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Assessment of Nutrient Balance in Sugarcane Using DRIS and CND Methods

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Abstract

Many methods of nutritional diagnosis present discordant reports. It is necessary to study how these diagnoses relate to agricultural productivity and nutrient balance for a more efficient nutritional monitoring of the crops. This study had two objectives: (1) evaluate and compare Diagnosis and Recommendation Integrated System (DRIS) and Compositional Nutrient Diagnosis (CND) methods for nutritional diagnosis of sugarcane cultivated in the Northeast of Brazil; (2) establish standards, identify and hierarchize nutritional limitations. The database consisted of 183 samples, in which 31 were in areas with high productivity (≥ 80 Mg ha^{-1}) and 152 of areas with low productivity (< 80 Mg ha^{-1}). Sugarcane leaves were collected and contents of N, P, K, Ca, Mg, S, Fe, Zn, Cu, Mn and B were determined. The DRIS indexes were calculated by methods DRIS-Beaufils, DRIS-Jones, DRIS-Elwali and Gascho, M-DRIS Beaufils, M-DRIS Jones, and the indexes CND too were calculated. The DRIS-Beaufils, DRIS-Jones, M-DRIS Beaufils and M-DRIS Jones methods tended to agree on the nutritional diagnosis of sugarcane. The nutritional diagnosis of the CND method interpreted by the Potencial Fertilization Response (PFR) was different from the DRIS methods for N and Mn nutrients. The M-DRIS Beaufils and M-DRIS Jones methods showed a higher correlation with nutrient contents. However, there was no significant correlation between agricultural productivity and nutrient balance index mean (NBIm), suggesting that other factors influenced sugarcane production more than nutritional factors. The nutritional diagnosis methods identified excessive fertilization with N and limitations of Ca, Mg, K, S, Mn, Cu, Zn and B in sugarcane in the Northeast of Brazil.

Keywords: nutritional status, nutrient content, diagnosis nutrition, potential response to fertilization

1. Introduction

Sugarcane is one of the most cultivated crops in the world, occupying an area of approximately 26.9 million hectares in more than 109 countries (Choudhary, Wakchaure, Minhas, & Singh, 2016). The production of sugarcane in Brazil in the 20217/2018 harvest is estimated at 647.6 million tons, occupying an area of 8.74 million hectares. The expected average productivity is 72.73 Mg ha^{-1} of stems (CONAB, 2017).

Sugarcane is classified as crop that extracts nutrients from the soil in abundance, which requires considerable input of nutrients. It is estimated that production of 100 Mg ha^{-1} of sugarcane requires the input of 140, 34 and 332 kg ha^{-1} of NPK, respectively (Bokhtiar, Paul, Rashid, & Mafizur Rahman, 2001; Dotaniya et al., 2016). The recommendation for fertilization of sugarcane in Brazil is based on soil chemical analysis (Raij & Cantarella, 1997; Cavalcante, 2008). This high nutrient extraction capacity needs to be better evaluated to optimize fertilizer recommendations. Thus, nutritional diagnosis may be fundamental to evaluate this capacity. Therefore, several methods of foliar diagnosis were created, as the sufficiency range (SR) and critical level (CL) (Santos, Donha, Araújo, Lavres Júnior, & Camacho, 2013a).

SR and CL are methods that have the advantage of pre-established nutritional standards in the literature, as well as the ease of interpretation of analytical results (Souza & Lobato, 2004; Crester & Echer, 2010). These two

methods of nutritional diagnosis have the disadvantage of being univariate, disregarding the interactions between nutrients, besides being affected by uncontrolled factors such as the biomass accumulation rate of foliar tissues (Wadt, 2005), luminosity, temperature and water regime (Jarrel & Beverly, 1981). On the other hand, in the bivariate or multivariate methods such as DRIS and CND, respectively, the interactions between nutrients are considered, which makes it possible to indicate nutritional disorders due to the excess or deficiency of one or more nutrients.

DRIS was developed with a purpose to classify nutrients in order of limitation to growth and development, regardless of age or organ of plant. From DRIS, indexes are calculated for each nutrient and evaluated according to the ratios of the contents of each nutrient with the others, comparing two to two with other relationships considered standards because the mineral composition was obtained from a population of highly productive plants (Serra, Marchetti, Vitorino, Novelino, & Camacho, 2010). To calculate the functions of nutrient ratios some methods are adopted: a) the original method proposed by Beaufils (Beaufils, 1973); b) the Jones method (Jones, 1981); c) the method of Elwali and Gasho (Elwali & Gasho, 1984). According to Mourão Filho, Azevedo, and Nick (2002) there is no clear definition of what would be the best recommendation for calculating DRIS functions.

This high number of methods for calculating the DRIS indexes is the result of the search to find a better way to represent the variability of the data (Beverly, 1987). However, with the DRIS indexes it is possible to calculate the NBIm which provides a measure of the combined effects of nutrients on production. The disadvantage of the DRIS method is the dependency between indexes. For example, a very high index influences negatively the others, being able to diagnose deficiency for a nutrient that is in adequate concentrations. In addition, the use of NBIm as diagnostic technique can be influenced by the different methods of calculation of the DRIS indexes or the number of binary relations, not allowing evaluating the response to fertilization. Wadt et al. (1998) proposed the method of PFR. In this method the nutrient DRIS index is compared with the NBIm, establishing five classes of PFR.

In evolution to DRIS, the CND relates the nutrientes that were incorporated in a multivariate manner, similarly to the DRIS, nutritional indexes, but using the denominator in relation to geometric mean of nutritional composition of sample (Kurihara, 2004).

Although DRIS and CND presented greater complexity in the determination of foliar nutritional contents in comparison to CL and SR, both exclude the experimentation to define the calibration curves of nutrient foliar contents. However, it considers the variability of environmental conditions, allowing nutrition diagnosis of commercial crops for the DRIS and CND calculations (O. Rodríguez & V. Rodríguez, 2000).

In the last years, several studies have been conducted with the objective to develope nutritional standards from data collection of commercial crops using DRIS and/or CND (Partelli, Vieira, & Costa, 2005; McCray, Powell, Montes, & Perdomo, 2010; Politi et al., 2013), but limited to specific ecophysiological or management conditions (Partelli, Dias, Vieira, Wadt, & Paiva Júnior, 2014). However, obtaining regional standards can contribute to the rational use of inputs and productivity gains of crops production.

