AN EVALUATION OF DRIS BASED ON LEAF ANALYSIS FOR SUGARCANE IN SOUTH AFRICA

By J. H. MEYER
South African Sugar Association Experiment Station, Mount Edgecombe

Abstract

In recent years increasing attention has been given to the Diagnosis and Recommedation Integrated System (DRIS) for diagnosing the nutrient requirement of sugarcane and other crops. Sugarcane yield data and third leaf analysis from 96 fertilizer trials have been used to establish whether DRIS can be used to improve the quality of the fertilizer advisory service offered by the Experiment Station. In general it was found that predictions of a yield response to applied N, P and K were more reliable when DRIS was used than when the nutrient threshold approach was used at an early rather than a late stage of crop development. The results suggest that imbalances of N, P and K can be detected four to six weeks earlier by using DRIS than can be accomplished by using the threshold approach. DRIS can be used fairly reliably to indicate N, P and K deficiencies in order of decreasing importance. It will now be possible to check the adequacy of fertilizer programmes at an early stage of crop development to recommend additional treatment where necessary for the benefit of the crop being sampled. Sometimes unsuspected problems related to P fixation and early losses of N due to leaching or denitrification may also now be identified when the crop is very young. DRIS soil norms are currently being investigated.

Introduction

The Experiment Station of the South African Sugar Association has successfully conducted a fertilizer advisory service, based on soil and leaf analysis, for almost 27 years. While the demand for soil tests has always exceeded that for foliar diagnosis, the records show that the gap has steadily closed during the past decade, largely due to the wider acceptance by growers of whole cycle recommendations.

Foliar diagnosis has the important advantage over soil testing that by determining the nutrients the plant has actually taken up doubts about effective rooting depth of the crop and the choice of suitable chemical extractants for estimating plant-available nutrients are to a large extent eliminated. The sugarcane plant with its extensive root system will always provide a more representative sample under the highly variable soil conditions that occur in the sugar industry than will a man with an auger and somewhat arbitrary nutrient extraction procedures.

Despite the considerable merits of foliar diagnosis, it must be conceded that with its introduction a number of variables such as crop age, month and season of sampling and bioclimatic regions become important, and that these factors have little effect on soil testing. The effects of crop age and time of year on foliar N are well known, and although a standard sampling procedure and the use of a comprehensive set of threshold values may minimize these effects, it is not always possible or convenient to ensure that sugarcane is sampled at a standard physiological stage.

The major drawback to leaf analysis, however, is that the results can seldom be used to the benefit of the crop from which the sample was taken because the growing season, or most of it, has already passed. Because of these difficulties, and because current methods can be used neither to classify nutrient excesses nor to estabish the order of importance of nutrient deficiencies, interest has arisen in ratios of the amounts of nutrient elements in cane leaves. The DRIS technique (Diagnosis and Recommendation Integrated System) of Beaufils[3, 4] is based on nutrient ratios and it is being evaluated for sugarcane not only in South Africa but also in Brazil (Zambello[20]), Florida (Gascho[11]) and Hawaii (Jones[13]).

Interest in this approach for sugarcane arose in 1972 at the Experiment Station when it was found that the P requirement of sugarcane grown on high P-fixing soils could be assessed most reliably from the N:P and K:P ratios in the TVD (Top visible dewlap) leaf, using a DRIS chart (Anon[1]). A subsequent study of the results of twenty four 4Nx2Px3K Regional Fertilizer trials (Meyer[16]) indicated that the nutrient status of the crop with respect to both N and P could be predicted more reliably by DRIS than by the conventional nutrient threshold approach, although it appeared unlikely that the same DRIS norms could be used in all circumstances.

The use of DRIS for sugarcane was studied subsequently in a three-year project conducted by the Soil Science Department of the University of Natal. A number of diagnostic norms were developed for establishing the order of importance of both macro and micro nutrient deficiencies. Tentative leaf N, P, K, Ca and Mg norms were first developed from yield data obtained from South African cane growers' files in association with analytical results provided by the SASA Experiment Station's Fertilizer Advisory Service (FAS). A yield of five tons cane per hectare per month was used to discriminate between high-yielding and low-yielding crops. Because these data did not represent a sufficiently wide range of sampling conditions, a second set of norms was developed for diagnosing both macro and micro nutrient imbalances in leaf and soil samples. In this exercise a yield of seven tons cane per hectare per month was used to separate high yielding from low yielding cane. The results indicated that the order in which nutrients limit cane yield could be established at any stage of crop development (Beaufils and Sumner[6]). Similar findings have been reported for crops such as maize, rubber and cotton (Beaufils[2, 3]) wheat and soya beans (Sumner[17, 18]), potatoes (Meldal-Johnston[15]) and tea (Lea[14]).

Although these findings were promising, the testing of the newly-derived norms was unfortunately restricted to the results of a small number of trials. Crop yield data and leaf analysis from 96 fertilizer trials conducted throughout the South African sugar industry were therefore used to provide a more vigorous test of the system, and this paper concerns some of the more important conclusions that could be reached.

Procedure

The evaluation process was divided into four phases :

(i) selecting suitable DRIS norms and retrieving yield data and leaf and soil analysis in forms suitable for processing by computer into DRIS indices.

