SOIL ANALYSIS AS A GUIDE TO PREDICTING ZINC DEFICIENCY IN SUGARBELT SOILS

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Abstract

Zn in the TVD leaf samples from 84 cane fields on a wide range of soil types was correlated with Zn extracted from the soil by five widely used chemical extractants. Zn extracted by EDTA $(NH_4)_2CO_3$ was more closely correlated with leaf Zn than Zn extracted by methods based on 0,1N HCl, 1N KCl, 1N NH_4OAc or 2N $MgCl_2$. Linear and multiple regression analyses were used to study the relationship between leaf Zn and the four soil parameters EDTA $(NH_4)_2CO_3$ extractable zinc, clay, organic matter and extractable P. Following a study of the Zn content of leaf and soil samples from a further 400 cane fields, it was concluded that a tentative critical value of 1,50 ppm Zn in the soil gives the best separation of Zn deficient and non-deficient soils when assessed in relation to the widely used critical value of 15 ppm in the TVD leaf.

Introduction

In recent years attempts to define or measure plant available levels of trace elements in soils, as an aid to the diagnosis, correction and prevention of nutrient deficiencies in crops, have gained considerable impetus. Among the trace elements zinc is the one most frequently found to be deficient, and areas of zinc deficiency have been noted throughout the world, both in tropical and temperate climates, for a wide range of crops.[9, 10, 12, 16]

In the South African sugar industry, zinc deficiency was first recognised as a problem by Du Toit[7] in 1962, and subsequent field experiments in the Upper Tongaat and Doornkop areas of the sugarbelt have indicated that economic responses are obtained to zinc sulphate applied in the furrow at planting, as a topdressing or as a foliar spray, whenever third leaf samples contain 15 ppm Zn or less. Nutrient surveys conducted by Alexander[1] in the Natal Midlands and by Meyer *et al*[13] on an industry wide basis, confirmed, by means of foliar diagnosis, that zinc deficiency in sugarcane was mainly confined to soils derived from Table Mountain Sandstone sediments, both in the midlands and the coast hinterland regions.

Until recently zinc fertilizer recommendations have been based on foliar diagnosis but, because this system of measurement can only be carried out once the crop is well grown, the information is often obtained too late to provide advice for fertilizing the current crop. In view of the introduction of whole cycle fertilizer advice in 1973 by the Fertilizer Advisory Service, based on the analysis of a pre-plant soil sample, it became necessary to select a rapid and reliable method for determining the zinc requirement of soils in advance of planting.

As with most laboratory test investigations, the choice of a universal extractant to cover a wide range of soil conditions is not an easy one as it has been established that the ability of a plant to take up sufficient zinc from the soil can, in addition to climatological factors, be markedly affected by the following soil properties:[3]

(i) pH
(ii) phosphorus status
(iii) organic matter content
(iv) texture
(v) temperature
(vi) micro-organisms.

Of the many extractants proposed by different workers some are solutions of organic and mineral acids, salts of various kinds and chelating agents. In early work on extractants, zinc analyses based on dithizone[14] were found to correlate well with zinc uptake by plants but the procedure involved has some time-consuming steps and has not gained favour with routine soil testing laboratories. Probably the most widely used method is that of Weir and Sommer[17] which is based on extraction with 0,1N HCl. More recently, the extracting power of combinations of inorganic salt chelating agents has been investigated. Trierweiler and Lindsay,[16] for example, established that Zn extracted from neutral to high pH soils by a combination of 0,01M EDTA and 1N $(NH_4)_2CO_3$ consistently identified Zn deficient soils.

A major limitation common to many extractants is that, while they may give a useful measure of available zinc for soils which are alike in properties, they may prove less satisfactory when used with soils which vary appreciably in pH, texture, organic matter content and phosphorus status.

In view of the wide range of soil conditions that occur in the industry there was a need for an extractant of more universal application. This paper presents some of the more important findings of a comparative study of five widely used soil tests for predicting zinc deficiency in sugarcane.

Experimental

Procedure

The investigation was divided into three parts:

(i) selecting a suitable extractant by correlating Zn content of the third leaf of sugarcane from a number of fields on a range of soil types, with plant available soil Zn determined by five procedures.
(ii) formulating and testing a model for predicting the third leaf zinc content of cane from soil zinc levels, and other soil properties, by multiple regression.
(iii) establishing a tentative critical value for interpreting soil zinc levels from a representative range of soil series.

