ADVANCES IN THE INTERPRETATION OF FOLIAR ANALYSIS OF SUGARCANE IN THE SOUTH AFRICAN SUGAR INDUSTRY

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Abstract

The interpretation of mineral composition of plant tissue depends on all the dynamic factors of mineral uptake, distribution, redistribution and interactions. Foliar diagnosis based on the principle of minimum values has not always been satisfactory in interpreting the P status of sugarcane. The use of ratios between elements as an approach to interpreting leaf analyses has received widespread consideration in recent years. Attention in this paper has been focused on an evaluation of the Physiological Diagnosis approach in interpreting TVD leaf analyses, with special reference to phosphorus. It is concluded from correlation studies that an interpretation based on various ratios of N, P and K can greatly improve the chances of making a correct diagnosis particularly for P, provided sampling conditions are standardized. In addition ratios have proved to be useful in studying nutrient interactions, which helps in the understanding of how soil and sugarcane react to different fertilizer treatments.

Introduction

Foliar diagnosis is used throughout the cane-growing world as an adjunct to or as an alternative for soil analysis in the routine planning and evaluation of fertilizer programmes, the identification of possible major and minor nutrient deficiencies in poor growth areas, and in the planning of harvesting schedules.

Much of the theory underlying the foliar diagnostic techniques currently used for sugarcane has been developed by such workers as Lagatu and Maume,[12] Lundegardh,[13] and Macy[14] most of whom have done little or no work with sugarcane. In some cases the principles advanced have a number of points in common, particularly with regard to basic physiological issues, but in other cases there is no firm consensus regarding the interpretation of the analytical data for fertilizer recommendations.

Thomas[20] recognises two main schools of thought on procedures best adapted to bringing out the inter-relationship between foliar values and yields. The first of these is the traditional approach, based on the principle of critical or minimum values proposed by Macy[14] in 1936. The basic concept is that if a particular element is present in a quantity considerably above the minimum required then the assumption can be made that growth is limited for the time being by other factors. While methods based on this approach have been shown to have considerable merit, the main criticism has been that the interpretation is based on one element only being limiting over the whole range, whereas in practice, varying combinations of elements may be limiting.[18] Variations in climatic and agronomic factors also restrict the reliability of this approach but many workers use corrections for moisture, season, age and variety to minimise this limitation.

In the second school a number of workers [2, 12, 20] have preferred to evaluate the concept of inter-relationships as an approach to plant tissue diagnosis. Apparently only a few of these techniques have been used so far in foliar diagnostic methods for sugarcane. In Indonesia for example, Schylenborgh and Sarjadi[19] believed that ratios were of more value than actual nutrient contents in interpreting the foliar analyses of sugarcane. Clements[4] working in Hawaii and Halais and Parrish[10] from Mauritius have successfully used the Mn: Si ratio for defining Mn toxicity in sugarcane. In Northern Queensland, Farquhar[8] showed that the P:N ratio was more reliable in defining the P status of sugarcane than was P% leaf tissue alone, particularly as low leaf N values were shown to depress leaf P% tissue by as much as 25%.

The Experiment Station of the South African Sugar Association has conducted a fertilizer advisory service, based on soil and leaf analysis, for almost 21 years. Although the interpretation of leaf analytical data has been based essentially on the traditional approach, the merits of the inter-relationship approach have not passed unnoticed. As early as 1959 du Toit,[6] in assessing the results of a comprehensive series of 3×3×3 and 4×2×3 NPK fertilizer trials for interaction effects, commented that

> "It is really surprising how often phosphorus functions either with nitrogen or with potassium in these interactions even in some cases where phosphate deficiency would not have been expected from soil or leaf analysis".

In consequence he proposed a N:P ratio for interpreting third leaf P values in sugarcane, but it was not used in any working method. In recent years in the newly developed sugarcane areas of the Natal Midlands, the results of a number of field experiments conducted on high P fixing soils have also indicated that interpretation of analyses for P% oven dry third leaf laminae in terms of a critical value of 0,19%, are not always sufficiently reliable for detecting a P deficiency or for checking on the adequacy of P fertilizer applications.

In view of this limitation and the increased importance of the role of foliar diagnosis in the development of an efficient fertilizer programme, particularly in one aimed at recommending at one time P fertilizer for an entire sugarcane crop cycle, an investigation was undertaken to assess the value of using the nutrient ratio approach of Beaufils[1,2] to interpret foliar P values. He considered that the nutritional status of rubber trees and maize could be assessed more accurately by examining the nutritional balance existing between N, P and K expressed as ratios of the amounts of these nutrients present at any stage of crop development, than by considering percentages of the elements alone. It was thought possible that the foliar diagnosis of sugarcane could also be improved in this way and this paper presents some of the more important findings of the investigation.

Procedure

The investigation was divided into three phases:

(i) establishing reference norms for interpreting N/P, N/K and K/P ratios in third leaf tissue for cane growing under conditions where yield was not unfavourably affected by any factor known to limit plant growth.

(ii) using foliar analytical data to assess the tolerance of these norms to variations in sampling conditions such as age of crop, leaf position, variety etc.

(iii) evaluating the technique, in cane nutrition studies particularly, by considering how it could be used to supplement the critical value approach presently used. The progressive diagnosis technique of Beaufils[2] was applied to a number of trials. This involved considering the analytical data for the control plot in an experiment, deciding which element was the most severely limiting and proceeding to the data for the plot in which the deficiency was to be remedied. The procedure was repeated until all nutrients were present in adequate amounts.

