INTERIM EVALUATION OF PHOSPHOGYPSUM AS AN AMELIORANT FOR SOIL ACIDITY IN SUGARCANE

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Abstract

Results are reported of a 3x3x3 factorial trial in which phosphogypsum (PG), dolomitic limestone (DL) and single superphosphate (SS) were applied to sugarcane. The trial was situated on a Kranskop form soil with a moderately toxic aluminium (Al) content. Based on the combined yield responses from the plant and first ratoon crops, treatments with SS were superior to those with PG, and little response was obtained from DL. The high P in-furrow treatment (90 kg P/ha) gave a highly significant response of 3 t/ha sucrose compared with 2,1 t/ha from the best PG treatment (5 t/ha). Leaf P and Ca also increased with both PG and SS application. Chemical changes in the soil following PG application resulted in considerable leaching of Mg below the 400 mm soil depth. Improved chemical changes included increased pH and Ca levels in the subsoil together with a reduction in exchangeable Al. The SS/PG interaction, evidence from third leaf P analyses, and lack of any marked response to liming coupled with good root development to depth indicated that yield response to PG was due mainly to its P content. Enhanced Ca content and diminished acid saturation in the subsoil may be beneficial.

Introduction

The detrimental effects on plant growth of toxic levels of exchangeable aluminium (Al) and other problems associated with highly weathered soils, such as low levels of plant available phosphorus (P), calcium (Ca) and magnesium (Mg) and marked P fixation, are well known. In the South African sugar industry, a number of investigations have been conducted to improve the productivity of sugarcane on acid soils in the Natal Midlands (Meyer, 1970, Moberly and Meyer, 1975, Meyer and Dicks, 1979). Consequently, recommendations for the use of both lime and additional P at planting are frequently made by the Fertilizer Advisory Service (FAS) of the Experiment Station.

In large areas of the tropics, acid conditions in the subsoil may reduce effective rooting depth, resulting in inefficient exploitation of moisture reserves and increased susceptibility to moisture stress (Bouldin, 1979). Because of the low mobility of lime, subsoil acidity cannot be rectified by its incorporation into the plough layer, and this has led to increased research into the use of gypsum as a subsoil ameliorant in countries such as the USA (Hammel *et al.*, 1985), Brazil (Ritchey *et al.*, 1982, Pavan *et al.*, 1982) and South Africa (Fey, 1983, Farina, 1988). In all three countries research programmes have been based on the original work of Sumner (1970) and Reeve and Sumner (1972).

In 1983 the Waste Management Section of the Council for Scientific and Industrial Research (CSIR) began funding research at the University of Natal, in regard to the agricultural disposal of PG, a by-product in the manufacture of phosphoric acid. As part of this programme a joint co-operative trial was conducted with the university in 1984, to evaluate PG, an ameliorant for soil acidity in sugarcane. The main objective was to test whether PG could replace some or all of the lime required to neutralise toxic levels of Al in soils, and whether the P content of PG (about 1%) could provide any additional advantage in terms of residual P in the soil. This paper summarises yield data obtained from plant and first ratoon crops, and reports some of the chemical changes that occurred in the soil over a six year period.

Experimental procedure

Description of site

The trial was established in July 1984 on a site previously under a gum plantation, near Seven Oaks in the Natal midlands. The humic, deep yellow-red sandy clay loam of the Kranskop form (Kipipiri series) was characterised by its kaolin, chlorite, allophane and gibbsite clay minerals (le Roux, 1974). Selected physical and chemical properties of the soil profile to a depth of 1 000 mm are given in Table 1. The soil was strongly acid, while reserves of plant available nutrients such as P, K, Ca and Mg were low and declined rapidly with depth. Despite the low pH values, extractable acidity and exchangeable Al levels varied appreciably down