Materials

This study was based on composite soil samples and associated third leaf samples taken from nearly 500 sugarcane fields during the industry-wide nutrient survey, which has already been mentioned. Each soil sample was representative of the 0-20 cm depth and comprised 30 subsamples taken with the Mount Edgecombe soil sampler.[4] The composite leaf sample comprised 50 leaves associated with the top visible dewlap (TVD) and, for the purpose of standardisation, the sampling programme was confined to approximately seven-month-old plant or first ratoon cane, of varieties NCo 376, NCo 310 and NCo 293, sampled during the stage of rapid growth which occurs between January and February.

Determinations made on soil samples included pH, exchangeable bases, 0,02N H_2SO_4, extractable P, exchangeable

Al, organic matter content and texture. Analyses conducted on the corresponding leaf samples covered all the important major and minor elements.

For the first and second parts of this investigation 84 soil samples and their associated leaf samples, containing equal proportions of deficient, marginal and adequate zinc levels, were used at the start, while the remaining soil and leaf samples from the nutrient survey were used for calibration. Site classification and selected properties of the various soils studied are shown in Table 1.

Chemical Extraction Methods

The methods investigated were:

(i) 0,1N HCl. An acid extraction procedure first described by Weir and Sommer[17]

(ii) EDTA $(NH_4)_2CO_3$. This slightly alkaline extractant developed by Trierweiler and Lindsay[16] contains 0,01M ethylene-diaminetetraacetic acid (EDTA) and 1N $(NH_4)_2CO_3$, adjusted to pH 8,6.

(iii) 1N KCl, a neutral extractant first proposed by Hibbard[8] because this solution does not materially alter soil pH during the extraction process.

(iv) 1N NH_4OAc. An acid extractant adjusted to pH 4,8 with acetic acid as described by Lyman and Dean[12]

(v) 2N $MgCl_2$. Another neutral extractant, proposed by Stewart and Berger[15] because Mg ions, being alike in charge and similar in ionic radius to Zn ions, can displace available zinc from the soil more effectively than can other cations.

Details of soil solution ratios, extraction times etc. are given in Table 2. The extracted Zn ions were determined with a Perkin-Elmer Model 303 Atomic Absorption Spectrophotomer at a wavelength of 214 mµ.

Results and discussion

Comparative efficiency of extractants

From the data given in Table 1, it is apparent that the sites selected cover a fairly wide range of environmental, soil physical and chemical conditions, a prerequisite for testing the general applicability of a soil extractant. On the basis of mean values, the majority of soils were moderately to strongly acid, contained 2-3% organic matter and had total bases ranging from 3 to 10 me%.

TABLE 1

Some chemical properties of soils from 84 cane fields (average values)

Physiographic Region	Parent material	Soil Series	Description	No. of fields	% Clay	pH (H_2O)	Organic matter (%)	Ca	Mg	K	P	EAI*
								(ppm)				
Coast Lowlands	Table Mountain Sandstone	Cartref	Moderately deep grey loamy sand	11	14	5,2	1,9	222	87	127	35	26
	Dolerite	Shortlands	Deep red blocky clay	10	40	5,8	2,2	1 414	547	127	36	0
	Lower Ecca Shale	Milkwood	Shallow black blocky clay	11	40	5,3	2,2	981	536	133	34	8
	Dwyka Tillite	Waldene	Grey sandy loam on iron concretions	9	20	5,3	2,0	750	266	79	24	1
Midlands Mistbelt	Table Mountain Sandstone (ordinary)	Trevanian	Brown topsoil on a red porous clay	9	20	4,9	2,6	234	58	137	35	62
	Table Mountain Sandstone (Mistbelt)	Inanda	Deep humic topsoil over a red porous subsoil	10	35	5,2	4,2	730	123	161	14	79
	Dolerite	Sprinz	Deep red blocky clay	10	55	4,9	3,3	570	221	232	14	43
	Lower Ecca	Clovelly	Shallow brown topsoil over yellow clay	8	45	4,8	3,2	513	180	173	19	105
Lowveld	Schist	Glendale	Deep red blocky clay	11	37	6,8	1,9	2 073	850	262	59	Trace