In the first phase, yield and associated third leaf data from 4 to 6 months old plant cane (variety NCo 376) were obtained from over 750 plots in a representative number of $4N \times 2P \times 3K$ Regional Fertilizer Trials scattered throughout the industry. The data were processed in accordance with the statistical technique used by Beaufils in order to establish the critical N/P, N/K and K/P norms needed to define:

(i) the nutritional status of sugarcane not limited by N, P or K deficiency;

(ii) cane marginally deficient in N, P or K;

(iii) cane deficient or severely deficient in one or more of these elements.

The mean and standard error for the various ratios in the sub-population of cane which yielded more than 130 tons/ha (over 7,0 tons/ha/100 mm rainfall) was used as the basis for deriving the various norms. Details concerning the locality, soil type, rainfall, crop age, soil properties and mean plant cane responses obtained to applied N, P and K fertilizer treatments are shown in Table 1 for a selected number of trials.

Past experience had indicated that plant cane responded more to treatment with nitrogen fertilizer on soils derived from Table Mountain Sandstone and granite parent materials than it did on other soil types.[7] Consequently for experiments sited on soils of these types the levels of nitrogen used were 60, 120, 180 and 240 kg/ha as ammonium sulphate while on other soils the levels of fertilizer applied were equivalent to 0,50, 100 and 150 g/ha N. In the case of phosphorus treatments, the higher level of P was always 80 kg/ha P applied as single superphosphate, in the furrow, but the lower level was either equivalent to 40 kg/ha P in a soil with low reserves of P, or zero where the soil analysis indicated high reserves of P. Potassium dressings were all made with muriate of potash equivalent to rates of 80 and 160 kg/ha K.

The yield responses shown in Table 1 to P and K were calculated by subtracting the yields obtained where the minimum level of the nutrient had been applied from those where the maximum level was used. In the case of N, the differences between the 60 and 120 kg/ha treatment levels were used for experiments on TMS and granite derived soils and in all other cases the differences between the 0 and 100 kg/ha N treatment levels were used.

Results

PHASE 1 — ESTABLISHING REFERENCE NORMS

(a) Yield in relation to environmental factors

It is evident from the data given in Table 1, that the trials were conducted over a reasonably wide range of environmental conditions. Most of the trial sites were in the warm humid and sub-humid regions of the coastal plain extending from the Umfolozi Flats in the north to Port Edward in the south, in which 85% of the industry's cane is grown. The soils ranged from the light grey loamy sands of the Cartref series, com-

TABLE 1

Yield output of a range of RFT trials in relation to important environmental (rainfall and soil) and treatment parameters

Locality	Parent material	Soil series	Crop age (months)	Crop rainfall (mm)	Yield tc/ha Avg	Yield tc/ha High	Yield tc/ha Low	Yield tc/ha/100mm Avg	Yield tc/ha/100mm High	Yield tc/ha/100mm Low	Yield response (tc/ha) N	Yield response (tc/ha) P	Yield response (tc/ha) K	Pre-plant soil analysis (ppm) pH	Pre-plant soil analysis (ppm) P	Pre-plant soil analysis (ppm) K
Shakaskraal .	TABLE MOUNTAIN SANDSTONE	Trevanian	25	2 845	116	146	81	4,2	5,2	2,9	3,7	7,0	17,7†	5,13	11	110
Doornkop .		Inanda	23	2 325	128	151	93	5,5	6,5	4,0	6,0	2,8	22,5†	5,35	30	97
Compensation		Cartref	20	2 514	186	250	143	7,4	10,0	5,7	7,2	0,7	13,9*	5,26	23	168
Compensation		Cartref	22	2 525	139	157	111	5,5	6,2	4,4	13,3*	12,2*	7,9	5,30	12	59
Eston . . .		Inanda	24	1 825	105	121	70	5,8	6,6	3,8	11,8	5,0	14,3*	5,15	23	90
Port Shepstone		Cartref	23	2 300	101	135	75	4,4	5,9	3,3	4,9	9,8*	11,9*	4,70	9	56
Umhlali . .	RECENT SAND	Clansthal	23	2 925	60	83	31	2,1	2,8	1,1	13,5*	17,9†	9,4	5,35	21	46
Umhali . .		Clansthal	19	2 750	110	153	52	4,0	5,6	1,9	20,6†	9,3	30,3†	7,20	30	57
Empangeni .		Clansthal	23	1 700	90	128	53	5,3	7,5	3,1	38,5†	10,2	11,5	5,95	15	38
Scottburgh .		Clansthal	23	1 775	99	124	64	5,6	7,0	3,6	27,3†	5,8	18,9*	5,60	26	65
Mposa . .		Fernwood	20	2 175	72	90	49	3,3	4,1	2,3	6,7	4,7	17,9*	5,70	10	30
Darnall . .	LOWER ECCA SHALE	Milkwood	23	2 700	157	169	115	5,8	6,2	4,3	10,0*	6,7	3,8	5,32	13	100
Verulam . .		Milkwood	27	2 775	105	140	81	3,8	5,0	2,9	13,6*	−3,1	−9,5	5,76	18	247
Shakaskraal .		Milkwood	19	2 675	110	137	83	4,1	5,1	3,1	14,5*	1,9	4,8	5,76	15	121
Umhlali . .		Windermere	21	2 475	103	135	64	4,2	5,5	2,6	3,7	9,9	36,2†	5,38	90	121
Gingindhlovu		Milkwood	20	2 025	78	93	56	3,9	4,6	2,8	−0,5	−4,7	13,7*	6,20	25	122
Umzimkulu .		Windermere	21	1 750	76	128	29	4,3	7,3	1,7	11,5	32,9†	17,8†	5,80	13	108
Darnall . .	DWYKA TILLITE	Waldene	22	2 336	130	146	102	5,6	6,2	4,4	19,6†	−0,8	−6,5	5,70	10	247
Darnall . .		Waldene	20	1 825	87	108	60	4,8	5,9	3,3	0,8	−2,5	10,6	5,53	4	157
Esperanza . .		Williamson	24	2 450	99	130	67	4,0	5,3	2,7	8,5	6,3	11,2	5,70	17	54
Glen Echo. .	GRANITE	Glenrosa	22	2 150	114	157	73	5,3	7,3	3,4	12,3*	9,6	22,4†	6,20	17	43
Umzumbe .		Glenrosa	22	2 100	123	146	85	5,9	7,0	4,0	11,2	13,9*	6,4	5,60	37	177
Pongola . .	DOLERITE	Shortlands	17	1 200	143	189	92	11,9	14,9	7,5	1,1	−1,0	3,3	5,80	10	430
Newark . .	ALLUVIUM	—	23	2 200	141	180	109	6,4	8,2	5,0	8,8	1,7	2,6	6,50	103	180

