CHALLENGES AND OPPORTUNITIES IN LEAF NUTRIENT DATA INTERPRETATION

MILES N

South African Sugarcane Research Institute, P/Bag X02, Mount Edgecombe. 4300, South Africa
neil.miles@sugar.org.za

Abstract

Leaf analysis is an important diagnostic tool in the management of the nutrition of sugarcane. The Critical Nutrient Concentration (CNC) and Diagnosis and Recommendation Integrated System (DRIS) are the most commonly used methods of interpreting leaf nutrient data. Principles upon which these interpretive approaches are based are briefly considered. Attention is drawn to the impacts of variety, crop age and moisture stress on leaf nutrient concentrations, and the potential for incorrect interpretations where these factors are not taken into account. Data from field trials are presented to demonstrate potential pitfalls in the interpretation of leaf analyses where more than one nutrient is limiting. Restricted growth arising from a severe deficiency of one particular nutrient may result in deficiencies of other nutrients being masked in the leaf concentration data.

Interactions between nutrients in terms of their uptake by plants may markedly impact on the diagnostic process. In the case of sugarcane, N x K and N x S interactions are of particular significance, with seasonal variations in K uptake adding to the difficulties associated with the interpretation of leaf K data. The pivotal role of N in yield optimisation and its importance in the leaf-analysis diagnostic process imply an urgent need for a more rigorous approach to establishing N critical levels in sugarcane. In particular, there is a requirement to take into account decreases in the critical N% with increasing biomass (crop age), as has been done successfully for a range of other crops.

Keywords: leaf analysis, DRIS, critical nutrient concentrations, nutrient ratios, multiple deficiencies, nutrient interactions

Introduction

Analysis of leaf samples from crop plants is usually undertaken with the objectives of diagnosing nutrient deficiencies and imbalances, and evaluating the effectiveness of the current nutrient management programme. Leaf analysis is widely used as a nutrient management tool in sugarcane production (Schroeder _et al_., 1993), and in the South African Sugar Industry, many thousands of leaf samples are processed annually (Meyer _et al_., 1998). If carried out timeously, leaf analysis permits the application of supplementary fertilisers before yields are adversely affected by deficiencies or imbalances.

The numerous complications inherent in the interpretation of plant analytical data have long been recognised (Reuter and Robinson, 1997). Nutrient concentrations in plant tissues are not only a reflection of soil nutrient supply levels and plant genetic characteristics, but are influenced by numerous other factors, including the plant growth stage (age), temperature and moisture supply, and factors which impact on plant growth and vigour, such as diseases and insect damage (Mengel and Kirkby, 2001). Furthermore, interactions between nutrients have been found to strongly influence their final concentrations in plant tissues (Robson and Pitman, 1983; Wilkinson *et al*., 2000).

Over the years, methods of interpreting plant nutrient data have received much attention. Currently, the Critical Nutrient Concentration (CNC) and Diagnosis and Recommendation Integrated System (DRIS) are widely used methods in the routine interpretation of leaf nutrient data (Meyer, 1981; Reuter and Robinson, 1997).

In this paper, brief consideration is afforded the principles upon which the CNC and DRIS approaches are based. Thereafter, various factors affecting plant nutrient concentrations are discussed, with data from field trials being used to illustrate the nature of these effects as well as their potential impacts on the interpretive process. Finally, recommendations are proposed for the more reliable interpretation of sugarcane leaf data.

Methods of interpreting leaf data

Critical Nutrient Concentration (CNC)

The CNC approach is the most widely accepted method for interpreting plant nutrient concentration data (Reuter and Robinson, 1997), and is based on the relationship between nutrient concentration and yield (Figure 1). The transition zone between the deficient and adequate zones indicates the critical level for the nutrient in question. The critical level is therefore the concentration below which supplies of the nutrient begin to limit growth. Interpretation of plant analyses based on critical nutrient levels simply involves comparing the sample nutrient concentrations with established critical values. Where the sample concentration is less than the critical value for the nutrient in question, a deficiency is assumed to be indicated.