Table 1

Selected physical and chemical properties of the Kranskop form soil profile

Horizon	Depth (mm)	Clay %	Organic matter %	pH (H_2O)	Extractable cations me %				Extractable acidity me %			Extractable anions ppm		
					Ca	Mg	K	CEC	EAI	Al + H	Acid satn %	P	S	PDI
Humic A	0– 200	27	5,8	4,5	0,70	0,84	0,19	3,13	0,51	1,40	34	4	54	0,28
	200– 400	24	5,1	4,7	0,57	0,38	0,14	3,01	0,76	1,92	64	4	68	0,30
Yellow-brown Apedal B	400– 600	27	3,8	4,8	0,22	0,36	0,09	1,72	0,56	1,05	48	2	43	0,32
Red Apedal B	600– 800	32	2,4	4,8	0,24	0,21	0,06	1,85	0,24	0,64	35	1	19	0,38
	800–1 000	36	1,8	4,9	0,26	0,25	0,05	0,85	0,10	0,28	33	1	12	0,41

the profile. There was a distinct zone of high acidity (acid saturation more than 60%) at the 200 to 500 mm soil depth, in which exchangeable Al levels exceeded the threshold value of 0,6 me% (54 ppm), but there was a rapid decline in Al content below this depth.

Treatment design

Previous studies with PG had indicated that its use, in combination with dolomitic lime, was more effective in neutralizing Al to depth than if used alone (Pavan *et al.*, 1982) and that the P content of PG could be significant. It was decided to test PG in combination with lime and phosphorus in a 3^3 factorial trial with the following treatments: 0,5 and 10 t/ha PG, 30, 60 and 90 kg/ha P as single superphosphate and 1,5, 3 and 6 t/ha dolomitic lime. Lime and PG were incorporated to a depth of 150 mm with two passes of a double gang disc harrow about six weeks prior to planting. P as single superphosphate (10,5%) was applied in the furrow at planting, together with zinc fertilizer material (22% Zn) at a rate of 12 kg Zn/ha. All plots were top-dressed with 1-0-1 (47) fertilizer mixture. Each plot consisted of six cane rows, 12 m long and 1,1 m apart, while the harvested plot area comprised four rows each 10 m long. The PG was moist (30% H_2O) and contained on a dry mass basis 33% Ca, 19% S and about 0,75% citric acid soluble P. The crystalline dolomitic lime used was from Umzimkulu and contained 70% $CaCO_3$ and 25% $MgCO_3$.

Planting and management

The trial was planted with variety N12 in August 1984. Stalk counts and heights were recorded at regular intervals, while third leaf samples were taken periodically during growth to monitor changes in nutrient status. The plant and first ratoon crops were harvested at 21 and 23 months respectively. All plots were soil sampled to a depth of 600 mm prior to planting, and then annually in order to assess the effect of the treatments on chemical soil properties. Saturated paste measurements were also carried out on samples from all plots to study the effect of gypsum application on the composition of the main cations and anions in the soil solution. Results were used for calculating solution activities of all ions, using the GEOCHEM programme of Sposito and Mattigod (1979). The effect of PG on root development was studied by applying the root washing technique to two pairs of adjacent plots each containing a control (no PG) and PG treatment (Swinford and Boevey, 1984).

Results

Yield and sugarcane quality

The plant and first ratoon crop yields are summarised in Table 2 and, for comparative purposes, the two sets of data have been used to calculate the cumulative responses.

Table 2

Summary of yield and crop characteristics at harvest of plant and first ratoon crops

Treatment	Rate		Plant Aug 1984 - June 1986			1st Ratoon June 1986 - May 1988			Cumulative response	
	No.	Units t/ha	tc/ha	suc % cane	ts/ha	tc/ha	suc % cane	ts/ha	tc/ha	ts/ha
Phosphogypsum	G_0	0	114	13,56	15,4	126	12,95	16,3	-	-
	G_1	5	117	13,11	15,3	140	13,14	18,4	+17*	+2,0*
	G_2	10	104	12,80	13,2	143	12,66	18,1	+ 7	−0,4
		kg/ha								
Single supers	P_0	30	102	12,95	13,7	129	12,80	16,8	-	-
	P_1	60	116	13,25	15,1	136	13,01	17,5	+21**	+2,1**
	P_2	90	117	13,27	15,1	144	12,93	18,4	+30**	+3,0**
		t/ha								
Lime	L_1	1,5	111	13,45	14,3	135	13,03	17,3	-	-
	L_2	3,0	113	13,08	14,9	136	12,93	17,7	+3	1,0
	L_3	6,0	111	12,94	14,6	138	12,78	17,8	+3	0,8
LSD	P = 0,05		13	0,62	1,4	8	1,56	0,85	11	1,13
	P = 0,01		22	1,05	2,3	13	2,37	1,41	18	1,85