(ii) using the computed data to compare the relative effectiveness of nutrient threshold values and DRIS in predicting responses to applied nutrients at various stages of crop development and for cane grown in the coast lowlands, midlands and lowveld regions of the industry.

(iii) testing whether DRIS norms correctly predict the order of importance of nutrient deficiencies, and whether the results can be related to actual fertilizer requirements.

(iv) establishing how DRIS could best be implemented for advisory purposes.

Although the main object of this investigation was to test the norms supplied by the University of Natal it was considered worthwhile to include the set developed previously by the SASA Experiment Station, and a further set from the Florida Sugar Experiment Station (Gascho[11]).

Five sets of N P K norms, designated A, B, C, D and E, were thus selected and details are given in Table 1. The general principles used in establishing a data bank and selecting parameters with significant co-variance ratios have been outlined previously by Beaufils[4].

Since the DRIS approach is intended to include as many nutrient elements as possible, a sixth set of norms, developed from the University data bank for minor elements, was also tested and the average values are shown in Table 2. These are subsequently referred to as the "general" set of norms.

Considering that the data to establish the various norms come from such widely divergent sources, the norms shown in Table 1 are surprisingly similar. The N/P and K/P norms established in Florida deviated most from the overall mean values.

These norms were used to convert approximately 1 200 sets of leaf analyses, obtained from the results of 96 fertilizer trials, into N, P, K, Ca, Mg and Zn indices using the general formula developed by Beaufils[4]. The equation used for calculating the N index is given by :

$$\text{N index} = \frac{f(N/P) + f(N/K) - f(Mg/N) - f(Ca/N)}{4}$$

$$\text{where } f(N/P) = 100\left(\frac{N/P}{n/p} - 1\right) 10/CV \text{ when } N/P > n/p$$

$$\text{or } f(N/P) = 100\left(1 - \frac{n/p}{N/P}\right) 10/CV \text{ when } N/P < n/p$$

N/P is the value of the ratio (N% oven dry third leaf tissue ÷ P% oven dry third leaf tissue) for a particular sample, and n/p is the value of the norm for this ratio given in Table 1. CV is the coefficient of variation for the population of high yielding plants. The indices for the other nutrients are calculated similarly. The DRIS indices may be positive or negative but their sum is always zero because they measure the balance among the nutrients N, P, K, Ca and Mg. The more negative the value of an index, the greater the probability of the nutrient concerned being deficient and the crop yields being reduced. Conversely, the more positive the value of an index the smaller is the likelihood of the nutrient under consideration being deficient. An index close to zero indicates that the nutrient concerned is in adequate supply. From their indices for a given leaf sample, the nutrients can be classified in order of deficiency, adequacy and excess, the most negative index indicating the nutrient most required and the most positive index the nutrient least required.

The details concerning the sources of data used for the assessment of DRIS discussed in this paper, according to the main physiographic regions, are given in Table 3. Data from only two trials in the midlands were used for evaluating N and K indices for this area, but otherwise the distribution of trials represents fairly adequately the soil and climatic conditions which occur in the sugar industry.

Responses to treatment with nitrogen in the 72 crops examined varied from 12 to 62 tons cane per hectare, the average being 33,0 tons cane per hectare.

TABLE 1
Details of the five sources of data, and the average third leaf norms for N, P and K

Norms	A	B	C	D	E	Overall means
Source of data bank	University Survey 1	University Survey 2	University (Growers' files)	Florida Sugar Expt Stn	SASA Expt Stn	
Yield criterion	7 tc/ha/month	8 tc/ha/month	5 tc/ha/month	125 tc/ha/crop	130 tc/ha/crop	
Total No. of samples	972	972	1 300	1 600	767	—
N/P	8,54	8,61	8,19	8,71	8,35	8,48
N/K	1,75	1,72	1,51	1,54	1,75	1,65
K/P	5,11	5,42	5,46	5,63	5,10	5,34

TABLE 2
Third leaf norms for Ca, Mg and Zn

Norm	Ca/N	Ca/P	Ca/K	Mg/N	Mg/P	Mg/K	Ca/Mg	Zn/N	Zn/P	Zn/K	Zn/Ca	Zn/Mg
Value	0,15	1,21	0,27	0,12	0,96	0,19	1,16	13	108	22	91	94

TABLE 3
Sources of data for the assessment of DRIS discussed in this paper

Region	Nitrogen			Phosphorus			Potassium			Calcium and Magnesium			Zinc		
	No. of trials	No. of crops	No. of leaf samples	No. of trials	No. of crops	No. of leaf samples	No. of trials	No. of crops	No. of leaf samples	No. of trials	No. of crops	No. of leaf samples	No. of trials	No. of crops	No. of leaf samples
Coast Lowlands ..	26	45	79	20	36	63	32	70	91	1	1	3	14	20	42
Midlands	1	1	9	8	11	68	1	4	6	9	22	85	5	5	26
Lowveld	7	27	82	3	12	21	2	10	22	Nil	Nil	Nil	1	3	12
Overall	34	72	161	31	59	152	35	84	119	10	23	88	20	28	80
Average response to treatment, tc/ha ..	33,0			16,0			17,5			5,2			11,5		
*ters/ha	4,3			2,0			2,6			0,6			1,7		

* ters = tons estimated recoverable sugar
ers % cane = S − 0,485N − 0,057 F
Where S = sucrose % cane
N = non-sucrose % cane
F = fibre % cane.

