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Diagnosis and Recommendation Integrated System, its application and use in agriculture. A review

Sistema Integrado de Diagnóstico y Recomendación, su aplicación y utilidad en la agricultura. Una Revisión

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ABSTRACT: Nutrient balance determines crop yield and quality. The Diagnosis and Recommendation Integrated System-DRIS uses a holistic analysis based on interrelation between nutrients, compares crop mineral element proportions with optimal values known as DRIS norms and identifies imbalances, deficiencies, and/or excesses in plant nutrients, ranking them in order of importance. There are scientific reviews geared towards the development of methodological proposals to obtain DRIS norms in various crops and the calculation of their respective indices, but they do not elucidate the real functionalities of this diagnosis system. Therefore, the objective of this review was to present the applications and uses of DRIS developed during the last 10 years in agriculture worldwide. Scientific studies have shown that the nutritional status of crops can be understood with the nutrient balance in leaf tissue and soil, the dynamics of mineral elements according to the phenological stage, the Critical Levels and Sufficiency Ranges, the soil-plant relationship, the nutritional balance provided by fertilizers and green manure, the spatial variability and DRIS, the heavy metal translocation, the nutrition and incidence of phytosanitary problems, the phytotoxicity in plants irrigated with wastewater from agricultural irrigation, the Sufficiency Ranges in leaf tissue under saline conditions, the sap analysis, and the DRIS norms in seeds. DRIS is a tool for nutritional diagnosis that is capable of validation in agricultural systems worldwide.

KEYWORDS: Dris, Nutritional Diagnosis, Mineral Nutrition, Nutritional Dynamics, Crop Nutrition.

RESUMEN: El equilibrio de nutrientes determina el rendimiento y calidad de los cultivos. El Sistema Integrado de Diagnóstico y Recomendación-DRIS propone un análisis holístico sobre la base de la interrelación entre nutrientes, compara las proporciones de los elementos minerales de los cultivos con valores óptimos conocidos como normas DRIS e identifica desequilibrios, deficiencias y/o excesos en los nutrientes de la planta para clasificarlos por orden de importancia. Existen trabajos de revisión científica orientados al desarrollo de propuestas metodológicas para obtención de las normas DRIS en diversos cultivos y el cálculo de sus respectivos índices, pero, estos no dilucidan las funcionalidades reales de este sistema de diagnóstico; por lo tanto, la siguiente revisión tiene como objetivo, dar a conocer las aplicaciones y utilidades del DRIS en la agricultura a nivel mundial desarrolladas durante los últimos 10 años. Considerando lo anteriormente expuesto los estudios científicos sugieren: balance de nutrientes en tejido foliar y suelo, dinámica de elementos minerales según etapa fenológica, niveles críticos y rangos de suficiencia, relación suelo-planta, balance nutricional por uso de fertilizantes y abonos verdes, variabilidad espacial y DRIS, translocación de metales pesados, nutrición e incidencia de problemas fitosanitarios, fitotoxicidad en plantas irrigadas con aguas residuales de riego agrícola, Rangos de Suficiencia en tejido foliar bajo condiciones salinas, análisis de savia y normas DRIS en semillas. El DRIS es una herramienta para el diagnóstico nutricional, susceptible de validación en los sistemas agrícolas a nivel mundial.

PALABRAS CLAVE: DRIS, Diagnóstico Nutricional, Nutrición Mineral, Dinámica Nutricional, Nutrición De Cultivos.

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I. Introduction

The nutritional diagnosis of crops is done with the results of chemical fertility analysis of soils, using the nutritional requirements of the studied species (Chacón-Pardo et al., 2013a; González, 2017; Herrera, 2015) and frequently the interpretation of nutrient concentrations in leaf tissue with widely used methods such as Critical Levels and Sufficiency Ranges (Bangroo et al., 2010; Savita et al., 2016). These methods are based on the individual comparison of the nutrient concentration in the sample with an accepted value of normality for a certain phenological stage without taking into account the relationships between nutrients and their possible imbalances (Kania & Callejas, 2011).

Because of the limitations caused by traditional interpretation methods, the Diagnosis and Recommendation Integrated System (DRIS) was proposed, which is a set of norms used to evaluate the nutritional status of a crop, using the composition of plant tissues, the chemical fertility of the soil, the climatic conditions, and the integrated management practices of such crop as the reference (González, 2017; López-Montoya et al., 2018).

DRIS, which is the acronym for "Diagnosis and Recommendation Integrated System", was proposed by Beaufils (1973), based on studies on physiology and plant nutrition, initially in rubber trees cultivated in Vietnam and then in maize and sugarcane in South Africa. In 1975, Sumner introduced DRIS to the United States (González, 2017). Since then, diagnosis norms have been determined for several extensive, forage, fruit, and vegetable crops and for timber species (Bangroo et al., 2010; Kania & Callejas, 2011; Savita et al., 2016).

The dynamic processes of leaf composition require a holistic diagnostic evaluation beyond the comparison of analytical results of each nutrient, comparison to the critical value or existing sufficiency ranges for each particular species (Kania & Callejas, 2011). DRIS uses the results of leaf analysis or chemical fertility of the soil to identify the most limiting nutrient in the development of a crop. The evaluation is done by comparing the relative balance of the content of a nutrient against the DRIS nutritional diagnosis norms established for the species (Savita et al., 2016). According to Walworth and Sumner (1987), the theoretical bases of this system are founded on the fact that the relationship between nutrients is a better indicator of the nutritional status of the plant than the isolated values.

Maximum productions are achieved when the relationships between these nutrients are close to an optimal value obtained from the selection of a population with high yields (reference population). DRIS indices can be calculated for the identification of deficiencies, excesses, or ideal values of nutrients in a crop. Furthermore, DRIS indices establish the Nutritional Balance Index that represents the global balance of the nutrients involved in the nutrition of the plant (Bangroo et al., 2010; Chacón et al., 2013b).

In the last ten years, three scientific reviews have been published by Bangroo et al. (2010), Kania & Callejas (2011), and Savita et al. (2016) on the development of methodological proposals to obtain DRIS norms in various crops of agronomic interest and the calculation of their respective nutritional indices, but they do not elucidate the real functionalities that this diagnosis method in agriculture. This review aimed to present the applications and uses of the Diagnosis and Recommendation Integrated System developed during the last 10 years in agriculture worldwide through the systematic review of databases such as Redalyc, Scielo, ScienceDirect, Scopus, Springer Nature, Taylor & Francis, and Web of Science.