* 5% level of significance † 1% level of significance

prising about 20% of the industry to the deep red clays of the Shortlands series which cover about 7% of the industry. The rainfall received during crop growth varied widely from 1 775 mm to 2 700 mm for a 23 month cycle. Because rainfall was generally above average, moisture was unlikely to have been the factor most severely limiting growth in many of the trials.

It has been estimated that it is possible to produce at least 9 tons of cane per hectare per 100 mm of rainfall when there are no known factors limiting cane growth. By comparing the highest and lowest yielding plots in terms of tc/ha/100 mm rain the extent of nutritional limitations on yield become evident. However, the average yields of the best yielding treatments were still below the potential 9 ton/ha/100 mm rain limit suggesting the existence of some other yield limiting factor, or even that nutrition was still a limiting factor. A full discussion of the responses obtained to treatments, in relation to soil and leaf analysis has been dealt with previously by du Toit.[6]

(*b*) *Proposed norms*

A summary of the yield data, subdivided on the basis of 20 ton/ha production class intervals, together with the associated treatment levels, mineral composition of the third leaf and relevant statistical parameters is shown in Table 2. The $\bar{X} \pm 2/3\ \sigma$ and $\bar{X} \pm 4/3\ \sigma$ confidence intervals for each of the three main ratios (N/P, N/K and K/P) for cane yielding in excess of 130 ton/ha were combined to form the chart shown in Figure 1.

This chart is essentially a three-way schematic presentation of the relative balances existing between N, P and K in terms of the N/P, N/K and K/P ratios. The inner circle, defined by the limits ($\bar{X} \pm 2/3\ \sigma$), represents the NPK balance of cane not limited by a deficiency of N, P or K (denoted→). The zone between the inner and outer circles represents a marginal condition where the nutrition of the crop tends toward an imbalance (↘or↗). Ratios which lie beyond the outer circle ($\bar{X} \pm 4/3\ \sigma$) suggest definite excess (↑) or deficiencies (↓).

Thus a leaf sample with a composition of 2,18% N, 0,20 %P and 1,46% K on a dry matter basis will have nutrient ratios of N/P = 10,90 N/K = 1,49 and K/P = 7,30 which when applied to the chart give the following nutrient balance indications:

N/P (↑) since 10,90 lies beyond the outer circle (P↓)
N/K (↘) since 1,49 lies within the outer circle (N↘)
K/P (↑) since 7,30 lies beyond the outer circle (P↓)

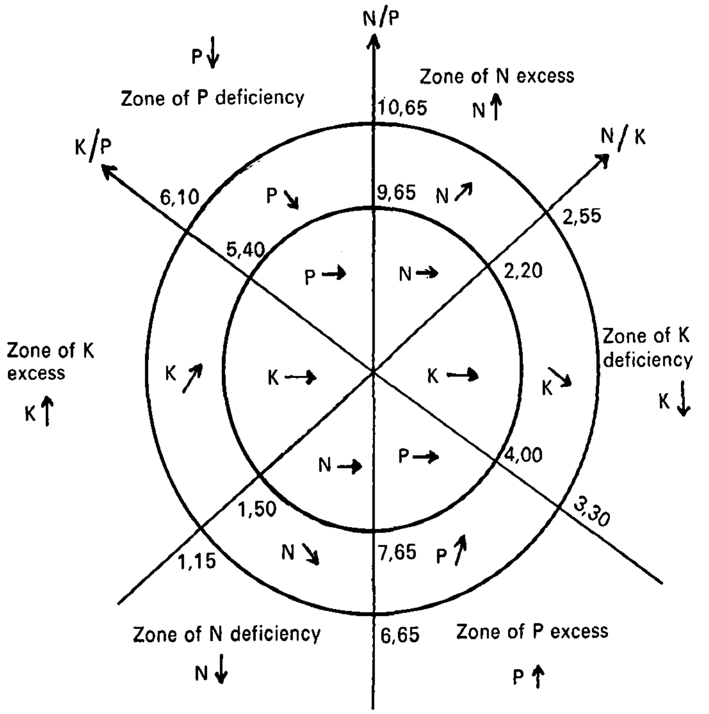

FIGURE 1 Diagram used for assessing the relative balance between N, P and K in third leaf samples of sugarcane (variety NCo: 376).