Comparisons between the DRIS and CND diagnostic methods are relatively extensive in the literature (Parent & Dafir, 1992; Parent, Cambouris, & Muhawenimana, 1994; Khiari, Parent, & Tremblay, 2001; Urano et al., 2007; Serra et al., 2010; Camacho, Silveira, Camargo, & Natale, 2012; Politi et al., 2013). However, few studies have compared these diagnoses in sugarcane (Reis Junior & Monnerat, 2002; Santos et al., 2013a). Sugarcane is grown in different regions in Brazil and the world, and optimal nutrient contents for high yields are strongly influenced by different growing conditions. It is important to find diagnostic methods that assess the nutritional status of sugarcane more accurately, such as DRIS and CND because of their multivariate characteristics, which are capable of integrating these different growing conditions.

Our hypothesis is that the nutritional diagnosis is not influenced by the calculation method of DRIS indexes, especially when using the PFR as a criterion. The CND method can better identify and hierarchize nutritional limitations in high variability environments, such as in Northeast Brazil.

This study had two objectives: (1) evaluate and compare DRIS and CND methods for nutritional diagnosis of sugarcane cultivated in the Northeast of Brazil; (2) establish standards, identify and hierarchize nutritional limitations.

2. Method

2.1 Description of Experimental Site

The present study was conducted in commercial sugarcane plantations, located in the sugarcane region of Northeast in State of Alagoas, Brazil. The region presents a hot and humid climate, high annual rainfall (1,500-2,000 mm) and an annual average temperature of 28 °C (Souza et al., 2004). The predominant soils in this

region are Argisols Yellow dystrophic fragipic, Argisols Gleyish dystrophic fragipanic and duripanic, Argisols Yellow dystrophic latosols and Spodosols Ferrocárbicos fragipanic and duripanic (Santos et al., 2013b).

2.2 Fertilizers and Plant Material

Liming was performed before to planting aiming to raise base saturation to 70%. The planting fertilization [sugarcane in the first crop cycle (cane-plant)] was carried out with the following management: a) the winter fertilization was performed using: Crotalaria spectabilis (green adubation) associated to 42 kg ha^{-1} of N; 60 kg ha^{-1} of P_2O_5; 144 kg ha^{-1} of k_2O; 0.48 kg ha^{-1} of B; 0.84 kg ha^{-1} of Cu; 2.52 kg ha^{-1} of Mn; and 0.84 kg ha^{-1} of Zn; b) the summer fertilization was performed using: organic waste (filter cake) (20 Mg ha^{-1}) associated to 30 kg ha^{-1} of N; 30 kg ha^{-1} of P_2O_5; 72 kg ha^{-1} of K_2O; 0.24 kg ha^{-1} of B; 0.42 kg ha^{-1} of Cu; 1.26 kg ha^{-1} of Mn; and 0.42 kg ha^{-1} of Zn. The first fertilization of ratoon [sugarcane in the second crop cycle (cane-ratton)] was performed after the issuance of the fourth leaf using: 96 kg ha^{-1} of N; 36 kg ha^{-1} of P_2O_5; and 144 kg ha^{-1} of K_2O; From of the second ratoon (sugarcane in the third crop cycle) the fertilization was carried out after the issuance of the fifth leaf using: 90 kg ha^{-1} of N and 140 kg ha^{-1} of K_2O.

The varieties commercial planted in sampled areas were: RB72454, RB75126, RB83594, RB845210, RB855113, RB855463, RB855536, RB867515, RB92579, RB93509, RB98710, SP75-3046, SP79-1011, SP81-3250, SP83-2847 and Co997. The varieties RB92579, RB93509, RB867515, SP79-1011 and Co997 were predominant in commercial cultivation.

2.3 Foliar Sampling and Nutrient Analysis

Leaf sampling of sugarcane was performed in 183 samples, being 31 of areas with high productivity (≥ 80 Mg ha^{-1}) and 152 of areas with low productivity (< 80 Mg ha^{-1}). The collection was performed in the rainy season because is the period of high nutrient uptake and always 30 days after fertilization (cane-plant and cane-ratoon). The average third of leaves +3 according to the system of kuijper was collected and dried in a greenhouse at 65 °C with forced air circulation for 72 h and then, ground to determine the nutrient contents. The analyzed nutrients were N, P, K, Ca, Mg, S, Fe, Zn, Cu, Mn and B. The N was mineralized in sulfuric digestion and dosed using the micro Kjeldahl method (Horneck & Miller, 1998). The other nutrients were mineralized by nitroperchloric digestion and extracts dosed by the following methods: P was analyzed colorimetrically by the molybdate method; the K by flame photometry; Ca, Mg, Mn, Zn, Fe and Cu by atomic absorption spectrophotometry; S by turbidimetry; B was solubilized by dry route and dosed by colorimetry (Azomethine-H). All analyzes were performed according to Kalra (Kalra, 1998).

The agricultural productivity data were recorded in sampled sites for determination of nutrient contents and formed the database that was used to generate the indexes DRIS, M-DRIS and CND for sugarcane.

In order to obtain the DRIS, M-DRIS and CND standards were calculated binary ratios between nutrient contents in each group and determined the values of median (med), mean ($\bar{x}$), standard deviation (s), coefficient of variation (CV), variance (s^2), asymmetry (Asy) and kurtose (kurt). The ratio between the variances of the low and high productivity groups (s^2_b/s^2_a) was calculated. The comparison of the mean values of productivity and nutrient contents between the low and high productivity groups was performed using Student's t-test ($p < 0.05$), considering the homoscedasticity among the variances (Beiguelman, 2002). The normalization of data of high productivity group was based on the ratio between the asymmetry coefficient-g1 (Equation 1) and its estimated error-Fisher's Sg1 (Equation 2), compared with Student's t-test ($p < 0.10$) (Beiguelman, 2002) and an equivalent asymmetry coefficient of |0.715|. This same procedure was adopted for kurtosis values, which was also based on the ratio of the kurtosis coefficient-g2 (Equation 3) and its estimated error-Fisher's Sg2 (Equation 4), compared with the Student t-test ($p < 0.10$), with an equivalent kurtosis coefficient of |1.395|. Therefore, values of asymmetry and kurtosis coefficients, equal to or less than |0.715| and |1.395|, respectively, indicated normality of data.

$$g_1 = \left\{ \frac{n}{(n-1)(n-2)} \sum_{i=1}^{n} \left(\frac{Xi - \bar{X}}{s} \right)^3 \right\} \quad (1)$$

$$S_{g1} = \sqrt{\frac{6n(n-1)}{(n-2)(n+1)(n+3)}} \quad (2)$$

$$g_2 = \left\{ \frac{n\,(n+1)}{(n-1)(n-2)(n-3)} \sum_{i=1}^{n} \left(\frac{Xi - \bar{X}}{s} \right)^4 \right\} - \frac{3\,(n-1)^2}{(n-2)(n-3)} \quad (3)$$

$$S_{g2} = \sqrt{\frac{24n(n-1)^2}{(n-3)(n-2)(n+3)(n+5)}} \quad (4)$$

Where,

g_1 = Asymmetry coefficient; S_{g1} = Asymmetry error; g_2 = Kurtosis coefficient; S_{g2} = Kurtosis error; n = Sample size; Xi = Value of binary relation between observed nutrients; $\overline{X}$ = Mean of binary relation between observed nutrients; S = Standard deviation of binary relation between observed nutrients.