II. Establishment of DRIS norms

To make use of this method for nutritional diagnosis in a crop, it is necessary to establish DRIS norms or standards that can be obtained for the plant tissue and/or physical and chemical properties of the soil. The best norms are generated from a large database for a specific genotype within a particular agro-ecological zone, where variables of relief, climate, integrated crop management practices, crop yield, concentration of nutrients in the plant, and chemical and physical variables of the soil are related to the soil-plant-environment relationship (Behera et al., 2016; Chacón et al., 2013a; Franco-Hermida et al., 2017, 2020; González, 2017; Herrera, 2015; Landriscini et al., 1997; Pereira & Justino, 2021).

Local calibration of DRIS norms offers greater precision in the diagnosis of deficiencies or imbalances in a crop, using those produced for other regions and providing reliability, rigor, and accuracy (Franco-Hermida et al., 2017, 2020; Landriscini & Galantini, 2018).

In the absence of local norms, those developed under other edaphoclimatic conditions can be used as long as the nutrient concentrations in the high-yielding population used to generate the norms are similar to the nutrient concentrations of the high-yielding population under study (reference population) (Kania & Callejas, 2011). That is, local regulations must have strong statistical support to be applied in environments other than where they were generated (Landriscini & Galantini, 2016, 2018).

III. Calculation of DRIS indices

Once the DRIS norms for a crop are known, along with reference average values of the concentrations of the nutrient pairs in the high-yielding population (Kania & Callejas, 2011), the DRIS indices (DRIS-I) are found to identify possible nutritional imbalances and to define the order of nutrient requirements at the foliar or edaphic level (Franco-Hermida et al., 2017).

The indices are established when determining the calculation of the functions, which in turn, consider the relationships between nutrients analyzed in the sample (tissue and/or soil) and the functions of the DRIS indices (Herrera, 2015; López-Montoya et al., 2018). After the calculation of the function of each relationship, the DRIS-IN of the nutrients in the study are obtained (Kania & Callejas, 2011; Giner, 2015).

Subsequently, the Nutritional Balance Index (NBI) is calculated, which is an index of production related to crop yield, which determines the general balance of nutrients involved in plant nutrition (Chacón-Pardo et al., 2013a). Likewise, the Nutritional Balance Index (mNBI) is calculated, which qualifies the degree of sufficiency of each nutrient (Herrera, 2015; López-Montoya et al., 2018).

IV. Application and uses of DRIS in agriculture

The DRIS system has had a dynamic advance worldwide during the last 10 years, which has made it possible to address plant nutritional diagnosis holistically. This system is becoming a key tool for the integrated management of production systems, expanding its use in agriculture. The studies below suggest the importance of these studies being done at the local and/ or regional level on a specific genetic material or cultivar to achieve reliable results capable of validation (Table I).

TABLE I. Application and use of DRIS systems in agriculture worldwide during the last 10 years.

Crops	Country-Region	Author	Use
Maize (*Zea mays*) var. DMR-ESRW1	África-Benin	Dagbenonbakin et al., 2013	DRIS norms-Leaf tissue
Yam (*Dioscorea rotundata*)	África-Benin	Dagbenonbakin et al., 2012	DRIS norms-Leaf tissue
Wheat (*Triticum aestivum*)	Argentina (Semi-arid Pampas)	Landriscini & Galantini, 2018	DRIS norms-Leaf tissue
Wheat (*Panicum maximum*) 2 genotypes (Tanzania and Massai)	Brazil	Silveira et al., 2020	Biochemical and physiological events induced by Cadmium.
Common bean (*Phaseolus vulgaris*): cv. Pérola of the Carioca group	Brazil-Goiás	Partelli et al., 2014	DRIS norms-Leaf tissue
Atemoya (*Annona* spp.) cv.Thompson	Brazil-São Paulo	Haitzmann & Rozane, 2017	DRIS norms-Leaf tissue
Conilon coffee (*Coffea canephora*)	Brazil-Bahía	Partelli et al., 2018	DRIS norms-Leaf tissue-pre-flowering and grain filling
Banana (*Musa* spp.) subgroup Prata and Pacovan	Brazil-Ceará	Pereira et al., 2015	DRIS norms-Leaf tissue
Banana (*Musa* spp.): Prata-Anã (AAB) and Grande Naine (AAA)	Brazil-Ceará, Bahía	Rodrigues-Filho et al., 2021	DRIS norms-Leaf tissue

Continued

TABLE I CONTINUATION. Application and use of DRIS systems in agriculture worldwide during the last 10 years.

Crops	Country-Region	Author	Use
Conilon coffee (*Coffea canephora*): genotype Bamburral	Brazil-Espírito Santo	Da Silva et al., 2020	DRIS + *GIS = Nutrition and incidence of leaf rust and berry borer
Peroba amarela (*Paratecoma peroba*). Brazilian timber specie	Brazil-Espírito Santo	França et al., 2020	DRIS norms-Leaf tissue. Nursery phase
Cacao (*Theobroma cacao* L.) clones CCN51 and PS1319	Brazil-Espírito Santo and Bahía.	Oliveira et al., 2019	DRIS norms- Leaf tissue and soil
Common bean (*Phaseolus vulgaris*): var. Perola	Brazil-Goiás	Partelli et al.,2019 Partelli et al., 2014	DRIS norms and Sufficiency Ranges in leaf tissue and soil
Cactus pear (*Opuntia fícus-indica* L.)	Brazil-Guanambi	Batista et al., 2019	DRIS norms- Leaf tissue
Cotton (*Gossypium hirsutum*) 6 varieties	Brazil-Mato Grosso do Sul	Pereira et al., 2013	DRIS norms- Leaf tissue
Soybean (*Glycine max* L. Merr.)	Brazil-Minas Gerais	Dos Santos et al., 2019	DRIS norms-Leaf tissue-Zero tillage
Garlic (*Allium sativum* L.) var. Ito	Brazil-Minas Gerais	Pereira et al., 2016	DRIS norms- Leaf tissue
Banana (*Musa* spp.) cv. Prata-Anã	Brazil-Minas Gerais	Alves & Vilela, 2013	Nutrition Vs *Fusarium oxysporum* incidence
Potato (*Solanum tuberosum*) cv. Asterix	Brazil-Minas Gerais	Araújo et al., 2019	DRIS norms- Leaf tissue
Carrot (*Daucus carota* L.) 9 cultivars	Brazil-Minas Gerais	Reis et al., 2017	DRIS norms and Sufficiency Ranges
Hybrid coconut tree (*Cocus nucifera* L.)	Brazil-Pará	Medeiros et al., 2015	DRIS norms-Leaf tissue-adult plants
Oil palm (*Elaeis oleifera* × *E. guineensis*)	Brazil-Pará	Bastos et al., 2017	DRIS norms - Leaf tissue
Soybean (*Glycine max*. L.) 6 cultivars	Brazil-Paraná	Fávero et al., 2020	DRIS norms in seeds as diagnosis tissue
Carrot (*Daucus carota* L.) 8 varieties	Brazil-Paranaíba	Dezordi et al., 2016	DRIS norms- Leaf tissue
Sugarcane (*Saccharum officinarum* L.). 6 varieties	Brazil-São Paulo	Pereira & Justino, 2021	DRIS-Leaf tissue
Orange (*Citrus sinensis* L. Osbeck) var. Pera	Brazil-São Paulo	Alves et al., 2014	Crop leaf nutritional balance using green manures
Guava (*Psidium guajava*) cv. Paluma	Brazil-São Paulo	Souza et al., 2015	DRIS norms and Sufficiency Ranges on seedling leaf tissue
Sugarcane (*Saccharum officinarum* L.). 4 varieties	Brazil-Alagoas	Da Silva et al., 2018 Da Silva et al., 2021	DRIS norms - Leaf tissue and optimal ranges of leaf nutrients
Orange (*Citrus sinensis* L. Osbeck) var. Pera	Brazil-Manaus	Machado et al., 2013	DRIS norms - Nutrient optimal ranges in adult trees
Açaí palm (*Euterpe oleracea* Mart.)	Brazil-Pará	Oliveira et al., 2020	DRIS + GIS = Nutritional balance *Vs* yield of adult plants
Sugar maple (*Tilia americana* L. and *Betula alleghaniensis* B.)	Canada-Quebec	Arseneau et al.,2021	Nutritional balance of leaf tissue by using ashes

