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Different criteria for determining DRIS standards influencing the nutritional diagnosis and potential fertilization response of sugarcane

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Abstract

Integrated System of Diagnostic and Recommendation (DRIS) require establishment of norms for calculation of dual relationships between nutrients. Depending on the criteria used to establish the norms, nutritional diagnosis may vary. The objective of this study was to establish DRIS standards for sugarcane by different criteria and to evaluate the influence of these standards on the nutritional diagnoses. Four criteria were used: Nutrient relations with higher variance ratio between population of low and high productivity (C1); Nutrient relations with higher variance ratio and lower coefficient of asymmetry with partial transformation of Box and Cox (C2) and with total transformation of Box and Cox (C3); Nutrient relations with logarithmic neperian transformation (C4). The database consisted of 183 samples, in which 31 were in areas with high productivity (≥80 Mg ha^{-1}) and 152 in areas with low productivity (<80 Mg ha^{-1}). Sugarcane leaves in posicion (+3) were collected and contents of N, P, K, Ca, Mg, S, Fe, Zn, Cu, Mn and B were determined, according to the Kuijper system. The results implied that criteria for choosing nutritional relations with high ratios of variance for establishment of the DRIS norms were not adequate because the data were not standardized and presented a high probability of diagnosing nutritional imbalance. Criteria of the nutritional relations with high ratios of variance with a lowest asymmetry coefficient were more adequate because the data were normalized, providing similar nutritional diagnoses. Nutritional diagnoses were influenced by the criteria used to generate DRIS standards, diagnosing differences in positive response to fertilization.

Keywords: Sugarcane; nutrient content; nutritional balance; nutritional relations.
Abreviation: DRIS_integrated system of diagnosis and recommendation; C1_nutrient relations with higher variance ratio between population of low and high productivity; C2_nutrient relations with higher variance ratio and lower coefficient of asymmetry with partial transformation of Box and Cox; C3_ nutrient relations with higher variance ratio and lower coefficient of asymmetry with total transformation of Box and Cox; C4_nutrient relations with logarithmic neperian transformation; PFR_potential fertilization response; NBIm_nutrient balance index (mean).

Introduction

Cultures of agronomic interest are cultivated about 15 million km^2 of planet and provide much of essential food and fiber to humans (Monfreda et al., 2008). In parallel with increase in the area of agricultural production, the demand for fertilizers was increased proportionally. It is estimated that fertilizer consumption (N, + P_2O_5 and + K_2O) in 2013 was 183.2 million tonnes, with subsequent increase in consumption at a rate of 1.8% per year. It is estimated that fertilizer consumption is 200.5 million tons in 2018 (FAO, 2015). However, fertilizer consumption is not necessarily based on fertilization recommendations but based on foliar plant diagnoses. In this sense, the correct interpretation of results of foliar diagnoses provides information that favors the rational use of inputs, prevents the waste, improves the nutritional balance of plants, and consequently increases productivity (Serra et al., 2010).

Knowledge of nutritional composition of crops is important to evaluate the nutritional status, agricultural yield potential and adequate nutritional balance can also be evaluated. Thus, some studies have demonstrated the dynamic nature of plant tissue nutritional composition in response to factors such as plant age (Beverly, 1993), climate (Walworth and Sumner, 1987) and soil (Serra et al., 2013). Therefore, methods such as Integrated Diagnosis and

Recommendation System (DRIS) has been considered to assess nutritional balance aiming at higher yields in plants (Reis Junior and Monnerat, 2003; Serra et al., 2012; Wadt et al., 2013).

The DRIS proposed by Beaufils (1973) is a nutritional diagnosis method based on calculation of indexes for each pair of nutrients. It involves the comparison of each pair of nutrients with the mean ratios of reference population, called DRIS standards (Dias et al., 2010). This method was developed with a purpose of classifying nutrients according to limitation of growth and development of plants, independently of age or organ to be sampled. By this method, nutrient balance in crops can be easily identified, allowing the determination of whether plant growth is being affected by nutritional or non-nutritional limitation (Nachtigall and Dechen, 2007).

From DRIS, indexes expressing the relative nutrient balance in plant are calculated by comparing nutrient dual ratios (*i.e* N/P, P/K, K/Ca, Ca/Mg etc.) in diagnosed sample (Serra et al., 2010). Thus, DRIS index of a nutrient consists of mean of deviations of relations of a nutrient with others in relation to their respective optimal values (Saldanha et al., 2017). Each relationship between nutrients in high productivity population is a DRIS standard and has its respective mean and coefficient of variation (Reis Junior and Monerat, 2003). A negative value of DRIS index indicates that a nutrient is below the recommended optimum level for crop. On the other hand, if DRIS index of a nutrient is zero, it indicates that nutrient is in balance with the other nutrients (Rocha et al., 2007).

DRIS as a method of foliar diagnosis is efficient because plant is a nutrient extractor from the soil, enabling a direct nutritional diagnosis (Beaufils, 1973). DRIS has advantage of being able to identify a nutritional imbalance, in which agricultural production is limited even when none of nutrients is below the critical level. However, it is disadvantageous because of complexity of calculations. Furthermore, it presents no probability of response to addition of nutrient identified as limiting and by the dependence between the indexes, where the content of one nutrient can influence the interpretation of another (Wadt et al., 2012).

The comparison between the criteria adopted in determination of DRIS norms is very important, because in literature there is concordance between studies on possible differences in interpretations, depending on type of DRIS procedure adopted, especially those related to establishment of standard values or norms. In coffee crops, it was observed that adoption of four different criteria for establishment of DRIS standards implied a change due to nutrient limitation (Partelli et al., 2006). Therefore, the understanding of principles considered by different diagnostic methods, as well as the comparison of their results is important for careful use of these nutritional diagnostic tools (Urano et al., 2006).

Although there are several criteria for obtaining DRIS standards, the diagnoses obtained by them may or may not be similar, even considering intra and interregional standards (Wadt and Dias, 2012). Reis Junior and Monnerat (2002) compared DRIS standards established by Beaufils and Samner (1976); Elwali and Gascho (1983) and Reis Junior (1999) for sugarcane cultivated in different locations (Brazil, South Africa and the United States). They found significant differences to DRIS standards established in these countris. Santos et al. (2013) commented that the use of nutritional diagnosis methods that include specific regions increases the interpretation efficiency.

The main purpose of a nutritional diagnosis is to evaluate the crop fertilization program and contribute to an adequate fertilization recommendation. If nutritional diagnosis depends on the criteria used to define the DRIS standards, it may compromise the potential fertilization response. Therefore, the objective of this study was to establish the DRIS standards for sugarcane by different criteria and to evaluate if the nutritional diagnosis was influenced, generating discordant potential fertilization response.

Results and discussion

Criteria for determination DRIS standards

When the criteria of choice for determining the DRIS standards was the relationship between nutrients with highest ratios of variance (C1), it was found that 41.8% of relationships presented positive asymmetry, suggesting a compromised reliability of standards (Table 1). The presence of positive asymmetry favored a greater tendency for nutrient deficient diagnosis for nutrient positioned in numerator of binary relation and greater tendency for nutritional diagnosis of excess for nutrient positioned in the denominator. Thus, it is possible to obtain more negative DRIS index for nutrient of the numerator, indicating a higher probability of positive response to fertilization, overestimating the occurrence of deficient diagnosis. For the nutrient in denominator of binary relation, it is possible to obtain a more positive DRIS index, indicating a higher probability of negative response to fertilization, overestimating the occurrence of excess diagnosis. When negative asymmetry was found, the diagnoses were reversed. It should be emphasized that this fact will depend on the amount of asymmetric relationships of nutrient. For example, Mn that positioned in numerator of binary relation presented about 90% of selected asymmetric relationships (Table 1). The occurrence of positive asymmetry indicated that data set was concentrated in values smaller than mean, being skewed to the right of curve.