For each binary relation, in the direct and inverse form (N/P and P/N), norm selection was based on the ratio between the variances (s^2_b/s^2_a) and asymmetry coefficient values. That is, rules were chosen to compose the relations with a higher ratio of variance and with an asymmetry coefficient less than |0.715|. For relationships that were selected and yet presented asymmetric values and/or coefficients of variation greater than 35%, were proceeded to transform the data, applying the criteria proposed by Box and Cox (1964) according to Equation 5:

$$Yi = \begin{cases} \frac{Xi-1}{\lambda}, \lambda \neq 0 \\ \ln Xi, \lambda = 0 \end{cases} \quad (5)$$

Where,

Yi = Value of binary relation between transformed nutrients; Xi = Value of binary relation between observed nutrients; λ = Value of transformation (2.0 to -2.0).

With different values λ, for values of binary relation among the observed nutrients, the ideal λ was selected by a maximum likelihood ratio estimation (Equation 6):

$$EMV = -\frac{n}{2}\ln\left(\frac{1}{n}\sum_{i=1}^{n}\left(Yi-\overline{Y}\right)^2\right) + (\lambda-1)\sum_{i=1}^{n}\ln Xi \quad (6)$$

Where,

EMV = Estimation of maximum likelihood; n = Sample size; Yi = Value of binary relation between transformed nutrients; $\overline{Y}$ = Mean of binary relation between transformed nutrients; λ = Considered value; Xi = Value of binary relation between observed nutrients.

2.4 Procedures for Calculating DRIS Methods

The DRIS indexes were calculated using the following methods: DRIS-Beaufils, DRIS-Jones, DRIS-Elwali and Gascho, M-DRIS Beaufils and M-DRIS Jones. The DRIS functions were calculated by formula proposed by Beaufils (Beaufils, 1973), updated by Maia (Maia, 1999). The nutrient ratio in the sample was expressed by (A/B) and in the population of high productivity or reference by (a/b). The standard deviation of relation between the nutrients of reference population was expressed by (s) and the constant of sensitivity by (k) with a value of 10. In this way, the function f (A/B) was calculated according to criteria described in Equations 7, 8 and 9:

a) A/B > a/b

$$f(A/B) = \left(\frac{(A/B)-(a/b)}{s(a/b)}\right)k \quad (7)$$

b) A/B = a/b

$$f(A/B) = 0 \quad (8)$$

c) A/B < a/b

$$f(A/B) = \left(\frac{(A/B)-(a/b)}{s(a/b)}\right)k\left(\frac{(a/b)}{(A/B)}\right) \quad (9)$$

The calculation of DRIS-Jones (Jones, 1981) was based on Equation 10:

$$f(A/B) = \left(\frac{(A/B)-(a/b)}{s(a/b)}\right)k \quad (10)$$

The DRIS-Elwani and Gascho method (Elwani & Gascho, 1984) establishes a modification in the function calculation, which consists in considering as balanced the relation between two nutrients that is within the range (a/b)±s(a/b) (Equations 11, 12 and 13). The procedures for calculations were the same as those proposed to Beaufils (Beaufils, 1973).

a) A/B > a/b + s(a/b)

$$f(A/B) = \left(\frac{(A/B) - (a/b)}{s(a/b)} \right) k \quad (11)$$

b) a/b – s(a/b) ≤ A/B ≤ a/b + s(a/b)

$$f(A/B) = 0 \quad (12)$$

c) A/B < a/b – s(a/b)

$$f(A/B) = \left(\frac{(A/B) - (a/b)}{s(a/b)} \right) k \left(\frac{(a/b)}{(A/B)} \right) \quad (13)$$

With the result of each calculation of DRIS function, DRIS index was calculated for all DRIS methods:

$$Index\ A = \frac{\sum_{i=1}^{n} f(A/Bi) - \sum_{i=1}^{m} f(Bi/A)}{n+m} \quad (14)$$

Where,

Index A = DRIS index of nutrient "*A*"; $\sum_{i=1}^{n} f(A/Bi)$ = Sum of functions in which nutrient "*A*" is in the numerator; $\sum_{i=1}^{m} f(Bi/A)$ = Sum of functions in which nutrient "*A*" is in the denominator; *n* = Number of functions in which nutrient is in numerator; *m* = Number of functions in which nutrient is in denominator of relationship.

The M-DRIS method proposed by Hallmark, Mooy, and Pesek (1987) in addition to considering the relationships among nutrients, incorporates the nutrient contents in their calculations. Thus, the M-DRIS Beaufils was calculated according to the following equations:

a) A > a

$$f(A) = \left(\frac{A-a}{s(a)} \right) k \quad (15)$$

b) A = a

$$f(A) = 0 \quad (16)$$

c) A < a

$$f(A) = \left(\frac{A-a}{s(a)} \right) k \left(\frac{a}{A} \right) \quad (17)$$

M-DRIS Jones was calculated according to the following equation:

$$f(A) = \left(\frac{A-a}{s(a)} \right) k \quad (18)$$

Where,

f (*A*) = Function of nutrient content; *A* = Nutrient content of sample; *a* = Nutrient content of the reference population (rule); *s*(*a*) = Standard deviation of the nutrient content of the reference population (rule); *k* = Sensitivity constant with a value equal to 10.

With the result of each M-DRIS function, the DRIS index was calculated for each nutrient, showing that in addition to nutrient ratios, the nutrient content was also used:

$$Index\ A = \frac{\sum_{i=1}^{n} f(A/Bi) - \sum_{i=1}^{m} f(Bi/A) + f(A)}{n+m+1} \quad (19)$$

NBIm was calculated after calculating the nutrient DRIS indexes and consisted in sum of the absolute values of DRIS indexes obtained for each nutrient and for each method of calculating the DRIS indexes, divided by the number of nutrients (z), according to the following equation:

$$\mathrm{NBIm} = \frac{1}{z} \sum_{i=1}^{z} \left| \mathrm{Indice\ Ai} \right| \quad (20)$$

2.5 Procedures for Calculating the CND Method

For the calculation procedures of CND method (Parent & Dafir, 1992), the contents nutrients (Ai) of the reference population were used and calculated the multinutrient variables (Vi) according to following equations.

$$Vi = \ln\left(Ai / G\right) \tag{21}$$

$$G = (N \cdot P \cdot K \cdot \ldots \cdot R)^{\left(\frac{1}{d+1}\right)} \tag{22}$$

$$R = 10^6\,(mg\ kg^{-1}) - \sum_{i=1}^{d} Ai \tag{23}$$

Where,

Vi = Multinutrient variable; Ai = Content nutrient (mg kg^{-1}); G = Geometric mean of the plant nutritional composition; R = Total nutritional composition in relation to sum of nutrient contents; d = Number of nutrients involved in the diagnosis.