* Exchangeable Aluminium Index

TABLE 2

Selected features of extraction procedures used for soil Zn

Extractant	1N HCl	0,01MEDTA and 1N $(NH_4)_2CO_3$	1N KCl	1N NH_4OAc	1N $MgCl_2$
Worker(s)	Hibbard	Trierweiler and Lindsay	Ravikovitch	Lyman and Dean	Stewart and Berger
Soil pH range tested . .	near neutral	near neutral to alkaline	near neutral to alkaline	acid to neutral	acid to near neutral
Soil: Soln ratio . . .	1 : 10	1 : 2	1 : 5	1 : 10	1 : 5
Time of extraction (minutes) . .	15	30	15	15	15

TABLE 3
Mean TVD Leaf Zinc in comparison with extractable soil Zn

Parent Material	Soil Series	TVD Leaf Zn (Mean ppm)	Soil Zn (mean ppm) extracted by:				
			0,1 N HCl	EDTA $(NH_4)_2CO_3$	1N KCl	1N NH_4OAc	1N $MgCl_2$
Table Mountain Sandstone	Cartref . . .	15,2	1,24	1,71	1,48	1,38	1,32
	Trevanian . .	18,6	1,77	2,41	3,06	2,10	3,46
	Inanda . . .	17,8	1,03	1,47	1,41	1,64	1,32
Range	High . . .	26,4	4,55	5,60	7,30	3,00	5,00
	Low . . .	11,7	0,50	0,36	0,90	0,85	0,70
Dolerite	Shortlands . .	17,1	1,79	2,09	1,43	1,57	1,59
	Sprinz . . .	16,4	1,92	1,98	1,63	1,98	1,47
Range	High . . .	23,8	3,65	4,00	2,30	3,30	3,6
	Low . . .	10,4	0,50	0,72	1,00	1,44	0,9
Lower Ecca Shales	Milkwood . .	18,6	1,42	2,08	1,34	1,54	1,54
	Clovelly . .	18,6	2,04	2,36	1,87	1,62	1,13
Range	High . . .	26,2	3,25	6,00	2,20	2,00	2,90
	Low . . .	13,0	0,55	0,72	1,15	1,40	1,35
Dwyka Tillite	Waldene . .	17,3	1,76	1,86	1,53	1,52	1,84
Range	High . . .	24,4	3,88	4,10	2,10	1,70	2,80
	Low . . .	12,2	0,68	0,55	1,10	1,40	1,05
Schist	Glendale . .	17,9	1,50	1,92	1,06	2,16	1,23
Range	High . . .	22,0	2,00	5,50	1,80	2,60	1,55
	Low . . .	14,6	0,35	0,44	0,70	1,90	0,75
Overall Average		17,6	1,65	1,93	1,56	1,78	1,60

TABLE 4
Relationship between third leaf Zn content in cane and soil Zn extracted by five different solutions

Third leaf Zn content		No. of fields	Mean Zn content (ppm)	Mean soil Zn extracted by:				
Class	(ppm)			0,1N HCl	EDTA $(NH_4)_2CO_3$	1N KCl	1N NH_4OAc	1N $MgCl_2$
Deficient . .	< 13	6	11,70	1,07	0,66	1,31	1,57	1,39
	13-15	21	14,06	1,13	1,14	1,41	1,48	1,37
Medium . . .	15-17	19	15,92	1,46	1,41	1,40	1,75	1,36
	17-19	15	18,12	1,99	2,20	1,42	2,00	1,69
High	19-21	10	19,69	1,90	2,71	1,50	1,85	1,37
	> 21	13	23,50	2,46	3,64	2,42	2,13	2,45
Overall means			17,60	1,65	1,93	1,56	1,78	1,60
Correlation coefficients			—	0,49**	0,69**	0,32	0,39	0,18