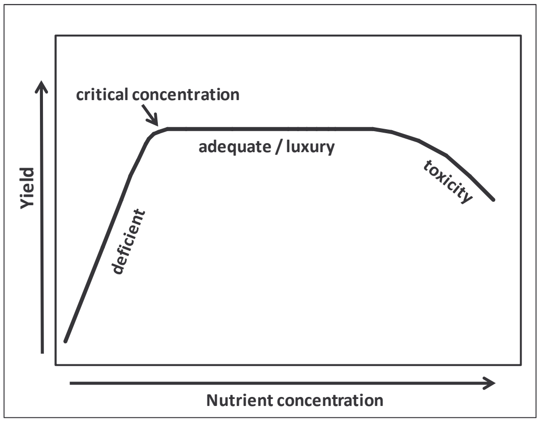

Figure 1. Typical relationship between nutrient concentration and yield, showing the 'critical' concentration.

Diagnosis and Recommendation Integrated System (DRIS)

The DRIS technique is based on nutrient ratios, and purportedly provides a means of simultaneously identifying imbalances, deficiencies and excesses in nutrient levels in crops, and ranking them in order of importance (Walworth and Sumner, 1987). This methodology has been applied to a wide range of crops, including sugarcane (Meyer, 1981; Elwali and Gascho, 1984).

DRIS involves ordering nutrient ratios into expressions called DRIS indices. Essentially, a DRIS index is a mean of the deviations of the ratios containing a given nutrient from their respective optimum or norm values. The norm values are typically derived using mean nutrient concentrations of the top-yielding 10 to 25% of cases in a population for which yield and plant analysis are available (Walworth and Sumner, 1987). In general, nutrient ratios have been found to be relatively stable with crop age, and the ability of DRIS to identify nutrient problems irrespective of crop age is viewed as a particular advantage of this approach (Sumner, 1977).

Factors affecting leaf nutrient concentrations

Temperature and moisture

Uptake of certain nutrients, in particular K, is markedly temperature dependent (Barber, 1994). This is due to the effects of temperature on nutrient uptake by roots, on nutrient supply to the roots, and possibly also on root growth and activity. Temperature effects on nutrient availability in the soil relate largely to the effect of temperature on the rate of diffusive transport of nutrients to the roots. In studies on maize, Ching and Barber (1979) found that K uptake by roots at 15°C was only about half that at 29°C. Furthermore, in the same study, root growth was eight times greater at 29°C than at 15°C. Marked increases in sugarcane leaf K levels from September to January in trials in Swaziland were attributed by Meyer and Wood (1985) to increasing soil temperatures.

The crucial role of moisture supply on nutrient uptake in sugarcane was highlighted in the investigations of Schroeder (2000), where reductions in leaf N concentrations, in particular, were found to accompany moisture stress. In drawing attention to the major impact of soil moisture content on diffusive transport of K to the roots, Askegaard *et al*. (2004) point out that crop response to K fertilisers is often greater in dry than in wet seasons because of the limited bio-availability of K where soil water is limited.

Plant age

Nutrient concentrations vary with the age of the tissue or organ, with this being essentially a reflection of variations in water content (Mengel and Kirkby, 2001). Young tissues have relatively high water contents and are rich in nutrients, particularly N, P and K, which are dissolved in the water. Concentrations of these nutrients decrease with increasing age of the tissue. An example of the effect of plant age on leaf N, P and K concentrations is presented in Figure 2. Decreases in nutrient concentrations as the plant ages relate mostly to N, P and K. Concentrations of less mobile nutrients, such as Ca, Mg, Mn and B, are less affected by plant age, and may even increase in concentration with ageing (Mengel and Kirkby, 2001).

In the use of the CNC approach, in order to minimise the complications of ageing effects on the interpretation, a specific physiological age is stipulated for the taking of leaf samples for most crops (Reuter and Robinson, 1997). In the case of the DRIS approach, as noted earlier, an oft-cited advantage is that age effects on the interpretive process are minimised since ratios rather than actual concentrations are used in the diagnostic process. However, the work of Meyer (1981) suggests that this claim is not valid in the case of sugarcane. In that study DRIS was found to provide a reliable diagnosis only when the crop was less than five months old.