The CND index (I_A) was calculated by the difference between the multinutrient variable of the sample (Vi) and mean of reference population (Va), divided by the standard deviation of this variable in reference population ($s(a)$), according to the following equation:

$$I_A = \frac{(V_i - Va)}{s(a)} \tag{24}$$

NBIm was calculated after calculating the nutrient CND indexes and consisted in sum of the absolute values of CND indexes obtained for each nutrient, divided by the number of nutrients (z), according to the Equation 20.

2.6 Interpretation of DRIS and CND Indexes

The DRIS, M-DRIS and CND indexes were interpreted using the DRIS index and the NBIm (Wadt, 2005). This method is based on the comparison of DRIS index module of each nutrient with the NBIm. In this method is verified whether the imbalance attributed to a nutrient is greater or less than imbalance attributed to average of all nutrients (Wadt, 2005).

The diagnosis produced by the different methods of nutritional diagnosis were interpreted by the PFR and divided into five classes: positive (PS) for nutrients that were deficient; positive or zero with low probability (PS/Z) for nutrients that were probably deficient; zero (Z) for balanced nutrients; negative (NG/Z) for nutrients that were probably excessive; and negative with high probability (NG) for the excessive nutrients (Wadt et al., 1998) (Table 1).

Table 1. Criteria for the interpretation of DRIS index based on potential fertilization response (PFR)[(1)]

Nutritional state	Potential response fertilization	Criteria
Deficient and limiting	Positive, with higher probability (PS)	1. Index NT[(2)] < 0
		2. |Index NT| > NBIm[(3)]
		3. Index NT is lower index value
Probably deficient	Positive or null, with lower probability (PS/Z)	1. Index NT < 0
		2. |Index NT| > NBIm
Balanced	Null (Z)	1. |Index NT| ≤ NBIm
Probably excessive	Negative, with lower probability (NG/Z)	1. Index NT > 0
		2. |Index NT| > NBIm
Excessive	Negative, with higher probability (NG)	1. Index NT > 0
		2. |Index NT| > NBIm
		3. Index NT is higher index value

Note. [(1)]Wadt et al. (1998) and Wadt (2005); [(2)]Index NT = DRIS index nutrient; [(3)]NBIm = Nutrient balance index mean.

The degree of agreement between the diagnoses obtained using the different methods used to calculate the DRIS indexes and CND was evaluated of the following form: a) If the diagnosis (PS, PS/Z, Z, NG/Z and NG) was the same between the two distinct methods, it were considered concordants; b) If the diagnosis was different, it were considered non-concordants. The percentage of concordant diagnoses was calculated for the total of evaluated

methods. The frequency with which each nutrient was identified in PS, PS/Z, Z, NG/Z and NG classes was calculated and compared by Chi-Square Probability Ratio Test or G-test. This test is used in biological phenomena in the evaluation of the adjustment quality in multivariate statistics, with logistic regression and independence in contingency tables (Wilks, 1935; Sokal & Rohlf, 1994), according to following equation:

$$G = 2\sum_{i=1}^{k} fo \ln\left(\frac{fo}{fe}\right) \quad (25)$$

Where,

G = Chi-Square Probability Ratio Test (G-test); fo = Observed frequency; fe = Expected frequency; k = Number of classes.

Pearson correlation analysis between the nutrient contents and their respective DRIS indexes obtained by methods DRIS-Beaufils, DRIS-Jones, DRIS-Elwali and Gascho, M-DRIS Beaufils, M-DRIS Jones and CND was performed.

3. Results and Discussion

3.1 DRIS, M-DRIS and CND Standards

The agricultural productivity data showed that in 16.9% of the samples the productivity was ≥ 80 Mg ha^{-1}, constituting high productivity subpopulation and 83.1% constituted the low productivity subpopulation (< 80 Mg ha^{-1}). From a total of 55 nutrient ratios to determine the DRIS standards, only 26 had Box-Cox transformation for data normalization (Table 2).

Table 2. Relationship among nutrients selected as DRIS standards for sugarcane in the Northeast of Brazil, transformation factor Box-Cox, mean ($\bar{x}$), standard deviation (s), coefficient of variation (CV), asymmetry (Asy) and kurtose (kurt)