The average amounts and ranges of zinc determined by the various extractants from the soils studied are shown in relation to amounts of total zinc obtained from the associated third leaf samples (Table 3). A comparison of the amounts of soil zinc extracted shows that, on average the largest amount is removed by the EDTA-$(NH_4)_2CO_3$ extractant, hereafter referred to as EDTA, while the amounts extracted by the other reagents decrease in the order:

$$\text{EDTA} > 1\text{N } NH_4OAc \sim 0{,}1\text{N } HCl > 1\text{N } MgCl_2 > 1\text{N } KCl$$

Since the major source of plant-available Zn is considered to be the portion that is adsorbed and complexed by colloidal materials, it is likely that the greater removal of zinc by EDTA is related to the effectiveness of this reagent in extracting both exchangeable zinc and zinc chelated by organic matter, while the other extractants tend to remove predominantly exchangeable zinc.

Although the leaf Zn values in Table 3 show no marked relationship with the various soil extractant values, a different picture emerges, as shown in Table 4, when the analytical data for each of the extractants are pooled and ranked in increasing order of zinc availability as measured by leaf concentration of zinc. Comparison of the mean leaf Zn values in the various class intervals with the respective soil extractant mean values shows well defined trends for 0,1N HCl and EDTA.

A graphical representation of the same data is shown in Figure 1 which indicates that the EDTA extractable Zn bears the closest relationship with leaf zinc.

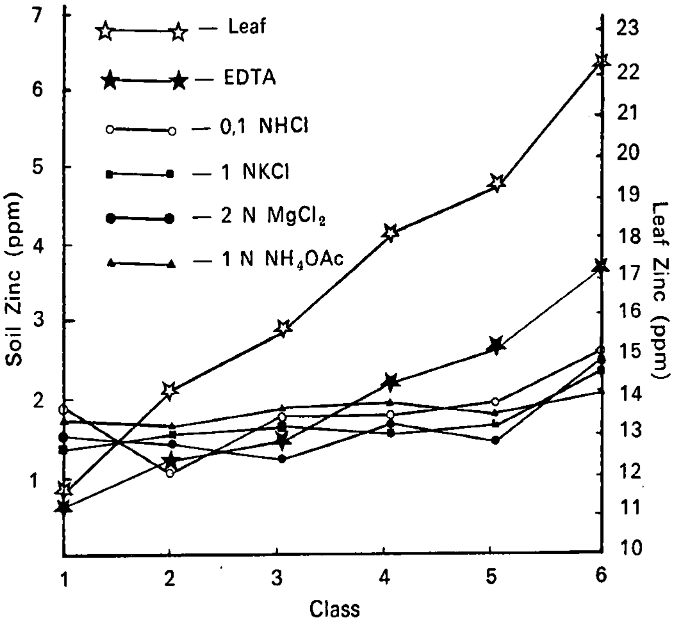

FIGURE 1 Relationship between average leaf Zn values and soil Zn extracted by five methods.

Regression analysis of the 84 paired observations confirmed this relationship and indicated that leaf Zn was positively correlated with EDTA Zn (r = 0,69**). The regression line obtained and equation describing this relationship are given in Figure 2. Results with the other extractants showed that 0,1N HCl extractable Zn was also positively correlated with leaf Zn, the relationship being significant at the 5% level. On the basis of these data the EDTA extractant was judged to be the most promising for the sugarbelt and was consequently retained for further evaluation.

Leaf Zn in relation to EDTA extractable Zn and other soil properties

The correlation coefficient for the relationship between leaf Zn and EDTA Zn observations, graphed in Figure 2, shows that nearly 50% of the leaf Zn variability can be attributed directly to the EDTA soil Zn variable studied. This figure compares favourably with that of other workers, for example Juang *et al*,[10] obtained a value of 45% for a range of sugarcane soils in Hawaii. The equation obtained for predicting leaf zinc in this investigation, i.e.

y = 13,52 + 1,884 EDTA Zn — (equation 1),

did not, however, prove to be very reliable when compared with actual leaf zinc levels below 15 ppm. A second regression analysis of leaf zinc values below 17 ppm and the associated soil EDTA values showed a much improved correlation (r = 0,78**) with a relatively small change in the prediction formula for leaf Zn

y = 12,0 + 1,981 EDTA Zn — (equation 2).

