Norms establishment of the Diagnosis and Recommendation Integrated System (DRIS) for nutritional diagnosis of sugarcane[1]

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Abstract – The objectives of this study were to establish DRIS norms for sugarcane crop, to compare mean yield, foliar nutrient contents and variance of nutrient ratios of low- and high-yielding groups and to compare mean values of nutrient ratios selected as the DRIS norms of low- and high-yielding groups. Leaf samples (analyzed for N, P, K, Ca, Mg, S, Cu, Mn and Zn contents) and respective yields were collected in 126 commercial sugarcane fields in Rio de Janeiro State, Brazil and used to establish DRIS norms for sugarcane. Nearly all nutrient ratios selected as DRIS norms (77.8%) showed statistical differences between mean values of the low- and high-yielding groups. These different nutritional balances between the low- and high-yielding groups indicate that the DRIS norms developed in this paper are reliable. The DRIS norms for micronutrients with high S^2_l/S^2_h ratio and low coefficient of variation found can provide more security to evaluate the micronutrient status of sugarcane.

Index terms: *Saccharum officinarum*, foliar nutrient content, plant analysis, nutritional status, productivity.

Estabelecimento de normas do Sistema Integrado de Diagnose e Recomendação (DRIS) para a diagnose nutricional da cana-de-açúcar

Resumo – Os objetivos deste trabalho foram estabelecer normas DRIS para a cultura da cana-de-açúcar, comparar médias de produtividade, médias de teores foliares de nutrientes e variâncias das razões entre nutrientes dos grupos de baixa e alta produtividade e comparar valores médios das razões selecionadas como normas DRIS dos grupos de baixa e alta produtividade. Amostras foliares (analisadas quanto a N, P, K, Ca, Mg, S, Cu, Mn e Zn) e respectivas produtividades foram coletadas em 126 lavouras comerciais, em Campos dos Goytacazes, RJ, e usadas para estabelecer as normas DRIS para a cana-de-açúcar. As médias de produtividade e de teores foliares não foram similares entre os grupos de baixa e alta produtividade. As razões entre variâncias dos grupos de alta e baixa produtividade foram diferentes. A maioria das razões entre nutrientes selecionadas como normas DRIS apresentaram médias estatisticamente diferentes entre os grupos de baixa e alta produtividade. Estes diferentes equilíbrios nutricionais entre os grupos de alta e baixa produtividade indicam que as normas DRIS estabelecidas neste trabalho são confiáveis. As normas DRIS obtidas com valores altos de razão entre variâncias dos grupos de alta e baixa produtividade e baixos coeficientes de variação oferecem maior segurança para avaliar o estado nutricional da cana-de-açúcar em relação aos micronutrientes.

Termos para indexação: *Saccharum officinarum*, teor foliar de nutriente, análise vegetal, estado nutricional, produtividade.

Introduction

Almost 20 million hectares of sugarcane are grown around the world and about 25% of that area are located in Brazil (FAO, 1999). The crop is grown extensively in this country with an average 5.0 million ha in production and annual yield reaches nearly 340 million Mg (IBGE, 1999). Although Brazil has the highest growing area and production in the world, it presents a low productivity, 67.8 Mg ha^{-1}. Therefore systematic research should be carried out to identify the causes of this low productivity.

The fertilizers input in the sugarcane crop represents a significant portion of its production cost, hence constant evaluation and calibration of the fertilizer programs in this crop is necessary, which may be supported by nutritional diagnosis.

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The Diagnosis and Recommendation Integrated System (DRIS) is a method to evaluate plant nutritional status that uses a comparison of the leaf tissue nutrient concentration ratios of nutrient pairs with norms from a high-yielding group (Soltanpour et al., 1995). The first step to implement DRIS or any other foliar diagnostic system is the establishment of standard values or norms (Walworth & Sumner, 1987; Bailey et al., 1997).

