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Sugarcane Response to DRIS-Based Fertilizer Supplements in Florida

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Abstract

Soil testing is the primary basis for fertilizer recommendations in Florida sugarcane (*Saccharum* spp.), but it has the limitations of generally being performed only before the plant cane crop and not providing information for nitrogen or micronutrient availability. Leaf analysis is a useful diagnostic tool that can complement soil testing and may allow more cost-effective fertilizer applications for each crop. The Diagnosis and Recommendation Integrated System (DRIS) was used to determine leaf nutrient status in a study evaluating the effectiveness of a summer fertilizer supplement. There were 19, 24 and 26 paired commercial field comparisons in 2004/05, 2005/06 and 2006/07 respectively. Each field of each test pair received normally recommended fertilizer applications based on pre-plant soil tests, with one field of each pair receiving a June/July fertilizer supplement based on DRIS indices of leaf samples collected in April/May. There was no response in tonnes of sugarcane ha^{-1} or sugar tonne $cane^{-1}$ to the fertilizer supplements for organic or mineral soils or for plant or first ratoon crops. A more cost-effective use of leaf analysis appears to be with the adjustment of the next amendment or fertilizer application, generally for next year's crop or at the next sugarcane planting, rather than adding an additional fertilizer supplement to the current crop.

Introduction

Sugarcane (*Saccharum* spp.) is a major world crop with 22 million ha producing 1558 million Mg in 2007 (Food, Agriculture Organization 2009). Brazil, India and China have the largest area in sugarcane production with 6.7, 4.9 and 1.2 million ha, respectively, harvested in 2007. Sugarcane is grown on approximately 163 000 ha in Florida (Glaz 2007), which contributes an estimated 48% of the cane sugar and 24% of the total (from sugarcane and beets combined) sugar produced in the United States (Baucum et al. 2006).

Soil testing is used by Florida sugarcane growers as the basis for fertilizer application and is an important best management practice (Rice et al. 2006). However, there are two primary limitations with soil testing for Florida sugarcane. First, soil tests are either not available or are not calibrated for nitrogen (N) and micronutrients, although organic matter content is used as a guide for N fertilization. Secondly, soil samples are routinely taken only before sugarcane is planted, not in ratoon crops, because of problems in obtaining representative soil samples after banding of fertilizers in the furrow at planting and in later sidedress applications (Gascho and Kidder 1979).

Leaf nutrient analysis has been widely used as a diagnostic tool to complement soil testing in sugarcane production (Samuels 1969, Meyer 1975, Gascho and Elwali 1979, Anderson and Bowen 1990, Reis and Monnerat 2002). Leaf analysis has been used intensively by a limited number of Florida sugarcane growers and has the potential for an expanded role in growers' fertility programs. There are two methods for evaluating leaf nutrient status, the critical nutrient level (CNL) approach and the Diagnosis and Recommendation Integrated System (DRIS). The CNL approach defines the critical concentration of a nutrient as the point at which plant growth is reduced by 5 % or 10 % from optimum and below which deficiency symptoms appear (Ulrich and Hills 1973). On a nutrient response curve, the critical concentration occurs within a transition zone from the deficiency range to the sufficiency range. The sufficiency or optimal range of leaf nutrient concentrations is also used as part of the CNL approach. The critical values and optimum ranges for sugarcane have been defined by Anderson and Bowen (1990) and McCray et al. (2006).

The DRIS was first introduced by Beaufils (1973) and provides for examination of nutrient balance. In this approach, nutrient indices relative to zero are calculated by comparing leaf nutrient ratios with those determined in a high-yielding population. In the mid-1980s, a DRIS application for Florida sugarcane was developed (Elwali and Gascho 1983, 1984). Development of DRIS reference norms was accomplished using a large number of observations of nutrient concentrations and crop yield to obtain estimates of means and variances of certain nutrient ratios that discriminated between high- and low-yielding subpopulations (Elwali and Gascho 1984). A calibration formula uses the means and standard deviations of the nutrient ratios to calculate relative indices for individual nutrients that can range from negative to positive and that when equal to zero indicate the associated nutrient ratios are similar to those determined in the high-yielding population. The more negative index for a given nutrient, the more insufficient that nutrient is and the greater the probability of response to application of that particular nutrient. In addition to providing information about nutrient balance, the DRIS provides the advantage of less sensitivity to growth stage, thus allowing a wider time frame in which to collect samples (Beaufils and Sumner 1977).

