SULPHUR AVAILABILITY IN SOILS OF THE SOUTH AFRICAN SUGAR INDUSTRY

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Abstract

An investigation was conducted in the laboratory and glasshouse to assess the sulphur (S) supplying ability of the important soil forms of the sugar industry. The amount of S in the soil as measured by a 0,5N ammonium acetate extraction procedure, was compared with the availability of S during continuous cropping of sorghum in pots. The number of crops required to exhaust the reserves of S was fairly consistent with the S status of each prior to planting. Soils with a S content of 20 ppm or less required between one and three crops to produce symptoms of a S deficiency compared with four to six crops for soils with S values between 20 and 30 ppm and seven or more crops for soils with values of S greater than 30 ppm. The response of the crop and data on the uptake of S indicate that the current threshold value of 15 ppm is too low for advisory purposes, and that a value of 20 ppm would be more appropriate. Sugarcane growing in the grey, light textured soils of the Cartref, Fernwood, Glenrosa, Longlands and Kroonstad forms, is therefore likely to be most prone to a S deficiency. A random survey of soil and leaf samples indicated that 13% of the samples were deficient in S. In future, greater emphasis will have to be placed on the plant's requirement of S, particularly with the increased use of high grade fertilizers that have a low S content.

Introduction

In recent years, the frequency of S deficiency in various grain, fibre, forage and oil crops has increased and greater attention has been focused on the importance of this element in plant nutrition (Spencer[14]). Many consider S to be the fourth most important nutrient after nitrogen (N), phosphorus (P) and potassium (K). S deficiency in sugarcane has been reported in Brazil (McClung[10]), India (Dutt[4]), Puerto Rico (Bonnett[3]), Australia (Sedl[13]), Zimbabwe (Gosnell and Long[7]), USA (Golden[6]), and in several fields on a large estate in Malawi (Johnston[8]).

In sugarcane, symptoms of S and N deficiencies are similar: yellowish green foliage, especially the young leaves. As a S deficiency advances, however, the leaves develop a purplish tinge.

The greater incidence of S deficiency in crops in recent years is thought to be due to:

- increased crop yields which cause larger quantities of S to be removed from the soil. A 100 ton crop of cane may remove as much as 35 kg S ha^{-1}
- increasing use of high grade, essentially S-free fertilizers. Previously some of the requirement for S was met by S impurities in fertilizers
- with more effective pollution control, the use of fuel and energy sources with a high S content has decreased, thereby reducing the amount of atmospheric S reaching agricultural land
- less S being used in herbicide and insecticide formulations.

Although S deficiency is not a problem in the South African sugar industry, the potential effect of the above factors was recognized during the early seventies when leaf samples collected during an industry-wide nutrient survey were analysed (Meyer *et al*[12]). The S content in approximately 14% of the samples from nearly 500 fields was found to be marginal to deficient when a threshold value of 0,13% was used. Approximately half of the deficiencies occurred in the irrigated areas of Swaziland and the Eastern Transvaal. However, in follow-up trials that were established at several sites in the lowveld where S deficiency was suspected, the crop showed no response to treatment with S. More recently, interest in S was renewed because information on the S status of soils in the sugar industry and their capacity to supply S to sugarcane was limited. As with K and P, most soils have only limited reserves of S and the amount of S removed by cropping may eventually exceed the amount being supplied by the soil. Consequently, an investigation in the laboratory was conducted to develop a rapid test procedure for assessing the amount of S available to plants in different soils.

Numerous methods have been proposed and these include extracting sulphates from the soil with water, with various salt solutions (eg $Ca(H_2PO_4)_2$, $CaCl_2$, $KHCO_3$, NH_4COON_3), by incubation, and using techniques based on measuring the rate of microbial growth (Beaton[2]). The extractants do not perform equally well on all soils: some remove only readily soluble sulphate while others also remove some adsorbed sulphate. Some extractants can remove both these fractions and some organic S. Although methods in which calcium dihydrogen phosphate is used for extraction are most commonly used, in this exercise the method of Bardsley and Lancaster[1] in which ammonium acetate is used, was evaluated. This soil extractant is being used in the SASA Experiment Station's Fertilizer Advisory Service laboratory to determine the available K, Ca and Mg contents of soil. Some of the more important findings of the investigation into the S status of soils through laboratory and glasshouse studies are presented in this paper.

