REVIEW OF RESEARCH ON THE MICRONUTRIENT REQUIREMENT OF SUGARCANE IN SOUTHERN AFRICA

JH MEYER[1], AW SCHUMANN[1], BL SCHROEDER[2], RA WOOD[3] AND AL RAMPERSAD[1]

[1] *South African Sugar Association Experiment Station, Private Bag X02, Mount Edgecombe, 4300, South Africa*
[2] *Bureau of Sugar Experiment Stations and Cooperative Research Centre for Sustainable Sugar Production, Australia*
[3] *35 Dan Pienaar Road, Kloof, 3610, South Africa*

Abstract

A review is given of the research on micronutrients in the South African sugar industry, with special reference to zinc (Zn), iron (Fe) and manganese (Mn). The results of a number of field experiments are summarised and the measured responses related to the micronutrient content of third leaf samples. The main outcomes of a recent survey of the micronutrient status of 2 000 fields throughout the industry are reported and compared with the results of other surveys conducted between 1967 and 1990.

Introduction

While much is known about the nitrogen (N), phosphorus (P) and potassium (K) requirements of sugarcane, relatively little has been published about the micronutrient needs of this crop in South Africa, despite the fact that a number of investigations have been carried out over the past four decades in various parts of the industry. Of the 16 elements that are known to be essential for vigorous, healthy growth, the micronutrients iron (Fe), copper (Cu), zinc (Zn), boron (B), manganese (Mn) and molybdenum (Mo) are considered as important as the other macro and secondary micronutrients. An important characteristic separating micronutrients from macronutrients is the high efficiency value of micronutrients, since very small amounts are sufficient to produce optimum effects while slight deficiencies or excesses can result in severe yield decline.

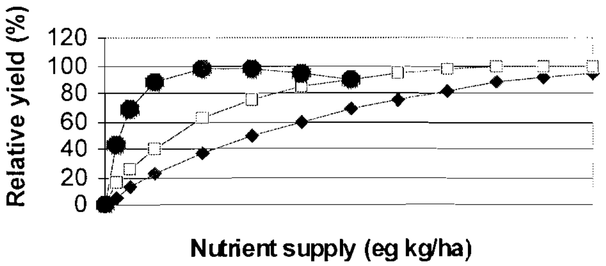

Figure 1. Yield response curves for nitrogen (◆), phosphorus (❑) and micro nutrients (●) (Marschner, 1986).

Ever since the discovery by von Sachs in 1860, that plants would grow satisfactorily on mineral salts and water, research workers have remained alert to the possibility of micronutrient deficiencies in crops. In sugarcane, it was not until the early 1930s that some of the first deficiency symptoms were produced by Martin (1934) in "controlled" nutrient culture solutions. Since these pioneering investigations, instances of micronutrient deficiency have been reported from a number of cane producing countries and, in recent years, trace elements such as Zn, Fe, Mn and Cu have received considerable attention (Bowen, 1975; Meyer, 1977; Reuter and Robinson, 1997).

Several possibilities may account for the increased frequency of micronutrient deficiencies:

- Declining soil fertility under a system of monocropping. Sugarcane is a gross feeder of nutrients and the production of large tonnages of cane over many years on the same soil has resulted in a net export of soil nutrients in the form of molasses and filtercake. As very few countries recycle these by-products back to the fields, the capacity of the soil to supply nutrients is greatly diminished.
- Introduction of higher yield potential varieties which tend to have higher nutrient requirements.
- Micronutrient deficiencies could have existed but may not have been sufficiently severe to produce visible symptoms.
- Concentrated fertilisers with fewer trace element impurities are being more widely used.
- Rapid advances in analytical methods for the detection and quantitative measurement of small quantities of elements in plants and soils.

The objectives of this paper are threefold:

- to highlight the role of Zn, Cu, Fe, Mn and B in sugarcane nutrition
- to review the results of both published and unpublished work, with special reference to quantifying the yield responses to corrective applications of micronutrients in past field trials in South Africa
- to summarise the the results of past nutrient surveys to assess the micronutrient status of sugarcane growing on a range of soils in the main extension areas of the sugar industry.

Discovery of micronutrient deficiency symptoms

Zinc

It is most likely that a combination of the above factors led to the discovery of Zn deficiency in the Upper Tongaat area.

(Du Toit, 1962). Subsequent field experiments conducted on acid soils in the Upper Tongaat and Doornkop areas of the sugarbelt showed marked responses to both soil and foliar applied treatments of zinc sulphate. The greater awareness of a zinc deficiency hazard in particularly acid soils has led to an increase usage of fertiliser mixtures containing zinc not only in the sugar industry but also in maize and other crops.

A deficiency of Zn disturbs the development of chloroplasts, causing the leaves to initially assume a very pale green colour, followed by an overall chlorosis of the leaves as the deficiency progresses (Anderson and Bowen, 1990). Phosphate metabolism is also impaired resulting in an accumulation of phosphate compounds, phosphatases and phenoloxydases (Marschner, 1986). In severe stages of the deficiency, leaf deformation may result through the inhibition of indolacetic acid which is formed from tryptophan by an enzymatic reaction (Schrotri, 1983).

Iron

Of all micronutrient deficiencies, that of Fe is probably the most frequently cited in the literature, perhaps because of the dramatic symptoms that develop. Initially a pale striping occurs in the youngest leaves, which in time progresses to pronounced interveinal chlorosis along the entire length of the leaf. Sometimes the chlorophyll between the vascular bundles disappears completely and the leaves turn almost white (Anderson and Bowen, 1990), while the middle leaves remain striped and the older leaves green. In South Africa this condition is commonly referred to as 'ratoon chlorosis' and is frequently seen in young cane grown on Recent Sands, particularly where the pH of the soils has been artificially increased to above a value of 8, due to the incorporation of large quantities of lime-enriched filtercake (Anon, 1965). It also occurs on the high pH soils (8,0-8,5) associated with former termitaries (isidulis [Zulu]) The chlorotic symptoms generally disappear but occasionally cane stools do not recover. Although Fe is not a constituent of chlorophyll, it is essential for the synthesis of chlorophyll and is also an essential constituent of various enzymes as well as an important redox catalyst, controlling the oxidation of carbohydrates (Marschner, 1986).

While Fe deficiency may be induced by excessive Ca, P or nitrate dressings (Samuels 1968), a fourth mechanism due to excessive uptake of Mn has been confirmed in cane growing on acid soils in the Natal Midlands. The presence of toxic levels of Mn in the soil leads to an imbalance of Fe, and in some instances an unfavourable ratio of Ca and Mg in the plant. Mn toxicity in the early stages resembles a mild iron deficiency, as high levels of Mn tend to inhibit absorption and translocation of Fe in the plant. Leaf analysis from a number of sites has indicated that, in the chlorotic cane, Mn levels ranged from 200 to 500 ppm compared with 50 to 150 ppm in healthy, non-chlorotic cane (Meyer and Wood, 1985).

The typical symptoms of interveinal chlorosis in young ratoon cane are best seen between October and December, particularly following periods of cool, wet growing conditions which favour the reduction of Mn from the trivalent to the mobile divalent form. Observations indicate that N12 is more susceptible than other varieties to induced Fe chlorosis through excessive Mn uptake (Anon, 1991). The condition is also known as 'acid chlorosis'.