Ratio	Factor	$\bar{x}$	s	CV	Asy	Kurt	Ratio	Factor	$\bar{x}$	s	CV	Asy	Kurt
N/P	-	9.467	1.722	18.2	-0.114	-0.719	S/Ca$^{(2)}$	0.20	5.041	0.693	13.7	0.023	-0.172
K/N$^{(1)}$	-	6.112	1.076	17.6	0.231	-0.534	Zn/Ca$^{(1)}$	-0.35	2.077	0.104	5.0	0.028	-1.072
N/Ca	-	4.784	1.399	29.1	0.333	-0.470	Fe/Ca	-0.10	2.232	0.265	11.9	-0.044	0.241
Mg/N$^{(2)}$	-	13.770	4.387	31.9	-0.034	-1.469	Ca/Mn$^{(3)}$	0.20	9.633	2.037	21.1	-0.008	-0.615
N/S	-	15.073	5.126	34.0	0.333	-0.420	Cu/Ca$^{(1)}$	-	11.966	3.576	29.9	0.379	-0.567
Zn/N$^{(2)}$	-	9.459	2.600	27.5	0.544	0.377	B/Ca$^{(1)}$	0.20	4.490	0.675	15.0	0.009	-0.457
N/Fe$^{(2)}$	-	37.233	7.181	19.3	-0.489	-0.097	Mg/S$^{(1)}$	0.15	3.681	0.623	16.9	-0.048	-1.103
N/Mn$^{(2)}$	0.15	6.565	1.221	18.6	-0.044	-0.408	Zn/Mg	-0.20	1.600	0.270	16.9	0,009	-0.654
Cu/N$^{(2)}$	-	25.432	4.859	19.1	0.101	-0.514	Fe/Mg	0.10	3.569	0.520	14.6	-0.020	-0.969
N/B$^{(1)}$	-	19.210	3.711	19.3	-0.217	-0.572	Mg/Mn$^{(3)}$	0.30	11.00	2.563	23.3	0.001	0.229
P/K$^{(2)}$	-	18.073	2.931	16.2	0.376	0.024	Cu/Mg$^{(1)}$	-	20.059	6.221	31.0	0.435	-0.732
P/Ca$^{(1)}$	-0.10	1.468	0.317	21.6	0.006	-0.607	B/Mg	-0.25	1.172	0.254	21.7	0.009	-1.132
P/Mg$^{(1)}$	-	8.680	2.806	32.3	0.270	-0.956	Zn/S	0.40	4.544	1.074	23.6	-0.040	-0.162
P/S$^{(1)}$	-	16.568	6.515	39.3	0.136	-1.435	Fe/10 S	-0.25	1.141	0.257	22.5	0.027	-0.160
P/Zn$^{(3)}$	-	121.469	29.790	24.5	0.108	-0.764	Mn/S	0.30	4.322	1.387	32.1	-0.001	-0.323
Fe/P	-	26.485	7.400	27.9	0.548	-0.348	Cu/S$^{(1)}$	-	36.772	9.436	25.7	-0.245	-0.248
P/Mn$^{(3)}$	0.10	6.894	1.018	17.3	0.002	-0.773	B/S	0.35	3.001	0.878	29.3	-0.070	-1.092
Cu/P$^{(1)}$	-	23.988	5.921	24.7	-0.011	-1.055	Fe/Zn$^{(1)}$	-	31.391	9.213	29.3	0.338	-0.447
B/P	-	5.040	1.021	20.3	0.409	0.348	Zn/Mn$^{(1)}$	-0.05	2.027	0.580	28.6	-0.008	-0.932
K/Ca$^{(1)}$	0.40	7.027	1.404	20.0	-0.033	-0.655	Zn/Cu$^{(1)}$	-0.25	2.367	0.138	5.8	-0.078	-0.130
Mg/K$^{(2)}$	0.10	3.612	0.534	14.8	-0.031	-0.590	B/Zn$^{(1)}$	-	6.052	1.688	27.9	0.341	-0.443
K/S	0.10	2.406	0.564	23.4	-0.015	-0.925	Fe/Mn$^{(1)}$	0.20	4.657	1.278	27.4	-0.079	-1.167
Zn/K$^{(1)}$	-	15.684	4.281	27.3	0.696	0.171	Cu/Fe$^{(2)}$	-	9.388	2.176	23.2	-0.359	-0.302
Fe/K	-	4.710	1.263	26.8	0.603	-0.202	Fe/B	-	5.392	1.641	30.4	0.689	-210
K/Mn$^{(2)}$	0.00	4.035	0.698	17.3	-0.011	-0.962	Cu/Mn$^{(2)}$	0.20	4.468	1.169	26.2	-0.008	-0.615
Cu/K$^{(2)}$	-	43.070	11.323	26.3	-0.249	-01.009	B/Mn$^{(2)}$	0.15	5.374	1.198	22.3	0.000	-0.411
K/B$^{(2)}$	-	115.697	23.061	19.9	0.070	-0.490	Cu/B$^{(2)}$	-	48.540	12.093	24.9	0.201	-0.706
Mg/Ca$^{(1)}$	-	6.242	1.808	29.0	0.316	-0.227		-	-	-	-	-	-

Note. $^{(1)}$ Multiplied relation by 10; $^{(2)}$ Multiplied relation by 100; $^{(3)}$ Multiplied relation by 1000.

For determination of M-DRIS standards, only the nutrients S, Zn and Mn had their values normalized by Box-Cox transformation (Table 3).

Table 3. Nutrients contents selected as M-DRIS standards for sugarcane in the Northeast of Brazil, transformation factor Box-Cox, mean ($\bar{x}$), standard deviation (s) and coefficient of variation (CV)

Nutrient	Factor	($\bar{x}$)	s	CV
N (g kg^{-1})	-	17.29	2.516	14.60
P (g kg^{-1})	-	1.85	0.249	13.50
K (g kg^{-1})	-	10.39	1.329	12.80
Ca (g kg^{-1})	-	3.92	1.246	31.80
Mg (g kg^{-1})	-	2.35	0.763	32.50
S (g kg^{-1}) (1)	-0.6	1.28	0.013	6.40
Zn (mg kg^{-1})	-0.1	0.94	0.013	1.40
Fe (mg kg^{-1})	-	48.10	11.230	23.40
Mn (mg kg^{-1})	-0.1	2.50	0.492	19.60
Cu (mg kg^{-1})	-	4.40	0.989	22.50
B (mg kg^{-1})	-	9.30	1.848	19.90

Note. (1) Sulphur value multiplied by 10 before proceedding Box-Cox transformation.

Regarding the CND standards, it was observed that N and Mn nutrients had the lowest and highest standard deviation, respectively. For the other nutrients, the standard deviation varied between 0.168 and 0.299 (Table 4). In the CND standards, negative values indicated that the geometric mean of nutritional composition was higher than the foliar contend of the nutrient in the multinutrient variable (Table 4).

Table 4. Multinutrient variables and geometric mean of dry mass constituints (G) selected as CND standards for sugarcane in the Northeast of Brazil, mean ($\bar{x}$), standard deviation (s), coefficient of variation (CV) and asymmetry (Asy)

Variable	$\bar{x}$	s	CV	Asy
G	589.945	77.775	13.2	0.131
V_N	3.375	0.127	3.80	0.529
V_P	1.144	0.172	15.0	0.346
V_K	2.868	0.206	7.20	0.548
V_{Ca}	1.852	0.265	14.30	0.249
V_{Mg}	1.339	0.266	19.9	-0.103
V_S	0.722	0.299	41.4	0.573
V_{Zn}	-3.625	0.244	6.70	-0.150
V_{Fe}	-2.525	0.209	8.30	0.445
V_{Mn}	-3.469	0.568	16.4	0.206
V_{Cu}	-4.920	0.168	3.40	-0.890
V_B	-4.166	0.200	4.80	0.170

3.2 Comparison of the Nutritional Diagnosis of DRIS and CND Methods

Concordance of more than 90% was observed between the nutritional diagnosis produced by DRIS-Beaufils, DRIS-Jones, M-DRIS Beaufils and M-DRIS Jones. However, when diagnoses obtained by DRIS-Jones, DRIS-Elwali and Gascho, and CND methods were compared, the agreement was less than 90%. The DRIS-Beaufils and M-DRIS Beaufils methods presented concordant diagnosis for 95.6% of the nutrients (Table 5). The nutrients that presented lower values of agreement were N, Mn and Cu with less than 80% of agreement (Table 5). Similar to what was observed in this study, Urano et al. (2006) in his evaluation about nutritional diagnosis of soybean and Serra et al. (2010) in other study of nutritional diagnosis of cotton observed that these methods were concordant. Parent et al. (1994) evaluated nutritional imbalances in the potato crop and observed a high correlation

between the DRIS-Beaufils and CND methods, indicating agreement in nutrient diagnosis. In sugarcane, Santos et al. (2013a) studying the establishment of normal ranges by the DRIS and CND methods, found that these ranges were similar.

