FERTILIZATION RESPONSE LIKELIHOOD FOR THE INTERPRETATION OF LEAF ANALYSES[(1)]

Celsemy Eleutério Maia[(2)]

SUMMARY

Leaf analysis is the chemical evaluation of the nutritional status where the nutrient concentrations found in the tissue reflect the nutritional status of the plants. Thus, a correct interpretation of the results of leaf analysis is fundamental for an effective use of this tool. The purpose of this study was to propose and compare the method of Fertilization Response Likelihood (FRL) for interpretation of leaf analysis with that of the Diagnosis and Recommendation Integrated System (DRIS). The database consisted of 157 analyses of the N, P, K, Ca, Mg, S, Cu, Fe, Mn, Zn, and B concentrations in coffee leaves, which were divided into two groups: low yield (< 30 bags ha^{-1}) and high yield (≥ 30 bags ha^{-1}). The DRIS indices were calculated using the method proposed by Jones (1981). The fertilization response likelihood was computed based on the approximation of normal distribution. It was found that the Fertilization Response Likelihood (FRL) allowed an evaluation of the nutritional status of coffee trees, coinciding with the DRIS-based diagnoses in 84.96 % of the crops.

Index terms: modeling, nutritional status, DRIS.

RESUMO: *PROBABILIDADE DE RESPOSTA À ADUBAÇÃO PARA INTERPRETAÇÃO DE ANÁLISE FOLIAR*

A análise foliar é uma avaliação química do estado nutricional, em que as concentrações de nutrientes encontradas no tecido refletem o estado nutricional das plantas. Assim, a correta interpretação dos resultados de análise foliar é fundamental para o uso eficaz dessa ferramenta. O objetivo deste trabalho foi propor e comparar o método da Probabilidade de Resposta à Adubação (PRA) para interpretação da análise foliar com a do Sistema Integrado de Diagnose e Recomendação (DRIS). O banco de dados foi composto de 157 análises das

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(2) Departamento de Ciências Ambientais e Tecnológicas (Department of Environmental and Technological Sciences), Universidade Federal Rural do Semi-Árido (UFERSA), 59625-900, Mossoró, RN, Brazil. E-mail: celsemy@ufersa.edu.br

concentrações de N, P, K, Ca, Mg, S, Cu, Fe, Mn, Zn e B nas folhas de café, que foram divididas em duas populações: baixa produtividade (< 30 sc ha^{-1}) e alta produtividade (≥ 30 sc ha^{-1}). O cálculo dos índices DRIS foi feito usando o método proposto por Jones (1981). A PRA foi calculada com base na aproximação da distribuição normal. Conclui-se, para a cultura do café, que a PRA possibilitou avaliar o estado nutricional do cafeeiro, com 84,96 % das lavouras avaliadas, o que coincidiu com o diagnóstico feito pelo DRIS.

Termos de indexação: modelagem, estado nutricional, DRIS.

INTRODUCTION

Leaf diagnosis has served to evaluate the nutritional status of plants based on chemical analyses of a plant tissue that is sensitive enough to show variations in nutrient levels. The use of leaf analysis as a diagnostic criterion is based on the premise that there is a relationship between nutrient supply and the levels of the leaf elements, and that concentration increases or decreases are related to higher or lower yields. The nutrient content in the plant is a composite value of all factors that interact to affect it. To interpret the results of chemical analysis of plants adequately, it is necessary to know the factors that affect nutrient concentrations, the standardized sampling procedures and the pertinent relationships. For this purpose, various researchers have used different methods to assess the nutritional status of plants, e.g., Tonin et al. (2009), Urano et al. (2007) and Maia et al. (2001) using the critical level (CL), Serra et al. (2010) and Farnezi et al. (2009) using the sufficiency range and Ramakrishna et al. (2009) and Wadt (2005) using DRIS. For coffee, this last method is most commonly used to assess the plant nutritional status.

In practice, the calculated values of the DRIS indices are used to interpret the result of leaf analysis. The nutrient with the most negative DRIS index is considered the most limiting for crop yield. However, Wadt (1996) proposed a safer criterion for the interpretation of DRIS indices, called Fertilization Response Potential. Based on this criterion, the mean Nutritional Balance Index (NBI_m) is estimated, which consists of the arithmetic mean of the module of all DRIS indices. According to the above author, NBI_m was chosen as a value that reflects the mean deviation of each nutrient from the reference value; different degrees of expectation of response to fertilization can be attributed to a nutrient according to the order of limitation and of comparison of the DRIS index with the NBI_m value, such that the nutritional status of a plant for each nutrient can be classified in five categories of fertilization response likelihood: "most deficient", "deficient", "balanced", "excessive" and "highly excessive". Thus, it is expected that these five classes of Fertilization Response Potential may guide the adjustments of the quantity of each nutrient to be applied to the coffee crops (Wadt & Alvarez V., 2005).

The purpose of this study was to propose a new method of interpretation of leaf analysis based on the use of Fertilization Response Likelihood (FRL), and compare it with the Diagnosis and Recommendation Integrated System (DRIS), using leaf analysis data for coffee.

