Establishment of DRIS norms for the nutritional diagnosis of rubber (*Hevea brasiliensis* Muell Arg.) clone RRIM 600 on the Eastern Plains of Colombia

Establecimiento de la norma de DRIS para el diagnóstico nutricional del caucho (*Hevea brasiliensis* Muell Arg.) clon RRIM 600 en la altillanura de Colombia

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ABSTRACT

The diagnosis and recommendation integrated system (DRIS) is an efficient method for evaluating the nutritional status of crops and was initially developed for rubber. In Colombia, the size of the rubber crop has grown significantly during the last decade, but recommendations do not yet exist for crop nutrition management at a local level. The aim of the present study wasto determine preliminary DRIS norms for rubber clone RRIM 600 under the conditions found on the Eastern Plains of Colombia. To this end, 78 leaf samples were collected, 19 of which were classified as high-yield, showing production above 2,690 kg ha^{-1}, while the remaining 59 samples were classified as low-yield. The highest variance ratio and the value of R were used as criteria for selecting DRIS norms and were found to present differences, only coinciding for 32 of the studied ratios. The calculation of the DRIS indexes was carried outusing the determined norms; and K was found to be the element that most strongly limited production and showed the greatest probability of exhibiting a response upon exogenous application. Additionally, small quantities of Cu and S can generate imbalances that influence the yield of this clone.

Key words: nutrient balance, leaf tissue analysis, plant production, nutritional status.

RESUMEN

El sistema de diagnóstico y recomendación integral (DRIS) es un método eficiente para evaluar el estado nutricional de los cultivos, desarrollado inicialmente para el caucho. En Colombia, el cultivo de caucho ha crecido de manera significativa en la última década, pero aún no existen recomendaciones de manejo nutricional a nivel local. El presente trabajo tuvo como objetivo obtener la norma preliminar DRIS para el cultivo de caucho clon RRIM 600 bajo condiciones de la altillanura Colombiana. Se tomaron 78 muestras de tejido foliar, de las cuales 19 se clasificaron como de alto rendimiento con producciones superiores a los 2.690 kg ha^{-1}, las restantes 59 muestras se clasificaron como de baja productividad. Para la selección de las normas DRIS se utilizó el criterio de mayor relación entre varianzas y el criterio de valor de R, encontrando que los métodos presentan diferencias y solo coinciden en 32 de las relaciones estudiadas. Con las normas obtenidas se realizó el cálculo de los índices DRIS encontrando que el K es elemento que más limita la producción y mayor probabilidad de respuesta tiene a la aplicación y que pequeñas cantidades de Cu y S pueden generar desequilibrios que influyan en la productividad de este clon.

Palabras clave: balance nutricional, análisis de tejido foliar, producción vegetal, estado nutricional.

Introduction

The cultivation of rubber (*Hevea brasiliensis* Muell Arg.) is growing rapidly in Colombia, especially in the Orinoquia region (also known as the Eastern Plains), and is seen as a new production option for small and large producers in that zone. In spite of the growth of rubber cultivation in this area, there is no information on the nutritional status of plantations corresponding to technical fertilization criteria, which would allow for good recommendations and interpretations made based on leaf and soil analyses such that these results might be applied on the basis of the edaphological and environmental conditions of the Eastern Plains.

The nutritional diagnosis of a plant depends on reference values, such as the critical and optimal concentrations of one or more nutrients, principally in the leaves. Generally, these values are obtained under controlled conditions, which results in poor fertilization responses when applied to real crop conditions (Bhargava and Chadha, 1988).

An effective alternative is to determine values based on highly productive farms, which may be applicable to the

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edapho-climatic conditions of the region in which they are found. In this sense, the diagnosis and recommendation integrated system (DRIS) relates soil properties to the foliar composition as a function of crop yield, thus constructing a set of diagnostic norms.

Considering the limitations of traditional diagnostic methods, Beaufils (1973) developed the DRIS on the basis of physiological and plant nutrition research on the rubber crops of Vietnam and, subsequently, the sugar and corn crops of South Africa.

