General discussion and conclusions

The fact that leaf analysis continues to be a widely used for diagnostic and advisory purposes is evidence that it is considered a very useful tool in determining and monitoring the nutrient levels in sugarcane production. Despite ongoing development and re-assessment of nutrient critical values to ensure that varietal, climatic and other factors are taken account of, there has been continued concern about the interpretation of leaf analysis data that may possibly have been affected by moisture stress.

The evidence presented in this dissertation highlighted the fact that misinterpretation of leaf analysis data associated with moisture stressed sugarcane is indeed possible. As moisture stress has been shown to affect both total and third leaf N and P values, induced nutrient 'deficiencies' due to drought effects could easily be mistaken for nutrient deficiencies *per se*. Although the avoidance technique of precluding the collection of leaf samples during periods when cane is affected by moisture stress has in the past served to ensure that interpretation of leaf analysis data is as meaningful as possible, it has not been totally satisfactory. Not only do sampling restrictions hinder on-farm activities, but latent moisture stress effects may result in misdiagnosis of nutrient problems and/or erroneous fertiliser recommendations.

This investigation, conducted under semi-controlled conditions, was aimed at quantifying the response of young sugarcane to moisture stress and stress/relief and then relating this to third leaf nutrient values in particular. In this way, it was shown that the original hypothesis (derived from anecdotal evidence) of declining third leaf N values associated with moisture stress, followed by substantial improvement once the stress was relieved, was indeed valid. However, the delay in recovery of the third leaf values once stress was relieved suggested that N (absorbed into the stalk under stressed conditions) was redistributed to the younger actively growing spindle and young leaves rather than to existing fully expanded leaves. As such it would be necessary to ensure that the existing spindle (at the time of stress relief) developed to the third leaf stage before leaf sampling was conducted. Although the arbitrary chosen four week waiting period, advocated in the past in this regard, was a reasonable

estimate to allow for moisture effects to dissipate, a newly developed moisture stress indicator would need to be less subjective. The proposed use of D%W(Sp) and D%W (L3T) provides such an opportunity and has the added value in allowing the estimation of 'unstressed' third leaf N (and P) values corresponding to third leaf values affected by moisture stress.

This investigation has also shown that total and third leaf N, P and K values are differentially affected by moisture stress and stress/relief. While P is less sensitive than N to changes in plant moisture status, plant K was generally found to be insensitive to moisture stress. These findings, together with the fact that no evidence was found to support the hypothesis that moisture stressed cane would preferentially absorb K, have important implications for interpreting leave analysis data associated with moisture stressed cane. The use of nutrient ratios would not appear to be useful under such conditions.

Although a conscious effort was made to select varieties that apparently differed in their tolerance to moisture stress, there was no indication that such differences existed in terms of their nutrient status under moisture stress or stress/relief. As such, it should be assumed, until shown to the contrary, that the trends in nutrient status and the use of D%W (L3T) and D%W (Sp) for determining the extent of moisture stress in cane at the time of leaf sampling are applicable for use across varieties.

Whether, leaf analysis is simply used for diagnostic purposes or for more advanced techniques in determining nutrient requirements and/or trends, it is considered extremely important that any moisture stress effects are recognised. As such, the work reported here has provided one more step in the overall progression towards a more versatile and robust use of leaf analysis in sugarcane production. The better understanding of the effect of moisture stress and stress/relief on plant nutrient status that has resulted from these investigations will allow more confidence in the interpretation of leaf analysis data irrespective of moisture stress effects. In the event of acceptance of the proposed use of D%W in routine leaf sampling, the constraints in sampling periods will be markedly eased. It is hoped that not only will these advances encourage ongoing leaf sampling in the South African sugar industry, even in seasons when drought effects would normally have curtailed such operations, but will also

stimulate renewed interest in leaf sampling for better nutrient management in countries such as Australia. Any advances that widen the scope of a particular nutritional tool can only be of benefit to the grower community and world sugar industries as a whole

List of colour photographic plates

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Plate 7. Plants were partitioned into different plant parts.

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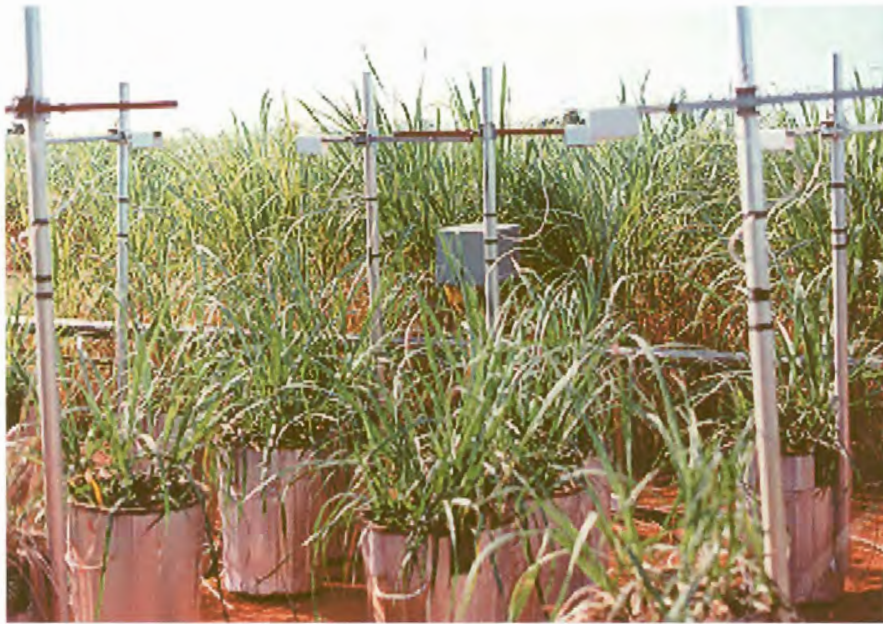**Plate 4.** Growth transducers were used to measure plant extension rate.

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Plate 8. Three different sugarcane varieties (NCo310, Q141 and Q136) were included in the glasshouse trial at Indooroopilly.

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List of Appendices

Appendix A. Standard methods for chemical analysis of sugarcane leaves – SASEX and BSES

Appendix B. Hourly plant growth patterns associated with the different moisture treatments during a 24-hour period prior to each sampling (harvest) in Trial 1

Appendix C. Proposed modified leaf sampling procedures for sugarcane

Appendix A.

Standard methods for chemical analysis of sugarcane leaves

Sample preparation:
Leaf/plant samples are dried in a forced-draught oven at 70°C for 48 hours. The dried material is finely ground using a stainless-steel hammer mill, passed through a 0.5mm perforated screen and stored in sealed containers until they are analysed. If delays occur, the samples are redried in the oven.

Analysis (SASEX):
A single wet digestion with selenised sulphuric acid is used for the determination of N, P and K.
Method of digestion:
0.25g of milled plant material is weighed on a square of tissue paper, which is then folded and transferred to a 100ml Kjeldahl flask. 2.0ml of selenised sulphuric acid and a few glass beads are added. The flasks are heated in a block digester and boiled for a minimum of 1.25 hours or until the digestion is complete. The contents of each flask is allowed to cool and is then quantitatively transferred into 25ml volumetric flasks, and made up to volume with deionised water.

Nitrogen in the digest is determined colorimetrically, using a nitroprusside catalysed indophenol reaction and reading absorbance at 665nm (Burrows, 1977).
Phosphorus in the digest is determined colorimetrically, using a phosphomolybdate complex reduced with stannous chloride and reading absorbance at 660 nm (Burrows and Meyer, 1976).
Potassium in the digest is determined by atomic absorption spectroscopy after the addition of lanthanum oxide.

Analysis (BSES):
Two separate digestions are used - one for N and a separate digestion for P and K.
Nitrogen is determined using a semi-micro Kjeldahl digestion in concentrated sulphuric acid (in the presence of selenium) similar to that described above, followed by auto-colorimetry using the indophenol method (Warner and Jones, 1970; Chapman and Haysom, 1984).

P and K are determined by ICP following digestion using a mixture of nitric and perchloric acids.
Method of digestion (Chapman and Haysom, 1984): 1.0g of milled plant material is weighed into a 125ml erlenmeyer flask. A few glass beads and 10ml of nitric/perchloric acid mixture is added. After the initial reaction has subsided, digested continues at 250°C. Once the reaction is complete, the contents of the flask is quantitatively transferred to a 50ml volumetric flask and made up to volume with deionised water.

Phosphorus is determined in the digest using ICP (214.914nm emission line).
Potassium is determined in the digest using ICP (766.491nm emission line)
(Z.A. Ostatek-Boczynski - pers. comm.)

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Appendix B.

Hourly plant growth patterns associated with the different moisture treatments during a 24-hour period prior to each sampling (harvest) in Trial 1.

Appendix B(i)	Period 1: prior to imposition of the stress treatments (week 13 after planting).
Appendix B(ii)	Period 2: prior to first sampling (week 14 after planting).
Appendix B(iii)	Period 3: prior to second sampling (week 15 after planting).
Appendix B(iv)	Period 4: prior to third sampling (week 17 after planting).
Appendix B(v)	Period 5: prior to fourth sampling (week 18 after planting).

