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PLANT ANALYSIS BASED ON THE DRIS SYSTEM: PROGRAMMING INTERFACE WITH A CASE STUDY IN PLANTAIN CROP (*Musa AAB*)

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ABSTRACT

The Diagnosis and Recommendation Integrated System (DRIS) is a tool to evaluate the nutritional status and obtain fertilizer recommendations of several crops. Unlike other methods, DRIS works directly with farmer's information, focusing on understanding the nutritional balance of the crop. However, the selection of indexes is long and time-consuming. The objective of this work was to develop an algorithm to estimate reference and DRIS indexes for crops in order to facilitate the use of the DRIS methodology. The construction of the algorithm included four stages, (1) theoretical bases, (2) conceptual model design, (3) algorithm implementation, and (4) validation. For a database of crop yield and foliar analyses, the developed algorithm is divided into two subsets (high and low yield), estimating nutrient ratios and variability. For leaf sample diagnosis, the algorithm compares nutritional balance with highy-ield population, generating DRIS indexes numerically and graphically. A nutrient is imbalanced if its DRIS index in the graph is outside the whiskers. The efficiency and operability of the algorithm was tested with foliar analyses of fifty plantain crops distributed in two subregions of the Antioquia Department, Colombia. The developed procedure allowed determining quantitative and graphical information of the nutrient balance in foliar samples.

Keywords: standards, yield, nutritional balance, plant nutrients.

INTRODUCTION

Nutrient management planning is a key strategy for proper crop development and high yield. Achieving balanced crop nutrition requires a comprehensive analysis of factors such as soil, climate, macro and microorganisms, and crop characteristics (White and Brown, 2010). Soil and plant tests are useful tools for nutritional diagnoses, reporting on soil and plant nutrient status (Barker and Pilbean, 2007), and helping identify hidden hunger or incipient deficiencies in the crops. Minimum or 'critical' nutrient concentration refers to the level of nutrient concentration in plant tissue below which either plant growth or crop yield is affected. The

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diagnosis or identification of incipient nutrient deficiencies requires comparing laboratory results with critical values or ranges, which assess nutritional status as deficient, low, sufficient, high, or other terms (Fageria et al., 2009; Barker and Pilbean, 2007). Mineral nutrients are the most useful strategy for deficiency correction. Mineral nutrition refers to the supply, availability, absorption, translocation, and utilization of inorganically applied elements for crop growth and development (Fageria et al., 2009; Taiz et al., 2015). Although high yield depends greatly on mineral nutrients, the level of mineral nutrition needs to balance economic benefit and environmental impact.

Plant analysis requires evaluations of a specific tissue of a particular organ at a specific developmental stage. Critical values, standard values, and sufficiency ranges are the most used strategies in plant nutrition status assessment (Benton, 2012). The methods work well only when one nutrient is deficient or in excess; however, nutrient deficiencies may not occur alone, and more than one nutrient may be deficient. Factors such as developmental stage, environmental conditions, and nutrient balance can also influence nutrition requirements. Beaufils (1973) developed the experimental method Diagnosis and Recommendation Integrated System (DRIS), which relates the concentration of a nutrient to other nutrient concentrations within the plant. The DRIS method allows integrating other factors that can also affect crop yield, while these characteristics are part of the experimental error in traditional methods (Rodríguez and Rodríguez, 1997). Beaufils (1957; 1971) evaluated the applicability of the DRIS methodology in some preliminary studies on rubber and corn crops. Later, Beaufils and Sumner (1976) implemented and applied the method in the nutrition management of sugar cane, while subsequent works were conducted in other crops, such as coffee (Nick, 1998; Arboleda et al., 1988), mango (Hundal et al., 2005), cotton (Serra et al., 2012), soybean (Urano et al., 2006), horn plantain (González, 2017; Rodríguez and Rodríguez, 2000), orange (Rodríguez and Rojas, 1993), oil palm (Herrera, 2015), rubber (Chacón, 2012), and sugar beet (Barłóg, 2016). When relating nutrient contents in dual ratios in the DRIS method, plant analysis becomes independent of age and concentration of individuals or tissues, allowing the diagnosis at any plant growth stage (Sumner, 1990; 1977a). Furthermore, the DRIS method has another advantage over traditional methods since it defines the degree of deficiency or excess of nutrients, classifying them from the most deficient to the most excessive (Manzoor et al., 2022). In fact, it detects yield-limiting nutrients regardless of whether they are below or above the critical point, finally summarizing the total nutritional status of the plant as an imbalance index (Baldock and Schulte, 1996). On the contrary, the principal disadvantage of the DRIS method is that it requires training in the use of several mathematical and statistical expressions. In addition, the selection of indexes is a long process, and thus the use of the method becomes tedious and time-consuming, whereas the database needs updating due to genetic (breeding) advancement. Consequently, users tend to discard the method as a nutritional management method in commercial crops.

The objective of this work was to develop an algorithm to estimate the reference and DRIS indexes for crops in order to facilitate the use of the DRIS method. The algorithm will generate a plot that graphically shows balance state nutrients in the diagnosis, facilitating foliar analysis interpretation.

MATERIALS AND METHODS

The guide was the original work developed by Beafuils (1973), titled Diagnosis and Recommendation Integrated System (DRIS), for algorithm construction. The DRIS method algorithm was developed in four stages, (1) Conceptual aspects of the DRIS method, (2) conceptual model design, (3) algorithm implementation, and (4) validation.