This method employs the ratios between nutrients for the interpretation of foliar analyses, instead of their absolute or individual concentrations. Thus, the DRIS method expresses the results of a nutritional diagnosis using indexes with a continuous numerical scale, which are positive if the nutrient is in excess or negative if the nutrient is deficient. The nearer the index is to a value of zero, the closer the plant is to an adequate nutritional balance, which results in better development and yield (Beverly, 1991).

Initially, it is necessary to determine reference norms for the establishment and calculation of DRIS indexes, which are obtained by selecting a high-yield population, designated the reference population, under the premise that there is a significant relationship between the nutrient supplies and the contents of nutrients in plants according to which increases or decreases in concentrations will give rise to yield variations (Nachtigall and Dechen, 2007). Some authors have noted that the construction of local and specific norms for each specific crop condition is better and that a nutritional diagnosis can vary between general and specific norms for some nutrients. In any case, there is general agreement that DRIS indexes are a good indicator of nutritional balance, as well as crop responses to fertilization (Silva and Carvalho, 2005; Rocha *et al*., 2007; Landriscini *et al*., 2010; Dias *et al*., 2011).

In Colombia, there is no precedent for the implementation and development of nutritional diagnosis systems for rubber crops, but they have been developed for other crops, such as roses (*Rosa* sp.) (Franco, 2007). The DRIS has seen increasing international use, and its application has been growing faster than alternative methods (e.g. critical levels and sufficiency ranges) for the generation of diagnostic norms, though it is mainly employed for horticultural or fruit crops. Beverly (1991) reported diagnostic norms for rubber (*H. brasiliensis*) and eucalyptus (*Eucalyptus deglupta*) in woody areas, among other species.

Thus, the present study aimed to establish DRIS norms for the rubber crop under the conditions of the Eastern Plains of Colombia.

Materials and methods

Study area

This research was carried out on commercial rubber (*H. brasiliensis*) plantations of 12-year-old trees located in the municipality of Puerto López (Meta, Colombia), at the geographic coordinates of 40°5'46" N, 72°57'30" W and an altitude of 184 m. The zone exhibits annual precipitation between 2,100 and 2,300 mm, temperatures between 24.8 and 26.2°C, and relative humidity of 85% during the rainy season and 65% in the dry season. The soil is a Typic Hapludox that is very acidic, showing aluminum saturation greater than 50%, saturation of bases below 25%, and a low CEC (2.33 $cmol_{(+)}$ kg^{-1}), with a sandy loam texture. At the time of this research, the soil displayed a pH of 4.78, low P content (0.60 mg kg^{-1}), high Al content (1.40 $cmol_{(+)}$ kg^{-1}), and low Ca, Mg, K, and Na contents (0.41, 0.12, 0.07, and 0.06 $cmol_{(+)}$ kg^{-1}, respectively).

Sampling and laboratory analysis

For this study, 78 foliar samples were collected in the month of Junein the form of two to three mature shade leaves, located at the base of the highest third of the crown of the second branching and on the due north side of each tree between 06:00 AM and 10:00 H. The aim of this timing wasto diminish variability because there are changes in the nutritional contents of leaves during the day, as suggested by Malavolta *et al*. (1997). The pecioles were removed from these samples, and the obtained films were washed with water and dried in a coolenvironment before being sent to the laboratory.

The leaf samples were then transported to the laboratory and the contents of K, Ca, Mg, Na, K, Fe, Cu, Mn, and Zn were determined by means of dry digestion and atomic absorption. Colorimetry was used for the determination of P and B, while wet digestion and Kjeldahl methods were employed for N quantification (Jones *et al*., 1991) and turbidimetry for S.

Three latex samples were collected for yield determinations. These samples were obtained during the months of June, when a high-yield and the highest precipitation (328.1 mm) were observed; August, a month of medium productivity and precipitation (184.1 mm); and December, when production and precipitation were low (69.3 mm). These measurements were carried out using a lined pipette in 2010 at rubbing (harvest) in two of the trees from which leaf samples were collected, and the obtained values were averaged for each sampling point.