The normality of data was obtained, when criteria of greater variance was added to lower asymmetry value of binary nutrient ratios, with partial transformation of Box and Cox (C2), with Box and Cox transformation of all nutrients (C3) and neperian (C4) (Tables 2, 3 and 4). All nutrient ratios selected by criteria C2 and C3 were normal (Box and Cox partial or total transformation) and also by criterion C4 (neperian logarithm transformation), with only 5.4% asymmetric data (N/Fe, Fe/N, S/Cu, Cu/S, Fe/Cu and Cu/Fe).

Classes of potential fertilization response (PFR)

For Mn, it was observed that C2, C3 and C4 criteria provided similar nutritional diagnoses, indicating a higher occurrence of positive responses to fertilization and reduction in occurrence of positive values, being statistically the same compared to C1 (Tables 5 and 6). This response was observed for Cu and Fe micronutrients (Tables 1, 2, 3 and 4) that showed positive asymmetric relationships in only 60 and 40% of the cases, respectively.

Table 1. Mean ($\bar{x}$), standart deviation (s), coefficient of variation (CV), asymmetry (Asy) and kurtosis (Kurt) of the relationships among nutrients selected as DRIS norms for sugarcane obtained by of the criterion: nutrient relations with higher variance ratio between population of low and high productivity.

Ratio	$\bar{x}$	s	CV	Asy	Kurt	Ratio	$\bar{x}$	s	CV	Asy	Kurt
N/P	9.467	1.722	18.2	-0.114	-0.719	S/Ca$^{(2)}$	34.193	11.77	34.4	0.787	1.092
N/K$^{(1)}$	16.869	3.030	18.0	0.479	-0.312	Zn/Ca$^{(1)}$	44.966	17.966	39.7	0.748	-0.468
N/Ca	4.784	1.393	29.1	0.333	-0.470	Fe/Ca	13.297	4.720	35.5	1.168	2.097
N/Mg	8.120	2.879	35.5	0.672	-0.884	Ca/Mn$^{(3)}$	257.571	191647	74.4	2.045	5.155
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$^{(1)}$	9.459	2.600	27.5	0.544	0.377	B/Ca$^{(1)}$	25.845	9.095	35.2	0.604	-0.204
Fe/N$^{(1)}$	28.042	6.555	23.4	1.480	1.952	Mg/S$^{(1)}$	19.990	7.767	38.9	0.389	-1.048
N/Mn$^{(2)}$	111.895	66.825	59.7	1.073	1.048	Zn/Mg	7.554	3.105	41.1	0.840	-0.081
n/Cu$^{(1)}$	40.810	8.263	20.2	0.744	0.132	Fe/Mg	22.524	8.489	37.7	0.546	-0.297
B/N$^{(1)}$	5.421	1.179	21.7	1.045	0.627	Mg/Mn$^{(3)}$	144.894	84.069	58.0	1.341	2.830
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	5.267	2.012	38.2	1.001	1.505	B/Mg	4.334	1.588	36.6	0.658	-0.452
P/Mg	8.680	2.806	32.3	0.270	-0.956	Zn/S	13.888	5.150	37.1	0.588	0.778
P/S$^{(1)}$	16.568	6.515	39.3	0.136	-1.435	Fe/S	4.154	1.604	38.6	1.191	1.592
P/Zn	121.469	29.790	24.5	0.108	-0.754	Mn/S	17.961	10.345	57.6	0.878	0.141
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	122.016	75.759	62.1	0.935	0.176	B/S	8.227	3.363	40.9	0.303	-1.001
P/Cu	44.484	12.099	27.2	0.844	0.095	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$^{(1)}$	10.418	6.610	63.4	0.840	-0.508
K/Ca	29.466	10.549	35.8	0.394	-0.487	Zn/Cu$^{(1)}$	38.651	13.772	35.6	1.133	1.581
K/Mg	4.974	2.012	40.5	0.929	0.519	B/Zn$^{(1)}$	6.052	1.688	27.9	0.341	-0.443
K/S	9.423	4.179	44.3	0.544	-0.941	Fe/Mn$^{(1)}$	31.451	18.965	60.3	0.495	-1.140
Zn/K$^{(1)}$	15.684	4.281	27.3	0.696	0.171	Fe/Cu	11.369	3.407	30.0	1.979	5.328
Fe/K	4.710	1.263	26.8	0.603	-0.202	Fe/B	5.392	1.641	30.4	0.689	-0.210
K/Mn	70.878	48.515	68.4	1.115	0.840	Cu/Mn$^{(2)}$	27.993	16.596	59.3	0.942	0.432
Cu/K$^{(2)}$	43.070	11.232	26.3	-0.249	-1.009	B/Mn$^{(2)}$	61.088	39.459	64.6	1.076	0.480
B/K$^{(1)}$	9.001	1.895	21.1	0.587	-0.808	B/Cu$^{(1)}$	21.963	5.908	26.9	0.950	1.147
Mg/Ca$^{(1)}$	6.242	1.808	29.0	0.316	-0.227	-	-	-	-	-	-

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

Table 2. Transformation factor of Box-Cox, mean ($\bar{x}$), standart deviation (s), coefficient of variation (CV), asymmetry (Asy) and kurtosis (Kurt) of relationships among nutrients selected as DRIS norms for sugarcane obtained by of the criterion: nutrient relations with higher variance ratio between population of low and high productivity and lower coefficient of asymmetry with partial transformation of Box and Cox.

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	0.20	5.041	0.693	13.7	0.023
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
Ca/N	-	4.784	1.393	29.1	0.333	-0.470	Fe/Ca	-0.10	2.232	0.265	11.9	-0.044	0.241
Mg/N	-	13770	4387	31.9	-0034	-1469	Ca/Mn$^{(3)}$	0.20	9.633	2.037	21.1	-0.008	-0.615
N/S	-	1.5073	5.126	34.0	0.333	-0420	Cu/Ca$^{(1)}$	-	11.966	3.576	29.9	0.379	-0.567
Zn/N$^{(1)}$	-	9.459	2.60	27.5	0.544	0.377	B/Ca$^{(1)}$	0.20	4.490	0.675	15.0	0.009	-0.457
N/Fe $^{(1)}$	-	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$^{(1)}$	-	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	2.562	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	-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	-	8.680	2.806	32.3	0.270	-0.956	Zn/S	0.40	4.544	1.074	23.6	-0.040	-0.164
P/S$^{(1)}$	-	16.568	6.515	39.3	0.136	-1.435	Fe/S	-0.25	1.141	0.257	22.5	0.027	-0.160
P/Zn	-	121.467	29.790	24.5	0.108	-0.764	Mn/S	0.30	4322	1.387	32.1	-0.001	-0.323
Fe/P	-	26.485	7.40	27.9	0.548	-0.348	Cu/S$^{(1)}$	-	36.772	9.436	25.7	-0.245	-0.248
P/Mn	0.10	5.894	1.018	17.3	0.002	-0.773	B/S	0.35	3.001	0.878	29.3	-0.070	-1.092
Cu/ P	-	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	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	0.10	3.612	0.534	14.8	-0.031	-0.590	B/Zn$^{(1)}$	-	6.052	1.0688	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	Fe/Cu	-	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	-0.210
K/Mn	-	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	-1.009	B/Mn$^{(2)}$	0.15	5.374	1.198	22.3	0.0	-0.411
K/B $^{(1)}$	-	115.697	23.061	19.9	0,070	-0,490	B/Cu$^{(1)}$	-	48.540	12.093	24.9	0.201	-0.706
Mg/Ca$^{(1)}$	-	6.242	1.808	29.0	0.316	-0.227	-		-	-	-	-	-

