[8] In all, four subregions were identified. Of the twelve growers initially approached, four were located in the Mistbelt Evergreen region, two in the Mistbelt Thicket, two in the Coast Hinterland and four in the extensive Highland Montane region, as shown in Fig. 1.

To facilitate further the selection of sites, growers were asked to comment, where possible, on the following:

(i) cropping and fertilizer history of the field concerned, particularly with regard to liming;
(ii) previous soil analysis;
(iii) type of land preparation equipment available;
(iv) rainfall distribution;
(v) frequency of hailstorm incidence.

Environmental assessment

Important bioclimatic features of the identified subregions are given in Table 1. There is a marked difference in altitudes, which is reflected in the mean diurnal temperature ranges as well as in historical rainfall distribution trends. In the Highland Montane region, which lies at nearly twice the altitude of the Coast Hinterland, it might be expected that the significantly milder conditions could exert a marked effect on the production cycle. A comparison of rainfall data shows that distribution is most favourable in the Mistbelt Evergreen area, with no more than two months of the year likely to receive less than 25 mm. This suggests that, in this subregion, sufficient moisture might be available to cover both a Spring sowing and an Autumn drilling, whereas in the Highland Montane area, with 3 to 4 months of the year with less than 25 mm rainfall, the feasibility of an Autumn planting appears less likely.

Soil assessment

(i) Soil sampling

Composite top soil samples (0–20 cm) were taken for analysis, as well as single profile samples (0–60 cm), for identification of the soil series present. A Polymetrohm portable pH meter was used in the field for an assessment of soil acidity to depth.

(ii) Analytical

After extraction with 1N ammonium acetate in the laboratory, the amounts of Ca, Mg, K and Na were determined by atomic absorption spectrophotometry. Exchangeable Al and 0,02N H_2SO_4 soluble P were determined colorimetrically, using methods based on the reagents pyrocatechol violet[4] and molybdenum blue, respectively. Plant available Zn was determined by the

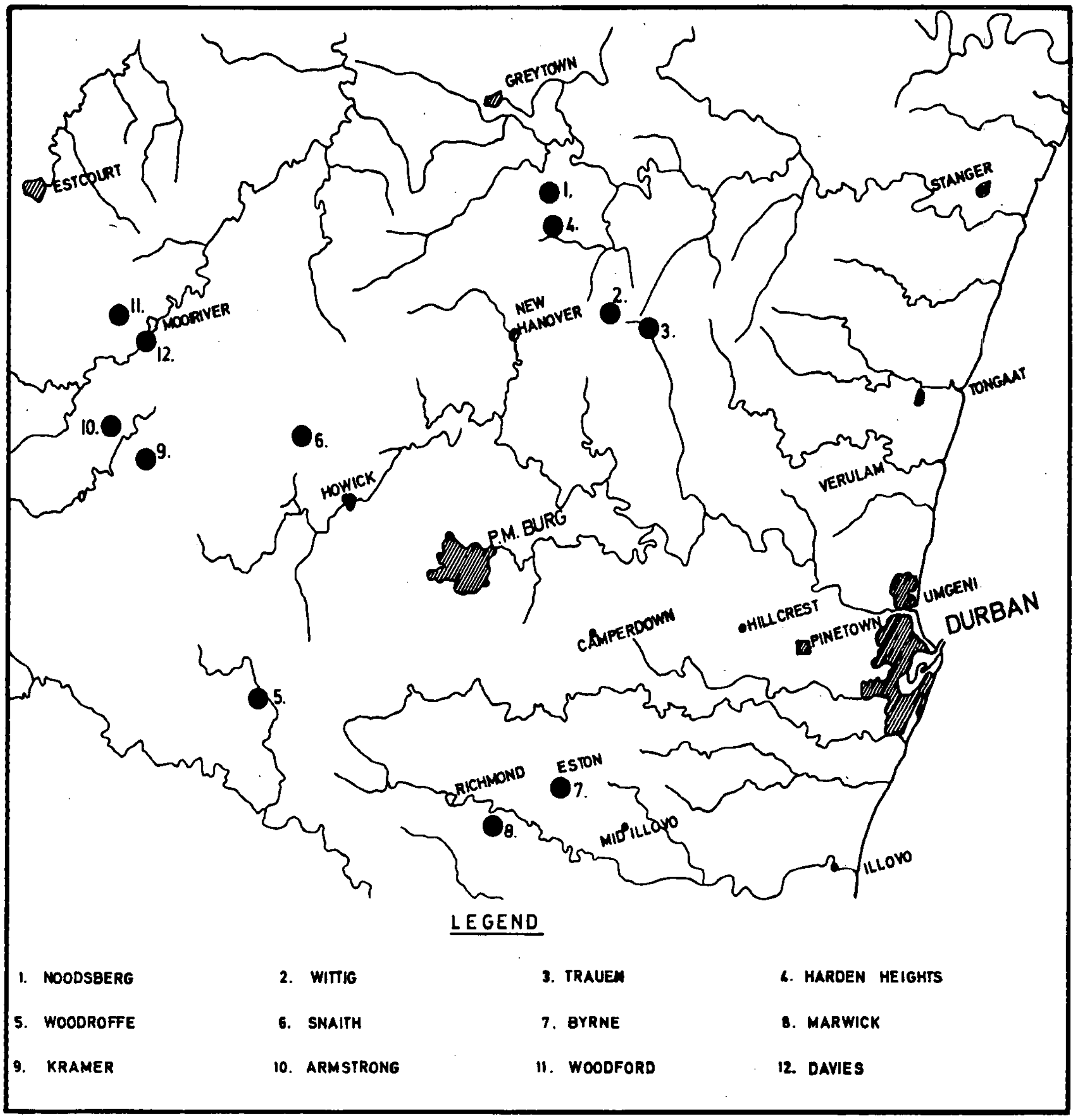

FIGURE 1 The location of prospective co-operators for sugar beet field experiments.