To separate the population into high and low-yield populations, the quartiles were calculated, and the highest quartile was considered to correspond to the high-yield population for each of the three measurements carried out in the field. Additionally, the average of the three measurements was multiplied by the planting density per hectare, which was 450 trees, with the aim of determining the production of dry rubber. This result was multiplied by 72, which was the number of rubbings (harvestings) per year. Finally, it was estimated that 33% of this value corresponded to the production of dry rubber, from which the productivity of dry rubber per year was determined. The same descriptive statistical procedure was applied to these values to verify that the populations were adequately separated.

Development of the DRIS norm

A foliar database and yield data were collected and complemented to determine DRIS norms, and the population was divided into two groups, one with a high-yield and the other with a low-yield. Values above the highest yield quartile were taken for the high-yield population, and the means and standard deviations were calculated for all possible ratios between the elements for each group. This operation was carried out by expressing the mean nutrient concentrations in dry matter and the ratios in the form of a quotient between the pairs for each element. Thus, the elemental concentrations that diminish with leaf age, such as that of N, and their relationship to those that increase with age were expressed in the form of a product, rather than a quotient, between nutrients. Then, the ratios to be converted into norms were selected, which resulted in the formation of an expression for each pair of elements, with a choice of three possible ratios. For this purpose, the relationships that showed the highest ratios among the low-and high-yield population variances were chosen, which were considered norms. Finally, the function and DRIS indexes were determined for all of the elements, leading to the interpretation of results. With the aim of unifying the forms of expression for nutrients and facilitating data management, the elements reported as a percentage were multiplied by 100 in the foliar analysis (Arboleda *et al.*, 1988).

The criterion of the value of R was also taken into account, as proposed by Nick (1998) and described by Mourão-Filho *et al.* (2002), which is obtained by calculating the correlation coefficients between the yield values and the ratios between nutrient pairs, either in direct order or in reverse order, by selecting the ratio that shows the greatest absolute value of the correlation coefficient (r) as the norm, as follows:

$$\text{If: } | r\ A / B | > | r\ B / A | \text{ norm} = A / B \quad (1)$$

$$\text{If: } | r\ A / B | < | r\ B / A | \text{ norm} = B / A \quad (2)$$

Where, $| r\ A / B |$ is the absolute value of the correlation coefficient between the yield and the ratio between the concentrations of nutrients A and B, and $| r\ B / A |$ is the absolute value of the correlation coefficient between the yield and the ratio between the concentrations of nutrients B and A in the population.

The original methodology proposed by Beaufils (1973) and described by Silva and Carvalho (2005) was employed for the calculation of the DRIS index.

Results and discussion

A total foliar sample analysis was performed including 78 samples (Tab. 1), following filtering and selection of the total database and the respective yields. The productivity data in the global database showed high variation, with production varying from 382.04 to 4,330.26 kg ha^{-1} yr^{-1} of dry rubber. Considering that the average production for this zone is 1,800 kg ha^{-1} yr^{-1} and that the minimum threshold established for the reference population was 2,690.82 kg ha^{-1} yr^{-1}, it can be verified that there is a difference between the production in the study zone and that of the reference population, showing that the proposed sampling is sufficient for establishing norms.

TABLE 1. Mean contents of foliar nutrients for the total population of the rubber clone RRIM 600 on the Eastern Plains of Colombia.

Parameter	Total population			
	Mean	cv (%)	Minimum	Maximum
Yield (kg ha^{-1} yr^{-1})	2234.1	32.35	392	4330.3
N (%)	2.71	8.80	2.14	3.39
P (%)	0.48	21.49	0.25	0.72
K (%)	0.90	34.04	0.26	1.86
Ca (%)	1.09	30.46	0.43	2.4
Mg (%)	0.18	41.40	0.03	0.38
Na (%)	0.01	29.58	0	0.02
S (%)	0.09	59.27	0.05	0.36
Fe (mg kg^{-1})	118.8	42.68	30.68	409.54
Cu (mg kg^{-1})	12.65	33.37	9.33	40.02
Mn (mg kg^{-1})	119.3	26.26	72.7	212.11
Zn (mg kg^{-1})	14.94	30.11	9.33	32.01
B (mg kg^{-1})	132.10	23.53	74.66	219.07

cv: coefficient of variation.