A method of more accurately accommodating the effects of age on the critical N concentration is offered by the modelling approach of Greenwood *et al*. (1990) and Lemaire

(1997). These workers found a remarkable similarity in the way the critical N concentration of a wide range of crops declines with increasing plant mass. This decline was described by the following simple equation:

$$N\% = a(W)^{-b}$$

where W is the weight of above-ground biomass, and a and b are species-dependent coefficients. This model has proved valid for widely differing crops, including sorghum, wheat, cabbage, potatoes and a range of pasture species. It also appears to successfully describe the decrease in critical K concentration with time in certain species (Greenwood and Stone, 1998). In terms of the potential of this approach for use with sugarcane, the problem of the measurement of plant mass at the time of leaf sampling could potentially be addressed through the development of relationships between plant height and standing biomass.

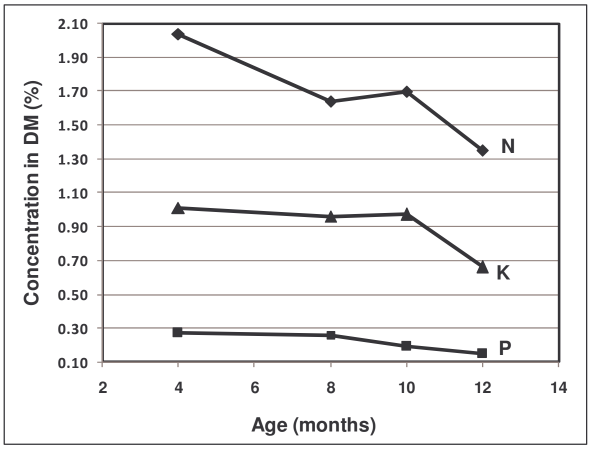

Figure 2. Variations in sugarcane leaf N, P and K concentrations with increasing plant age (Meyer, 1975).

Seasonal effects

Of significance, in terms of the interpretation of sugarcane leaf data, is widespread evidence of marked within-season variations in nutrient concentrations which are not consistent with the typical dilution effect associated with increasing age, as illustrated in Figure 2. This relates in particular to leaf K concentrations. Results from numerous field trials under both irrigated and rainfed conditions have shown that leaf K concentrations frequently increase from relatively low values in late winter/early summer to a peak in the January to March period (Meyer and Wood, 1985; Donaldson *et al*., 1990). Such increases in K are generally accompanied by significant decreases in leaf Ca and Mg concentrations. Typical examples of these variations in cation concentrations are presented in Table 1 and Figure 3.

Increases in K concentration from spring to late summer are thought to be due largely to soil temperature effects on K uptake, as discussed earlier. Possible reasons for the decreases in Ca and Mg concentrations will be considered later in this paper.

Large variations in leaf nutrient concentrations, not consistent with the typical age-dilution effect, imply serious difficulties in the diagnostic process. Data presented in Figure 3 were drawn from a K trial in which there was no response to this nutrient; however, leaf K levels in November and December were marginal in terms of published critical levels, which generally lie in the range 0.90 to 1.11 (Reuter and Robinson, 1997). In an effort to address this problem, Donaldson *et al*. (1990) proposed a 'seasonal correction factor' for leaf K norms for winter harvested irrigated cane in Swaziland and Mpumalanga. This phenomenon is, however, not restricted to the Lowveld, but occurs throughout the industry (see Table 1), and its accommodation in the interpretive process presents a formidable challenge. In this regard, associated wide variations in the N:K ratio (Table 1 and Figure 3) raise particular concerns in terms of the use of a ratio-based interpretive approach such as DRIS.

Table 1. Variations from December to April in sugarcane third leaf N and K concentrations and N:K ratio in a trial at Umzinto on the South Coast (age of cane at sampling (months) is indicated in brackets; data drawn from South African Sugar Industry Agronomists Association report FT10NK/80/R6).

Nutrient	**Dec** (2.5 m)	**Jan** (3.4 m)	**Feb** (4.5 m)	**Mar** (5.5 m)	**Apr** (6.5 m)
N%	2.61	2.42	2.29	2.20	1.92
K%	1.11	1.09	1.08	1.13	1.35
N:K ratio	2.35	2.22	2.12	1.95	1.42

