

RECENT ADVANCES IN DETERMINING THE N REQUIREMENT OF SUGARCANE IN THE SOUTH AFRICAN SUGAR INDUSTRY

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Abstract

An improved system of nitrogen (N) recommendations for plant and ratoon cane has recently been made available to growers in the South African sugar industry. Data from more than 40 field trials and extensive laboratory studies have indicated that the N requirement of plant and ratoon cane can be more reliably estimated from a knowledge of the soil form and bioclimatic region. In general, the N requirement of sugarcane was found to be inversely related to the capacity of the soil to supply N but it was also influenced by other factors such as temperature, irrigation, soil depth, poor drainage and crop cycle. For advisory purposes, soils are divided into four categories according to their potential to supply N and this can be estimated by visually assessing properties such as colour, texture, structure and bulk density. Details are also given of a new system based on infra-red reflectance for rating the N mineralization potential of soils.

Introduction

Interest in the importance of soil as a factor for determining the nitrogen (N) requirement of ratoon cane was renewed when the first results of a new series of field experiments conducted in the Natal Midlands on the humic soils of the Inanda form, showed that the amounts of N applied to ratoon cane on these soils could be greatly reduced, whilst cane yields and quality were improved (Moberly *et al.*⁵). The results showed that the previous method of estimating the N requirement of ratoon cane was inadequate and this, together with the escalating prices of fertilizer, provided the incentive for expanding the field experimental programme to the Natal coast lowlands and lowveld regions of Swaziland.

Simultaneously a laboratory incubation study had been initiated to determine the amount of mineral N released by soils from the various trial sites and to establish a rapid method for determining the N requirement of cane. Preliminary results and an interim guide for improving N recommendations based on soil form and organic matter content were reported by Meyer *et al.*³ and Moberly *et al.*⁵. Additional results have now permitted the introduction of a more accurate system of recommendations based on soil form, organic matter content and bioclimatic region. The more important aspects of the work that led to the improved system of recommendations are discussed in this paper.

Experimental programme

Field

Since 1977, 41 trials have been established by the Agronomy department to determine the optimum amounts of N and potassium (K) for ratoon cane grown on a wide range of soil forms in the midlands mistbelt, the coastal hinterland, the coast lowlands and the semi-arid northern areas of the Eastern Transvaal and Swaziland.

Soils were classified according to the binomial system of classification (Macvicar *et al.*⁷) and a total of 19 soil forms were represented. These soils ranged from deep porous humic clay loams of the Inanda form, to the black clays of the Arcadia and Mayo forms and the shallow grey loams of the Glenrosa form. Some of the main soil forms and the more important soil parent materials that were included in this investigation are shown in Table 1. Most of the trials had at least four N treatments ranging from nil to 220 kg N ha⁻¹. The experiments were designed as factorials or randomised blocks and the N treatment varied according to soil type and whether the crop was rainfed or irrigated. In the eight Swaziland trials, six levels of N were tested and these ranged from nil to 240 kg N ha⁻¹ at 40 kg N ha⁻¹ intervals. NCo 376 was the main cane variety used together with NCo 293 in a number of the midlands trials.

Laboratory

Investigations were conducted in three phases over a five year period. The initial studies were aimed at quantifying the amount of N released in terms of soil organic matter content for a range of soil forms. Seventy composite topsoil samples, representing 11 soil forms and varying in organic matter from 0,5 to 8,0 %, were incubated for two weeks and the amount of N mineralized by the soils (NH₄-N + NO₃-N) was determined using the method reported by Wood.⁶ The regression equation relating N release to soil organic matter content was used to estimate the probable N release of a further 400 composite topsoil samples of known organic matter content that formed part of an industry-wide nutrient survey. The laboratory work was extended to study N release from soil samples collected from untreated control treatments that formed part of the 41 agronomy field experiments.