TABLE 1

Selected environmental characteristics of the sites sampled

Co-operators	Locality	Eleva-tion (m)	Bioclimatic* Subregion	Rainfall* (mm)					Temperature*		
				Mean Annual (x 100mm)	Distribution (mths)			Pot Evap. Trans. (mm)	Mean Annual	Mean daily	
					Wet >100mm	Med. 25–100	Dry <25			Max.	Min.
Noodsberg Sugar R. Wittig Trauen Est. G. Rawlinson	Seven Oaks Jaagbaan Glenside Harden Heights	1000 to 1200	Mistbelt Evergreen	8–16	5–7	3–5	1–2	680–800	10–17	23–24	8–9
G. Woodroffe J. Snaith	Elandskop Howick	1300–1500	Mistbelt Thicket	8–10	5	4–5	2–3	680–800	17–18	22–23	11–12
M. Byrne	Eston	800 to 1000	Coast hinterland Evergreen	8–13	4–6	4–6	1–3	840–940	17–20	22–28	10–15
T. Marwick	Richmond		Coast hinterland Thicket	7,5–11	4–6	4–5	2–3	840–940	17–18	22–23	10–14
B. Kramer G. Armstrong Woodford G. Davies	Nottingham Rd Rosetta Mooi River Mooi River	1500 to 1600	Highland Montane	8,5–11	4–5	4	3–4	680–740	13–16	20–23	5–10

* After Phillips[8]

TABLE 2

Physical and chemical composition of soils in relation to depth

Bioclimatic Subregion	Co-operator	Section/ field	Soil Series	Horizon (cm)	Clay %	pH (H_2O)	EAI ppm	P ppm	PDI	K ppm	Ca ppm	Mg ppm
Mistbelt Evergreen	Noodsberg Sugar	Ryehill	Balmoral	Comp 0–20	55	5,0	70	7	0,11	165	330	165
				A 0–30	56	5,0	74	3	0,08	61	230	97
				B 30–50	64	5,0	24	2	0,03	35	110	56
	R. Wittig	Driefontein	Longlands	Comp 0–20	13	5,0	16	14	0,76	57	270	67
				A 0–30	15	4,9	69	4	0,68	27	90	29
				B 30–50	10	5,1	17	8	0,76	37	150	42
	Trauen Estate	Adjac. House	Doveton	Comp 0–20	44	5,6	4	21	0,27	117	590	169
				A 0–25	44	5,6	5	26	0,32	95	630	130
				B 25–50	45	5,3	6	1	0,13	25	330	71
	Harden Heights Wattle	Old Maize Land	Farningham	Comp 0–20	44	4,8	39	18	0,35	177	470	153
				A 0–30	44	5,5	74	8	0,35	107	270	107
				B 30–50	48	5,1	26	2	0,20	31	210	250
Mistbelt Thicket	G. Woodroffe	Milk Depot	Griffin	Comp 0–20	47	4,7	164	26	0,25	151	670	75
				A 0–20	50	4,8	175	18	0,22	113	790	65
				B 20–70	50	4,9	256	5	0,21	67	250	29
	J. Snaith	Topfield	Griffin	Comp 0–20	46	5,7	3	30	0,14	197	1 290	213
				A 0–40	46	5,6	1	20	0,09	221	1 290	207
				B 40–60	44	5,2	25	1	0,02	73	590	121
Coast Hinterland	M. Byrne	54	Fountain-hill	Comp 0–20	—	4,9	10	1	0,01	37	130	65
				A 0–75	15	5,5	12	13	0,02	123	550	105
				B 75+	21	5,1	5	1	0,02	33	130	17
	T. Marwick	Old Maize Land	Farningham	Comp 0–20	51	5,5	5	23	0,07	189	970	166
				A 0–25	23	5,4	22	21	0,03	117	470	124
				B 25–70	45	4,9	24	2	0,04	41	150	70
Highland Montane	B. Kramer	Lintrose I	Farningham	Comp 0–20	36	4,7	47	48	0,22	201	830	77
				A 0–20	32	4,8	93	10	0,15	227	430	73
				B 20–40	44	4,4	140	4	0,13	101	130	31
	G. Armstrong	Solitude	Doveton	Comp 0–20	35	5,4	6	43	0,15	173	1 030	53
				A 0–20	28	5,3	10	52	0,15	143	950	63
				B 20–40	42	4,8	52	4	0,08	79	350	51
	Woodford	Hutton I	Hutton	Comp 0–20	36	4,9	90	35	0,23	303	350	69
				A 0–20	35	4,8	83	15	0,23	243	390	69
				B 20–40	35	4,7	58	5	0,18	175	230	51
	G. Davies	Beca	Doveton	Comp 0–20	44	4,9	78	37	0,19	265	570	209
				A 0–20	35	5,2	28	7	0,14	339	530	250
				B 20–40	47	4,9	74	4	0,11	179	270	153

method of Trierweiller and Lindsay,[13] and pH by using a 1:2,5 soil : water ratio. Since many of the soils were atypical of the series in the sugarbelt, the system of classification developed by Van Eyck *et al*,[15] based on soil form, texture and chemical composition, was used to classify the soils at each site. Selected results are shown in Table 2.

(iii) Soil series

At least seven soil series were identified, of which at least four (Hutton, Doveton, Farningham and Balmoral) fell into the Hutton form. The soils from the four Highland Montane sites also belong to this form and it is likely that these, together with the Avalon form, comprise most of the arable land in this subregion.

Texture ranged from a grey loamy sand, at Driefontein farm, to a red heavy clay, at Noodsberg Sugar Company. More than 70% of the soils sampled were either clays or sandy clay loams. Under these conditions, since mainly 1:1 lattice clay minerals are present, moisture holding properties should vary from good to excellent.