Sufficiency range is static and based only on leaf nutrient concentration. DRIS is dynamic and performs leaf nutrient diagnosis using the relation of nutrients by pairs and according to various authors (Reis and Monnerat 2002, Partelli et al. 2006, 2007, Wortmann et al. 2008), DRIS is efficient to perform nutritional diagnosis in commercial farms and plantations. DRIS efficiency can be observed by the high correlation between DRIS index and nutrient concentration, as well as existence of a negative correlation between productivity and Nutrient Balance Index (NBI) (Partelli et al. 2006, 2007). In addition to Florida, sugarcane DRIS norms have been developed for many other areas of the world (Beaufils and Sumner 1976, Jones and Bowen 1981, Reis and Monnerat 2002, Ruiz-Bello and Cajuste 2002).

The DRIS has been used to as the basis for corrective fertilizer treatments in small-plot tests (Elwali and Gascho 1983) and commercial field comparisons in Florida sugarcane (El Hout 2008). Leaf samples were collected in May and July for fertilizer applications in a study by Elwali and Gascho (1984). Apparently, the first fertilizer applied in that study was in May, which is later than is typically applied by growers for ratoon crops and much later than the basic fertilizer application for plant cane. Elwali and Gascho (1984) determined that DRIS-based fertilizer applications resulted in increased TCH compared with the applications based on soil tests or leaf nutrient concentrations. The problem with that approach is that sugarcane yield will likely be reduced if a fertilizer application cannot be made until a representative leaf sample can be analysed for each crop. Growers must base initial fertilizer applications on information available from soil samples or leaf samples from previous crops. For that reason, the approach of using leaf analysis from the current crop as the basis for a fertilizer supplement and not the initial fertilizer application was chosen for investigation. The objective of this study was to evaluate the effectiveness of commercial DRIS-based fertilizer supplements in Florida sugarcane as determined by comparison of cane and sugar produced in paired field tests.

Materials and Methods

Commercial field comparisons

Three sugarcane growers in south Florida cooperated in a study of DRIS-based fertilizer supplements in the 2004/05, 2005/06 and 2006/07 crop years. Each year, paired fields were selected so that each paired comparison had fields of similar size with the same soil type, sugarcane cultivar, previous fertilization, planting method and other cultural practices. There were 19, 24 and 26 paired comparisons in 2004/05, 2005/06 and 2006/07 respectively. Of the 69 total comparisons in the test, 47 were plant cane and 22 were first ratoon. Comparisons were started with the plant cane crop with most being continued through first ratoon. When a comparison was continued for consecutive years, the initial treatment randomization was continued in the second year. There were 52 and 17 comparisons on organic and mineral soils respectively.

Within each pair of fields, one was randomly assigned to receive a fertilizer supplement based on DRIS indices of a leaf sample taken in April–May. The other paired field was assigned to be the control. Each field in a comparison received equivalent fertilizer rates with the treatment field of a comparison also receiving an additional supplemental fertilizer application. The basic fertilizer applied to each pair in a comparison was determined as normally done by each grower using recommended fertilizer rates based on pre-plant soil tests.

In the case of organic soils, the test supplement required an additional fertilizer application. With mineral soils, the test supplement was added to a normally scheduled supplement of N and potassium (K).

Leaf sample collection and analysis

The April–May period for leaf samples was selected as the earliest time to collect a sample reflecting nutrient availability in the spring. Leaf samples were collected in treatment and control fields in April–May. For leaf sample collection, separate samples were taken on each end of each test field. For each sample, in two locations on that end of the field, samples were taken in a V-pattern between 30 and 120 m from the end. Samples were taken no closer than 10 m from field drainage ditches. Sixteen top visible dewlap (TVD) leaves were taken in each of the two locations on that end of the field and combined into a single sample consisting of 32 leaves. Leaf midribs were separated from leaf blades and discarded before washing the blades in deionized water and drying at 60 °C. The dried leaf material was ground to pass a 1 mm screen in a stainless steel Wiley mill. All ground samples were dried for 12 h at 65 °C before weighing for digestions. Total leaf N was determined by micro-Kjeldahl digestion on an aluminium digestion block and analysis with a flow analyser (Lachat Instruments, 2003). Leaf samples were also digested with concentrated nitric acid (2 h, 150 °C) followed by 30% hydrogen peroxide (1 h, 150 °C) on an aluminium digestion block. Leaf phosphorus (P) concentrations were determined with the phosphomolybdate blue method (Murphy and Riley 1962). Leaf K, calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) concentrations were determined using atomic absorption spectrophotometry. The means of leaf analyses for the two samples of each test field were used for determination of fertilizer supplements and for comparison of leaf values. Leaf samples were also taken in late August in treatment and control fields to examine effects of fertilizer supplements on nutrient concentrations and DRIS indices.