Table 3

Sucrose yield of the first ratoon crop and selected soil properties in relation to PG and DL treatment

	Sugar yield (t/ha)				EAl (200–400 mm) ppm			P (0–200 mm) ppm			Mg (0–200 mm) ppm		
Levels of lime (t/ha)	Levels of PG t/ha				Levels of PG t/ha			Levels of PG t/ha			Levels of PG t/ha		
	0	5	10	Average	0	5	10	0	5	10	0	5	10
1,5	16,6	17,9	17,4	17,3	63	55	48	5	7	5	29	24	21
3,0	15,8	17,9	19,4	17,7	52	50	36	3	6	6	100	56	43
6,0	16,6	19,2	17,6	17,8	44	46	27	5	11	9	145	65	61
Average	15,3	18,3	18,1	17,6	53	50	37	4	8	7	91	48	41

- In the plant crop there were no beneficial effects from the low rate of PG (5 t/ha) on either cane or sucrose yields. The high rate of PG (10 t/ha) significantly depressed both cane and sucrose yields at the 5% level.
- In the first ratoon crop a significant residual response in cane and sucrose yields was obtained to the low rate of PG (5 t/ha) applied at planting. The high rate of PG (10 t/ha) also produced a significant residual response, but this treatment was no better than the low rate of PG.
- By combining the plant and first ratoon yield responses, the cumulative benefit from the low rate of PG (17 tc/ha) was markedly superior to the high rate (7 tc/ha).
- The efficacy of applied PG declined with increasing rate of P. For example, the residual response to 5 t/ha PG in the presence of 30, 60 and 90 kg P/ha decreased in the order 2,8, 2,3 and 1,1 ts/ha respectively (see Figure 1).
- A significant interaction between PG and lime applied at 3 t/ha was also apparent. Residual responses to the 5 and 10 t/ha PG treatments were 2,1 and 3,6 ts/ha respectively at the 3,0 t/ha rate of lime compared with 1,3 and 0,8 ts/ha at the 1,5 t/ha rate of lime (see Table 3).

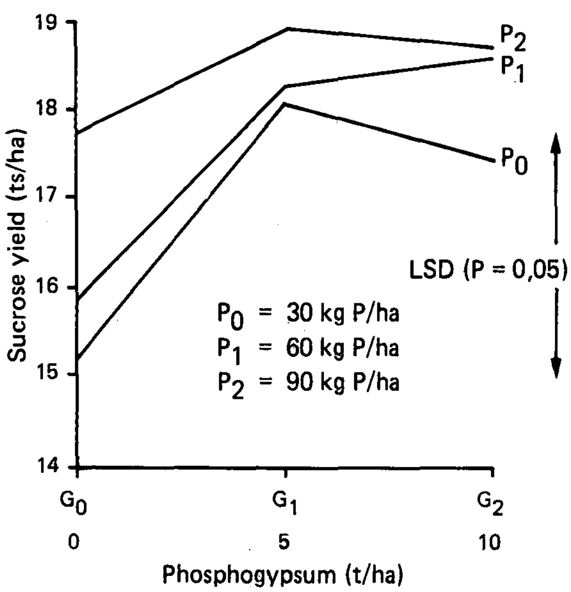

FIGURE 1 The effect of PG treatment at three levels of superphosphate on sucrose yield.

Single superphosphate:

- In the plant crop a significant response in cane and sucrose yields was obtained to the FAS recommended in-furrow P treatment of 60 kg P/ha when compared with 30 kg P/ha. Additional P in the furrow (90 kg P/ha) was no better than the standard FAS treatment.
- The residual effects of the in-furrow P treatments on both cane and sucrose yields were marked. The 90 kg P/ha treatment provided a cumulative response of 30 tc/ha cane compared with a response of 17 tc/ha for the best PG treatment (5 t/ha).
- Residual response to supers was more marked in the absence of PG. Responses to 60 and 90 kg P/ha were 0,7 and 2,6 ts/ha respectively at the G_0 level compared with 0,2 and 0,9 ts/ha respectively at the G_1 level.