In the second phase, the field and laboratory results were compared to determine whether the yield response to applied N and the optimum N requirement could be related to N release and organic matter content. This information was required for the grouping of soil forms into N mineralization and N requirement categories.

The final phase concentrated on developing a test that could be used by the Fertilizer Advisory Service (FAS) on a routine basis for rapidly categorising the N mineralization potential of soils submitted by growers. The standard method for determining mineral N is too time-consuming to be used for routine testing so two alternative methods were tested.

(a) **Visual assessment and sample density rating:** colour, structure, texture, and organic matter content of over 200 samples were used to establish the probable nature of the topsoil sample in terms of the binomial system diagnostic topsoil horizons (organic O, humic A, vertic A, melanic A, and orthic A). Sample densities were obtained by weighing a fixed volume of oven-dried soil which had passed through a 2 mm screen. The regression equation obtained relating sample density to clay and

Table 1
Summary of yield data and nitrogen release rates of soils from selected trial sites

Bio-climatic region	Trials		Locality	Soil parent material	Soil form	Clay (%)	OM (%)	Mineral N (ppm)		N release		Optimum N* (kg ha ⁻¹)	Av yield (t ha ⁻¹ a ⁻¹)		
	Site no	Code						Before incub	After incub	N (ppm)	kg ha ⁻¹		Zero N	Optimum N	Relative response (%)
Coast lowlands	1	TMS5/77	Emoyeni	TMS (ordinary)	Cartref	5	0,6	14	21	7	16	190	28	55	96
	2	FT11NK/80	Umzinto	Granite	Glenrosa	11	1,7	26	52	26	59	183	54	67	28
	3	FT15N/78	La Mercy	Dwyka tillite	Kroonstad	5	0,6	5	21	16	36	160	44	64	45
	4	FT7N	Shakaskraal		Longlands	14	1,8	19	46	27	61	220	73	102	40
	5	FT16N/79	La Mercy		Swartland	3	2,9	23	58	35	79	100	83	95	15
	6	FT9NK/80	Umhlanga	Red Recent Sand	Hutton	12	0,9	42	49	7	16	107	48	61	33
	7	FT10NK/80	Esperanza	Granite	Mayo	35	4,0	32	79	47	106	113	79	89	13
Coastal hinterland	8	TMS7/77	Upper Umhlali	TMS (ordinary)	Cartref	4	0,7	6	20	14	31	145	44	68	57
	9	COF1/75	Upper Tongaat	TMS (mistbelt)	Inanda	35	10,8	7	48	41	93	78	69	75	10
	10	FT14NK	Hillcrest	TMS (mistbelt)	Inanda	44	6,0	24	58	34	76	90	63	79	25
Midlands mistbelt	11	FT7NK/80	Harburg	TMS (mistbelt)	Inanda	39	5,5	12	56	44	99	55	36	32	12
	12	FT8NK/80	Richmond	Dolerite	Hutton	47	8,6	98	26	72	162	100	45	53	18
	13	FT6NK/80	Mid-Illovo	TMS (mistbelt)	Inanda	29	5,4	54	106	52	117	80	49	59	20
Lowveld	14	RVTN1/78	Pongola	Alluvium	Hutton	41	1,4	19	57	38	86	110	113	144	27
	15	NK1/80	Swaziland	Dolerite	Mayo	33	2,6	11	37	28	63	167	71	116	63
	16	NK2/81	Swaziland	Dolerite	Bonheim	53	4,1	31	81	50	112	67	71	77	8
	17	NK3/81	Swaziland	Middle Ecca Sed	Tambankulu	46	2,8	14	35	21	47	200	73	143	96
	18	NK4/81	Swaziland	Basalt	Arcadia	61	2,5	32	56	24	54	160	74	123	66
	19	NK6/81	Swaziland	Alluvium	Dundee	6	1,0	7	20	13	29	200	79	114	44
	20	NK7/82	Swaziland	Dolerite	Shortlands	45	2,5	17	79	60	135	80	69	100	45
	21	NK1/81	Swaziland	Middle Ecca Sed	Estcourt	20	1,6	34	46	12	27	160	69	100	45

* N rate coinciding with maximum sucrose production

organic matter contents was tested by using a different set of soil samples of known composition.