In order to establish the DRIS norms, it is necessary to use a representative value of leaf nutrient concentrations and respective yields to obtain accurate estimates of means and variances of certain nutrient ratios that discriminate between high- and low-yielding groups. This is done using a survey approach in which yield and nutrient concentration data are collected from commercial crops and/or field experiments from a large number of locations (Bailey et al., 1997) to form a databank.

Pair of nutrient ratios are calculated from the data bank of nutrient concentrations and then, the mean, the variance and the coefficient of variation of each ratio are calculated. There are two forms of expression for a pair of nutrients, although in DRIS calculations only one form is used. The way to select the form of ratio for a pair of nutrients to be used in DRIS calculation is described by Walworth & Sumner (1987) and Hartz et al. (1998).

After the establishment of the DRIS norms, the formula proposed by Beaufils (1973) calculates an index for each nutrient that range from negative to positive values. All nutrient indices always sum to zero (Elwali & Gascho, 1984). Essentially, a nutrient index is a mean of the deviations from the optimum or norms values (Bailey et al., 1997). Negative DRIS index values indicate that the nutrient level is below optimum, consequently the more negative index, the more deficient the nutrient. Similarly, a positive DRIS index indicates that the nutrient level is above the optimum, and the more positive the index, the more excessive the nutrient is relative to normal, and DRIS index equal to zero indicates that the nutrient is at the optimum level (Baldock & Schulte, 1996). The DRIS also computes an overall index, which is the sum of the absolute values of the nutrient indices (Baldock & Schulte, 1996), called nutrient balance index (NBI) (Rathfon & Burger, 1991). The smaller the absolute sum of all DRIS indices, the lesser the imbalance among nutrients (Snyder & Kretschmer, 1987).

The objectives of this study were to establish DRIS norms for sugarcane crop, to compare mean yield, foliar nutrient contents and variance of nutrient ratios of low- and high-yielding groups and to compare mean values of nutrient ratios selected as the DRIS norms of low- and high-yielding groups.

Material and Methods

A total of 126 sugarcane fields were sampled during the 1996-1997 season in Campos dos Goytacazes, RJ, Brazil. Leaf samples were collected in commercial sugarcane fields of both plant-cane and ratoon crops (variety CB45-3, RB72-454, RB73-9735 and SP70-1143), four months after sugarcane plant sprout. Samples consisted of 15 leaf blades of the second leaf below the top visible dewlap (leaf +3) collected in nearly one ha.

Central portion of the sampled leaf, after discarding the midrib, was dried at 70°C for 72 hours. Dried leaf samples were ground to pass through a 20-mesh screen using a stainless steel mill. Leaf samples were analyzed for organic N by Nessler method (Jackson, 1965), after subsamples (0.1 g) of the dried leaf had been digested by a mixture of concentrated H_2SO_4 (1.5 mL) and H_2O_2 30% (1 mL) until the digest mixture was clear. The digest was analyzed for P colorimetrical by the method of molybdate, for K by flame atomic emission spectroscopy, for Ca, Mg, Cu, Mn and Zn by atomic absorption spectroscopy and for S by turbidimetric method after the subsamples (0.5 g) of the dried leaf were digested with a mixture of 65% HNO_3 (4 mL) and 70% $HClO_4$ (2 mL) until the digest mixture was clear.

Sugarcane yield data were collected from sampled fields. Yield and foliar nutrient concentrations built a databank, which was divided into high- ($\geq$75 Mg ha^{-1}) and low-yield (<75 Mg ha^{-1}) groups. The mean, according to Beaufils (1973), variance and coefficient of variation (CV) for each possible ratio for all pairs of nutrient (i.e.: N/P or P/N) were calculated for both yield groups. A Lilliefors test was performed to ensure that nutrient ratios were based on Gaussian distribution. For each nutrient pair, the mean and CV of the ratio that maximized the variance ratio between the low- and high-yielding group was selected as the DRIS norms for that pair of nutrient, as described by Walworth et al. (1986) and Hartz et al. (1998).