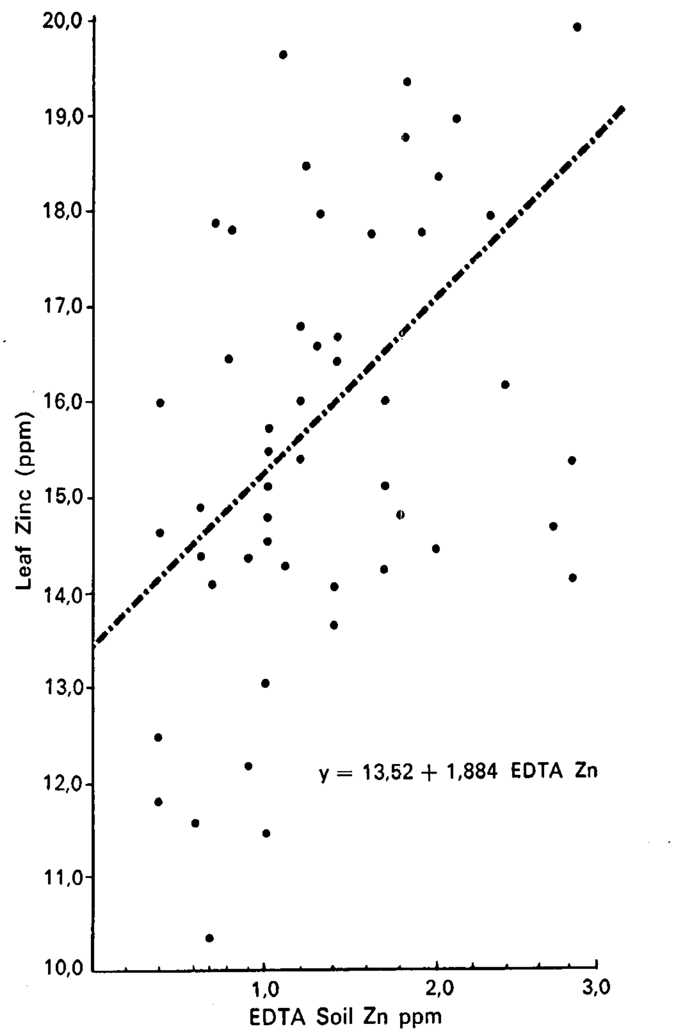

FIGURE 2 Relationship between leaf Zn and EDTA extractable Zn in samples from 84 sugar cane fields.

Comparison of the predicted leaf values obtained by both equations with the actual values shows that the second equation is superior in predicting values below 17 ppm. This will be illustrated by reference to an example in subsequent discussion.

A number of studies concerning the influence of soil properties and extractable zinc on zinc availability have emphasised

TABLE 5

Relationship between third leaf Zn content and selected soil properties

Third leaf Zinc		No. of fields	Mean leaf Zn (ppm)	Mean soil properties			
Class	ppm			EDTA Zn (ppm)	% clay	% organic matter	Truog P (ppm)
Low	< 15	27	13,5	0,85	26	2,70	26
Medium . . .	15-19	34	16,6	1,82	32	2,85	63
High	> 19	23	21,6	3,16	34	2,30	72

the important role of clay, soil reaction organic matter and phosphorus in unravelling the chemistry of soil Zn. Bezdicek *et al*,[5] for example, have developed a multiple regression model for predicting corn leaf Zn based on EDTA $(NH_4)_2CO_3$ extractable Zn, pH, extractable P and organic matter. They established by soil and leaf analyses from 91 fields that 68% of the observed leaf analyses can be estimated from a regression equation which they derived.

In this investigation an initial grouping of leaf Zn analyses into low (< 15 ppm), medium (15-19 ppm) and high (> 19 ppm) categories suggests a possible trend with texture, organic matter and, to a lesser extent, extractable P. These data are shown in Table 5.

TABLE 6

Correlation of third leaf zinc and four soil properties from 84 cane fields

Variables	EDTA Zn	Organic matter	Truog P	Clay
Leaf Zn	0,69**	−0,16	0,14	0,07
Clay	−0,10	0,36*	−0,10	
Truog P	0,21	0,06		
Organic matter	−0,19			
P = 0,05 P = 0,01	0,22 0,28			

Linear and multiple regression analyses were therefore used to study these relationships further in order to decide whether there would be any merit in including them in the prediction formula. The linear correlations obtained for the various combinations are shown in Table 6. With the exception of the positive leaf Zn x soil Zn interaction, none of the relationships between leaf Zn or soil Zn and the other soil variables reached a level of statistical significance. Soil organic matter in relation to clay content, however, showed a significant positive relationship at the 5% level of significance.