- (b) **Infra-red reflectance analysis:** the use of infra-red reflectance to estimate total soil N, organic matter, clay contents and the N mineralizing potential was investigated on a 1 to 4 point scale as an alternative to the visual system of rating. Approximately 100 soil samples of known mineralizing potential, and total N, clay and organic matter contents were used to programme two Technicon Infra-Alyzers (models 300 and 400). Details concerning the principles and operation of the technique are described by Meyer.⁴ Coded soil samples from 21 N/K trials were used to test the reliability of this method.

Results and Discussion

Field

Assessments of provisional results have been made for the trials conducted in the rainfed areas (Moberly *et al*⁵) and the irrigated areas of Swaziland (Leibbrandt¹). A summary of the optimum N levels and relative responses obtained for a selected range of trials is given in Table 1. The relative yield response was calculated by subtracting the yield of sugarcane obtained when no N fertilizer was used from the yield obtained when the optimum amount of N was used, and expressing this difference as a percentage of the zero control yield.

Response to N was least in the humic soils of the mistbelt region (Inanda and Hutton forms), averaging about 15% while optimum N levels for ratoon cane ranged from 55 to 100 kg N ha⁻¹. In trials conducted in the coast lowlands region, the optimum amount of N and the slopes of the response curves were greatly influenced by rainfall and the nature of the soil form. In the trials that received more than 75% of long term mean annual rainfall (LTM), the optimum levels of N declined from 160 kg N ha⁻¹ for cane grown on the grey soils of the Glenrosa, Kroonstad, Cartref and Longlands form to about 110 kg N ha⁻¹ for cane grown on the red soils of the Hutton form. Where the yield potential was limited by shallow soils (less than 400 mm depth), eldana, nematodes and other limiting factors, the optimum N levels declined by about 20 kg N ha⁻¹. However, where irrigation was available, the optimum N requirement averaged 220 kg N ha⁻¹ over seven ratoon crops.

For irrigated trials in the lowveld the response to applied N and the optimum N requirement varied considerably, ranging from 7 to 96% and from 40 to 200 kg N ha⁻¹ re-

spectively. The relative response to applied N and the optimum N requirement was generally related to the soil form. Responses to N treatment on the well-drained red soils were small and averaged 15% while the optimum level of N ranged from 75 to 120 kg N ha⁻¹. However, responses to applied N on the sandy Dundee and hydromorphic Tambankulu forms were large and optimum N levels reached a maximum of 200 kg N ha⁻¹. In general, the N response curves of both rainfed and irrigated trials confirmed that soil form should be considered when determining the optimum N requirement of ratoon cane. Factors such as organic matter content, drainage, soil depth and other properties which can affect N release are fairly specific at the soil form level. Other factors such as moisture availability, temperature and crop cycle can influence the slope of the response curve and thus affect the optimum N requirement. The temperature and moisture availability effects were reflected in the wide range of average cane yields that were obtained where no N was applied in the major bioclimatic regions of the industry. These yields (t ha⁻¹ a⁻¹) were as follows: midlands mistbelt 40, coastal hinterland 55, coast lowlands 60, lowveld (irrigated) 110.

Laboratory

N release in relation to soil form and organic matter content: The average amounts of N released by composite topsoil samples from 21 selected trials are shown in Table 1 while the average N release in relation to the four main topsoil diagnostic horizons is shown in Table 2.