Manganese

Mn, together with iron, forms an essential triad in numerous redox reactions in the soil. It is absorbed by sugarcane mainly as Mn^{2+} and is translocated predominantly as the free divalent cation in the xylem from the roots to the shoot (Evans, 1960). An important role of Mn is to act as a bridge between ATP and enzyme complexes such as in phosphokinases. Mn activates a number of enzymes *in vitro*, particularly decarboxylases and dehydrogenases of the tricarboxylic acid cycle (Marschner, 1986). Another important role of Mn is its involvement in photosynthetic oxygen evolution. Below a critical level of 15 ppm in mature leaves, dry matter production, net photosynthesis and chlorophyll content decline rapidly, whereas rates of respiration and transpiration remain unaffected (Ohki, 1981).

The symptoms of Mn deficiency are somewhat similar to those of Fe deficiency in the early stages, and consist of yellowish green to whitish longitudinal stripes alternating with the normal green colour. It can be distinguished from Fe deficiency in that the chlorotic stripes are of uniform width and usually confined to the middle and tips of leaves and seldom extend the full length of the leaf (Samuels, 1968). Unlike Fe deficiency, Mn deficiency is far less common and has been identified mainly in cane grown under irrigation in the lowveld.

As previously mentioned, instances of Mn toxicity are far more common, leading to an induced Fe deficiency. A mild form of freckling has also been observed in cane affected by Mn toxicity in the Midlands. Leaf analysis has indicated that this form of freckling is associated with low levels of Si in the plant (<0,50%) (Clements, 1967). In Hawaii (Gascho *et al.*, 1977) and Mauritius (Halais and Parish, 1964), leaf $Mn:SiO_2$ ratios are used on a routine basis to diagnose potential Mn toxicity problems. Ratios higher than 100 indicate likely responses to treatment with silicate slag or lime. Excessive Fe and Mn uptake is also associated with soluble divalent forms that are present under the reducing conditions that develop with waterlogging of soils, such as extended periods of flooding (Marschner, 1986).

Boron

B is an essential nutrient involved in sugar translocation, protein synthesis, seed and cell wall formation (Anderson and Bowen, 1990). The necessity for B in crop development has been recognised for a long time from nutrient culture studies (Martin, 1934). However, it was only in 1969 that the distinctive symptoms of long parallel interveinal streaks which disintegrate or split into ladder-like lesions, coupled with serrations of the leaf edge, was first observed in the field in Ecuador (Tollenaar, 1969). B deficiency symptoms were also identified for the first time in Africa at Dwangwa sugar estate in Malawi. With advanced B deficiency, the apical meristem of the main shoot dies and sideshooting gives the appearance of bunching or rosetting, as well as the development of a large number of tillers. Although numerous leaf samples from growth affected areas and healthy fields showed little difference in B content, average leaf B values at Dwangwa (3,7 ppm) were less than half of those found on other irrigated cane estates such as at Sucoma (7,5 ppm) in Malawi, and Simunye (8,0 ppm) and Ubombo Ranches (7,7 ppm) in Swaziland (Wood and Meyer, 1991). For many years the generally accepted critical value for B in the third leaf ranged from 1 to 4 ppm, but recent evidence from research conducted in Florida placed the optimal value for B in the third leaf at 4 ppm (Anderson and Bowen, 1990). On this basis, at least 30% of the cane fields at Dwangwa were deemed to be deficient in B (Wood and Meyer, 1991). Hot water soluble B levels at Dwangwa (0,42 ppm) were also on average substantially lower than those found at Sucoma (0,63 ppm), Ubombo Ranches (0,74 ppm) and Simunye (0,84 ppm). Based on this evidence and the presence of B deficiency in bananas, pawpaws and other subsistence related crops on the estate, a programme of boronating the irrigation water was implemented, in conjunction with regular monitoring of the B content of irrigation water and uptake by sugarcane through routine leaf sampling.

Copper

Cu is essential to the activity of various enzymes such as phenolases, ascorbic acid oxidase, cytochrome oxidase and several respiratory and photosynthetic oxidoreductases (Marschner, 1986). Cu deficiency was first recognised in 1932 in the Florida sugar industry (Allison, 1932) but almost 20 years elapsed before it was seen in Australia, where the term 'droopy top' was coined to describe the tendency of leaves to droop, together with the reluctance of the spindle to unroll (Anderson, 1956; Egan and Whitaker, 1961). In 1956, in South Africa, a small area of cane growing on granite derived soils near Sezela was found to be deficient in Cu and a foliar application of copper sulphate gave a quick and spectacular response (Du Toit, 1956).

Of the remaining micronutrients, Mo deficiency still remains a glasshouse curiosity, although an unconfirmed report of a field deficiency emanated from British Guiana in 1939 (Arnon and Stout, 1939).

Sugarcane yield responses to micronutrient treatment in the South African sugar industry

The first experiments with Zn were established in 1961, when four observation trials in the Upper Tongaat area were conducted where yields were poor despite adequate fertilisation with N, P and K. Dramatic responses were obtained to furrow applications and top-dressings of 55 kg zinc sulphate per hectare and to a foliar spray of 1% zinc sulphate in solution applied at a rate of 160 litres per hectare. Although the foliar treatments produced the quickest response the effects were not as long lasting as the soil applied treatments. The main effect of the Zn treatments was to improve stalk elongation to increase stalk populations and to restore the healthy green colour of the foliage. Foliar diagnosis was also used for the first time to monitor the effects of the various treatments on Zn uptake by the crop. Third leaf values improved from an average of 5 ppm for the untreated plots to over 10 ppm where Zn had been applied.

Since the exploratory trials were conducted, a number of replicated trials which included Zn as a treatment, have been carried out as part of the Upper Tongaat co-ordinated project (Thompson, 1985), mainly on humic Inanda form and series soils in the Upper Tongaat and Doornkop areas of the sugarbelt. A summary of the responses obtained to the application of zinc sulphate applied at an average rate of 50 kg per hectare in the furrow for plant cane, and as a top-dressing in ratoon cane, is shown for 10 trials in Table 1. The responses are expressed both in tons cane per hectare (tc/ha) and as a percentage increase in tc/ha over the untreated control.

Table 1. Summary of field responses to treatments with zinc sulphate.