Continued

TABLE I CONTINUATION. Application and use of DRIS systems in agriculture worldwide during the last 10 years.

Crops	Country-Region	Author	Use
Apple (*Malus domestica*) var. Fuji	China-Bohai, Loess	Shunfeng et al., 2018.	DRIS norms-Leaf tissue in 15 to 20-to year-old trees
Satsuma mandarin (*Citrus unshiu* Marc.)	China-Hubei	Huang et al., 2012	Iron leaf deficiency identification in 16 to 25-to year-old trees
Kale (*Brassica oleracea* L.) var. acephala DC	China-Xiamen	Hu et al., 2016	DRIS norms and phytotoxicity in plant tissue that was irrigated with wastewater from agricultural irrigation.
Rubber tree (*Hevea Brazilensis*) clone FX 3864 and clone RRIM 600	Colombia-High-plains	Chacón-Pardo et al., 2013a Chacón-Pardo et al., 2013b	DRIS norms- Leaf tissue and soil
Hartón and D. Hartón plantain (*Musa* AAB Simmonds)	Colombia-Antioquia.	González, 2017	DRIS norms- Leaf tissue
Pineapple (*Ananas comosus*) var. Golden MD-2	Colombia-Cauca	López-Montoya et al., 2018	DRIS norms- Leaf tissue
Greenhouse rose (*Rosa* × spp. L). Several cultivars	Colombia-Cundinamarca	Franco-Hermida et al., 2013 Franco-Hermida et al., 2017 Franco-Hermida et al., 2020	DRIS norms Leaf tissue and soil. Soil-plant-environment nutrient ratio
Oil palm (*Elaeis guineensis* Jacq.) – hybrid IRHO evaluating fresh fruit	Colombia-Central Region (Cesar, Santander)	Herrera, 2015	DRIS norms-Leaf tissue and soil + GIS = Critical Levels and Sufficiency Ranges
Banana (*Musa* spp.) cv. Vallery and Williams	Ecuador-El Oro	Villaseñor et al., 2020	DRIS norms- Leaf tissue
Arroz (*Oryza sativa* L.) var. INIAP 15	Ecuador-Guayas	Coloma, 2017	DRIS-Leaf tissue
Ornamental plants (*A. vera*, *K. blossfeldiana*, L. *multifidi*, and *R. officinalis*)	Spain-Almería	García-Caparrós et al., 2019	DRIS norms and Sufficiency Ranges in leaf tissue under saline condition
Vine (*Vitis vinifera* L.).cv. Tempranillo-patrón Richter-110	Spain-AOC La Rioja	Martín et al., 2013	DRIS norms for leaf blade and petiole.
Vine (*Vitis vinifera* L.) 6 varieties combined with 4 rootstocks	Spain-Valencia	Giner, 2015	DRIS norms- Leaf tissue
Wheat (*Triticum aestivum* L.)	Ethiopia-Addis Ababa	Girma & Beyene, 2018.	DRIS norms- Leaf tissue
Oil palm (*Elaeis Guineensis* Jacq.)	India-Goa	Behera et al., 2016	DRIS norms and Sufficiency Ranges in leaf tissue
Mango (*Mangifera indica* L.)	India-Jharkhand	Naik & Bhatt, 2017	DRIS norms and Sufficiency Ranges in leaf tissue on 7 to 9-year-old trees
Pomegranate (*Punica granatum* L.) 60 accessions	India-Maharashtra	Maity et al., 2016	DRIS norms-Nutrition *Vs Xanthomonas axonopodis* tolerance
Pomegranate (*Punica granatum* L.) cv. Bhagwa	India-Maharashtra	Gosavi et al., 2017	DRIS norms- Leaf tissue in pre-flowering and filling
Banana (*Musa* spp.) cv. Robusta	India-South	Raghupathi & Srinivas, 2014	DRIS norms- Leaf tissue and soil

Continued

TABLE I CONTINUATION. Application and use of DRIS systems in agriculture worldwide during the last 10 years.

Crops	Country-Region	Author	Use
Aonla (*Emblica officinalis* Gaertn) fruit tree	India-Uttar Pradesh	Nayak et al., 2011	DRIS norms and Sufficiency Ranges in leaf tissue of adult trees
Oriental beech, native timber specie (*Fagus orientalis* Lipsky)	Irán-Mazandaran	Alimohamadi et al., 2017	DRIS norms- for leaf nutrient balance in natural forests.
Teak (*Tectona grandis* Lin. F)	Indonesia-Ngawi	Chanan et al., 2019	DRIS norms-Leaf tissue for 17-year-old trees
Fruit tree: Apple, peach, persimmon, fig, vine, mandarine	Japón-Kioto	Freire et al., 2019	DRIS in leaf tissue for dynamics of nutrients according to the phenological stage.
Melon (*Cucumis melo* L.) hybrid Cruiser F1	México-Coahuila	Gómez, 2018	DRIS norms- Tissue nutrient balance comparing chemical and organic nutrient solutions
Maíze (*Zea mays*) Hybrid of forage maize RX717	México-Durango	Carrillo, 2019	DRIS norms- Leaf tissue
Red cedar (*Cedrela odorata* L.)	México-Puebla	Parr*a* et al., 2020	DRIS norms-Leaf tissue in trees with 15 to 19 cm of diameter
Tomato (*Solanum lycopersicum*): 2 cultivars	México-Querétaro	Ávila-Juárez & Rodríguez-Ruiz, 2020	Petiole Sap Analysis (PSA) *Vs* leaf analysis with DRIS