Soil forms varied substantially in their capacity to mineralise N. Soils of the Inanda, Shortlands and medium to heavy textured Hutton forms mineralized substantial amounts of N (86 to 162 kg N ha⁻¹) whereas soils of the Fernwood, Cartref, Longlands and Glenrosa forms had considerably lower release rates (16 to 61 kg N ha⁻¹). In terms of the main diagnostic horizons represented by the various forms, topsoils classified as humic A and humic orthic phase released on average the largest amount of N (110 kg N ha⁻¹) followed in decreasing order by the brown orthic group, the melanic and vertic group, and the grey orthic groups.

The release of N was positively correlated with soil organic matter content. Soils of low, medium and high N mineralizing capacity corresponded broadly with soils containing less than 2, 2 to 4 and more than 4% organic matter content respectively. Nitrogen release was also broadly related to clay content, particularly over the 5 to 35% clay range.

N release in relation to crop response: Data from the 21 trials were examined to determine whether yield response

Table 2
Nitrogen release in relation to main topsoil diagnostic horizons

Diagnostic topsoil horizon	No	Representative forms	Av. organic matter content (%)	N release (kg N ha ⁻¹)		
				Average	Low	High
Orthic (grey)	7	Cartref Glenrosa Kroonstad Longlands	1,7	43	16	59
Orthic (red to brown)	4	Hutton Shortlands	2,1	79	16	135
Melanic/vertic	5	Mayo Bonheim Arcadia	3,2	76	47	112
Humic/orthic humic phase	5	Inanda Hutton	7,2	110	93	162

to applied N and the optimum levels correlated with N release, the organic matter content of soil, and the type of diagnostic topsoil horizon. This was necessary in order to develop a system of N recommendations for advisory purposes. It was found that the relative yield response to applied N (in ts ha^{-1}) was inversely related to N release. This is illustrated in the regression curve for N release shown in Figure 1. The results imply that the probability of a response to applied N decreases markedly with increasing organic matter content and greater N release.

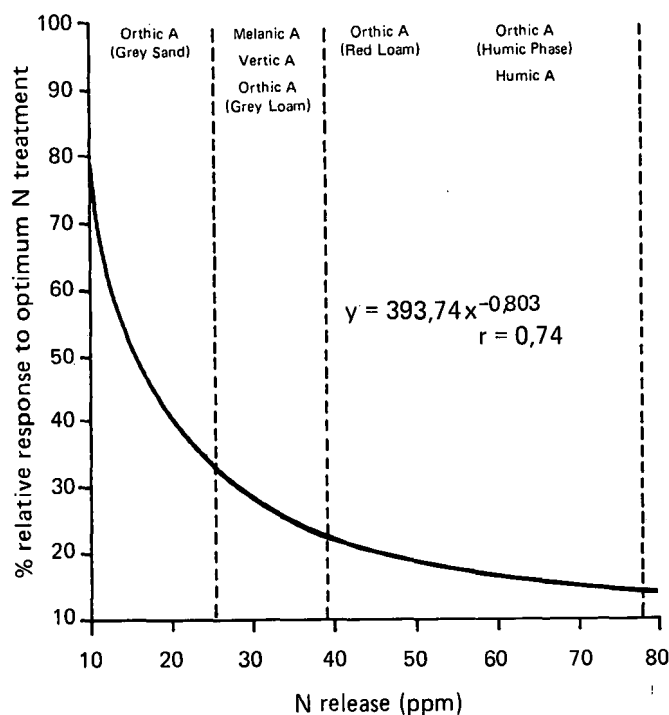


FIGURE 1 Relative response to optimum level of applied N in relation to N release.

The response to applied N was broadly related to the nature of the diagnostic horizon and declined in the order grey orthic > melanic and vertic > red to brown orthic > orthic humic phase and humic A horizons. The differences between these four groups is shown by the average response curves obtained for trials conducted in the rainfed areas (Figure 2). A similar relationship was obtained for the irrigated trials although the fourth group was not present as soils with humic A horizons do not occur in the lowveld region.