The overall diagnosis of the nutrient balance can therefore be given as N↘ P↓ ↓K→, suggesting that P is deficient, N marginally deficient and K is adequate.

Table 2 also shows the conversion of these ratios into indices for N, P and K in accordance with the formula given by Beaufils.[2] These indices provide a simple quantitative assessment of the degree of balance or imbalance between N, P and K. An index value which deviates from zero implies an imbalance of the nutrient concerned; the more negative the value of an index the greater the probability of the nutrient concerned being deficient and of yields being reduced. On the other hand indices which tend toward zero values indicate that the nutrients concerned are in balance and deficiencies are unlikely. However, the fact that nutrients are near zero and in balance does not necessarily imply optimum yield because some factor other than nutrition, for example nematodes, may be limiting yield. In general the values of the norms that define the limits of the chart in Figure 1, do not differ greatly

TABLE 2
Relationship between crop performance and mean tissue composition

Yield class (tc/ha)		Number in sample	Mean yield (tc/ha)	Mean treat. level	Average response (tc/ha)		%N	%P	%K	Ratios			Initial Indices			Transformed Indices		
				N P K	* Actual	† Potenl				N/P	N/K	K/P	N	P	K	N	P	K
Low	<50	10	38	1 2 2	0	67,2	1,97	0,29	0,79	6,79	2,50	2,72	4	50	−54	12	104	−104
	50–70	47	58	2 2 1	0	56,0	2,07	0,25	0,76	8,28	2,72	3,04	21	30	−51	63	81	− 81
	70–90	116	79	2 1 1	2,6	47,5	2,06	0,25	0,83	8,24	2,48	3,32	15	23	−38	45	61	− 61
Med	90–110	178	101	2 1 2	12,8	32,0	2,08	0,26	0,92	8,00	2,26	3,53	7	20	−27	21	47	− 47
	110–130	191	122	2 2 2	24,2	24,2	2,02	0,25	0,95	8,08	2,12	3,80	4	15	−19	12	34	− 34
High	130–150	128	143	3 1 2	26,3	21,5	2,08	0,24	1,10	8,66	1,89	4,58	1	8	− 9	3	17	− 17
	150–170	60	164	3 2 3	32,2	16,2	2,07	0,24	1,19	8,62	1,74	4,96	−3	−3	6	− 9	− 9	9
	>170	37	190	3 2 3	25,9	19,1	2,14	0,25	1,30	8,56	1,65	5,20	−7	−5	12	−19	−15	19
Overall Mean		Total 767	112	2 2 2	15,5	35,5	2,07	0,25	1,06	8,28	1,95	4,24	0	8	−8	0	16	− 16

* Mean difference between yield observations used in each yield class and the control plot yields of associated experiments.
† Mean difference between yield observations used in each yield class and the maximum yielding treatments of associated experiments.

Means ($\bar{X}$): N/P = 8,65 N/K = 1,85 K/P = 4,70
Standard error (σ) : N/P = 1,51 N/K = 0,52 K/P = 1,06

TABLE 3

Mean yield and leaf composition of plant cane in relation to applied N, P and K from 18 RFT trials

Treatment		Mean yield		Leaf composition								
				Conventional			Initial Indices			Transformed Indices		
Nutrient	Rate (kg/ha)	Tc/ha	ts/ha	N%	P%	K%	N	P	K	N	P	K
N1	0	106,5	16,25	2,01	0,28	0,95	−3	35	−32	−9	67	−67
N2	50	115,7	17,50	2,05	0,28	0,97	−2	32	−30	−6	62	−62
N3	100	119,3	18,00	2,09	0,26	0,97	4	17	−21	12	38	−38
N4	150	122,3	18,18	2,10	0,26	1,00	3	15	−18	9	33	−33
P1	40	113,8	17,16	2,06	0,26	0,97	3	17	−20	9	37	−37
P2	80	118,9	17,86	2,07	0,27	0,99	0	20	−20	0	40	−40
K1	0	108,6	16,26	2,08	0,27	0,90	6	27	−33	18	60	−60
K2	80	117,6	17,64	2,05	0,26	1,00	0	16	−16	0	32	−32
K3	160	122,9	18,63	2,06	0,26	1,03	−1	14	−13	−3	27	−27
N3−N1		12,8	1,75									
P2−P1		5,1	0,70									
K3−K1		14,3	2,37									
LSD (P= 0,01)		11,5	1,75									

from those of the first chart of this type for sugarcane[17] based on the results of an industry wide nutrient survey.[15]

(*c*) *Yield in relation to levels of fertilizer and plant composition*

It is evident, from a comparison of the mean yields, mean treatment levels and average yield responses (in each of the production classes in Table 2) that the performance of the high yielding plots (>130 ton/ha) can be attributed to the markedly better responses obtained at the higher levels of N, P and K. Likewise the low yielding plots (<90 ton/ha) are generally associated on average with the lowest applied levels of N and K. This marked effect of applied N and K treatments on yield may be more clearly seen from the mean results shown in Table 3 for 18 of the experiments with zero levels of N. Both for tons cane/ha and tons sucrose/ha, N and K applications show highly significant yield responses at the 1% level of significance.