Conceptual aspects of the DRIS method

Standard establishment. The DRIS method requires a database (total population) of nutritional plant analysis and yield of each field sample (Sumner, 1977b). The unit sample can be simple, representing a plant with its yield or composite describing plants and average yield of the lots, farms, or experimental units (Oliveira et al., 2022). The DRIS requires standards, which are reference values, like other methods. The quality of the database is the most prominent characteristic, more than its size in the standard definition (Walworth et al., 1988; Beaufils and Sumner, 1973). The database is split into two groups according to yield, the subset of the database formed by the upper quartile or at least 10% of the high-yield population represents the standards, and the rest corresponds to low-yield units, lots, or farms (Letzsch and Sumner, 1984).

Nutrient relationships. The DRIS method works with macro and micronutrients determined in foliar plant analyses, only considering high-yield subset. The macro and micronutrients of the subset data are separated into mobiles and non-mobiles. The DRIS method consists of a dual relationship between any pair of nutrients. The relationship between a couple of nutrients depends on the mobility group to which they belong; as a hypothetical example, suppose that a and b are mobile nutrients, while c and d are not. The method presents the nutrients of the same group as all possible dual quotients (a/b, b/a, c/d, d/c...), and from the different groups as a product (a*c, a*d, b*c, b*d) (Sumner, 1982; Nguyen et al., 2022). The dual relationship solves the problem of concentration effect or dilution on the nutrients due to mobility or age of plant tissues. The relationship between nutrients established for each of the foliar analysis samples of the reference population (plants, lots, or farms) allows estimating the average and coefficient of variation (Beaufils, 1973). In the nutrient relations of the same group, for usefulness, from each couple of nutrients, only one (either the direct or reciprocal) is selected, so it is advisable to define which nutrients go in the numerator (Walworth and Sumner, 1987). There are several approaches; however, the approach proposed by Beaufils (1973) or F proof is the best known and implemented. The F proof requires the estimation of direct and reciprocal ratios (A/B, B/A, C/D, and D/C), as well as the variance and coefficient of variation in the low-yield data subset. In the next steps, the variability of the relationships between high and low populations is analyzed through the variance; the selected ratio arises from the following analysis:

if

$$\left[\frac{s^2\left(\frac{A}{B}\right)}{s^2\left(\frac{a}{b}\right)}\right] > \left[\frac{s^2\left(\frac{B}{A}\right)}{s^2\left(\frac{b}{a}\right)}\right] \qquad [1]$$

where *A*/*B* and *a*/*b* are the dual nutrient ratio on the non-reference and reference population, respectively, and S^2 is the variance. Then, the relationship that will make part of the DRIS standards will be *a*/*b*; on the other, it will be *b*/*a*.

The selection of direct or inverse ratio to compose the DRIS standards with the F proof reduces to half the ratios between nutrients and makes it less tedious for the DRIS method application. However, Bataglia and Santos (1990) compared the dual (a/b and b/a) and nondual (a/b or b/a) relationships, concluding that the order can be interfered with the index values.

DRIS index calculation. To compare and quantify the status of each nutrient in any foliar analysis sample, Beaufils (1973) proposed a DRIS index, which summarizes nutrient relationships. In DRIS index estimation, DRIS functions were calculated as follows:

if (A/B ≥ a/b)

$$f(A/B) = \left[\left(\frac{A/B}{a/b}\right) - 1\right] * \left(\frac{100}{CV}\right) \qquad [2]$$

else (A/B < a/b)

$$f(A/B) = \left[1 - \left(\frac{a/b}{A/B}\right)\right] * \left(\frac{100}{CV}\right) \qquad [3]$$

where *a*/*b* and *A*/*B* are nutrient ratios in the reference and sample, respectively. *CV* corresponds to the variation coefficient of the standard.

Other functions with more nutrients, such as *f* (A/C) and *f* (A/D) are calculated in the same way, using appropriate standards and coefficient of variation. The form of expression selected for the use in DRIS computation is associated with the largest variance ratio and lowest coefficient variation. The average value of differences between functions, where a nutrient is in the numerator and those in the denominator, determines the DRIS index as illustrated in the following equations [4, 5]:

$$DIA = \frac{\sum_{i=1}^{n}[f\left(\frac{A}{B}\right)]}{n} \qquad [4]$$

$$DIA = \frac{\sum_{i=1}^{n}[f\left(\frac{A}{B}\right)] - \sum_{i=1}^{m}[f\left(\frac{B}{A}\right)]}{n+m} \qquad [5]$$

where DIA is the DRIS index for *A* nutrient; *B* corresponds to other nutrients to which A was related; *n* and *m* are the numbers of functions where nutrient A is in the numerator or denominator.

The DRIS index can take negative, positive, or zero values meaning deficiency, excess, or balance, respectively (Mourão Filho, 2004). The general status of foliar analysis (plant, lot, or farm), can be assessed with the nutritional balance index (NBI), which is obtained as the sum of the absolute values of each DRIS nutrient index. Values close zero in the NBI indicate balanced nutritional status; the higher the value, the greater the nutritional imbalance in the plant (Barłóg 2016; Wadt et al., 1999). However, the NBI does not indicate when a particular nutrient is yield-limiting.