Dolomitic lime:

Increasing rates of dolomitic lime produced no significant responses in cane or sucrose yield in either the plant or first ratoon crops. Cane quality (sucrose %) declined with increasing rate of lime but the effect was not significant. However, in combination with 5 t/ha PG, a significant residual response of 3,1 ts/ha was obtained to the 6 t/ha lime treatment. The treatment combinations producing the highest sucrose yield in the first ratoon crop were either 5 t/ha PG + 6 t/ha lime or 10 t/ha PG + 3 t/ha lime (see Table 3).

Soil analysis

The effects of selected treatments on chemical properties of the soil profile sampled at the end of the plant crop are shown in Figure 2, while changes in selected soil properties as affected by PG treatment over a six year period are shown in Table 4. Comparison of the main treatment effects revealed the following changes in nutrient composition:

Phosphogypsum

- Marked accumulation of S between 300 to 500 mm depth. Improved Ca status at depth though not as marked as S. Comparative changes over the six year period showed that Ca movement from PG reached a peak two years after application, with a progressive decline thereafter.
- Severe reduction in Mg levels in the upper part of the profile with the translocated Mg accumulating at depth prior to its removal from the soil profile. Leaching of K from the topsoil, although K did not appear to accumulate at depth.
- Consistent reduction of pH in the topsoil (0-200 mm) but an improvement of 0,2 to 0,3 pH units in the subsoil. Initial reduction in exchangeable Al (EAI) from 70 to 38 ppm at the 400-600 mm depth in the 10 t/ha PG treatment (see Table 4, April '86 sampling). However, after six years the effect of PG on Al was hardly detectable.
- Improvement in the extractable P content of the topsoil (0-200 mm) from 4 to 8 ppm in the 5 t/ha PG treatment with a corresponding 10% reduction in P fixation as measured by P desorption index (PDI).

Lime and single superphosphate

- Increase in soil pH in the topsoil by an average 0,2 pH units for every 3 t/ha DL applied.
- Improved Ca and Mg status in the topsoil from 6 t/ha DL, with a considerable reduction in Al. Liming apparently improved pH, Ca and Mg at a soil depth of 600 mm (see Figure 2). At the 200-400 mm depth the 6 t/ha lime treatment appeared to be as effective in reducing Al as the 10 t/ha PG treatment.
- The combined action of PG and lime improved the Ca, Mg, S and P status of the profile and reduced Al content at depth, e.g. at a rate of 10 t/ha, PG reduced the Mg content of the topsoil from 55 to 26 ppm, but in the presence of 3 t/ha dolomitic lime the Mg content was restored to 43 ppm. The high rate of PG also reduced the Al content in the 200-400 mm subsoil horizon from 63 to 48 ppm, but in the presence of 3 t/ha lime this was further reduced to 36 ppm (see Table 3).
- In combination with 3 t/ha PG, the Truog P value increased on average by 3 ppm with increasing P treatment. P availability was further improved, increasing the rate of lime from 3 to 6 t/ha.