Experiment site number	Area	Soil taxonomy	Soil form (Soil series)	Crop	Average response	
		Soil Order			t cane/ha	% change
1	Doornkop	Ultisols	Inanda (Inanda)	Plant 1R 2R 3R	1,0 17,5 18,0 6,0	+ 2 +11 +10 + 1
2	Upper Tongaat	Ultisols	Inanda (Inanda)	Plant	8,0	+ 2
3	Thrings Post	Ultisols	Inanda (Inanda)	Plant 1R	14,4 5,2	+33 + 7
4	Upper Tongaat	Lithosol	Glenrosa (Trevanian)	Plant	-2,25	- 3
5	Upper Tongaat	Ultisol	Inanda (Inanda)	Plant	24,5	+39
6	Kearsney	Lithosol	Glenrosa (Trevanian)	Plant	1,2	+ 1
7	Upper Tongaat	Ultisol	Inanda (Inanda)	1R	8,0	+10
8	Upper Tongaat	Ultisol	Inanda (Inanda)	Plant 1R	10,0 9,0	+14 + 8
9	Upper Tongaat	Ultisol	Inanda (Inanda)	Plant	17,0	+17
10	Eston	Ultisol	Inanda (Inanda)	Plant 1R	3,0 6,0	+ 3 +10
Average response				Plant 1R	10,0s 9.,	+12 +10

Although significant responses to Zn were obtained in the plant crop, in three experiments it is evident that the responses varied widely, from +39% in the case of the Inanda series soil on site 5 to -3% for the shallow loamy Glenrosa form (Trevanian series) soil on site 4. Overall, the effect of Zn in the plant crops in nine of the trials resulted in an average increase of 12%, with an additional average residual response of 10% measured in the subsequent first ratoon crops in four of the experiments which were continued beyond the plant crop stage.

In three of the experiments the efficacy of Zn treatments was also tested in combination with Mo, B, Cu, Mn and Fe without any apparent additional benefits. The results of past trials in which a range of micronutrients were tested, are summarised in Table 2. Although substantial benefits were obtained from treatment with Fe (10 to 28%), the responses were not all significant. Results for other micronutrients were less convincing, and were often negative. In general, foliar applied treatments were more effective than soil applied treatments in correcting Fe deficiency.

Table 2. Summary of field responses to treatments with other micronutrients.

Treatment	Area	Soil Order	Soil form (series)	Crop	Average yield	
					t cane/ha	% change
Control	Doornkop NS	Inceptisol	Cartref (Cartref)	Plant	49,23	0
+B					46,11	-6
+Cu					47,35	-4
+Mn					47,46	-4
+Mo					47,93	-3
+Si					47,68	-3
+Zn					45,82	-7
Control	Triangle NS	Lithosol	Glenrosa (Glenrosa)	5R	182,7	0
+Zn					164,5	-10
+Cu					175,6	-4
+Mo					171,4	-6
+B					181,2	-1
Control	Upper Tongaat **	Ultisol	Inanda (Inanda)	Plant	30,3	0
+Zn					41,4	+37
+Zn+Cu					39,9	+32
+Zn+Mn					38,5	+27
Zn+Cu+Mn+Mo+B+Fe					38,8	+28
Control	Cornubia Estates NS	Alfisol	Hutton (Clansthal)	1R (chlorotic)	62,2	0
+Fe (SO_4)					68,5	+10
+Fe (Cl_3)					73,7	+18
Control	Cornubia Estates NS	Alfisol	Hutton (Clansthal)	2R (chlorotic) 1 mth split	30,3	0
+$FeSO_4$ 12lb split					38,8	+28
+$FeSO_4$ 6lb split					37,0	+22
+Fe SO_4 6lb split					36,4	+20
Control	Tambankulu Estates NS	Oxisol	Shortlands (Shortlands)	1R	117	0
+Wuxal 6 L/ha					97	-17
+8 L/ha					104	-11
+10 L/ha					105	-10
Control	Umhlanga Rocks NS	Entisol	Fernwood (Fernwood)	2R (chlorotic)	23,13	0
+Oxicoal					21,72	-6
+Wuxal					22,50	-3
+$FeSO_4$					22,50	-3

In another co-ordinated project conducted by the Experiment Station, known as the Weak Sands project (Thompson, 1983), 21 replicated field trials were established on the low clay coastal sands (Hutton and Fernwood forms) to identify the causes of poor cane growth on these soils. The main treatments included nematicide with and without micronutrients (B, Mo, Cu, Mn, Fe and Zn), compared with a standard Fertiliser Advisory Service (FAS) treatment. Some micronutrients were applied in the furrow as potassium borate (25 kg/ha), sodium molybdate (0,5 kg/ha), copper sulphate (25 kg/ha) and manganese sulphate (50 kg/ha), while Zn and Fe were applied as foliar applications of zinc sulphate (1%) and iron sulphate (2%).

Although overall there was a large response to nematicide (average 52%), there was no additional benefit where the nematicide treatment was augmented by micronutrients. However, in the five trials situated on the south coast, established on Fernwood or Kroonstad form soils, there was some advantage from the combined nematicide micronutrient. The responses ranged from 5 to 15%, but no trials reached statistical significance.

Foliar diagnosis and crop response to micronutrient treatment

Foliar diagnosis based on the analysis of the central portion of the third leaf laminae has played an invaluable role in nutritional studies throughout the cane growing world because it often permits the nutritional problems to be discovered and corrected before the visual symptoms appear in the plant.

Du Toit (1962) used this technique to great advantage in interpreting the responses to Zn treatment in the early trials, as well as delineating the extent of the Zn deficiency problem in the industry. He showed that responses to Zn were common where the third leaf Zn content was less than 15 ppm, but rare above this figure. This value was subsequently adopted as the threshold value for routine advisory purposes and showed good agreement with values used in other countries.

An assessment of accumulated yield and leaf data from all available trials confirmed Du Toit's observation that 15 ppm gives the best separation between Zn deficient and non-deficient cane. Leaf samples from the control treatments in five trials indicated Zn deficiencies, and the average response obtained to treatment with Zn in the plant crop of these trials was 14 tons per hectare cane (Meyer, 1976). Considering that a minimum response of only one ton of cane per hectare is needed to cover the cost of 50 kg of Zn fertilising material, it may be concluded that the application of Zn can be highly profitable where this treatment is needed.

Similarly, threshold values have been established for the other micronutrients by interpolation from response curves, and these are summarised in Table 3 (Samuels, 1968; Schroeder *et al.*, 1992; 1999).

Table 3. Leaf threshold values currently used by FAS.

Nutrient	Threshold third (or top visible dewlap) leaf values (%) macro and secondary nutrients; (ppm) Cu, Zn, Mn & Fe					
N	(3-9 months)	Area	Crop age (months)	Month of sampling	P	R
		North	3 - 5	Oct-Dec	1,9	1,8
				Jan-Feb	1,8	1,7
				Mar-Apr	1,7	1,6
		Coastal	4 - 7	Nov-Dec	1,9	1,8
				Jan-Feb	1,8	1,7
				Mar	1,7	1,6
		Midlands	4 - 9	Nov-Dec	1,9	1,8
				Jan-Feb	1,8	1,7
				Mar	1,7	1,6
P	(3-7 months)	Variety		Areas & crop ages as shown for N		
		N12		0,16		
		Other N & NCo varieties		0,19		
K	(3-7 months)	Variety	Harvest season	Month of sampling	Areas & crop ages as shown for N	
		N14	Winter (irrigated crop)	Oct-Nov	0,70	
				Dec-Jan	0,80	
				Feb-Apr	0,90	
			Other	Oct-Apr	0,90	
		All other N & NCo varieties	Winter (irrigated crop)	Oct-Nov	0,85	
				Dec-Jan	0,95	
				Feb-Apr	1,05	
			Other		1,05	
Ca	(3-7 months)	0,15				
Mg	(3-7 months)	0,08				
Si	(3-7 months)	0,70				
S	(3-7 months)	0,12				
Cu	(3-7 months)	3				
Zn	(3-7 months)	15				
Mn	(3-7 months)	15				
Fe	(3-7 months)	50				
B	(3-7 months)	3				

Soil testing and crop response to applied micronutrients

The use of soil tests to predict the micronutrient requirement of crops have generally proved to be less reliable than foliar diagnosis (Bezdicek, 1973; Reghenzani, 1990). Although foliar diagnosis can be useful in assessing the nutrient status of an existing crop, a rapid and reliable method for determining the Zn requirement of soils prior to planting is also considered essential.