Conceptual model design

The Fig. 1 shows the integration of overall concepts described in each step of the theoretical DRIS method. The model starts with a database including foliar nutrient concentration and yield; and by the foliar sample(s) involved in the diagnosis. In addition, if the foliar sample has been associated with production, it will

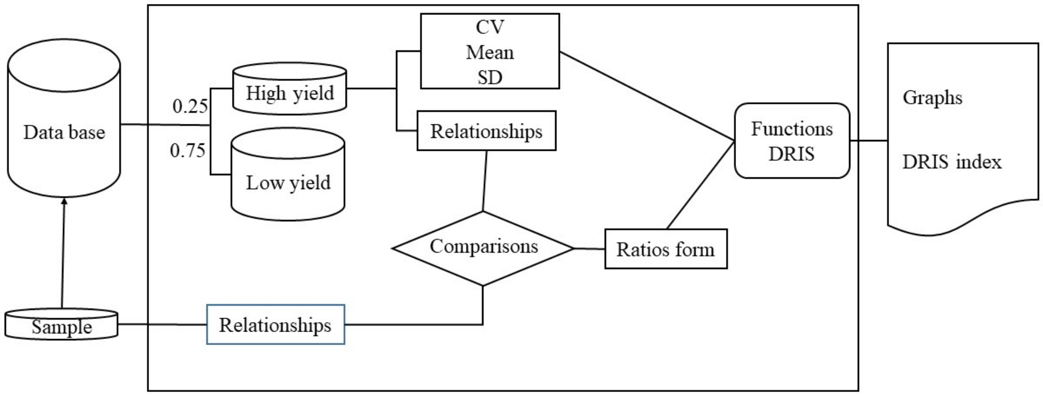


Fig. 1. Conceptual model desing of the DRIS method. The database and sample are input parameters of the model. The algorithm divides the database into two subsets. With the high-yield subset, standards are estimated and compared with the sample, generating the DRIS indexes.

be part of the database. In the second step, the algorithm divides the database into two subsets. A subset is composed of 25% units of the highest production, and 75% remaining units. In the third step, the algorithm estimates the ratios both in the reference subset and in the sample. The coefficient of variation is determined only in the reference subset. In a fourth step, the algorithm compares the reference and sample ratios, and applies the DRIS function to determine DRIS index and graphs.

Algorithm implementation

We implemented the algorithm script in the R language and environment for statistical computing and organized it into an Application Programming Interface (API) to ensure its functionality and accessibility to the databases. The license of the R package is under a general public license (GNU) (R core team 2022) and Plumber is an R open package (Barret-Schloerke and Jeff-Allen, 2021).

Validation

Two databases prepared by the Tropical Phytotechnie research group of the National University, Colombia, were used in the validation process. One represents the Uraba subregion, and the other the Southwest subregion, Antioquia Department, Colombia (Fig. 2). The model crop is plantain, and the cultivars planted are Harton (Uraba subregion) and Dominico Harton (Southwest subregion). Each database has foliar analyses and the bunch weight of the 25 farms. The nutrients defined in the foliar analyses were nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), and magnesium (Mg) as macronutrients and expressed in percent (%); and iron (Fe), copper (Cu), manganese (Mn), boron (B), and zinc (Zn) as micronutrients and expressed in μg^{-1}. Table 1 shows the methods used for nutrient determination.

We evaluated the precision of DRIS indexes by applying and not applying F proof in order to select the best option, only with nutrients N, P and K, which were taken randomly from the Southwest subregion database, four foliar analyses. The nutrients standards were estimated to the reference farms, choosing all six relationships (N/P, N/K, P/N, P/K, K/N, and K/P) in accordance with Battaglia and Santos (1990) and Leite (1993), and three ratios (N/P, N/K, and K/P) by applying F proof of variance discrimination.

RESULTS AND DISCUSSION

Precision of relationship alternatives. Six farms with the highest yield (> 25 kg $bunch^{-1}$) formed the reference or standard subset of the Southwest subregion database. Table 2 shows the six possible nutrient relationships for the standard and four randomly selected farms. Following the F proof strategy, the chosen ratios were N/P, N/K, and K/P for function application and DRIS index estimation.

In the calculation of the DRIS index presented in Table 3, the N index magnitudes are the same, with the F proof and all possible ratios in all farms. However, the values are different from the other nutrient indexes because, in the variance proof discrimination, nitrogen was in the numerator in all ratios, while the other nutrient were not. P has the most significant differences between the two strategies of DRIS index estimation in two cases with the opposite sign. The most relevant difference between the two alternatives occurs with those nutrients that predominantly remain in the denominator.

Another difference is that the nutritional balance index of the samples is zero according to the F test, while estimating across all proportions is different from zero, showing that all farms have