Method

The investigation consisted of:

- a trial in the glasshouse to test the suitability of the 0,5N ammonium acetate/0,25N acetic acid extraction procedure of Bardsley and Lancaster to predict plant-available S in a range of soils in the sugar industry
- studying the results of soil and leaf analyses to establish the distribution of S under a wide range of field conditions.

Glasshouse trial

The sixteen soils used in the study were of 10 different forms derived from seven different parent materials situated in four bioclimatic regions. Properties of the various soils which were studied are shown in Table 1. Samples of the surface 150 mm depth of soil were collected from various fertilizer trial sites, were air-dried, crushed and passed through a 2 mm sieve, thoroughly mixed and weighed into pots.

Treatments

Forage sorghum was grown in pots and each of the following treatments was replicated four times:

(a) no sulphur applied (SO)

(b) S added as $NaHSO_4$ (27% S) at a rate of 100 kg ha^{-1} before planting (S1)

(c) unseeded pots (in which no sorghum had been planted) with and without the above S treatment and where moisture content was maintained at 60% of field capacity (S2).

TABLE 1

Properties of the soils used in the glasshouse trial

Soil system	Locality	Soils			Soil properties						
		Parent material	Form	Series	Clay %	Organic matter %	pH (H_2O)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)
Umzinto coast lowlands	Nkwifa	Granite	Kroonstad	Kroonstad	7	1,3	5,10	20	88	378	81
	Nkwifa	Granite	Mayo	Mayo	22	2,3	6,10	23	108	1 800	230
	Esperanza	Granite	Glenrosa	Glenrosa	9	1,9	5,30	17	57	471	80
	Mt Edgecombe	Dolerite	Arcadia	Rydalvale	48	4,3	5,80	4	89	1 900	270
	La Mercy	Middle Ecca	Swartland	Swartland	30	2,9	5,20	45	56	154	11
	Shakaskraal	TMS (ord)	Cartref	Cartref	10	0,8	5,75	21	142	123	28
	Emoyeni	TMS (ord)	Cartref	Cartref	7	0,6	6,25	28	69	187	32
	Frosterly	TMS (ord)	Cartref	Cartref	5	0,8	6,00	19	20	97	36
Umzinto midlands	Mt Elias	TMS (ord)	Cartref	Cartref	6	1,0	5,35	20	26	84	13
	Eston	TMS (ord)	Longlands	Longlands	12	1,1	5,75	36	69	363	61
	Paddock	TMS (ord)	Longlands	Vasi	7	0,9	5,35	42	49	165	36
Nottingham	Mid-Illovo	TMS (mist)	Inanda	Fountainhill	31	4,1	5,35	5	73	464	192
	Baynesfield	Dolerite	Hutton	Balmoral	52	7,8	5,20	9	172	683	250
	Harden Heights	TMS (mist)	Inanda	Inanda	41	6,2	5,35	18	242	810	220
Komatipoort	Ubombo	Alluvium	Dundee	Dundee	6	0,7	6,20	31	63	589	220
	Pongola	Alluvium	Hutton	Makatini	50	1,6	6,45	13	130	844	240

A standard nutrient solution containing all the essential elements except S was applied regularly to the pots. Throughout the experiment all pots were maintained at 60% of their maximum water-holding capacity by watering them daily until they reached a predetermined weight.

Harvesting began five weeks after sowing and the sorghum was cut regularly. When necessary, the pots were re-seeded and crops were harvested until there was very little growth in the S0 and S1 treatments. All crops were oven-dried overnight at 70°C and weighed before being analysed for S and other selected elements. Changes in the available S in the soils were determined by extracting sulphates from samples taken from unseeded pots at the beginning of the experiment and from both seeded and unseeded pots before and after each cycle, as well as at the final harvest.

Analytical methods

S in the form of sulphate was measured in soil extracts and plant digestates by the turbidimetric determination of barium sulphate using a Beckmann UV-visible spectrophotometer set at 420 nanometers (Beaton[2]).

- *Total sulphur in plant material*

Digest 1 g of dried material in 15 ml of concentrated nitric acid for 30 minutes. Cool and add 5 ml of perchloric acid (72%) and continue digestion until a clear solution is obtained. Dilute the digestate with twice de-ionized water to 25 ml.

- *Available soil sulphur*

Extractable sulphur (soluble and adsorbed sulphate) was determined by the method of Bardsley and Lancaster.

Shake 20 g soil with 50 ml O,5N ammonium acetate/0,25N acetic acid solution for 30 minutes. Filter and use a 10 ml aliquot for the determination of sulphur as sulphate after adding barium chloride crystals.