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

Table 3. Transformation factor of Box-Cox, média ($\bar{x}$), standart deviation (s), coefficient of variation (CV), asymmetry (Asy) and kurtosis (Kurt) of relationships among nutrients selected as DRIS norms for sugarcane obtained by of the criterion: nutrient relations with higher variance ratio between population of low and high productivity and lower coefficient of asymmetry with total transformation of Box and Cox.

Ratio	Factor	$\bar{x}$	s	CV	Asy	Kurt	Ratio	Factor	$\bar{x}$	s	CV	Asy	Kurt
N/P	1.15	10.695	2.250	22.5	-0.062	-0.708	S/Ca[2]	0.200	5.041	0.693	13.70	0.023	-0.172
K/N[1]	0.30	2.386	0.304	12.7	-0.015	-0.625	Zn/Ca[1]	-0.350	2.077	0.104	5.00	0.028	-1.072
N/Ca	0.45	2.226	0.594	26.7	-0.021	-0.437	Fe/Ca	-0.100	2.232	0.265	11.90	-0.044	0.241
Mg/N	1.00	12.770	4.387	34.4	-0.034	-1.469	Ca/Mn[3]	0.200	9.633	2.037	21.10	-0.008	-0.615
N/S	0.50	5.653	1.337	23.7	-0.037	-0.509	Cu/Ca[1]	0.300	3.621	0.634	17.50	-0.006	-0.764
Zn/N[1]	0.15	2.629	0.386	14.7	-0.027	-0.453	B/Ca[1]	0.200	4.490	0.675	15.00	0.009	-0.457
N/Fe[1]	1.85	447.407	150.037	33.5	-0.089	-0.380	Mg/S[1]	0.150	3.681	0.623	16.90	-0.048	-1.103
N/Mn[2]	0.15	6.565	1.221	18.6	-0.044	-0.408	Zn/Mg	-0.200	1.600	0.270	16.90	0.009	-0.654
Cu/N[1]	0.70	12.281	1.847	15.0	-0.023	-0.511	Fe/Mg	0.100	3.569	0.520	14.60	-0.020	-0.969
N/B[1]	1.35	39.640	10.342	26.1	-0.078	-0.621	Mg/Mn[3]	0.300	11.00	2.562	23.30	0.001	0.229
P/K[2]	0.05	3.100	0.187	6.0	-0.011	-0.288	Cu/Mg[1]	0.100	3.440	0.421	12.20	-0.016	-0.865
P/Ca	-0.10	1.468	0.317	21.6	0.006	-0.607	B/Mg	-0.250	1.172	0.254	21.70	0.009	-1.132
P/Mg	0.35	3.158	0.698	22.1	-0.034	-1.064	Zn/S	0.400	4.544	1.074	23.60	-0.040	-0.164
P/S[1]	0.50	5.980	1.639	27.4	-0.074	-1.321	Fe/S	-0.250	1.141	0.257	22.50	0.027	-0.160
P/Zn	0.65	33.058	5.591	16.9	-0.047	-0.794	Mn/S	0.300	4.322	1.387	32.10	-0.001	-0.323
Fe/P	0.10	3.830	0.386	10.1	0.022	-0.396	Cu/S[1]	1.250	72.389	22.952	31.70	-0.083	-0.303
P/Mn	0.10	5.894	1.018	17.3	0.002	-0.773	B/S	0.350	3.001	0.878	29.30	-0.070	-1.092
Cu/P	0.80	14.555	3.153	21.7	-0.086	-1.027	Fe/Zn[1]	0.500	9.087	1.654	18.20	0.009	-0.412
B/P	0.30	2.059	0.329	16.0	0.009	-0.027	Zn/Mn[1]	-0.050	2.027	0.580	28.60	-0.008	-0.932
K/Ca	0.40	7.027	1.404	20.0	-0.033	-0.655	Zn/Cu[1]	-0.250	2.367	0.138	5.80	-0.078	-0.130
Mg/ K	0.10	3.612	0.534	14.8	-0.031	-0.590	B/Zn[1]	0.450	2.727	0.630	23.10	0.001	-0.418
K/S	0.10	2.406	0.564	23.4	-0.015	-0.925	Fe/Mn[1]	0.200	4.657	1.278	27.40	-0.079	-1.167
Zn/K[1]	-0.20	2.093	0.155	7.5	0.039	-0.745	Cu /Fe	1.500	18.891	6.512	34.50	-0.090	-0.672
Fe/K	-0.20	1.303	0.195	15.0	-0.009	-0.691	Fe/B	-0.100	1.510	0.253	16.80	0.048	-0.572
K/Mn	0.00	4.035	0.698	17.3	-0.011	-0.962	Cu/Mn[2]	0.200	4.469	1.169	26.20	-0.008	-0.615
Cu/K[2]	1.25	88.422	28.670	32.4	-0.152	-1.051	B/Mn[2]	0.150	5.374	1.198	22.30	0.000	-0.411
K/ B[1]	0.75	45.530	7.055	15.5	-0.030	-0.629	B/Cu[1]	0.500	11.827	1.749	14.80	-0.042	-0.643
Mg/Ca[1]	0.50	2.945	0.730	24.8	-0.045	-0.249	-	-	-	-	-	-	-

[1] Multiplied ratio by 10; [2] Multiplied ratio by 100; [3] Multiplied ratio by 1000.

Tabela 4. Mean ($\bar{x}$), standart deviation (s), coefficient of variation (CV), asymmetry (Asy) and kurtose (Kurt) of relationships among nutrients selected as DRIS norms for sugarcane obtained by of the criterion: nutrient relations with logarithmic neperian transformation.