A range of soil extractants was evaluated in a pot trial to study the relationship between the amount of Zn extracted from the soil and that taken up by the plant. An extractant comprising 1 N $(NH_4)_2$ CO_3/0,01 M EDTA (Trierweiler and Lindsay, 1969), showed the best correlation between the amounts of Zn extracted from the soil and the amount taken up by ryegrass (Meyer, 1976). In the paired soil/leaf sample trace element survey of 500 cane fields, soil EDTA Zn levels also showed the closest relationship with third leaf Zn values. Regression analysis confirmed this relationship and indicated that leaf zinc was positively correlated with EDTA Zn (R=0,68*). The prediction of leaf Zn improved by including soil factors such as clay, soil pH, organic matter and plant available phosphorus into the regression equation (R=0,75). The equation for the relationship was formulated as follows:

Leaf Zn (ppm) = 17,32 + 1,92 (EDTA Zn-2,02) + 0,034 (Clay %-30)

The nutrient survey results from 500 cane fields was used to establish a provisional soil EDTA critical value that showed the best agreement with the leaf threshold value. A value of 1,00 ppm Zn in the soil provided the best separation between leaf samples deficient (<15 ppm) or sufficient in Zn (>15 ppm). A subsequent validation exercise conducted at the Experiment Stationís Pongola farm confirmed that 1,00 ppm was a reliable value to use for diagnosing Zn deficiency in the soil. On a site where the amount of extractable Zn in the soil was 0,53 ppm, a substantial response of 2 ts/ha (P=0,05) was obtained to side-dressing ratoon cane with 50 kg of Zn fertiliser per hectare, with no increased response when greater amounts of Zn were applied. On a second site, where the amount of extractable Zn was 1,40 ppm, no response was obtained to applied Zn. At a third site, where there was 1,0 ppm of soil Zn, and where very high cane yields of 170 t/ha/an were obtained, small but consistent responses (ns) were measured to side-dressing of Zn fertiliser and to foliar sprays of zinc sulphate. Where high yields are anticipated and the soil Zn level is about 1,0 ppm or less, there seems a reasonable probability of obtaining a worthwhile response to applied Zn, and this value has been adopted for determining the Zn requirement of soils with more than 15% clay. For soils with less than 15% clay a threshold value of 0,5 ppm is used for advisory purposes.

In Australia, Reghenzani (1990) indicated that the use of 0,1 M HCl was superior to the other extractants tested and established a soil threshold value of 0,6 mg/kg.

Nutrient survey investigations

Having established that marked responses to Zn and Fe were possible where deficiencies occurred, a number of leaf analysis surveys have been conducted since 1967 to determine the micronutrient status of sugarcane in various parts of the sugar industry. The results are summarised below.

1967 Survey

- This involved the sampling and analysis of third leaf laminae from about 190 fields sited mainly on soils derived from Table Mountain Sandstone (TMS). One of the main findings was a fairly widespread Zn deficiency on the TMS Mistbelt humic acid clayey Inanda series soils occurring at higher altitudes, which was consistent with Du Toit's previous observations (Alexander, 1967).
- Deficiency symptoms such as chlorosis, smallness of the leaves, patchy growth and stunting were identified in a number of fields later found to be low in Zn, particularly in the higher altitude Paddock, Mid Illovo, Upper Tongaat, Doringkop, Entumeni and Eshowe areas. Apart from four instances where leaf Cu contents were marginal, no other nutrient deficiencies were recorded.

1971 Survey

- In a more comprehensive survey which was conducted by Experiment Station staff in 1971, soil and leaf samples were systematically taken from almost 500 fields distributed throughout the industry, including not only the coastal lowlands and Midlands , but also the lowveld areas of Pongola, Swaziland and the Eastern Transvaal (Meyer *et al.*, 1971).
- The proportion of fields sampled generally corresponded with the percentage area represented by the ten most common soil parent materials in the sugarbelt, and covered at least 30 soil series.
- Leaf samples from all regions apparently contained adequate amounts of B, Cu and Fe. Almost 12% of all the samples were deficient in Zn, the highest incidence of deficiency (13%) once again being detected in the higher altitude Midlands area where acid soils prevail. Surprisingly, 8% of all the coastal lowlands samples also indicated a Zn deficiency, together with several farms in the Pongola area.
- Mn values ranged from 25 ppm in the irrigated areas of Swaziland to over 70 ppm in the elevated Midlands mistbelt area. In all, 11 samples were found to be deficient in Mn, and five of these originated from Swaziland. A further 20% of the Swaziland samples bordered on deficiency.
- Third leaf Zn values were found on average to be the highest in alluvial soils, represented mainly by the hydromorphic Katspruit form and series soil, and the lowest in the TMS-derived Cartref form and series soils.
- Forty per cent of the leaf samples associated with the sandy Cartref form soil were found to be deficient compared with less than 20% for the Inanda form soil. This implied that the Cartref form soil is more prone to Zn deficiency than the Inanda form soil, and Zn deficiency may therefore be more extensive than originally thought.
- The relationship between Mn in the leaf and soil types proved to be interesting. High third leaf Mn contents were associated with acid soils in the Inanda, Hutton and Clovelly form while the lowest contents were associated with more alkaline soils occuring in the Shortlands form. The literature indicates that the availability of Mn is relat-

ed to soil reaction, and linear regression analysis confirmed a significant inverse relationship between soil pH and leaf Mn content in this study.

1989 Survey

- A programme referred to as the Nutrient Information Retrieval System (NIRS) was developed specifically to capture and store computerised analytical data from soil and leaf samples, in order to carry out surveys in which the frequency distribution of important soil and plant nutrients are categorised into various stages of sufficiency for different extension areas (Meyer *et al.*, 1989).
- The programme was applied for the first time to a data set that comprised analytical data from about 100 000 soil samples and 35 000 leaf samples.
- Based on a threshold value of 0,50 ppm for sandy soils, about 7% of all samples analysed were deficient in Zn. More than half of these deficiencies occurred in the Umzinto coast lowlands system and were associated mainly with TMS (ord), Carterf and Hutton form soils and Recent Sands, Hutton and Fernwood form soils. Using a 1,0 ppm threshold value for soils with more than 15% clay, 22% of the samples were marginal to deficient in Zn. These deficiencies were confined mainly to Shortlands form soils derived from Swaziland Basic Rocks and dolerite in the Komatipoort system.