Plant growth - week 13 after planting

Plant growth - week 14 after planting

Plant growth - week 15 after planting

Plant growth - week 17 after planting

Plant growth - week 18 after planting
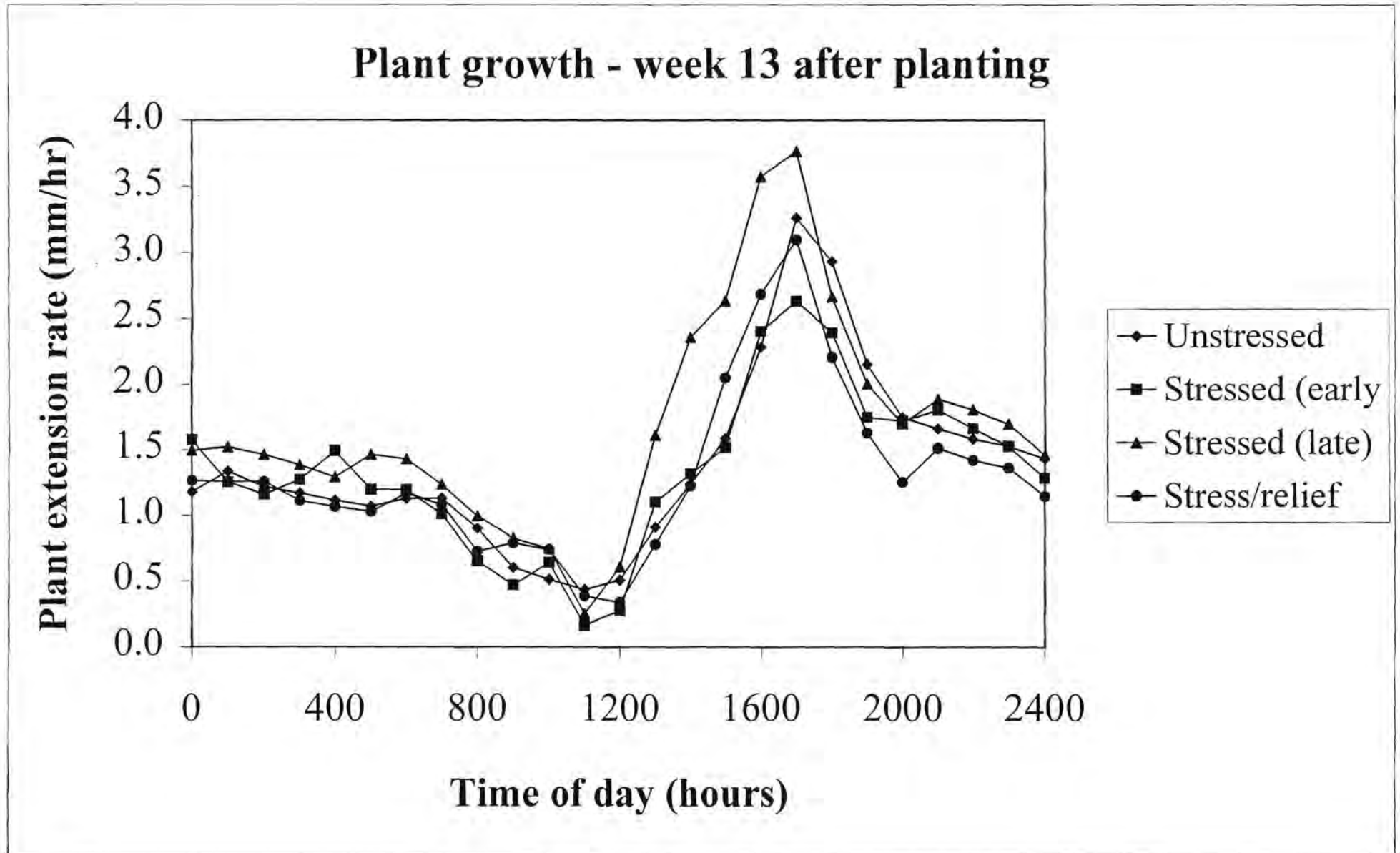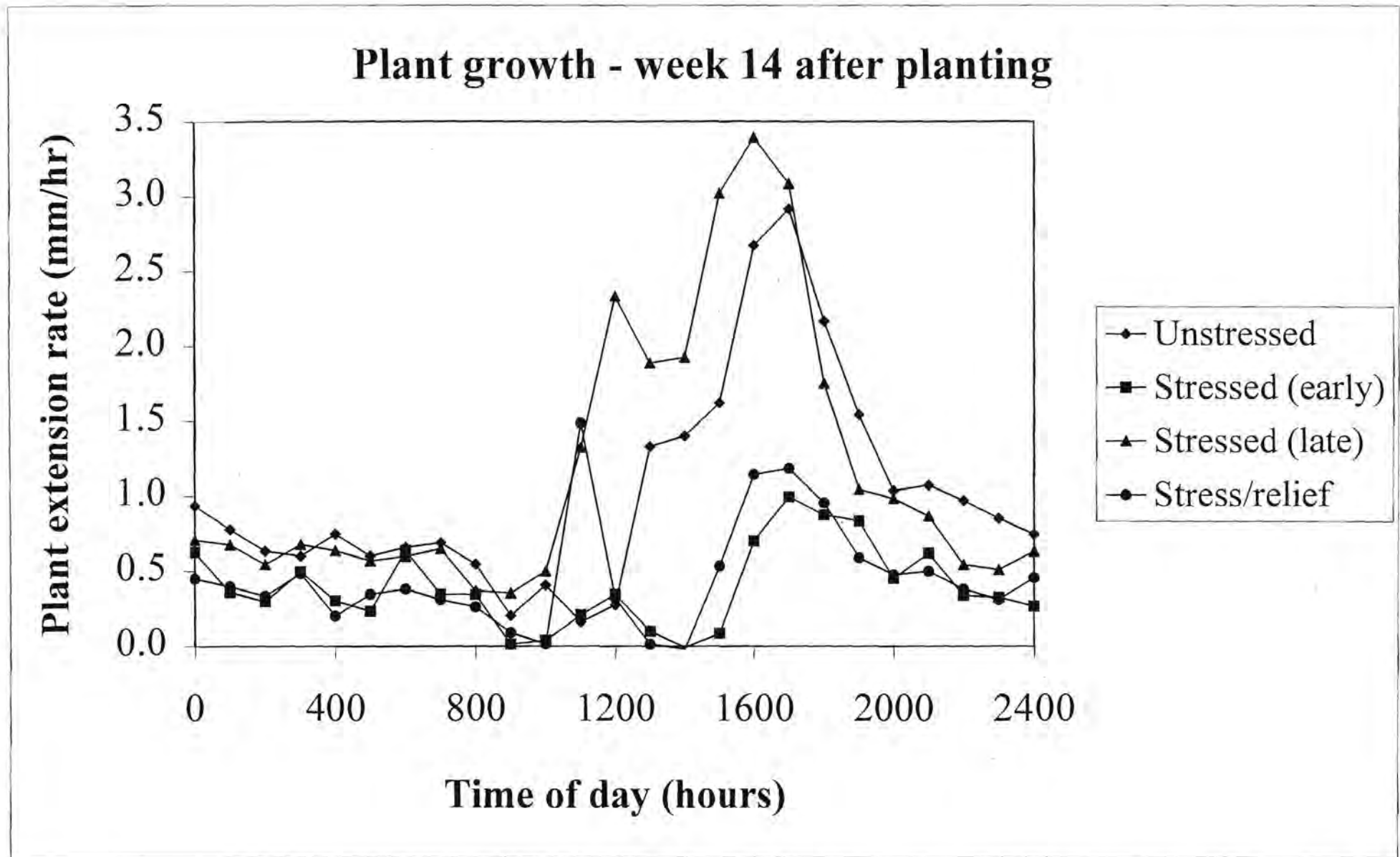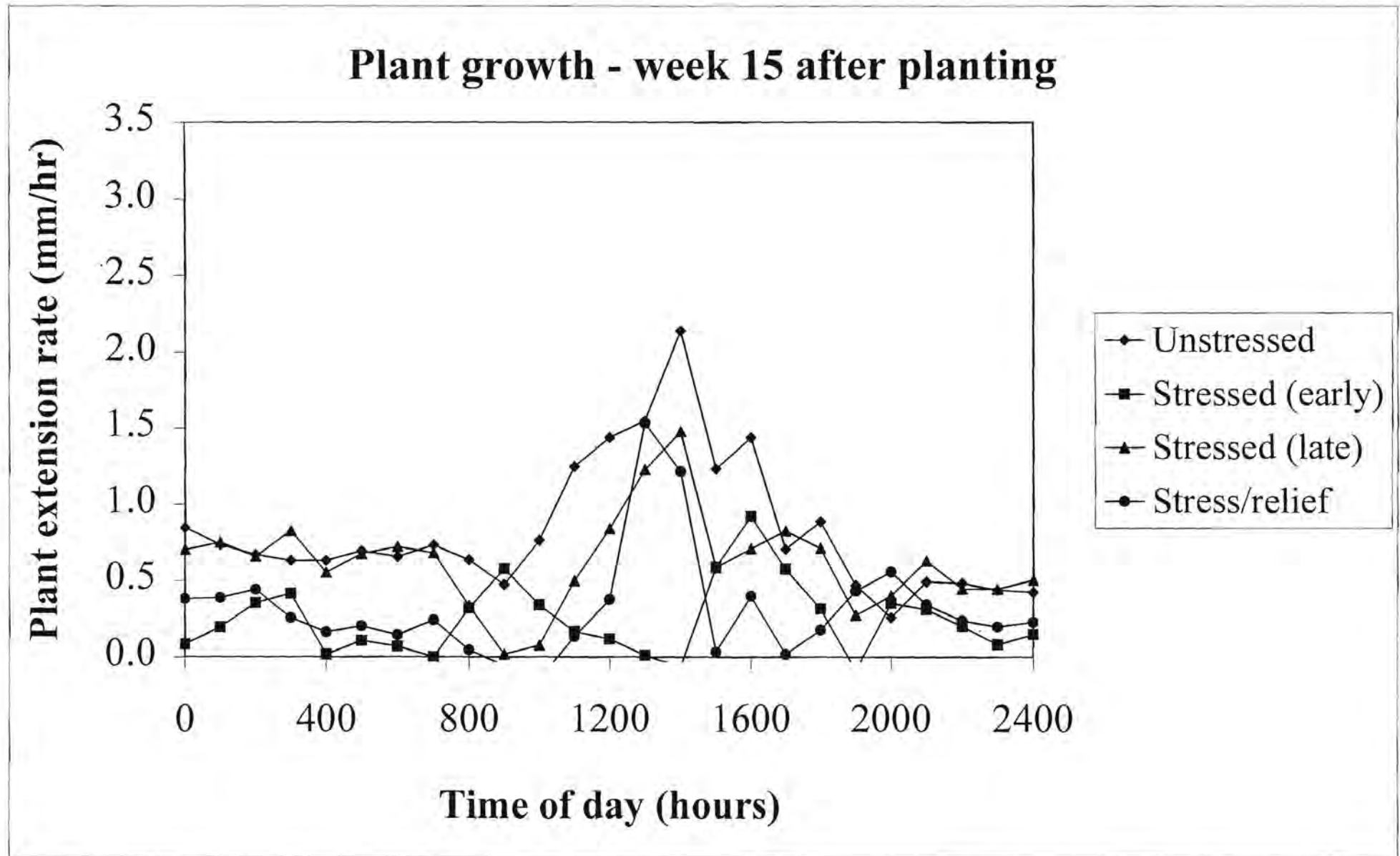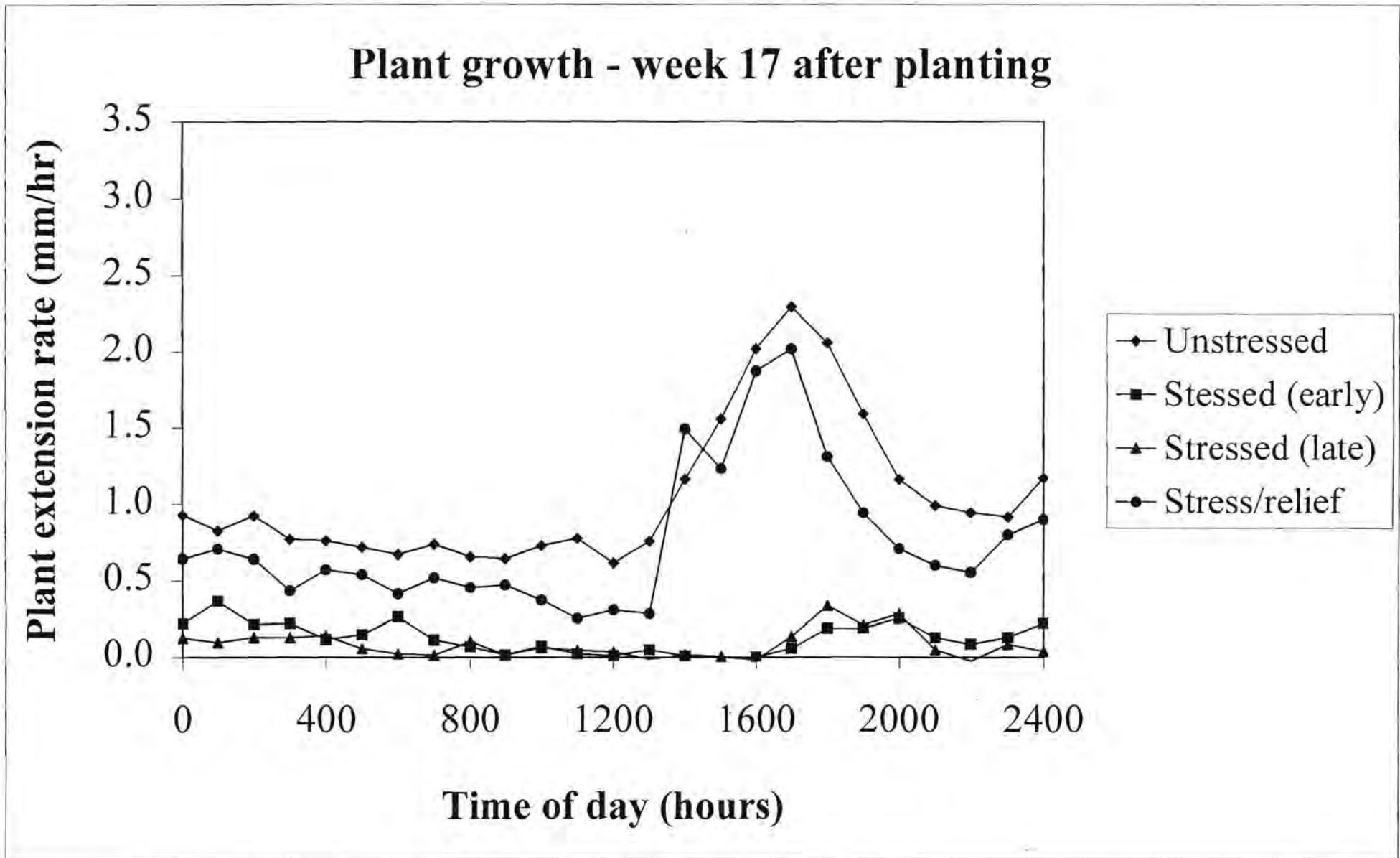
Appendix C