Ratio	$\bar{x}$	s	CV	Asy	Kurt	Ratio	$\bar{x}$	s	CV	Asy	Kurt
N/P	2.231	0.189	8.50	-0.450	-0.601	K/Mn	4.035	0.698	17.3	-0.011	-0.962
P/N[1]	2.374	0.189	8.00	0.448	-0.600	Mn/K	2.673	0.698	24.3	0.011	-0.962
N/K	2.810	0.178	6.30	0.121	-0.609	K/Cu	3.182	0.288	9.10	0.647	-0.630
K/N[1]	1.795	0.178	9.90	-0.124	-0.609	Cu/K	3.725	0.287	7.70	-0.648	-0.631
N/Ca	1.523	0.302	19.8	-0.336	-0.211	K/B	4.761	0.205	4.30	-0.296	-0.846
Ca/N	3.088	0.302	9.80	0.336	-0.212	B/K	2.177	0.205	9.40	0.296	-0.847
N/Mg	2.036	0.342	16.8	0.344	-1.299	Ca/Mg	2.817	0.303	10.8	0.436	0.107
Mg/N	2.569	0.342	13.3	-0.344	-1.298	Mg/Ca	1.789	0.303	16.9	-0.437	0.108
N/S	2.653	0.361	13.6	-0.434	-0.221	Ca/S	3.433	0.347	10.1	0.151	-0.239
S/N	1.952	0.361	18.5	0.433	-0.223	S/Ca	3.475	02.347	10.0	-0.153	-0.239
N/Zn	4.698	0.277	5.90	0.117	-0.516	Ca/Zn	3.175	0.386	12.2	-0.219	-1.029
Zn/N	2.210	0.277	12.5	-0.117	-0.517	Zn/Ca	3.733	0.386	10.3	0.219	-1.030
N/Fe	3.597	0.211	5.90	-0.987	0.712	Ca/Fe	4.377	0.341	7.80	-0.062	0.255
Fe/N	3.311	0,211	6.40	0.866	0.711	Fe/Ca	2.531	0.341	13.5	0.061	0.260
N/Mn	4.542	0.622	13.7	-0.265	-0.278	Ca/Mn	5.322	0.701	13.2	-0.167	0.143
Mn/N	2.366	0.622	26.3	0.266	-0.277	Mn/Ca	3.888	0.701	18.0	0.169	0.143
N/Cu	3.690	0.196	5.30	0.319	-0.381	Ca/Cu	4.470	0.306	6.80	0.171	-0.749
Cu/N	3.218	0.196	6.10	-0.319	-0.380	Cu/Ca	2.438	0.306	12.6	-0.170	-0.749
N/B	2.936	0.204	6.90	-0.627	-0.169	Ca/B	3.716	0.357	9.60	0.151	-0.390
B/N	1.669	0.204	12.2	0.627	-0.170	B/Ca	3.192	0.357	11.2	-0.151	-0.390
P/K	2.882	0.162	5.60	-0.027	-0.298	Mg/S	2.919	0.402	13.8	-0.131	-1.066
K/P	1.723	0.162	9.40	0.028	-0.290	S/Mg	3.989	0.403	10.1	0.131	-1.066
P/Ca	1.594	0.372	23.3	0.082	-0.542	Mg/Zn	4.963	0.399	8.00	-0.160	-0.705
Ca/P	3.011	0.372	12.4	-0.082	-0.541	Zn/Mg	1.944	0.400	20.6	0.160	-0.707
P/Mg	2.108	0.336	15.9	-0.201	-1.017	Mg/Fe	3.863	0.384	9.90	0.078	-0.976
Mg/P	2.497	0.336	13.5	0.200	-1.017	Fe/Mg	4.808	0.620	12.9	-0.542	0.345
P/S	2.725	0.426	15.6	-0.329	-1.035	Mg/Mn	4.808	0.620	12.9	-0.542	0.345
S/P	1.880	0.426	22.7	0.329	-1.036	Mn/Mg	4.402	0.620	14.1	0.542	0.347

P/Zn	4.769	0.255	5.30	-0.339	-0.648	Mg/Cu	3.956	0.314	7.90	0.068	-0.839
Zn/P	2.139	0.255	11.9	0.340	-0.646	Cu/Mg	3.956	0.314	7.90	0.068	-0.839
P/Fe	3.669	0.279	7.60	0.045	-0.351	Mg/B	2.952	0.314	10.6	-0.068	-0.843
Fe/P	3.239	0.279	8.60	-0.043	-0.348	B/Mg	1.403	0.361	25.7	0.133	-1.072
P/Mn	4.614	0.643	13.9	-0.116	-0.702	S/Zn	4.347	0.392	9.00	0.419	-0.161
Mn/P	2.294	0.643	28.0	0.116	-0.701	Zn/S	2.561	0.392	15.3	-0.419	-0.162
P/Cu	3.762	0.260	6.90	0.399	-0.754	S/Fe	3.247	0.363	11.2	-0.260	-0.129
Cu/P	3.146	0.260	8.30	-0.402	-0.749	Fe/S	1.359	0.363	26.7	0.259	-0.128
P/B	3.008	0.204	6.80	0.160	-0.016	S/Mn	4.192	0.626	14.9	0.490	0.259
B/P	1.598	0.204	12.8	-0.161	-0.020	Mn/S	2.716	0.626	23.0	-0.490	0.261
K/Ca	3.318	0.377	11.4	-0.323	-0.572	S/Cu	3.339	0.286	8.6	0.926	0.625
Ca/K	3.590	0.377	10.5	0.323	-0.572	Cu/S	3.568	0.286	8.00	-0.928	0.630
K/Mg	1.529	0.393	25.7	0.110	-0.570	S/B	4.888	0.437	8.90	0.285	-0.958
Mg/K	3.076	0.394	12.8	-0.11	-0.570	B/S	2.020	0.438	21.7	-0.286	-0.957
K/S	2.145	0.456	21.3	-0.090	-0.869	Zn/Fe	3.505	0.305	8.70	0.358	-0.095
S/K	2.460	0.456	18.5	0.090	-0.869	Fe/Zn	3.403	0.305	9.00	-0.358	-0.092
K/Zn	4.190	0.267	6.40	-0.141	-0.659	Zn/Mn	2.147	0.646	30.1	0.042	-0.973
Zn/K	2.718	0.267	9.80	0.139	-0.658	Mn/Zn	2.458	0.646	26.3	-0.042	-0.971
K/Fe	3.089	0.265	8.60	-0.093	-0.679	Zn/Cu	3.598	0.340	9.40	0.151	-0.007
Fe/K	1.516	0.265	17.5	0.092	-0.679	Cu/Zn	3.310	0.341	10.3	-0.151	-0.006
Zn/B	2.844	0.88	10.1	0.308	-0.147	B/Fe	2.964	0.299	10.1	-0.109	-0.577
B/Zn	1.761	0.288	16.4	-0.309	-0.144	Mn/Cu	3.753	0.626	16.7	0.259	-0.541
Fe/Mn	3.248	0.674	20.8	-0.260	-0.997	Cu/Mn	3.155	0.627	19.9	-0.260	-0.540
Mn/Fe	3.660	0.674	18.4	0.260	-0.997	Mn/B	2.999	0.670	22.3	0.236	-0.240
Fe/Cu	2.396	0.259	10.8	1.055	1.448	B/Mn	3.909	0.670	17.1	-0.236	-0.240
Cu/Fe	2.210	0.259	11.7	-1.055	1.447	Cu/B	3.851	0.257	6.70	-0.312	-0.355
Fe/B	1.642	0.299	18.2	0.109	-0.576	B/Cu	3.057	0.258	8.40	0.311	-0.356

(1) Multiplied ration by 10.

Table 5. Potential fertilization response (PFR) of nutrients for sugarcane obtained according nutritional evaluation using DRIS standards generated from four criteria (C1, C2, C3 and C4) and comparison of the diagnostic classes by the likelihood ratio test.