Small-plot comparisons

Additional comparisons were also made in two small-plot locations on organic soils. Each small-plot test was located on a Dania muck soil (euic, hyperthermic, shallow Lithic Haplosaprist). These experiments were conducted simultaneously with P fertilizer rate tests in randomized complete block designs. In each test, each of two treatments received identical fertilizer applications according to University of Florida recommendations (Rice et al. 2006) based on soil tests, with one of these treatments also receiving a DRIS-based fertilizer supplement in June (21/6/2005 and 30/6/2006). These treatments were randomized in each replication of each test site. Test plots were 9.1 m (6 rows) × 13.2 m with 3 m lengthwise alleys and 4.6 m cross alleys. There were seven replications at site 1 and six replications at site 2. The experiment at site 1 was conducted with the plant cane crop only (2004/05) and the experiment at site 2 was conducted with the plant cane (2004/05) and first ratoon crops (2005/06). Leaf samples were collected in each plot in May and in late August of each year (32 TVD leaves/samples).

DRIS calculations and test fertilizer applications

The DRIS indices were calculated using DRIS reference parameters and formulae described by Elwali and Gascho (1984). This includes a calculation modification of Beaufils (1973) original formula such that any two nutrients (X and Y) were considered to be in optimum balance [f(X/Y) = 0], if the ratio of their concentrations in a sample (X/Y) was within the range given by the general mean value plus or minus the standard deviation (SD) of that ratio in the reference population (Elwali and Gascho 1984). DRIS indices were calculated with either SAS (SAS Institute, Inc. 2003) or Excel (Microsoft Corporation, 2003) and fertilizer nutrients required for the test supplement were calculated with SAS.

Supplemental fertilizer applications included nutrients in Table 1 when a given nutrient had a negative DRIS index in April–May. Calcium was not considered for fertilizer supplements because Ca is not normally applied as a fertilizer for sugarcane in Florida (except as a component of calcium silicate, dolomitic limestone or triple superphosphate) and because inadequate leaf Ca values have been related to imbalances caused by other nutrients

Table 1 Minimum and maximum fertilizer rates in a study of DRIS-based supplements in Florida sugarcane in 2004–2006[1]

Nutrient	Minimum rate (DRIS Index −1) kg ha^{-1}	Maximum rate (DRIS Index ≤ −25) kg ha^{-1}
N	22.4	56.0
P	4.9	12.2
K	18.6	46.5
Mg	11.2	28.0
Fe	2.2	5.6
Mn	2.2	5.6
Zn	1.7	3.4
Cu	1.1	2.2

[1]These supplemental fertilizer rates were applied in June or July of each year in addition to basic fertilizer applied according to soil test.

(Elwali and Gascho 1984) that could be corrected at less expense by correction of the other nutrients in the overall nutrient management plan. Applied nutrient rates ranged from the minimum to the maximum on a continuous scale from a DRIS index of −1 to −25 (Table 1). The maximum rate for a given nutrient was applied at a DRIS index more negative than −25. The supplemental fertilizer rates were determined by considering University of Florida fertilizer recommendations for sugarcane and the quantity of each nutrient that could be expected to have a positive impact on yield. Most supplemental fertilizer applications were made by airplane with dry granular fertilizers. The sources of dry fertilizers were ammonium nitrate, triple superphosphate, muriate of potash, sulphate of potash magnesia and sulphate sources of Mg, Fe, Mn, Zn and Cu. In some cases, ground equipment was used to apply the supplement with either dry or liquid fertilizer. When liquid fertilizer was applied, soluble sources were used. Most test fertilizer supplements were applied between the period of June 15 and July 15 each year, with nine fields in 2006 not being completed until the end of July.