The global database shows that some elements display a low foliar contentaccording todatafrom Guha (1969), who found that the N content of rubber leaves on the basis of dry matter is between 3.20 and 3.70%, while that of P is between 0.19 and 0.27%, and that of K is between 1.0 and 1.5%. These authors further showed that N is the most necessary element for rubber plant leaves.

The total population was subdivided into two subpopulations, one with a high-yield and the other with a low-yield (Tab. 2). For the high-yield population, a dry rubber threshold of 2,690.82 kg ha^{-1} per year was determined, and the low-yield population was determined on the basis of values below this level. Out ofthe 78 total samples analyzed, 19 were classified as high-yield and 59 were classified as low-yield.

This division meets the premises of Letzsch and Sumner (1984), who believed that the high-yield population should include at least 10% of the observations in a global database, which would guarantee a high-yield population with significant differences from the low-yield population.

Comparison of the two populations revealed that the high-yield population presented a lower mean nutrient content when compared to the low-yield population. Only Ca and Mg exhibited higher levels in the high-yield population. This result is a consequence of the foliar sampling having been carried out at the peak of harvesting, which would indicate the potential ability of clone RRIM 600 to transform nutrients into latex through primary metabolic processes in its cells (García and Pérez-Urria, 2009) because the levels were low in the leaves. In contrast, in the high-yield population, the plants dedicated the nutrients extracted from the soil to sustenance activities and not metabolic activities related to latex production, so the levels in the leaves were higher when comparing elements such as N, Ca, and Mg.

Murbach *et al.* (2003) confirmed that K and then P are the nutrients that show the highest translocation rates from the leaves to the woody parts of rubber clone RRIM 600, followed by N, Mg, and S. In terms of the quantities transported from the leaves to other parts of the plant, N was the nutrient that showed the highest values. Where as Mg, its main role in rubber cultivation photosynthetic activity is associated mainly as enzyme activator (Mesquita *et al.*, 2006) and its rate of organ re-translocation timber is lower than that of other elements such as K, N and P, so that the Mg content in the tissue will be higher in populations with high productivity. With respect to the higher P content in the leaves of the low-yield population, Murbach *et al.* (2003) noted that rubber plants display a high P absorption efficiency, so its contents in leaves are generally found at adequate levels.

Once the high-and low-yield populations were selected, we determined all the possible ratios between the elements (Tab. 3). The ratios of Ca and Mg to N, P, and K were expressed as a product because the contents of N, P, and K generally diminish with the age of the tissue, while those of Ca and Mg increase, and thus, their best form of expression is not a quotient but a product (Beaufils, 1973).

The quotients or products that wereselected as norms indicate the adequate nutritional balance for rubber trees for the studied zone because an element at a certain time and under certain conditions will be influenced by diverse factors, including its relationship to the other elements present

TABLE 2. Mean values of foliar nutrients for the high- and low-yield populationsofrubber clone RRIM 600 on the Eastern Plains of Colombia.