(iv) Nutritional limitations

The chemical characteristics of these soils may be summarised as follows:

(1) Top and subsoils are generally moderately to strongly acid. The minimum pH value to avoid acid damage is generally agreed to be 5,3, and application of this criterion to the pH data in Table 2 indicates that eight of the sites require lime.

(2) Moderate to high levels of exchangeable Al are associated with soils having pH values below 5,3. While Al toxicity is likely to appear at only three sites if sugarcane is the intended crop, the hazard of a metal toxicity for sugar beet is much greater and excessive uptake of Al and Mn would occur in the majority of cases where pH values are below 5,3. A significant feature of the result is the relatively high level of subsoil exchangeable Al at all four sites in the Highland Montane region.

(3) In terms of the PDI (Phosphorus Desorption Index)[8] six of the soils are strongly (<0,20), five moderately (0,20–0,40) and the balance weakly P sorbing (>0,40).

TABLE 3

Summary of rainfall distribution and chemical and physical properties of main environment sites

Site	Rainfall dist.	Physical properties		Chemical properties				
		FMC**	Drainage	K	P	P fix.	Al toxicity hazard	
							Topsoil	Subsoil
Noodsberg	Good	Good	Good	Adequate	Low	Severe	Moderate/severe	Slight
Wittig	Good	Low	Variable	Low	Low	Low	Slight/moderate	Slight
Trauen	Good	Med/good	Good	Med.	Mod.	Mod.	Absent	Absent
Harden Heights* . .	Good	Med/good	Good	Adequate	Low	Mod.	Slight	Slight
Woodroffe	Moderate	Med.	Good	Adequate	Mod.	Mod.	Severe	Severe
Snaith*	Moderate	Med/good	Good	Adequate	Mod.	Low	Absent	Slight
Byrne	Good/mod	Med/good	V. Good	Low	Low	Severe	Absent	Absent
Marwick	Mod/variable	Med/good	Good	Adequate	Mod.	Severe	Slight	Slight
Kramer	Variable	Med/good	Good	Adequate	High	Low	Moderate	Severe
Armstrong* . . .	Variable	Med/good	Good	Adequate	High	Low	Moderate	Moderate
Woodford	Variable	Med/good	Good	Adequate	Mod.	Mod.	Moderate/severe	Moderate
Davies*	Variable	Med/good	Good	Adequate	Mod.	Low	Moderate/severe	Moderate

* Critical trial sites. ** FMC — field moisture capacity.

(4) In the absence of reliable threshold values for sugar beet based on the extractants used, it would seem that, by sugarcane standards, the soils are in general fairly well supplied with K, Ca and Mg, while P tends to be marginal to deficient.

Overall assessment

From the overall assessment of the main environmental, soil physical and chemical properties summarised in Table 3, it is clear that Rose's observation on degree of soil acidity is well founded. While conventional liming will serve to correct this limitation in the top soil, amelioration of acid subsoils is a major, costly operation and best avoided. Sites with strongly acid subsoils and high exchangeable Al levels were therefore generally not favoured for use in critical trials. Sites considered to be suitable for field experiments, by climatic, soil physical and chemical criteria, are indicated with an asterisk in Table 3.

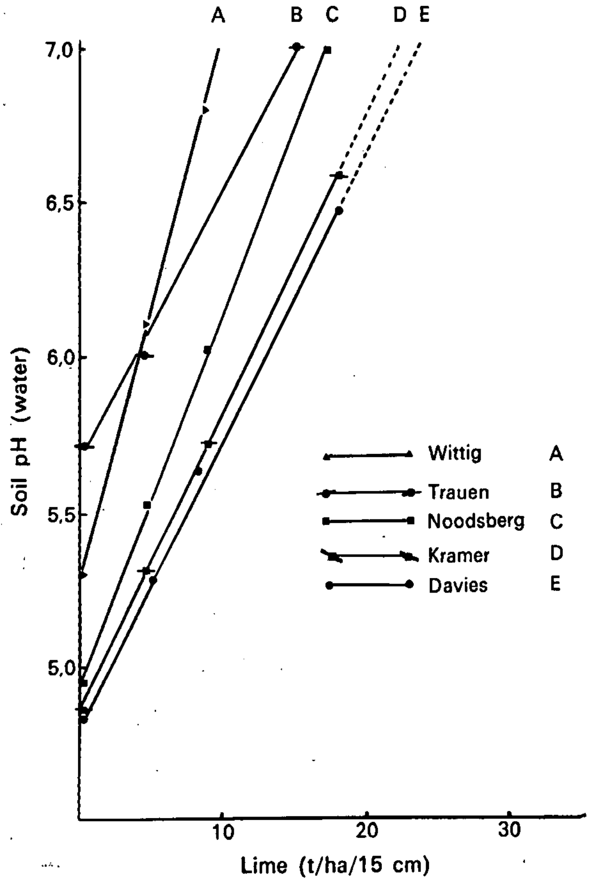

FIGURE 2 Lime calibration curves for soils from selected sites.

Lime recommendation procedure

Traditional methods of determining lime requirement[2] are based on the amount of lime needed to raise the pH of the soil to a value of 7,0. Local experience with sugarcane has shown that this method grossly overestimates the amount of lime necessary for maximum yields, and may even lead to a yield decline through a reduction in the availability of micronutrients such as zinc.[6] In Natal it has been shown, by glasshouse and field experiments with sugarcane and other crops, that a response to limestone is unlikely to occur in soils with pH values above 5,6 (water) and that below this pH level response to lime is closely correlated with exchangeable Al and texture, rather than pH *per se*.[9,10]

To determine the effect of increasing levels of lime on soil pH and exchangeable Al, samples of soil from the various trial sites were equilibrated with four rates of lime (equivalent to 0, 4,5, 9,0 and 18 tons/ha) for one week at 60% of field moisture capacity. The relationship between lime applied and resulting pH in soils tested from selected sites is shown in Fig. 2.