The average responses to the other nutrients were considerably lower. In the second and third phases of the evaluation a number of tests were made concerning responses to treatment with a nutrient and the relative DRIS indices. One test was a simple assessment of the frequency of correctly predicting responses to applied nutrients, whilst another involved using Beaufils[5] iterative procedures.

Results

Probability of predicting responses to applied nutrients correctly

In this phase the probability of correctly predicting responses to applied nutrients, based on leaf samples from cane between the ages of four and nine months, was determined using threshold values alone and the DRIS procedures described above. Responses of 10% or more were deemed to have been predicted correctly when the third leaf nutrient values, expressed on a dry matter basis, were below the appropriate threshold value, or in the case of DRIS, when the value of the index was negative and the nutrient either the first or second most deficient. If the responses were associated with nutrient concentrations close to the threshold values or with DRIS indices close to zero, the predictions were considered to be doubtful. In the event of the yield responses being associated with nutrient levels above the threshold values, or with positive DRIS indices, the predictions were considered to be incorrect. In instances where there was little or no response to treatment, the data were assessed in a similar way. A comparison of the effectiveness of the two methods and the different norms, based on the proportions of correct, doubtful and incorrect predictions, is given in Table 4.

Reliability of predictions for macronutrients

Predictions of a yield response to N were found to be correct in 70% of the cases examined, based on the appropriate threshold values shown in Table 5. The predictions when using the various DRIS norms were generally slightly better, ranging from 67% for the C set to 80% for the general set. In the case of P all the DRIS sets were clearly superior to the threshold value of 0,19% used alone. For K, however, there was very little difference between the two methods, although it was interesting to note that the norms developed in Florida gave the most reliable prediction of a K deficiency. The performance of the Florida norms was remarkably good when it is considered that the situation in Natal differs so much in terms of soil, climate and varieties from those which occur in Florida.

DRIS appears to be particularly useful for N, a single set of norms being equally reliable for predicting responses in the three regions, whereas five different threshold values are required for this nutrient. This implies that a diagnosis based on ratios is not significantly affected by factors such as stage of crop (plant or ratoon cane), month of sampling (between October and April) and region, all of which have to be considered in selecting one of the critical threshold values for N.

It can be seen from Table 4 that the reliability of predictions when using the general set of norms, based on ratios involving five elements (N, P, K, Ca and Mg) is better than those obtained when using the A set, which was derived from the same N, P and K data. There may therefore be some advantage to be gained from including Ca and Mg results as well as those for the major elements when assessing the balance of nutrients in the plant and with respect to N in particular.

Reliability of predictions for micro-nutrients

The results in Table 4 show that the threshold values provided more reliable predictions of the Ca and Zn requirements of sugarcane, but were slightly less reliable than DRIS for predicting Mg requirements. However, these results cannot be regarded as conclusive, because on some of the experiment sites the response to treatment with lime was due largely to the suppression of Al toxicity. In these instances positive Ca indices were invariably obtained, indicating the adequacy of Ca as a nutrient. On the other hand there were a number of trials when no response was obtained to treatment with lime, where DRIS indicated that Ca was the first or second most important deficiency.

In several of the trials there was no response to treatment with Zn, but the Zn indices were strongly negative, indicating a deficiency. The average value of 25 ppm Zn obtained from the University data bank is much higher than the leaf

TABLE 4
A comparison of the reliability of threshold values and DRIS for predicting yield responses to treatment with nutrients

Nutrient	No. of crops	No. of leaf samples	Average response		Reliability of predicting a response to applied nutrients (per cent)																							
					Threshold values			DRIS norms																		
								General			A			B			C			D			E		
			tc/ha	ters/ha	√	?	×	√	?	×	√	?	×	√	?	×	√	?	×	√	?	×	√	?	×
N	58	138	33,0	4,3	70	2	28	80	1	19	74	1	24	74	1	24	67	1	32	70	5	25	74	1	25
P	59	116	16	2,0	59	12	29	72	6	22	71	8	22	68	8	24	69	6	24	68	7	25	71	6	22
K	84	119	17,5	2,6	70	4	26	71	5	24	67	4	29	70	3	27	77	0	23	78	0	22	66	4	29
Ca	23	88	5,2	0,6	76	10	14	59	8	23															
Mg	23	88	5,2	0,6	69	6	25	76	5	19															
Zn	28	80	11,5	1,7	72	2	26	56	2	42															

√ = Correct ? = Doubtful × = Incorrect

TABLE 5
A list of threshold values used in evaluating yield responses to treatment with various nutrients

Nitrogen				
Area	Crop age	Months of sampling	N% Plant	N% Ratoon
Northern Irrigated	4-6 months	Oct-Dec Jan-Feb March-April	2,0 1,9 1,8	1,8 1,7 1,6
Coastal Lowlands	4-9 months	Nov-Dec Jan-Feb March	1,8 1,7 1,6	
Midlands	5-12 months	Nov-Dec Jan-Feb March	1,9 1,8 1,7	
Other nutrients P: 0,19% K: 1,05% Ca: 0,15% Mg: 0,08%	Zn: 15 ppm Cu: 3 ppm Mn: 15 ppm S: 0,14%			

Zn levels found generally in the industry. This high value has probably biased the various ratios which involve Zn, thereby indicating Zn deficiencies when they do not exist. The norms involving Zn will clearly have to be revised before they can be used for advisory purposes.