*GIS: Geographic Information System

Source: Own elaboration

According to the consolidated results of 63 studies (Table I), eight uses for DRIS with a wide application in agriculture were elucidated, along with five important less-impactful uses given their current apex, detailed as follows:

A. Nutrient balance in leaf tissue

After the establishment of DRIS norms, DRIS-I, NBI, and mNBI indices are applied to identify deficiencies, excesses, or nutritional balance of macronutrients (N, P, K, Ca, Mg, S) and micronutrients (Fe, Mn, Zn, Cu, Mo, B) in leaf tissue. The results of these studies have been applied mainly in Brazil, in crops of wide commercial interest such as cotton, banana, soybean, potato, cacao, and sugarcane (Araújo et al., 2019; Dos Santos et al., 2019; Oliveira et al., 2019; Pereira et al., 2013; Pereira & Justino, 2021; Rodrigues-Filho et al., 2021), and in other agricultural species, including beans, garlic, carrots, atemoya, and cactus pear (Table I).

In Colombia, DRIS studies have been carried out on rubber trees, banana, and roses (Chacón-Pardo et al., 2013a; Franco-Hermida et al., 2017; González, 2017), along with studies in Africa on maize (Dagbenonbakin et al., 2013), in India on banana (Raghupathi & Srinivas, 2014), and in Argentina on wheat (Landriscini & Galantini, 2018).

B. Dynamics of mineral elements according to the phenological stage

The accumulation and absorption of nutrients is a continuous process during the growth of plants, mediated by metabolism, phenological stage, and response to environmental factors. The DRIS method elucidates the dynamics of macro and micronutrients in plants for a determined phenological period. Also, it identifies the order of requirement, excess, deficiency, and nutritional balance. The fertilizer application rate, depending on the nutrient demand for each of the growth stages, can maximize yield and increase the efficient use of fertilizers.

DRIS usefulness has been evidenced in studies on timber species, such as Peroba amarela in the nursery phase in Brazil (França et al., 2020), in the development for Red Cedar in Mexico (Parra et al., 2020), and in adult teak trees in Indonesia (Chanan et al., 2019).

In perennial and short-cycle fruit trees in Brazil, research in the nursery, development, flowering, and fruit filling phases has been documented for crops such as coconut, oil palm, Conilon coffee, and carrot (Bastos et al., 2017; Medeiros et al., 2015; Partelli et al., 2018; Reis et al., 2017), along with studies in India on pomegranate (Gosavi et al., 2017), on apple in China (Shunfeng et al., 2018), on pineapple in Colombia (López-Montoya et al., 2018), and on apple, peach, persimmon, fig, vine, and mandarin in Japan (Freire et al., 2019). Research has also been found for roots and tubers, including yam in Africa (Dagbenonbakin et al., 2012) and in flowers, mainly roses, in greenhouses in Colombia (Franco-Hermida et al., 2013).

C. Critical Levels and Sufficiency Ranges

DRIS proposes five groups for the Sufficiency Ranges in leaf tissue and/or soil (deficiency, tendency to deficiency, sufficient, tendency to excess, and excess), and an optimal level for Critical Concentration. Both the Sufficiency Ranges and the Critical Concentration are a reliable tool for nutrition diagnosis, enabling the development of programs with economic feasibility and environmental sustainability. DRIS indices establish the probability of response to the application of nutrients (Herrera, 2015).

In recent years, this method has been used to update and validate the Critical Levels and Sufficiency Ranges of soils planted with oil palm in Colombia (Herrera, 2015) and beans in Brazil (Partelli et al., 2019). The greatest use is at the level of leaf tissue for oil palm in Colombia (Herrera, 2015), carrot (Reis et al., 2017), orange var Pear (Machado et al., 2013), irrigated beans (Partelli et al., 2014), guava (Souza et al., 2015), and sugarcane (Da Silva et al., 2021) in Brazil, and aonla (Nayak et al., 2011), oil palm (Behera et al., 2016), and mango in India (Naik & Bhatt, 2017).

D. Soil-plant-environment relationship

Once DRIS norms have been defined for both soil and plant tissue, DRIS indices are determined to correlate the balance of nutrients in leaf tissue with the mineral elements present in the soil and their interaction with the relief and climatic factors, such as light, temperature, relative humidity, and rainfall, among others, to explain the nutritional response of plants from a holistic perspective.

Foliar analyses determine the more limiting nutrients for high yield, and soil analyses enable the correction of formulations in fertigation or edaphic applications. Said analyses are a powerful tool for integrated nutritional diagnosis (Gonzáles, 2017; Franco-Hermida et al., 2017). DRIS has been used successfully in Colombia for rubber trees (Chacón-Pardo et al., 2013a, Chacón-Pardo et al., 2013b), and roses in greenhouses (Franco-Hermida et al., 2017), cacao in Brazil (Oliveira et al., 2019), and banana in India (Raghupathi & Srinivas, 2014).

E. Nutritional balance from the use of fertilizers and green manure

The DRIS system uses the nutritional balance index (NBI) to elucidate the concentration and dynamics of nutrients in plant tissue thanks to the contribution of mineral elements through fertilization or the availability of these in the soil, as a result of the association of different crops with species of green manure. Studies on the use of nutritive solutions (chemical and organic synthesis) for hydroponic melons in Mexico (Gómez, 2018) and green manure in orange var. Pera in Brazil (Alves et al., 2014) and the nutrients available through the use of ash on sugar maple in Canada are documented (Arseneau et al., 2021).

F. Spatial variability and DRIS

Geographic Information Systems (GIS) analyze the spatial variability of the physical and chemical properties of the soil (Herrera, 2015) and the dynamics of biotic factors such as incidence of diseases or damage from pests in productive systems.

The combination of GIS with DRIS provides a better understanding of the interrelation of nutritional and non-nutritional variables on crop yield. In Brazil, these tools have identified the relationship of the incidence of rust (*Hemileia vastatrix*) and CBB (*Hypothenemus hampei*) with the NBI in terms of yield for Conilon coffee (Da Silva et al., 2020), along with the zoning of areas with a nutritional imbalance and low yield in adult Açaí palm plants (Oliveira et al., 2020). Meanwhile, in Colombia, the spatial distribution of NBI in the soil and leaf tissue of plants has led to the validation of Critical Levels and Sufficiency Ranges in oil palm (Herrera, 2015).