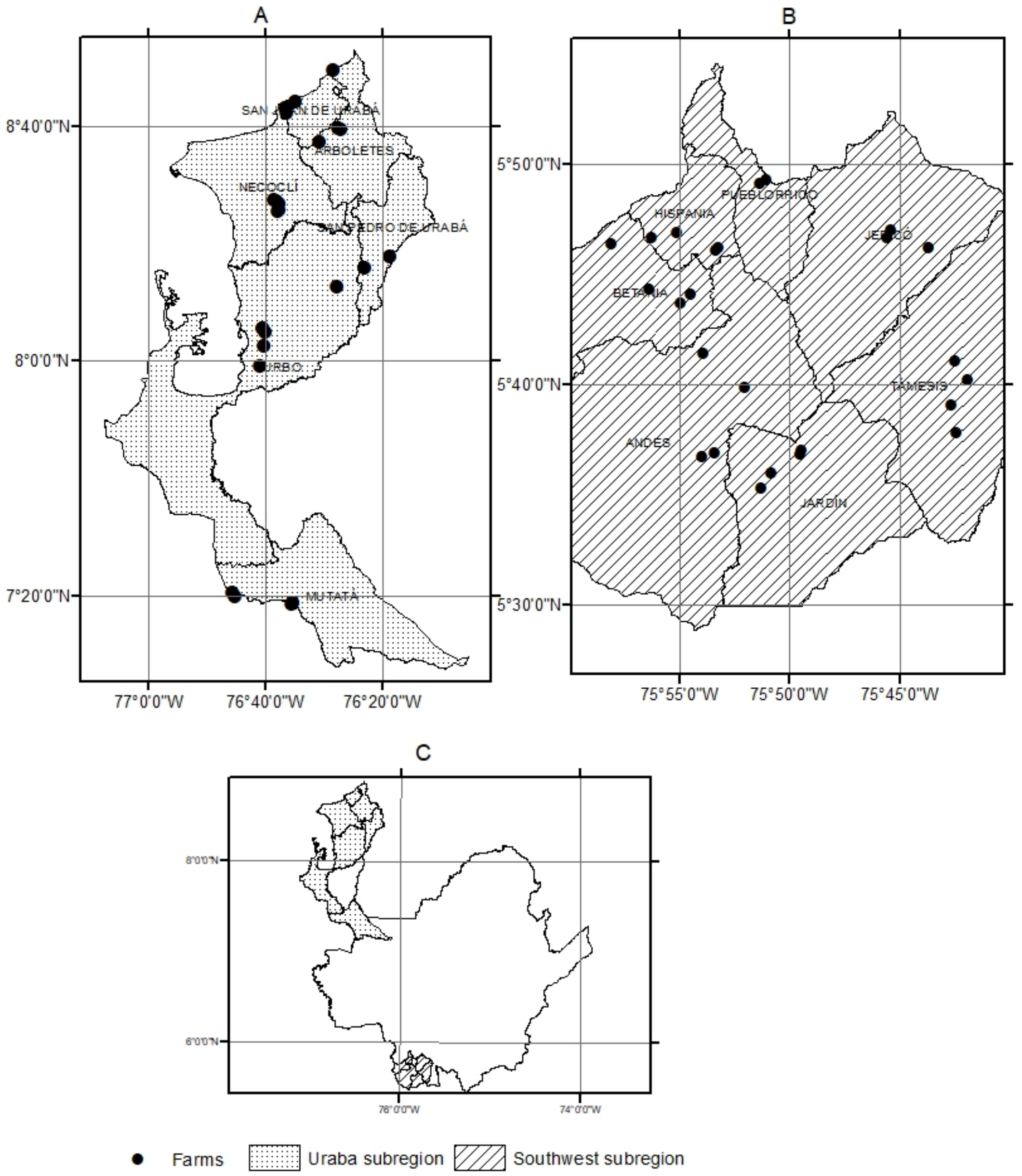


Fig. 2. Geographical distribution of foliar analysis and yield databases of fifty farms dedicated to banana cultivation, A) Harton variety grown in the Urabá subregion, and B) Dominico Harton grown in the Southwest subregion of C) Antioquia Department, Colombia.

some degree of imbalance. The reduction to half of the nutrient relationships in the F proof balances, the negative and positive effects of nutrient relationships in the DRIS functions, do not allow showing the status of the nutritional balance in the sample (Serra et al., 2013; Mourão, 2004). Given the problems previously described, we implemented an algorithm that calculates both direct and inverse relationships in DRIS index estimation.

Optimal DRIS index ranges. The DRIS indexes allow identifying nutrient imbalance or limiting nutrients by excess or deficiency (Beaufils, 1973; 1977). However, the index *per se* does not indicate what critical points will affect crop yield and suggests changes in the nutritional plan. The closer to zero the DRIS index for a nutrient, the better balanced it will be. However, establishing when a value is close to zero and when it is not can be a subjective task. In this sense, Walworth and Sumner (1987) and Battaglia and Santos (1990) recommend DRIS index ordering from the most negative to the most positive, suggesting a gradient of limiting nutrients between deficiency

Table 1. Methods used in foliar nutrient determination (IGAC, 2006 and Múnera, 2012).

Nutrient	Method	Unit
Nitrogen (N)	Kjeldhal	%
Phosphorus (P)	Colorimetric (rhodamine B-phosphomolybdate complex)	
Potasium (K), calcium (Ca), magnesium (Mg)	Atomic absorption spectrometry	
Sulfur (S)	Turbidimetry (BaCl$_2$-gelatin)	
Iron, copper, manganese, zinc	Atomic absorption spectrometry	μg^{-1}
Boron	Colorimetric (rhodamine B-phosphomolybdate complex)	

Table 2. Basic parameters of the nutrient relationships both in the high and low population as in the diagnosed samples (farms).

Nutrient ratios	High-yield population (Norm)			Low-yield population		Diagnosed Sample (farm)			
	a/b	CV (1)	S^2(a/b) (2)	S^2(A/B)	S^2(A/B)/S^2(a/b) (3)	211	223	261	274
N/P	18.75	22.39	17.99	14.96	0.83(4)	18.55	16.50	14.58	16.44
N/K(3)	1.08	24.82	0.06	0.08	1.50(4)	1.14	0.82	0.81	1.21
P/N	0.06	19.17	0.00	0.00	0.71	0.05	0.06	0.07	0.06
P/K	0.06	20.47	0.00	0.00	3.59	0.06	0.05	0.06	0.07
K/N	0.97	21.55	0.07	0.04	0.58	0.88	1.22	1.23	0.83
K/P(3)	17.41	25.84	4.27	22.82	5.35(4)	16.30	20.06	18.00	13.63

(1) Coefficient of variation. (2) The variance of the ratios. (3) Ratio A/B selected if [S^2 (A/B)/S^2 (a/b)] > [S^2 (B/A)/S^2 (b/a)], B/A in other case (F proof).