Criterion	Potential fertilization response (PFR)					Likelihood ratio test chi-square (G)		
	P(5)	PZ(6)	Z(7)	NZ(8)	N(9)	C2	C3	C4
							Nitrogen	
C1(1)	5	7	147	17	7	1.70^{ns}	2.38^{ns}	1.61^{ns}
C2(2)	8	9	138	18	10	-	0.29^{ns}	1.17^{ns}
C3(3)	8	11	136	19	9	-	-	2.08^{ns}
C4(4)	5	7	140	19	12	-	-	-
							Phosphorus	
C1	9	22	124	16	12	2.99^{ns}	6.02^{ns}	0.98^{ns}
C2	9	22	121	11	20	-	9.80^{*}	1.15^{ns}
C3	16	30	120	10	7	-	-	9.60^{*}
C4	7	21	125	14	16	-	-	-
							Potassium	
C1	25	20	117	9	12	0.86^{ns}	8.13^{Δ}	0.89^{ns}
C2	24	21	114	13	11	-	5.57^{ns}	1.39^{ns}
C3	15	16	115	20	17	-		11.33^{*}
C4	26	21	119	9	8	-	-	-
							Calcium	
C1	20	24	97	17	25	1.33^{ns}	1.2^{ns}	1.65^{ns}
C2	20	21	107	14	21	-	0.53^{ns}	1.35^{ns}
C3	20	25	104	15	19	-	-	0.80^{ns}
C4	23	27	100	12	21	-	-	-
							Magnesium	
C1	22	17	117	23	4	1.66^{ns}	2.81^{ns}	0.97^{ns}
C2	22	22	117	17	5	-	0.38^{ns}	0.13^{ns}
C3	22	21	121	14	5	-	-	0.56^{ns}
C4	22	20	118	18	5	-	-	-
							Sulphur	
C1	32	25	89	17	20	0.99^{ns}	0.48^{ns}	2.05^{ns}
C2	32	27	92	12	20		0.29^{ns}	1.10^{ns}
C3	33	26	92	14	18		-	0.66^{ns}
C4	37	26	93	12	15		-	-
							Zinc	
C1	17	19	117	19	11	1.46^{ns}	2.00^{ns}	2.26^{ns}
C2	16	15	118	18	16	-	0.27^{ns}	0.86^{ns}
C3	16	13	122	17	15	-	-	1.72^{ns}
C4	14	19	116	16	18	-	-	-
							Iron	

C1	11	13	126	12	21	1.77^{ns}	4.08^{ns}	4.37^{ns}
C2	10	11	120	18	24	-	0.70^{ns}	1.07^{ns}
C3	8	11	116	20	28	-	-	0.36^{ns}
C4	7	9	120	19	28	-	-	-
							Manganese	
C1	20	10	90	19	44	9.79^{ns}	8.26$^{\Delta}$	8.26$^{\Delta}$
C2	18	20	103	17	25	-	0.26^{ns}	1.46^{ns}
C3	20	20	100	16	27	-	-	1.56^{ns}
C4	20	14	109	15	25	-	-	-
							Copper	
C1	17	8	103	36	19	1.45^{ns}	1.74^{ns}	2.69^{ns}
C2	22	11	97	33	20	-	0.11^{ns}	3.10^{ns}
C3	21	12	97	32	21	-	-	2.65^{ns}
C4	17	8	104	27	27	-	-	-
							Boron	
C1	136	19	113	22	16	3.66^{ns}	4.66^{ns}	4.30^{ns}
C2	12	13	107	26	25	-	0.30^{ns}	0.06^{ns}
C3	13	11	107	28	24	-	-	0.12^{ns}
C4	12	12	107	27	25	-	-	-

[1]C1: nutrients relations with higher variance ratio; [2]C2: nutrients relations with higher variance ratio and lower coefficient of asymmetry with partial transformation of Box and Cox (1964); [3]C3: nutrients relations with higher variance ratio and lower coefficient of asymmetry with total transformation of Box and Cox (1964); and [4]C4: nutrient relations with logarithmic neperian transformation; [5]P: positive response with higher probability; [6]PZ: positive response with lower probability; [7]Z: null response; [8]NZ: negative response with lower probability; [9]N: negative response with higher probability, in according Wadt (2005); ^{ns}no significant; * and $^{\Delta}$ significant by Likelihood ratio test chi-square (G) at 5 and 10% probability, respectively.

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Table 6. Potential fertilization response (PFR) in the classes of nutrients: deficient, balanced and excessive for sugarcane obtained according to the nutritional evaluation using DRIS standards generated from four criteria (C1, C2, C3 and C4) and comparison of the diagnostic classes by the likelihood ratio test.

Criterion	Class			Likelihood ratio test chi-square (G)		
	Deficient (P[5] e PZ[6])	Balanced (Z[7])	Excessive (NZ[8] e N[9])	C2	C3	C4
					Nitrogen	
C1[1]	12	147	24	1.46^{ns}	2.33^{ns}	1.06^{ns}
C2[2]	17	138	28	-	0.13^{ns}	1.03^{ns}
C3[3]	19	136	28	-	-	1.80^{ns}
C4[4]	12	140	31	-	-	-
					Phosphorus	
C1	31	124	28	0.19^{ns}	5.72^{ns}	0.23^{ns}
C2	31	121	31	-	7.09*	0.23^{ns}
C3	46	120	17	-	-	8.17*
C4	28	125	30	-	-	-
					Potassium	
C1	45	117	21	0.24^{ns}	7.08*	0.48^{ns}
C2	45	114	24	-	5.39^{ns}	1.35^{ns}
C3	31	115	37	-	-	10.9*
C4	47	119	17	-	-	-
					Calcium	
C1	44	97	42	1.23^{ns}	1.10^{ns}	1.51^{ns}
C2	41	107	35	-	0.24^{ns}	1.19^{ns}
C3	45	104	34	-	-	0.36^{ns}
C4	50	100	33	-	-	-
					Magnesium	
C1	39	117	27	0.81^{ns}	1.66^{ns}	0.44^{ns}
C2	44	117	22	-	0.30^{ns}	0.07^{ns}
C3	43	121	19	-	-	0.43^{ns}
C4	42	118	23	-	-	-
					Sulphur	
C1	57	89	37	0.45^{ns}	0.45^{ns}	1.96^{ns}
C2	59	92	32	-	0.00^{ns}	0.56^{ns}
C3	59	92	32	-	-	0.56^{ns}
C4	63	93	27	-	-	-
					Zinc	
C1	36	117	30	0.63^{ns}	0.92^{ns}	0.38^{ns}
C2	31	118	34	-	0.19^{ns}	0.08^{ns}
C3	29	122	32	-	-	0.47^{ns}
C4	33	116	34	-	-	-
					Iron	
C1	24	126	33	1.43^{ns}	3.79^{ns}	4.22^{ns}
C2	21	120	42	-	0.57^{ns}	0.96^{ns}
C3	19	116	48	-	-	0.34^{ns}
C4	16	120	47	-	-	-

					Manganese	
C1	30	90	63	6.05^{*}	5.76^{ns}	7.25^{*}
C2	38	103	42	-	0.11^{ns}	0.44^{ns}
C3	40	100	43	-	-	0.98^{ns}
C4	34	109	40	-	-	-
					Copper	
C1	25	103	55	1.32^{ns}	1.32^{ns}	0.01^{ns}
C2	33	97	53	-	0.00^{ns}	1.36^{ns}
C3	33	97	53	-	-	1.36^{ns}
C4	25	104	54	-	-	-
					Boron	
C1	32	113	38	2.93^{ns}	3.50^{ns}	3.50^{ns}
C2	25	107	51	-	0.03^{ns}	0.03^{ns}
C3	24	107	52	-	-	0.00^{ns}
C4	24	107	52	-	-	-

(1)C1: nutrients relations with higher variance ratio; (2)C2: nutrients relations with higher variance ratio and lower coefficient of asymmetry with partial transformation of Box and Cox (1964); (3)C3: nutrients relations with higher variance ratio and lower coefficient of asymmetry with total transformation of Box and Cox (1964); and (4)C4: nutrient relations with logarithmic neperian transformation; (5)P: positive response with higher probability; (6)PZ: positive response with lower probability; (7)Z: null response; (8)NZ: negative response with lower probability; (9)N: negative response with higher probability, in according Wadt (2005); nsno significant; * and △ significant by Likelihood ratio test chi-square (G) at 5 and 10% probability, respectively.