MATERIAL AND METHODS

To interpret leaf analysis using the new method proposed in this study (FRL) and compare it with the DRIS method, leaf analysis and yield results of 157 coffee plantations from the state of Espirito Santo, Brazil were used (data revised in Leite, 1993). Only leaf tissues of high-yielding crops were considered (yield > 30 bags ha^{-1} of coffee) to create a reference population, and analyzed for the nutrients N, P, K, Ca, Mg, S, Fe, Zn, Mn, B and Cu. The methods DRIS and FRL were compared for the most limiting nutrient only, defined as the nutrient with the most negative DRIS index and highest FRL.

Before computing the DRIS indices, the nutrient ratios were calculated, expressed by the relationships A/B for sample and a/b for the high-yielding population. Thus, the function $f(A/B)$ was calculated according to Jones (1981) by equation 1.

$$f(A/B) = \left(A/B - a/b\right)\frac{10}{s_{a/b}} \qquad (1)$$

where A/B is the quotient of nutrient content "A" divided by nutrient content "B", evaluated in the sample; a/b is the mean of the quotients of nutrient content "A" divided by nutrient content "B", evaluated in the reference population; $s_{a/b}$ is the standard deviation associated with the mean a/b.

The DRIS index for each nutrient was obtained by equation 2.

$$I_i = \frac{\sum_{i=1}^{n} f(A/B) - \sum_{i=1}^{m} f(B/A)}{n+m} \qquad (2)$$

where $\sum_{i=1}^{n} f(A/B)$ is the sum of the functions in which nutrient "A" appears in the numerator; $\sum_{i=1}^{m} f(B/A)$ is the sum of the functions in which nutrient "A" appears in the denominator; n is the number of times the nutrient appears in the numerator m is the number of times the nutrient appears in the denominator.

The model proposed to calculate the Fertilization Response Likelihood is based on an approximation of the normal distribution function. Thus, with $z_i = \frac{x - \bar{x}}{s}$, where x is the nutrient concentration in the sample and $\bar{x}$ and s the mean and the standard deviation of the nutrient concentration in the high yield group, respectively, the approximate normal distribution function is given by $Y = \frac{1}{1+\beta}$, with $\beta = \exp(-1{,}6266\ Zi)$. The complementary function is given by $Y = 1 - \frac{1}{1+\beta}$, with Y being the Fertilization Response Likelihood (*FRL*) for nutrient *i*, calculated by equation 3:

$$FRLi = \frac{\beta}{1+\beta} \quad (3)$$

The Nutritional Balance Index (NBI) for DRIS was calculated by equation 4, according to Beaufils (1973), and the Nutritional Imbalance Index (NII) for *FRL* was calculated by equation 5.

$$NBI = \sum \left| Index \quad DRIS \right| \quad (4)$$

$$NII = Largest\ FRL - Smallest\ FRL \quad (5)$$

RESULTS AND DISCUSSION

The DRIS and FRL indices for coffee yields of up to 10 bags ha^{-1}, respectively, are shown in tables 1 and 2. A comparison of the two tables shows that the DRIS has no homogeneous scale to identify any nutritional limitations in the areas. For example, for the crops with yields of 6 bags ha^{-1} the DRIS indices of the most yield-limiting nutrient ranged from -70.55 to -15.26, and when using the *FRL*, the values ranged from 0.94 to 0.99. Taking into consideration that the DRIS index is the mean of the functions in the direct (*f(A/B)*) and inverse (*f(B/A)*) form, for *f(A/B) = -f(B/A)* and that these relationships are calculated using the equation proposed by Jones (1981), the relationship between *A/B* and *f(A/B)* is linear. Thus, the greater the distance of *A/B* from the mean of the relationship, the greater the deviation in absolute values. Contrary to the DRIS, the *FRL* calculates the Fertilization Response Likelihood between 0 and 1, according to the leaf nutrient concentration and that at this leaf concentration, the plant responds to fertilization, expressed in the high likelihood of response, with a non-linear relationship (Figure 1).

Taking into consideration only the most yield-limiting nutrient, with the most negative DRIS index and the greatest likelihood of response to fertilization *FRL* for low-yielding crops (< 30 bags ha^{-1}), it was observed that of 133 crops, the diagnoses by the two methods do not coincide in only 20 of them (15.04 %). In crops with yields below 11 bags ha^{-1} (51 samples), only 3 were at variance (5.88 %) and for yield between 11-21 and above 21 bags ha^{-1}, 12 (22.64 % of 53 samples) and 5 (17.24 % of 29 samples) samples were at variance, respectively (Table 3).