Harvest data collection

Sugarcane production data were obtained in the commercial field experiment from the growers participating in the study. Tonnes (megagrams) sugarcane ha^{-1} (TCH) was determined at harvest by the grower and/or mill from net sugarcane railcar or truck weights from a particular field divided by net sugarcane hectares for that field. Some mills also reported kg recoverable sugar tonne $cane^{-1}$ (STC), whereas other mills reported only sugarcane juice sucrose levels for each field. Recoverable sugar per tonne cane incorporates trash levels and other mill factors to give an estimate of actual recoverable sugar produced by the mill. In the small-plot experiment, harvestable stalks were counted in two of the four middle rows of each plot in August of each year. Stalk weights were determined each year (November–January) by cutting and weighing 20 stalks from each of two of the middle four rows of each plot (40 stalks total). TCH was calculated by multiplying stalk number by stalk weight, and dividing by unit area. Ten stalks from each plot were crushed for determination of Brix and Pol, and STC was determined according to the theoretical recoverable sugar method (Glaz et al. 2002).

Statistical analysis

Statistical analyses were performed with SAS version 9.1 (SAS Institute, Inc. 2003). Comparisons of harvest data treatment effects in commercial fields were made using paired *t*-tests. Comparisons of small-plot harvest data treatment effects were made using ANOVA for a randomized complete block design. *F*-tests for the small-plot tests were conducted at probability levels of 0.05, 0.01 and 0.001. Mean separation tests for small-plot tests were conducted using LSD (P = 0.05). Comparisons of leaf nutrient concentrations or leaf DRIS indices between treatments or between sample dates for the commercial and small-plot tests were made using paired *t*-tests. Significance levels of paired *t*-tests were reported at probability levels of 0.05, 0.01 and 0.001.

Results and Discussion

Yield response

There were no significant responses in TCH to the test supplement in any of the 3 years of the commercial field study (Tables 2–4). Hurricane damage in each of the first 2 years of the study (September 2004 and late-October 2005) could have increased field variability and decreased potential time of response to the fertilizer supplement. However, there was no hurricane damage in 2006 and so no consistent response to the supplement could be shown even in a year free of storm damage. This is in contrast

Table 2 Sugarcane production for commercial fields on organic and mineral soils with and without a DRIS-based fertilizer supplement in Florida

	tonnes cane ha^{-1}				kg sugar tonne $cane^{-1}$			
	2004/05	2005/06	2006/07	All	2004/05	2005/06	2006/07	All
Supplement	107.1	84.1	105.1	98.3	116.0	101.7	113.3	110.3
Control	107.2	83.4	105.0	98.1	118.9	101.8	114.6	111.7
Paired *t*-test	ns†	ns	ns	ns	*	ns	ns	*
Comparisons	19	24	26	69	16	18	21	55
Plant cane	19	9	19	47	16	5	17	38
1st Ratoon	0	15	7	22	0	13	4	17

*Significant differences between supplement and control fields at P = 0.05.
†ns, not significant at P = 0.05.

Table 3 Sugarcane production for commercial fields on organic soils with and without a DRIS-based fertilizer supplement in Florida

	tonnes cane ha^{-1}				kg sugar tonne cane^{-1}			
	2004/05	2005/06	2006/07	All	2004/05	2005/06	2006/07	All
Supplement	109.5	87.0	111.4	102.9	116.2	100.7	110.8	107.1
Control	110.7	86.3	110.0	102.4	118.2	101.5	112.2	108.5
Paired *t*-test	ns†	ns	ns	ns	*	ns	ns	**
Comparisons	15	17	20	52	15	17	20	52
Plant cane	15	5	16	36	15	5	16	36
1st Ratoon	0	12	4	16	0	12	4	16

Significant differences between supplement and control fields at *P = 0.05 and **0.01.
†ns, not significant at P = 0.05.