The amount of lime needed to raise the pH level to a value of 7,0 ranged from 8 tons/ha/15 cm, for a poorly buffered soil such as the Longlands series, to over 25 tons/ha/15 cm for strongly buffered soils such as the Doveton series from Trauen Estates. Clearly this criterion could not be applied in assessing lime requirement. Previous investigations and the present results indicate that, when exchangeable Al is plotted against soil pH, an inverse curvilinear relationship is obtained (see Fig. 3) and that, above a pH value of 5,6, exchangeable Al is virtually non-existent. This level was therefore selected as the cut-off point for recommending lime.

The quantities of lime corresponding to this value were then determined by reference to the various calibration curves given for a selected number of sites in Fig. 2. A comparison of the lime requirements based on the two methods is given in Table 4. On average, lime requirement based on a pH value of 5,6 is about 35% of the amount needed to raise the soil to a neutral pH level.

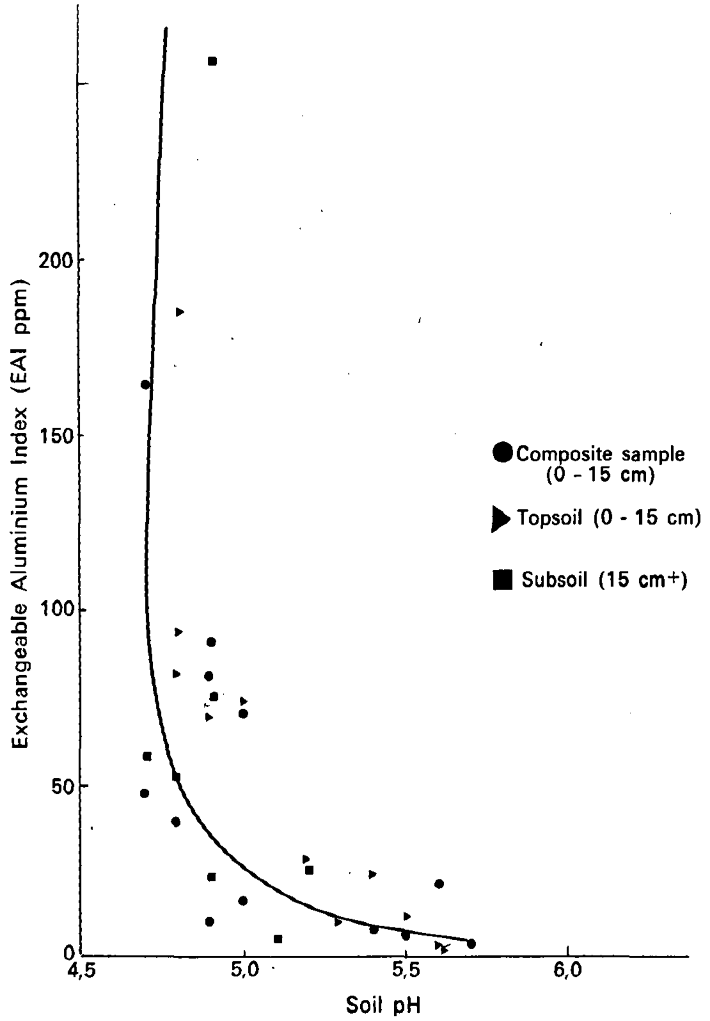

FIGURE 3 Relationship between soil pH and exchangeable aluminium.

TABLE 4
Comparison of lime requirements based on two different criteria for 12 potential sites

Co-operator	Liming to pH 7,0* (tons/ha/15 cm)	Liming to pH 5,6 (tons/ha/15 cm)	Difference (tons/ha/15 cm)
Noodsberg Sugar Co.	17	7	10
R. Wittig	10	3	7
Trauen Estate . .	15	0	15
G. Rawlinson . .	20	6	14
G. Woodroffe . .	24	12	12
J. Snaith	16	0	16
M. Byrne	22	6	16
T. Marwick . . .	20	4	16
B. Kramer . . .	22	8	14
G. Armstrong . .	19	3	16
Woodford. . . .	22	9	13
G. Davies. . . .	24	9	15
Average	20	6	14

* Rates > 18 t/ha lime are estimates based on projection of graph.

Phase II — Glasshouse experimental programme

On the subject of liming, Draycott[2] has reported that "surprisingly few thorough investigations have been made to determine optimum pH for sugar beet". In a number of experiments conducted overseas, liming to increase soil pH to 7,0 has been shown to be beneficial in increasing root yields by an average of nearly 16%. Recent investigations conducted by Draycott[3] on rooting depth, using a neutron probe, have shown that a neutral profile to a depth of at least a metre is desirable as sugar beet is considered to be a deep-rooted plant (tap root penetration is up to 1,7 metres according to Rose[11]).

It is possible that lime recommendations based only on eliminating exchangeable Al are inadequate for sugar beet and that there may also be merit in incorporating lime to depth where subsoils are strongly acid. To examine this somewhat more critically and objectively, a programme of pot experimentation was initiated to test the following:

(i) the effect of varying rates of limestone on the yield and quality of sugar beet;
(ii) the relationship between response to limestone and various chemical parameters such as pH, exchangeable Al, etc.;
(iii) the comparative effect of shallow (± 20 cm) or deep (± 60 cm) incorporation of lime on the yield and development of the tap root.

Experimental procedure

Soils

Before the establishment of the field experiments bulk samples of top and subsoil (± 2 tons) were collected from the farms Lintrose and Rondebosch, situated in the Nottingham Road/Mooi River area. These sites were selected because of fairly high levels of exchangeable Al distributed to a depth of 60 cm (refer to Table 2).

The bags of top and subsoil, as received from the field, were each thoroughly mixed, passed through a 2 mm screen and mixed again to ensure as uniform a sample as possible. Samples of soil were taken for the determination of available moisture capacity and for routine chemical analysis.