Parameter	High-yield population			Low-yield population		
	Mean (cv %)	Minimum	Maximum	Mean (cv %)	Minimum	Maximum
Yield (kg ha^{-1} yr^{-1})	3,138(12.66)	2,690.8	4,330.3	1,933(27.74)	392	2,655.2
N (%)	2.65(7.27)	2.34	3.13	2.74(9.1)	2.14	3.39
P (%)	0.47(17.34)	0.31	0.57	0.49(22.66)	0.256	0.73
K (%)	0.88(33.49)	0.44	1.60	0.91(34.45)	0.262	1.86
Ca (%)	1.17(37.48)	0.60	2.40	1.08(27.3)	0.431	1.68
Mg (%)	0.21(46.36)	0.05	0.39	0.18(38.8)	0.039	0.32
Na (%)	0.02(29.6)	0.01	0.03	0.02(29.76)	0.006	0.03
S (%)	0.08(38.4)	0.06	0.19	0.10(62.19)	0.052	0.36
Fe (mg kg^{-1})	127.60(56.91)	74.00	409.50	115.8(35.7)	30.68	267.47
Cu (mg kg^{-1})	11.55(17.65)	9.34	18.01	13.02(36.01)	9.338	40.02
Mn (mg kg^{-1})	111.92(26.02)	75.37	174.09	121.80(26.19)	72.70	212.11
Zn (mg kg^{-1})	14.50(31.04)	9.34	23.35	15.10(30.01)	9.338	32.02
B (mg kg^{-1})	135.52(20.46)	81.41	182.19	131.00(24.65)	74.66	219.07

CV: coefficient of variation.

in the leaves of the plant. Thus, an element's absorption, transport and dynamics may or may not be influenced, positively or negatively, or not at all, by the presence of another element (Malavolta *et al*., 1997).

Some ratios show high coefficients of variation, which does not lead to problems regarding the interpretation of norms according to Flores *et al*. (2004), because in this situation, these values represent real, existing variation in nutrient contents within average-yield rubber populations.

The average contents of the elements and the ratios found in the reference population employed for norm development were lower than those reported by authors such as Flores *et al*. (2004) from Venezuela, except for P, K, and Ca. However, in the previous study, the average productivity was lower (2,070 kg ha^{-1} yr^{-1}). This difference indicates that although the elemental contentsfound by these authors were lower, theirrelationship or proportion within the productive system was better, which causes less antagonism among nutrients, associated with better productivity.

Comparison of the two methods used for norm selection, *i.e*., the greatest difference between the variances (F) (proposed by Sumner, 1990) and the value of R (proposed by Nick, 1998),indicated that they coincided in only 32 of the 132 ratios over the selection. Ultimately, the higher ratio between variances was given priority out of the two selection criteria because it displayed a larger difference in its values.

The ratios that involve P stand out because this element is found in high quantities according to the foliar analyses (Tab. 1). This result could be explained by the low N

TABLE 3. DRIS norms for rubber clone RRIM 600 on the Eastern Plains of Colombia.