Average yield and foliar nutrient concentrations for the low- and high-yielding groups were compared by confidence intervals evaluation (P<0.05). Differences between variances from the low- and high-yielding groups were evaluated by F test. Differences between mean of the nutrient ratios selected as DRIS norms were evaluated by t test.

Results and Discussion

DRIS norms established for sugarcane crop (Table 1) should be useful to evaluate sugarcane nutritional status and to calibrate fertilizer programs, but they must be validated before sugarcane growers adopt them.

Sugarcane crops in 21 fields were ranked in the high-yielding group (yield ≥75 Mg ha^{-1}), while 105 fields yielded <75 Mg ha^{-1}. The average yield in the high-yielding group was 89.4 Mg ha^{-1}, while the average yield in the low-yielding group was 54.1 Mg ha^{-1} (Table 2). This difference was statistically significant ($P<0.05$) and could be a good

Table 1. Mean, coefficient of variation (CV) and variance (S^2) of nutrient ratios of the low- and high-yielding groups, the variance ratio (S^2_l/S^2_h) and the selected ratios for sugarcane DRIS norms [(1)].

Nutrients	High-yielding group			Low-yielding group			S^2_l/S^2_h	Selected ratios
	Mean	CV (%)	Variance (S^2_h)	Mean	CV (%)	Variance (S^2_l)		
N/P	7.21***	20.5	2.192	8.62	28.7	6.099	2.78***	X
P/N	0.145	21.9	0.001	0.128	34.8	0.002	2.00**	
N/K	1.24***	26.1	0.105	1.59	24.7	0.154	1.46	X
K/N	0.841	18.8	0.025	0.671	26.8	0.032	1.28	
N/Ca	4.94	46.0	5.175	4.01	45.6	3.347	0.64	
Ca/N	0.244***	42.2	0.011	0.304	46.7	0.020	1.82*	X
N/Mg	6.18	35.6	4.847	6.63	36.2	5.777	1.19	X
Mg/N	0.188	42.3	0.006	0.169	33.6	0.003	0.50	
N/S	8.07***	19.1	2.373	10.6	47.9	25.94	10.9***	X
S/N	0.129	21.0	0.001	0.108	33.9	0.001	1.00	
N/Cu	3.04	18.5	0.315	3.32	25.3	0.670	2.12**	X
Cu/N	0.340	19.0	0.004	0.331	27.9	0.008	2.00**	
N/Mn	0.211	21.9	0.002	0.207	42.8	0.008	4.00***	
Mn/N	4.95**	20.2	0.998	5.62	37.3	4.409	4.42***	X
N/Zn	1.05***	12.9	0.018	1.27	39.6	0.259	14.3***	X
Zn/N	0.968	13.8	0.018	0.914	39.6	0.131	7.28***	
P/K	0.181	40.5	0.005	0.192	25.3	0.002	0.40	
K/P	6.03*	24.4	2.171	5.49	21.4	1.384	0.63	X
P/Ca	0.672	33.7	0.051	0.467	39.1	0.033	0.65	
Ca/P	1.66***	34.4	0.325	2.37	28.6	0.461	1.42	X
P/Mg	0.887	42.8	0.141	0.781	25.1	0.039	0.27	
Mg/P	1.30	32.8	0.182	1.36	23.2	0.099	0.54	X
P/S	1.14*	19.5	0.049	1.27	41.0	0.271	5.53***	X
S/P	0.906	18.1	0.027	0.876	29.2	0.066	2.44***	
P/Cu	0.427	12.1	0.003	0.039	25.0	0.010	3.33***	
Cu/P	2.38***	13.3	0.100	2.73	28.4	0.602	6.02***	X
P/Mn	0.0312	38.9	0.0001	0.026	57.1	0.0002	2.00**	
Mn/P	36.3***	33.5	147.4	48.1	45.4	477.9	3.24***	X
P/Zn	0.150	18.9	0.001	0.149	27.5	0.002	2.00**	
Zn/P	6.87	17.4	1.428	7.29	32.9	5.742	4.02***	X
K/Ca	4.02	39.1	2.469	2.61	51.8	1.831	0.74	
Ca/K	0.300***	56.2	0.028	0.461	39.3	0.033	1.18	X
K/Mg	5.07**	32.5	2.717	4.23	30.3	1.642	0.60	X
Mg/K	0.231	54.9	0.016	0.257	28.5	0.005	0.31	
K/S	6.74	22.8	2.370	6.87	45.2	9.646	4.07***	X
S/K	0.161	39.9	0.004	0.165	32.2	0.003	0.75	