Treatment design

Experiment 1 (levels of lime)

Sugar beet was grown in plastic pots containing 4 kg of top soil of either the Farningham (Kramer) or Doveton (Davies) series soils. Lime was applied at four levels equivalent to 0, 4, 8 and 20 tons/ha/15 cm depth to the first of these soils and at 0, 4, 9 and 22 tons to the second (see Table 5). There were four replications of each treatment. A basal dressing equivalent to 1 200 kg/ha of fertilizer mixture 2:3:2 (22% + 1% Zn) was applied to all pots. The lime was thoroughly incorporated into the soil about 10 days before planting.

TABLE 5
Treatments used in pot experiments

Site and soil series	Experiment 1	Experiment 2	
	Rate of lime tons/ha	Rate of lime tons/ha	Depth (cm)
Kramer (Lintrose)	0	0	0
(pH = 5,0 EAI = 17 ppm) .	4	8	0–25
Farningham	8	8	0–25
	20	8	25–60
Davies (Rondebosch) . . .	0	0	0
(pH = 4,9 EAI = 34 ppm) .	4	8	0–25
Doveton	9	8	0–25
	22	8	25–60

Experiment 2 (deep liming)

Sugar beet was grown in large, heavy-duty plastic dustbins containing approximately 50 kg subsoil, plus 27 kg top soil from either the Farningham or Doveton series. The soils received lime at three levels equivalent to 0, 8 or 16 tons/ha as shown in Table 5. There were three replicates of each treatment. A basal dressing of fertilizer was applied at a level similar to that in Experiment 1 above. In the 8 ton/ha treatment, lime was applied to the top soil while in the 16 ton/ha treatment it was incorporated both in the top and subsoil.

Planting and management

In both experiments, 8–10 seeds (variety Hilleshog Nomo) were planted in each pot and, after three to four weeks' growth, the seedlings were thinned down to 3 per replicate. The moisture content of the small pots was maintained at near field capacity by daily watering to a predetermined weight, allowance for the increase in weight of the plants being made after six weeks' growth. In the bins, the moisture content of the soils was raised at the start to near field capacity, after which a daily addition of a fixed volume of water was made to each bin. Every week the bins were weighed and watered, where necessary, to near field capacity. All containers were also regularly rotated, in sequence, within each replication to minimise differential effect of light and temperature in the glasshouse.

Leaf area measurements were made on the three oldest leaves of each seedling after five weeks' growth. Both experiments were harvested when the beet was about 3½ months old. The following measurements were made:

- (i) total fresh matter production (top and root weight);
- (ii) weight of crown and roots after topping. In Experiment 2, tap root length was measured;
- (iii) moisture content, sugar percentage and purity of the fresh beet juice, determined on composite samples from the various treatments taken shortly after harvest;
- (iv) analysis of petioles and leaves dried at 80 °C for total N, P, K, Ca, Mg, S and Zn;
- (v) analysis of clarified juice for pH, K, Na, Ca and α-amino nitrogen from composite beet samples in Experiment 2;
- (vi) tops were oven-dried at 80 °C, re-weighed dry and petioles and laminae analysed separately for total N, P, K, Ca, Mg, S and Zn.

Results

To facilitate comparison, the yields produced by liming in Experiments 1 and 2 have been expressed as a percentage of maximum yield.

Experiment 1

The yield response to liming top soil only is shown in Table 6, while the effect of lime on selected soil properties and nutrient uptake by the sugar beet tops is shown in Tables 6 and 7 respectively.

TABLE 6

Effect of liming on yield and quality of sugar beet (Experiment 1)

Site	Lime (t/ha)	Leaf area (cm²) 5 weeks	Yield (g fresh)		% of max. output			Beet quality			
			Tops	Roots	Leaf area	Tops	Roots	Dry matter %	Juice purity	Sucrose %	Sugar (kg/m²)
Kramer . . .	Nil	25,7	175	105	50	67	82	20,5	85	12,6	0,44
	4	51,4**	229	120	100	88	94	21,4	90	14,4	0,57
	8	27,4	244	104	53	93	82	19,3	90	12,5	0,43
	20	17,1	260	127	33	100	100	20,0	90	12,9	0,54
L S D	5%	13	64	31	25	24	25	—	—	—	—
	1%	18	89	44	35	34	34	—	—	—	—
Davies. . . .	Nil	6,1	60	15	13	24	8	—	—	—	—
	4	22,1**	202*	111**	47	80	60	22,9	88	14,9	0,55
	9	46,6	220	185**	100	88	100	20,7	89	13,9	0,85
	22	30,6	251	140	65	100	76	20,6	88	13,5	0,63
L S D	5%	14	72,3	40,2	30	29	22	—	—	—	—
	1%	18	101,4	56,4	39	39	30	—	—	—	—

TABLE 7

Influence of lime on selected soil properties and mineral composition of sugar beet

Site	Lime (t/ha)	Beet yield (g)	Soil			Sugar Beet							
						Laminae				Petioles			
			pH	Base sat. %	EAI (ppm)	N%	P%	K%	Zn ppm	N%	P%	K%	Zn ppm
Kramer	0	105	5,25	34	15	2,37	0,20	3,33	440	0,80	0,19	2,90	96
	4	120	5,50	50	1	2,42	0,21	4,04	265	0,81	0,20	2,48	70
	8	104	6,35	81	Tr	2,70	0,21	3,70	120	0,81	0,20	2,17	52
	20	127	6,60	90	Tr	2,74	0,21	3,40	105	0,82	0,19	1,87	40
Davies	0	15	4,85	25	39	2,34	0,11	4,06	234	0,90	0,14	3,67	59
	4	111	5,23	33	7	2,43	0,18	4,30	195	0,90	0,13	3,80	60
	9	185	5,95	63	Tr	2,84	0,23	4,18	140	0,91	0,18	3,25	45
	22	140	6,70	80	Tr	2,94	0,25	4,14	138	1,00	0,19	3,00	42
Critical concentrations			5,30	—	—	—	0,10	1,00	9	—	0,07	1,00	—