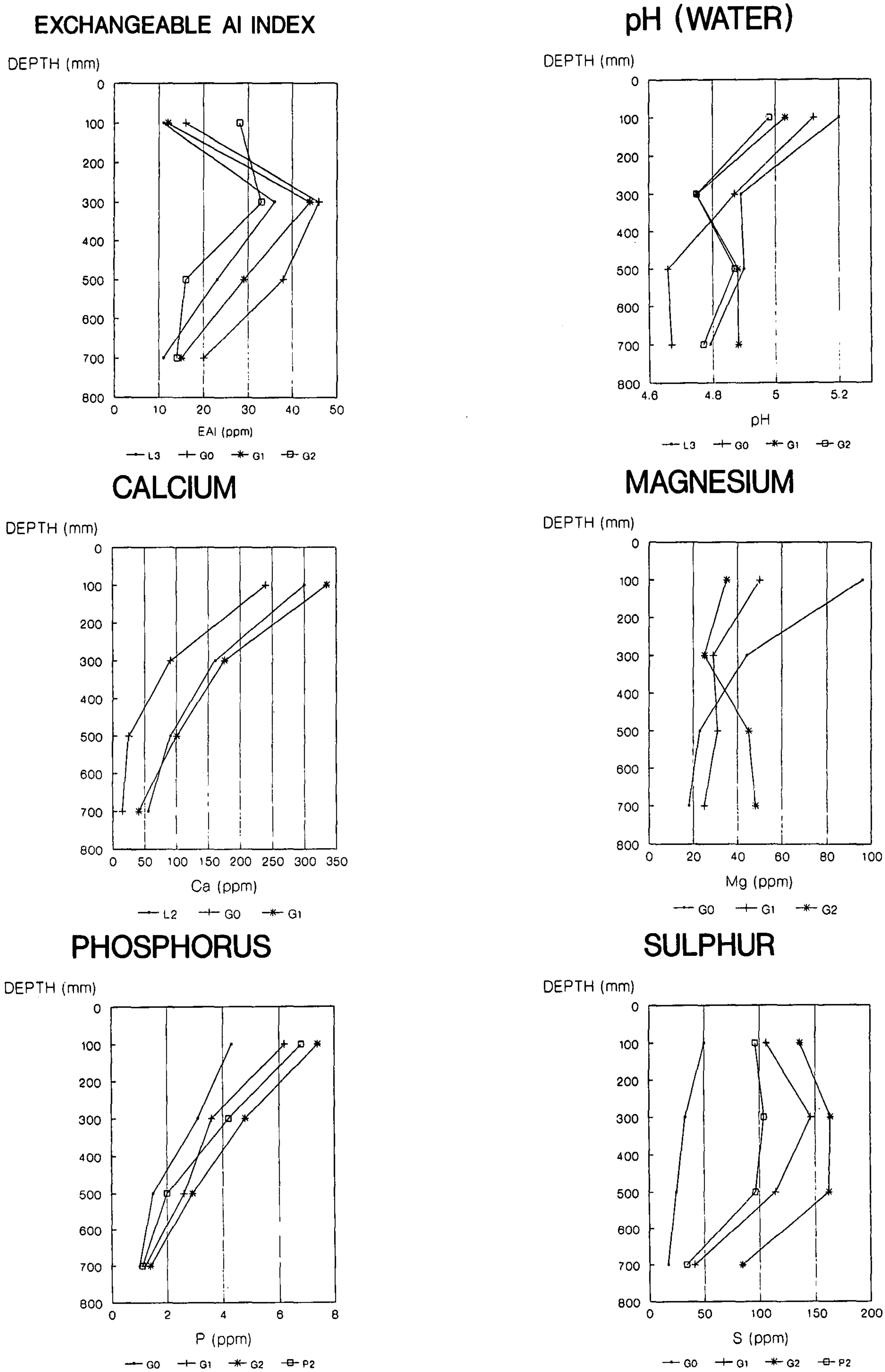

FIGURE 2 The effect of selected treatments on the distribution of nutrients down the soil profile.

Table 4

Residual effects of PG treatment on soil pH, exchangeable Al and Ca to depth measured over a six year period

		pH (H_2O)					Ex aluminium index (ppm)					Calcium (ppm)				
		Plant		1st Ratoon		2nd Ratoon	Plant		1st Ratoon		2nd Ratoon	Plant		1st Ratoon		2nd Ratoon
Phosphogypsum	Depth (mm)	Oct 1984	Apr 1986	Jan 1987	June 1988	June 1990	Oct 1984	Apr 1986	Jan 1987	June 1988	June 1990	Oct 1984	Apr 1986	Jan 1987	June 1988	June 1990
Control	0-200	4,82	5,16	5,17	5,18	5,23	23	15	15	21	21	299	344	299	321	248
	200-400	4,65	4,87	4,49	4,90	5,06	48	48	51	56	65	140	154	118	105	113
	400-600	4,55	4,84	4,28	4,99	5,27	59	70	42	44	39	34	44	35	50	71
	Average	4,67	4,95	4,64	5,02	5,18	43	44	36	40	42	158	181	151	158	144
5 t/ha	0-200	4,64	4,93	5,03	5,01	5,16	24	15	17	29	23	532	495	346	365	260
	200-400	4,57	4,7	4,49	4,75	4,92	55	45	50	65	65	187	315	181	205	150
	400-600	4,67	4,78	4,64	4,85	5,05	64	52	32	40	50	59	193	120	200	146
	Average	4,62	4,8	4,72	4,87	5,04	48	37	33	45	46	259	334	216	256	185
10 t/ha	0-200	4,6	4,84	4,84	5,03	5,16	22	22	23	20	21	1 080	558	381	453	313
	200-400	4,48	4,71	4,5	4,79	5,00	50	33	42	48	61	340	426	226	248	179
	400-600	4,46	4,87	4,64	4,86	5,11	56	38	24	34	46	58	263	204	219	164
	Average	4,51	4,81	4,66	4,89	5,09	43	31	30	34	43	493	416	270	306	219