Although 15 samples did not coincide in the diagnosis of nutritional status, in some cases the *FRL* diagnosed a response likelihood, e.g., for the two crops that produced 7 bags ha^{-1} (Table 4). By the DRIS, the order of limitation, with its respective indices for the three most limiting nutrients, was Cu (-17.33) > Mg (-11.28) > Ca (-7.51) and Fe (-16.27) > Ca (-13.35) > Mg (-11.45), respectively, and for the *FRL* it was Mg (0.94) > Ca (0.94) > Cu (0.91) and S (0.92) > Fe (0.92) > Ca (0.92). This shows that for the first sample, Cu was the most limiting element by

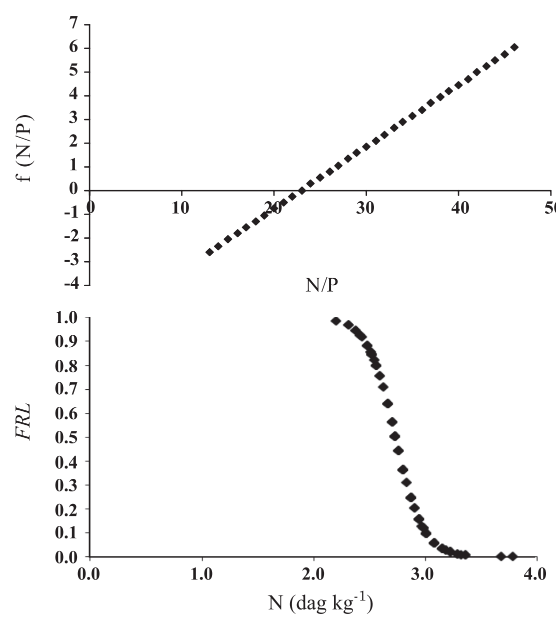

Figure 1. Linear relationship between N/P and f(N/P) and non-linear relationship between N and *FRL*, for mean and standard deviation of N/P of 22.93 and 3.83, respectively, and 2.73 and 0.21 dag kg^{-1} for N

Table 1. DRIS index for coffee yields up to 10 bags ha^{-1}

Yield	N	P	K	Ca	Mg	S	Fe	Zn	Mn	B	Cu
bag ha^{-1}						DRIS Index					
2	2.06	-13.30	15.35	-9.34	-4.58	0.65	-3.96	-7.32	22.91	-2.84	0.37
3	3.23	10.03	-28.26	-11.04	15.78	4.98	-2.72	2.22	-6.09	8.74	3.11
3	-5.28	-11.55	1.77	-13.51	-2.02	-8.03	26.76	-6.95	1.38	2.00	15.44
3	-6.25	-10.23	1.76	-7.09	-0.93	7.91	4.59	-22.23	5.73	7.15	19.59
3	11.19	4.64	11.33	-15.16	0.34	-19.07	-14.95	-1.42	4.30	-2.51	21.31
4	8.32	10.68	11.89	4.84	7.04	-3.63	5.61	6.25	-17.46	-32.49	-1.05
4	-3.81	-11.04	-8.23	2.94	0.51	-9.22	7.82	24.71	-5.58	-0.16	2.07
4	2.17	-9.52	5.19	-5.09	-2.64	9.66	0.74	-0.71	-8.13	9.21	-0.87
4	5.84	2.75	-11.25	-14.36	10.54	-3.87	-12.46	-6.01	-1.21	18.82	11.20
4	-12.68	13.77	4.96	-18.93	-9.57	2.45	5.44	-12.64	-1.75	8.91	20.04
5	-1.83	5.34	9.40	-10.43	-4.92	-4.52	-14.40	4.65	16.96	5.19	-5.44
5	2.50	2.27	2.55	-12.59	-4.67	-1.53	8.82	4.53	6.17	-6.12	-1.92
6	1.03	0.83	6.34	0.34	1.32	-0.81	-3.82	-0.06	9.37	-32.94	18.39
6	11.99	12.56	0.16	5.83	22.29	2.21	3.32	1.59	-70.55	19.74	-9.13
6	16.15	4.66	-15.26	2.14	-6.24	-6.56	-13.31	-3.36	22.11	7.73	-8.07
6	7.14	2.40	3.52	4.09	-1.00	-1.22	-20.46	5.20	20.61	-5.28	-15.00
6	7.76	-4.76	9.98	-1.25	-10.68	-5.92	22.99	-17.28	3.83	-14.22	9.56
7	1.27	-6.32	-5.72	10.03	0.51	4.96	3.40	8.51	-5.46	-23.54	12.35
7	-2.24	-16.74	6.14	1.10	-1.36	-4.98	0.57	-6.42	0.65	16.35	6.95
7	2.31	1.53	0.22	-0.84	3.58	-4.51	5.88	0.67	1.70	-10.78	0.24
7	8.08	-3.20	-8.94	5.10	9.58	-3.04	-16.66	5.85	-12.59	9.81	6.02
7	12.38	-22.19	-17.51	-8.58	2.52	-10.38	8.79	-10.84	17.74	10.74	17.32
7	-1.77	-13.77	1.71	0.56	-6.69	3.15	-1.02	-8.13	2.83	14.24	8.88
7	3.07	-2.28	-6.13	0.55	-0.92	-2.07	-12.25	0.43	-1.60	2.94	18.27
7	3.67	-1.07	-5.60	-5.45	1.16	-7.62	-12.65	4.07	7.94	1.93	13.62
7	0.22	-4.13	6.07	-0.48	-1.76	5.79	-4.36	-7.02	-9.12	7.55	7.24
7	16.55	5.29	-4.11	-7.51	-11.28	1.58	0.72	-5.95	12.61	9.43	-17.33
7	3.34	5.55	-1.67	-13.35	-11.95	-11.45	-16.27	-5.12	32.10	3.01	15.83
8	2.33	6.98	-27.71	-8.48	12.21	-3.24	-15.05	7.70	-6.05	7.04	24.28
8	-3.02	-11.65	-22.82	0.29	13.13	-4.85	20.89	-16.92	45.23	-42.56	22.29
8	0.82	-0.19	-11.87	-6.76	4.71	-3.96	-8.38	-0.64	2.73	17.37	6.17
8	-14.75	10.56	-14.47	-10.28	1.66	0.41	23.14	-10.54	-5.56	-2.85	22.67
8	1.57	-1.33	8.57	-15.57	-6.14	13.30	-15.16	-0.76	19.66	-9.76	5.62
8	10.53	-3.44	19.04	-10.53	-15.57	-2.09	7.36	0.90	9.49	-4.62	-11.07
8	1.32	-10.67	-11.08	-7.47	8.27	-9.42	-0.50	-6.31	13.97	11.92	9.97
9	0.35	-12.22	3.32	-10.50	-3.98	4.80	-2.84	0.05	-0.94	12.23	9.72
9	5.85	0.23	-13.60	6.01	2.24	-1.35	-12.53	2.62	-1.12	8.43	3.21
9	8.85	14.29	-7.72	-17.64	2.69	-3.37	-12.86	-4.09	9.72	1.29	8.83
9	4.33	2.42	-12.40	-9.94	5.99	-8.22	-19.67	-1.17	36.90	10.50	-8.74
10	2.78	-1.44	-2.38	-18.01	-1.92	8.39	-10.39	-4.75	10.44	-5.06	22.33
10	9.59	-12.80	-10.43	-18.99	-18.57	16.91	-7.54	1.08	14.30	16.10	10.35
10	5.11	-8.38	3.13	-7.73	-2.33	0.36	-5.09	-0.36	6.69	2.25	6.35
10	0.33	6.28	-13.15	-3.17	10.06	-2.69	-11.63	-1.43	7.41	5.76	2.24