Table 4 Sugarcane production for commercial fields on mineral soils with and without a DRIS-based fertilizer supplement in Florida

	tonnes cane ha^{-1}				Juice sucrose[1]			
	2004/05	2005/06	2006/07	All	2004/05	2005/06	2006/07	All
Supplement	98.2	76.9	83.9	84.4	NA[2]	16.2	16.3	16.3
Control	93.9	76.4	88.3	84.7	NA	16.4	16.5	16.5
Paired *t*-test	ns*	ns	ns	ns		ns	ns	ns
Comparisons	4	7	6	17		6	5	11
Plant cane	4	4	3	11		4	2	6
1st Ratoon	0	3	3	6		2	3	5

[1]These juice sucrose values are in per cent sucrose but do not include mill factors to reflect actual sugar recovery values.
[2]Sucrose data is not available for 2004/05.
*ns, not significant at P = 0.05.

with the 4.3 TCH response observed in a similar study of fertilizer supplements in Florida by El Hout (2008). STC was higher in control fields on organic soils in 2004/05 and for all 3 years combined (Table 3). There were a limited number of comparisons of juice sucrose available for mineral soils, but no significant differences were detected between supplement and control fields (Table 4). In comparisons of supplement and control fields for all soils, there were no significant differences in TCH for either plant or first ratoon crops, but STC was significantly ($P < 0.05$) higher in control fields compared with supplement fields of plant cane comparisons. The differences in STC indicate that on organic soils, the additional fertilizer supplement was actually detrimental to sucrose production in some situations. High N and P availability in the soil have been shown to decrease sucrose levels in sugarcane (Muchow et al. 1996, Andreis and McCray 1998), and thus differing levels of fertility might be expected to influence sucrose concentration. The small differences in sucrose may be attributable to an increase in nutrient concentration in the soil solution of fields with the test supplement. In small-plot tests, there were no significant differences in TCH or STC between supplement and control plots at either of two sites (Table 5).

Table 5 Sugarcane production in test plots with and without a DRIS-based fertilizer supplement in Florida in 2005/06 and 2006/07

	tonnes cane ha^{-1}			kg sugar tonne cane^{-1}		
	Site 1	Site 2		Site 1	Site 2	
	Plant	Plant	1st Ratoon	Plant	Plant	1st Ratoon
Supplement	87.8	137.3	116.7	117.3	124.3	134.9
Control	92.5	136.2	111.6	119.4	125.7	133.4
F-test	ns*	ns	ns	ns	ns	ns

*ns, not significant at P = 0.05.

Numerous studies have demonstrated the usefulness of DRIS in terms of diagnosis of nutritional deficiencies and imbalances (Ruiz-Bello and Cajuste 2002; Reis and Monnerat, 2003a). Fertilizer additions to the succeeding sugarcane crop based on DRIS indices from the preceding year have resulted in yield responses (Reis and Monnerat, 2003b). Greenhouse and field evaluation of perennial ryegrass response to fertilizer nutrients demonstrated that DRIS indices were useful in diagnosing nutrient deficiency and making corrections in the following crop year (Bailey et al. 1997a,b). The approach of using DRIS indices from 1 year to make fertilizer corrections the following year appears most promising in that needed fertilizer can be applied early in the growing season. In our study, leaf analysis and fertilizer applications were made in the same crop year. In this approach, fertilizer timing appears to be a major limitation, with nutrient application occurring too late in the growing season to allow for a complete response.

Influence on leaf nutrients

Comparisons of leaf nutrient concentrations, DRIS indices and NBI, before and after supplement application, were used to determine the influence of the test supplement on leaf nutrients (Tables 6 and 7). In commercial field comparisons, leaf Fe, Mn and Zn concentrations and leaf DRIS Fe, Mn and Zn indices increased in August samples compared with April/May samples for both control and supplement fields (Table 6). A recent survey of leaf nutrient concentrations in Florida sugarcane fields determined that leaf Fe and Mn concentrations consistently increased in summer compared with spring (McCray et al. 2009). Increases in Fe and Mn concentrations in summer may have been because of increases in soil moisture following the onset of the rainy season in June and the associated increase in reducing conditions in the soil, which increases Fe and Mn solubility (Weil and Holah 1989). This may occur in aerated soils in localized areas within the root zone that have reduced O_2 availability compared with the bulk soil solution (Bohn et al. 1979). There were also small, but consistent increases in leaf Zn concentration from April/May to August that may not be explained by changes in soil oxidation/reduction potential (Table 6). Unlike Fe and Mn, Zn ions do not become more soluble as soils become more reduced (Bohn et al. 1979). Leaf P concentration decreased slightly in August compared with April/May for control fields. Leaf Mn and Zn concentrations increased significantly more in supplement fields from April/May to August than in control fields. There were no significant differences in changes of DRIS indices from April/May to August between control and supplement fields. NBI decreased significantly from April/May to August in control and supplement fields, but there was no significant difference in the amount of decrease in NBI between the control and supplement treatments.