Soil solution composition

- Gypsum treatment increased the conductivity of the saturated paste of the surface horizon (0-200 mm) from 83 to 137 and 160 mS/m for the 0,5 and 10 t/ha PG treatments respectively. Salinity was even more marked in the subsoil where 10 t/ha PG was applied (234 mS/m) and might account for the depression in cane yield that occurred in the plant crop under this treatment.
- Marked increase in solution pH, Ca and SO_4 levels from PG treatment.
- Slight increase in total Al concentration due to the formation of soluble $AlSO_4^+$. The concentration and activity of Al^{3+} decreased.
- Soluble Mn, Si, NO_3, Cl and F levels tended to increase with PG treatment.

Foliar diagnosis

Differences in third leaf P values between the various treatments were generally marked, ranging from 0,14 to 0,16% P for treatment combinations containing the lowest rate of P (30 kg/ha) to over 0,19% P for treatments containing the highest rate of P (90 kg/ha) (see Figure 3). Treatment with PG also resulted in significant increases in Ca, and in S uptake. In the 5 t/ha PG treatment, P levels improved on average by 0,02 units from 0,16 to 0,18% P, Ca from 0,24 to 0,31% and S from 0,13 to 0,16%. Treatment with lime showed little effect on Ca uptake. However, the combination of PG and lime resulted in improved uptake of Ca, Mg and P.

Root washing

Root washing conducted on four plots showed no major differences in root development between the gypsum treated and control plots. Root development was generally good in both the control and PG treatments, with distribution down to a metre. In all four plots root development was poor at the 150-300 mm depth but improved greatly below this depth. There was no evidence from root count measurements that the root system was any better where PG had been applied. Analysis of soil samples taken at 150 mm intervals down the profile showed that root activity was better correlated with EAI levels than with extractable acidity *per se*. The weaker band of roots in both the control and PG treated plots was generally associated with EAI levels in excess of 70 ppm or Al saturation values in excess of 50%. An Al saturation of 67% in the 150-300 mm layer of the control plot did not restrict root development completely, confirming that sugarcane is very tolerant of Al toxicity.

Discussion

Crop response relative to P

The highly significant yield responses obtained to P treatment were consistent with the extremely low P level in the soil (4 ppm) and confirmed previous results (Meyer and Dicks, 1979). Leaf analysis also clearly showed the beneficial effects of P application. The effects of P treatment on P uptake were more marked at the G_0 level when compared with the G_1 and G_2 levels (see Figure 3). In the absence of PG, the residual effects of 90 kg P/ha were sufficient to raise the P level from deficient 0,14% (P_0) to satisfactory 0,18% (P_2). Regression analysis between cane yield response to P treatment and third leaf P values showed a significant inverse correlation between these two variables (r = -0,75).

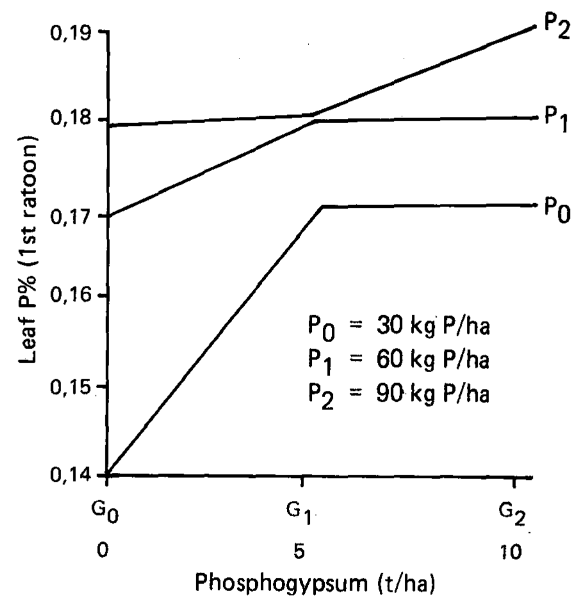

FIGURE 3 The effect of PG treatment on third leaf P values at three levels of superphosphate.