Table 3. DRIS index comparisons (N, P, K), obtained through both F proof and all ratios.

Farm or sample	Index (F proof)				Index (all ratios)			
	N	P	K	NBI(1)	N	P	K	NBI
211	0.08	0.16	-0.24	0.00	0.08	-0.18	-0.37	-0.47
223	-0.95	0.01	0.94	0.00	-0.95	-0.13	0.88	-0.20
261	-1.32	0.57	0.75	0.00	-1.32	0.54	0.70	-0.09
274	-0.09	0.85	-0.77	0.00	-0.09	0.93	-0.93	-0.09

(1) Nutritional balance index of the sample.

and excess. When assessing the nutritional status of plants, Manzoor et al. (2022) recommend using the nutritional balance index (NBI), seeking for nutrient balance of the plants. The NBI is generated by summing up the module values of all DRIS indexes generated in the sample. It can also be seen as the average NBI divided by the number of nutrients. The higher the NBI, the greater the nutritional imbalance (Serra et al., 2013).

The two previous methods use the unit in diagnosis and ordering or estimation of the average DRIS index, being particular to it, which is a disadvantage. Furthermore, it does not indicate how negative or positive the index of each nutrient can be without affecting crop yield.

We propose a new alternative, the optimal DRIS index ranges (ODIR), to adjust the crop nutritional plan for limiting nutrients due to deficiency or excess. The strategy is to know the variability of the DRIS index in a high-yield population. In this sense, the algorithm assumes each nutrient foliar analysis of the standard as a sample, generating the respective nutrient DRIS index, average, and standard deviation for each one. Knowing the variability in the high population of the DRIS index, the ODIR is the mean plus and minus one standard deviation. As the reference for the ODIR is the average DRIS index of each nutrient; it is not distributed around zero symmetrically, revealing slight imbalances of the DRIS index in the high-yield population. A diagnosed sample will be in a imbalanced state for a nutrient if its DRIS index is outside the range of variation of the high-yield population DRIS indexes for that nutrient.

Fig. 3 shows the DRIS indexes for six macronutrients and five micronutrients and their respective whisker, obtained as the DRIS index means of the high-yield population. The ranges of the bars are fixed for all farms, since they represent the DRIS index variability in the subset of the high yield. The plot scale varies due to the imbalance level presented by the nutrients in the diagnosed sample. The most imbalanced farms are 211 and 261, because they have several nutrients outside the whisker, and nutrients such as Fe and Mg are several units outside the range of variation in excess.

Generalization of the algorithm

Authors such as Summer (1977b) and Bangroo et al. (2010) refer to the DRIS method as universally independent of plant tissue, crop age, and local conditions such as soil, climate, and cultivars. However, authors such as Jones (1981) suggest being critical regarding the reliability of DRIS standards. Similarly, Mourão (2004) has indicated that many factors require more in-depth analysis such as the criteria for choosing reference populations. Furthermore, Llanderal et al. (2018) conducted a study on the variation of DRIS norms during plant growth and development of greenhouse tomato. The authors developed the norms, including all data of crop cycle and for each subset of the corresponding phenological stage of tomato, and found significant variability when setting DRIS standards based on phenological stage compared with general DRIS norms, suggesting that DRIS norms based on phenological stage would allow better nutritional adjustment. In addition, Villaseñor et al. (2020) determined DRIS norms and limiting nutrients in banana crop, specifically cultivars Vallery and William from the Cavendish subgroup, grown in the south of Ecuador. They found that foliar nutrient levels and DRIS indexes of the high-yield subpopulation were significantly correlated, except for P and Mn, indicating that the non-significance relationship may be related to edaphoclimatic conditions in the growing region. The authors did not find a significant adjustment between the nutritional balance index and yield, suggesting the influence of other factors. Similar results were observed in studies conducted by Silva et al. (2013) in coffee and by Gonzalez (2017), who found significant differences in DRIS norms between regions and plantain cultivars Harton and Dominico Harton, in the Uraba and Southwest subregions, Antioquia Department, Colombia.

Although the developed algorithm applies to any crop as long as there is a database of foliar analyses and yields, it is important to be careful when using the method in order to guarantee data quality, especially considering that the DRIS method has as a basis on the selection of a high-yield population, being the benchmark for comparisons with any other sample (Escano et al., 1981). Please consider the following recommendations for representativeness: 1. The database must represent the agroecological conditions of users' farms. 2. Agronomic aspects should be used with samples of the same cultivar and similar agronomic practices. 3. For new regions and varieties, implement a new database.

Use and validation

An application programming interface (API) integrates both the algorithm and two databases for plantain crops from two subregions (Uraba and Southwest) of the Antioquia Department. The API has a general description of its functioning, defining the file format of sample(s).

A diagnosis in the API requires the entry of the following parameters: *Sample ("mtra")*. The file to be diagnosed is in .txt or .csv format. *Decimal fraction ("dec")*. A separator character of the decimal fraction of the values of the sample. *Column separators ("sep")*. A separator character of fields (columns) between samples records. *Yield ("y")*. Character or string indicating the name of the yield variable. *Subregion*. A string specifying the database (Uraba, Southwest) to select in the diagnosis of the sample. *Proportion (p)*. Fraction of the low-yield subdatabase; in this sense, the high-yield population will be 1-p (Fig. 4).