Of the supplemental nutrients applied in the small-plot test, only leaf K concentration changed significantly from April/May to August, with a small decrease in leaf K concentration in August in control plots only (Table 7). Unlike the commercial field test, leaf Fe and Mn concentrations did not increase in August compared with April/May. DRIS P, K and Fe indices increased significantly in August compared with April/May in control and supplement plots. DRIS Mg index increased significantly in

Table 6 Sugarcane leaf nutrient concentrations and DRIS indices before and after DRIS-based fertilizer supplements were applied in tests in commercial fields in Florida in 2004–2006[1]

	P ($g\ kg^{-1}$)	Mg ($g\ kg^{-1}$)	Fe ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)	Cu ($mg\ kg^{-1}$)	DRIS Index P	Mg	Fe	Mn	Zn	Cu	NBI
April/May (pre)													
Supplement	2.28	1.74	58.2	10.9	19.1	3.0	−2.9	−10.4	−9.1	−24.1	−3.9	−31.3	81.5
Control	2.33	1.80	58.5	13.5	20.1	3.5	−2.1	−7.8	−9.5	−17.2	−2.4	−12.6	69.7
Paired *t*-test	ns[†]	ns	ns	ns	*	ns	ns	*	ns	ns	ns	ns	*
August (post)													
Supplement	2.18	1.76	70.2	29.1	23.5	6.0	−4.1	−10.4	0.3	0.2	3.3	3.5	46.7
Control	2.17	1.81	70.6	27.6	23.1	5.0	−3.6	−8.2	0.9	−0.1	3.1	0.5	37.7
Paired *t*-test	ns	ns	ns	ns	ns	*	ns	*	ns	ns	ns	ns	*
Post–pre													
Supplement (S)	−0.10	0.02	11.9	18.2	4.4	3.0	−1.2	−0.1	9.4	24.3	7.1	34.8	−34.8
t-test post–pre (S)	ns	ns	***	***	***	ns	ns	ns	***	**	***	ns	***
Control (C)	−0.17	0.01	12.1	14.1	2.9	1.5	−1.6	−0.4	10.4	17.1	5.5	13.1	−32.0
t-test post–pre (C)	*	ns	***	***	**	ns	ns	ns	***	***	**	ns	***
t-test post–pre S vs. C	ns	ns	ns	*	**	ns	ns	ns	ns	ns	ns	ns	ns
n	17	26	30	20	14	3	17	26	30	20	14	3	35

[1]Data is included for each nutrient only for comparisons in which that nutrient was included in the test supplement. Nutrients were not included in the table with n < 3. August leaf data was only available for 35 of the 69 total comparisons. Nutrient balance index (NBI) is compared for all of these 35 comparisons.

Differences were significant at *P = 0.05, **0.01 and ***0.001.

[†]ns, not significant at P = 0.05.

Table 7 Sugarcane leaf nutrient concentrations and DRIS indices before and after DRIS-based fertilizer supplements were applied in tests in small-plots in Florida in 2005–2006[1]

	P (g kg^{-1})	K (g kg^{-1})	Mg (g kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	DRIS Index P	K	Mg	Fe	Mn	NBI
April/May (Pre)											
Supplement	2.02	12.3	1.48	53.2	12.0	−11.7	−7.0	−22.4	−18.8	−13.8	102.4
Control	2.07	12.8	1.58	54.4	12.3	−11.2	−3.0	−20.6	−17.1	−16.9	101.8
Paired *t*-test	ns†	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
August (Post)											
Supplement	2.09	12.3	1.51	52.7	10.8	−2.0	9.7	−12.0	−6.9	−14.8	73.9
Control	2.12	12.3	1.46	52.8	11.4	1.1	12.4	−15.0	−8.5	−15.3	83.2
Paired *t*-test	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Post–pre											
Supplement (S)	0.07	0.1	0.03	−0.5	−1.2	9.6	16.6	10.3	12.0	−0.9	−28.4
t-test post–pre (S)	ns	ns	ns	ns	ns	***	**	*	**	ns	ns
Control (C)	0.04	−0.5	−0.12	−1.6	−0.9	12.3	15.5	5.6	8.5	1.6	−18.6
t-test post–pre (C)	ns	*	ns	ns	ns	***	**	ns	*	ns	ns
t-test post–pre S vs. C	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
n	7	4	10	13	10	7	4	10	13	10	14

[1]Data are included for each nutrient only for comparisons in which that nutrient was included in the test supplement. Nutrient balance index (NBI) is compared for all available comparisons.
Differences were significant at *P = 0.05, **0.01 and ***0.001.
†ns, not significant at P = 0.05.