Testing the reliability of DRIS norms in predicting order of nutrient requirement

(1) By comparing order of response with order of nutrient requirement. According to Beaufils[4] a diagnosis with the indices N = –7, P = –5, K = –3, Ca = +5 and Mg = +10 implies the following order of requirement of nutrients : N P K Ca Mg. The results of 25 N P K fertilizer trials were used to assess the reliability of DRIS predictions of the order of requirement for N, P and K. Of the 25 trials, 24 were conducted in the South African sugar industry (du Toit[8]) and the other was a long term NPK experiment conducted by the Zimbabwe Sugar Association at the Chiredzi Research Station (Gosnell[12]). For each trial the average responses obtained to applied N, P and K were ranked in decreasing order of magnitude and compared with the DRIS order of nutrient requirement. A comparison of the orders of response obtained for the six possible NPK combinations and the corresponding DRIS orders of requirement for the five different sets of DRIS norms is given in Table 6.

Overall agreement between the order in terms of yield response and the DRIS order ranged from 46% for the C set to 60% for the E set of norms. The K N P order was generally predicted most reliably (82%). In contrast the N P K and K P N orders of response agreed with the DRIS orders of nutrient requirement only on 42% and 40% of occasions respectively. Variations in reliability of predictions may have been due partly to the small differences in the values of the N/P, K/P and N/K values used to calculate the indices, but they are more likely to have been associated with the relatively small differences between the P and K and P and N yield responses in the N P K and K P N treatment combinations respectively.

The results of only two crops could be used to assess the P N K and P K N treatment combinations, and hence

TABLE 6
Comparison between order of response to applied N P and K in 25 trials and apparent NPK requirement based on five sets of DRIS norms

N P K response class	No. of crops and leaf samples	Average response tc/ha			Predominant DRIS nutrient requirement					% Agreement between DRIS order of response and diagnosis						
		N	P	K	A	B	C	D	E	Nutrient order	A	B	C	D	E	Over-all
> >					> >	> >	> >	> >	> >							
N K P	21	18,7	5,0	8,1	N K P	N K P	N P K	N K P	N K P	N K P	48	48	33	43	43	43
N P K	10	18,8	9,9	5,8	N P K	N K P	N K P	N K P	N P K	N P K	50	40	30	30	60	42
K N P	16	6,1	1,8	8,5	K N P	K N P	K P N	K N P	K N P	K N P	81	87	75	81	87	82
K P N	6	2,5	7,2	15,9	K P N	K N P	K N P	K N P	K P N	K P N	50	33	33	33	50	40
P N K	2	7,0	12,0	2,0	P N K	P N K	P N K	N P K	P N K	P N K	50	50	50	50	50	50
P K N	2	− 2,5	5,1	3,9	P N K	P N K	P N K	P N K	P N K	P K N	50	50	50	50	50	50
							Overall Agreement (%)				58	56	46	51	60	54

TABLE 7
Effect of increasing age on the reliability of a DRIS diagnosis for N

Kg N/ha	Yield tc/ha	At 3 months N%	At 3 months N index	At 5,4 months N%	At 5,4 months N index	At 9,5 months N%	At 9,5 months N index	At 11,3 months N%	At 11,3 months N index
0	126	1,87	− 4,2	1,80	− 9,3	1,43	1,7	1,59	− 3,1
25	141	2,14	− 1,5	1,97	− 6,0	1,51	5,2	1,62	− 2,8
50	147	2,15	− 0,2	1,86	− 7,3	1,49	3,8	1,61	− 2,3
250	150	2,57	4,4	2,06	− 3,0	1,73	6,8	1,74	0,2

the reliability of predictions when the greatest response is obtained due to treatment with P has not been tested adequately.

(2) By progressive diagnosis and application of most limiting nutrient.

The reliability of the various sets of DRIS norms was also evaluated by means of a modified version of Beaufils[5] progressive diagnosis technique, using data from a number of trials suited to this purpose. The procedure involves the identification of the treatment combination giving the lowest crop yield, and the selection of the nutrient in this combination shown by DRIS to be most deficient. The treatment combination which provides an application of this most deficient nutrient only is then selected, and the crop yield response noted. DRIS is then used again to identify the nutrient deficient in the new combination, and the process is repeated as many times as the treatment combinations allow.