DRIS and the third most limiting by *FRL*; however, by *FRL*, even with Cu being the third most limiting nutrient, the fertilization response likelihood was 0.91. For the second sample, by *FRL*, the most limiting nutrient was S, and the fourth most limiting by DRIS; however, the fertilization response likelihood for S, Fe and Ca was similar, differing only in the third decimal place, and rounded, the *FRL* was 0.92 for the three nutrients.

Evaluating the Nutritional Balance Index (NBI) and the Nutritional Imbalance Index (NII) in accordance with the coffee yield it was observed that, for the two indices, the relationship was negative (Figure 2). For the DRIS, this negative effect was already discussed in the literature, as reported by Silva et al. (2009), Guindani et al. (2009) and Partelli et al. (2006); however, this same behavior was observed for *FRL,* although with a greater correlation coefficient for NII than for NBI.

When the *FRL* was related to the DRIS indices for the nutrients evaluated, a non-linear relationship was observed between the two indices (Figure 3) and also that the fertilization response likelihood was highest and lowest with DRIS indices less than

Table 2. Fertilization Response Likelihood (*FRL*) for coffee yields up to 10 bags ha^{-1} and reference standards using the mean ($\overline{x}$) and standard deviation (*s*) of nutrients in the high yield group (> 30 bags ha^{-1})