The API provides two types of results. In the API's *response body* appears the quantitative results. It is a text file with averages and standard deviations for nutrients and DRIS indexes for both norms and samples (Table 4). Graphic results show

Table 4. DRIS indexes for four farms of the Southwest subregion, Antioquia Department, Colombia, compiled from the API.

Farm	N	P	S	Mg	K	Ca	Fe	Mn	Cu	Zn	B
211	2.8	4.5	1.7	2.4	3.1	-1.3	20.8	-3.2	-0.8	-2.5	-0.1
223	-0.4	-0.1	-0.1	0.6	0.8	-1.7	-0.7	0.3	2.0	-1.0	-0.3
261	-2.6	-2.1	-2.6	4.4	-1.6	-0.3	-2.8	1.5	1.0	-2.7	-3.1
274	-1.0	-0.6	-1.1	-0.8	-2.1	-0.4	-2.6	0.9	-1.7	-0.9	-1.1

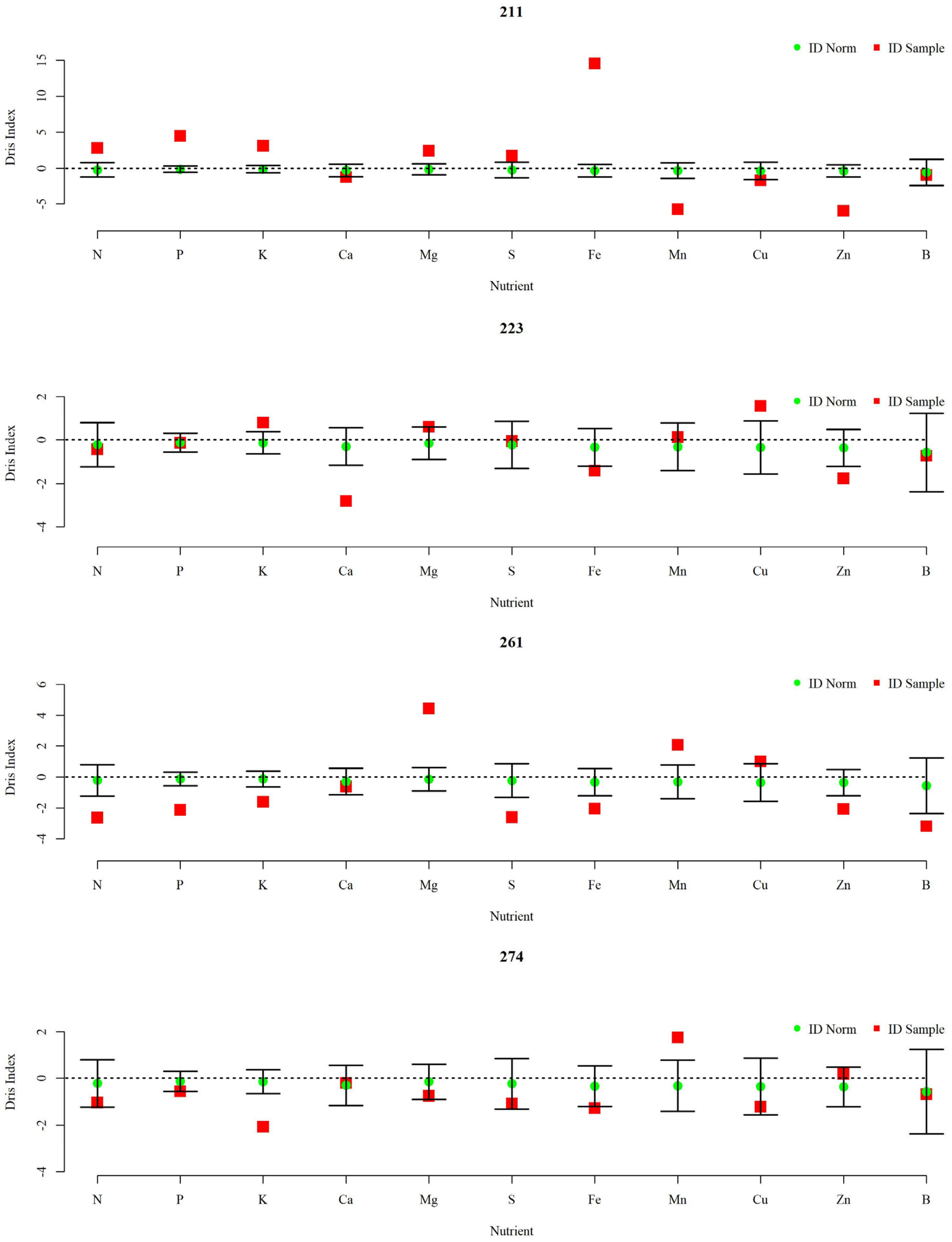
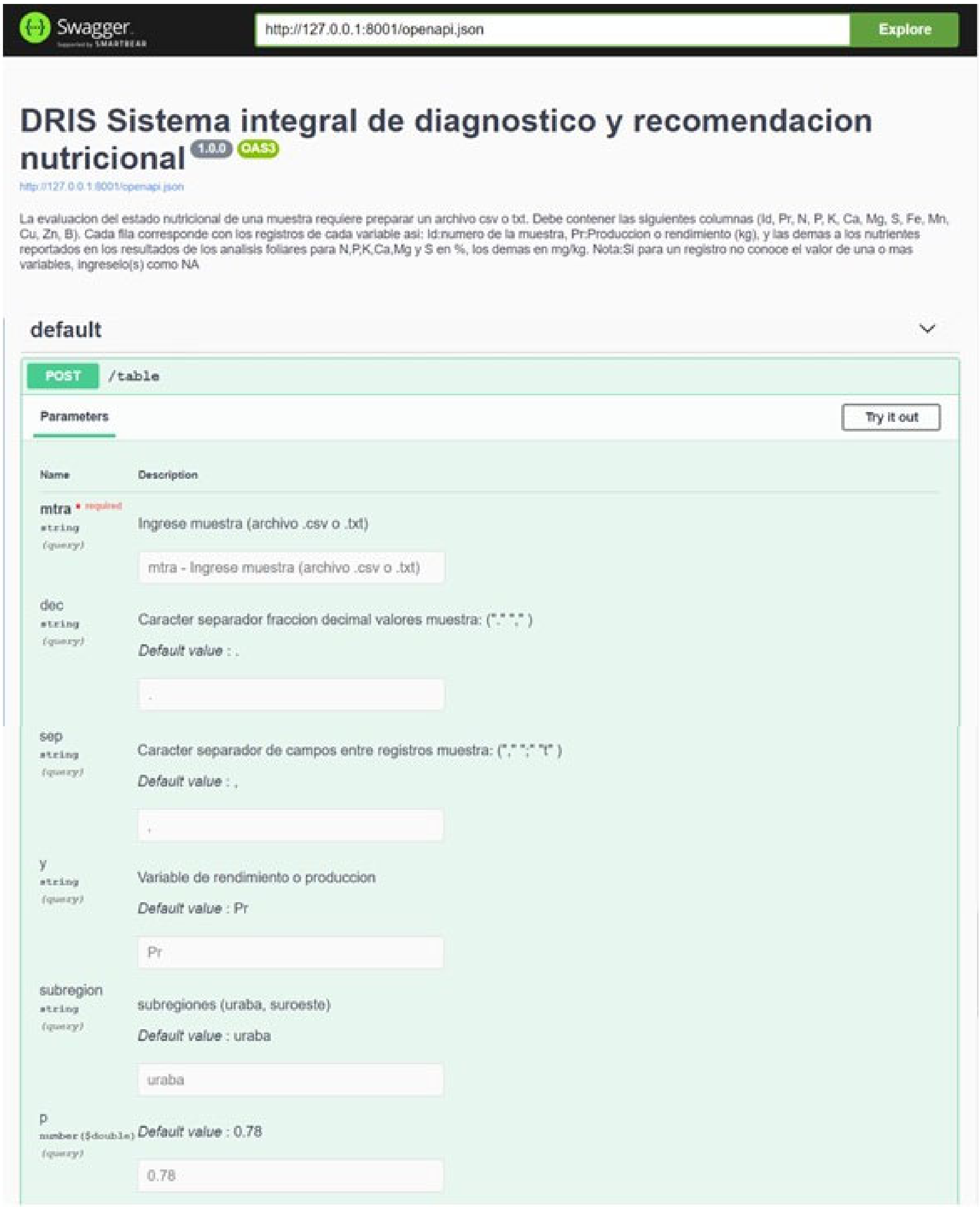