Multiple regression analysis showed that including all four soil parameters in the prediction formula gave no improvement over the use of EDTA Zn alone in estimating leaf Zn. Omitting organic matter and extractable P from the regression improved the position marginally by increasing r^2 from 0,47 to 0,49. The equation for this relationship was formulated as follows:

$$\text{Leaf Zn} = 17{,}32 + 1{,}921\ (\text{EDTA Zn} - 2{,}02) + 0{,}0346\ (\text{Clay}\,\% - 30{,}08)$$

Testing the equation indicated a small gain in predicting Zn deficiency but the improvement was not statistically significant.

Establishing a basis for interpreting EDTA extractable Zn values

EDTA/$(NH_4)_2CO_3$ extractable Zn was determined on soil samples from a further 400 cane fields which constituted the balance of the nutrient survey samples which were not used in the first part of this investigation. The data were used to estimate leaf Zn from the first two prediction formulae. A comparison of the actual analyses of associated leaf samples with predicted data for low, medium and high categories of leaf Zn, as shown in Table 7, confirms that equation 2 is

TABLE 7

Comparison of leaf Zn values predicted from soil zinc analyses with actual leaf Zn values from 394 cane fields

Third leaf Zn content		No. of samples	Mean soil Zn (ppm)	Mean leaf Zinc (ppm)					% Agreement	
				Actual	Predicted		Difference			
Class	(ppm)				Equation 1	Equation 2	Equation 1	Equation 2	Eqn 1	Eqn 2
Deficient	< 15	85	1,38	13,4	15,7	14,5	+ 2,3	+ 1,1	30	62
Medium	15-17	61	1,60	15,9	16,6	15,5	+ 1,0	− 0,4	66	55
	17-19	116	2,28	17,4	17,6	16,5	+ 0,2	− 0,9	50	37
High	19-21	50	2,50	19,9	18,6	17,0	− 1,3	− 2,9	26	19
	> 21	82	3,65	26,1	22,4	19,3	+ 3,7	− 6,8	20	10

Equation 1: Leaf Zinc = 13,52 + 1,884 EDTA Zn

Equation 2: Leaf Zinc = 12,00 + 1,981 EDTA Zn

TABLE 8

Relationship between actual and predicted leaf Zn values for cane fields under diverse climatic conditions

PONGOLA (Alluvium)							MIDLANDS (Middle Ecca)						
Lab. No.	Soil Zn	Leaf Zn	Predicted Zn		Difference		Lab. No.	Soil Zn	Leaf Zn	Predicted Zn		Difference	
			Eqn. 1	Eqn. 2	Eqn. 1	Eqn. 2				Eqn. 1	Eqn. 2	Eqn. 1	Eqn. 2
77	1,64	16,0	16,6	15,2	+ 0,6	− 0,8	504	1,12	18,4	15,6	14,2	− 2,8	− 4,2
78	0,96	16,8	15,3	13,9	− 1,5	− 2,9	505	3,90	17,5	20,9	19,7	+ 3,4	+ 2,2
79	1,04	13,6	15,5	14,0	+ 1,9	+ 0,6	506	1,36	17,5	16,1	14,7	− 1,4	− 2,8
80	0,88	13,2	15,2	14,8	+ 2,0	+ 1,6	507	1,28	17,1	15,9	14,5	− 1,2	− 2,6
81	2,08	15,0	17,4	16,1	+ 2,4	+ 1,1	508	1,28	18,7	15,9	14,5	− 3,8	− 4,2
82	2,24	16,0	17,7	16,4	+ 1,7	+ 0,4	509	6,00	20,8	24,8	23,8	+ 4,0	+ 3,0
84	1,00	16,1	15,4	14,0	− 0,7	− 2,1	510	1,56	18,8	16,4	15,1	− 2,4	− 3,7
85	1,00	14,1	15,4	14,0	+ 1,3	− 0,1	511	2,60	16,8	18,4	17,1	+ 1,6	+ 0,3
89	1,04	15,8	15,5	14,1	− 0,3	− 1,7	521	1,24	15,8	15,8	14,6	0	− 1,2
Mean	1,32	15,2	16,1	14,7	+ 0,8	− 0,5	Mean	2,26	17,9	17,7	16,5	− 0,2	− 1,4