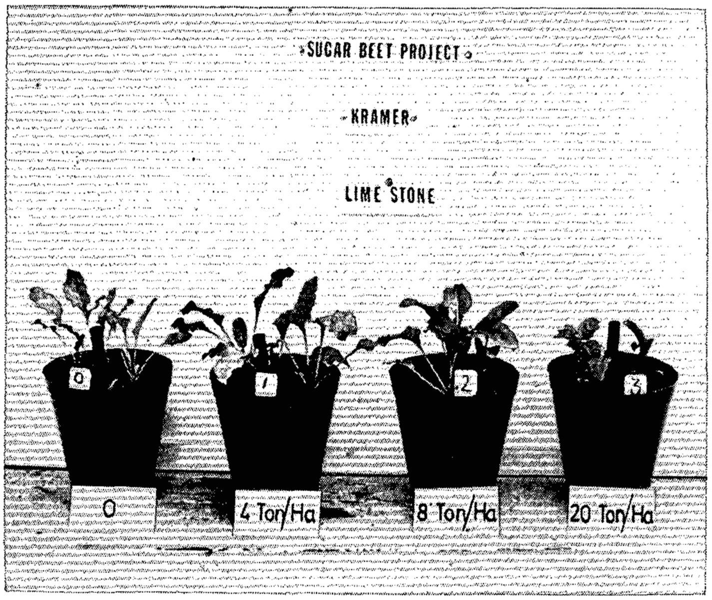

FIGURE 4 Sugar beet growth at 5 weeks as affected by rate of lime (Kramer).

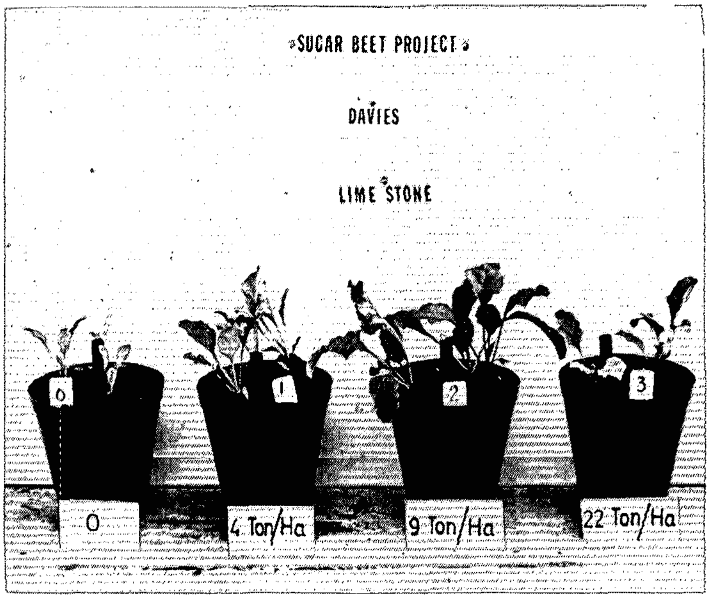

FIGURE 5 Sugar beet growth at 5 weeks as affected by rate of lime (Davies).

The following treatment effects were shown:

(i) Leaf area

Leaf area development when the beet was five weeks old shows the marked influence of lime at this early stage, particularly in the soil from the Davies site, as depicted by the photographs shown in Figs. 4 and 5. The best leaf areas were associated with a rate of 9 ton/ha lime in the Davies soil, and with 4 ton/ha in the Kramer soil. Levels of lime in excess of these rates depressed green matter production on soils from both sites, particularly on that from the Kramer site (see Fig. 5).

(ii) Top and root yields

The top and root response to liming was markedly superior in the soil from Davies to that in the soil from Kramer, which confirms the trend shown by leaf area measurements. In the former soil the response to liming was significant and linear up to 9 tons/ha ($p = 0{,}01$),

TABLE 8

Effect of deep liming on sugar beet yield and quality (Experiment 2)

Site	Lime		Leaf area (cm²)	Yield (g fresh)		Tap root length (cm)	% of max. output				Beet quality			
	t/ha	Depth (cm)		Tops	Root		Leaf area	Tops	Root	Root length	Dry matter %	Juice purity	Sucrose %	Sugar (kg/m²)
Kramer (Farningham Series)	0	0	49,1	817	523	24,0	64	67	58	59	19,3	83	13,2	0,35
	8	0–25	69,8	1 058	810	24,4	91	87	90	60	18,4	82	11,4	0,47
	16	0–60	76,6	1 217	902	40,7	100	100	100	100	18,5	81	11,4	0,52
LSD	5%		23	383	272	—	30	31	30	—	—	—	—	—
	1%		32	536	391	—	42	44	43	—	—	—	—	—
Davies (Doveton Series)	0	0	12,4	500	187	19,0	21	46	16	63	20,0	83	12,8	0,12
	8	0–25	52,8	892	1 047	24,5	89	81	88	80	20,3	87	13,3	0,70
	16	0–60	59,1	1 097	1 193	30,5	100	100	100	100	19,5	85	12,6	0,76
LSD	5%		15	226	229	—	25	22	20	—	—	—	—	—
	1%		21	316	339	—	35	29	28	—	—	—	—	—

TABLE 9

Effect of deep liming on soil pH and exchangeable aluminium, and nutrient composition of the beet tops