August compared with April/May with the supplement treatment but not in control plots, but the paired *t*-test comparing the change in DRIS Mg index over time between the control and supplement treatments was not significant. Leaf Mg concentrations for the two treatments suggest that the Mg supplement may have prevented a slight decrease in leaf Mg in the August sample relative to the control. There were no other significant differences in changes of leaf nutrient concentrations, DRIS indices, or NBI from April/May to August between control and supplement treatments.

The influence of the fertilizer supplement treatment on leaf nutrient content was relatively minor. The only nutrients with an increase in leaf nutrient concentration attributable to the fertilizer supplement in the commercial test were Mn and Zn (Table 6). In the small-plot test, there were no significant differences in leaf nutrient concentration attributable to the fertilizer supplement (Table 7).

Prediction of yield response

With a lack of overall response in TCH or STC to the fertilizer supplement in the study, it is also important to answer the question of whether there are certain situations that can be defined in which a response to the supplement can be expected. The TCH increase in fields receiving the test supplement compared with control fields (TCH supplement response) correlated significantly with leaf Mn concentration ($r = -0.25$) and NBI ($r = 0.20$) of treatment fields in April/May before the test supplement was applied. There were no other leaf nutrient concentrations or DRIS indices that correlated significantly with TCH supplement response. NBI appears to be the most useful overall selection criterion, as it is a measure of leaf nutrient balance and has been shown to relate to crop response to DRIS-based fertilizer applications in previous studies (Elwali and Gascho 1984). Commercial field data were divided into comparisons with TCH supplement response < and >2.24 [< and >1 ton (2000 lb) cane/acre]. NBI means of treatment fields in April/May corresponding to <2.24 and >2.24 TCH supplement response were 89.5 and 99.3 respectively. NBI of 100 was then chosen as a potential break point for selecting fields that might respond to a DRIS-based fertilizer supplement (Table 8). Treatment fields with NBI ≥100 had a mean TCH supplement response of 1.7. That is higher than the overall mean difference between treatment and control fields (Table 2), but only 2.3 TCH higher than fields with NBI <100. Some of the April/May DRIS indices for individual nutrients in fields with NBI ≥100 had lower means than fields with NBI < 100, but there was a large degree of variability and NBI could not be used to define fields that had an acceptable level of response.

As leaf Mn concentration was another characteristic that correlated significantly with TCH supplement response, it was also examined as a potential selection

Table 8 Comparison of April/May DRIS indices and tonnes sugarcane ha^{-1} (TCH) response to DRIS-based fertilizer supplements at nutrient balance indices (NBI) < and ≥100 in Florida[1]

	TCH response[2]	DRIS Index N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	NBI
NBI < 100 (n = 43)											
Mean	−0.6	6.8	1.2	2.8	7.5	−7.6	−10.1	−5.9	−0.8	6.1	65.6
SD	10.6	5.8	5.9	7.3	11.6	8.9	7.5	9.7	5.1	6.0	20.8
Min.	−31.5	−13.4	−12.5	−14.6	−26.0	−34.1	−28.0	−33.6	−11.2	−3.9	29.5
Max.	29.8	15.7	17.4	23.8	33.6	9.3	3.7	6.8	11.9	19.8	99.3
NBI ≥ 100 (n = 26)											
Mean	1.7	13.4	5.2	17.1	−1.8	−13.1	−10.4	−26.6	5.8	10.5	137.6
SD	9.7	10.6	11.6	9.0	23.8	10.9	12.7	25.5	9.2	15.8	37.8
Min.	−11.6	−4.1	−13.4	−1.2	−41.9	−31.7	−35.0	−126.2	−9.0	−48.2	103.2
Max.	30.7	36.7	45.6	34.9	59.9	16.2	15.7	0.0	36.5	38.5	254.4

[1]DRIS indices and NBI values are for April/May leaf samples taken before application of test supplements.
[2]TCH response is the increase in TCH in fields receiving the test supplement compared to control fields.