G. Dynamics of heavy metals

In DRIS, the NBI shows the dynamics of heavy metals from the root to the leaves of plants (biochemical and physiological events), and the identification of deficiencies or excesses of micronutrients, which are not easy to analyze with conventional diagnosis methods. In Brazil, the translocation of cadmium to the shoots has been studied in wheat, finding that the concentrations of this metal increase those of Fe and Mn in plants (Silveira et al., 2020). Similarly, Fe deficiencies have been identified in adult Satsuma mandarin trees in China (Huang et al., 2012), and the correction of excess Fe and deficiencies in Zn, Cu, and Mn in roses grown under greenhouse in Colombia (Franco-Hermida et al., 2020) has been shown.

H. Nutrition and disease incidence

Studies are based on the calculation of the NBI in plants to define the nutritional balance and correlate it with the incidence of diseases caused by fungi and bacteria. Alves and Vilela (2013) reported that banana plants in Brazil with a good potassium balance have a lower incidence of *Fusarium oxysporum* f. sp. *cubense*, the highest performance, and the best economic feasibility. Likewise, Maity et al. (2016) reported tolerance and susceptibility to *Xanthomonas axonopodis* in pomegranate plants in India according to their nutrition level.

I. Other applications in agriculture

These uses for the DRIS system mean it is important to know the existence of other applications with less use in agronomy, which have been studied in different crops in recent years in some countries.

In Spain, for example, it has been reported that the development of DRIS norms for nutritional diagnosis in leaf limb and petiole in vines (Martín et al., 2013), and Sufficiency Ranges have been determined for leaf tissue under saline conditions in ornamental crops (García- Caparrós et al., 2019). Additionally, DRIS norms and evaluation of phytotoxicity in plants irrigated with agricultural irrigation wastewater in kale in China (Hu et al., 2016), Petiole Sap Analysis (PSA) Vs DRIS leaf analysis in tomato in Mexico (Ávila-Juárez & Rodríguez-Ruiz, 2020), and DRIS norms in seeds used as diagnostic tissue of the nutritional status for soybean in Brazil (Fávero et al., 2020) have also been found.

V. Advantages and disadvantages of DRIS

In general, this system has some advantages compared to other diagnostic methods. It has a continuous scale, is easy to interpret, and ranks nutrients in order of importance required by the plant (from the most deficient to the one with the greatest excess).

DRIS also takes into account the interaction and balance of mineral elements both in the soil and in the plant, can perform diagnosis at any stage of crop development because it is less sensitive to tissue aging, and eliminates problems associated with determining critical concentrations. Furthermore, DRIS has good potential for assessing nutrient levels under local conditions, incorporates the dry biomass of crops into the diagnosis, and eliminates limitations imposed by environmental factors (González, 2017; Herrera, 2015; Kania & Callejas, 2011; Landriscini & Galantini, 2018).

Among the evident disadvantages, DRIS requires norms, which are still scarce for various crops of agronomic interest. It also needs large volumes of information (which may be lacking in quality) to obtain DRIS norms. The data used for norms must come from units with similar agronomic management and have a yield record. Because the reliability of the generated models depends on this and automation is needed to improve adoption, DRIS is a complex method to develop (González, 2017; Herrera, 2015; Kania & Callejas, 2011).

VI. Conclusions

DRIS is a valid tool for nutritional diagnosis and requires norms for implementation. Consequently, a large database is needed at the local and/or regional level on a particular genetic material, considering climatic and relief factors, plant tissue analysis, physical and chemical properties of the soil, and agronomic management and yield to achieve reliable results that can be validated.

DRIS approaches the nutritional diagnosis of crops holistically through the relationship of the nutrient balance of plants and soil, with dynamics according to the phenological stage, identification of Critical Levels, Sufficiency Ranges, and correlation of the nutritional status with phytosanitary problems.

This system has elucidated complex processes to be interpreted with conventional diagnostic methods such as the dynamics of heavy metals in plants, phytotoxicity in plant tissue irrigated with wastewater from agricultural irrigation, Sufficiency Ranges in leaf tissue under saline conditions, analysis of sap, and evaluation of the nutritional status from seeds used as diagnostic tissue.

Currently, the modified DRIS (M-DRIS) takes into account the dry biomass of crops, as an additional constituent for the calculation of indices, which have been used in species such as alfalfa and artichoke.

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References

Alves, C.R., Leonel, S. & Tecchio, M.A. (2014). Nutritional balance and yield for green manure orange trees. *Ciência Rural,* 44(4), 616-62. https://doi.org/10.1590/S0103-84782014000400007

Alves, J.T. & Vilela, M.G. (2013). Avaliação nutricional, produção e incidência do mal-do-panamá em bananeira 'Prata-Anã' (Aab) adubada com K, no quarto ciclo. *Rev. Bras. Frutic., Jaboticabal,* 35(4), 1170-1177. https://doi.org/10.1590/S0100-29452013000400028

Alimohamadi, A., Jalilvand, H., Akbarinia, M., Shafiei, B.A. & Afzali, K. (2017). Nutritional diagnoses of oriental beech trees in damaged Caspian Forest sites, using the Diagnosis and Recommendation Integrated Systems (DRIS). *Reforesta*, 3, 11-18. https://dx.doi.org/10.21750/REFOR.3.02.26

Araújo, A., Cardoso, A.F., Oliveira, C., De Camargo, R., Quintão, R.M. & Queiroz, J.M. (2019). Productivity and establishment of DRIS indexes for cultivation of potato cultivar Asterix tubers in a dystrophic Red Latosol. *AJCS*, 13(06), 1017-1024. https://doi.org/10.21475/ajcs.19.13.06.p1381

Arseneau, J., Bélanger, N., Ouimet, R., Royer-Tardif, S., Bilodeau-Gauthier, S., Gendreau-Berthiaume, B. & Rivest, D. (2021). Wood ash application in sugar maple stands rapidly improves nutritional status and growth at various developmental stages. *Forest. Ecol. Man.*, 489, e119062. https://doi.org/10.1016/j.foreco.2021.119062

Ávila-Juárez, L., Rodríguez-Ruiz, M.A. (2020). Rapid NPK diagnosis in tomato using petiole sap analysis with the DRIS method. *Horticultura Brasileira,* 38, 306-311. http://dx.doi.org/10.1590/s0102-053620200311

Bangroo, S.A., Bhat, M.I., Tahir, A., Aziz, M.A., Bhat, M.A. & Wani, M.A. (2010). Diagnosis and Recommendation Integrated System (DRIS). A Review. *J. Curr. Res.*, 10, 084-097. https://www.academia.edu/39390634/Diagnosis_and_Recommendation_Integrated_System_DRIS_A_Review