Recommended leaf sampling procedure

- Select leaves from stalks of average height.
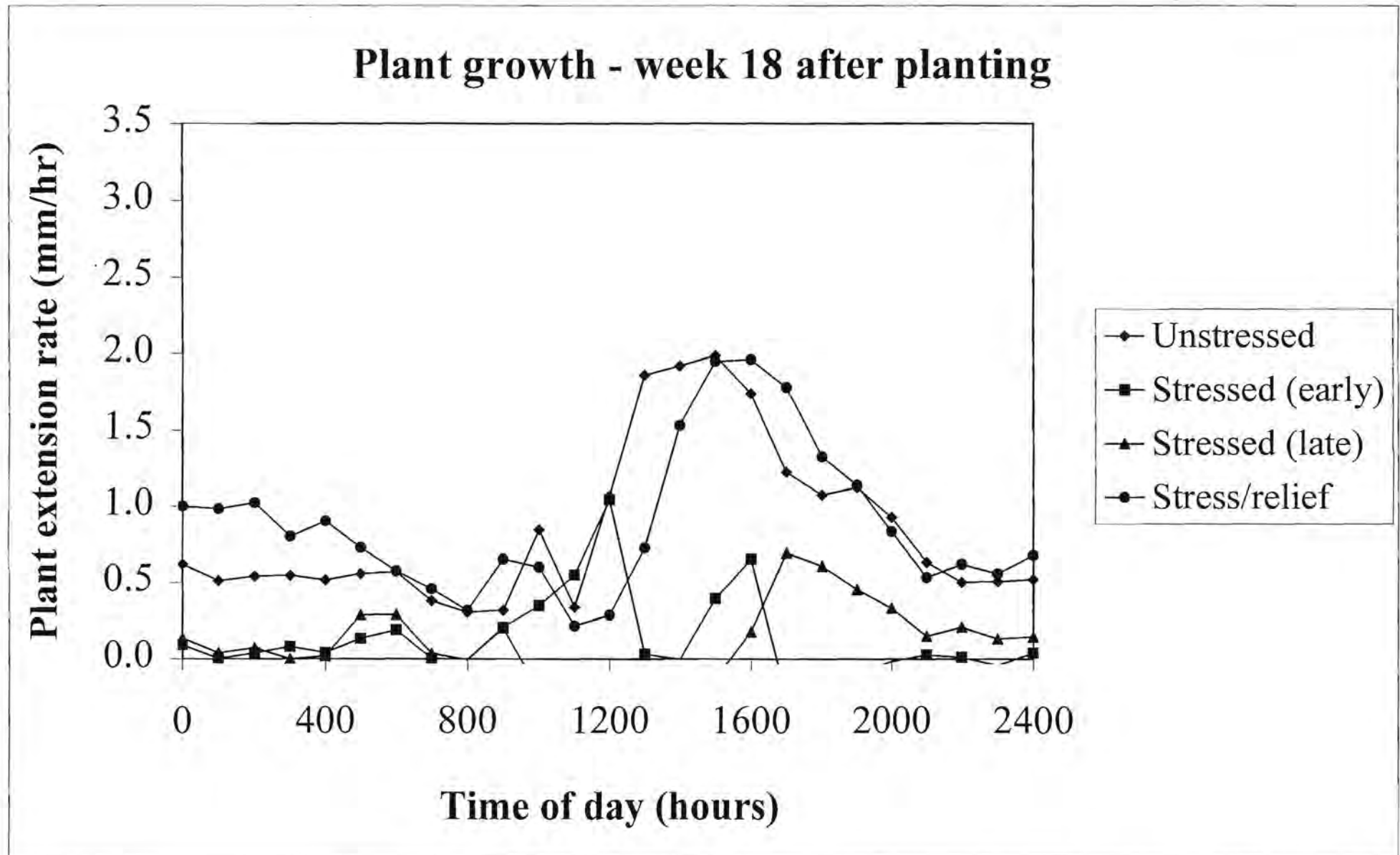- Sample the third leaf from the top of the stalk. The first leaf is the one that is more than half unrolled.
- Collect 40 such leaves from the block / field of sugarcane, preferably using a diagonal sampling pattern.
- **If it is suspected that the sugarcane may be affected by moisture stress**, collect about 20 spindle leaves from the same stalks and place directly into a plastic bag and seal it as soon as possible once the sampling is complete.
- Fold the third leaves in half (tip to base) and cut a 100mm length from the folded leaf (giving a total of 200mm).
- Strip out and discard the midrib from the 200 mm section.
- Place the sample in a clean paper bag.
- **If it is suspected that the sugarcane may be affected by moisture stress**, collect the top-sections of the leaves (above the removed 200mm section) and place in a clean plastic bag (preferably with a zip top). Seal this bag a soon as possible.
- Keep all the samples in a cool environment (polystyrene cooler) until the 200mm sections of the third leaves can be dried in an oven, or in a well-ventilated area.
- Do NOT dry the spindle or tops of the third leaves (keep them sealed in their respective plastic bags).
- Send the samples to the laboratory for analysis as soon as possible. The moist samples (spindle and third leaf tops) should be dispatched within 24 hours samples (preferably by courier or post) to prevent the growth of mould in the plastic bags.
- Supply the following information:
  - Name, address and mill area.
  - Block/field number
  - Variety
  - Crop (plant or ratoon number)
  - Sampling date and age of cane at sampling
  - Details of fertiliser applied (type and rate)
- Always ensure
  - Requirements for sampling in terms of season, age, time lapse from fertiliser applications are met
  - Hands are clean when sampling
  - Cane is not affected by some other factor such as disease, insect damage or abnormal climatic factors. Interpretation of third leaf data samples from sugarcane slightly affected by moisture stress is possible as long as the spindle and third leaf tops are sampled as well.
  - Samples are not contaminated by fertilisers and/or other chemicals

Supplement to the thesis

Published papers associated with the thesis "Assessment of leaf analysis and the major nutrient content of sugarcane under moisture stress conditions"

Contents
(in chronological order)

Schroeder, B.L., Wood, R.A. and Meyer, J.H. (1992). Advances in leaf analysis techniques and interpretation in the South African sugar industry. Proc. Int. Soc. Sugar Cane Technol. 21: 123-135.

Schroeder, B.L., Wood, R.A. and Meyer, J.H. (1993). Foliar analysis in the South African sugar industry for diagnostic and nutrient trend purposes. In N.J. Barrow (ed.). Plant nutrition – from genetic engineering to field practice: 299-302. Kluwer Acedemic Publishers, Dordrecht, The Netherlands.

Schroeder, B.L., Wood, A.W., Kingston, G., Meyer, J.H. and Barnard, R.O. (1999). Leaf analysis – What does it offer the Australian sugar industry? Proc. Aust. Soc. Sugar Cane Technol. 21: 122-130.

ADVANCES IN LEAF ANALYSIS TECHNIQUES AND INTERPRETATION IN THE SOUTH AFRICAN SUGAR INDUSTRY

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ABSTRACT

For many years leaf analysis has served as an important diagnostic tool in the sugar industry in South Africa. The use of X-ray fluorescence spectroscopy and near infra-red reflectance have largely eliminated the need for routine wet chemical procedures for foliar analysis. Several useful applications have been developed based on these techniques, including the establishment of a data base for trend analysis within the industry. More meaningful interpretation of results in now possible due to the recognition of the effects of varietal differences, climatic conditions and soil properties on leaf nutrient values. In particular, the leaf threshold values for P and K in terms of varieties N12 and N14 respectively have been modified and a correction factor for the leaf K threshold value for winther cut cane has been introduced. Possible alternatives for countering the effects of moisture stress on leaf N and P values are suggested.

Key words: Leaf analysis, X-ray fluorescence spectroscopy, near infra-red reflectance, threshold values.

INTRODUCTION

The primary objective of the Fertilizer Advisory Service (FAS) which was established by the South African Sugar Association Experiment Station in 1954, is to provide growers with whole cycle fertilizer advice based on the analysis of soil samples taken prior to planting. Recommendations are made for the plant and four successive ratoon crops. Leaf analysis of ratoon cane is subsequently used for evaluating the adequacy of the original advice based on soil analysis. The use of foliar analysis as a diagnostic tool in the South African sugar industry was originally evaluated in the fifties (Du Toit[7]). The methods of analysis which were based on the chemical digestion of leaf tissue were further developed and improved (Bishop[1], Long[11], Burrows and Meyer[3], Burrows[3]) until the introduction in 1984 of X-ray fluorescence spectroscopy (Wood et al[4].) and near infrared reflectance (NIR) (Meyer[14]) as the routine methods of foliar analysis. X-ray fluorescence spectroscopy (XRF), although widely used in the geological and metallurgical fields for the

determination of a range of elements in rock and ore samples (Jenkins and de Vries[9], Willis[22]) and also reported as a technique for foliar analysis overseas (Jenkins et al[10], Norrish and Hutton[18]) is not commonly used in agricultural laboratories in South Africa.