Fig. 3. **DRIS indexes for four farms randomly selected (211, 223, 261, 274) of the Southwest subregion database, Antioquia Department. The whisker was estimated as one standard deviation around the mean of each DRIS index nutrient in the high population.**



DRIS Sistema integral de diagnostico y recomendacion nutricional

http://127.0.0.1:8001/openapi.json

La evaluacion del estado nutricional de una muestra requiere preparar un archivo csv o txt. Debe contener las siguientes columnas (Id, Pr, N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn, B). Cada fila corresponde con los registros de cada variable asi: Id:numero de la muestra, Pr:Produccion o rendimiento (kg), y las demas a los nutrientes reportados en los resultados de los analisis foliares para N,P,K,Ca,Mg y S en %, los demas en mg/kg. Nota:Si para un registro no conoce el valor de una o mas variables, ingreselo(s) como NA

Name	Description
mtra * required string (query)	Ingrese muestra (archivo .csv o .txt) mtra - Ingrese muestra (archivo .csv o .txt)
dec string (query)	Caracter separador fraccion decimal valores muestra: ("." ",") *Default value* : . .
sep string (query)	Caracter separador de campos entre registros muestra: ("," ";" "\t") *Default value* : , ,
y string (query)	Variable de rendimiento o produccion *Default value* : Pr Pr
subregion string (query)	subregiones (uraba, suroeste) *Default value* : uraba uraba
p number ($double) (query)	*Default value* : 0.78 0.78

Fig. 4. API of the diagnosis and recommendation integrated system (DRIS) for plant analysis interpretation

nutrient mean values and DRIS indexes of the high-yield population, simultaneously graphing the behavior of the sample (Figs. 3 and 5).