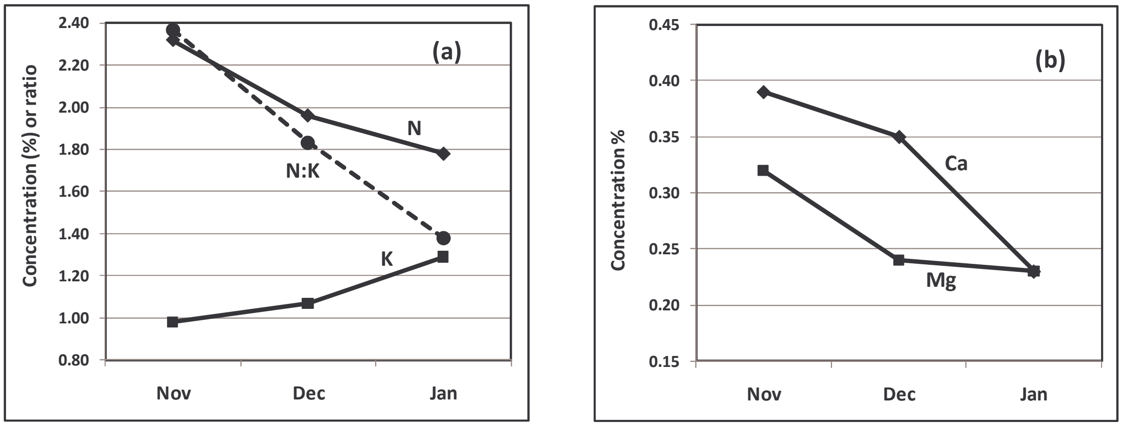

Figure 3: Variations from November to January in sugarcane third leaf nutrient concentrations for a trial conducted in Swaziland. (a) N and K and the N:K ratio, and (b) Ca and Mg. (Data drawn from Swaziland Sugar Association Extension Services Reports, 1996/97; trial code K23/94/Sw/UboK.)

Nutrient interactions

Interactions between nutrients may induce deficiencies, toxicities, modified growth responses and/or modified nutrient composition, and may be specific or non-specific in their mode of action (Robson and Pitman, 1983; Wilkinson *et al*., 2000).

Non-specific interactions are theoretically possible for any nutrient combination (Wilkinson *et al*., 2000), and assume particular importance when two or more nutrients are near the deficiency range. When the supply of one nutrient is increased, dilution accompanying increased growth may induce a deficiency of another nutrient (Marschner, 1995). A typical example of a non-specific interaction is provided by yield and nutrient composition data from a ryegrass field trial (Table 2). The expected ryegrass yield on the site was 2.5 to 3.0 t/ha. The control yield (no P or K applied) was well below the expected yield and a comparison of the leaf composition data of the control with the listed critical values indicated a P deficiency, with other nutrients (including K) being in adequate supply. The substantial yield increase with the addition of P was confirmation of a deficiency of this nutrient. The yield was still below the target level, however, and comparison of the leaf data for the +P treatment with the critical values revealed that the site was also K deficient. Addition of K corrected this, with the yield of the +P+K treatment being 2.9 t/ha. Clearly, therefore, in the leaf data of the unfertilised (control) treatment, an inadequate supply of K was masked by a more acute P deficiency. Upon addition of P, the K deficiency became apparent due to a dilution effect in the resultant higher biomass. Concentration/dilution effects of this nature occur where more than one nutrient is in short supply, and are responsible for what is often termed 'masked deficiencies'. Diagnostic systems such as CNC and DRIS clearly do not have the capability of detecting masked deficiencies, and this therefore poses a limitation in the use of plant analysis where multiple nutrient deficiencies limit yields.

Table 2. Ryegrass yield (dry matter), leaf analysis and treatments applied in a factorial field trial in the KwaZulu-Natal Highland Sourveld (Miles, unpublished data).

Yield (t/ha)	**Concentration (% in dry matter)**					**Treatment**
	N	**P**	**K**	**Ca**	**Mg**	
0.8	5.20	0.19	3.84	0.61	0.29	Control
1.7	4.50	0.28	2.32	0.78	0.35	+P
2.9	4.70	0.31	4.08	0.73	0.28	+P, +K
Critical concentration	*3.50*	*0.24*	*3.00*	*0.25*	*0.10*	

Specific nutrient interactions occur in the plant when (1) there is competition between nutrient ions which have similar physicochemical properties (valence and diameter); and (2) nutrient ions with similar chemical properties compete for adsorption (on soil colloids or cell walls), or absorption (influx and/or efflux) sites (Wilkinson *et al*., 2000).