Regression analysis on all the observations shows that yield is significantly correlated with leaf K% (r = 0,74 **) and K index values (r = 0,70 **) which is consistent with the large number of trials that showed a marked response to 180 kg K/ha. Likewise an interpretation of the leaf K values in terms of the critical value of 1,05% and indices tending toward zero indicates from Tables 2 and 3 that on average, plots yielding less than 120 ton/ha, accounting for about 40% of the total number examined, were likely to be deficient in K.

An examination of the data from the individual control plot treatments in these experiments also indicates that predictions of a yield response to applied K were correct in 85% of the cases when examined in terms of the critical value for K, compared with 72% on the basis of indices. With regard to nitrogen and phosphorus however, the situation is reversed. Predictions of a yield response to applied N in terms of N indices were found to be correct in 67% of the cases examined, compared with 60% on the basis of a critical value of 1,8% for N.

In the same way, in terms of P indices, a yield response to applied P could be predicted correctly 70% of the time, compared with only 55% on the basis of a critical value of 0,19% for this element.

PHASE 2 — VALIDITY OF NORMS IN RELATION TO SAMPLING CONDITIONS

An important characteristic of Beaufils diagnosis and recommendation system for maize is that it can be used without any restrictions on sampling conditions, such as at any stage of plant development and this has permitted successive diagnoses and corrective treatments to be carried out on a single crop. Since this is a radical departure from the standardized sampling procedure required in the critical value method, it might be worthwhile to assess the effects unrestricted sampling may have on the interpretation of results for sugarcane in terms of the proposed norms under our conditions. To this end available leaf analytical data from a number of trials were processed so that the effects of important variables such as leaf position, sampling age and varietal effects could be considered.

(*a*) *Leaf position*

Although a number of different leaves are used in various diagnostic methods, the Top Visible Dewlap (TVD) leaf is that most commonly used and this leaf forms the basis of our sampling programme. A comparison of the nutrient content of this leaf with that of leaves 4, 5 and 6 is given in Table 4.

TABLE 4

Mineral composition in relation to leaf position

Leaf	%N	%P	%K	Ratios			Transformed Indices		
				N/P	N/K	K/P	N	P	K
TVD (3rd) .	1,76	0,21	1,12	8,4	1,6	5,3	−35	−15	35
4th . . .	2,15	0,21	0,91	10,2	2,4	4,3	41	−15	−41
5th . . .	2,01	0,19	0,81	10,6	2,5	4,3	40	−18	−40
6th . . .	1,93	0,18	0,80	10,7	2,4	4,4	45	−27	−45
Sheath . .	0,63	0,19	1,58	3,3	0,4	8,3	−482	126	482

TABLE 5

Mean nutrient composition of third leaf samples in relation to age and selected N P and K treatments

Treatments		Yield (23 mths)		Conventional (%)												Transformed indices											
Nutrient	Rate (kg/ha)	tons cane per ha	tons sucrose per ha	4 months			8 months			10 months			12 months			4 months			8 months			10 months			12 months		
				N	P	K	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Control	—	151,4	25,7	2,07	0,27	0,92	1,57	0,24	0,93	1,74	0,19	0,91	1,17	0,13	0,44	12	54	−54	−48	48	−15	8	−8	0	64	51	−64
N_1	0	156,6	26,4	2,01	0,27	1,05	1,61	0,26	0,95	1,67	0,19	0,93	1,25	0,13	0,61	−18	30	−30	−58	58	−27	0	−6	6	16	−16	−16
N_3	100	158,3	26,4	2,11	0,26	0,99	1,62	0,25	0,90	1,77	0,20	0,99	1,36	0,15	0,69	12	34	−34	−50	50	−42	−3	−8	8	8	0	−8
P_1	44	160,4	26,6	2,09	0,27	1,05	1,70	0,26	0,96	1,71	0,20	0,99	1,34	0,15	0,69	−6	30	−30	−38	38	−33	−10	−6	10	7	0	−7
P_2	88	153,4	25,3	2,00	0,26	1,00	1,65	0,26	0,97	1,68	0,19	1,01	1,33	0,14	0,68	−6	32	−32	−53	53	−24	−12	−20	20	13	−13	−3
K_1	0	157,0	26,4	2,02	0,27	0,98	1,69	0,26	0,89	1,72	0,20	0,97	1,34	0,14	0,57	−6	42	−42	−45	54	−54	−6	−3	6	40	6	−40
K_3	167	160,8	26,8	1,95	0,26	1,08	1,61	0,26	1,03	1,62	0,19	1,00	1,26	0,14	0,69	−23	23	−15	−58	58	0	−20	−15	20	3	−7	7
	Mean	156,8	26,2	2,04	0,27	1,01	1,64	0,26	0,96	1,70	0,19	0,97	1,35	0,15	0,66	−6	37	−37	−55	55	−27	−3	−13	13	16	3	−16
		Order of average NP and K requirement														K>N>P			N>K>P			P>N>K			K>P>N		

The distribution of nutrients is generally consistent with trends reported in the literature.[18] Potassium shows the widest variation with the highest concentrations occurring in the youngest leaf. The associated indices on the other hand, tend to show wider variation with changes in leaf age. In this example the TVD (third leaf) indicates a nitrogen deficiency compared with a potassium deficiency in leaves 4, 5 and 6. The tendency for greater variation in indices than in percentage composition, is even more marked in tissue other than leaf as shown by the analytical data in the 3rd leaf sheath.