Continue...

Table 1. Continuation.

Nutrients	High-yielding group			Low-yielding group			S^2_l/S^2_h	Select ratios
	Mean	CV (%)	Variance (S^2_h)	Mean	CV (%)	Variance (S^2_l)		
K/Cu	2.57	26.7	0.470	2.12	26.9	0.395	0.84	
Cu/K	0.425**	36.2	0.024	0.515	31.4	0.026	1.08	X
K/Mn	0.177	27.8	0.002	0.137	50.0	0.05	2.50***	
Mn/K	6.17***	34.3	4.469	8.83	42.3	13.96	3.12***	X
K/Zn	0.879*	18.3	0.026	0.796	27.5	0.048	1.84*	X
Zn/K	1.20	33.2	0.159	1.36	31.0	0.178	1.12	
Ca/Mg	1.34***	32.3	0.188	1.81	32.7	0.353	1.88**	X
Mg/Ca	0.813	28.9	0.055	0.616	35.9	0.049	0.89	
Ca/S	1.86***	21.2	0.338	3.03	51.7	2.442	7.22***	X
S/Ca	0.606	42.2	0.065	0.406	42.9	0.030	0.46	
Ca/Cu	0.707***	32.3	0.052	0.919	34.7	0.102	1.96**	X
Cu/Ca	1.61	40.9	0.432	1.26	52.5	0.439	1.01	
Ca/Mn	0.0525	50.0	0.001	0.062	71.0	0.02	2.00**	X
Mn/Ca	25.4	62.1	249.2	22.6	53.4	138.2	0.55	
Ca/Zn	0.247***	35.3	0.008	0.354	40.6	0.021	2.62***	X
Zn/Ca	4.61	39.7	3.351	3.42	52.9	3.270	0.97	
Mg/S	1.43**	27.1	0.150	1.71	58.6	1.001	6.67***	X
S/Mg	0.759	31.0	0.055	0.669	31.8	0.045	0.82	
Mg/Cu	0.551	33.6	0.034	0.524	28.8	0.023	0.67	
Cu/Mg	2.05	38.7	0.634	2.10	35.9	0.572	0.90	X
Mg/Mn	0.0391	44.6	0.0003	0.0345	52.0	0.0003	1.00	
Mn/Mg	30.3**	39.5	143.0	36.8	51.5	360.5	2.52***	X
Mg/Zn	0.189	30.3	0.003	0.200	33.9	0.005	1.66*	
Zn/Mg	5.77	29.7	2.94	5.67	46.3	6.882	2.34**	X
S/Cu	0.384	17.7	0.005	0.337	33.4	0.013	2.60***	
Cu/S	2.69***	17.8	0.228	3.39	45.8	2.415	10.6***	X
S/Mn	0.0272	30.2	0.0001	0.0225	56.2	0.0002	2.00**	
Mn/S	39.9***	28.2	127.3	60.8	67.2	1,670.3	13.1***	X
S/Zn	0.133	12.7	0.0003	0.131	41.5	0.003	10.0***	
Zn/S	7.66***	13.4	1.050	9.31	59.1	30.24	28.8***	X
Cu/Mn	0.0729	35.4	0.001	0.0698	56.9	0.002	2.00**	
Mn/Cu	15.3**	31.9	23.732	18.5	48.5	80.4	3.38***	X
Cu/Zn	0.353***	16.8	0.003	0.406	43.0	0.031	10.33***	X
Zn/Cu	2.91	15.9	0.214	2.83	33.9	0.918	4.28***	
Mn/Zn	5.23***	27.0	1.991	6.95	49.1	11.63	5.84***	X
Zn/Mn	0.205	25.8	0.003	0.184	54.2	0.010	3.33***	