Yield	N	P	K	Ca	Mg	S	Fe	Zn	Mn	B	Cu
bag ha^{-1}						FRL					
2	0.80	0.97	0.07	0.94	0.84	0.78	0.82	0.89	0.01	0.81	0.61
3	0.50	0.19	0.99	0.94	0.05	0.50	0.78	0.57	0.80	0.18	0.52
3	0.71	0.86	0.24	0.87	0.47	0.78	0.00	0.71	0.34	0.27	0.02
3	0.36	0.73	0.13	0.61	0.31	0.01	0.12	0.94	0.11	0.04	0.00
3	0.00	0.10	0.02	0.90	0.31	0.96	0.88	0.42	0.19	0.41	0.00
4	0.06	0.10	0.07	0.29	0.27	0.78	0.29	0.28	0.92	0.99	0.69
4	0.64	0.86	0.79	0.17	0.36	0.87	0.09	0.00	0.70	0.41	0.43
4	0.64	0.93	0.41	0.87	0.77	0.13	0.65	0.71	0.85	0.21	0.69
4	0.64	0.73	0.97	0.98	0.27	0.96	0.95	0.89	0.70	0.03	0.20
4	0.88	0.00	0.06	0.92	0.73	0.04	0.11	0.81	0.43	0.03	0.00
5	0.84	0.35	0.16	0.93	0.81	0.87	0.94	0.42	0.03	0.34	0.77
5	0.56	0.54	0.50	0.95	0.81	0.78	0.21	0.42	0.33	0.86	0.69
6	0.16	0.35	0.10	0.35	0.36	0.35	0.60	0.42	0.08	0.99	0.01
6	0.16	0.19	0.81	0.54	0.04	0.78	0.65	0.71	0.98	0.09	0.87
6	0.01	0.54	0.98	0.70	0.87	0.96	0.95	0.81	0.01	0.30	0.83
6	0.02	0.35	0.30	0.31	0.58	0.50	0.95	0.28	0.01	0.75	0.87
6	0.03	0.73	0.06	0.54	0.87	0.78	0.00	0.94	0.33	0.93	0.15
7	0.64	0.86	0.83	0.11	0.58	0.35	0.41	0.18	0.76	0.98	0.11
7	0.84	0.97	0.29	0.56	0.64	0.87	0.56	0.81	0.53	0.02	0.26
7	0.50	0.54	0.60	0.64	0.42	0.87	0.29	0.57	0.53	0.92	0.61
7	0.03	0.73	0.91	0.32	0.13	0.78	0.95	0.28	0.87	0.10	0.34
7	0.00	0.97	0.94	0.76	0.23	0.87	0.08	0.81	0.00	0.03	0.01
7	0.56	0.93	0.39	0.48	0.77	0.22	0.56	0.81	0.36	0.02	0.15
7	0.36	0.73	0.86	0.61	0.64	0.78	0.92	0.57	0.62	0.41	0.02
7	0.10	0.54	0.77	0.75	0.42	0.87	0.90	0.28	0.14	0.34	0.04
7	0.44	0.73	0.20	0.59	0.64	0.13	0.75	0.81	0.82	0.16	0.26
7	0.01	0.54	0.89	0.94	0.94	0.78	0.75	0.89	0.20	0.30	0.91
7	0.10	0.19	0.55	0.92	0.87	0.92	0.92	0.71	0.00	0.27	0.02
8	0.25	0.19	0.99	0.85	0.06	0.78	0.93	0.18	0.72	0.14	0.00
8	0.50	0.86	0.96	0.28	0.02	0.65	0.00	0.89	0.00	0.99	0.00
8	0.36	0.54	0.93	0.83	0.27	0.78	0.85	0.57	0.40	0.01	0.26
8	0.92	0.01	0.81	0.62	0.16	0.08	0.00	0.71	0.57	0.34	0.00
8	0.16	0.54	0.08	0.95	0.77	0.01	0.92	0.57	0.01	0.86	0.26
8	0.12	0.86	0.03	0.95	0.96	0.87	0.39	0.71	0.28	0.87	0.87
8	0.12	0.86	0.87	0.75	0.07	0.87	0.45	0.71	0.02	0.02	0.08
9	0.50	0.93	0.38	0.91	0.73	0.22	0.71	0.57	0.58	0.05	0.15
9	0.36	0.73	0.97	0.44	0.58	0.87	0.94	0.57	0.69	0.24	0.52
9	0.01	0.02	0.83	0.96	0.36	0.65	0.91	0.71	0.10	0.37	0.15
9	0.06	0.35	0.91	0.87	0.19	0.87	0.95	0.57	0.00	0.05	0.77
10	0.10	0.54	0.57	0.96	0.58	0.04	0.86	0.71	0.07	0.69	0.00
10	0.16	0.97	0.95	0.99	0.97	0.04	0.91	0.71	0.08	0.06	0.20
10	0.44	0.93	0.58	0.92	0.77	0.78	0.85	0.71	0.31	0.57	0.34
10	0.76	0.35	0.96	0.81	0.16	0.87	0.92	0.71	0.27	0.30	0.52
$\overline{x}$	2.73	0.12	2.11	1.44	0.33	0.24	110.08	11.46	56.50	47.83	9.21
S	0.212	0.021	0.370	0.257	0.076	0.027	26.855	2.828	22.502	10.349	4.606

Table 3. Number of crops per yield class, number of non-coincident crops between the DRIS and the *FRL* in the low-yielding coffee group

Yield	Number of Crops	At variance	Percentage within the class
bag ha^{-1}			%
Yield ≤ 11	51	3	5.88
11 < Yield ≤ 21	53	12	22.64
Yield > 21	29	5	17.24

-10 and greater than +10, respectively. Thus, when DRIS indices are below -10, the *FRL* is greater than 0.8. For DRIS indices greater than 10, the *FRL* is below 0.1.

It should be noted that for a concentration of a determined leaf nutrient equal to the mean of the same nutrient in the high yield group ($x = \overline{x}$), the *FRL* will be 0.5. This is the case because one is working with the mean and, even in the high yield group, there are samples with yields greater than the mean of this group, justifying a fertilization response likelihood of 50 %, since the derivative of equation 3 is an approximation of the normal distribution. Thus, the lower x is in relation to $\overline{x}$, the greater is the fertilization response likelihood, and, on the contrary, the greater x is in relation to $\overline{x}$, the lower is this probability.

An advantage of the *FRL* is that the index calculated is independent of the others, in contrast to the DRIS. For example, with the same coffee data, performing DRIS only for N, P and K, the DRIS correctly detected the deficiency only for samples 1 and 2 (P and K) (Table 6); however, as the other nutrients were ignored, DRIS detected deficiency among N, P and K in samples 3, 4, 5 and 6; however, working with all nutrients, deficiency was observed for other nutrients (Ca, Zn, S and B) by DRIS. On the other hand, when the *FRL* is used, even working only with N, P and K, it was observed that for samples 1 and 2, the fertilization response likelihood for P and K, respectively, was high, similar to the DRIS, and that for samples 5 and 6, the nutrients N, P and K have no fertilization response likelihood, so the limitation was due to deficiency of S and B for these two samples.