The results if the plant crop in a 3N x 3P x 3K factorial trial conducted at Sezela (Thompson[19]) were used to conduct such an exercise, and they are given in Appendix 2. For each of the 27 treatment combinations the yield responses obtained to treatment with the most deficient nutrient are compared with those obtained after treatment with one, two or three deficient nutrients according to the full progressive DRIS diagnosis, and also with the responses obtained when treatments were applied to overcome the deficiencies indicated by leaf anlysis in relation to the threshold values for each nutrient element. When the sum of the three DRIS indices, ignoring signs, was less than 10, it was assumed that nutrition was balanced and that no further treatment was required. Similarly when percentages of N, P or K in the leaf exceeded the threshold values it was assumed that nutrition was adequate.

If the results for each of the 27 treatment combinations is regarded as a possible field situation to be treated according to DRIS or to nutrient levels in relation to threshold values, then the summated yield responses provide an opportunity to compare the effectiveness of the different procedures over a wide range of conditions. It appears that treatments made according to the full progressive DRIS diagnosis would have been most successful (366,6 tc/ha), and that the treatments based on threshold values would have been more effective (304,6 tc/ha) than those which supplied only the most deficient nutrient according to DRIS (263,6 tc/ha). Analyses of the data from several other NPK factorial trials led to a similar conclusion.

Reliability of DRIS in relation to age of the crop at time of sampling

The acceptable ages of the crop at the time of leaf sampling for nutrient assessment based on threshold values are shown in Table 5. Beaufils and Sumner[6] concluded that DRIS could be used at any stage of crop growth, ie at any time of the year and at any crop age, to assess the nutritional status of the crop.

The results of this evaluation do not generally support this conclusion. The results of most of the trials investigated here indicated that the nutrient status of the crop could be predicted more reliably by DRIS (than by evaluation in terms of threshold values for each nutrient), more particularly when the crop was young than when it was old. For example, in a 4N x 2P x 3K factorial trial on a Makatini series soil at Pongola, DRIS N indices predicted an observed response to treatment with N only when the crop was between two and five months of age. When the crop was older, DRIS gave no indication that an N deficiency would have been corrected by treatment with N. The advantage of using DRIS when the crop is young was demonstrated for N also in an experiment conducted in the midlands (See Table 7). The

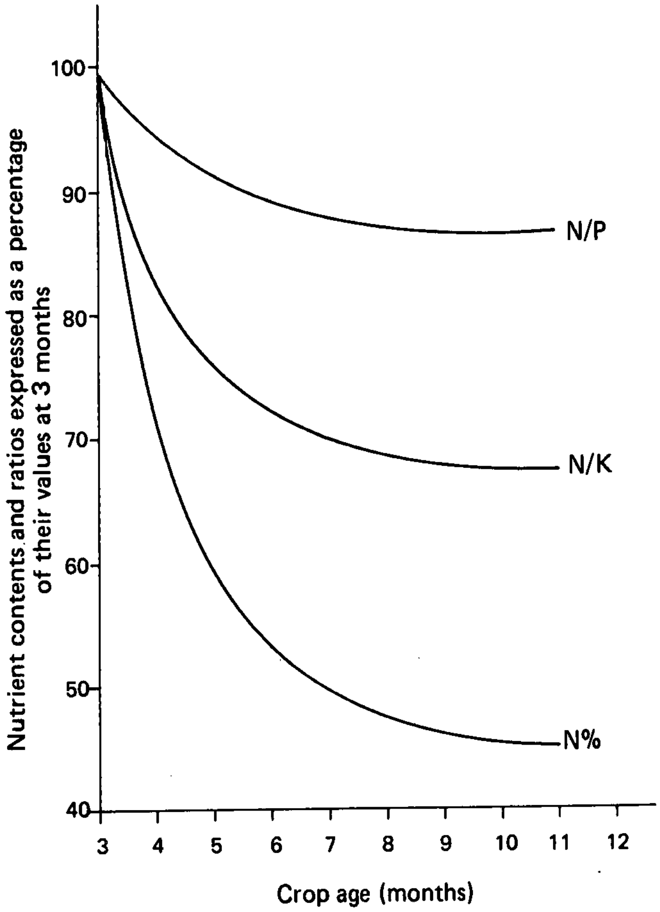

FIGURE 1 Variation of third leaf N% and N/P and N/K ratios with age for ratoon cane at Pongola.

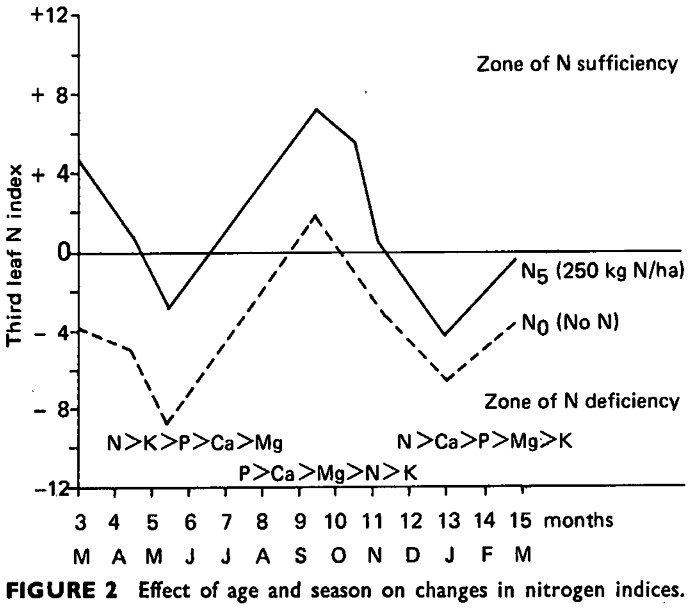

FIGURE 2 Effect of age and season on changes in nitrogen indices.

response to N applied in this trial correlated better with the DRIS indices when the crop was 3 and 5,4 months old than when it was 9,5 and 11,3 months old.