Ratio	cv (%)	S^2	F(Sb/Sa)	R	Ratio	cv (%)	S^2	F(Sb/Sa)	R
P/N	0.18(18.98)	0	1.70	-0.29	100Ca/Fe	1.07(53.10)	0.33	0.96	-0.03
N/K	3.34(37.02)	1.53	1.21	0.46	Cu/100Ca	0.11(30.40)	0	2.44	-0.25
CaXN	3.09(38.14)	1.38	0.48	0.14	Mn/100Ca	1.03(28.88)	0.09	2.93	-0.1
MgXN	0.54(45.97)	0.06	0.65	-0.19	Zn/100Ca	0.14(40.47)	0	1.78	-0.1
N/Na	159.30(31.76)	2558.7	1.90	-0.28	B/100Ca	1.31(37.60)	0.24	1.08	-0.15
S/N	0.03(42.13)	0	3.86	-0.06	Na/Mg	0.11(48.19)	0	0.49	0.05
100N/Fe	2.38(30.17)	0.52	4.40	-0.32	S/Mg	0.53(67.33)	0.13	8.69	-0.08
Cu/100N	0.04(16.99)	0	7.50	-0.06	100Mg/Fe	0.18(52.02)	0.01	1.19	-0.06
Mn/100N	0.42(24.71)	0.01	1.36	0.01	Cu/100Mg	0.73(67.13)	0.24	1.06	0.09
Zn/100N	0.05(28.40)	0	1.02	-0.3	Mn/100Mg	6.80(54.88)	13.93	2.09	-0.01
100N/B	2.04(24.20)	0.24	1.60	-0.34	Zn/100Mg	0.90(64.43)	0.33	1.44	0.18
P/K	0.59(42.05)	0.06	1.17	0.46	B/100Mg	8.65(06.92)	27.77	0.93	0.21
PXCa	0.54(34.86)	0.04	0.85	0.52	S/Na	4.91(44.54)	4.78	8.16	-0.25
PXMg	0.10(45.31)	0	0.97	0.48	100Na/Fe	0.02(31.45)	0	2.64	-0.17
P/Na	28.08(39.09)	120.55	1.07	0.47	100Na/Cu	0.16(27.85)	0	1.48	0.27
S/P	0.19(50.15)	0.01	2.68	0.15	Mn/100Na	67.00(35.74)	573.57	2.05	-0.2
Fe/100P	2.79(50.38)	1.98	0.64	0.46	Zn/100Na	8.37(31.41)	6.91	2.96	0.35
Cu/100P	0.25(22.64)	0	4.61	0.52	B/100Na	79.05(26.97)	454.4	2.07	-0.16
Mn/100P	2.46(30.16)	0.55	1.19	0.31	100S/Fe	0.07(48.25)	0	10.69	-0.09
Zn/100P	0.31(27.95)	0.01	1.41	0.31	100S/Cu	0.74(37.98)	0.08	3.75	0.25
100P/B	0.36(26.93)	0.01	2.34	0.23	100S/Mn	0.08(35.82)	0	4.29	0.26
CaXK	1.12(68.24)	0.58	0.38	0.38	100S/Zn	0.62(47.13)	0.09	3.19	-0.03
MgXK	0.20(71.21)	0.02	0.57	0.51	100S/B	0.06(23.91)	0	12.01	0.35
K/Na	51.14(37.07)	359.26	1.50	0.55	Cu/Fe	0.10(25.60)	0	15.86	-0.08
S/K	0.11(52.90)	0	6.85	0.36	Mn/Fe	1.04(44.39)	0.21	2.31	0.39
100K/Fe	0.79(36.69)	0.1	2.03	0.44	Zn/Fe	0.13(31.95)	0	3.03	0.42
Cu/100K	0.14(30.04)	0	2.35	0.11	B/Fe	1.21(33.44)	0.16	4.30	-0.04
Mn/100K	1.37(34.44)	0.22	2.53	-0.05	Cu/Mn	0.11(24.59)	0	2.61	0.46
Zn/100K	0.18(33.43)	0	2.77	-0.34	Cu/Zn	0.84(20.31)	0.03	5.34	-0.17
100K/B	0.69(53.87)	0.14	1.23	-0.32	Cu/B	0.09(38.38)	0	1.66	-0.42
Mg/Ca	0.17(29.48)	0	0.80	0.02	Mn/Zn	8.35(37.96)	10.05	0.67	-0.22
Na/Ca	0.02(38.20)	0	0.63	-0.21	Mn/B	0.87(39.04)	0.12	1.19	-0.1
S/Ca	0.08(41.25)	0	7.69	0.19	Zn/B	0.11(40.89)	0	1.41	-0.4

CV: coefficient of variation; F(Sa/Sb):variance ratio between the high- and low-yield populations.

contents detected as it has been reported that the P concentration in the leavesis more dependent on the quantity of N than of P itself, with P acting as a weak antagonist of N (Rodríguez, 1978). Therefore, in this case, the antagonism was less marked, allowing high P contents to exist in the leaf tissue.

With respect to the other elements, there was a high concentration of Ca, which is an element that also occurs at high levels because of its relationship to N. In acidic soils, Rodríguez (1978) noted that low levels of N result in high Ca levels in the leaves, showing the importance of this ratio in the nutrition and development of rubber plants. With respect to this finding, Roque *et al*. (2004) observed a positive relationship between the levels of leaf Ca and rubber productivity. Marenco and Lopes (2007) also suggested that an imbalance in the Ca ratio could be related to the antagonism of K and Ca, where an excess of one can cause a deficiency of the other.