Bastos, G.S., Rodrigues, A., Salvador, P.G., De Abreu, A.J., Ide, V., Nascimento, H.M. (2017). The use of DRIS for nutritional diagnosis in oil palm in the state of Pará. *Rev. Bras. Cienc. Solo,* 41, e0150466. https://doi.org/10.1590/18069657rbcs20150466

Batista, M., Rodrigues, S.L., Da Silva, J.A. & Rodrigues, P.E. (2019). Establishment of DRIS norms for cactus pear grown under organic fertilization in semiarid conditions. *Rev. Caatinga, Mossoró*, 32(4), 952-959. http://dx.doi.org/10.1590/1983-21252019v32n411rc

Behera, S.K., Suresh, K., Rao, B.N., Manoja, K. & Manorama, K. (2016). Soil nutrient status and leaf nutrient norms in oil palm (*Elaeis Guineensis* Jacq.) plantations grown in the west coastal area of India. *Communications in Soil Science and Plant Analysis,* 47(2), 255-262. https://doi.org/10.1080/00103624.2015.1118120

Carrillo, J.A. (2019). *Mejoradores al suelo y fertilizante foliar en componentes de rendimiento e índice de desbalance nutrimental en maíz* (Tesis de Maestría). Tecnológico Nacional de México. 62 pp.

Chacón-Pardo, E., Camacho-Tamayo, J.H. & Bernal, J.H. (2013a). DRIS norms for the rubber Clone FX3864 in the eastern plains of Colombia. *Rev. U.D.C.A Act. & Div. Cient.,* 16(1), 113-120.http://www.scielo.org.co/pdf/rudca/v16n1/v16n1a14.pdf

Chacón-Pardo, E., Camacho-Tamayo, J.H. & Arguello, O. (2013b). Establishment of DRIS norms for the nutritional diagnosis of rubber (*Hevea brasiliensis* Muell Arg.) clone RRIM 600 on the Eastern Plains of Colombia. *Agron. Colomb.*, 31(2), 215-222. http://www.scielo.org.co/pdf/agc/v31n2/v31n2a11.pdf

Chanan, M., Hardiwinoto, S., Agus, C., Purwanto, R.H. & Purwanta, S. (2019). The identification of macro nutrient status of superior teak plantation (*Tectona grandis* Lin.F) by means of DRIS norms (Diagnosis and Recommendation Integrated System) in Indonesia. *Forest Sci. Tech.*, 15(1), 17-12. https://doi.org/10.1080/21580103.2018.1544935

Coloma, J.J. (2017). *Aplicación de N, Zn, Mn y B y su efecto sobre el rendimiento y nutrición del cultivo de arroz* (*Oryza sativa* L.) (Tesis Pregrado). Universidad de Guayaquil. 84 pp. http://repositorio.ug.edu.ec/handle/redug/21542

Da Silva, L.C., Freire, F.J., Moura, G., Almeida, E.C., Barbosa, A., Tenório, J.V., Rodrigues, F.J. & Silva, A. (2018). Different criteria for determining DRIS standards influencing the nutritional diagnosis and potential fertilization response of sugarcane. Australian. *J. Crop Sci.,* 12(06), 995-1007. https://doi.org/10.21475/ajcs.18.12.06.PNE1147

Da Silva, L.C., Freire, F.J., Moura, G., Oliveira, E., G. dos S., MB., Moura, A.B., Da Costa, J.V. & Rezende, J.S. (2021). Nutrient balance in sugarcane in Brazil: diagnosis, use and application in modern agriculture. *J. Plant. Nutr.* https://doi.org/10.1080/01904167.2021.1889591

Da Silva, M.B., Partelli, F.L, Gontijo, I. & Caldas, M.M. (2020). Nutritional balance and its relationship to yield in a coffee field: Inferences from geospatial analysis. *Rev. Bras. Eng. Agríc. Ambiental,* 24(12), 834-839. https://doi.org/10.1590/1807-1929/agriambi.v24n12p834-839

Dagbenonbakin, G.D., Srivastava, A.K., Gaiser, T. & Goldbach, H. (2013). Maize nutrient assessment in Benin republic: case of upper ouémé catchment. *Journal of Plant Nutrition*, 36(4), 587-606. https://doi.org/10.1080/01904167.2012.754031

Dagbenonbakin, G.D., Srivastava, A.K., Gaiser, T. & Goldbach, H. (2012). Diagnosis and Recommendation Integrated System: a tool for detecting nutrient deficiencies in yam. *Journal of Plant Nutrition*, 35(14), 2124-2134. https://doi.org/10.1080/01904167.2012.724492

Dezordi, L.R., De Aquino, L.A., De Almeida, R.F., Clemente, J.M. & Silva, N. (2016). Diagnostic methods to assess the nutritional status of the carrot crop. *Rev. Bras. Cienc. Solo*, 40, e0140813. http://dx.doi.org/10.1590/18069657rbcs20140813

Dos Santos, J., Da Silva, L., Cardoso, A.F., De Lima, L.C., Quintão, R.M., Gómez, R. & Rodrigues, J.L. (2019). Establecimiento de índices DRIS para la soya (*Glycine max* L. Merr.) en función de la aplicación de micronutrientes. *Magistra, Cruz das Almas,* 30, 423-434.
https://magistraonline.ufrb.edu.br/index.php/magistra/article/view/786

Fávero, E., Poltronieri, R. & Margarete, A. (2020). Soybean seed analysis as a nutritional diagnostic tool, communications in soil. *Science and Plant Analysis*, 51(21), 2712-2725. https://doi.org/10.1080/00103624.2020.1845360

França, E., De Oliveira, E., Ramalho, A., Leão, E., Winckler, M.V. & Macedo, J.E. (2020). Controlled release fertilizer in the rooting and performance of clones of *Paratecoma peroba*. *Cerne,* 26(2), 202-211. http://dx.doi.org/10.1590/01047760202026022693

Franco-Hermida, J.J., Henao-Toro, M.C., Guzmán, M. & Cabrera, R.I. (2013). Determining nutrient diagnostic norms for greenhouse roses. *Hortscience*, 48(11), 1403-1410. https://doi.org/10.21273/HORTSCI.48.11.1403

Franco-Hermida, J.J., Quintero, M.F., Cabrera, R.I. & Guzman, J.M. (2017). Determination of diagnostic standards on saturated soil extracts for cut roses grown in greenhouses. *Plosone,* 12(5), e0178500. https://doi.org/10.1371/journal.pone.0178500

Franco-Hermida, J.J., Quintero-Castellanos, M.F., Guzmán, A.I., Guzmán, M. & Cabrera, R.I. (2020). Validating integrative nutrient diagnostic norms for greenhouse cut roses. *Scientia Horticultura*, 264, e109094. https://doi.org/10.1016/j.scienta.2019.109094