The use of a univariate relationship (*FRL*) in relation to a bivariate relationship (DRIS) proves to be viable, in spite of the fact that, according

Table 4. Classification of the nutritional limitation using the DRIS index for crops that did not coincide with the *FRL*

Yield	Nutritional limitation										
bag ha^{-1}											
4	-11.04	-9.22	-8.23	-5.58	-3.81	-0.16	0.51	2.07	2.94	7.82	24.71
	P	S	K	Mn	N	B	Mg	Cu	Ca	Fe	Zn
7	-17.33	-11.28	-7.51	-5.95	-4.11	0.72	1.58	5.29	9.43	12.61	16.55
	Cu	Mg	Ca	Zn	K	Fe	S	P	B	Mn	N
7	-16.27	-13.35	-11.95	-11.45	-5.12	-1.67	3.01	3.34	5.55	15.83	32.10
	Fe	Ca	Mg	S	Zn	K	B	N	P	Cu	Mn
12	-12.08	-11.89	-11.13	-7.61	-4.19	-1.20	-0.28	1.54	6.84	13.69	26.30
	K	S	P	N	Zn	Mg	B	Ca	Mn	Fe	Cu
12	-8.04	-7.41	-7.00	-3.91	-2.52	1.06	2.09	4.37	6.94	7.15	7.27
	Mn	Cu	Mg	S	Zn	Ca	Fe	B	P	K	N
12	-9.94	-9.74	-8.70	-6.04	-0.75	0.20	1.52	1.79	6.63	11.63	13.40
	Mn	Cu	Fe	K	Ca	S	Zn	P	B	N	Mg
12	-12.78	-10.36	-9.68	-8.76	-6.10	1.63	4.82	6.89	8.57	11.42	14.34
	K	Fe	S	Ca	Mg	P	C	N	B	Zn	Mn
13	-12.32	-10.07	-8.20	-2.77	-1.41	-0.68	-0.50	0.47	3.08	5.93	26.47
	Fe	S	Ca	Mg	Zn	K	B	Mn	N	P	Cu
13	-20.92	-19.24	-18.60	-6.69	-6.39	-5.11	-0.60	0.35	4.28	20.16	52.74
	Cu	Mg	Ca	Fe	B	Zn	N	P	K	Mn	S
13	-13.25	-11.14	-10.26	-6.96	-3.04	-2.13	0.12	6.06	7.71	9.14	23.76
	K	Ca	P	S	Zn	Fe	N	Mg	B	Cu	Mn
15	-11.92	-11.77	-7.55	0.40	1.67	1.71	1.96	4.04	4.76	5.07	11.64
	Fe	Ca	Cu	S	Mg	K	B	Mn	N	Zn	P
16	-9.55	-8.26	-6.21	-5.82	-2.02	1.16	1.91	2.61	5.45	8.01	12.72
	Mn	N	Ca	K	Zn	S	Mg	Fe	P	Cu	B
17	-15.92	-14.16	-7.34	-5.17	-5.06	-2.93	2.97	6.99	7.22	8.17	25.23
	Cu	Mn	S	Mg	Fe	Zn	Ca	N	K	B	P
17	-9.92	-7.79	-5.63	-5.53	-4.96	-0.78	-0.20	0.69	3.77	11.07	19.30
	Mg	P	N	Ca	B	Zn	Fe	S	K	Mn	Cu
21	-19.83	-15.81	-15.04	-4.94	-3.11	-1.31	0.23	4.02	6.18	19.69	29.93
	P	K	S	N	B	Mn	Zn	Ca	Mg	Fe	Cu
22	-11.65	-11.63	-1.94	-1.35	0.36	1.90	2.10	2.98	4.65	5.71	8.85
	Fe	K	N	S	Ca	B	Zn	P	Cu	Mn	Mg
22	-15.26	-13.94	-7.60	-2.14	-1.53	1.89	2.67	3.96	4.18	8.43	19.34
	Fe	Ca	Mg	S	B	P	Mn	K	Cu	N	Zn
22	-8.28	-6.91	-5.76	-5.37	0.32	0.85	1.26	2.85	4.72	5.02	11.31
	Ca	Cu	S	Fe	B	Zn	Mg	K	N	P	Mn
26	-10.68	-7.78	-6.53	-5.39	-1.80	-1.23	-0.98	5.78	8.46	9.39	10.78
	P	Mn	B	N	Mg	S	K	Fe	Zn	Ca	Cu
27	-12.99	-11.23	-8.41	-0.92	-0.64	-0.13	1.97	2.56	6.18	11.14	12.46
	Fe	Cu	S	Mn	Zn	Mg	K	Ca	N	B	P

Table 5. Classification of the nutritional limitation using the *FRL* for coffee crops that did not coincide with the DRIS