Further evidence that the age of the crop can affect the reliability of a DRIS diagnosis is presented in Appendix 1. The data from 11 N P K trials show that the probability of predicting the correct order of response to N, P and K based on DRIS was much greater when the crop was less than four months old than at any later stage. The only instances where the reliability of DRIS remained good when the crop was older than four months was when a nutrient deficiency was severe.

Discussion

The superiority of DRIS over the system based on threshold values, particularly when the crop is young, is due partly to the fact that ratios generally vary less with increasing crop age than do the values for nutrients % dry matter in the leaf, and partly to the fact that DRIS takes the nutrient balance into account, including 'synergistic' and 'antagonistic' effects. The relatively smaller variations that occur in the ratios of N/P and N/K when the crop is between 3 and 5 months old, compared with N% dry matter, are illustrated in Figure 1, using data for ratoon cane cut in spring at Pongola. While N% dry matter declined by 45% over this period, the N/P and N/K ratios declined by approximately 10% and 20% respectively. However, not all ratios investigated were equally stable. Ca/P and K/P ratios, while fairly constant during the vegetative stage of crop development, increased markedly during the autumn and winter, and when the crop began to mature.

Diagnosis should be expected to change with time because the soil/plant atmosphere continumum is dynamic. For example the effects of season and increasing crop age on the N index for a crop of cane grown for 24 months in the midlands is illustrated in Figure 2. As the season progressed from the first spring to autumn, the N index indicated a change from deficiency to sufficiency, and P and Ca were then shown to be most deficient. As warmer conditions developed in the following spring and summer, the situation changed once again and N became the nutrient that was most deficient. In this instance DRIS correctly indicated a deficiency of N even when the crop was 15 months old. Complex relationships or interactions between pairs of nutrient elements in plant tissues have been described (Clements[7]). The influence exerted by one element upon another may be either synergistic or antagonistic but the direction of the interaction is constant among many plant species (Emmert[9]). Studies carried out by Evans[10] showed that antagonism between K and Mg was very marked in sugarcane grown in certain areas of British Guiana. The phenomenon was associated with Mg levels higher than 0,35% in the leaf blade. DRIS should permit such antagonistic effects to be detected when the crop is still very young. In several of the trials investigated, leaf Mg levels were found to be above 0,35% when the crop was young and the associated Mg indices were invariably highly positive (+15). It was mainly in these trials that a DRIS diagnosis based on the 'general' set of norms (using 5 elements) was found to be superior to the norms based on N, P and K only. Previous studies have shown the usefulness of DRIS in studying lime-induced antagonisms between Ca and K (Meyer[16]).

Conclusions

DRIS can be used to improve the value of the fertilizer advisory service offered by the Experiment Station. In general, imbalances of N, P and K can be detected by means of DRIS before a deficiency can be diagnosed reliably by means of threshold values. By taking leaf samples from the crop when it is only three months old, and perhaps even two months old after being cut in spring in the lowveld, deficiencies can be diagnosed and corrected for the immediate benefit of the crop.

Another advantage is that N, K and P can be ranked in order of importance, thereby identifying which nutrient the crop requires most urgently.

Items requiring further attention include a revision of the Zn norms; testing the applicability of the norms to different sugarcane varieties; and calibration of the norms in terms of fertilizer requirements. It will be possible in time to include a DRIS diagnosis, showing the order of nutrient requirement, in the FAS computer printout sheet for growers. This will provide a useful means of checking the balance being achieved when following a "whole cycle" fertilizer programme. It will also help to deal more effectively with such problems as P fixation; early losses of N due to leaching, denitrification or volatilization; and faulty fertilizer placement.

DRIS soil norms are currently being evaluated.

Acknowledgements

Thanks are due to my colleagues at the Experiment Station for their advice and assistance in this investigation.