The yield obtained, in both tc and ts ha^{-1} , where no N was applied was linearly related to the amount of N mineralized by the soil, for example in the lowveld region, soils of the Shortlands and Hutton forms released over 85 kg N ha^{-1} and the zero N treatments produced more than $100 \text{ tc ha}^{-1} \text{ a}^{-1}$. In comparison, the Dundee and Estcourt soil forms released less than $50 \text{ kg N ha}^{-1} \text{ a}^{-1}$ and cane yields on these soils averaged 79 and $69 \text{ tc ha}^{-1} \text{ a}^{-1}$ respectively.

Optimum levels of N for ratoon cane, as determined from response curves, were inversely related to soil organic matter levels and soil N release (Figure 3). For rainfed cane the highest optimum N rates (160 kg N ha^{-1} and higher) were mainly associated with the grey orthic soil group containing less than 2% organic matter content and releasing less than 50 kg N ha^{-1} . By comparison, trials with the lowest optimum N rates were associated with the brown humic soil group containing more than 4% organic matter content and releasing over 100 kg N ha^{-1} . For irrigated cane a similar

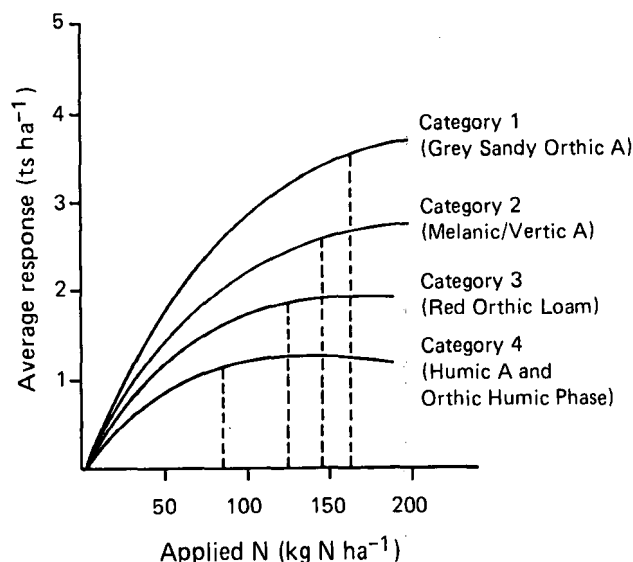


FIGURE 2 Average response to applied N in relation to soil diagnostic horizons.

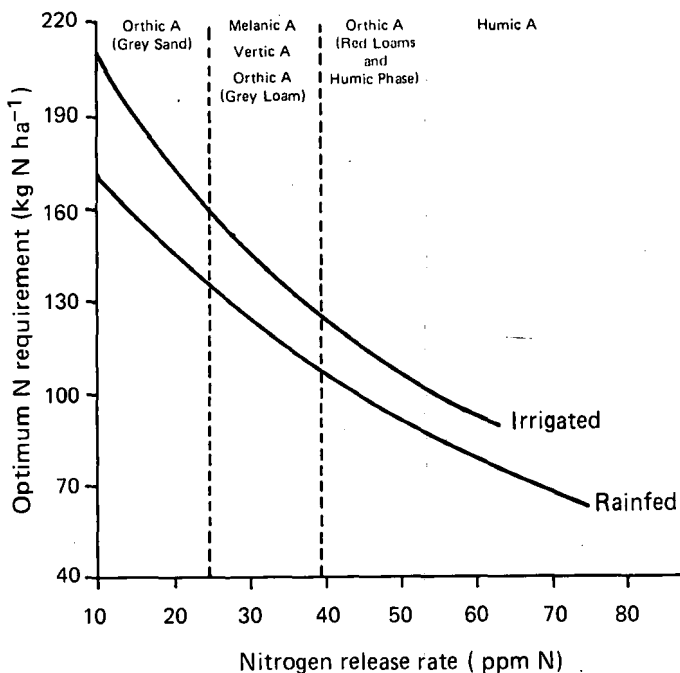


FIGURE 3 Optimum N requirement of ratoon cane in relation to nitrogen release.

relationship existed but results were not as clearly defined, mainly because most soils fall within the 2 to 4% organic matter content category.