Level	Soil factors	Increased risk of deficiency											
		N	P	K	Ca	Mg	S	Zn	Fe	Mn	Cu	B	Mo
High chemical	PH		■					■	■	■	■	■	
	Salinity/sodicity			■		■		■	■	■	■	■	
	Ammonium N			■	■	■			■				■
	Bicarbonate				■				■				
	Carbonate							■	■	■			
	Chloride	■					■						■
	Nitrate								■				
	Sulphate	■											■
	Aluminium		■	■	■	■	■	■			■		■
	Calcium		■	■		■		■		■		■	
	Magnesium	■		■	■			■	■				
	Potassium	■			■	■	■					■	
	Phosphorus					■		■	■	■	■		
	Copper							■	■				■
	Iron		■					■		■			■
	Manganese		■		■			■		■	■		■
	Zinc		■						■	■	■		
Low chemical	PH	■	■		■	■		■				■	■
	Ammonium N	■						■		■			
	Nitrate	■		■	■								■
	Sulphate						■	■					
	Calcium				■							■	
	Magnesium					■							■
	Potassium			■					■			■	
	Phosphorus		■										■
	Copper										■		
	Iron								■				
	Manganese										■		
	Zinc							■	■				
	Molybdenum												■
Physical/ Management	High sand content	■		■	■	■	■	■					
	High sesquioxides		■		■	■		■					■
	Overliming			■					■	■	■	■	
	Heavy composting			■					■	■	■		
	Low organic matter	■	■				■					■	
	Poor drainage			■					■				
	Moisture stress	■	■							■		■	■

Figure 2. Risk of nutrient deficiency in relation to soil factors and management practices.

1996 Survey

- This covered the analysis of leaf samples from nearly 2 000 fields from 10 extension areas in the industry.
- The mean results for Zn, Fe, Mn and Cu and the proportion of samples deficient in each region is summarised in Appendix 1.
- In the case of Zn, overall only 4% of the fields showed deficient levels of Zn with the Durban-North Coast growers showing the highest incidence and the Mpumalanga the lowest. This is well down from the 12% level of Zn deficiency recorded in the 1971 survey.
- With Fe, there was a marked increase in the proportion of samples deficient in Fe, from 1% in 1971 to 6% in 1996. Regions with the highest incidence of Fe deficiency included the South Coast and Durban-North Coast areas.
- For Mn and Cu there was very little change from the 1971 survey with only 1% of the samples showing a Cu deficiency and no samples with deficient levels of Mn.

1998 Survey

- In 1998, further results were reported of comparative changes in nutrient availability over a 17-year period, for the main extension regions in relation to four bioclimatic regions, six soil parent materials, using the NIRS FAS data base, comprising well over 200 000 soil and 75 000 leaf samples.
- Industry wide there was a marked increase in soil acidification with average soil pH values declining from a value of 6,17 in 1980-82 to 5,61 in 1996-97. This represented a 5,6-fold increase in acidification in terms of hydrogen ion activity over this period. The extent of acidification may also be assessed from the increase in the proportion of soil samples that were below pH 5,0, from 18% in 1980 to 43% in 1997 (Meyer *et al.*, 1998).
- The survey results showed that the coastal areas had acidified at a more rapid rate than their Midlands counterparts. Since 1980 areas that have shown the biggest increase in the proportion of samples that are strongly acid (below a pH of 5,0), included the South Coast (from 13 to 51%), North Coast small scale growers (from 19 to 61%), Zululand South (from 14 to 48%) and Zululand North (from 13 to 42%).
- Sub-optimal pH conditions will influence micronutrient availability in both the acid and alkaline range (Figure 1). To this end, Zn deficiency has increased in areas showing the greatest soil acidification rates, such as the South Coast and Durban-North Coast (12 and 13% Zn deficient, respectively), as well as in the irrigated areas prone to alkalinisation such as Mpumalanga and Pongola (9 and 12% Zn deficient, respectively).
- Compared with the 1980-89 period, the proportion of leaf samples deficient in S declined on an industry wide basis from 10 to 1% owing to the re-introduction of S in a number of fertiliser blends. Average soil S levels over the same period initially increased from 23 to 42 ppm but since 1989 have stabilised at around 25 ppm.

Future opportunities for research

Unfortunately micronutrient deficiencies are frequently induced by other more fundamental chemical imbalances in the soil, especially pH, high salinity and redox potential, often caused by waterlogging. Over-application of lime or agricultural products such as filtercake and poultry manure, the use of poor quality irrigation water, and imbalanced fertigation programmes under drip irrigation can also cause imbalances in micronutrient uptake. Thus corrective applications of micronutrients in such situations may only provide temporary growth improvement, or no response at all; the underlying cause for the nutrient imbalance may be overlooked by the grower. Fe deficiency in sugarcane is a typical example where soil reserves of this nutrient are inevitably high, but deficiecies are commonly induced by extremes in soil pH, both in the high and low pH range. Under strongly acid conditions, Fe deficiency can be induced through an excessive uptake of Mn, especially under wet cool conditions. Examples of other soil factors that increase the risk of nutrient deficiency are illustrated in Figure 2.

An important challenge to future researchers is to develop a model that will quantify the risk of a micronutrient deficiency based on the factors shown in Figure 2. To this end the merits of DRIS (Meyer, 1981), particularly in terms of the nutrient ratios rather than the full DRIS indices suggested by Beaufils (1973) for interpreting leaf analysis should be reassessed as a means of detecting induced micronutrient deficiencies. Other avenues of further reseach include:

- determining and modelling micronutrient uptake curves for sugarcane growing on spring, summer, autumn and winter cycles for the main bioclimatic regions in the sugar industry
- assessing the need for varietal correction factors when interpreting leaf micronutrient analyses
- improving the reliability of soil extraction procedures for predicting Cu, Fe and Mn deficiency
- studying the residual effects of micronutrient fertiliser applications on a range of soils and establishing micronutrient toxicity levels for both crop and environmental requirements
- calibrating the hot water test for plant available B in soils
- studying the Mo requirement of sugarcane in relation to nitrate reductase activity in solution culture.

Conclusions

It may be concluded from the work presented in this review that there is little justification for suspecting widespread micronutrient deficiencies in the South African sugar industry, but that nevertheless zinc and iron deficiencies are important growth limiting factors in certain areas of the sugar industry. Field trials with Zn and Fe have indicated that substantial yield responses may be obtained to treatment with these nutrients. Nutrient surveys based on foliar analysis have confirmed that Inanda form soils are prone to Zn deficiency and that certain other more sandy soils in the

Fernwood, Cartref, Glenrosa and Longlands form also fall into the high deficiency risk category. Unlike some occurrences of Cu deficiencies that have been noted in the Australian sugar industry, few have been noted in the South African sugar belt.

With the prospect of declining reserves of micronutrients in soils due to factors such as monocropping, introduction of high yielding varieties, the use of concentrated fertilisers and anti-pollution legislation, there can be little doubt that micronutrients other than Zn are destined to become more important in the sugar industry. Nutrient surveys should be carried out on a regular basis to monitor changes in soil fertility and consideration given to conducting further research as previously discussed.

REFERENCES

Alexander, KEF (1967). A nutrient survey of cane on TMS soils in Natal. *Proc S Afr Sug Technol Ass* 41: 197-200.