A brief resumé of the development of the leaf analysis techniques used by FAS is given together with some of the advantages of the non-destructive procedures over the conventional chemical methods. Some useful applications of foliar analysis are discussed and improvements in the understanding and interpretation of results are highlighted.

METHODS

Chemical methods

Prior to the purchase of the X-ray spectrometer all leaf samples were analysed after chemical digestion of leaf tissue. To facilitate the determination of both macro- and micro- elements, two separate digestions were necessary. One using selenized sulphuric acid for N, P, K, Ca and Mg, and the other, using a mixture of concentrated nitric and perchloric acids for Zn, S, Mn, Cu and Fe. The analytical procedures originally included techniques such as flame photometry for K, Ca and Na, colorimetric determinations for P, Mg, Zn, Cu and Mn and a distillation/titration procedure for N (Bishop[1]). The semi-automated analytical equipment which was introduced into the laboratory in 1975 eliminated the manual recording of reading from hand operated instruments with no loss in accuracy or precision (Burrows and Meyer[4]). In addition it was found that this instrumentation provided the opportunity of replacing the extremely time consuming N determination with a colorimetric procedure (Burrows[3]). These advances in methodology although contributing to a more efficient system, still relied on the digestion of samples which is time consuming and hazardous.

Non-destructive techniques

The introduction of XRF spectroscopy as a technique for analyzing leaf samples was made possible once it had been established that NIR could be used effectively for the determination of leaf N values, as nitrogen is too low on the periodic table for analysis by XRF. An integrated approach based on these two techniques was first described for sugarcane by Wood et al[24]. X-ray fluorescence spectroscopy is based on the principle that sample matter irradiated with X-rays will emit secondary or fluorescent X-ray wavelengths of which are characteristic of the elements within the sample. The intensity of these secondary X-rays, once dispersed into individual wavelengths, will indicate the concentration of the constituent elements present. The instrumentation currently used in the laboratory consists of a Philips sequential

semi-automatic X-ray spectrometer and a Hewlett Packard computer for calculating and printing results (Schroeder et al[20]). Near infrared spectroscopy, on the other hand, uses the intensity of reflected radiation as a measure of the constituent protein (or N) in a sample. The reflected light is inversely proportional to the energy absorbed at a particular wavelength. This absorbed energy coincides with the vibrational energy of the molecules composing the sample (Meyer[14]). Two Technicon NIR spectrometers are currently used for this purpose. The XRF and NIR techniques, apart from being non-destructive, are both rapid and compatible with future laboratory automation. In an initial assessment, it was found that these methods of analysis produced results which were comparable with those obtained by the colorimetric and atomic absorption procedures with little loss in accuracy or precision (Wood et al[24]). Reproducibility of the methods was found to be extremely precise for K and Ca (CV less than 5%) and while less precise for P, Mg, S and Zn (CV of 7 – 9%), nonetheless acceptable.

PROCEDURE

Sample preparation

Third leaf samples randomly collected from a field or plot are stripped of their midribs. The middle 300 mm of the laminae are dried in a forced draught oven at 70°C for 48 hr. The dried material is finely ground and passed through a 0.5 g mm perforated screen. Five grams of the sample are thoroughly mixed with 3 g of binder and compacted by means of a hydraulic press into a disc at 153 megapascals pressure for 20 sec (van Zyl[25]). The discs are then stored in a desiccator prior to analysis.

Calibration and analysis

Once the instruments have been calibrated for each element over the usual operating range, recalibration is not often required. Calibrations are however checked daily using reference material before analyzing the unknown samples. The sample discs are compatible with both instruments. The N content is however determined prior to insertion into the X-ray spectrometer as the high intensity radiation appears to affect the NIR readings. In addition NIR is particularly sensitive to moisture, necessitating adequate drying before sample analysis. Whilst sample discs are individually inserted by hand into the NIR spectrometer and results printed within 15 sec, the X-ray spectrometer allows four prepared samples to be placed in the sample chamber. Each sample sequentially moves into the analyzing position and is automatically analyzed for P,K, Ca, Mg, S and Zn. This procedure takes about six min for the four samples.

APPLICATIONS

Routine leaf analysis

Between March 1990 and February 1991, over 32, 000 soil and leaf samples were received by FAS. Based on a trend analysis conducted by Burrows[3] and updated in 1990, it is estimated that this number could increase to 44, 000 per annum by the year 2000. The spread of leaf and soil samples received is generally similar each year. While the peak of the soil sampling season is reached during June, July and August, the bulk of the growers' leaves are usually received during February and March. Over 80, 000 leaf samples have been analyzed since the inception of the non-destructive techniques (Table 1). The average number of leaf samples analyzed annually over the past 7 years was 11, 450, while the average number of soil samples analyzed per year, over the same period, was 14,772. Of the total number of samples received in the 1990/1991 season, 13,451 were growers' soils and 8,091 growers' leaves. This represents a ratio of about 5:3 for the whole industry. In addition to the routine XRF and NIR analyses conducted in the laboratory, every tenth leaf sample is digested and chemically analyzed (Figure 1). Comparison of results serves as a useful quality control mechanism (Table 2).
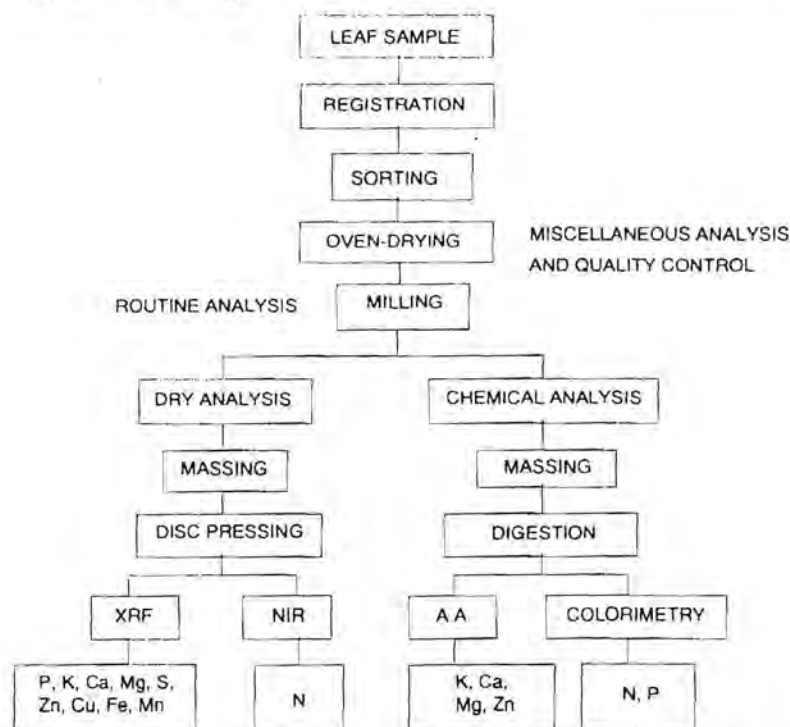

FIGURE 1. Flow diagram illustrating the current laboratory procedures for foliar analysis.

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TABLE 1. Soil and leaf samples analyzed (1983 – 1991).

Season	Samples analyzed	
	Soil	Leaf
84/85	16 515	11 188
85/86	12 837	11 083
86/87	14 853	11 343
87/88	13 391	13 444
88/89	13 452	10 839
89/90	16 450	11 594
90/91	15 911	10 653
Mean	14 772	11 450
Total	103 409	80 144

TABLE 2. Comparison of XRF and NIR values with chemical digestion values of tenth sample checks.

Sample No.	Chemical digestion					NIR	Integrated system XRF			
	N %	P %	K %	Ca %	Mg %	N %	P %	K %	Ca %	Mg %
GL6840	1.72	0.20	1.34	0.17	0.13	1.68	0.21	1.37	0.20	0.15
GL6850	1.87	0.20	0.95	0.29	0.19	1.89	0.20	0.95	0.33	0.21
GL6860	1.88	0.19	1.18	0.20	0.27	1.79	0.18	1.18	0.22	0.27
GL7130	1.71	0.15	0.87	0.28	0.37	1.73	0.15	0.81	0.41	0.37
GL7140	2.24	0.21	1.61	0.28	0.16	2.12	0.20	1.55	0.29	0.18
GL7160	1.34	0.15	0.75	0.28	0.21	1.28	0.14	0.76	0.30	0.23
GL0270	1.24	0.17	1.68	0.18	0.13	1.27	0.18	1.62	0.19	0.15
GL0280	1.34	0.22	1.77	0.16	0.18	1.33	0.21	1.69	0.16	0.19
GL0290	1.05	0.17	1.52	0.15	0.12	1.15	0.18	1.54	0.14	0.14
GL0300	0.98	0.19	1.28	0.17	0.17	0.96	0.19	1.27	0.18	0.16

Non-routine leaf analysis

While all sugarcane leaf samples submitted are routinely analyzed for N, P, K, Ca, Mg. S and Zn, trace elements (Cu, Fe and Mn) are analyzed on request. The determination of all elements in the periodic table from Na to U is theoretically possible by XRF. Difficulties may however be experienced with some elements, depending on the particular X-ray tube used, in setting up instrument parameters in some instances and where concentrations are below attainable detection limits. The possible analysis of Al and Si in cane leaves was investigated in order to assist in identifying problems associated with acid soils. Du Preez[6] recognized the fact that Si plays an important role in the elimination of minor element toxicities in *Gramineae* spp. and it is thought that the use of the Mn: Si ratio may be of some value in diagnosing Mn toxicity in cane showing acid chlorosis symptoms. Further work needs to be conducted to determine whether the Al content of leaves is correlated with toxic levels of Al in acid soils.

Nutrient surveys

The computerized recommendations, first introduced by the Experiment Station in 1980, have resulted in a data bank of some 120,000 soil and more than 60,000 leaf analysis results. In a recent nutrient survey based on this information, the leaf data revealed a fairly high proportion (28%) of samples deficient in K (Meyer *et al*[17]). Approximately 13% and 12% of the samples respectively were found to be deficient in N and P, while there were relatively few deficiencies of Ca, Mg and Zn (Table 3). It was concluded that despite a 12% reduction in fertilizer usage within the industry since 1984 (Ranwell[19]), no large scale deficiencies, apart from potassium, had occurred. A micro-nutrient survey conducted throughout the industry in 1970 (Meyer, Wood and du Preez[16]) indicated that, apart from zinc no widespread trace element deficiencies were evident (Table 4). Despite the fact that this survey was based on chemical digestion procedures, the current XRF calibrations allow for similar surveys in the future.

Unfortunately XRF cannot be used for B analysis, but NIR is however showing some promise in this respect.

INTERPRETATION

Threshold values

Threshold or critical values (Table 5) have been established (Wood[23]) to assess the nutrient status of leaf samples, and include recognition of decreasing leaf N values with age (Meyer[13]). As leaf nutrient values are highly dependent on a number of factors (Bishop[1], Gosnell and Long[8]), certain conditions are specified to allow

TABLE 3. Average nutrient content of leaf samples for the various
bioclimatic regions (after Meyer et al[17]).