Nutrient survey

The amount of S available to sugarcane in a wide range of soils in the industry was determined by analysing two groups of samples. The first group comprised composite soil samples and associated third leaf samples taken from nearly 500 sugarcane fields during an industry-wide nutrient survey in 1970 (Meyer *et al*[12]). The second group comprised approximately 1 000 soil and 1 000 leaf samples that had been submitted by growers to the Fertilizer Advisory Service laboratories for routine analysis during 1982 and 1983. The same methods of chemical analysis were used as those in the glasshouse trial.

Results and discussions

Glasshouse trial

- *Yield in relation to exhaustive cropping*

The number of crops of sorghum harvested from each soil and the amount of dry matter produced are shown in Table 2. The results may be summarized as follows:

(a) exhaustion of plant available S was achieved in 14 of the 16 soils that were cropped. Permanent symptoms of S deficiency were not induced in the untreated controls of the two Inanda form soils

(b) in general, from one to six crops were required to exhaust the reserves of plant available S in the lighter, sandier soils, compared with five to twelve crops for the heavier textured soils. Signs of S deficiency were evident in the first crop that was grown in soil of the Dundee form

(c) the relative response obtained to applied S also varied considerably, but was greatest in the lighter textured soils. For example, the yields of treated crops relative to those of the untreated controls ranged from 180% on the Dundee

TABLE 2

Cumulative response obtained in 100 kg S ha⁻¹ on 16 soils

Locality	Soils			Pre-plant soil S ppm	No. of crops	Point of first symptoms of S deficiency		Accumulated yields (g dry matter)		
	Parent material	Form	Series			No. of crops	Soil S ppm	SO	S1	% diff
Ubombo B set	Alluvium	Dundee	Dundee	11	6	1	12	12,92	36,20	180
Nkwifa (FT12)	Granite/ alluvium	Kroonstad	Kroonstad	13	7	2	13	23,28	35,66	52
Ringleman (TMS 4)	TMS (ord)	Cartref	Cartref	16	7	2	14	14,81	28,01	89
Frosterley	TMS (ord)	Cartref	Cartref	20	6	4	15	15,85	26,40	66
Esperanza (FT110)	Granite	Mayo	Mayo	21	11	5	19	44,47	61,12	37
Nkwifa (FT11)	Granite	Glenrosa	Glenrosa	22	8	4	19	25,20	45,07	79
Van der Riet	TMS	Cartref	Cartref	22	7	4	20	22,38	34,76	55
Eston (TMS 1)	TMS (ord)	Longlands	Longlands	23	11	6	18	37,42	56,47	51
Paddock (TMS 3)	TMS (ord)		Vasi	24	11	6	15	34,21	39,12	14
Emoyeni (TMS 6)	TMS	Cartref	Cartref	27	9	6	19	23,69	29,06	23
Pongola	Alluvium	Hutton	Makatini	30	15	8	15	45,52	88,25	94
Mid-Illovo (FT6)	TMS (mist)	Inanda	Fountainhill	31	11	11	10	48,08	55,51	15
La Mercy (FT16)	Middle Ecca	Swartland	Swartland	34	12	8	16	35,31	37,26	5
BT 1	Dolerite	Arcadia	Rydalvale	36	13	12	11	63,81	74,30	16
Baynesfield	Dolerite	Hutton	Balmoral	38	11	7	10	46,99	60,02	28
Harden Heights	TMS (mist)	Inanda	Inanda	49	11	10	11	54,41	59,36	9

form soil derived from alluvium to an average of 50% for soils derived from TMS (Cartref and Longlands forms) and granite (Glenrosa and Kroonstad forms).

By comparison, responses to S in the soils with the heaviest texture were generally lower and averaged 25% for the Arcadia, Hutton, Inanda, Mayo and Shortland soil forms. The exception was the Hutton form soil derived from alluvium in which there was a response of 94% to applied S.

- *Yield response in relation to S status of soil*

The number of crops required to exhaust the reserves of plant available S was fairly consistent with the S status of each soil prior to planting. For example, in soils with a S value of 20 ppm or less, only one to three crops were sufficient to produce a S deficiency compared with four to six crops for soils with S values between 20 to 30 ppm and seven or more crops for soils with a S valve of more than 30 ppm. Regression analysis confirmed that the response to applied S was negatively correlated with the pre-plant ammonium acetate extractable soil S value (R = 0,71*). The relationship and regression equation are shown in Figure 1. These data suggest that a soil S value of at least 20 ppm is necessary to sustain a crop yield of 80% of the maximum yield.