Once the populations were established and the norms selected, a preliminary analysis of the effect of each of the elements and their relationship to productivity was carried out, with the intention of correlating the selected norms for the high-yield population by means of an analysis of correlations (Tab. 4). Thus, the ratios that were found to display the greatest influence on production were those that related N, P, K, and Mg to elements such as Ca, S, Fe, and B.

The ratios that showed the strongest correlation with production were P x Mg, K x Ca, and K x Mg, which, according to Casierra *et al*. (2004), indicate the strong interaction that occurs between these elements and their positive relationship with production.

TABLE 4. Significant correlations ($P \leq 0.05$) in the population of high-performance rubber clone RRIM 600.

Ratio	Correlation
N x Ca	0.45
N x Mg	0.47
P x Ca	0.49
P x Mg	0.51
K/N	0.46
K x Ca	0.51
K x Mg	0.54
K/Na	0.48
K/S	0.44
100K/Fe	0.47
100K/B	0.46
Mg/Na	0.47
100Mg/Fe	0.44
Zn/B	0.46

Ratios involving K presented a positive correlation. This finding can be explained if it is taken into account that K plays a fundamental role in the growth and development of rubber, in which the growth of conductor vessels stands out (Bataglia *et al*., 1999), leading to an increase in the volume of tissues responsible for latex production.

The ratio between K and N displayed a significant and positive correlation, suggesting an adequate balance between these nutrients, which positively influences production as imbalances between these two elements cause low yields (Bataglia *et al*., 1999), especially in high productivity clones, as is the case for RRIM 600.

According to Reis and Monnera (2003), with a very low variance in the norms of a high-yield population, together with F values greater than 2 and coefficients of variation below 25%, it can be presumed that the crop is susceptible to small changes in this balance.

When this concept is put into practice, the ratios Cu/100N, Cu/100P, Cu/Mn, Cu/Fe, Cu/Zn, and 100S/B meet these conditions. Therefore, small changes in Cu and S contents will have repercussions of some kind on the rubber yield and can cause nutritional imbalances with the other elements. This situation was observed in the present study because of the high quantities of S and Cu, which was verified by the DRIS index values for those elements (Tab. 5).

TABLE 5. Nutritional balance index (NBI) for rubber clone RRIM 600 on the Eastern Plains of Colombia for the low-yield population.

Nutrient	NBI
N	-0.61
P	-0.53
K	-3.7
Ca	-2.05
Mg	-1.7
Na	-2.54
S	6.89
Fe	4.21
Cu	4.5
Mn	2.26
Zn	1.17
B	-2.64
IBN	32.8
IBNm	2.73

The DRIS index calculations were carried out after norm determination (Tab. 5), with the aim of identifying possible positive or negative effects of deficiencies, excesses, or imbalances for each of the elements. The average of the low-yield population was taken as a sample for DRIS index calculation because it was thought that this value showed the aforementioned conditions.

According to the methodology reported by Beaufils (1973) and Mourão-Filho (2004) for nutritional balance indexes, the elements with the greatest deficiencies were K, Ca, Mg, and B. Because the indexes for these elements exhibited a negative sign and were far from zero, their values are considered to represent the equilibrium or optimal nutritional balance. On the other hand, the elements S, Fe, and Cu were present in excess, with indexes above zero.

Although Ca showed higher levels in the low-yield population with respect to the high-yield population (Tab. 2), deficiencies were observed in the determination of the index (-2.05) for this element. This situation that can be interpreted as representing an imbalance with other nutrients within the tissue of the plant and not as a deficiency (Ruiz and Cajuste, 2002).

When relating the indexes of each element to the IBNm, it can be observed that the elements exhibiting the greatest probability of a response following an increase or reduction of their application are K, S, Fe, and Ca.

Conclusions

Nutritional diagnosis by means of the DRIS index indicated that K is the element that most strongly limits production and shows the greatest probability of responding to exogenous applications in the rubber clone RRIM 600 on the Eastern Plains of Colombia.

The DRIS norms found for rubber on the Eastern Plains of Colombiadiffer from those obtained in other parts of the world, and thus, the importance of establishing a local DRIS was validated.

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