Natural region	Soil system	N %	P %	K %	Ca %	Mg %	Zn ppm
Coastal lowland	Berea	1.84	0.21	1.21	0.27	0.22	18
	Umzinto	1.87	0.22	1.20	0.26	0.26	18
Coastal hinterland	Umzinto midlands	1.95	0.22	1.42	0.29	0.25	17
Mistbelt	Nottingham	1.94	0.20	1.29	0.26	0.24	18
Lowveld	Komatipoort	2.03	0.25	1.32	0.34	0.27	19
Threshold values		1.60	0.17	1.05	0.15	0.10	13
% samples deficient		13	12	28	4	1	8

meaningful interpretation of analysis results. Apart from prescribed sampling
periods and cane ages (Table 5), cane must also be growing vigorously, be
unaffected by moisture stress at the time of sampling, and no samples should be taken
until 6 weeks after fertilizer application.

Adjusted threshold values

Specific circumstances have recently been identified where certain threshold values
appear to be inappropriate. Numerous leaf analyses have indicated that K uptake by
winter cut cane growing on Ca and Mg saturated clays of the northern irrigated cane
areas is often depressed during much of the spring/early summer growth period
despite seemingly adequate amounts of available soil potassium. Following a
number of trails in which it became apparent that apart from the soil effects *per se*,
the pattern of leaf K uptake was also affected by season, Ca and Mg antagonism and
the prevailing soil moisture and temperature conditions. A seasonal correction factor
for the leaf K threshold value (Table 5) was suggested as an interim measure for cane
grown on a winter cycle under these conditions (Donaldson et al[1]). Although it is
recognized that differences exist in the critical nutrient concentrations between
cultivars (or genotypes) of the same species, these, in general, have not been
rigorously examined (Smith[21]). However, two sugarcane varieties, N12 and N14,
appear to exhibit lower threshold values than those of most other varieties in terms
of P and K respectively (Table 5).

TABLE 4. Average nutrient content of leaf samples for various natural regions (after Meyer et al[16]).

Natural region	No. of samples	B	Cu	Zn	Mn	Al	Fe
		- - - - - - - - - - - ppm - - - - - - - - - - -					
Coastal lowland	228	4.1	6.9	18.3	48	83	146
Midlands mistbelt	135	4.0	7.2	14.9	74	133	163
Sub-humid midlands	36	2.0	6.9	17.1	67	60	103
Lowveld							
– Pongola	13	2.6	7.5	15.6	42	40	91
– Swazilan	21	4.9	8.0	18.8	25	165	196
– Transvaal	39	4.4	7.6	17.4	38	112	182
– Natal	15	3.5	6.1	23.9	35	132	173
Total	487						

		B	Cu	Zn	Mn	Al	Fe
Range	Lowest	1.6	4.2	10.0	11	21	49
	Highest	10.0	12.2	55.3	270	800	915
Threshold value		1	3	14	15	–	50
No. deficient samples		nil	nil	57	11	–	1
% of total deficient		nil	nil	11.7	2.2	–	<1

Moisture stress effects

Leaf analysis data over the past two seasons have highlighted the marked effect that moisture stress can have on leaf nutrient values. The unusual rainfall pattern experienced in 1989/90, in which below average precipitation was recorded during much of the growing season, resulted in numerous low leaf N and P values. Resampling of the same fields indicated a recovery to acceptable values once the drought effects had dissipated. Despite the fact that growers are urged to sample only when conditions will exclude moisture stress, some of the larger estates find it difficult to reschedule their programs in this manner. Future work will include the use of nutrient ratios and the development of a model for interpreting analytical results of samples taken during or after stress conditions.

TABLE 5.   Leaf threshold values currently used by FAS.

Nitrogen				
Area	Crop age	Month of sampling	N (%) Plant	N (%) Ratoon
Northern irrigated	3 – 5 months	Oct to Dec	1.9	1.8
		Jan to Feb	1.8	1.7
		Mar to Apr	1.7	1.6
Coast lowlands	* 4 – 7 months	Nov to Dec	1.9	1.8
		Jan to Feb	1.8	1.7
		March	1.7	1.6
Midlands	*4 – 9 months	Nov to Dec	1.9	1.8
		Jan to Feb	1.8	1.7
		March	1.7	1.6

Other nutrients			
** P : 0.19%	Ca : 0.15%	S : 0.12%	Cu : 3 ppm
K : 1.05%	Mg : 0.08%	Zn : 13 ppm	Mn : 15 ppm

K (winter cut irrigated cane)			
Age of crop (months)	Months of sampling	K (%) All SA varieties except N14	K (%) N14
3 – 5	mid Oct – Nov	0.85	0.70
	Dec – Jan	0.95	0.80
	Feb – Apr	1.05	0.90

*In the case of summer cut ratoon cane it may be possible to sample when the crop is only three months old. For plant cane, sampling will normally only be possiblewhen the crop is five to six months old.

**The P threshold value for variety N12 is 0.03 percentage units lower than that of most other varieties.

Diagnosis and Recommendation Integrated System (DRIS)

Considerable attention was paid to evaluating DRIS for use in the sugar industry in the late seventies and early eighties (Beaufils and Sumner[2], Meyer[12]). Meyer[13] showed that this system which is based on the calculation of indices derived from nutrient ratios is particularly appropriate for young cane. This is partly due to the fact that nutrient ratios appear to vary less with increasing crop age than do the conventional nutrient percentages in leaf. As most of the cane in the sugar industry is leaf sampled when 4 months of age or older (Table 5), DRIS is not widely used except in the warmer northern irrigated areas where sampling of young cane is practiced. Under these latter conditions the system can be of benefit in providing corrective fertilizer treatment to the current crop, as N imbalances may be detected sooner than would be the case with the threshold value approach (Meyer and Wood[15]).

CONCLUSIONS

During the past 35 years, significant advances have been made in foliar analysis in the South African sugar industry. These have occurred not only in the development of the techniques and procedures used, but also in improvements of data interpretation. The system of analysis using X-ray fluorescence in conjunction with near infrared reflectance spectroscopy has been most successful since it was introduced in 1984. The rapidity of the techniques together with the reliability of the instrumentation has resulted in improved throughput of samples during the leaf sampling season. The introduction of nutrient surveys was made possible by the laboratory being able to handle a relatively large number of routine and non-routine leaf analyses. The updating and refining of leaf threshold values over the years has allowed better interpretation of leaf analysis data.

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PROGRES DANS LES TECHNIQUES D'ANALYSE FOLIAIRE ET DANS L'INTERPRETATION DES RESULTATS DANS L'INDUSTRIE SUCRIERE EN AFRIIQUE DU SUD

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RESUME

L'analyse foliaire a été utilitsée pendant longtemps comme moyen de diagnostique dans l'industrie sucrière en afrique du sud. La spectroscopie à fluorescence de rayons X et la reflectance à infra-rouges proches remplacent de plus en plus les méthodes d'analyse chimique traditionnelles. Diverses applications utiles ont été faites à partir de ces techniques, dont l'étalbissement d'une base de données qui permet de suivre l'évolution nutritionnelle de la canne à sucre. Avec l'identification des effets de différences variétales, de conditions climatiques et des caractéristiques du sol sur les niveaux de nutrients dans les feuilles, il est maintenant possible d'interpréter les résultats plus correctement. Par exemple, les niveaux critiques de P et K ont été modifiés pour les variétés N12 et N14 respectivement et un facteur de correction a été apporté aux valeurs de K pour la canne récoltée en hiver. Des moyens alternatifs sont suggérés dans le but d'éliminer les effets du stress hydrique sur les teneurs en N et P dans la feuille.

Mots clefs: Analyse foliaire, spectroscopie à fluorescence de rayons X, reflectance à infra rouge proche, niveaux critiques.

Foliar analysis in the South African Sugar Industry for diagnostic and nutrient trend purposes.

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Key words: leaf analysis, sugarcane

Abstract

In the South African sugar industry, soil and leaf analysis are used for providing fertiliser recommendations. Leaf analysis is more accessible as a diagnostic tool since the introduction of X-ray fluorescence and near infra-red reflectance spectroscopy as the methods of routine analysis.

The effects of climate and various soil properties on nutrient uptake are now recognised as important factors when interpreting leaf analysis data. The computerisation of results over the past decade has led to the effective use of a data bank of 60 000 leaf samples. Trends in nutrient status during this period have been used to evaluate the effects of fertiliser use in different regions of the industry.

Introduction

The South African Sugar Association Experiment Station has run a fertiliser advisory service (FAS) for cane growers since the early 1950's. Fertiliser advice for a cycle of plant crop and four successive ratoons is based on the analysis of soil samples collected before planting. Analysis of leaf samples taken during the ratoons is then used to check the original recommendations. Leaf analysis, as a diagnostic tool, has achieved greater impetus since 1984 when X-ray fluorescence and near infra-red reflectance spectroscopy were introduced as routine laboratory methods. In addition, trends in nutrient uptake are monitored by means of an information retrieval system based on about 60 000 leaf analysis results.

This paper describes the use of leaf analysis for diagnostic purposes, the effect of cane variety, climate and soil properties on leaf analysis data, and the use of the information retrieval system to monitor trends in the South African sugar industry.

Methods

Sugarcane leaf samples submitted to FAS are routinely analysed for N, P, K, Ca, Mg, S, Zn, Cu, Fe and Mn by an integrated, non-destructive technique involving X-ray fluorescence and near infra-red reflectance spectroscopy (Wood et al., 1985). All elements except nitrogen are determined using a Philips 1410 sequential semi-automatic X-ray spectrometer controlled by a 386XS IBM compatible personal computer (Schroeder et al., 1990). Leaf N is determined using a Technicon 300 NIR spectrometer (Meyer, 1983). Results are categorised by a computer programme into various stages of sufficiency (very low, low, moderate, high and excessive) based on threshold values for each element. All data is stored on mainframe disc files as part of the nutrient information retrieval system (NIRS). The data for each grower also includes location, month and age of sampling, and soil type. This large data bank is used to provide information on trends in leaf nutrient values for the whole industry, or for the different regions as defined

by climatic and soil systems (Macvicar, 1973), as well as for extension areas, individual farms or fields.

Results and Discussion

Samples analysed

Computers have been used by FAS since 1980 to store analysis data of more than 140 000 soil and 60 000 leaf samples. While the bulk of soil samples are received during the winter and spring, most of the leaf samples are received during the growing season (November to March) each year. An average of about 6000 growers leaf samples have been received annually since 1980.

Threshold (critical) values

Threshold values for N, P, K, Ca, Mg, S, Zn, Cu, and Mn are based on third-leaf samples (Table 1), and have been determined from a large number of fertiliser trials conducted over the past 40 years (Du Toit, 1959; Wood, 1989). Although these are generally in terms of variety NCo376, they are used for all varieties. Leaf sampling requirements are standardised in terms sampling periods and age of cane (Table 2).

Modified threshold values

A number of factors such as age, season, time of sampling and variety, affect the uptake of elements and leaf nutrient values (Gosnell and Long, 1971). Modified threshold values have been introduced as required to take these factors into account. Examples of these are given below.

As leaf N values generally decline through the season (Meyer, 1981), modified threshold values ranging from 1.9 to 1.6 %N are used depending on cane age and month of sampling (Table 2).