Allison, RV (1932). The use of less common elements as soil amendments for sugarcane production in South Florida. *Proc Int Soc Sug Cane Technol* IV Bulletin 112: 1-16.

Anderson, J (1956). Droopy top in cane. *Cane Growers Quart Bull* XIX: 146.

Anderson, DL and Bowen, JE (1990). *Sugarcane Nutrition*. Potash and Phosphate Institute, Norcross, Georgia, USA.

Anon (1965). Annual Report of the South African Sugar Association Experiment Station 1965-66: 51.

Anon (1991). Annual Report of the South African Sugar Association Experiment Station 1991-92.

Arnon, DI and Stout, PR (1939). Molybdenum as an essential element for higher plants. *Plant Physiology* 14: 599.

Beaufils, ER (1973). Diagnosis and Recommendation Integrated System (DRIS). Soil Science Bulletin 1. Department of Soil Science and Agrometerology, University of Natal, Pietermaritzburg.

Bezdicek, DF (1973). Use of routine soil tests in predicting corn leaf zinc. *Comm in Soil Sci and Plant Analysis* 4(2): 105-119.

Bowen, JE (1975). Recognising and satisfying the micronutrient requirements of sugarcane. *Sug Azucar* November 1975: 15.

Clements, HF (1967) Effects of silicate on growth and leaf freckle of sugarcane in Hawaii. pp 197-215 In: Proceedings of the XII Congress of the International Society of Sugar Cane Technologists, Puerto Rico, 28 March to 10 April 1965, Elsevier, Amsterdam.

Du Toit, JL (1956). Copper deficiency discovered in the sugar belt. *S Afr Sug J* 40: 797.

Du Toit, JL (1962). Zinc deficiency in the sugar belt indicated. *S Afr Sug J* 46: 399.

Egan, BT and Whitaker, GH (1961). Copper deficiency in the Mossman area and its control. *Proc Qld Soc Sug Cane Technol* 28: 133-137.

Evans, H (1960). Elements other than nitrogen, potassium and phosphorus in the mineral nutrition of sugarcane. pp 473-508 In: Proceedings of the X Congress of the International Society of Sugar Cane Technologists, Hawaii, 3-22 May 1959, Elsevier, Amsterdam.

Gascho, GJ, Isobe, M and Hagihara, HH (1978). Manganese availability in sugarcane soils of Hawaii and Florida. pp 971-984 In: Proceedings of the XVI Congress of the International Society of Sugar Cane Technologists, Brazil, 9-25 September 1977, Impres, Cia Bras de Impressao e Propaganda, Sao Paulo.

Halais, P and Parish, DH (1964). Silica and manganese contents of cane leaf sheaths in relation to soil nutrition. Mauritius Sugar Ind Res Inst Ann Rep. pp 74-76.

Martin, JP (1934). Symptoms of malnutrition in sugarcane when grown in culture solutions. *Hawaiian Planters Records* 38: 3-32.

Marschner, H (1986). *Mineral Nutrition in Higher Plants*. Academic Press Inc (London), 279 pp.

Meyer, JH (1976). Soil analysis as a guide to predicting zinc deficiency in sugar belt soils. *Proc S Afr Sug Technol Ass* 50: 135-140.

Meyer, JH (1977). Micronutrient studies in sugarcane. *Fert Soc S Afr J* 1: 61:68.

Meyer, JH (1981). An evaluation of DRIS based on leaf analysis for sugarcane in South Africa. *Proc S Afr Sug Technol Ass* 55: 169-176.

Meyer, JH and Wood, RA (1985). Report into an Fe chlorosis problem on a South Coast farm. South African Sugar Association Experiment Station Specialist Advisory Request.

Meyer, JH, Harding, RL, Rampersad, A and Wood, RA (1998). Monitoring long term soil fertility trends in the South African sugar industry using the FAS analytical database. *Proc S Afr Sug Technol Ass* 72: 61-68.

Meyer, JH, Wood, RA and du Preez, P (1971). A nutrient survey of sugarcane in the South African sugar industry with special reference to trace elements. *Proc S Afr Sug Technol Ass* 45: 196-204.

Meyer, JH, Wood, RA and Harding, RL (1989). Fertility trends in the South African sugar industry. *Proc S Afr Sug Technol Ass* 63: 159-163.

Ohki, K (1981). Manganese deficiency and toxicity sensitivities of soyabean cultivar. *Agron J* 72: 713-716.

Reghenzani, JR (1990). The effect of zinc deficiency as a growth factor limiting sugarcane growth. BSES and SRC Final Report BS14S, Brisbane, Australia.

Reuter, DJ and Robinson, JB (1997). *Plant Analysis – An Interpretation Manual*. CSIRO Publishing, Collingwood, Australia.

Samuels, G (1968). *Foliar Diagnosis for Sugarcane*. Adams Press, Chicago.

Schroeder, BL, Wood, RA and Meyer, JH (1992). Advances in leaf analysis techniques and interpretation in the South African sugar industry. *Proc Int Soc Sug Cane Technol* 21:123-134.

Schroeder, BL, Wood, AW, Kingston, G, Meyer, JH and Barnard, RO (1999). Leaf analysis – what does it offer the Australian sugar industry? *Proc Aust Soc Sug Cane Technol* 21 (in press).

Shrotri, CK (1983). Zinc deficiency limits the photosynthetic enzyme activation in *Zea mays L. Biochem Physiol Pflanz* 178: 213-217.

Thompson, GD (1983). The Weak Sands Project. Mount Edgecombe Research Report No.1. South African Sugar Association Experiment Station.

Thompson, GD (1985). The Upper Tongaat Project. Mount Edgecombe Research Report No.4. South African Sugar Association Experiment Station.

Tollenaar, D (1969). Boron deficiency in sugarcane, oil palm and other monocotyledons on volcanic soils of Ecuador. *Neth J Agric Sci* 17: 81-89.

Treirweiler, PJ and Lindsay, WL (1969). EDTA – Ammonium carbonate soil test for zinc. *Soil Sci Soc Amer Proc* 33: 49-54.

Von Sachs, J (1860). Berichte uber die physiologische Thatigheit an der Versuchsstation in Tharandt. *Landw Vers Stat* 2: 219.

Wood, RA and Meyer, JH (1991). Report dealing with the Dwangwa pool growth syndrone. SASEX Specialist Advisory Service Report.