Table 5. Agreement percentages of nutritional diagnostic of the sugarcane samples (deficient, probably deficient, balanced, probably excessive and excessive) obtained from the DRIS indexes generated by the methods DRIS-Beaufils (DB), DRIS-Jones (DJ), DRIS-Elwali and Gascho (DEG), M-DRIS Beaufils (MDB), M-DRIS Jones (MDJ), and CND indexes in the Northeast of Brazil

Diagnose method	Nutrients											Mean
	N	P	K	Ca	Mg	S	Zn	Fe	Mn	Cu	B	
DB × DJ	94.5	92.3	91.3	91.3	95.1	91.8	94.0	94.5	90.2	84.2	93.4	92.1
DB × DEG	89.6	90.2	90.7	89.1	87.4	89.1	90.7	90.7	80.9	86.3	86.9	88.3
DB × MDB	97.3	95.6	93.4	94.5	96.7	96.7	94.5	95.1	95.6	95.6	96.2	95.6
DB × MDJ	92.9	93.4	88.5	89.1	95.6	88.5	96.4	92.3	90.2	85.2	88.5	90.7
DB × CND	80.3	86.9	94.0	88.0	94.0	87.4	90.7	91.3	83.6	79.8	88.0	87.6
DJ × DEG	86.9	85.2	88.0	83.1	88.0	86.9	91.3	89.1	78.1	83.6	89.1	86.3
DJ × MDB	95.6	90.7	92.3	89.1	94.0	92.9	94.0	92.9	90.2	84.7	92.9	91.8
DJ × MDJ	95.1	91.3	92.9	95.6	95.1	94.5	94.0	93.4	97.8	94.0	90.7	94.0
DJ × CND	78.1	86.3	91.3	91.3	93.4	91.3	91.8	92.3	84.2	86.9	89.1	88.7
DEG × MDB	89.1	89.1	91.3	88.5	89.6	89.1	90.7	92.3	84.7	85.2	89.1	89.0
DEG × MDJ	87.4	86.9	86.3	84.7	88.5	86.3	89.6	89.1	79.8	83.6	86.3	86.2
DEG × CND	78.7	83.1	87.4	84.7	85.8	86.3	91.3	87.4	88.5	80.3	85.2	85.3
MDB × MDJ	95.1	95.1	95.1	90.2	95.6	90.6	95.6	92.9	91.3	87.4	91.3	92.8
MDB × CND	78.8	85.8	92.3	89.1	95.1	88.5	92.3	88.5	86.9	80.3	89.1	88.0
MDJ × CND	78.7	82.5	90.2	91.3	92.9	88.5	90.7	86.9	85.8	86.3	86.9	87.3

3.3 PFR of Sugarcane by the DRIS and CND Methods

The frequency of concurrent or discordant nutritional diagnoses showed that the CND method disagreed of all other methods for N diagnosis (Table 6). The CND method evaluated N and identified that a high number of samples were included in the positive/null (PS/Z) probability class and also in the negative response class (NG) in relation to the other methods.

The excess of N fertilization in commercial crops of sugarcane production in the Northeast of Brazil and using of N doses varying between 90 and 96 kg ha^{-1} may have been responsible for this diagnosis, which shows a probability of negative response to the N application. N fertilization that has been used in this region is well above of the recommendation for the crop (Cavalcante, 2008).

N is a macronutrient most absorbed by sugarcane, extracting up until 260 kg ha^{-1} of N, varying with genotype, soil and fertilization (Oliveira et al., 2010). Despite the high uptake of N, the responses of the plant to N fertilization have been very varied. Azeredo, Bolsanello, Weber, and Vieira (1986) observed that in 80% of the cases, plant-cane did not respond to N fertilization in evaluations carried out in 135 experiments. However, A. Oliveira (2012) in a study in the Northeast of Brazil, found an increase in agricultural productivity with increasing N dose. Oliveira, Gava, Trivelin, Otto, and Franco (2013) observed a positive variation of dry matter production of the aerial part of the crop in response to increased N dose, when cultivated the variety SP 813250.

Table 6. Potential fertilization response (PFR) of sugarcane crops in the Northeast of Brazil obtained from the nutritional diagnosis performed by methods DRIS-Beaufils (DB), DRIS-Jones (DJ), DRIS-Elwali e Gascho (DEG), M-DRIS Beaufils (MDB), M-DRIS Jones (MDJ) and CND, and frequency with which each nutrient was identified in the different PFR classes by likelihood ratio test