superior to equation 1 in estimating leaf Zn values below 17 ppm. For soil EDTA values above 1,6 ppm, but not higher than 3 ppm, however, equation 1 is more effective in predicting leaf Zn. Examples of the range of differences that can be obtained between actual leaf values and predicted values from both these equations are shown in Table 8 for a number of samples from cane fields in the Pongola and Midlands areas. Considering the large differences in climate and soil conditions the reliability of these predictions is reasonably satisfactory.

Trierweiler and Lindsay,[16] in developing the EDTA $(NH_4)_2CO_3$ extractant for Colorado soils, reported a good separation into Zn deficient and Zn sufficient categories based on a critical value of 17 ppm in the corn leaf. By our leaf critical value of 15 ppm, 82 of the 400 cane fields may be rated as potentially deficient in zinc. Table 9 shows the probabilities of predicting a deficiency (< 15 ppm) or adequacy of zinc (> 15 ppm) in sugarcane by interpreting the EDTA extractable Zn of corresponding soil samples in accordance with a range of tentative critical values.

TABLE 9

Probability of predicting a deficiency or a sufficiency of leaf Zn from soil EDTA-Zn

Leaf Zinc		% agreement with soil Zn critical values			
Class	No. of fields	<0,80 ppm	1,00 ppm	1,25 ppm	>1,50 ppm
Deficiency < 15 ppm	82	34	59	67	75
Sufficiency @ 15 ppm	321	91	82	67	60
Overall % agreement (403 fields) . . .		77	78	67	64

On one hand, if 0,8 ppm is used as a tentative critical value, only 34% of the deficient leaf samples are associated with soil values below 0,8 ppm. On the other hand more than 90% of the soil samples associated with leaf values in excess of 15 ppm are associated with soil values greater than 0,8 ppm. Increasing the critical value to 1,5 ppm improves the probability of predicting a Zn deficiency from 0,34 to 0,75 but at the same time the chance of correctly forecasting a sufficiency is reduced from 0,91 to 0,60. The use of 1,25 ppm as a critical value appears to strike the correct balance in predicting either a deficiency of a sufficiency of Zn in the cane plant with a probability of 0,67. For diagnosis it was considered important to err on the safe side and to use a value of 1,50 ppm rather than 1,25 ppm in giving advice when treatment with zinc fertilizer material is necessary. This value agrees very well with a figure of 1,40 ppm established independently by Trierweiler and Lindsay[16] and Bezdicek[5] *et al* for maize and 1,66 ppm established by Gangwar and Orandra for rice.[9]

It may be concluded that the standard recommended rate of 50 kg/ha zinc fertilizer (22% Zn) in the furrow, based on leaf analysis (< 15 ppm), will suffice whenever soil values are below 1,50 ppm. The cost per hectare of this application (± R6,00) will be more than covered by a minimum response of 1,0 ton cane per hectare, which is small by comparison with the responses of up to 20 ton cane/ha that have been obtained under experimental conditions.

Conclusions

This investigation confirms that the EDTA $(NH_4)_2CO_3$ extractant method is very promising for rapidly assessing the zinc requirement of sugarcane before planting. Although direct correlation studies between this procedure and the response of sugarcane to applied zinc treatment in the field have not been completed, the examination of leaf and soil Zn data from 400 sugarcane fields has shown that a value of 1,50 ppm gives a good separation between Zn deficient and non-Zn deficient soils when assessed on the basis of a 15 ppm critical value in the leaf.

In originally developing this method Trierweiler and Lindsay[16] tested mainly neutral to high pH soils. The results of the present study suggest that the extractant has a more general application and can be used for extremely acid soils with relatively high organic matter contents such as are commonly found in the Natal Midlands. Further progress in the calibration of this method will be possible when the results from a number of field experiments, which include zinc treatments, have been assessed.

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