System adopted for advisory purposes

Both field and laboratory investigations indicated that the major factor that should be considered when making N recommendations is the availability of natural soil nitrogen to the plant. Field evidence, based on response curves, showed that the optimum N requirement could be established more reliably from the soil form than from estimated cane yield.

For advisory purposes, three soil groups were initially proposed by Meyer *et al*³ and ratios of 1,6, 1,25 and $0,8 \text{ kg N t}^{-1}$ expected cane yield respectively were previously proposed for calculating the N requirement of ratoon cane for these soil groups. However, this system was never implemented as the ratios are greatly influenced by variations in seasonal potential and the age of cane at harvesting.

The re-assessment of the available field and laboratory data led to a more accurate system for determining the N requirement of plant and ratoon cane (Appendix I) based on soil form and bioclimatic region. Soils are now classified by their diagnostic topsoil horizons into four categories; low, moderate, high and very high. According to their potential to mineralize N from organic matter in the soil for use by the crop. The change from the previous three-stage system was implemented by upgrading the Shortlands and medium to heavy textured Hutton soil forms from the moderate to high N mineralizing category thus creating a new very high N mineralizing category for humic soil forms.

Provision has been made for the effect of regional differences in yield potential and N requirement of cane. It seems that the amount of N applied to ratoon cane grown in the drier, cooler Umzinto midlands region should be reduced by 20 kg ha⁻¹. Under rainfed conditions, soil depth can limit yield potential, particularly in the light textured soils which comprise Category I. The standard N recommendations for ratoon cane in this category have therefore been reduced by 20 kg ha⁻¹ where soil depth is less than 400 mm. In the coastal system, N recommendations for cane grown on Category I and II soils have been increased by 20 kg ha⁻¹ if

irrigation is practised, and for cane older than a fourth ratoon crop, which is grown in Category III soils in the low-veld, the amount of N has been increased from 120 to 140 kg ha⁻¹.

Where specific factors such as nematodes, low rainfall, salinity/sodicity are known to limit crop growth, it is recommended that applied N be reduced by 20 kg ha⁻¹. Also where the ratio of cane price to cost of fertilizer is likely to be lower than usual or in times of cane restriction. Where fields have a history of severe eldana infestation, particular care should be taken not to apply more than the recommended amount of N.

Methods for rating the N mineralization potential of soils

The FAS uses one of two methods to categorize the N mineralization potential of soils which a grower submits. The first method uses the soil form and/or parent material entered on the soil sample label where this is known and stated by the grower. The second method is used when this information is not supplied by the grower. Soil samples are rated into low, moderate, high and very high N mineralizing categories based on the diagnostic topsoil horizon. The cat-