(*b*) *Age and season*

It has been established by many workers[9, 10, 11, 18] that age can have a marked effect on the nutrient composition of the leaf blade. For this reason it is necessary to standardise either the age of cane at which leaf samples are taken or to use age correction factors. Our requirements for rainfed cane are that the crop should be growing vigorously before leaf sampling is carried out and be between 4 and 7 months of age. Leaf samples taken at various intervals from the plant crop of a high yielding 4×2×3 experiment have been used to illustrate the effect of age on leaf composition as shown in Table 5. The mean percentage values obtained indicate that increasing age caused a marked reduction in the N and P contents while K values declined more slowly. These trends however, are not apparent from the transformed indices in Table 5, the order of plant requirement for N, P and K clearly changing with increasing age. While these variations are indicative of changes in nutrient balance of the plant, which in turn may be regarded as a function of the soil environment conditions prevailing at the time of sampling, the severe N deficiency apparently present in all treatments of the 8-month-old cane does not seem to have affected growth, as evidenced by the high yields obtained, and the lack of a significant response to N.

Following application of fertilizer N, cane takes up the bulk of its N requirement within a few weeks[3] and under these circumstances an apparent deficiency of N in the leaf could be expected in the ensuing months as the N is redistributed throughout the growing plant. The difficulty in using data of this type is that an exact evaluation of the effect of age is not always possible due to the confounding effects of age and season.

(*c*) *Varietal effect*

The different nutrient content of different varieties has been noted by a number of workers including Farquhar and Lee,[8] Halais[10] and Gosnell and Long.[9] The range in nutrient contents of varieties under the same fertilizer regime is illustrated by the foliar analyses of five-month-old cane taken from a recent variety trial and presented in Table 6.

The wide range in N contents from 2,22% in the case of NCo 376 to 1,77% for N6, is also shown in the N index values. In contrast, the narrower range in leaf K and P contents is associated with greater variation in their index values. Also of importance is the fact that in certain of the varieties the index values indicate an N and/or K deficiency, notwithstanding the application of above average amounts of fertilizer, the lack of any visual deficiency symptoms or the small yield differences that were obtained.

This evidence suggests that standardization of leaf position and age at sampling under rainfed conditions will be as important in a system based on the physiological diagnosis approach as one based on the critical value concept. It is also envisaged that to overcome varietal effects either separate charts will have to be prepared for different groups of varieties or varietal corrections will have to be used, as is practised in other countries.[18]

TABLE 6
Average nutrient content (3rd leaf) in relation to variety

Variety	Yield		%N	%P	%K	Ratios			Transformed Indices		
	tc/ha	ts/ha				N / P	N / K	K / P	N	P	K
NCo 376	93	13,5	2,22	0,28	1,07	7,93	2,07	3,82	3	33	−33
NCo 310	80	12,9	2,05	0,26	1,10	7,88	1,86	4,23	−13	15	−15
N53/216	81	11,8	1,90	0,30	1,15	6,33	1,65	3,83	−53	53	−15
N55/805	82	13,1	2,11	0,26	1,08	8,12	1,95	4,15	0	18	−18
N7	84	13,1	2,21	0,28	1,05	7,89	2,10	3,75	6	37	−37
N8	81	11,3	1,97	0,28	1,14	7,04	1,73	4,07	−34	34	−12
CB 36/14	80	10,9	1,92	0,27	0,98	7,11	1,96	3,63	−24	42	−42
N6	90	11,7	1,77	0,24	1,02	7,37	1,73	4,25	−24	24	−6
Mean	84	12,3	2,02	0,27	1,07	7,46	1,88	3,97	−18	27	−27
LSD (P=0,01)	9,4	1,6									

TABLE 7
Effect of P and shallow incorporated lime treatments on yield, soil and third leaf nutrient content