With the decline in use of variety NCo367, it became apparent that variety N12, now widely planted in the higher altitude areas, had a somewhat lower leaf P threshold value than most other varieties. Variety trial data showed that, on average, the leaf P value for N12 was about

Table 1. Leaf threshold values for some elements

Macro elements		Trace elements	
Nutrient Leaf TV (%)		Nutrient Leaf TV (ppm)	
N	1.70 (Mean)	Zn	12
P	0.19	Mn	15
K	1.05	Cu	3
Ca	0.15		
Mg	0.08		
S	0.12		

85% of the value for NCo376. A leaf P threshold value which was 0.03% P lower than the standard 0.19% P value was accepted for variety N12.

Leaf threshold values for K have been modified for two reasons. In the first case, for winter-cut irrigated cane, growing on base-saturated soils, low leaf-K values have been associated with high leaf Ca and/or Mg, low soil temperatures and moist conditions in the early part of the growing season (Donaldson et al., 1990). Consequently increasing K threshold values with month of sampling have been introduced (Table 3). In the second case, the leaf-K threshold value for variety N14 has been found to be 0.15% K lower than for other varieties.

Leaf analysis and moisture stress

Sugarcane in South Africa is largely grown under rainfed conditions. Water stress affects growth, sucrose accumulation and restricts the uptake of elements. When leaf samples were collected

Table 2. Leaf N threshold values

Area	Crop age (months)	Month of sampling	N (%)	
			Plant	Ratoon
Northern irrigated	3-5	Oct-Dec	1.9	1.8
		Jan-Feb	1.8	1.7
		Mar-Apr	1.7	1.6
Coastal lowlands	4-7	Nov-Dec	1.9	1.8
		Jan-Feb	1.8	1.7
		March	1.7	1.6
Midlands	4-9	Nov-Dec	1.9	1.8
		Jan-Feb	1.8	1.7
		March	1.7	1.6

NCo376

N12
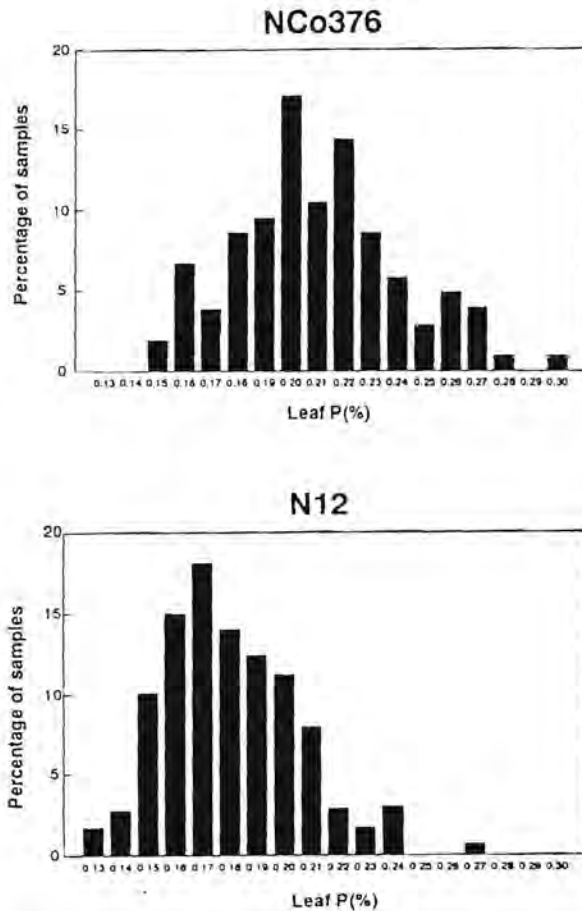
Fig. 1. Distribution of leaf P values based on samples from varieties N12 and NCo376

Table 3. Leaf K threshold values for winter cut cane irrigated cane (after Donaldson et al., 1990)

Age of crop (months)	Months of sampling	Leaf K (%)	
		All except N14	N14
3-5	Oct-Nov	0.85	0.70
	Dec-Jan	0.95	0.80
	Feb-Apr	1.05	0.90

1970 (Meyer et al., 1971), little use had been made of analytical data for examining trends in leaf data until the computerisation of FAS recommendations in 1980. The computer-based system resulted in a large data bank which is continually updated. The data (Table 5) show that there was a relatively high proportion of samples deficient in K (28%), somewhat fewer deficiencies in N (13%) and P (12%) and only infrequent deficiencies of Ca (4%), Mg (1%) and Zn (8%) for the whole industry (Meyer et al., 1989). On a regional basis, it was found that the highest incidences of N deficiency (19%) occurred in the coastal lowlands. Most P deficiencies (15%) occurred in the coastal hinterland and higher altitude areas. The majority of K deficiencies (41%) occurred in the irrigated, warm semi-arid region.

As the industry is divided up into 15 extension areas, it is useful to monitor nutrient trends in

during moisture stress, leaf nutrient values associated with adequately-fertilised cane were often below the threshold values. An example is shown in Table 4. Rainfall for the three-month period before sampling (December 1989 to February 1990) was only 190 mm compared with the long-term average of 365 mm. Data for the February sampling showed low to very low leaf N, P and K values. By comparison, leaf samples taken in April from the same crop, after good rains (160 mm) had fallen in March 1990, indicated substantial improvement in the nutrient status despite the fact that the cane was two months older.

Table 4. Leaf nutrient values of samples collected from commercial cane in February and April, 1990.

Field	Variety	Ratoon	Age (mths)	N (%)	P (%)	K (%)
Sampling date: 20/2/90						
48	NCo376	5	5	**1.48	***0.12	*0.90
49	Mixed	5	5	**1.44	***0.14	**0.83
50	NCo376	7	5	***1.30	***0.12	**0.88
66	Mixed	2	4	***1.32	***0.14	1.31
Sampling date: 24/4/90						
48	NCo376	5	7	1.71	0.18	1.46
49	Mixed	5	7	1.87	0.19	1.32
50	NCo376	7	6	1.61	0.19	1.43
66	Mixed	2	6	1.76	0.20	1.52

* Marginal
** Low
*** Very low

Nutrient trends

Apart from a micro-nutrient survey conducted in

these areas. Due to the large amounts of fertilisers applied each year, extension officers should be aware of changes in nutrient consumption and soil fertility in their areas. For instance, the most-southerly cane-growing area (Lower South Coast) in South Africa is generally confined to the coastal lowlands and coastal hinterland regions. According to the 1988 investigation, which included all leaf data from that area since 1980, about 14% of samples were deficient in N and 9% deficient in P (Table 6). These figures were close to those for the whole industry. All other nutrients appeared to be well-supplied and deficiencies were well below the industry averages. In comparison, the 1989/90 leaf data (Table 6) indicated large proportions of deficient leaf N and P values (48 and 43% respectively). These low values were probably due to moisture stress in a dry year. That the low leaf N and P values were drought-induced was subsequently supported by the 1990/91 data which indicated substantially improved values (Table 6).

Conclusions

Leaf analysis remains the most effective way of assessing the nutrient status of ratoon cane and checking on the adequacy of fertiliser recommendations. Threshold values for diagnostic purposes are continuously updated and modified as required. Although growers are urged not to leaf sample when cane is affected by

Table 5. Average nutrient content of leaf samples for the various natural regions (after Meyer et al., 1989)

Natural regions	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Zn (%)
Coastal lowland	1.84	0.21	1.21	0.27	0.22	18
Coastal hinterland	1.95	0.22	1.42	0.29	0.25	17
Midlands	1.95	0.20	1.29	0.26	0.24	18
Lowveld	2.03	0.25	1.32	0.34	0.27	19
Threshold value	1.60	0.17	1.05	0.15	0.10	13
% samples deficient	13	12	28	4	1	8

Table 6. Leaf nutrient assessment - Lower South Coast extension area

Leaf nutrient	Period	Ave	Percentage of total			
			Deficient	Marginal	Adequate	High
N (%)	1980/88	1.92	14	23	60	1
	1989/90	1.69	48	23	29	0
	1990/91	1.89	15	23	62	0
P (%)	1980/88	0.22	9	28	56	4
	1989/90	0.18	43	25	32	0
	1990/91	0.19	18	35	47	0
K (%)	1980/88	1.30	3	15	59	20
	1989/90	1.18	6	25	57	12
	1990/91	1.16	3	19	76	2

moisture stress, drought is not uncommon in South Africa. Consequently there is a need to study the effects of moisture stress on leaf nutrient values. The use of nutrient ratios and/or a computer model for interpreting nutrient uptake under various moisture regimes will be considered. The development of a data bank such as the NIRS, not only serves to identify trends of diminishing fertility, but will also aid in preventing over application of fertilisers.

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Leaf analysis—what does it offer
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LEAF ANALYSIS—WHAT DOES IT OFFER THE AUSTRALIAN SUGAR INDUSTRY?

By

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Abstract

Although leaf analysis is routinely used in many Australian and overseas agricultural industries for nutrient diagnostic and/or advisory purposes, it is seldom used for commercial purposes within the Australian sugar industry. This paper reviews the local and international experiences relating to foliar testing in sugarcane production, and reports on investigations aimed at improving the interpretative skills associated with leaf analysis. The need for increased local usage of leaf analysis is explained, particularly in light of important potential roles within the industry. These include improved diagnostic capabilities, monitoring of nutrient trends within the industry and providing a basis for checking on the adequacy of fertiliser recommendations. Leaf sampling requirements, prerequisites and procedures are explained to ensure effective leaf analysis. It is concluded that there is a need to take account of varietal differences, age of the crop at sampling, climatic conditions and soil properties when interpreting leaf analytical data. As moisture stress can affect leaf nutrient values, it is important that strategies exist either to preclude this effect or to identify its occurrence. Renewed usage of leaf analysis within the Australian industry will not only have important implications for nutritional research and extension, but will also ensure that growers are able to make more informed decisions regarding nutrient management on the farm.

Introduction

Leaf analysis was probably first established as a useful diagnostic tool by the early chemists who recognised that relationships existed between crop yield and the nutrient content of plant ash (Hall, 1905; Liebig, 1840; Mitscherlich, 1909). Following the work of Macy (1936), which established methods for interpreting these relationships, much effort has been devoted to providing information on the nutrient status of plants with a view to managing nutrition for optimum plant production (Smith and Loneragan, 1997). This has resulted in leaf analysis being used for a number of different applications, which include:

- Diagnosis of existing problems (nutrient deficiencies, toxicities and/or nutrient imbalances);

- Prediction of nutrient problems in current (likely between sampling and harvest) or succeeding crops;

- Monitoring the crop nutrient status (effectiveness of fertiliser practice, crop removal, overall nutrient status of regions, districts, soil types, etc) (Smith, 1986; Smith and Loneragan, 1997).