REFERENCES

1. Anon. (1972). A new foliar diagnostic technique for sugarcane. Ann. Rep. Exp. Sta. S. Afr. Sug. Ass. 1971/72 : 20.
2. Beaufils, E. R. (1958). Physiological Diagnosis — Its status as a method of estimating plant requirements of nutrient elements. Rev. Gen. Caoutch **35** : 769.
3. Beaufils, E. R. (1971). Physiological Diagnosis — a guide for improving maize production based on principles developed for rubber trees. J. Fert. Soc. S. Afr. **1** : 1-31.
4. Beaufils, E. R. (1973). Diagnosis and Recommendations Integrated System (DRIS) Soil Sci. Bul. 1 Univ. of Natal.
5. Beaufils, E. R. and Sumner, M. E. (1976). Application of the DRIS approach in calibrating soil and plant requirements for sugarcane. *SASTA Proc* **50** : 188-124.
6. Beaufils, E. R. and Sumner, M. E. (1977). Effect of time of sampling on the diagnosis of the N, P, K, Ca and Mg requirements of sugarcane by the DRIS approach. *SASTA Proc* **51** : 123-217.
7. Clements, H. F. (1941). Composition of sugar cane plants grown in deficient nutrient solutions. Hawaiian Plant Rec. **45** : 227-239.
8. du Toit, J. L. (1959). Recent advances in the nutrition of sugarcane in South Africa. *ISSCT Proc* **10** : 432.
9. Emert, F. H. (1961). The bearing of ion interactions on tissue analysis results, plant analysis and fertilizer problems. Am. Inst. Biol. Sci., Washington D.C. 231-243.
10. Evans. (1959). Elements other than N, P and K in the mineral nutrition of sugarcane. *ISSCT Proc* **10** : 473-508.
11. Gascho, G. J. and El Wali, A. M. O. (1978). Tissue testing of Florida Sugarcane. Belle Glade AREC Research Report EV-1978-3.
12. Gosnell, J. M. (1971). Annual review of experiments. Rhodesia Sugar Association Experiment Station.
13. Jones, C. A. (1979). Evaluation of DRIS. Hawaiian Sugar Planters' Ass. Ann. Rep. 25-26.
14. Lea, P. F. W. (1980). Initial observations on the application of DRIS to tea. Crop production Vol. IX : 207-209.
15. Meldal-Johnsen, A. (1975). An Analysis of some factors influencing potato production. Msc. thesis. Univ. of Natal.
16. Meyer, J. H. (1975). Advances in the interpretation of foliar analysis of sugarcane in the SA sugar industry. *SASTA Proc* **49** : 129-136.
17. Sumner, M. E. (1977). Preliminary N, P and K foliar diagnostic norms for soyabeans. Agron. J. **69** : 266-230.
18. Sumner, M. E. (1979). Interpretation of foliar analysis for diagnostic purposes. Am. Soc. Agron. J. **71** : 343-348.
19. Thompson, G. D. (1954). Private Communication SASA Sugar Experiment Station.
20. Zambello, É. (1979). Application of DRIS for different soils and time of sampling of sugarcane grown in Brazil. MSC. dissertation, Univ. of Sao Paulo.

APPENDIX 1

Effect of the age of the crop at the time of sampling on predicting the correct order of N P and K requirements in 11 trials

Trial No.	Crop	Average response tc/ha				Sampling age (months)				
						< 4	4-6	6-8	8-10	10-12
		N	P	K	> >	> >	> >	> >	> >	> >
1	Plant	2,69	1,25	10,86	K N P	K N P	K P N	K P N	K N P	P N K
	Ratoon	6,09	7,29	21,65	K N P	K N P	K N P	K P N	K P N	K P N
	P	13,63	– 1,33	1,89	N K P	N P K	P N K	P N K	P N K	P N K
	1R	22,28	– 0,35	3,41	N K P	N K P	N P K	P N K	P N K	N P K
3	P	14,98	7,99	4,21	N P K	K N P	P K N	K P N	K P N	K N P
4	P	9,22	4,14	13,52	K N P	K N P	K N P	K P N	P K N	N P K
5	P	14,51	0,84	5,92	N K P	K N P	K N P	K P N	K P N	K N P
	1R	8,87	1,61	7,23	N K P	K N P	K N P	K N P	K N P	N P K
6	P	6,65	– 1,1	4,72	N K P	N K P	N K P	P N K	P N K	N P K
7	P	10,91	– 0,3	6,22	N K P	N K P	N K P	N P K	K N P	N P K
	1R	4,20	4,9	2,1	P N K	K N P	N K P	N P K	N K P	P N K
8	P	13,21	5,45	3,56	N P K	N K P	P N K	P N K	P N K	N P K
	1R	6,1	4,71	5,41	N K P	N K P	N P K	P N K	N P K	K P N
9	P	9,47	5,01	12,60	K N P	K N P	K P N	P N K	K P N	K P N
	1R	1,08	8,45	16,05	K P N	K P N	K N P	K P N	K P N	N K P
10	P	12,46	– 1,53	11,94	N K P	K N P	K P N	K P N	K P N	P N K
11	P	7,0	6,2	18,0	K N P	K N P	K P N	K P N	K P N	K P N
	1R	6,0	4,0	17,0	K N P	K P N	K N P	K P N	K P N	K P N
Total number of diagnoses						18	18	18	18	18
No. with entirely correct order						9	4	1	2	2
No. with main deficiency correct only						13	11	7	7	10
Remainder						5	7	11	11	8

APPENDIX 2

Comparison of the threshold value and DRIS approaches to diagnosis of N, P and K requirements of cane sampled at 4 months