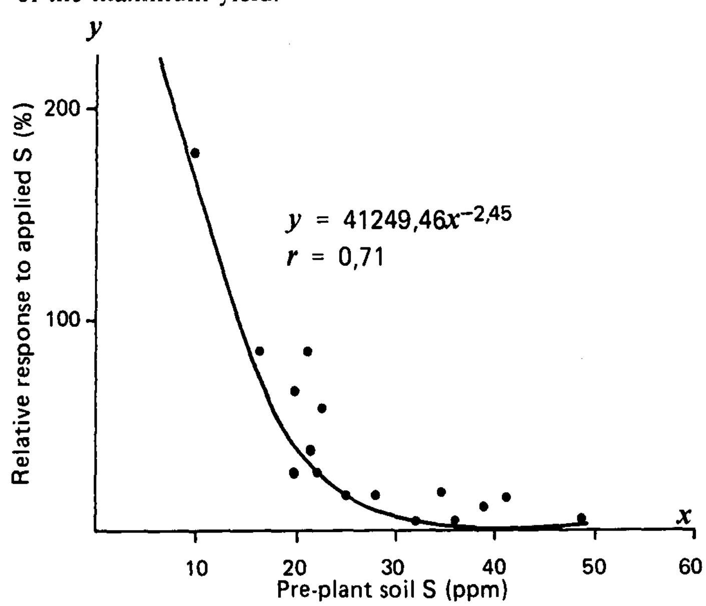

FIGURE 1 Relative response to applied S in relation to pre-plant soil S levels.

- *Yield response in relation to S uptake*

The yield of dry matter and the S content of successive crops were used to calculate the total uptake of S by plants after six crops had been grown with and without added S (Table 3). The addition of S increased uptake from 2,0 mg kg⁻¹ of soil for the Inanda soil on which there was little yield response, to over 13 for soils on which the yield was more than doubled.

TABLE 3

Uptake of S by plants and changes in extractable soil S over six crops

Soil form	Plant S uptake (mg kg⁻¹ soil)			Changes in soil extractable S (ppm)			
	SO	S1	Ratio	Initial S (ppm)	Decline in S from initial value in seeded pots	Increase in S from initial value in unseeded pots	Net change in soil S
Dundee	12	197	16,4	12	7	2	9
Kroonstad	18	245	13,6	14	6	9	15
Cartref	12	184	15,3	16	4	7	11
Cartref	22	326	14,8	20	10	8	18
Mayo	29	131	4,5	21	7	22	29
Glenrosa	17	159	9,4	22	6	12	18
Cartref	24	161	6,7	23	12	9	21
Longlands	29	162	5,6	24	11	10	21
Longlands	27	114	4,2	24	14	11	25
Cartref	25	218	8,7	28	14	10	24
Hutton	32	165	5,2	31	13	18	31
Inanda	41	118	2,9	32	15	30	45
Swartland	22	224	10,2	35	9	15	24
Arcadia	49	196	4,0	36	6	34	40
Hutton	53	118	2,2	38	15	40	55
Inanda	60	119	2,0	49	23	42	62

Continuous cropping on the untreated soils resulted in two to three times more S being removed from the heavier soils than from the lighter soils. This is illustrated in Figure 2 where the cumulative S uptake for some of the untreated soils is compared. Regression analysis confirmed that S uptake was positively correlated with the S status of the soil measured prior to cropping, and the organic matter content of the soil (r = 0,74*). On this basis, the Inanda form soils on average released the largest amount of sulphur followed by the Hutton and Arcadia form soils with the Cartref, Glenrosa, Longlands, Dundee and Kroonstad forms releasing progressively less S.