Leaf analysis has, over the years, been more extensively used and/or investigated in some sugar producing countries than others. Although much effort has been directed towards establishing and/or confirming critical leaf values (Smith and Loneragan, 1997), attempts to base fertiliser recommendations directly and/or solely on leaf analysis values (Farquhar, 1965; Malavolta, 1994 citing Poidevin, 1964, and Poidevin and Robinson, 1964; Samuels, 1959) have

largely been unsuccessful. However, leaf analysis continues to be widely used for diagnostic purposes, as a means to check on the adequacy of fertiliser recommendations (Malavolta, 1994; Schroeder *et al.*, 1992), and to identify nutrient trends (Meyer *et al.*, 1989). Nonetheless, the current inability to interpret leaf nutrient values associated with samples collected under conditions of moisture and other stress, often results in unfair criticism of leaf testing as a useful tool for diagnostic and advisory purposes. In particular, it has been noted that low leaf N values could be a result of moisture stress rather than a nutrient deficiency *per se* (Gosnell and Long, 1971).

This paper reviews the Australian and international experiences relating to foliar testing in sugarcane production, and reports on investigations aimed at improving the interpretative skills associated with leaf analysis.

Procedure

Data and information relating to the use of leaf analysis for diagnostic, advisory and nutrient trend purposes in sugarcane production were obtained from various sources. These included results from field and pot trials conducted in the Australian and South African sugar industries, and from records held by the Bureau of Sugar Experiment Stations (BSES), the South African Sugar Association Experiment Station (SASEX) fertiliser advisory service (FAS), CSR Ltd, and other published sources.

In order to improve the interpretive skills associated with leaf analysis, a replicated trial using large pots was conducted to determine the effect of moisture stress on the nutrient content of sugarcane. Sugarcane variety NCo376 was grown in an adequately fertilised sandy loam in 80 litre bins under an automatic rain-shelter for about four months. Moisture stress was applied by withholding water once the cane reached three months of age. Plant growth was measured on an hourly basis using electronic growth transducers linked to a data logger. The young plants (three per bin) were serially harvested at weekly intervals. Total above ground yields were determined for each bin prior to partitioning of the plants into samples corresponding to the spindle and different leaf numbers. The separate components were dried and weighed prior to chemical analysis in the laboratory.

Results and discussion

Critical values

A range of leaf nutrient values (marginal, critical, and/or those considered adequate for cane production) has been established for

diagnostic purposes in various sugarcane producing countries (Reuter and Robinson, 1997). For the sake of brevity, only the critical third leaf nutrients values from four world sugar industries are presented in Table 1. These cover the full range of macro and secondary nutrients and some micronutrients or trace elements. Although the nutrient values are not always totally consistent with each other, they most often relate to the middle 300 mm section of the lamina associated with the top visible dewlap (TVD) of the sugarcane plant, which usually corresponds to the third leaf below the spindle (Clements and Ghotb, 1968). Some differences exist in terms of recommended sampling growth stages. The critical values that have been established in the Australian and Mauritian sugar industries refer to samples that need to be collected when the cane is 3–4 and 5 months old respectively. In South Africa and Guyana, the period for sampling has been extended by establishing modified critical values based on crop age. This allows recognition of the fact that N values, in particular, decline with age and time of season. Recognition of varietal differences has also resulted in some 'fine-tuning' of critical values in the South African industry.

Leaf analysis in combination with soil testing is a very useful method for determining balanced nutritional programs for sugarcane. While soil analysis procedures estimate the amount of plant available nutrients, leaf analysis reflects the actual plant nutrient uptake until the sampling date (Smith and Loneragan, 1997). In relation to some micro-nutrients in particular, leaf analysis offers a strong alternative to soil testing in determining the nutrient status of a crop. For example, in the Australian sugar industry, it has been found that the third leaf critical value for zinc is a more reliable index for determining deficiencies than any of the three soil test procedures that were tested (Reghenzani, 1990).

Interpretation of leaf analysis data

As a number of factors influence leaf nutrient content, it is important that guidelines are in place to ensure uniformity in sampling procedure (Appendix 1), sampling season and age of cane. As such, a number of sampling prerequisites exist to enable meaningful interpretation of leaf analysis data. It is commonly accepted that sampling should occur during active growth. Although Evans (1965) suggested that stalk elongation should be greater or equal to 20 mm/day, active growth will normally occur during the months of November to April in Queensland and

Table 1—Critical third leaf nutrient values for sugarcane.

Critical third (or top visible dewlap) leaf values (%) macro and secondary nutrients; (mg/kg)Cu, Zn, Mn, B, Mo.

	Australia[a]	South Africa[b]					Mauritius[c]	Guyana[d]		
N	1.8 (3 mnths)	Area	Crop age (mnths)	Month of sampling	P[e]	R[f]	1.95 (5 mnths)	Crop age (mnths)	P[e]	R[f]
		North	3 – 5	Oct–Dec	1.9	1.8		2		2.4 – 2.5
				Jan–Feb	1.8	1.7		3	2.4 – 2.5	2.1
				Mar–Apr	1.7	1.6		4.5		1.9
								5	2.1	
								6	1.9	
		Coastal	4 – 7	Nov–Dec	1.9	1.8				
				Jan–Feb	1.8	1.7				
				Mar	1.7	1.6				
		Midlands	4 – 9	Nov–Dec	1.9	1.8				
				Jan–Feb	1.8	1.7				
				Mar	1.7	1.6				
P	0.19 (3–4 mnths)	Variety	Areas & crop ages as shown for N				0.21 (5 mnths, ratoon)	Crop age (mnths)	P	R
		N12	0.16					2		0.21
		Other N & NCo varieties	0.19					3	0.21	
								4.5		0.18
								6	0.18	
K	1.1 (3–4 mnths)	Variety	Harvest season	Month of sampling	Areas & crop ages as shown for N		1.25 (5 mnths, ratoon)	Crop age (mnths)	P	R
		N14	Winter (irrigated crop)	Oct–Nov	0.70					
				Dec–Jan	0.80					
				Feb–Apr	0.90			3–6 2–4.5	1.25	1.25
			Other	Oct–Apr	0.90					
		All other N & NCo varieties	Winter (irrigated crop)	Oct–Nov	0.85					
				Dec–Jan	0.95					
				Feb–Apr	1.05					
			Other		1.05					
Ca	0.2 (3–4 mnths)	0.15 [g]					0.20 (5 mnths)	0.13–0.15 (3 mnths)		
Mg	0.08 (3–4 mnths)	0.08 [g]					0.10 (5 mnths)	0.08 [h]		
S	0.13 (3mnths) S low if N:S>17	0.12 [g]					—	—		
Cu	2 (3–4 mnths)	3 [g]					5 (5 mnths)	3.5 [h]		
Zn	10 (3–4 mnths)	15 [g]					20 (5 mnths)	15 [h]		
Mn	15 (3–4 mnths)	15 [g]					15 (5 mnths)	15 [h]		
B	1 (3–4 mnths)	1 [g]					1 (5 mnths)	1 [h]		
Mo	0.08 (3–4 mnths)	—					0.1 (5 mnths)	0.08 [h]		
Si	0.7 (3–4 mnths)	—					0.7 (5 mnths)	—		

[a] Calcino,1994; [b] Schroeder *et al.*,1992 or Meyer *et al.*,1971; [c] Bassereau, 1988 or Halais, 1962; [d] Evans, 1965.
[e] Plant or replant cane; [f] Ratoon cane; [g] Areas & crop ages as shown for N(S. Afr.); [h] During 'rapid' growth.

December to March in New South Wales, provided that enough well distributed rain fell in the month prior to sampling. Apart from the seasonal consideration, sampling should also take place when the cane is at a satisfactory age. Based on experiences elsewhere (Table 1), it is suggested that sampling ages of 3–5 and 4–7 months be used in Queensland and New South Wales, respectively. In addition, when leaf sampling sugarcane, a period of at least six weeks should have passed since any fertiliser application.

Variety

Variety is another factor that appears to affect nutrient uptake and consequently leaf nutrient values. It has been reported from South Africa that the P and K critical values for sugarcane varieties N12 and N14 respectively (Table 1) are somewhat lower than those associated with the other N and NCo varieties (Schroeder *et al.*, 1993). The CSR leaf testing system that was operative in the Australian sugar industry during the 1960s and 1970s also recognised considerable differences in critical values (referred to as optimum nutrient indices) associated with Queensland varieties for N and K expressed as % dry matter, and P as the P:N ratio, using top visible dewlap leaves (Farquhar, 1965). The optimum nutrient index for Q57 was reported to be 95% of that of Pindar for N, 110% for P and 105% for K. A substantial range in leaf N values have also been reported for varieties grown in Mauritius (Bassereau, 1988).

Diagnosis and Recommendation Integrated System (DRIS) indices

In the development of DRIS, Beaufils (1973), questioned the use of single-valued critical values as he considered the optimum concentration of a particular nutrient to be dependent on the concentrations of other nutrients (Bassereau, 1988). Evaluations of the use of DRIS for sugarcane have indicated that the calculated indices, based on leaf nutrient ratios, are probably more efficient in detecting nutrient imbalances and deficiencies than conventional critical values in young cane (Meyer, 1981; Ng Kee Kwong and Deville, 1983). Despite this, the system is not widely used, as the nutrient index sensitivity appears to diminish with crop age, and there is a general absence of information relating to rates of supplementary nutrient applications based on the DRIS indices.

Moisture stress

It is widely accepted that moisture stress affects leaf nutrient values and restricts interpretation of data (Evans, 1965; Gosnell and Long, 1971; Schroeder *et al.*, 1992). As a result, sampling guidelines emphasise the need to collect samples only when the crop has received enough well distributed rainfall and/or irrigation to preclude any moisture stress. In particular it has been noted, in South Africa, that the analyses of third leaf samples taken from adequately fertilised cane showed low N, P and K values when sampling was conducted during periods of moisture stress (Table 2). However, these values improved substantially when the same blocks were sampled two months later after a number of good rainfall events.

Results from the moisture stress bin experiment showed that 'typical' daily growth patterns occurred in unstressed treatments with a maximum plant extension rate of 2.5 mm/hr being measured in the late afternoon, with daily growth exceeding 25 mm/day. Growth was severely affected during moisture stress, but increased

Table 2—Leaf nutrient values of samples collected from commercial cane in February and April, 1990
(Schroeder *et al.*, 1993)

Field	Variety	Ratoon	Age (mnths)	N (%)	P (%)	K (%)
Sampling date: 20/2/90 (moisture stressed)						
48	NCo376	5	5	** 1.48	***0.12	* 0.90
49	Mixed	5	5	** 1.44	***0.14	** 0.83
50	NCo376	7	5	***1.30	***0.12	** 0.83
66	Mixed	2	4	***1.32	***0.14	1.31
Sampling date: 24/4/90 (stress relieved)						
48	NCo376	5	7	1.71	0.18	1.46
49	Mixed	5	7	1.87	0.19	1.32
50	NCo376	7	6	1.61	0.19	1.43
66	Mixed	2	6	1.76	0.20	1.52
* Marginal, ** Low, *** Very low						

substantially once moisture stress was relieved. The same trend occurred in the leaf N values (Figure 1), and was also reflected in the measured leaf moisture potential and photosynthetic rate values (not presented here).

Although, in this instance, moisture stress has been singled out as an important factor that influences leaf nutrient values, cognisance should always be taken of other factors, such as pests, disease, etc., which may contribute towards non-representative leaf nutrient values. Cane affected by such conditions should always be avoided during sampling.