Site	Lime (t/ha)	Root production		Soil				Sugar Beet							
				pH		EAI (ppm)		Laminae				Petioles			
		Yield (g fresh)	Length (cm)	top	sub	top	sub	N%	P%	K%	Zn (ppm)	N%	P%	K%	Zn (ppm)
Kramer	0	523	24,0	5,30	4,50	17	140	3,0	0,18	4,5	336	1,1	0,17	4,2	97
	8	810	24,4	5,85	4,60	Nil	140	3,9	0,21	4,1	105	1,5	0,21	4,0	33
	16	902	40,7	6,10	6,30	Nil	Nil	4,1	0,22	3,1	107	1,6	0,23	4,1	43
Davies	0	187	19,0	4,90	4,50	34	74	2,5	0,12	4,1	310	1,3	0,10	6,5	72
	8	1 047	24,5	5,70	5,20	Nil	74	2,6	0,18	3,7	169	0,7	0,90	2,9	70
	16	1 193	30,5	5,70	6,50	Nil	Nil	2,6	0,18	3,3	139	1,0	0,12	3,8	77

but beyond this level additional lime resulted in a significant decline in the yield of beet ($p = 0{,}05$). By comparison, the response to liming in the Kramer soil is small and not statistically significant, for reasons which will be considered in later discussion.

Throughout the experiment the control plants in the Davies soil showed characteristic symptoms of acid injury, starting with irregular germination which was followed by slow growth of seedlings and pronounced yellowing of the leaves. In addition to these foliar symptoms, the roots were affected and very poorly developed.

(iii) Soils

Marked increases in soil pH and decreases in exchangeable Al occurred in both soils with liming. Base saturation increased on an average from 25 to 90% at the highest level of lime.

(iv) Plant uptake

In both soils, liming produced an improvement in nitrogen uptake as indicated by higher nitrogen values in the leaf blade. P uptake improved by over 100% in the Davies soil, but liming caused a marked reduction in Zn uptake from both soils. The abnormally high levels of Zn found are most probably associated with the use of a zincated basal fertilizer. An assessment of the foliar analyses in terms of available critical values which have been published[14] revealed no deficiency of any of the major or minor elements.

(v) Beet quality

Sucrose production tended to be low, which is not surprising in view of the age of the crop and the relatively high moisture conditions in the soil. A statistical evaluation of thc effect of treatments on sucrose quality was not possible, as there was insufficient root material in individual treatment replicates for evaluation.

Composite values are given in Table 6 and suggest that an inverse trend may exist between levels of lime and sucrose percent in the Davies soil. The decline in sucrose percent has not been sufficient, however, to offset the beneficial effects of liming.

Experiment 2 (liming top and subsoil)

Liming to a depth of 60 cm produced the following effects (see Tables 8 and 9):

(i) Leaf area

Maximum leaf area development resulted from deep liming, although the increase over shallow liming was not statistically significant. Yellowing of the leaf tissue in the Davies controls was at first very pronounced but the symptoms were less noticeable after two months' growth. Here Experiment 2 differed from Experiment 1.

(ii) Yield and quality

Development of the tap root was better with deep than with shallow placement of lime. Despite this observation, overall yields from deep liming were, on average, only about 10% better than those from conventional placement. Root penetration in the unlimed Davies soil was often limited, with signs of discoloured, fibrous and fangy lateral roots which contrasted markedly with the well-proportioned symmetry of a healthy root system

FIGURE 6a Abnormal root development under acid conditions.

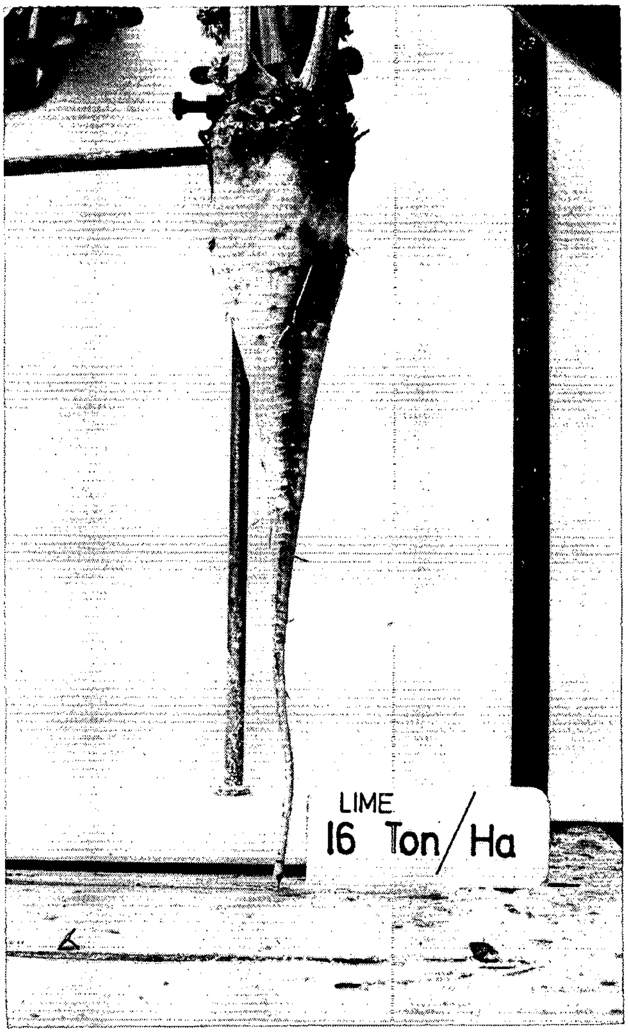

FIGURE 6b Normal root development after liming.

associated with deep liming, as shown by the examples in Fig. 6. Deep liming produced no significant effect on the quality of the beet.

(iii) Soils and nutrient uptake

Deep placement of lime increased subsoil pH to over 5,3 in both cases, and this was accompanied by a sharp decline in exchangeable Al levels (see Table 9). With the exception of a lower content of K in the leaf blade liming to depth did not affect nutrient uptake to any large degree.