Table 7. Percentage of agreement in nutritional diagnoses deficient, probably deficient, balanced, probably excessive and excessive nutrients for sugarcane using DRIS standards generated from four criteria (C1, C2, C3 e C4).

Nutrient	C1(1) x C2(2)	C1 x C3(3)	C1 x C4(4)	C2 x C3	C2 x C4	C3 x C4	Mean
			%				
N	92.9	91.8	94.5	94.5	95.1	92.9	93.6
P	94.0	94.5	90.7	97.8	94.0	92.9	94.0
K	91.8	93.4	92.9	95.1	92.0	92.9	93.0
Ca	91.8	90.2	87.4	97.3	92.3	92.9	92.0
Mg	94.0	91.8	94.5	97.8	92.2	95.1	94.2
S	92.3	90.7	85.8	97.3	89.6	92.3	91.3
Zn	90.7	90.7	90.7	96.7	93.4	95.6	93.0
Fe	91.8	85.2	84.2	92.3	89.6	92.9	89.3
Mn	75.4	75.4	77.6	97.3	93.4	92.9	85.3
Cu	85.8	86.3	88.5	95.1	88.0	85.8	88.3
B	85.8	84.2	84.7	95.1	94.5	94.0	89.7
Mean	89.7	88.6	88.3	96.0	92.2	92.7	91.3

(1)C1: nutrients relations with higher variance ratio; (2)C2: nutrients relations with higher variance ratio and lower coefficient of asymmetry with partial transformation of Box and Cox (1964); (3)C3: nutrients relations with higher variance ratio and lower coefficient of asymmetry with total transformation of Box and Cox (1964); and (4)C4: nutrient relations with logarithmic neperian transformation.

Table 8. Percentage of agreement in nutritional diagnoses deficient, balanced and excessive of nutrients for sugarcane using DRIS standards generated from four criteria (C1, C2, C3 e C4).

Nutrient	C1(1) x C2(2)	C1 x C3(3)	C1 x C4(4)	C2 x C3	C2 x C4	C3 x C4	Mean
			%				
N	95.1	94.0	96.2	96.2	96.2	94.2	94.5
P	97.3	97.3	95.1	98.9	96.7	95.6	96.8
K	94.0	95.6	96.7	97.3	94.0	95.6	95.5
Ca	93.4	92.9	90.7	98.4	94.0	95.6	94.2
Mg	94.5	92.3	95.1	97.8	96.2	95.1	95.2
S	95.1	95.1	91.3	100.0	95.1	95.1	95.3
Zn	94.0	95.1	96.2	97.8	95.6	97.8	96.1
Fe	93.4	88.5	88.0	95.1	94.5	97.3	92.8
Mn	84.2	85.8	85.2	98.4	95.6	95.1	90.7
Cu	91.3	90.2	95.1	97.8	92.9	91.8	93.2
B	89.1	88.5	88.0	97.3	96.5	97.3	92.8
Mean	92.9	92.3	92.5	97.7	95.2	95.5	94.4

(1)C1: nutrients relations with higher variance ratio; (2)C2: nutrients relations with higher variance ratio and lower coefficient of asymmetry with partial transformation of Box and Cox (1964); (3)C3: nutrients relations with higher variance ratio and lower coefficient of asymmetry with total transformation of Box and Cox (1964); and (4)C4: nutrient relations with logarithmic neperian transformation.

Although there were no significant statistical differences between the nutritional diagnoses obtained by four criteria for choosing DRIS standards (Tables 5 and 6), the individual values in classes P, PZ, Z, NZ and N (Table 5) were grouped in three classes (Table 6) revealed that C2, C3 and C4 criteria showed a tendency to increase the values for these studied nutrients. The Fe presented asymmetric positive relations with predominance of positioning in the numerator, being observed values concentrated in classes deficient (P), probably deficient (PZ) (Table 5) and deficient (P + PZ) (Table 6) by criterion C1. The Fe presented an inverse behavior to what happened in criterion C1, when the criteria C2, C3 and C4 were used, in which relationships between nutrients were transformed. Micronutrient Cu presented same behavior as Mn (Tables 1, 2, 3 and 4), although it did not present significant differences (Tables 5 and 6). The coefficients of variation (CV) of selected nutritional ratios for standards were very variable (Tables 1, 2, 3 and 4). Through C1, values ranged from 16.2% (P/K) to 74.4% (Ca/Mn). Values ranged from 20.2% (N/Cu) to 74.4% (Ca/Mn) in asymmetric relationships. However, symmetric values with CV >35% occurred. In this case, the use of CV as a criterion for choosing symmetric values may not be appropriate without considering the asymmetry coefficients. The other C2, C3 and C4 criteria provided a reduction in CV values, improving the reliability of data and norms generated. According to Rocha et al. (2007), relationships between nutrients that have high ratio between variances are trustable for nutritional diagnosis. This same selection based on high ratio of variance was studied by Reis Junior et al. (2002), Santana et al. (2008) and Mourão Filho et al. (2002). Saldanha et al. (2017) reported that relationships among nutrients selected as DRIS standards for coconut showed a high variance ratio (s^2_b/s^2_a) and reduced CV, which could be very important for production. Therefore, relationships among nutrients that present high s^2_b/s^2_a indicate low variability of data of high productivity group. Thus, high ratio of small variance and CV found for nutrient ratios establishes a balance between nutrient pairs and is fundamental for high sugarcane production. This same pattern of response was described by Reis Junior (1999), in a study with sugarcane in Brazil.

The use of Neperian logarithm transformation as criteria for choosing nutritional relations to establish the DRIS (C4) norms provided greater normality in data set. However, some relationships were asymmetric, even after transformation (Table 4). Urano et al. (2006) also found higher data normality after transformation, although they used normality test of Lillifors. Beverly (1987), aimed at reducing asymmetry values and normalizing data. The authors found values of asymmetry >1, even after transformation, when proposing the use of transformation of data through neperian logarithm. Ramakrishna et al. (2009) selected relationships between nutrients that presented a s^2_b/s^2_a >1, asymmetry coefficient <1 and CV ≤ 35%, with the purpose of normalizing data for generation of standards.

The criterion C4 is one of easiest operation because it only considers the population of reference or high productivity for generation of norms DRIS.