Yield	Nutritional limitation										
bag ha^{-1}											
4	0.87	0.86	0.79	0.70	0.64	0.43	0.41	0.36	0.17	0.09	0.00
	S	P	K	Mn	N	Cu	B	Mg	Ca	Fe	Zn
7	0.94	0.94	0.91	0.89	0.89	0.78	0.75	0.54	0.30	0.20	0.01
	Mg	Ca	Cu	Zn	K	S	Fe	P	B	Mn	N
7	0.92	0.92	0.92	0.87	0.71	0.55	0.27	0.19	0.10	0.02	0.00
	S	Fe	Ca	Mg	Zn	K	B	P	N	Cu	Mn
12	0.92	0.88	0.87	0.86	0.57	0.42	0.37	0.24	0.11	0.02	0.00
	S	N	K	P	Zn	Mg	B	Ca	Mn	Fe	Cu
12	0.84	0.84	0.83	0.78	0.71	0.54	0.50	0.37	0.20	0.19	0.06
	Mg	Mn	Cu	S	Zn	Ca	Fe	B	K	P	N
12	0.93	0.92	0.89	0.87	0.87	0.83	0.73	0.71	0.45	0.16	0.10
	K	Fe	Mn	Cu	S	Ca	P	Zn	B	Mg	N
12	0.96	0.95	0.90	0.90	0.81	0.54	0.34	0.14	0.11	0.10	0.04
	S	K	Fe	Ca	Mg	P	Cu	B	Zn	N	Mn
13	0.92	0.90	0.84	0.64	0.57	0.55	0.49	0.45	0.19	0.16	0.00
	S	Fe	Ca	Mg	Zn	K	B	Mn	P	N	Cu
13	0.97	0.96	0.91	0.84	0.83	0.81	0.54	0.50	0.28	0.03	0.00
	Ca	Mg	Cu	Fe	B	Zn	P	N	K	Mn	S
13	0.83	0.74	0.73	0.50	0.42	0.38	0.06	0.05	0.03	0.03	0.00
	K	Ca	P	S	Zn	Fe	Mg	Cu	N	B	Mn
15	0.95	0.93	0.83	0.65	0.58	0.57	0.53	0.47	0.42	0.25	0.10
	Ca	Fe	Cu	S	Mg	K	B	Mn	Zn	N	P
16	0.99	0.86	0.86	0.85	0.71	0.65	0.53	0.52	0.35	0.26	0.07
	N	K	Ca	Mn	Zn	S	Mg	Fe	P	Cu	B
17	0.96	0.92	0.91	0.87	0.86	0.81	0.65	0.40	0.37	0.36	0.00
	S	Mn	Cu	Mg	Fe	Zn	Ca	K	B	N	P
17	0.92	0.87	0.86	0.78	0.75	0.57	0.55	0.50	0.32	0.07	0.01
	N	Mg	P	Ca	B	Zn	Fe	S	K	Mn	Cu
21	0.98	0.97	0.95	0.88	0.61	0.49	0.42	0.21	0.16	0.01	0.00
	S	P	K	N	B	Mn	Zn	Ca	Mg	Fe	Cu
22	0.87	0.85	0.35	0.32	0.28	0.26	0.25	0.24	0.19	0.19	0.06
	K	Fe	S	Ca	Zn	Cu	N	B	P	Mn	Mg
22	0.96	0.95	0.87	0.78	0.69	0.54	0.49	0.43	0.43	0.06	0.02
	Ca	Fe	Mg	S	B	P	Mn	K	Cu	N	Zn
22	0.96	0.94	0.87	0.83	0.72	0.71	0.69	0.66	0.64	0.54	0.19
	S	Ca	Fe	Cu	B	Zn	Mg	K	N	P	Mn
26	0.97	0.93	0.86	0.81	0.78	0.69	0.69	0.29	0.18	0.15	0.13
	N	P	B	Mn	S	K	Mg	Fe	Zn	Cu	Ca
27	0.96	0.94	0.87	0.71	0.70	0.69	0.63	0.61	0.25	0.14	0.10
	S	Fe	Cu	Zn	Mn	Mg	K	Ca	N	B	P

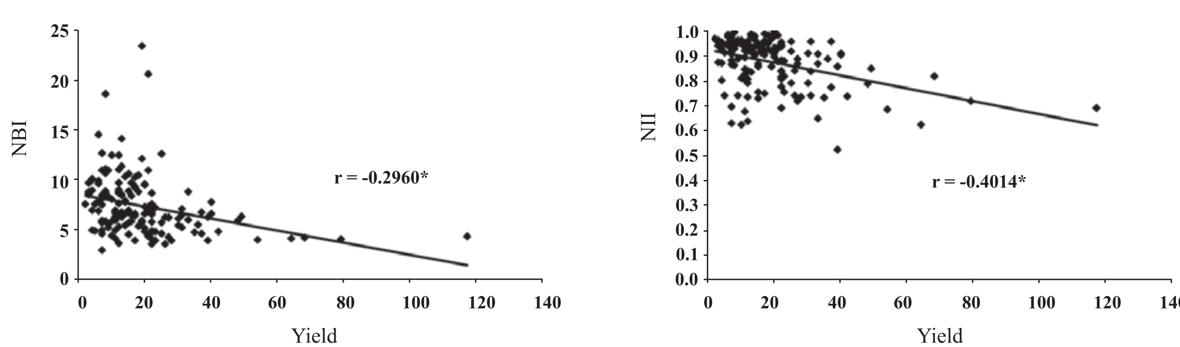

Figure 2. Relationship between the Nutritional Balance Index (NBI) and the Nutritional Imbalance Index (NII) with coffee yield