APPENDIX 1.
Leaf analysis assessment summary

ZINC

Area	No. of samples	Lowest	Highest	Mean	Percentage of Total			
					Deficient	Marginal	Adequate	High
					<12,0	12,0-15,0	15,0-25,0	>25,0
Mpumalanga/Kom	30	15	27	21	0	5	90	5
Zululand North	160	15	29	19	4	14	72	10
Zululand Central	60	18	30	20	2	18	68	12
Zululand South	143	13	26	17	2	20	75	3
Midlands North	350	11	34	20	2	11	76	11
North Coast	184	13	27	21	0	14	67	19
Durban North	281	12	24	17	13	23	58	6
Midlands South	276	11	24	20	8	18	58	16
South Coast	227	14	25	17	7	22	70	1
Lower South	93	14	30	18	2	21	71	6
Average Trend	1804	14	28	19	4	16	70	10

IRON

Area	No. of samples	Lowest	Highest	Mean	Percentage of Total			
					Deficient	Marginal	Adequate	High
					<50	50-100	100-150	>150
Mpumalanga/Kom	30	70	360	178	0	16	84	0
Zululand North	160	30	263	107	6	51	43	0
Zululand Central	60	44	315	132	3	45	52	0
Zululand South	143	42	220	91	7	60	33	0
Midlands North	350	38	382	128	2	36	62	0
North Coast	184	34	268	111	8	44	48	0
Durban North	281	39	286	88	12	60	28	0
Midlands South	276	38	382	107	3	56	41	0
South Coast	227	36	266	94	12	49	39	0
Lower South	93	30	347	118	5	49	46	0
Average Trend	1804	40	309	115	6	46	48	0

MANGANESE

Area	No. of Samples	Lowest	Highest	Mean	Percentage of Total			
					Deficient	Marginal	Adequate	High
					<12,0	12,0-15,0	15,0-25,0	>25,0
Mpumalanga/Kom	30	24	58	37	0	20	80	0
Zululand North	160	30	114	61	0	1	95	4
Zululand Central	60	33	76	49	0	0	100	0
Zululand South	143	33	116	60	0	0	97	3
Midlands North	350	25	137	67	0	1	97	2
North Coast	184	23	149	61	0	2	93	5
Durban North	281	19	90	50	0	9	91	0
Midlands South	276	31	110	59	0	0	98	2
South Coast	227	23	114	55	0	5	92	3
Lower South	93	18	90	51	0	10	90	0
Average Trend	1804	26	131	55	0	5	93	2

COPPER

Area	No. of Samples	Lowest	Highest	Mean	Percentage of Total			
					Deficient	Marginal	Adequate	High
					<12,0	12,0-15,0	15,0-25,0	>25,0
Mpumalanga/Kom	30	3	7	5	0	43	57	0
Zululand North	160	3	9	5	0	65	35	0
Zululand Central	60	2	7	5	2	71	27	0
Zululand South	143	2	8	5	2	63	35	0
Midlands North	350	2	8	5	1	52	47	0
North Coast	184	3	7	5	0	61	39	0
Durban North	281	3	7	5	0	58	42	0
Midlands South	276	3	9	6	0	45	55	0
South Coast	227	3	10	5	0	60	40	0
Lower South	93	3	7	5	0	48	52	0
Average Trend	1804	3	8	5	1	57	42	0

FEASIBILITY OF IN-FIELD SOIL ANALYSIS BY NEAR-INFRARED SPECTROSCOPY

AW SCHUMANN AND JH MEYER

South African Sugar Association Experiment Station, Private Bag X02, Mount Edgecombe, 4300, South Africa

There is increasing demand for intensive soil sampling, which facilitates soil mapping, site specific water, fertiliser, pesticide and herbicide recommendations as specified in the rapidly developing management system known as precision agriculture. The high cost of soil sampling and analysis in conventional laboratories has restricted the full implementation of this technology, and Near-Infrared Spectroscopy (NIRS) could be a cost effective solution. Recent improvements in NIRS instrument design have produced models that are small, light, vibration resistant and fast, capable of collecting a complete scanned spectrum in one second.

Intensive topsoil grid sampling (n=575) of a small 0,342 ha field and subsequent analysis on a laboratory NIR spectrometer NIRS6500 was conducted to test the feasibility of in-field portable NIRS sampling and on-line analysis of soils. Good calibrations were obtained with ISI software using modified partial least squares regression on a smaller sample subset (for example, clay % R^2=0,97, n=72). Other soil properties including gravimetric soil water, buffer capacity, pH, electrical conductivity, titratable acidity, organic matter, mineralisable nitrogen, potential ammonia volatilisation from urea, potential nitrification rate, and urease activity could be calibrated despite the use of field-moist unprepared soils in the NIR instrument. Validation of the clay equation demonstrated that an acceptable standard error of 2,1% clay (Figure 1) may be possible with this technique. Predicted NIRS results for the complete sample set (n=575) were mapped as shown for clay (Figure 2) and discussed in relation to sampling strategies, precision agriculture (lime and herbicide application), and simulation modelling (soil nitrogen processes). A portable NIRS unit would allow intensive fresh in-field sample analysis, which is essential for measuring biological processes, and eliminate the need for costly sample collection, transport, preparation and storage.

Keywords: grid sampling, near-infrared, precision agriculture, soil mapping

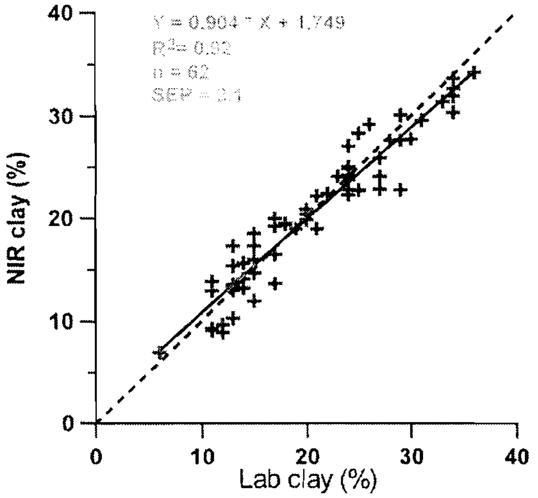

Figure 1. Prediction of soil clay content by NIRS using independent validation samples.

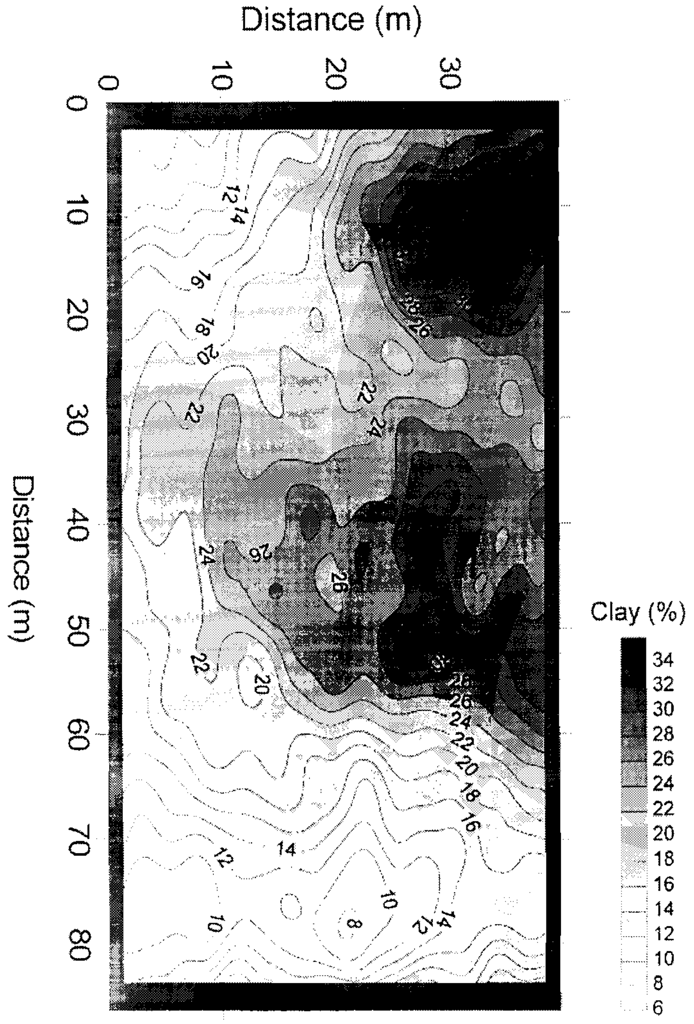

Figure 2. NIR-predicted soil clay map constructed from the 575 grid sample points.