Similarly, the P content of PG helped to explain the response obtained to this treatment. This can largely be inferred from the similarity in the relationship between leaf P uptake and PG treatment, compared with the observed interaction in yield response between PG and the three rates of P (compare Figures 1 and 3). The P factor in PG was also quantitively assessed in a P x lime factorial trial with maize in Natal, and the results showed that 5 t/ha PG in combination with 40 kg/ha P was as effective as 80 kg/ha P without any PG (Shainberg *et al.*, 1989).

Crop response to Ca

Supplementary benefits of enhanced Ca and Mg nutrition coupled with a reduction of Al toxicity in the 200-400 mm subsoil layer cannot be discounted. Regression analysis showed that yield of the plant crop was significantly correlated with pre-plant extractable Ca levels in the topsoil ($r = 0,65$), while first ratoon yields correlated better with the enriched Ca status of the 200-400 mm subsoil layer ($r = 0,54$) following treatment with PG. Sucrose yields of the first ratoon crop were also significantly correlated with third leaf Ca levels ($r = 0,67$) from PG treatment, whereas liming showed little or no effect on Ca uptake. In Brazil it was concluded that the benefit from PG treatment was due to better distribution of Ca throughout the profile (Morelli *et al.*, unpublished data) rather than to a reduction in Al toxicity. Recently, Noble *et al.*, (1988) proposed a Calcium-Aluminium Balance (CAB) parameter that best describes the phytoxicity of a solution containing Al.

Crop response in relation to Al toxicity

Whilst Al toxicity was not considered to be a major growth limiting factor, the combined PG and lime treatments compared with the no PG treatment may have caused more effective lowering of Al levels in the 200-400 mm subsoil layer. Regression analysis showed a low but significant inverse correlation between cane yield from various plots and EAI levels within the 200-400 mm zone ($r = -0,41$).

Currently, the mechanisms that have been proposed for correcting Al toxicity include:

(i) the self-liming effect which was originally proposed by Reeve and Sumner (1972), whereby SO_4^{2-} displaces OH^- from surfaces of Al and Fe hydrous oxides

(ii) reduction in Al^{3+} activity by the formation of a less toxic but soluble $AlSO_4^+$ ion pair (Pavan *et al.*, 1982, Noble *et al.*, 1988)

(iii) possible formation of one or more new mineral phases such as basalalumnite, alunite or jurbanite (Nordstrom, 1982).

Evidence for all three mechanisms was found in this investigation. It is likely that the first two mechanisms which are largely adsorption-based, initially dominated the reaction of gypsum in the soil. Factors such as an increase in pH, a reduction in EAI and the significant retention of sulphate ions at a depth of 400 mm add support to this contention.

Conclusions

- Phosphorus deficiency was the major factor limiting growth in the Kranskop form soil and the yield response to PG was due primarily to its P content. This is supported by the similarity in the response curves between single supers and PG treatments, the interactions between these treatments in favour of P evident in third leaf P analysis, the overall lack of any marked response to liming and the generally favourable rooting depth in the untreated control plots.
- There were other benefits from the use of PG, such as enhanced Ca status, better distribution of Ca to depth and diminished Al levels in the 200-400 mm depth.
- PG is not an economic substitute either for lime when topsoils are acid, or for superphosphate when soil P levels are deficient. Two to three times the quantity of PG relative to lime would be required to achieve the same short term effect on exchangeable Al and Al saturation in the topsoil. The negative effect that PG has in leaching Mg from the profile means that PG should not be used without dolomitic lime.
- To date there has been no evidence from field trials with sugarcane that significant improvements in yield may be obtained by correcting subsoil acidity in midlands soils. Trials are in progress in the Eston area and, until results from these become available, no recommendations can be made with regard to the use of PG on sugarcane.
- Caution should be exercised by growers on large scale use of PG. As no benefit was shown to PG treatment in the plant crop, marked residual effects would be needed in the first and second ratoon crops for its use to be economically viable. High moisture content and high transportation costs also are major constraints on its use.

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