Leaf analysis for advisory purposes

Apart from the diagnostic role associated with leaf analysis, a number of attempts have been made to use foliar analysis data, either solely or partially, for calculating crop nutrient requirements. These include the so-called 'Clements crop log system' as devised and developed in

Hawaii, the CSR leaf analysis service and the SASEX concept of 'whole cycle fertiliser advice'.

Crop logging

The sugarcane crop log system (Clements, 1959), that was established in the 1940s, is aimed at providing a means of detecting and correcting any nutrient (and/or water) deficiencies with minimum delay (Whalley and Clarkson, 1950). With this system, samples (leaves 3–6 for N analysis and their sheaths for fresh weight, moisture, total sugars, P, K, Ca and Mg) are collected every 35 days. The resulting nutrient indices (N, Ca and Mg as a percentage of dry matter, and P and K as percentages of sugar-free dry matter) are recorded and charted throughout the life of the crop (Bassereau, 1988) and compared with desirable index values. Fertiliser additions would be made to alleviate any deficiencies that were identified as the crop progressed. Despite wide use in Hawaii in earlier years, crop logging has
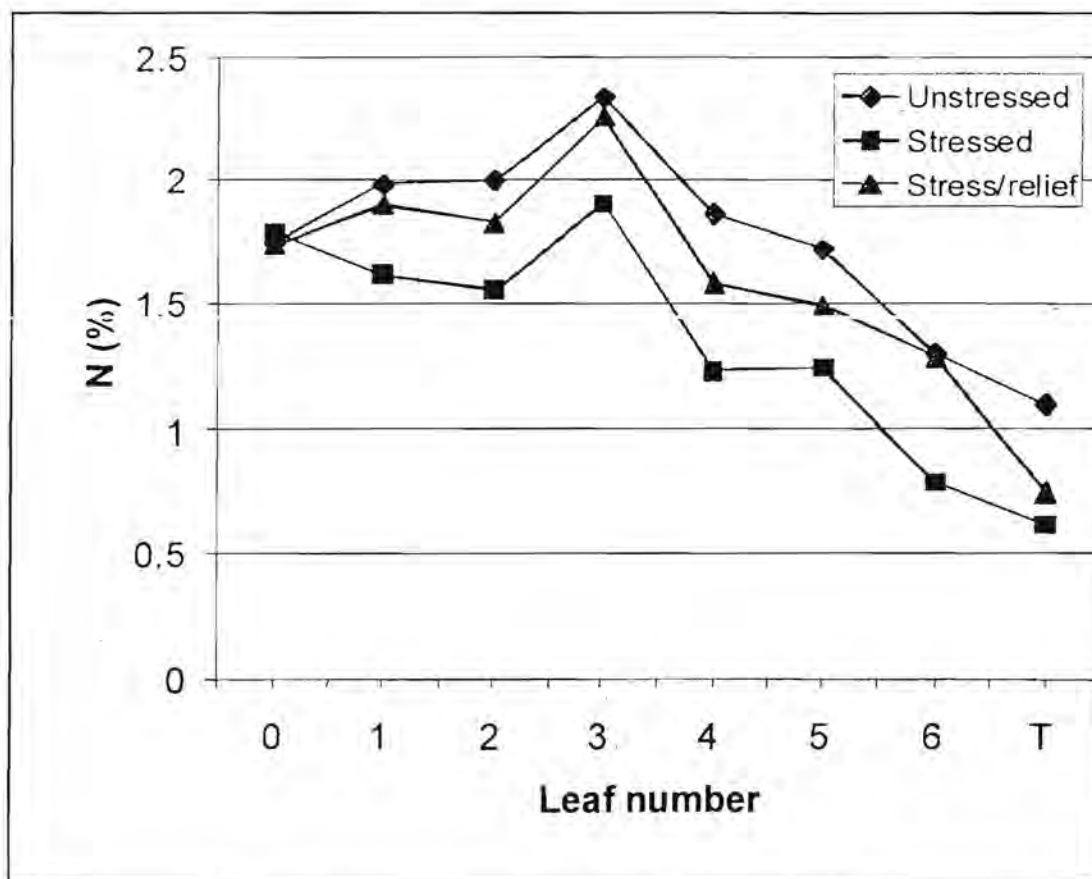

Fig. 1—Leaf N (%) values of the partitioned plants associated with no moisture stress, moisture stress and stress/relief conditions. (T = trash)

not been widely accepted, probably as a result of the very intense sampling program associated with the system.

CSR

In Australia, the CSR leaf testing service provided fertiliser recommendations for growers supplying cane to their mills, by using optimum leaf nutrient indices and a number of nutrient action levels (range of values above and below the optimum nutrient indices). These were updated on an annual basis from the results of NPK factorial trials in each mill area. Analysis data of leaf samples from individual blocks were compared to the appropriate action levels (based on variety) to determine appropriate adjustments to previous fertiliser application rates. For instance, the 1973 N advice for the Herbert River district (Table 3) was based on the action levels that had been compiled from the results of the 1972 trials. A third leaf analysis value of 2.15% for a particular block of cane would have resulted in no change to the N fertiliser program (as used for the previous crop) if the variety were Triton. However for variety Q68 and Pindar, the recommendation would have been respectively 52 kg/ha less and 52 kg/ha more than the previous application rates.

This service was withdrawn during the mid-1970s due to an apparent lack of support by the grower community and as a result of resources being required elsewhere.

SASEX whole cycle fertiliser advice

The primary objective of the SASEX fertiliser advisory service is to provide growers with fertiliser recommendations for a cycle of plant (or replant) crop and four successive ratoons. Such 'whole cycle' fertiliser advice is based on the analysis of soil samples collected prior to planting. Leaf analysis, particularly taken during the ratoon crops, is used to check on the

adequacy of the original recommendations (Schroeder *et al.*, 1993). Although the system is essentially geared for confirmation or correction of the fertiliser program for the subsequent crop, guidelines for additional fertiliser applications to the current crop are available for N, P and K (Table 4). The proviso exists that the cane should be young enough (3–5 months of age) to enable effective crop utilisation of any supplementary nutrient dressings.

Conclusions

The evidence presented in this paper suggests that leaf analysis is a useful diagnostic and advisory 'tool' that has not yet been fully utilised in the Australian sugar industry. Attempts by CSR, in the past, to provide fertiliser recommendations based on leaf analysis apparently failed because it was used in isolation from other diagnostic 'tools' such as soil testing. Apart from the recognition of varietal differences, it appears that not enough consideration was given to the other factors that influence leaf nutrient values such as time of sampling, crop age, moisture stress, etc.

It is now widely accepted that the most reliable assessment of the nutrient requirement for sustainable production in a particular block of sugarcane will undoubtedly be obtained from the use of a combination of the various 'tools' available to the grower and/or his adviser. Apart from its popular use for diagnosing nutrient deficiencies, leaf analysis has been successfully used in certain other sugar industries to amended fertiliser programs for the following season. However, if the cane is sampled early enough, it may also be used to determine supplementary fertiliser applications for the existing crop. Leaf analysis has also been found to be a useful means of conducting nutrient surveys at regional and industry levels to identify nutrient trends and/or potential imbalances. At the farm scale, leaf analysis offers a very useful way of ensuring

Table 3—CSR nitrogen action levels—Herbert River, 1972 (CSR unpublished data—Report on technical field work 1972–1973).

Sugarcane variety			Recommendation
Pindar	Triton	Q68	
Leaf N (%)			
> 2.49	> 2.30	> 2.29	Previous N rate − 103 kg/ha
2.35 − 2.49	2.16 − 2.30	2.15 − 2.29	Previous N rate − 52 kg/ha
2.20 − 2.34	2.01 − 2.15	2.00 − 2.14	Previous N rate + 0
2.05 − 2.19	1.86 − 2.00	1.85 − 1.99	Previous N rate + 52 kg/ha
1.90 − 2.04	1.71 − 1.85	1.70 − 1.84	Previous N rate + 103 kg/ha
< 1.90	< 1.71	< 1.70	Investigate

Table 4—Recommendations for additional N, P and K application based on leaf analysis data in the South African sugar industry (Anon., 1996).

	Leaf nutrient value (%)			
	Nitrogen			
Leaf N (%)	< CV–0.4	CV–0.2 to CV–0.4	CV to CV–0.2	> CV
N required (kg/ha)	100	75	50	0
	Phosphorus			
Leaf P (%)	< CV–0.03	CV–0.03 to CV–0.02	CV–0.01 to CV	> CV
P required (kg/ha) Weakly P sorbing soils Strongly P sorbing soils	30 80	20 50	20 30	0 0
	Potassium			
Leaf K (%)	<CV–0.2	CV–0.2 to CV–0.1	CV–0.1 to CV	>CV
K required (kg/ha)	150	100	50	0

CV = Critical value as indicated in Table 1.
Leaf nutrient value = CV minus a specified value.

balanced nutrition and the prevention of trace element deficiencies in particular.

The fact that general leaf critical values and guidelines for sampling already exist in the Australian sugar industry could enable leaf analysis to be easily incorporated into the local diagnostic and advisory system. Although it is at present recommended that samples be collected within the current guidelines to ensure meaningful interpretation of the analytical data, due consideration should be given to factors such as age of crop at sampling, climatic conditions and soil properties. Current glasshouse investigations could provide valuable data and information for improving the interpretive skills required to assess varietal differences and the effects of moisture stress on nutrient uptake. The use of leaf nutrient ratios could be useful in this regard, particularly in relation to drought-affected cane. The development of a chemical/biochemical indicator of moisture stress and modified sampling strategies, currently under consideration, could have important implications for identifying samples affected by such conditions at the time of collection. Similar investigations relating to waterlogged conditions following above average rainfall could also be rewarding.

Renewed usage of leaf analysis within the Australian sugar industry will not only be important for nutritional research and extension, but will also ensure that growers are able to make more informed decisions regarding nutrient management on the farm and therefore maximise their own potential economic returns.

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Appendix 1

Recommended leaf sampling procedure for the Australian sugar industry

- Select leaves from stalks of average height.
- Sample the third leaf from the top of the stalk. The first leaf is the one that is more than half unrolled.
- Collect about 40 such leaves from the block of sugarcane, preferably using a diagonal sampling pattern.
- Fold the leaves in half (tip to base) and cut a 100 mm length from the folded leaf (giving a total of 200 mm).
- Strip out and discard the midrib from the 200 mm section.
- Place the sample in a clean paper bag and keep in a cool environment (polystyrene cooler) until the sample can be dried in an oven, or in a well-ventilated area.

- Once the sample is dry, send it to the laboratory for analysis.
- Supply the following information:
  - Name, address and mill area;
  - Block number;
  - Variety;
  - Crop (plant or ratoon number);
  - Sampling date and age of the cane at harvest;
  - Details of fertiliser applied (type and rate).
- Always ensure:
  - Requirements for sampling in terms of season, age, time lapse from fertiliser application, etc. are met;
  - Hands are clean when sampling;
  - Cane is not affected by some other factor, e.g., disease, insect damage, abnormal climatic factor, etc.;
  - Samples are not contaminated by fertilisers and/or other chemicals.