Freire, A., De Almeida, G.M., Salvador, P.G., De Carvalho, M. & Gerosa, M.L. (2019). Seasonal variation of plant mineral nutrition in fruit trees. *Brazilian Archives of Biology and Technology*, 62, e19180340. http://dx.doi.org/10.1590/1678-4324-2019180340

Giner, J.F. (2015). *Análisis foliar, interpretación y obtención de las Normas DRIS para la viticultura de la comarca de Utiel-Requena. Estudio de sus relaciones con los parámetros que caracterizan su aptitud enológica* (Tesis de Doctorado). Universidad Miguel Hernandez Elche. 351 pp. https://docplayer.es/79841695-Escuela-politecnica-superior-de-orihuela.html

Gómez, N.M. (2018). *Soluciones orgánicas y químicas en la eficiencia fisiológica y desbalance nutrimental en plantas de melón* (Tesis de Maestría). Tecnológico Nacional de México. 95 pp.

González, R.A. (2017). *Implementación de las normas DRIS en el cultivo del plátano (Musa AAB Simmonds) en las regiones de Urabá y Suroeste Antioqueño* (Tesis de Maestría). Universidad Nacional de Colombia. 131 pp. https://repositorio.unal.edu.co/handle/unal/59751

Girma, A.A. & Beyene, S. (2018). Assessment of the limiting nutrients for wheat (*Triticum aestivum* L.) growth using Diagnosis and Recommendation Integrated System (DRIS). *Communications in Soil Science and Plant Analysis*, 49(21), 2653-2663. https://doi.org/10.1080/00103624.2018.1526951

Gosavi, A.B., Deshpande, A.N. & Maity, A. (2017). Identifying nutrient imbalances in pomegranate (Cv. Bhagwa) at different phonological stages by the Diagnosis and Recommendation Integrated System. *Journal of Plant Nutrition*, 40(13), 1868-1876. https://doi.org/10.1080/01904167.2016.1267209

García-Caparrós, P., Llanderal, A., Majsztrik, J., Maksimovic, I., & Lao, M.L. (2019). Preliminary nutrient diagnosis norms and optimum ranges in potted ornamental plants grown under saline conditions. *J. Plant Nutr.*, 42(20), 2805-2813. https://doi.org/10.1080/01904167.2019.1659327

Herrera, G.E. (2015). *Obtención del sistema integrado de diagnóstico y recomendación integral (DRIS) en el cultivo de palma de aceite* (*Elaeis guineensis* Jacq.) (Tesis de Maestría). Universidad Nacional de Colombia. 165 pp. https://repositorio.unal.edu.co/handle/unal/54819

Haitzmann, E.M. & Rozane, D.E. (2017). DRIS standard and normal ranges of foliar nutrients for the culture of 'Thompson' atemoya. *Ciência Rural*, 47(04), e20160613. http://dx.doi.org/10.1590/0103-8478cr20160613

Hu, H., Zhang, L. & Wang. Y. (2016). Crop development based assessment framework for guiding the conjunctive use of fresh water and sewage water for cropping practice. A case study. *Agricultural Water Management*, 169, 98-105. http://dx.doi.org/10.1016/j.agwat.2016.02.017

Huang, H., Hu, C.X., Tan, Q., Hu, X., Sun, X. & Bi, L. (2012). Effects of Fe–EDDHA application on iron chlorosis of citrus trees and comparison of evaluations on nutrient balance with three approaches. *Scientia Horticulturae*, 146, 137-142. http://dx.doi.org/10.1016/j.scienta.2012.08.015

Kania, K. & Callejas, R. (eds.). (2011). Sistema integrado de diagnóstico y recomendación (DRIS) herramienta para la interpretación del análisis foliar. Universidad de Chile. 68 pp. http://bibliotecadigital.fia.cl/handle/20.500.11944/145626

Landriscini, M.R., Galantini, J.A. & Rosell, R.A. 1997. Determinación de normas para la aplicación del sistema DRIS en cultivo de trigo de la región semiárida bonaerense. *Ciencia del Suelo*, 15, 17-21. https://www.suelos.org.ar/publicaciones/Vol_15n1/Landricini.pdf

Landriscini M.R. & Galantini, J.A. (2016). Diagnóstico nutricional en el cultivo de trigo: Aplicación de la metodología DRIS en la región semiárida bonaerense de Argentina. Ed. Acad. Española. 57 pp. https://ri.conicet.gov.ar/handle/11336/106635

Landriscini, M.R. & Galantini, J.A. (eds.). (2018). El Sistema Integrado de Diagnóstico y Recomendación (DRIS) para conocer el balance nutricional del trigo. *Siembra directa en el So Bonaerens*, 13-20. https://ri.conicet.gov.ar/handle/11336/107297

López-Montoya, J., Fernández-Paz, J.A., Vásquez, H.D. & Menjivar-Flores, J.C. (2018). Sistema Integrado de Diagnóstico y Recomendación (DRIS) para piña (*Ananas comosus*), variedad Oro Miel (MD-2). *Rev. Colomb. Cienc. Hortic.*, 12(2), 319-328. https://doi.org/10.17584/rcch.2018v12i2.7387

Machado, J.R., Franco, C.A., Salvador, P.G., Mendonça, A. & Lopes, J.Z. (2013). Níveis críticos e faixas de suficiência nutricional em laranjeira-pêra na Amazônia Central obtidas pelo método DRIS. *Acta Amazónica*, 43(3), 239-246. https://doi.org/10.1590/S0044-59672013000300001

Maity, A., Sharma, J., Sarka, A., Morea, A.K. & Pal, R.K. (2016). Nutrient imbalance indices are closely related with susceptibility of pomegranate to bacterial blight disease. *Scientia Horticultura,* 211, 79-86.
http://dx.doi.org/10.1016/j.scienta.2016.08.012

Martín, I., Benito, A., Romero, I., Domínguez, N. & García-Escudero, E. (2013). Preliminary Diagnosis and Recommendation Integrated System norms for leaf nutrient diagnosis of Tempranillo Grapevine in the Rioja appellation. *Communications in Soil Science and Plant Analysis,* 44(1-4), 655-667. https://doi.org/10.1080/00103624.2013.745388

Medeiros, E.C., Da Silva, M.L., Okumura, R.S. & Salvador, P.G. (2015). Normas DRIS para a cultura do coqueiro híbrido no estado do pará. *Rev. Caatinga Mossoró*, 28(4), 99-109. http://dx.doi.org/10.1590/1983-21252015v28n411rc