criterion. Leaf Mn concentration mean and DRIS Mn index mean corresponding to TCH supplement response >2.24 were approximately 14 mg kg^{-1} and −15 respectively. Treatment fields with leaf Mn concentration <14 mg kg^{-1} and DRIS Mn index <−15 had mean TCH supplement response of 2.2 and 3.3 respectively. These values were higher than those determined using NBI (Table 8) or other individual nutrients (data not shown) as criteria and suggest more of a potential response specifically to a summer Mn supplement than other nutrients in south Florida, but the margin of potential response remained relatively small. Also, the consistent increase in leaf Mn concentrations in the summer rainy season compared with the drier spring make assessing the severity of leaf Mn deficiency difficult before June.

Economics

Based on the lack of a response in TCH to the DRIS-based fertilizer supplement (Tables 2–4), the approach of applying a summer supplement to all potential sugarcane fields would not be recommended. If specific fields are selected to receive a fertilizer supplement based on leaf analytical criteria such that some level of response could be expected, then a cost/benefit analysis is required. For the purpose of the calculations made here, it is assumed that a net standard tonne of cane (biomass + sugar content) has a value of $28.07 (US) (J. Alvarez 2000, personal communication). If there is a response of 1.7 TCH (Table 8, NBI ≥ 100), the additional cane produced with the supplement would have a value of $47.72 compared with an estimated cost of $59.70 or $43.90 for fertilizer and application in 2005 (Table 9). Using NBI as a selection criterion would not have made the fertilizer supplement profitable. If DRIS Mn index is used to select fields specifically for Mn application and a response of 3.3 TCH is assumed, there would be a potential net profit based on 2005 fertilizer costs. It is not clear if a response of 3.3 TCH would be possible from only applying Mn to selected fields as test fields in this study included any of the eight nutrients under consideration with negative DRIS indices. Fertilizer costs have increased dramatically since 2005 and so even if the response value of 3.3 TCH is reasonable, a profit would not be certain for fields selected based on the leaf Mn criterion.

Table 9 Fertilizer cost estimates for a study of DRIS-based fertilizer supplements in Florida from 2004 to 2006[1]

Soil type	US $ ha^{-1} Mean	Min.	Max.
Organic	59.70	23.75	103.83
Mineral	43.90	13.09	72.67

[1]Fertilizer costs were based on local fertilizer prices in 2005 and used supplement requirements for the 69 commercial field comparisons in the study. For the cost calculations, prices of dry fertilizer materials were used. Fertilizer cost includes $14.81 ha^{-1} for an added air application on organic soils and $4.94 ha^{-1} for added application costs to a planned air application on mineral soils. Ground application costs would be slightly lower.

El Hout (2008) observed a response of 4.3 TCH to a DRIS-based summer fertilizer supplement in a similar commercial field study in Florida. That level of response would correspond to an estimated net profit of $59.88 ha^{-1} for 2005 fertilizer costs. However, even at 2005 fertilizer costs, the profit margin would have been less than the value of 2.24 TCH [1 ton (2000 lb) cane acre^{-1}]. Also, no selection criteria were suggested in that study to potentially increase the level of response for specific situations.

Conclusions

There was no response in TCH or STC to a DRIS-based summer fertilizer supplement for organic or mineral soils or for plant or first ratoon crops. Small increases in leaf Mn and Zn concentrations or DRIS indices were observed with the supplement compared with control fields, but these increases were insufficient to result in sugarcane production increases. The approach of using leaf analytical selection criteria to select specific treatment fields suggested that NBI and DRIS Mn index were most useful, but the production response levels using these were not sufficient to be profitable. Small responses observed in similar studies (El Hout 2008) would not likely be sufficient to be profitable with current fertilizer prices. The impact of nutrition on sugarcane production in Florida indicated by a survey of leaf nutrient concentrations (McCray et al. 2009) suggests that there is a large potential for yield increases with improved nutrition, whereas, these summer fertilizer supplements are too late in the annual growth cycle to result in substantial yield improvements. A more cost-effective approach appears to be the use of leaf and soil analysis to optimize the next amendment or fertilizer application, generally for the following crop year or the next sugarcane planting. This would not require adding unplanned fertilizer applications and will allow for long-term improvements in growers' nutrient management programs.

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