(1) Mean of nutrient ratios of low- and high-yielding groups are significantly different at the 1% (***), 5% (**) and 10% (*) level (t test); variances of nutrient ratios of low- and high-yielding groups are significantly different at the 1% (***), 5% (**) and 10% (*) level of probability by F test.

indicator of the reliability of the DRIS norms developed in this paper.

Although the absolute average foliar N, P, K, Mg, S, Cu and Zn concentrations were higher in the high-yielding group than in the low-yielding group, only the mean foliar P, K and S concentrations were significantly higher (P<0.05) in the high-yielding group than in the low-yielding group (Table 2). Although foliar average Ca and Mn concentrations were lower in the high-yielding group than in the low-yielding group, they were not significantly different. The variances of yield and nutrient concentration were not similar for both yield groups (Table 1). These differences (P, K and S) could be good indicators of the reliability of the DRIS norms developed in this work.

All nutrient ratios from the high-yielding group showed Gaussian distribution (p<0.01). The mean, coefficient of variation, variance of all nutrient ratios of the high- (S^2_h) and low-yielding group (S^2_l) and the variance ratio between the low- and high-yielding group (S^2_l/S^2_h) are shown in Table 1. Thirty-six nutrient ratios were used as DRIS norms because they showed the highest S^2_l/S^2_h ratio. The selection of a nutrient ratio as DRIS norms (i.e.: N/P or P/N) is indicated by the S^2_l/S^2_h ratio (Hartz et al., 1998). The higher S^2_l/S^2_h ratio, the more specific the nutrient ratio must be in order to obtain a high yield (Payne et al., 1990). Nearly all selected parameters showed a significant difference between the variance of low- and high-yielding groups (75%). Most of the selected nutrient ratios showed a lower coefficient of variation (CV) than the other possible nutrient ratio for the same pair of nutrients (i.e.: $CV_{K/P}$ = 24.4% < $CV_{P/K}$ = 40.5%).

Although Beaufils (1973) suggests that every parameter which shows a significant difference of variance ratio between the two groups under comparison (low- and high-yielding) should be used in DRIS, other researchers have adopted the ratio which maximized the variance ratio between the low- and high-yielding group (Snyder et al., 1989; Payne et al., 1990; Malavolta et al., 1997; Hartz et al., 1998). The aim of this procedure is to determine the norms with the greatest predictive precision (Caldwell et al., 1994). The discrimination between nutritionally healthy and unhealthy plants is maximized when the ratio of variances of low- vs. high-yielding groups is also maximized (Walworth et al., 1986).

Table 2. Mean, coefficient of variation (CV), variance and variance ratio between the low- and high-yielding groups (S^2_l/S^2_h) of both yield and foliar nutrient contents in the leaf dry matter of sugarcane at high- and low-yielding groups[(1)].