Naik, S.K. & Bhatt, B.P. (2017). Diagnostic leaf nutrient norms and identification of yield-limiting nutrients of mango in Eastern plateau and hill region of India. *Communications in Soil Science and Plant Analysis,* 48(13), 1574-1583. https://doi.org/10.1080/00103624.2017.1374396

Nayak, A.K., Sharma, D.K., Singh, CS., Mishra, V.K., Singh, G. & Swarup, A. (2011). Diagnosis and Recommendation Integrated System approach for nitrogen, phosphorus, potassium, and zinc foliar diagnostic norms for aonla in central Indo-Gangetic plains. *J. Plant Nutr.,* 34(4), 547-556. http://dx.doi.org/10.1080/01904167.2011.538116

Oliveira, F., Rodrigues, A., Rodrigues, J., Bastos, G.S., Morita, M., Costa, C.R. & Borges, M.J. (2020). DRIS and geostatistics indices for nutritional diagnosis and enhanced yield of fertirrigated acai palm. *J. Plant Nutr*., 43(12), 1875-1886. https://doi.org/10.1080/01904167.2020.1750643

Oliveira, M.G., Partelli, F.L., Cavalcanti, A.C., Gontijo, I. & Duarte, H. (2019). Soil patterns and foliar standards for two cocoa clones in the states of Espírito Santo and Bahia, Brazil. *Ciência Rural*, 49(10), e20180686. http://dx.doi.org/10.1590/0103-8478cr20180686

Pereira, G. & Justino, H.L. (2021). Limitation due to nutritional deficiency and excess in sugarcane using the Integral Diagnosis and Recommendation System (DRIS) and Nutritional Composition Diagnosis (CND). *Communications in Soil Science and Plant Analysis*, 52(12), 1458-1467. https://doi.org/10.1080/00103624.2021.1885690

Parra, L.A., López, M.A., Gómez, A. & Ordaz, V.M. (2020). Concentraciones críticas nutrimentales y normas DRIS para árboles de medio turno de *Cedrela odorata* L. *Rev. Mexicana de Ciencias Forestales,* 11(58), 69-91.

Partelli, F.L, Machado, J.R., Duarte, H., Salvador, P.G. & Paiva, E. (2014). Avaliação nutricional de feijoeiro irrigado pelos métodos CND, DRIS e Faixas de suficiência. *Rev. Bras. Cienc. Solo,* 38, 858-866. https://doi.org/10.1590/S0100-06832014000300017

Partelli, F.L., Mozena, W., Cayô, A. & Duarte, H. (2019). Diagnóstico integrado y rangos de nutrientes en el suelo para el cultivo del frijol (*Phaseolus vulgaris*) en la región de Cerrado. *Cultivos Tropicales*, 40(4), e03.

Partelli, F.L., Oliveira, M.G., Monzoli, A., Duarte, H., Machado, J.R. & Braun, H. (2018). Nutritional standards and nutritional diagnosis of the Conilon coffee plants in phenological growth stages. *J. Plant Nutr*., 41(19), 2536-2546. https://doi.org/10.1080/01904167.2018.1510513

Pereira, A., Estevão, M., Pouyú, E., Soares, H., Do Amaral, V. & Nunes, F.C. (2013). Estabelecimento de normas DRIS para o algodoeiro com diferentes critérios de seleção da população de referencia. *Pesq. Agrop. Bras*., 48(11), 1472-1480. https://doi.org/10.1590/S0100-204X2013001100008

Pereira, M.L., Aquino, L.A., Ferreira, R., Clemente, J.M., De Aquino, P.M. & Oliveira, T.F. (2016). Diagnosis of the nutritional status of garlic crops. *Rev. Bras. Cienc. Solo*, 40, e0140771. https://doi.org/10.1590/18069657rbcs20140771

Pereira, N.S., Oliveira, A.M., do Nascimento, J.A., Lima, L.T. & Limeira, F. (2015). Obtenção de normas DRIS preliminares e faixas de suficiência para bananeira do subgrupo prata na região do Baixo Jaguaribe, CE, Brasil. *Rev. Agroambiente*, 9(3), 347-351. https://doi.org/10.18227/1982-8470ragro.v9i3.2451

Raghupathi, H.B. & Srinivas, S. (2014). Spatial variability studies in banana for identification of nutrient imbalance using diagnosis and recommendation integrated system. *Communications in Soil Science and Plant Analysis*, 45(12), 1667-1686. https://doi.org/10.1080/00103624.2014.907914

Reis, F.A., De Aquino, L.A., Dezordi, L.R., Clemente, J.M. & Ferreira, R. (2017). DRIS indices in three phenological stages of the carrot crop. *Pesq. Agropec. Trop., Goiânia,* 47(1), 31-40. http://dx.doi.org/10.1590/1983-40632016v4742449

Rodrigues-Filho, V.A., Lima, J.C., Rodrigues, S.L. & Castro, B.V. (2021). Universality of Kenworthy and DRIS norms for Prata and Cavendish bananas grown in two environments. *Rev. Bras. Cienc. Solo,* 45, e0200120. https://doi.org/10.36783/18069657rbcs20200120

Savita, S., Krishnappa, R., Bidyapati, M., Devi, T., Mishra, G., Rawat, D. & Srivastava, P.C. (2016). Diagnosis and Recommendation Integrated System (DRIS) approach on nutritional diagnosis in fruit crops. A Review. *J. App. Nat. Science*, 8(4), 2337-2345. https://doi.org/10.31018/jans.v8i4.1134

Shunfeng, G., Zhanling, Z., Ling, P., Qian, C. & Yuanmao, J. (2018). Soil nutrient status and leaf nutrient diagnosis in the main apple producing regions in China. *Hort. Plant J.,* 4(3), 89-93. https://doi.org/10.1016/j.hpj.2018.03.009

Silveira, F.H., Lavres, J., Gentil, T. & Ferracciú, L.R. (2020). Diagnosis and Recommendation Integrated System and nutritional balance index reveal Cd-induced nutritional disorders in *Panicum maximum* assayed for Cd phytoextraction. *Bioremediation Journal*, 24(4), 265-282. https://doi.org/10.1080/10889868.2020.1841727

Souza, H.A., Rozane, D.E., Amorim, D.A., Dias, M.J., Modesto, V.C. & Natale, W. (2015). Assessment of nutritional status of guava seedlings using preliminary DRIS norms and Sufficiency Ranges. *J. Plant Nutr.,* 38(10), 1611-1618. https://doi.org/10.1080/01904167.2015.1017050

Villaseñor, D., De Mello, R., Pereira, G., Carrillo, M & Durango, W. (2020). DRIS norms and limiting nutrients in banana cultivation in the South of Ecuador. *Journal of Plant Nutrition*, 43(18), 2785-2796. https://doi.org/10.1080/01904167.2020.1793183