N	P	K	Yield		Leaf analysis							Responses to treatments supplying limiting nutrients								
					N%	P%	K%	DRIS indices				DRIS deficient nutrient			Full Progressive DRIS diagnosis			Threshold values		
			Tons cane	Tons sucrose				N	P	K	Order	Level	Yield tc/ha	Response tc/ha	Level	Yield tc/ha	Response tc/ha	Level	Yield tc/ha	Response tc/ha
0	0	0	84,4	12,0	1,67	0,13	0,90	13	−18	5	P>K>N	010	107,6	+ 23,2	110	108,6	+ 24,2	111	108,4	+ 24,0
0	0	1	71,6	9,2	1,42	0,14	1,17	− 5	−16	21	P>N>K	011	83,0	+ 11,4	111	108,4	+ 36,8	111	108,4	+ 36,8
0	0	2	81,6	10,3	1,61	0,13	1,20	4	−26	22	P>N>K	012	95,6	+ 14,0	112	103,0	+ 21,4	112	103,0	+ 21,4
0	1	0	107,6	13,6	1,57	0,19	1,11	− 5	− 1	6	N>P>K	110	108,6	+ 1,0	110	108,6	+ 1,0	110	108,6	+ 1,0
0	1	1	83,0	10,46	1,37	0,19	1,11	−13	3	10	N>P>K	111	108,4	+ 25,4	111	108,4	+ 25,4	111	108,4	+ 25,4
0	1	2	95,6	12,16	1,24	0,18	1,05	−16	4	12	N>P>K	112	103,0	+ 7,4	112	103,0	+ 7,4	121	119,0	+ 23,4
0	2	0	85,4	10,68	1,52	0,27	1,12	−18	19	− 1	N>K>P	120	108,4	+ 23,0	111	108,4	+ 23,0	120	108,4	+ 23,0
0	2	1	131,4	17,9	1,54	0,18	0,98	− 2	0	2	N>P>K	—	—	—	—	—	—	122	119,0	− 12,4
0	2	2	76,4	9,6	1,49	0,21	1,15	−12	5	7	N>P>K	122	119,0	+ 42,6	222	127,6	+ 51,2	122	119,0	+ 42,6
1	0	0	98,4	13,32	1,77	0,13	0,95	15	−21	6	P>K>N	110	108,6	+ 10,2	110	108,6	+ 10,2	111	108,4	+ 10,0
1	0	1	89,0	11,34	1,78	0,11	1,10	19	−39	20	P>N>K	111	108,4	+ 19,4	111	108,4	+ 19,4	111	108,4	+ 19,4
1	0	2	70,2	10,00	2,00	0,14	1,18	15	−28	13	P>K>N	112	10,30	+ 32,8	112	103,0	+ 32,8	112	103,0	+ 32,0
1	1	0	108,6	16,14	2,11	0,25	1,15	1	4	− 5	K>N>P	111	108,4	− 0,2	—	—	—	—	—	—
1	1	1	108,4	15,58	2,10	0,27	1,29	− 4	6	− 2	N>K>P	211	113,6	+ 5,2	112	103,0	− 5,4	—	—	—
1	1	2	103,0	14,40	1,99	0,23	1,26	− 2	0	2	N>P>K	—	—	—	—	—	—	—	—	—
1	2	0	108,4	14,46	2,04	0,31	1,06	− 5	20	−15	K>N>P	121	91,4	− 17,0	222	127,6	+ 19,2	—	—	—
1	2	1	91,4	11,46	2,27	0,31	1,28	− 3	11	− 8	K>N>P	122	119,0	+ 27,6	222	127,6	+ 37,2	—	—	—
1	2	2	119,0	14,06	1,94	0,32	1,13	−10	22	−12	K>N>P	123	119,0	0	222	127,6	+ 8,6	—	—	—
2	0	0	85,4	11,18	1,80	0,11	1,00	22	−36	14	P>K>N	210	124,8	+ 39,4	211	113,6	+ 28,2	211	113,6	+ 28,2
2	0	1	113,4	15,70	2,01	0,13	1,05	21	−30	9	P>K>N	211	113,6	+ 0,2	212	101,0	− 12,4	211	113,6	+ 0,2
2	0	2	99,2	14,60	1,96	0,12	1,21	20	−40	20	P>N>K	212	101,0	+ 1,8	212	101,0	+ 1,8	212	101,0	− 1,8
2	1	0	124,8	16,92	1,16	0,26	0,93	9	11	−20	K>N>P	211	113,6	− 11,2	222	127,6	+ 2,8	211	113,6	+ 11,2
2	1	1	113,6	14,96	2,04	0,25	1,15	− 1	6	− 5	K>N>P	212	101,0	− 12,6	222	127,6	+ 14,0	—	—	—
2	1	2	101,0	14,34	2,94	0,24	1,13	1	3	− 4	K>N>P	—	—	—	—	—	—	—	—	—
2	2	0	107,6	14,88	2,04	0,32	0,97	− 3	25	−22	K>N>P	221	127,8	+ 20,2	221	127,6	+ 20,0	221	127,8	+ 20,2
2	2	1	127,8	17,58	2,04	0,33	1,16	− 9	21	−12	K>N>P	222	127,6	− 0,2	222	127,6	− 0,2	—	—	—
2	2	2	127,6	16,60	2,02	0,25	1,05	1	8	− 9	K>N>P	222	127,6	0	222	127,6	0	—	—	—
												Total yield responses for 37 crops		263,6			366,6			304,6