Variable	Group	Mean	CV(%)	Variance	S^2_l/S^2_h
Yield (Mg ha^{-1})	High	89.4**	15.1	181.3	0.98
	Low	54.1	24.6	177.4	
N (g kg^{-1})	High	14.9	14.4	4.63	1.56
	Low	14.5	18.6	7.22	
P (g kg^{-1})	High	2.12**	15.0	0.100	1.74*
	Low	1.77	23.6	0.174	
K (g kg^{-1})	High	12.4**	15.9	3.885	0.68
	Low	9.36	17.4	2.653	
Ca (g kg^{-1})	High	3.44	30.3	1.09	1.93**
	Low	4.15	34.9	2.10	
Mg (g kg^{-1})	High	2.68	30.3	0.657	0.57
	Low	2.36	26.0	0.378	
S (g kg^{-1})	High	1.89**	15.4	0.084	2.57***
	Low	1.51	30.7	0.216	
Cu (mg kg^{-1})	High	5.00	15.5	0.603	2.65***
	Low	4.70	26.9	1.597	
Mn (mg kg^{-1})	High	74.4	28.9	464.1	2.16**
	Low	80.5	39.3	1,001.7	
Zn (mg kg^{-1})	High	14.3	11.3	2.58	6.06***
	Low	12.6	31.4	15.65	

[(1)]High-yield ≥75 Mg ha^{-1}; low-yield <75 Mg ha^{-1}; mean yield and foliar nutrient contents of low- and high-yielding groups are significantly different at the 5% (**); variances of low- and high-yielding groups are significantly different at the 1% (***), 5% (**) and 10% (*) level of probability by F test.

Twenty-three out of 36 nutrient ratios selected as DRIS norms had S^2_l/S^2_h ratio ≥2, and 17 of the ratios that had variance ratios ≥2 contained a micronutrient (Cu, Mn or Zn). Payne et al. (1990) suggest the possible importance of DRIS norms for micronutrients with high variance ratios between low- and high-yielding groups to nutritional diagnosis in bahiagrass because micronutrient fertilization requirements are not easily determined by soil testing. As pointed by Bailey et al. (1997), DRIS norms (nutrient ratios) with large S^2_l/S^2_h ratios and small coefficient of variation imply that the balance between these specific pairs of nutrients could be of critical importance for crop production. Therefore, nutrient ratios with large S^2_l/S^2_h ratio and small coefficient of variation indicate that the obtainment of high yield should be associated to small variation around the average nutrient ratio. The DRIS norms for micronutrients with high S^2_l/S^2_h ratio and low coefficient of variation (CV) found in this paper probably can provide more security to evaluate the micronutrient status of sugarcane. There is a speculation that the large S^2_l/S^2_h ratio and the small CV found for specific ratios between nutrients probably imply that the balance between these pairs of nutrients could be important to sugarcane production.

For most nutrient ratios, there were statistical differences in mean values between the high-and low-yielding groups (N/P, N/K, Ca/N, N/S, Mn/N, N/Zn, K/P, Ca/P, P/S, Cu/P, Mn/P, Ca/K, K/Mg, Cu/K, Mn/K, K/Zn, Ca/Mg, Ca/S, Ca/Cu, Ca/Zn, Mg/S, Mn/Mg, Cu/S, Mn/S, Zn/S, Mn/Cu, Cu/Zn and Mn/Zn).

Mean nutrient ratios selected as DRIS norms were not similar in the low- and high-yielding groups

(Table 1). Nearly all nutrient ratios selected as DRIS norms showed statistical difference between its mean value in the low- and high-yielding groups (28/36). When there are no differences of nutritional balance between the low- and high-yielding groups, it is possible that the yield difference between the groups is not caused by nutritional effect; and the DRIS norms developed under this situation probably will not produce reliable diagnosis. The different nutritional balance between the low- and high-yielding groups indicates that the DRIS norms developed in this paper are reliable.

Conclusions

1. Mean yield and foliar nutrient concentrations are not similar in the low- and high-yielding groups.
2. Variance of nutrient ratios of low- and high-yielding groups are different.
3. Nearly all nutrient ratios selected as DRIS norms (28/36) show statistical differences between mean values in the low- and high-yielding groups.
4. These different nutritional balances between the low- and high-yielding groups indicate that the DRIS norms developed in this paper are reliable.

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