Discussion

So far this study has provided an indication of the extent to which sugar beet can respond to shallow and deep placement of lime. In order to determine whether the criterion that was used for establishing the lime requirement of the field experiments (based on raising pH value to 5,6) was justified, it is necessary to examine the plant-soil pH-exchangeable Al relationship a little more closely.

Some of the data from Experiment 1, given in Tables 6 and 7, are shown plotted in Fig. 7. A comparison of the response, pH and exchangeable Al curves, for the two soils reveals the following:

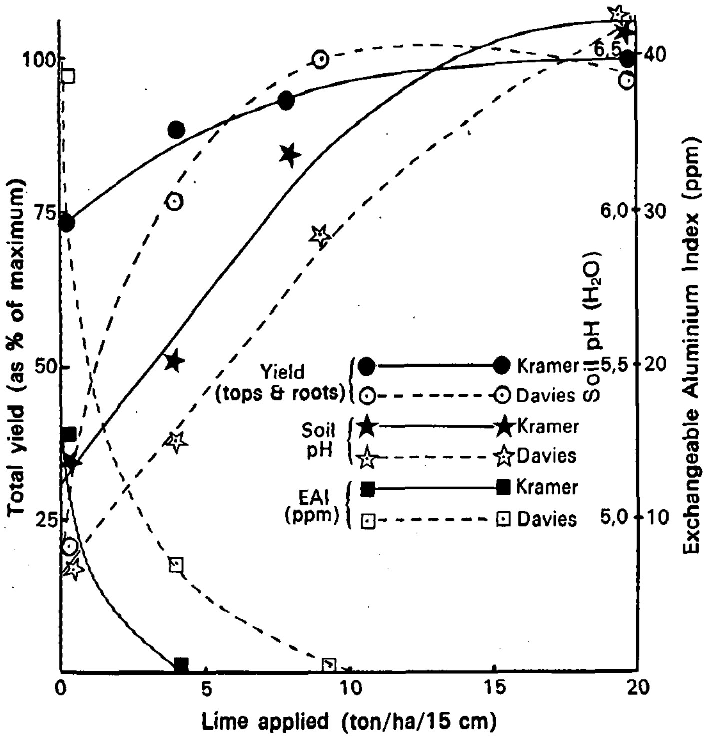

FIGURE 7 Effect of lime on yield of sugar beet (total) in relation to Soil pH and EAI.

(i) the response to liming is directly proportional to pH and inversely proportional to EAI;

(ii) the intersection of the two response curves corresponds to just over 90% of maximum yield, and reference to the two pH curves shows that this is associated with a pH value lying between 5,4 and 5,9 and trace amounts of exchangeable Al;

(iii) the greater response to liming in the Davies soil than in the Kramer soil is associated with an initial higher level of exchangeable Al as well as a more rapid decline of Al with increasing levels of lime;

(iv) the additional amount of lime needed to raise the pH value from 5,6 (selected for field trial purposes) to a value of 7,0 (traditional criteria) would amount to over 15 ton/ha for an increase in yield of approximately 10 per cent which, in practice, would be uneconomical.

Although the experimental data are somewhat limited, the lack of a response to liming above the pH level at which exchangeable Al is eliminated provides some evidence that Al toxicity is the primary growth-limiting factor in these soils, as has been established for a range of crops in previous investigations. In view of the sensitivity of sugar beet to soil acidity, the critical value of toxic Al will be considerably lower than the value of 1,1 me% (100 ppm)[5, 6] used for sugaracne in clay soils and is likely to fall within the following range of critical values:

(i) 0,09 me% (8 ppm) for soyabean (Moschler *et al*)[7]
(ii) 0,10 me% (9 ppm) for Ladino clover (Shoop *et al*)[12]
(iii) 0,10 me% (9 ppm) for cotton (Adams and Lund)[1]
(iv) 0,20 me% (18 ppm) for alfalfa (Moschler *et al*)[7]

On the basis of Reeve and Sumner's investigations,[10] which pointed to a critical value of 0,2 me% (18 ppm) for trudan grown in soils similar to those used in this study, and the small response obtained to lime on the Kramer soil (EAI — 0,2 me%), it seems likely that the critical value for sugar beet lies between 0,1 and 0,2 me%. Further experiments would have to be carried out to establish this more accurately.

The lack of a significant response to deep lime placement should not be interpreted as indicating that subsoil acidity is unlikely to be a serious limiting factor. The deeper tap root penetration into the subsoil after deep liming is very probably due to the elimination of toxic levels of Al which, in the unlimed treatments, are far in excess of the levels in the top soil. Since moisture was never really a limiting factor during the experiment, the potential benefits of the deep liming have to a certain extent been masked. If a period of moisture stress had been induced, as happens under normal field conditions, a significant response to deep liming would seem likely.

Conclusions

The results of this investigation confirm that soil acidity is an important limiting factor in the growth of sugar beet and the indications are that, in the event of commercial production of sugar beet in the Natal Midlands, substantial areas will benefit from amelioration with lime. The need, however, for placement of lime deeper than 20–25 cm requires further investigation under conditions of simulated moisture stress.

Although, at this stage, a policy on lime requirement procedure is somewhat premature, there seems little justification in basing lime requirement on the traditional method of raising the soil pH to a value of 7,0. Liming to eliminate toxic aluminium (to pH 5,6) would seem preferable because, in general, only 30–40% of the amount of lime based on the traditional method would suffice. This would mean a saving in material and handling costs. At the same time, the risk of trace element deficiencies that frequently result from heavy lime application would be minimised.

Acknowledgements

Thanks are due to Messrs Kramer and Davies for their assistance and co-operation in providing soil for the glasshouse investigation; to Dr A. P. Draycott of the Broom's Barn Experimental Station in Great Britain for his assessment of the nutritional status of the soils used in this glasshouse study; to Mr P. A. Donovan for organising the visits to prospective sugar beet co-operators.

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