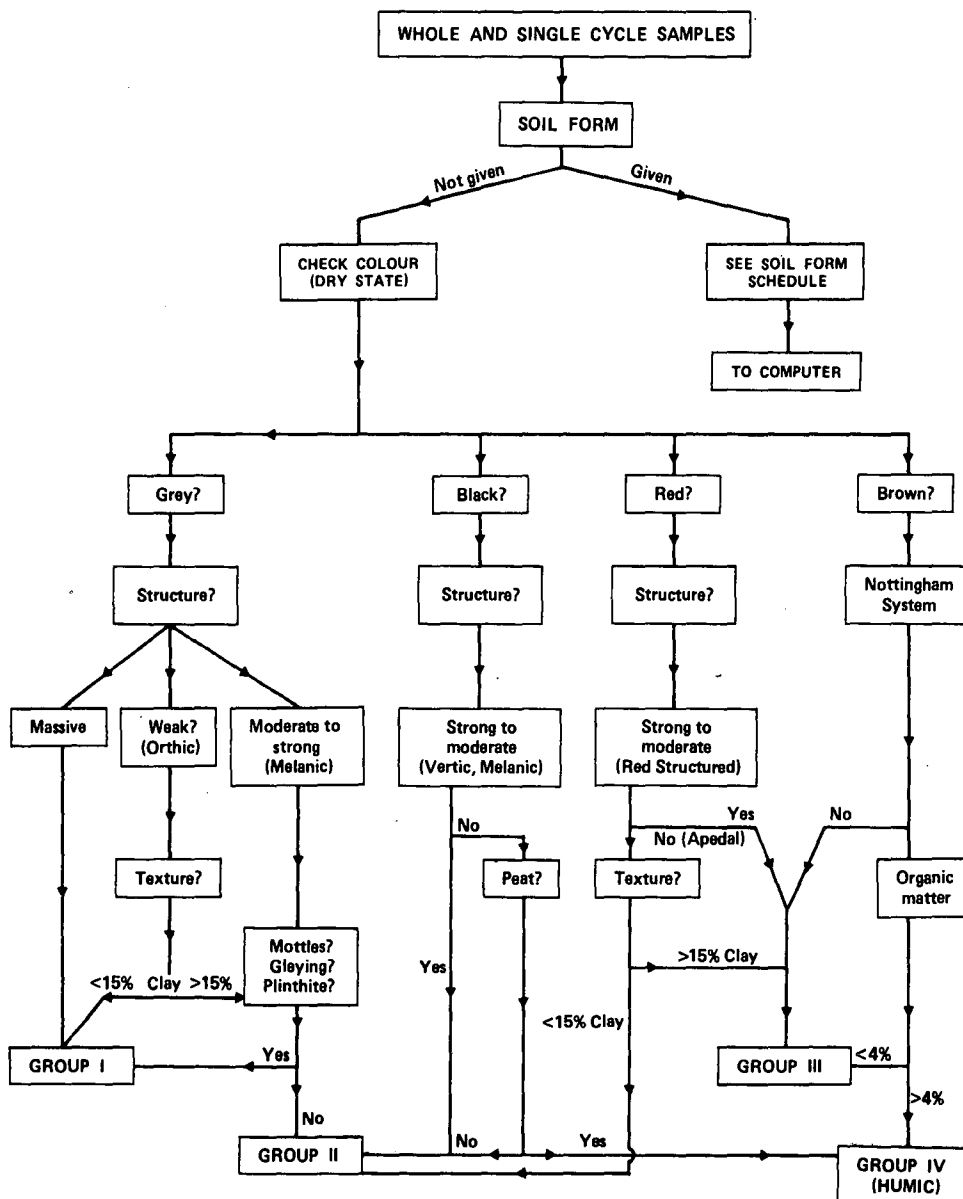


FIGURE 4 Steps involved in using soil property matrix guide.

egory is determined from a visual assessment of soil properties and a density rating of soil samples.

Basis of the visual rating procedure

Distinctive differences in soil properties such as colour, texture, structure and organic matter content between the diagnostic topsoil in each category permitted the development of a simple, rapid method for rating growers' soil samples into the appropriate categories given in Appendix I. For advisory purposes, these differences have been used to draw up a property matrix guide for rating soils into their appropriate categories. An outline of the main steps is shown in the flow diagram given in Figure 4.

The results of a pilot scheme in which approximately 700 soil samples of known soil form were classified in this way has indicated that at least 80% of the soil samples received may be correctly categorized. Of the samples examined 26, 48, 18 and 8% were grouped into the low, moderate, high and very high N mineralization categories respectively.