Nutritional diagnosis

Different criteria for interpretation of DRIS norms can lead to different nutritional diagnoses. According to Beaufils (1973), when the value of a relation tends to approach ideal values to reach high yields, the variance of this relation is more likely to diagnose nutritional imbalance, especially for Mn, Cu and B. It tends to be lower among low and high yield sub-populations. In this way, nutritionally balanced crops tend to have smaller variances between these sub-populations. According to Serra et al. (2013), the criterion C1 would favor the choice of relations with lower variation in high productivity sub-population. For Ca and S, the discordance of nutritional diagnosis revealed, when DRIS norms were generated by C1 only. It also occurred when faced with nutritional diagnosis of norms generated by criterion C4 (Table 7). In general, the nutritional diagnosis provided by DRIS standards and generated by criteria C2, C3 and C4 were concordant (Table 7).

When nutritional diagnoses were grouped in to three classes (Table 8), the agreement or disagreement of diagnoses provided by different selection criteria for generation of DRIS norms presented the same grouping behavior in five classes (Table 7). The nutritional diagnosis performed, when DRIS norms were generated by criterion C1, rejecting the hypothesis that percentages of agreement in nutritional diagnoses were equal. It suggests the influence of selection of criteria adopted to generate DRIS norms to diagnose differences in probability of positive response to nutrient fertilization (Tables 7 and 8).

Materials and methods

Description of experimental site

The present study was conducted in commercial sugarcane plantations in sugarcane region of Northeast in State of Alagoas, Brazil. The region presents a hot and humid climate, high annual rainfall (1500-2000 mm) and an annual average temperature of 28 ºC (Souza et al., 2004). The predominant soils in region are fragilic Dystrophic Yellow Argisols, Fragiphic and Dystrophic Dystrophic Argisols, Latosol Dystrophic Yellow Argisols and Fragipanic and Duripanic Ferrocassic Spodosols (EMBRAPA, 2013).

Fertilizers and plant material

Before planting, liming was performed to raise base saturation to 70%. The planting fertilization was carried out with following management: a) winter fertilization using as green manure *Crotalaria spectabilis* associated with 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) summer fertilization using organic waste (filter cake) from the sugar-alcohol industry (20 Mg ha^{-1} at the bottom of furrow) associated with 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 regrowth (sugarcane in the second cropping cycle) was performed using 96 kg ha^{-1} of N, 36 kg ha^{-1} of P_2O_5 and 144 kg ha^{-1} of K_2O, at the fourth leaf stage. From the second regrowth (sugarcane in the third crop cycle) onwards, the fertilization was carried out with 90 kg

ha^{-1} of N and 140 kg ha^{-1} of K_2O, always when the fifth leaf is issued.

Commercial crops of sugarcane were planted with varieties RB72454, RB75126, RB83594, RB845210, RB855113, RB855463, RB855536, RB867515, RB92579, RB93509, RB98710, SP75-3046, SP79-1011, SP81-3250, SP83-2847 and Co997. However, the varieties that predominated in the planting were RB92579, RB93509, RB867515, SP79-1011 and Co997.

Foliar sampling and nutritional determinations

Leaf sampling of sugarcane was performed in the first crop cycle (cane plant) and in the second (cane soca), making a total of 183 samples. The collection was performed in the beginning of rainy season, which includes period of high nutrient uptake to meet the establishment and growth stage for crop formation. The average of +3 leaves 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 N in the leaves was mineralized in sulfur digestion and dosed using the Kjeldahl micro method (Horneck and Miller, 1998). The other nutrients were mineralized in nitricorchloric digestion and extracts obtained by the following methods: P was analyzed colorimetrically by molybdate method; the K by flame photometry; Ca, Mg, Mn, Zn, Fe and Cu by atomic absorption spectrophotometry; or S by turbidimetry; and B by dry digestion by incineration method. Nutritional analyzes were performed according to Kalra (1998).

Statistical procedures for determining DRIS standards

With data of agricultural productivity and nutritional contents of areas of sugar cane, a database was formed and divided into two groups: a low productivity group (<80 Mg ha^{-1}) and a high productivity group (≥80 Mg ha^{-1}). The database consisted of 183 samples, 31 from high productivity areas (reference population) and 152 from low productivity areas. The minimum values (min), maximum (max), median (med), mean (standard deviation), coefficient of variation (CV), variance (s^2), asymmetry (Asy) and kurtosis (Kurt) for the data of agricultural productivity and nutrient contents in the groups of high and low productivity (Beiguelman, 2002) were evaluated.

The comparison of mean values of productivity and nutrient contents between high and low productivity groups was performed using Student *t* test (p<0.05), considering the homoscedasticity among the variances (Beiguelman, 2002). The binary ratios between nutrient contents were calculated in each group to obtain the Min, Max, Med, $\bar{x}$, s, CV, s^2, Asy and Kurt values. In addition, the ratio between the variances of low and high productivity groups (s^2_b/s^2_a) was calculated.

The normalization of data of high productivity group was based on the ratio between the asymmetry coefficient - g_1 (equation 1) and its estimated error - Fisher's Sg_1 (equation 2), compared with Student's *t* test at 10% of probability (Beiguelman, 2002) and an equivalent asymmetry coefficient of |0.715|. This same procedure was adopted for kurtosis values, which was also based on ratio between kurtosis coefficient - g_2 (equation 3) and its estimated error - Fisher's Sg_2 (equation 4), compared with Student *t* test at 10% probability, with an equivalent kurtosis coefficient of |1.395|. Therefore, $g_1 \leq |0.715|$ and $g_2 \leq |1.395|$ indicated normality of data.

Criteria for determining DRIS standards

The nutrient indexes were calculated using the DRIS (Beaufils, 1973), using four criteria (C) to obtain the standards: C1 - nutrient ratios with higher ratio of variance; C2 - nutrient ratios with higher ratio of variance and lower coefficient of asymmetry with partial transformation of Box and Cox (1964); C3 - nutrient ratios with higher ratio of variance and lower asymmetry coefficient with total transformation of Box and Cox (1964); and C4 - nutrient ratios with logarithmic neperian transformation.

The coefficient g_1 for all standards were determined according to Fisher and described by Beiguelman (2002), according to equation 1:

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

Thus:

g_1 = asymmetry coefficient;

n = sample size;

Xi = value of binary relation between observed nutrients;

$\bar{X}$ = mean of binary relation between observed nutrients;

s = standard deviation of binary relation between observed nutrients.

The coefficient g_1 is equal to zero when the distribution is normal and symmetric. When g_1>0, the asymmetry is positive, with the tail distribution stretching to the left of the mean; when g_1<0 the asymmetry is negative, with the tail distribution stretching to the right of mean. The coefficient g_1 that estimates the parametric value has normal distribution in large samples. The estimated error (Sg_1) of asymmetry coefficient was calculated according to equation 2:

$$Sg_1 = \sqrt{\frac{6n(n-1)}{(n-2)(n+1)(n+3)}} \qquad (2)$$

Thus:

Sg_1 = Asymmetry error;

n = sample size.

The ratio of g_1 to Sg_1 was calculated and Student *t* test was performed to verify that g_1 value deviated significantly from zero. The *t* was calculated with 30 degrees of freedom and level of significance of up to 10% (tc = 1,697). Value of *t* ≥1.697 indicated that g_1>0 (positive asymmetry). Value of *t* < 1.697 indicated that g_1<0(negative asymmetry).