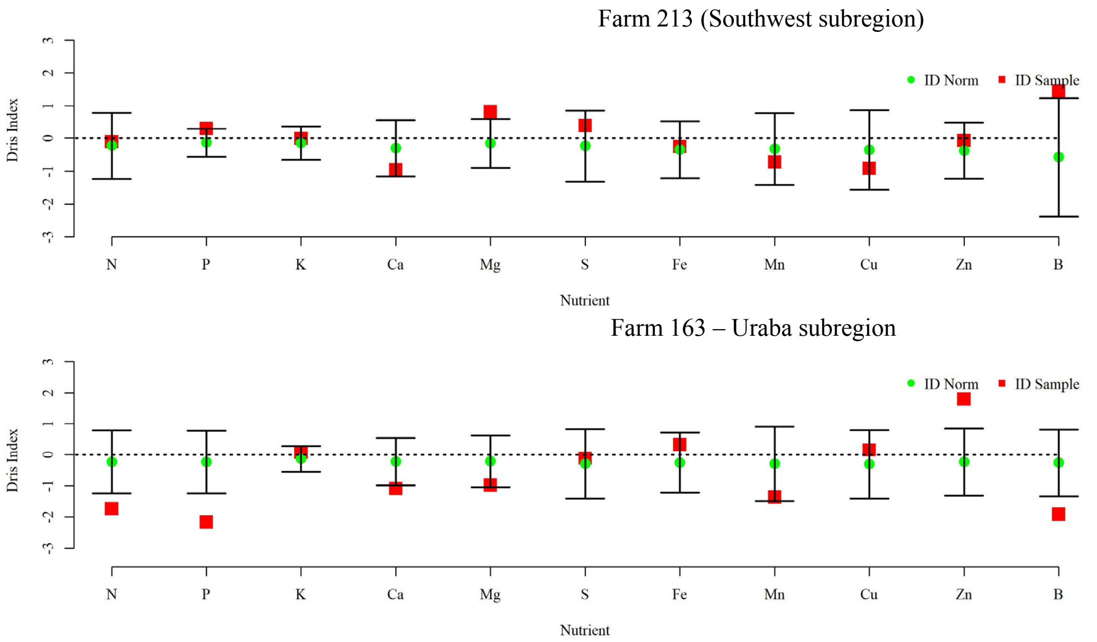
Fig. 5 shows DRIS indexes and differences in the whiskers between farms 163 and 213. These two farms belong to two distinct subregions with differences in DRIS index variability, and consequently whisker behaviour is different.

When comparing the DRIS index with sufficiency ranges in farm F_211, sufficiency ranges present problems by excess nitrogen and iron nutrients (Fig. 6), while the DRIS index reveals an imbalance in eight nutrients, showing a more sensitive method (Fig. 3).

Finally, the algorithm works well with any database and does not require modification to be applied with a crop.

CONCLUSIONS

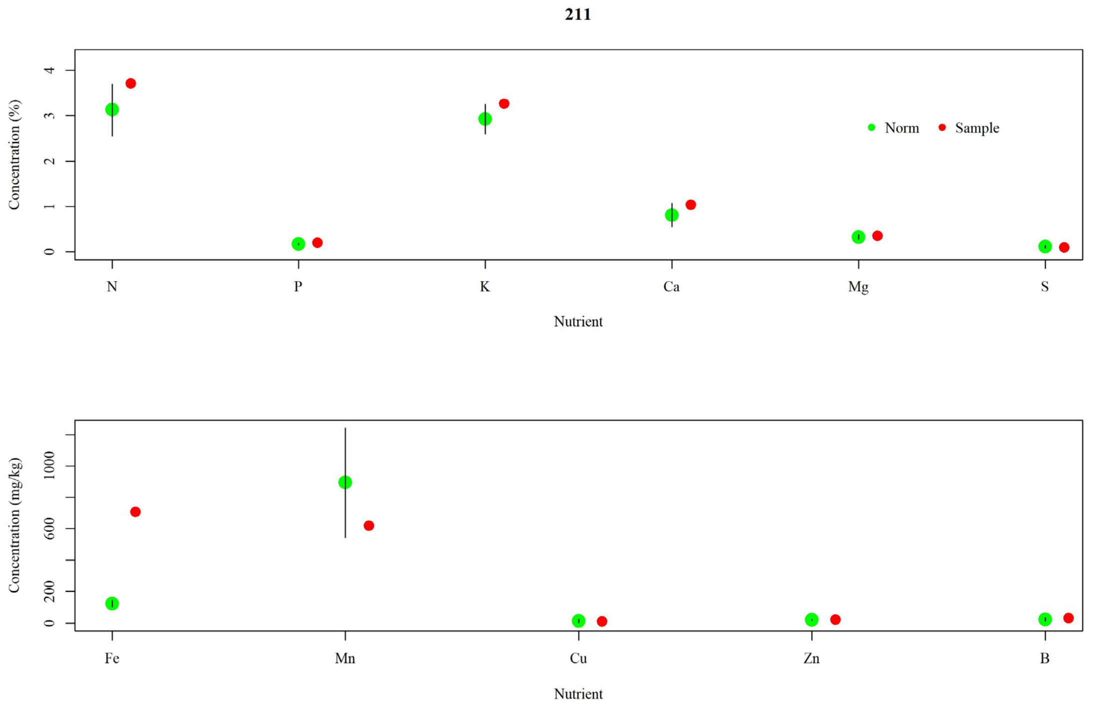
The developed algorithm promotes sample diagnosis in crops by using the DRIS method. If the database is available, it also helps the implementation of DRIS standards in other



Farm 213 (Southwest subregion)

Farm 163 – Uraba subregion

Fig. 5. **DRIS indexes for farm 213 (Southwest subregion) and farm 163 (Uraba subregion), Antioquia, Colombia.**



211

Fig. 6. Report from foliar nutrient content in the high-yield population and the sample of the farm 211, located in the Southwest subregion, Antioquia Department, Colombia. N, P, S, Ca, Mg and K are expressed as %; and Fe, Mn, Cu, Zn and B are expressed as μg g^{-1}.

crops or cultivars. The optimal DRIS index range avoids subjectivity in the interpretation of DRIS indexes, incorporating high-yield population to determine when a nutrient is imbalanced, excess, or deficient. The graphical presentation facilitates the visual understanding of nutrient imbalance by users.

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