1. Interactions involving nitrogen

Increasing N supply promotes growth, and thereby increases the demand for other nutrients. This demand can result in increased or decreased concentrations of other nutrients, depending on their supplies in the root zone (dilution-accumulation effects). In addition, specific interactions between N and several other nutrients influence plant chemical composition. Gosnell and Long (1971) reported that N deficiency caused a marked reduction in uptake of P, K, Ca, Mg, Mn, Cu and Zn. In the ensuing discussion, N interactions with P, K and S are afforded consideration in view of their particular agronomic importance.

Nitrogen x phosphorus interactions

Interactions between N and P in terms of yields are common (Marschner, 1995), and are primarily due to N-induced increases in P absorption by the plant (Sumner and Farina, 1986).

The magnitude of such increases in plant P uptake is often large. Mechanisms include (i) N-induced increased root growth, (ii) enhanced root ability to absorb and translocate P, and (iii) increases in P solubility as a result of decreasing soil pH which accompanies NH_4^+ absorption (Wilkinson *et al*., 2000). Of concern, in the context of this paper, is evidence from field trials that under conditions of N deficiency, sugarcane leaf P concentrations may be below critical levels, yet adequate where N supply is corrected.

Nitrogen x potassium interactions

In most grass plants, N and K are the macronutrients required in the greatest quantities. A high-yielding sugarcane crop requires large amounts of these nutrients, and interactions of economic significance often accompany the correction of imbalances of N and K in sugarcane production (Miles, 2009).

In terms of the interpretation of sugarcane leaf data, N x K interactions are of particular significance. The effect of increasing N supply on K concentrations in the plant is related to the extent of K bioavailability in the root zone (Wilkinson *et al*., 2000). Where soil K levels are marginal or limiting, an increase in N supply typically results in decreases in K concentrations in the plant due to dilution effects (non-specific interaction). Under conditions of adequate K supply, however, increasing N supply increases K uptake (Figure 4). Where N deficiency is severe, there is often poor uptake of K and a K deficiency may be indicated despite the bioavailability of K being non-limiting. The latter effect is clearly illustrated by leaf data from a trial in the Umzinto area (Figure 5). Increasing concentrations of K (and frequently Mg and Ca) with increasing supply of N is largely due to increased uptake of cations arising from the need for cation-anion balance accompanying nitrate uptake (Wilkinson *et al*., 2000). Where soil N is mostly in the ammonium form, however, there may be inhibition of K uptake due to competition between ammonium and K for absorption (Marschner, 1995). Since the rate of conversion of ammonium to nitrate increases with increasing soil temperature (Mengel and Kirkby, 2001), ammonium inhibition of K uptake could be implicated in the lower uptake of K in late winter and early summer when soil temperatures are relatively low.

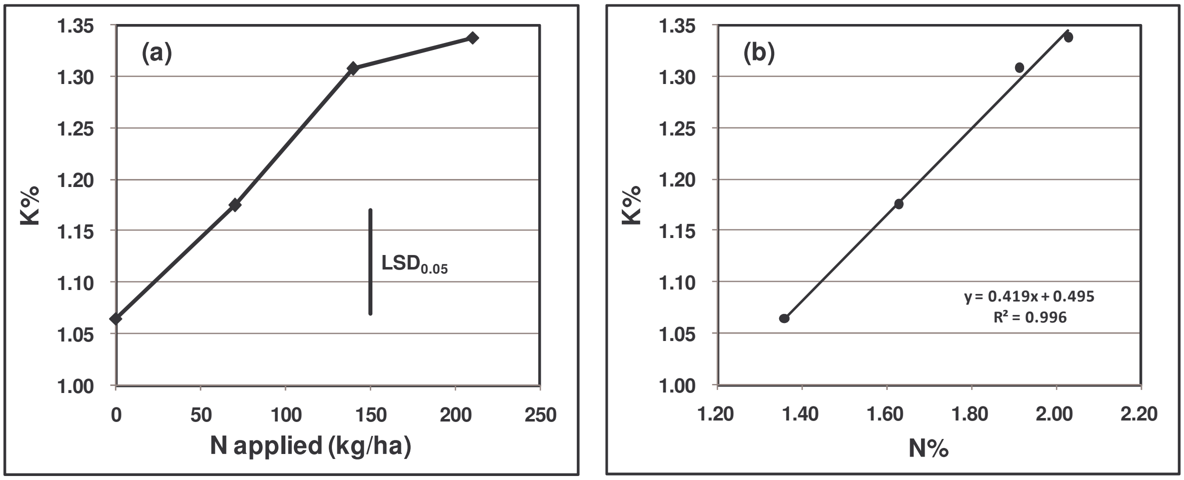

Figure 4: Effect of increasing N supply on sugarcane leaf K concentrations in a trial on the North Coast (a). The relationship between leaf N and K concentrations in the same trial is illustrated in (b).