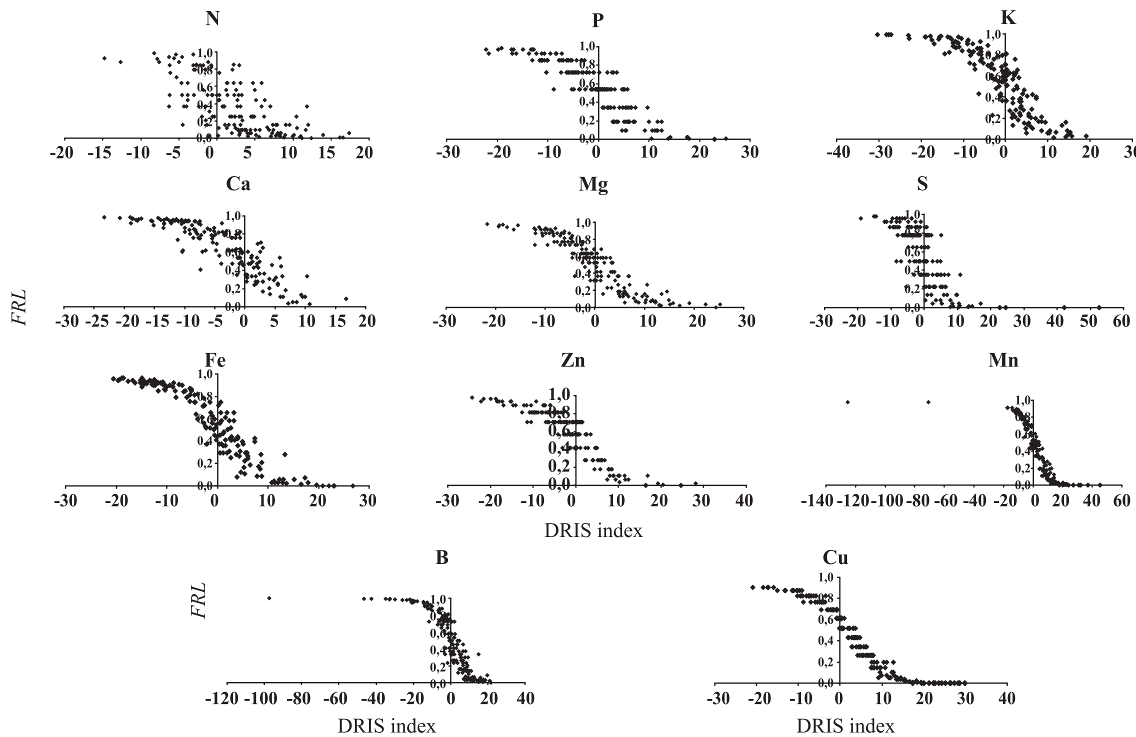

Figure 3. Relationship between the DRIS index and the Fertilization Response Likelihood (*FRL*) for the nutrients evaluated

Table 6. Comparison between the interpretation of leaf contents of N, P and K using DRIS and *FRL*

Sample	Yield	I_N	I_P	I_K	FRL_N	FRL_P	FRL_K	Limiting nutrient
	bag ha^{-1}							
1	2	1.76	-27.28	25.51	0.80	0.97	0.07	P
2	3	15.11	26.88	-41.99	0.50	0.19	0.99	K
3	3	-0.08	-11.78	11.87	0.71	0.86	0.24	Ca
4	3	-0.88	-10.21	11.09	0.36	0.73	0.13	Zn
5	3	2.06	-6.57	4.51	0.00	0.10	0.02	S
6	4	-6.00	1.86	4.14	0.06	0.10	0.07	B

to Jones (1981), one of the main presuppositions for DRIS applications is that the relationships between two nutrients are better indicators of the nutritional status than the simple use of isolated concentrations and that the use of the relationships minimizes the effects of concentration and dilution (Walworth & Sumner, 1987). Thus, the use of relationships between nutrients was developed for DRIS to reduce the dependence of interpretations on sampling variations with regard to age and origin of the plant tissue. However, Epstein & Bloom (2006) commented that the rational physiological analysis by DRIS is frequently not obvious for many nutrient proportions and that the statement that the standards are relatively independent of plant age and location is unconfirmed (Jones Jr., 1993), while from a more general point of view, the presuppositions of other estimation methods were not maintained for DRIS (Reuter & Robison, 1997).

CONCLUSION

The Fertilization Response Likelihood (FRL) allowed an assessment of the nutritional status of coffee where 84.96% of the crops evaluated coincided with the DRIS diagnosis.

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