Diagnosis methods	Potential fertilization response (PFR)					Chi-square likelihood ratio test (G)				
	PS[(1)]	PS/Z[(2)]	Z[(3)]	NG/Z[(4)]	NG[(5)]	DJ	DEG	MDB	MDJ	CND
Nitrogen										
DB	8	9	138	18	10	2.38^{ns}	0.77^{ns}	0.69^{ns}	0.92^{ns}	9.00$^{\Delta}$
DJ	7	4	146	16	10		4.68^{ns}	0.56^{ns}	1.63^{ns}	17.00**
DEG	9	11	133	17	13		-	2.24^{ns}	3.24^{ns}	5.59^{ns}
MDB	8	6	142	17	10		-		0.83^{ns}	12.82**
MDJ	6	7	142	20	8		-			12.94**
CND	7	16	115	24	21		-			
Phosphorus										
DB	9	22	121	11	20	0.25^{ns}	0.87^{ns}	0.21^{ns}	0.18^{ns}	2.53^{ns}
DJ	8	22	121	13	19		1.70^{ns}	0.17^{ns}	0.61^{ns}	1.99^{ns}
DEG	11	18	125	9	20		-	1.91^{ns}	0.36^{ns}	3.57^{ns}
MDB	8	24	119	12	20		-		0.71^{ns}	2.69^{ns}
MDJ	9	20	124	10	20		-			3.14^{ns}
CND	12	19	115	18	19					
Potassium										
DB	24	21	114	13	11	1.34^{ns}	6.03^{ns}	1.68^{ns}	0.56^{ns}	0.57^{ns}
DJ	21	25	116	9	12		4.42^{ns}	2.45^{ns}	2.32^{ns}	1.99^{ns}
DEG	26	17	125	4	11		2.13^{ns}	4.51^{ns}	4.51^{ns}	6.30^{ns}
MDB	25	16	121	9	12		-		0.53^{ns}	2.34^{ns}
MDJ	25	17	117	12	12		-			1.35^{ns}
CND	23	21	118	13	8		-			
Calcium										
DB	20	21	107	14	21	2.78^{ns}	2.52^{ns}	0.27^{ns}	2.17^{ns}	1.14^{ns}
DJ	21	28	99	19	16		8.60$^{\Delta}$	3.00^{ns}	0.13^{ns}	1.05^{ns}
DEG	19	17	120	9	18			2.53^{ns}	7.07^{ns}	4.22^{ns}
MDB	21	23	106	12	21				2.16^{ns}	1.13^{ns}
MDJ	21	28	101	17	16					0.60^{ns}
CND	23	24	105	15	16					
Magnesium										
DB	22	22	117	17	5	0.06^{ns}	11.84*	0.38^{ns}	0.44^{ns}	0.15^{ns}
DJ	21	21	119	17	5		10.88*	0.33^{ns}	0.33^{ns}	0.24^{ns}
DEG	23	9	139	7	5		-	8.58$^{\Delta}$	8.51$^{\Delta}$	11.05*
MDB	22	21	121	14	5		-		0.03^{ns}	0.16^{ns}
MDJ	21	21	122	14	5		-			0.22^{ns}
CND	22	23	118	15	5		-			
Sulphur										
DB	32	27	92	12	20	1.14^{ns}	5.16^{ns}	0.06^{ns}	1.60^{ns}	2.63^{ns}
DJ	38	23	94	11	17		4.13^{ns}	1.27^{ns}	0.87^{ns}	1.46^{ns}
DEG	31	24	108	5	15			4.63^{ns}	6.36^{ns}	4.46^{ns}
MDB	32	28	92	11	20				1.86^{ns}	2.89^{ns}
MDJ	37	26	92	14	14					0.73^{ns}
CND	34	24	100	13	12					
Zinc										
DB	16	15	118	18	16	0.38^{ns}	2.19^{ns}	0.33^{ns}	0.57^{ns}	0.73^{ns}
DJ	14	14	122	16	17		1.17^{ns}	0.36^{ns}	0.33^{ns}	0.35^{ns}
DEG	16	11	127	12	17			1.61^{ns}	0.90^{ns}	1.18^{ns}
MDB	15	14	123	17	14				0.50^{ns}	0.24^{ns}
MDJ	16	15	122	14	16					0.83^{ns}
CND	14	12	125	17	15					

Iron										
DB	10	11	120	18	24	0.58 ^{ns}	0.87 ^{ns}	0.23 ^{ns}	0.64 ^{ns}	0.69 ^{ns}
DJ	10	8	120	19	26		1.97 ^{ns}	1.21 ^{ns}	0.06 ^{ns}	0.37 ^{ns}
DEG	8	12	125	14	24			0.23 ^{ns}	1.77 ^{ns}	2.50 ^{ns}
MDB	9	12	122	16	24				1.15 ^{ns}	1.47 ^{ns}
MDJ	9	8	121	19	26					0.34 ^{ns}
CND	9	9	118	22	25					
Manganese										
DB	18	20	103	17	25	1.38 ^{ns}	10.35*	0.30 ^{ns}	1.23 ^{ns}	8.40$^{\vartriangle}$
DJ	21	22	99	21	20		14.99**	1.34 ^{ns}	0.12 ^{ns}	9.69*
DEG	15	13	130	7	18			8.55$^{\vartriangle}$	13.88**	6.57 ^{ns}
MDB	17	20	107	17	22				1.11 ^{ns}	7.06 ^{ns}
MDJ	21	20	101	21	20					7.81$^{\vartriangle}$
CND	20	8	121	17	17					
Copper										
DB	22	11	97	33	20	4.87^{ns}	4.74 ^{ns}	0.07 ^{ns}	4.11 ^{ns}	6.89 ^{ns}
DJ	16	8	100	27	32		1.54 ^{ns}	3.90 ^{ns}	0.12 ^{ns}	4.06 ^{ns}
DEG	23	7	98	24	31			4.07 ^{ns}	1.25 ^{ns}	4.14 ^{ns}
MDB	21	11	98	32	21				3.20 ^{ns}	6.55 ^{ns}
MDJ	17	9	100	26	31					4.70 ^{ns}
CND	21	5	86	37	34					
Boron										
DB	12	13	107	26	25	0.65 ^{ns}	2.17 ^{ns}	0.03 ^{ns}	0.91 ^{ns}	0.10 ^{ns}
DJ	12	11	11	22	27		0.68 ^{ns}	0.72 ^{ns}	0.22 ^{ns}	1.18 ^{ns}
DEG	14	8	112	21	28			2.26 ^{ns}	0.93 ^{ns}	2.83 ^{ns}
MDB	12	13	108	26	24				1.09 ^{ns}	0.09 ^{ns}
MDJ	13	12	108	21	29					1.57 ^{ns}
CND	12	13	106	28	24					

Note. $^{(1)}$PS: Positive response with higher probability; $^{(2)}$PS/Z: Positive response with lower probability; $^{(3)}$Z: Null response; $^{(4)}$NG/Z: Negative response with lower probability; $^{(5)}$NG: Negative response with higher probability in accordance Wadt et al. (1998). ^{ns}No significant; *, ** $^{\&}$ $^{\vartriangle}$ Significant by Chi-square likelihood ratio test (G) at 5, 1 and 10% probablity, respectively.

The CND method differed from the DRIS-Beaufils, DRIS-Jones and M-DRIS Jones methods in evaluating nutritional diagnosis of Mn due to lower response to fertilization of this micronutrient (Table 6). This evaluation of the CND method was contrary to responses to Mn fertilization because the greatest responses to sugarcane foliar fertilization have been attributed to the Mn (Marinho, 1988; C. Benett, Buzetti, K. Benett, & Teixeira Filho, 2016). The DRIS-Elwali and Gascho method differed from the DRIS-Beaufils, DRIS-Jones, M-DRIS Beaufils and M-DRIS Jones methods because of their specificity to evaluate the nutrients considering the evaluation interval associated with the standard deviation, diagnosing a lower response to Mn fertilization, not deferring from the evaluation carried out by the CND method (Table 6). The DRIS-Elwali and Gascho method also evaluated a lower response to Mg fertilizer compared to the other methods (Table 6).

For the nutrients P, K, S, Zn, Fe, Cu and B there were no differences in the diagnostic evaluations among the studied methods. Cu was one of the nutrients that presented the lowest percentage of agreement among nutritional diagnostic methods (Table 5). However, the likelihood ratio test did not detect a disagreement among the methods (Table 6).

The highest probabilities of positive responses to fertilization were Ca, Mg, K, S, Mn, Cu, Zn and B (Table 6). Therefore, it is advisable to use limestone in both plant-cane and ratton-cane, as it is a management that aims to provide Ca and Mg for the crop, besides its corrective effect. Another important management is the recommendation of the use of gypsum, as source of Ca and S. For S management, when no to used gypsum, it is recommended the use of sulfate-based N sources, which will provide this nutrient as an accompanying element of the N fertilization. The source of N normally used in the region of this study is urea (Sampaio, Salcedo, Silva, & Alves, 1995), which does not supply S and may be contributing to lower yields of sugarcane in the region.