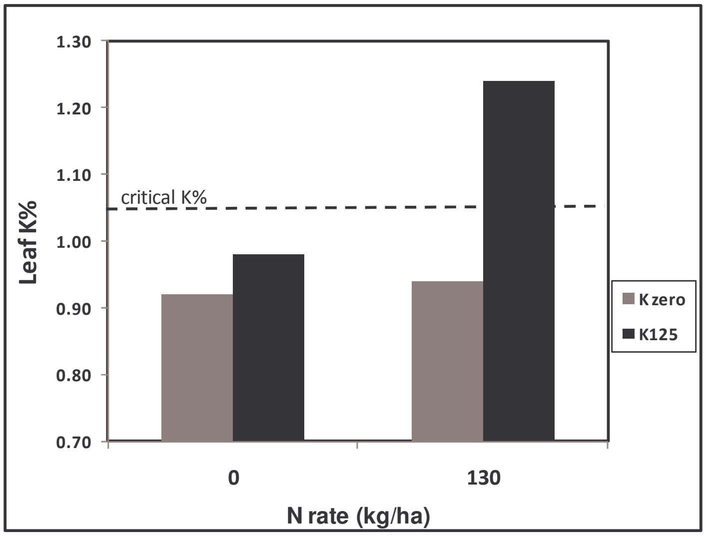

Figure 5: Effects on N and K treatments (zero and 125 kg K/ha) on sugarcane leaf K concentrations in a trial in the Umzinto area (Agronomists Association Report 1250; unpublished).

Nitrogen x sulphur interactions

Positive interactions between N and S in plant nutrition are due to the requirement for a balance of these nutrients for efficient protein synthesis (Mengel and Kirkby, 2001). Data from a recently conducted sugarcane field trial on the North Coast provide striking evidence of the synergistic effect of N fertilisation on S uptake by sugarcane, and the close relationship between N and S uptake by the crop (Figure 6). Of significance here is that at very deficient N concentrations, leaf S concentrations were below the critical level (0.12%), yet adequate at higher N levels.

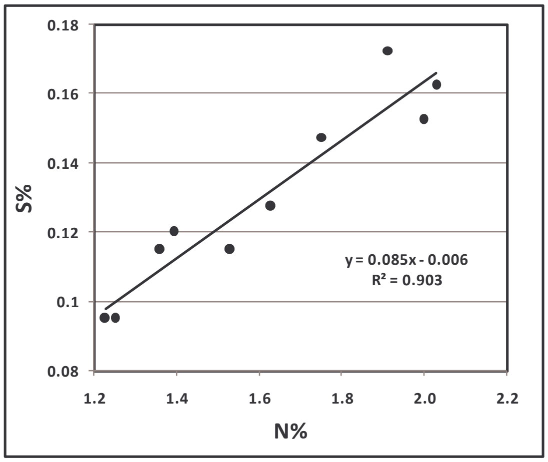

Figure 6. Relationship between leaf nitrogen and sulphur concentrations in a nitrogen response trial on the North Coast.

2. Interactions involving potassium and other nutrient cations

Root uptake systems for K are highly efficient relative to those for other cations (Marschner, 1995; Mengel and Kirkby, 2001), and inhibition of Ca, Mg and Na uptake with increasing K bio-availability is widely documented (Farina, 1977; Robson and Pitman, 1983; Kissel *et al*., 1985; Wilkinson *et al*., 2000). As a result, increases in plant K uptake accompanying K fertilization invariably result in depressed uptake of Ca and Mg, with such effects being widely noted in sugarcane field trials (Figure 7). Potassium inhibition of Ca and Mg uptake also no doubt accounts largely for the decreases in the concentrations of the latter ions in sugarcane in the late summer period, when K uptake is at a maximum (Figure 3).