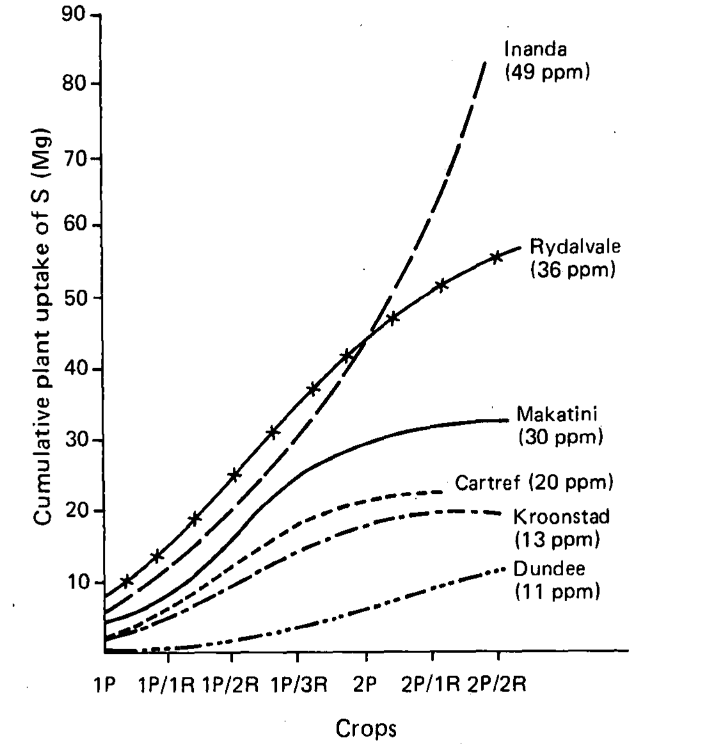

FIGURE 2 Cumulative uptake of S on untreated soils (So) with cropping.

The relationship between the concentration of S in the tops and the relative yields of plants that were grown without S, is shown in Figure 3. The fitted regression curve may be divided into a horizontal zone where S is adequate (a), a steeply descending part of the curve representing a zone of S deficiency (c), and a transition zone between these two (b). The critical concentration in the transition zone is defined as that which is just deficient for maximum growth. It is usually associated with a 10% reduction in yield. With the curve in Figure 3, a relative yield of 90% coincides with a concentration of 0,12% S. This value is the same as the critical value of 0,12% that has been accepted for sorghum and maize in Australia (McLachlan[11]) and it is also the tentative critical value that is currently used for interpreting the S content of third leaf samples in the South African sugar industry.

The ratio of total N to total S in the crops grown without added S was also calculated. The results confirmed that an N:S ratio of 15 corresponded with a S content of 0,12% in the leaf.

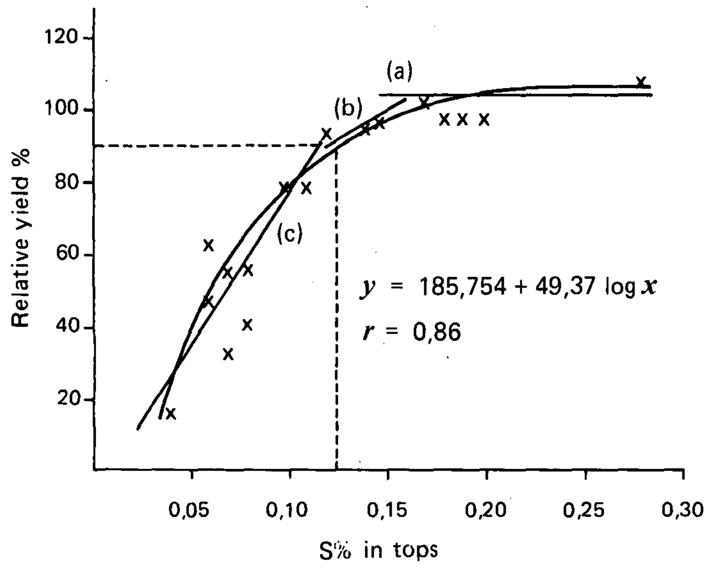

FIGURE 3 Relative yield in relation to S concentration in tops.

As relative yields decreased below 90%, the ratio increased from about 15 to 90. Dijkshoorn and van Wijk[5] have suggested that in graminaceous plants, the ratio is about 14 when the supply of S is adequate. With sugarcane a value of 17 has been recommended (Gosnell and Long[7]) and is being used by the Fertilizer Advisory Service.

- *The effects of S mineralization during cropping*

The balance sheet presented in Table 3 shows that the amount of S removed by cropping in the untreated control agreed closely with the net change in the value of extractable S in the soil during cropping. The net change was determined by combining the measured decline in extractable S in the seeded pots with the measured increase in the values of extractable S in the unseeded pots. In a similar pot experiment, Jones[9] regarded the increase in the values of extractable S in the unseeded pots as an indirect estimate of mineralization of organic S during the cropping period. In the present study, these increases ranged from 2 ppm in the Dundee form soil to 42 ppm in the Inanda form soil. It is therefore not surprising that the estimates of mineral S correlated well with the organic matter content of the soil (r = 0,76*). It may be inferred that mineralized S played an important role in supplying at least 70% of the crop's S requirement in soils with more than 4% organic matter. This release of mineralized S is analagous to the capacity of soils to release N. Some researchers have estimated apparent mineralization of S in a cropping situation to be the difference between the amount taken up by the plant and the amount by which the extractable S level decreases during the growth period (Jones[9]). Such estimates indicate that apparent mineralization was usually slightly higher than mineralization measured in the unseeded soils, the mean values for the 16 soils being 20 and 17 mg S kg^{-1} soil for the two estimates respectively.