Treatment				Yield		Soil (ppm) (0–15 cm)					Leaf (NCo 376)							
Lime (t/ha)	P carrier (t/ha)	P kg/ha																
		IF	BC	tc/ha	ters/ha	pH	P	Ca	Mg	K	N%	P%	K%	Ca%	Mg%	N	P	K
Zero	0,6 Supers	60	—	88	10,4	4,9	13	10	5	57	2,25	0,25	1,56	0,33	0,15	−15	−21	36
	2,25 Supers	60	220	109	12,7	4,8	21	80	8	36	2,39	0,26	1,30	0,43	0,19	1	− 9	8
	4,50 Supers	60	440	125	14,4	4,9	113	420	6	22	2,57	0,26	1,33	0,44	0,16	7	−13	6
	6,75 Supers	60	660	129	13,8	5,1	101	220	7	29	2,80	0,29	1,37	0,44	0,15	8	− 8	0
	45 F. Cake	—	235	122	14,2	—	—	—	—	—	2,31	0,30	1,39	0,38	0,23	−13	4	9
	6,75 Langfos	—		105	12,7	4,9	168	60	6	64	2,48	0,30	1,43	0,41	0,14	− 7	0	7
	Mean			113	13,0	4,9	83	158	6	41	2,46	0,27	1,39	0,40	0,17	− 3	− 7	11
	LSD (P = 0,05) . . .			±18	±2,8													
6,6	0,6 Supers	60	—	114	12,3	5,3	18	400	17	36	2,40	0,25	1,35	0,45	0,21	1	−15	14
	2,25 Supers	60	220	129	15,0	5,9	104	840	25	43	2,22	0,26	1,32	0,41	0,19	− 8	− 5	13
	4,50 Supers	60	440	138	14,8	5,4	78	440	13	29	2,32	0,26	1,17	0,42	0,22	2	− 2	0
	6,75 Supers	60	660	126	12,4	5,5	174	860	42	64	2,85	0,29	1,19	0,43	0,21	18	− 2	−16
	45 F. Cake	—	235	143	14,8	—	—	—	—	—	2,26	0,29	1,30	0,38	0,25	−10	5	5
	6,75 Langfos	—		123	13,2	5,7	62	600	22	43	2,55	0,27	1,21	0,45	0,21	8	− 4	− 4
	Mean			129	13,8	5,48	73	628	23	43	2,43	0,27	1,25	0,42	0,21	2	− 4	2
	LSD (P = 0,05) . . .			±18	±2,8													

I.F. = In Furrow B.C. = Broadcast

PHASE 3 — EVALUATION OF THE NUTRIENT RATIO APPROACH

Experimental data from a number of trials not included in the first phase of this investigation were examined in order to test the validity of the norms used in the chart and the resulting N, P and K indices.

(*a*) *Application to a P nutrition problem*

The majority of trials used to test the validity of the P norms, were conducted in the newly developed Midlands area of the industry where poor yields are often obtained on soils known as Oxisols.[16] The results of many of these trials, together with those of earlier pot experiments, nutrients surveys, chemical testing procedures and soil profile studies, have led to the conclusion that Al toxicity and P fixation are the factors limiting growth on these soils.

In the particular experiment selected to illustrate the use of this approach in studying P nutritional problems, significant yield responses were obtained to broadcast applications of single superphosphate with and without limestone. Some of the data obtained from selected treatments are summarized in Table 7 together with some of the chemical properties of the soil studies. On the basis of these data the following comments can be made:

(i) The average leaf P content on a dry matter basis of the control treatment (0,25 %) interpreted in terms of our present threshold values for P (0,19 %) is not in keeping with the large response obtained to P. Conversely an assessment of the P status in terms of the N/P, K/P and N/K ratios and diagnostic indices, clearly indicates that P was deficient. Furthermore, increasing the levels of single superphosphate considerably improved the P balance, particularly in the presence of limestone. Filtercake, an organic by-product from the sugar milling process (rich in organic P) was the only treatment that produced an excess P balance.

(ii) The P fixation characteristic of the soil is such that broadcasting up to 4,5 tons/ha single superphosphate was clearly superior to the normal in-furrow P application derived from the Truog soil P test. The response to lime was consistent with the predicted lime requirement based on soil pH, texture and exchangeable aluminium content.

While the response to treatments in this experiment substantiates earlier findings that the accuracy of P fertilizer requirements in high P fixing soils can be considerably enhanced by supplementing the Truog soil extraction procedure with a rapid phosphate desorption procedure,[16] it would seem that in severe cases of P fixation the foliar ratio approach can usefully complement the amended soil analytical procedure.

(b) *Application to the study of nutrient interactions*

According to Samuels[18] "whether one subscribes to the principle of minimum values or ranges, or to that of the interrelationships of the various values, due recognition must be given to the basic theory of ion interactions". Numerous examples are given in the literature which show that nutrient ions do not change in concentration in a tissue in a singular and isolated manner. A shift in the concentration of an ion is generally accompanied by secondary changes in the concentration of other ions. Heavy fertilizer applications are often responsible in this way for ion interactions which lead to imbalances and resulting problems in cane growth.

Part of the experimental data given in Table 7 illustrates how diagnostic indices can be used to study lime/P/K interaction effects. These data show that the increased levels of superphosphate have resulted in a synergistic effect between N and P, and in antagonistic effects between K and Ca from the gypsum component of the superphosphate. The P treatments containing lime also show consistently lower K index values when compared with the same treatments without lime, suggesting that calcium from the lime has interfered with K uptake i.e. negative-ion interaction. It is likely that the large amount of Ca present in the combined single supers and lime treatment was responsible for this, resulting in a K deficiency index (−16) and yield depression when compared with lower levels of P. This Ca/K interaction is consistent with the inverse relationship existing between the various soil Ca and K levels.

The mean whole plot indices for lime versus no lime also indicate an improvement in the uptake of N and P. These relationships between the various treatments and plant composition are not always apparent when examined strictly in terms of leaf N% and K% values.

(c) *Application of results in improving the basis of fertilizer advice*

Although it has been shown that large groups of field experiments often show good relationships between average analyses and average fertilizer responses, close correlation for individual fields are not usually expected. In a recent industry-wide nutrient survey[15] in which soil and leaf samples from nearly 500 fields were analysed (Truog P + leaf P%), it was shown that less than 50% of the leaf samples associated with a P deficiency in the soil (< 11 ppm) were apparently deficient in leaf P (< 0,19%).