The nutritional diagnosis of Mn, Cu, Zn and B showed that there is micronutrient deficiency in the region mainly due to the use of very productive varieties, but nutritionally very demanding (Oliveira et al., 2010). Wadt et al. (1998) indicated that recommendation of fertilization should be directed on the nutrient that presents high probability of positive response to fertilization. Similarly, management practices that reduce nutrient supply with a high probability of negative response to fertilization should be recommended.

3.4 NBIm of the Sugarcane Crops by the DRIS and CND Methods and Correlations With the Agricultural Productivity

Positive and significant correlations ($p < 0.01$) were observed between nutrient contents and DRIS indexes calculated by different methods and CND indexes (Table 7). This positive and significant correlation suggests the use of the DRIS and CND methods as good methods of evaluation nutritional, since low nutrient contents were associated with low DRIS and CND indexes, indicating nutritional limitation.

In general, correlations between nutrient contents and DRIS indexes were higher for micronutrients (Table 7). The M-DRIS Beaufils and M-DRIS Jones methods presented the highest correlations with the contents of the nutrients that may have been due to incorporation of the nutrient content in the formula that calculates the DRIS indexes by these methods.

Table 7. Pearson correlation coefficient among the sugarcane nutrient foliar contents and DRIS indexes generated by the methods DRIS-Beaufils, DRIS-Jones, DRIS-Elwali and Gascho, M-DRIS Beaufils, M-DRIS Jones, and CND indexes. Nutrient balance index mean (NBIm) calculated by different methods DRIS and CND, and Pearson correlation coefficient between NBIm and agricultural productivity of sugarcane in the Northeast of Brazil

Nutrient	DRIS-Beaufils	DRIS-Jones	DRIS-Elw./Gasc.	M-DRISB	M-DRISJ	CND
N	0.614^{**}	0.601^{**}	0.562^{**}	0.707^{**}	0.719^{**}	0.568^{**}
P	0.739^{**}	0.735^{**}	0.701^{**}	0.800^{**}	0.809^{**}	0.702^{**}
K	0.746^{**}	0.740^{**}	0.731^{**}	0.799^{**}	0.800^{**}	0.730^{**}
Ca	0.894^{**}	0.873^{**}	0.857^{**}	0.905^{**}	0.893^{**}	0.899^{**}
Mg	0.841^{**}	0.839^{**}	0.786^{**}	0.866^{**}	0.867^{**}	0.852^{**}
S	0.912^{**}	0.885^{**}	0.877^{**}	0.919^{**}	0.895^{**}	0.913^{**}
Zn	0.813^{**}	0.797^{**}	0.820^{**}	0.847^{**}	0.836^{**}	0.787^{**}
Fe	0.894^{**}	0.893^{**}	0.888^{**}	0.918^{**}	0.920^{**}	0.865^{**}
Mn	0.940^{**}	0.907^{**}	0.872^{**}	0.934^{**}	0.912^{**}	0.926^{**}
Cu	0.821^{**}	0.853^{**}	0.798^{**}	0.854^{**}	0.884^{**}	0.843^{**}
B	0.845^{**}	0.847^{**}	0.823^{**}	0.878^{**}	0.882^{**}	0.822^{**}
NBIm (mean)[(1)]	80.4	67.9	63.4	82.4	68.9	96.9
Productivity × NBIm	0.069^{ns}	0.008^{ns}	0.077^{ns}	0.074^{ns}	0.043^{ns}	0.094^{ns}

Note. [(1)]Mean of 183 samples; **Significant at 1% of probability; [ns]No significant.

N content showed the lowest correlation coefficients with the DRIS indexes and CND (Table 7). Mn content presented the highest correlation with the DRIS indexes calculated by the DRIS-Beaufils, DRIS-Jones, M-DRIS Beaufils and CND methods (Table 7). The Fe content had a better correlation with DRIS indexes calculated by DRIS-Elwali and Gascho and M-DRIS Jones methods (Table 7).

The highest values of NBIm occurred when the indexes CND (96.9), M-DRIS Beaufils (82.4) and DRIS-Beaufils (80.4) were used (Table 7). Wadt et al. (1999) carried out the nutritional diagnosis of coffee and reported that the greater range of NBIm values can diagnose nutritional imbalance. However, determining whether a nutrient is potentially limiting or excessive depends of the criterion adopted, which may be an index or an absolute value higher than the average NBIm or other criteria (Wadt et al., 1998). In addition, the definition of the best nutritional diagnosis method can be established by the correlation between agricultural productivity and NBIm (Mourão Filho et al., 2002), but in this study no significant correlations were observed between productivity and NBIm in any of the methods tested. This fact can be explained by the influence of other factors on productivity because good nutritional conditions do not necessarily reflect in high yields. However, when there is nutritional imbalance, the productivity is strong affected (Beaufils, 1973). Beaufils (1973) reports that high yield variability in low NBIm crops as well as low yield variability of high NBIm crops can be espected.

The good correlation between the nutrient contents and the DRIS indexes calculated by any method, as well as the CND indexes (Table 7), showed that the nutritional diagnoses were adequate.

The NBIm was very high (Table 7), distancing far from zero (0). This behavior suggests that there was nutritional imbalance due to excess nutrients, evidenced by the position of the absolute majority of the samples in the null class (z) of response to fertilization (Table 6). However, agricultural productivity did not correlate with nutritional diagnoses (Table 7), suggesting that other factors influenced sugarcane production more than nutritional factors.

Excess nutrients, mainly N, P and K, did not influence agricultural productivity. Plants may to store these nutrients without to convert into biomass through of metabolic and physiological mechanisms (Masclaux-Daubresse et al., 2010). The storage of N and especially K in the cell vacuole is a common physiological mechanism when these nutrients are in excess (Conn & Gillihan, 2010).

4. Conclusion

The methods of nutritional diagnosis for sugarcane were concordant. The nutritional diagnosis performed through the CND method and interpreted through the PFR was different from the diagnosis obtained by the DRIS methods for the N and Mn nutrients. The indexes DRIS calculated by M-DRIS Beaufils and M-DRIS Jones methods showed higher correlations with nutrient contents, but no significant correlation was found between agricultural productivity and NBIm, suggesting that other factors influenced sugarcane production more than nutritional factors. The methods to calculate DRIS indexes showed an excessive fertilization with N and deficiency of Ca, Mg, K, S, Mn, Cu, Zn and B in sugarcane in the northeast of Brazil.

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