ROBUST LEAF N THRESHOLDS FOR FOLIAR DIAGNOSIS BASED ON EXPONENTIAL - FOURIER FUNCTIONS

AW SCHUMANN AND JH MEYER

South African Sugar Association Experiment Station, Private Bag X02, Mount Edgecombe, 4300, South Africa

The importance of sampling season and crop age for correctly interpreting sugarcane leaf nitrogen (N) analysis is well established, but restricts this useful diagnostic method to about five months of the year and four to seven month old crops when using the current Fertiliser Advisory Services (FAS) thresholds. Leaf testing is particularly useful for ratoon crops since accurate diagnosis of short term soil N deficiency is not available. There is also renewed interest in crop fertigation through drip irrigation systems, where sustained N supply according to crop demand would be greatly assisted by a more complete leaf diagnosis system covering all months of the year and from 1 to 12 months of age. Early diagnosis of N deficiency (<4 months) would also enable more effective fertilisation to correct N deficiency in the current crop, since yield response is more likely and access to the crop for fertilisation is improved.

A continuous model function describing the concentration of leaf N in relation to crop age and season was developed for the coastal and Lowveld areas by least squares fitting of the exponential – fourier equation $N(\%)= AGE^{C}*(A+B*\sin(2*pi*(MONTHE)/W))$, using 14 000 FAS leaf samples of known age, season and variety (NCo376) covering the period 1981 to 1997. These mostly ratoon leaf data were restricted to exclude samples where P, K, Ca or Mg levels were deficient according to FAS thresholds. The resulting N function values cycle through a minimum in April and a maximum in October and decrease exponentially with age (Figure 1). Small adjustments (5 to 30%) to the function coefficients A and C were made until calculated N values corresponded with existing FAS thresholds for the same season and crop age (Figure 2).

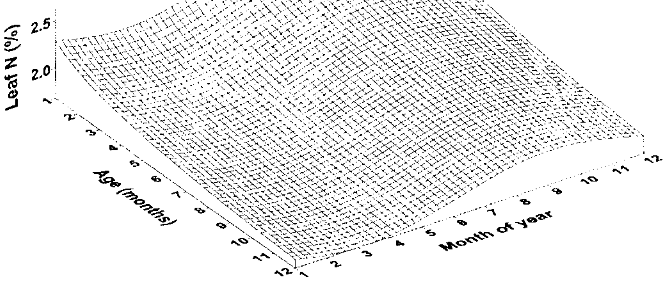

Figure 1. Relationship between sugarcane variety NCo376 leaf nitrogen, crop age and season.

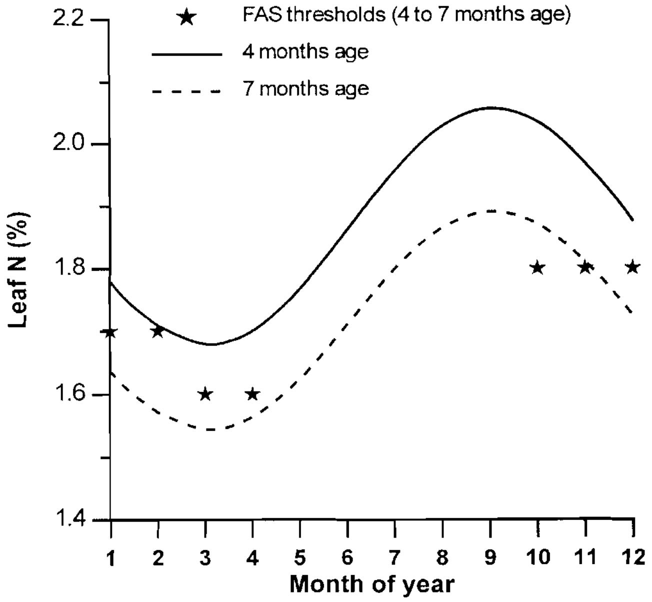

Figure 2. Correspondence between existing FAS leaf nitrogen thresholds for ratoon cane and new continuous thresholds developed for sugarcane variety NCo376.

New N thresholds (Table 1) were tested with trial data that included samples beyond the scope of the FAS thresholds. Results suggest that these thresholds could be used for early (less than three months) and late (greater than seven months) leaf N diagnosis, making them ideally suited for recommending corrective N fertiliser early enough for economic response of the current crop, or late enough to be useful for the following crop. Improved diagnoses should also be possible for any month of the year such as during continuous fertigation, provided that the crop is not stressed.

Tentative coefficients were derived by linear interpolation from FAS leaf sample data for application of these thresholds to three other sugarcane varieties. Values in Table 1 should be multiplied by 0,943 for N12, 0,942 for N14, and 0,988 for N16.

Acknowledgements

Leaf data supplied by the Fertiliser Advisory Services of the South African Sugar Association Experiment Station are gratefully acknowledged.

Table 1. Leaf N thresholds (% N) for sugarcane variety NCo376 at different crop ages and seasons.

Season (month)	Age (months)											
	1	2	3	4	5	6	7	8	9	10	11	12
1	2,19	1,98	1,86	1,78	1,72	1,68	1,64	1,61	1,58	1,55	1,53	1,51
2	2,10	1,90	1,78	1,71	1,65	1,61	1,57	1,54	1,51	1,49	1,47	1,45
3	2,07	1,86	1,75	1,68	1,62	1,58	1,54	1,51	1,49	1,46	1,44	1,42
4	2,09	1,89	1,78	1,70	1,64	1,60	1,56	1,53	1,51	1,48	1,46	1,44
5	2,18	1,96	1,84	1,77	1,71	1,66	1,62	1,59	1,56	1,54	1,52	1,50
6	2,29	2,06	1,94	1,86	1,80	1,75	1,71	1,68	1,65	1,62	1,60	1,58
7	2,41	2,17	2,04	1,96	1,89	1,84	1,80	1,76	1,73	1,70	1,68	1,66
8	2,50	2,25	2,12	2,03	1,96	1,91	1,86	1,83	1,80	1,77	1,74	1,72
9	2,53	2,28	2,15	2,06	1,99	1,94	1,89	1,85	1,82	1,79	1,77	1,74
10	2,51	2,26	2,13	2,04	1,97	1,92	1,87	1,83	1,80	1,77	1,75	1,73
11	2,42	2,19	2,06	1,97	1,90	1,85	1,81	1,77	1,74	1,72	1,69	1,67
12	2,31	2,08	1,96	1,88	1,81	1,77	1,73	1,69	1,66	1,64	1,61	1,59