A reassessment of the analytical data for these soils and leaves in terms of additional soil P fixation criteria (PDI values) and leaf P indices suggests that the reliability of predicting the availability of P in the soil by leaf analysis can be improved considerably. For example by using the following tentative limits for defining the degree of P imbalance, predictions of a P deficiency in the soil and therefore likely yield response to applied P were correct in some 70% of the cases examined:

P index, > 5 (above normal P), 5 to −5 (normal P), − 5 to − 15 (marginal P), − 15 to − 30 (P deficiency), < − 30 (severe deficiency).

With this procedure together with the policy of maintaining a case history of past soil and leaf analyses, past recommendations and performances, information on soil series etc., the difficulties that arise in making predictions after analysing a single sample will tend to disappear. This is particularly important to the successful implementation of the newly introduced system of recommending fertilizers for the entire crop cycle on the basis of a single pre-plant soil analysis.

(d) *Calibration of indices in relation to P requirement*

Apart from serving as a diagnostic tool for checking on the crop's nutritional status, a sound method should also provide some indication of the amount of a given nutrient that is required to correct a deficiency. In the critical levels procedure currently used for plant and ratoon cane if the third leaf P content is in excess of 0,19% no additional phosphatic fertilizer is recommended, while supplementary rates of 100 kg/ha and 150 kg/ha double superphosphate are recommended when the third leaf values lie between 0,17 and 0,19% and below 0,17% respectively.

When using leaf P index values an assessment of the experimental data indicates that in low to medium P fixing soils (covering about 90% of the industry) the above supplementary rates are likely to be sufficient to correct P deficiency or marginal P imbalance. For cane grown on high P fixing soils, however, considerably larger quantities of P fertilizer are needed. In the example of a P fixing soil, data for which are given in Table 7, 2,25 tons/ha of single supers (broadcast) was needed to shift the P index value from −21 to −9 without lime, or from −15 to −5 in the presence of lime.

Further progress in the determination of the leaf P indices for high P fixing soils will soon be possible when the results of a new series of field experiments designed for the purpose become available.

Discussion

The results of this investigation have emphasised the value and importance of using nutrient balance in cane nutrition studies. However, in comparison with Beaufils more recently developed DRIS approach (Diagnosis and Recommendation Integrated System),[2] several changes were made in the procedure for deriving and testing the tolerance of the norms in relation to sampling conditions and in the calibration of the diagnostic indices. Briefly these changes are:

(i) The data used were screened from the records of past field experiments in preference to conducting a survey of a large number of randomly selected sites within the plant/environmental complex.

The advantage of this procedure is that, in addition to yield, the response to given treatments under a given set of environmental conditions can be directly related to plant composition, enabling the calibration of leaf indices in terms of fertilizer requirement and expected yield responses. For example, from the historical data it can be shown that cane severely deficient in K, with initial diagnostic index values of less than −30 will require at least 350 kg/ha muriate of potash to correct the deficiency, and provided no other factor is limiting an average response of at least 20 ton/ha can be expected from this treatment. This compares favourably with the results established from correlation studies carried out by du Toit[7] using data from 75 fertilizer trials in which it was shown that in cases of severe K deficiency ($<0{,}90\%$ in third leaf), an average response of 25 tons cane per hectare could be expected from an application of 400 kg/ha muriate of potash.

(ii) Using the DRIS approach together with the systematic accumulation of data in a data bank, it would be possible to study the influence of a large number of yield factors under desired pre-selected sets of conditions. By reproducing field conditions in this way, simulated factorial fertilizer experiments would permit a rapid calibration of soil and leaf indices. While there is merit in this approach the major limitation would be the difficulty of obtaining reliable data representative of the wide range of conditions within the plant environmental complex.

In the sugar industry with its wide range of climatic, soil, topographical and cultural conditions, the number of representative permutations is likely to run into many thousands and in addition there would be the difficulty of obtaining reliable yield and rainfall information. It is partly for these reasons that preference was given to the use of reliably monitored observations from field experiments.

(iii) In the case of maize it has been shown that the norms established from data obtained in South Africa can apparently be used to diagnose and correct nutrient deficiency in maize at any stage of plant development, grown in any part of the world. The present position with sugarcane indicates that climate, stage of growth, age and variety are all likely to impose limitations on the universal and wider application of the system.

Conclusions

Despite criticisms in the literature that methods based on ratio interpretations of nutrients are of no greater value in diagnostic work than other forms of interpretation, the results of this investigation confirm that there is definite merit in using ratios of N and P and that a change in philosophy may be desirable in assessing the nutritional status of sugarcane. A system that utilises both of these approaches will offer the grower, agronomist and soil chemist alike a valuable means of determining whether soil fixation has allowed the cane plant to receive enough P, in detecting and correcting imbalances resulting from for example faulty fertilizer placement, excessive liming, early losses of nitrogen by leaching, denitrification or volatilization, etc.

Supplementing the critical value concept with an assessment of nutrient balance may also prove valuable in the interpretation of foliar analysis in relation to dilution and volume effects operative at the two extremes of plant growth. Ratios as well, will also assist the advisory chemist by providing a double check on the nutrient content of the leaf, particularly in those "grey areas" where the nutrient content according to the classical approach may be found to be borderline.

The search for further applications of this approach in sugarcane is a continuing one and more detailed investigations by the agricultural faculty of the University of Natal are currently in progress.

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