Of note is convincing evidence that K, Ca and Mg are not mutually antagonistic in their uptake by plants (Farina, 1977; Kissel *et al*., 1985). Thus, while increasing amounts of K reduce uptake of Ca and Mg, uptake of K is generally not affected by wide variations in soil Ca and Mg availabilities.

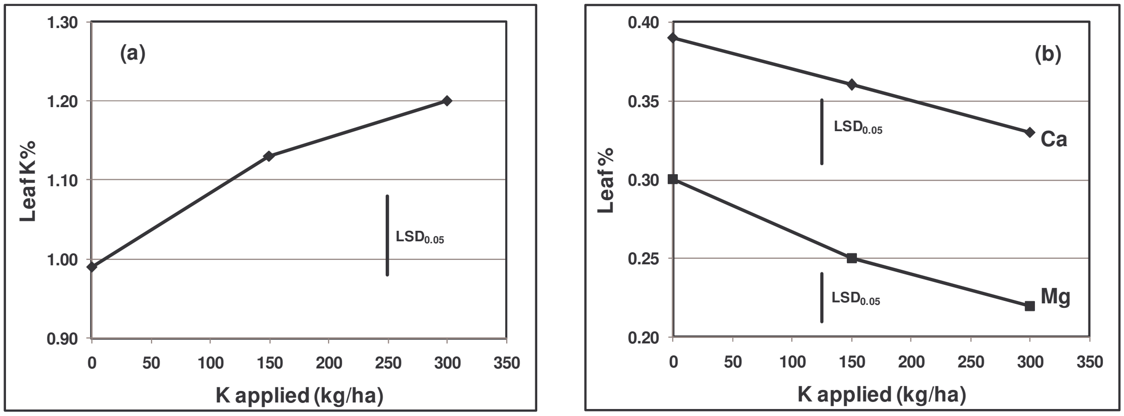

Figure 7. Effects of applied K on sugarcane leaf concentrations of (a) K and (b) Ca and Mg. (Data drawn from Swaziland Sugar Association Extension Services Reports, 1996/97; trial code NK7/82/Sw/SimR.)

CONCLUSIONS

The use of leaf analytical data to identify nutrient deficiencies and imbalances is a complex process, with numerous factors in addition to deviations from published critical norms needing to be taken into account. With respect to sugarcane, the following findings reported in this review warrant particular attention for the more successful use of leaf analysis.

- Results presented here and in the literature indicate unequivocally that N ‘drives’ uptake of P, K and S, and possibly other nutrients as well. Consequently, reliable interpretation of sufficiency levels of these nutrients in the leaf is possible only where N concentrations are non-limiting.
- The pivotal role of N in yield optimisation and its importance in the leaf analysis diagnostic process imply an urgent need for a more rigorous approach to establishing critical N levels in sugarcane. In particular, there is a requirement for an approach which takes into account decreases in the critical N% with increasing biomass (crop age). With this in mind, the modelling approach of Greenwood *et al*. (1990) would seem to be

eminently suited for use on sugarcane, and it is suggested that the development of such a model for sugarcane should receive priority in research programmes.

- Marked seasonal effects on leaf K concentrations create particular difficulties in the interpretation of leaf K data. Indications are that in both irrigated and rainfed sugarcane, only samples taken in the January to March period are likely to provide K values that are a reliable reflection of the adequacy of K supply to the crop.
- Opposing trends in the leaf concentrations of N and K from early to late summer result in massive variations in the N:K ratio during this period (and no doubt in other nutrient ratios which include K). This raises serious concerns regarding the use of the DRIS approach for diagnostic purposes.

REFERENCES

Askegaard M, Erikson J and Johnston AE (2004). Sustainable management of potassium. pp 85-102 In: P Schjonning, S Elmholt and BT Christenson (Eds), *Managing Soil Quality: Challenges in Modern Agriculture*. CAB International.

Barber SA (1994). *Soil Nutrient Bioavailability*. John Wiley and Sons, New York. 414 pp.

Ching PC and Barber SA (1979). Evaluation of temperature effects on K uptake by corn. *Agron J* 71: 1040-1044.