The kurtosis is degree of concentration of values of a continuous variable around the mean, considering the normal curve (mesocurtic curve) as reference. Thus, the distribution is leptokurtic when there is an excess of values close to mean, giving a sharp shape to distribution, particularly when flattening of representative curve of distribution occurs (Beiguelman, 2002).

The coefficient g_2 was calculated to determine the kurtosis type, according to equation 3:

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

Thus:
g_2 = kurtosis coefficient;

n = sample size;

Xi = value of binary relation between observed nutrients;

$\bar{X}$ = mean of binary relation between observed nutrients;

S = standard deviation of binary relation between observed nutrients.

The coefficient g_2 is zero when the distribution curve is normal; when $g_2>0$ the curve is leptokurtic; and when $g_2<0$ the curve is platicurtic. The coefficient g_2 has a normal distribution in large samples. The estimated error (Sg_2) of kurtosis coefficient was calculated according to equation 4:

$$Sg_2 = \sqrt{\frac{24\,n\,(n-1)^2}{(n-3)(n-2)(n+3)(n+5)}} \quad (4)$$

Thus:
S_{g2} = Kurtosis error;

n = sample size.

The ratio of g_2 to Sg_2 was calculated and Student *t* test was performed to verify if g_2 value deviated significantly from zero. The *t* was calculated with 30 degrees of freedom and level of significance of up to 10% (tc = 1,697). Value of $t \geq 1.697$ indicated that $g_2>0$ (leptokurtic distribution). Value of $t < 1.697$ indicated that $g_2<0$ (platicurtic distribution).

Criteria of nutrient ratios with high ratio of variance (C1)

The selections of direct and inverse relationships of nutrient contents for composition of norms were made by choosing the highest ratios of variance among low and high productivity population groups (s^2_b/s^2_a), as described by Walworth and Sumner (1986).

Criteria of nutrient ratios with high ratio of variance and low coefficient of asymmetry with partial transformation Box and Cox (C2)

The selection of standards was done by choosing relations with highest ratio of variance among groups of low and high productivity population (s^2_b/s^2_a) with $g_1<|0.715|$. The selected relationships that continued to present asymmetric values and/or CV>35%, were transformed data, applying the criteria proposed by Box and Cox (1964), according to equation 5:

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

Thus:

Yi = transformed value of binary relation between nutrients;

Xi = observed value of binary relation between nutrients;

λ = processing value (2,0 -2,0).

For different values λ, the ideal value selecion was selected by maximum likelihood estimation, according to equation 6:

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

Thus:

EMV = estimation of maximum likelihood;

n = sample size;

Yi = transformed value of binary relation between nutrients;

$\bar{Y}$ = mean of transformed values of binary relation between nutrients;

λ = value of lambda;
Xi = observed value of binary relation between nutrients.

The function of maximum likelihood estimator (*EMV*) is to maximize probability for transformed data to have symmetric or normal distribution. Box-Cox transformation allows selecting a transformation by solving the irregular distribution (non-normality) of the data and heterogeneity of errors (Box and Cox, 1964; Draper and Cox, 1969; Peltier et al., 1998). The result is the reduction of absolute value of asymmetry, which tends to zero. The values of $\lambda>1$ eliminate negative asymmetry, while valores values between $0<\lambda<1$ eliminate positive asymmetry (Coleman and Swanson, 2007).

Criteria of nutrient ratios with high ratio of variance and low coefficient of asymmetry with total transformation Box and Cox (C3)

The selection of standards was done using the same procedure of selection of criterion C2. The difference was that in all selected relations the data were transformed, according to criteria proposed by Box and Cox (1964).

Criteria of nutrient ratios with logarithmic neperian transformation (C4)

The selection of norms was carried out with transformation of all direct and inverse relations of high productivity population through neperian logarithm (Beverly, 1987; Alvarez and Leite, 1999).

Procedures to calculate DRIS indexes

The DRIS indexes was calculated by formula proposed by Beaufils (1973), updated by Maia (1999), expressed by ratio (A/B) for sample and (a/b) for population of high productivity or reference. 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

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

Thus,
f(A/B) = function between relation of nutrientes;
A/B = relation between nutrients of sample;
a/b = relation between nutrients of reference population;
S = standard deviation of relationship between nutrients of reference population;
k = sensitivity constant with a value equal to 10.

With result of each function, DRIS index of each nutrient was calculated according to equation 10:

$$Index\ A=\frac{\sum_{i=1}^{n}f(A/Bi)-\sum_{i=1}^{m}f(Bi/A)}{n+m} \quad (10)$$

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

The mean nutrient balance index (*NBIm*) was calculated by summing the absolute values of DRIS indexes obtained for each nutrient, divided by number of nutrients that make up the NBIm (*z*), according to equation 11:

$$NB\,\mathrm{Im}=\frac{1}{z}\sum_{i=1}^{z}\left|Index\ Ai\right| \quad (11)$$

Thus:
NBIm = index of mean nutritional balance;
z = number of nutrients;
Index A = nutrient DRIS index "A".

Diagnostics of nutritions

The DRIS were interpreted using the PFR from five classes (Wadt, 2005). This method is based on comparison of DRIS index module of each nutrient (|*Index A*|) with *NBIm*. In this case, it is verified whether the imbalance attributed to a particular nutrient is greater or less than imbalance attributed to mean of all nutrients (Wadt et al., 2013).

The diagnosis produced by different methods of nutritional diagnosis were interpreted by PFR and divided into five classes: positive (P) for nutrients that were deficient; positive or zero with low probability (PZ) for nutrients that were probably deficient: zero (Z) for balanced nutrients; negative (NZ) for nutrients that were probably excessive; negative with high probability (N) for excessive nutrients. This same procedure was adopted when only three classes of interpretation were chosen. In this case, the nutritional status was identified as deficient (P + PZ), balanced (Z) and excessive (NZ + N).

After that, the degree of agreement between diagnoses obtained using different methods. It was also used to calculate and evalute the DRIS indexes. For a nutrient, if the diagnosis (deficient, balanced or excessive) was the same between two distinct methods, it was considered concordant. If diagnosis was different, it was considered non-concordant. The percentage of concordant diagnoses was also calculated for all evaluated methods. The frequency with each nutrient was identified as having responses to P, PZ, Z, NZ and N classes and three classes (P + PZ, Z and NZ + N).

Then, we compared the classes observed by different methods of calculating the DRIS by Chi-Square Likelihood Ratio Test or G-test (equation 12). This test is used in biological phenomena, in evaluation of adjustment quality in multivariate statistics, with logistic regression and independence in contingency tables (Wilks, 1935; Sokal and Rohlf, 1994).

$$G=2\sum_{i=1}^{k}fo\ln\left(\frac{fo}{fe}\right) \quad (12)$$

Thus,
G = Chi-Square Probability Ratio Test (G-Test);
fo = observed frequency;
fe = expected frequency;
K = number of classes.

Conclusion

The criteria for choosing nutritional ratios with highest ratios of variance for establishment of DRIS norms was not adequate due to high probability of diagnosing nutritional imbalance, especially for micronutrients. The selection of dual relationships between nutrient contents was better, when highest variance ratio was associated with the lowest asymmetry coefficient. Since coefficients were reduced and data were normalized, they provided similar nutritional diagnoses. Nutritional diagnoses were influenced by selection of criteria used to generate DRIS standards, diagnosing differences in likelihood of positive response to nutrient fertilization.

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