- *Applying results to advisory work*

Indications are that the current threshold value of 15 ppm is too low for diagnosing a S deficiency. A value of 20 ppm gives a better distinction between soils which are and which are not deficient in S (Figure 1). This will need to be confirmed by field experiments conducted over a wide range of soil conditions. Results from a limited number of field trials suggest that the threshold value for S may even be higher than 20 ppm. For example, a significant response to 50 kg S ha^{-1} applied as elemental S, was obtained on a sandy Hutton soil with an extractable S value of 30 ppm. However, until more conclusive evidence is obtained, it is recommended that a threshold value of 20 ppm be used for advisory purposes.

- *Results of nutrient survey*

A comparison of the results of the 1970 and 1983 surveys showed that an interesting change had occurred in the average amount of available S in soils in the industry (Table 4). Using 20 ppm as the threshold value, the number of samples deficient in S increased slightly from 13 to 17%. The proportion of samples with a marginal S content (20 to 25 ppm) increased

TABLE 4
Distribution of plant-available S in soils

Survey	No of samples	Distribution of soil S (%)					
		<10 ppm	10–20 ppm	20–30 ppm	30–40 ppm	40–50 ppm	50 ppm
Industry -wide (1971)	487	3	10	34	17	22	14
FAS routine samples (1983)	1 030	1	16	44	16	13	10

from 34 to 44%. A similar trend was observed for leaf samples where the percentage which were deficient in S increased from 9 to 13 when the S threshold was 0,12%. The proportion of leaf samples with marginal S contents increased from 14 to 19%.

The 1971 survey data showed that more than half the soil and leaf samples that were deficient were from farms in the coast lowlands, and more than a quarter were from the lowveld area. Very few samples with deficiencies were from the midlands mistbelt area where soils generally have a high organic matter content. The TMS (ordinary) and granite-derived soils (mainly Cartref and Glenrosa forms) were most prone to a S deficiency, whereas S in the TMS (mistbelt) soils (mainly Inanda form) was not marginal or deficient. These findings are consistent with the results of the pot experiment which showed that, on average, the S reserves of Inanda soils were three to four times higher than those of the Cartref form soil, mainly because of their greater potential to mineralize S.

Conclusions

The results of the study have emphasized the importance of S deficiency as a potential factor limiting cane growth. Because a cane crop removes an average of about 30 kg S from the soil and the S reserves of most of the grey loamy sands appear to have declined over the past 12 years, the crop's requirement of S should be investigated, particularly with the increased use of high grade fertilizers. Under normal circumstances, an application of 600 to 700 kg single or ammoniated superphosphate ha^{-1}, applied in the furrow at planting, would meet the S requirement of two or three crops of cane. Where P is not required at planting, the same rate of agricultural gypsum could be used to supply sufficient S for four to five crops. Where a S deficiency is diagnosed in ratoon cane, ammonium sulphate should be included in the fertilizer programme, or single superphosphate where P is also required.

The results of the pot experiment indicate that there is merit in using Bardsley and Lancaster's technique for measuring the available S content of soils on a routine basis. However, before it is implemented, the tentative threshold value of 20 ppm will have to be verified by experiments in the field and levels of S deficiency will have to be calibrated in terms of the S requirement. The organic matter status of a soil may also have to be considered when determining the S requirement of sugarcane and further work in this connection would be valuable.

Until the field work on S has been completed, it is recommended that leaves be analysed where a S deficiency is suspected. Knowing the soil form will also assist in identifying a S deficiency. Soils of the Cartref, Kroonstad, Glenrosa and Longlands form are particularly likely to be deficient in S.

In Australia, it is standard practice to print the N:P:K:S ratio on fertilizer bags and manufacturers in South Africa should be requested to follow suit. Another improvement would be to upgrade the S content of the traditional ratoon fertilizer mixtures such as 5:1:5 and 1:0:1 from about 0,5% to approximately 4%. This would be a convenient way of maintaining the S status of soils.

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