Donaldson RA, Meyer JH and Wood RA (1990). Response to potassium by sugarcane grown on base saturated clay soils in the Eastern Transvaal Lowveld. *Proc S Afr Sug Technol Ass* 64: 17-21.

Elwali AMO and Gascho GJ (1984). Soil testing, foliar analysis and DRIS guides for sugarcane fertilization. *Agron J* 76: 466-470.

Farina MPW (1977). Interaction between potassium, calcium and magnesium in their uptake by field maize. *Crop Production* 6: 25-29.

Gosnell JM and Long AC (1971). Some factors affecting foliar analysis in sugarcane. *Proc S Afr Sug Technol Ass* 45: 1-16.

Greenwood DJ and Stone DA (1998). Prediction and measurement of the decline in the critical-K, the maximum-K and total cation plant concentrations during the growth of field vegetable crops. *Annal Bot* 82: 871-881.

Greenwood DJ, Lemaire G, Gosse G, Cruz P, Draycott A and Neetson JJ (1990). Decline in percentage N of C3 and C4 crops with increasing plant mass. *Annal Bot* 66: 425-436.

Kissel DE, Sander DH and Ellis R (1985). Fertilizer-plant interactions in alkaline soils. In: OP Engelstad (Ed), *Fertilizer Technology and Use*. Soil Science Society of America Inc, Madison, Wisconsin, USA.

Lemaire G (1997). *Diagnosis of the Nitrogen Status in Crops*. Springer-Verlag, Berlin, Germany. 239 pp.

Marschner H (1995). *Mineral Nutrition of Higher Plants*. Academic Press, New York, USA. 889 pp.

Mengel K and Kirkby EA (2001). *Principles of Plant Nutrition*. Kluwer Academic Publishers, London, UK. 849 pp.

Meyer JH (1975). Advances in the interpretation of foliar analysis of sugarcane in the South African sugar industry. *Proc S Afr Sug Technol* Ass 49: 125-136.

Meyer JH (1981). An evaluation of DRIS based on leaf analysis for sugarcane in South Africa. *Proc S Afr Sug Technol Ass* 55: 169-176.

Meyer JH and Wood RA (1985). Potassium nutrition of sugarcane in the south African Sugar Industry. *Proceedings Potassium Symposium*. Fertilizer Society of South Africa, Pretoria. pp 205-213.

Meyer JH, Harding R, Rampersad AL and Wood RA (1998). Monitoring long-term soil fertility trends in the South African sugar industry using the FAS Analytical Database. *Proc S Afr Sug Technol Ass* 72: 61-68.

Miles N (2009). Plant nutrition and yield: chasing efficiency in sugarcane production. *Fert Soc S Afr J* pp 51-57.

Reuter DJ and Robinson JB (1997). *Plant Analysis and Interpretation Manual*. Second edition. Australian Soil Analysis and Plant Analysis Council Inc. 572 pp.

Robson AD and Pitman MG (1983). Interactions between nutrients in higher plants. pp 147-180 In: A Lauchli and RL Bielski (Eds), *Encyclopaedia of Plant Physiology*. Springer-Verlag, Berlin, Germany.

Schroeder BL (2000). *Assessment of Leaf Analyses of Sugarcane under Moisture Stress Conditions*. PhD dissertation, University of Pretoria, South Africa.

Schroeder BL, Wood RA and Meyer JH (1993). Foliar analysis in the South African Sugar Industry for diagnostic and nutrient trend purposes. pp 299-302 In: NJ Barrow (Ed) *Plant Nutrition – from Genetic Engineering to Field Practice.* Kluwer Academic Publishers.

Sumner ME (1977). Use of the DRIS system in foliar diagnosis of crops at high yield levels. *Commun Soil Sci Plant Anal* 8: 251-268.

Sumner ME and Farina MPW (1986). Phosphorus interactions with other nutrients and lime in field cropping systems. *Adv Soil Sci* 5: 201-236.

Walworth JL and Sumner ME (1987). The diagnosis and recommendation integrated system (DRIS). pp 140-199 In: B Stewart (Ed), *Advances in Soil Science.* Springer-Verlag, New York, USA.

Wilkinson SR, Grunes DL and Sumner ME (2000). Nutrient interactions in soil and plant nutrition. pp D89-112 In: ME Sumner (Ed), *Handbook of Soil Science.* CRC Press, New York, USA.