Table 3

Reliability of infra-red measurements for organic matter, clay and total N content of soils

Organic matter		
Difference (infra-red vs Walkley Black)	% Agreement	
	Model 300	Model 400
0,25 %	19	27
0,50 %	40	51
0,75 %	61	70
1,00 %	72	82
Clay		
Difference (infra-red vs hydrometer)	% Agreement	
	Model 300	Model 400
3 %	28	27
5 %	40	50
7 %	51	70
10 %	75	87
Total N		
Difference (infra-red vs modified Walkley Black)	% Agreement	
	Model 300	Model 400
50 ppm	22	20
100 ppm	43	37
200 ppm	60	70
300 ppm	76	83

Infra-red reflectance

Comparative statistical information obtained for the two Technicon infrazalyzers assessing total N, organic matter and

clay content is shown in Table 3 and the results indicate that this technique shows potential. Reliability of this method decreased in the order organic matter, total N and clay content.

The larger 400 instrument proved to be more effective than the small 300 model for organic matter content, where differences were less than 0,75 units in 70% of the samples analysed with the '400' compared with 61% for the '300'. For total N, differences were negligible whilst for the clay determinations, the values obtained with the '400' were considerably more reliable than those of the '300'.

Coded samples submitted from 21 field experiments where N had been tested showed that the visual system correctly predicted N mineralizing category in 19 of the sites, whereas the infra-red method was correct in 16 instances.

Conclusions

The soil should be considered when assessing the amount of N to be applied to sugarcane. More accurate N recommendations can be made by categorizing soils according to their N mineralizing potential using criteria such as soil form where this is available, or by identifying the diagnostic horizon using soil colour, clay content, organic matter content and structure. The four category system described will ensure increased application of N fertilizer on the poorer less fertile soils, particularly under irrigated conditions. Equally, a reduction in rates of N fertilizer applied to soils with high mineralizing capacity and high organic matter content has already resulted in considerable savings for many growers. Provision has been made on the computer advice sheet sent to growers for showing the N mineralizing potential of a soil and recommendations for N are now based on the information given in Appendix I.

Although the infra-red method has shown considerable promise in categorizing the N mineralization potential of soils, further work on a wider range of soils will be necessary before this technique can be implemented for advisory purposes.

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APPENDIX I:
Recommendations for nitrogen according to soil form and soil system
Soil N Mineralization Groups

Crop criteria	Soil mineralization potential			
	Low I	Moderate II	High III	Very high IV
Soil forms	Cartref	Glenrosa (heavy)	Hutton (heavy)	Champagne
	Longlands Westleigh	Clovelly (light)	Hutton (moderate)	Inanda Nomanci
	Kroonstad	Hutton (light)	Shortlands	Kranskop
	Katspruit	Oakleaf	Bonheim (red)	Magwa
	Glenrosa	Swartland	Oakleaf (red)	Hutton (humic phase)
	Estcourt	Bonheim (non-red)	Glenrosa (Trevanian series)	Clovelly (humic phase)
	Sterkspruit	Valsrivier	Clovelly (moderate)	Griffin (humic phase)
	Dundee	Tambankulu	Griffin (moderate)	
	Shepstone Fernwood Oakleaf (light)	Willowbrook Rensburg Arcadia		
	Mispah (grey)	Milkwood		
		Mayo Inhoek Mispah (brown)		
Organic matter	<2%	2-4%	2-4%	>4%

New N Recommendations

Crop criteria	Soil mineralization potential			
	Low I	Moderate II	High III	Very high IV
Plant crop	All soil systems			
	Rainfed	120	100	80
	Irrigated	140	120	80
Ratoons	Coastal (Berea, Umzinto coast Lowlands)	Rooting depth <400 mm/ >400 mm		
	Rainfed	140 160	140	120
	Irrigated	160 180	160	120
	Midlands (Umzinto Midlands/ River valley and Nottingham)			
	Rainfed	140 160	120	120
	Irrigated	140 160	140	120
	Lowveld (Komatipoort, Nelspruit)			
	Irrigated	160 200	160	120** 140***

‡ Peat soils
 ** 1st to 4th ratoon
 *** older than 4th ratoon