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REVIEW ARTICLE

Diagnosis and Recommendation Integrated System (DRIS) – A Review

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ABSTRACT

Importance of nutrient balance in determining yield and quality of crops is well established but there was no means to quantify it until the introduction of the Diagnosis and Recommendation Integrated System (DRIS) in which leaf analysis values are interpreted on the basis of inter-relationship among nutrients, rather than nutrient concentration themselves. The DRIS is based on the comparison of crop nutrient ratios with optimum values from a high yielding group (DRIS norms). The DRIS provides a means of simultaneous identifying imbalances, deficiencies and excesses in crop nutrients and ranking them in order of importance. The major advantage of this approach lies in its ability to minimize the effect of tissue age on diagnosis, thus enabling one to sample over a wider range of tissue age than permissible under the conventional critical value approach. Several researchers affirm that once DRIS norms based on foliar composition has been developed for a given crop; they are universal and applicable to that particular crop grown at any place and at any stage of its development.

INTRODUCTION

Critical leaf nutrient concentrations have frequently been used to diagnose nutritional causes of crop under performance (Munson and Nelson, 1990). These criteria have been evaluated for a wide range of crops (Katyal and Randhawa, 1985, Jones *et al*., 1990, Westfall *et al*., 1990, Kelling and Matocha, 1990, O'Sullivan *et al.,* 1997). However the critical concentration approach is somewhat erroneous in that 'critical nutrient concentration' are not independent diagnostics, but can vary in magnitude as the background concentrations of other nutrients increase or decrease in crop tissue (Walworth and Sumner, 1986, Bailey 1989, 1991, & 1993). Recognition of this problem has led to use of nutrients ratio pairs in certain situations, e.g. N/K and N/S, rather than single nutrient concentrations, as more reliable diagnostic criteria (Stevens and Watson, 1986, Walworth and Sumner 1986, Dampney 1992). However, this approach only assesses the sufficiency status of a single nutrient (e.g. K) on the basis of its abundance relative to one other nutrient (e.g. N), and makes no allowance for potential imbalances with other essential nutrients. The Diagnosis and Recommendation Integrated System (DRIS) goes

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much further than single nutrient ratio approach, in that it employs a minimum of three nutrient ratios per diagnosis, and often as many as six or seven (Walworth and Sumner, 1987). In other words, the sufficiency status of an individual nutrient in plant tissue is diagnosed on the basis of its abundance of at least two, and often as many as eight, other plant nutrients, thereby taking account of nutrient balance within plant tissue. What is more, by simultaneously comparing the effects of different nutrients on crop yield, DRIS automatically ranks nutrient deficiencies or excesses in order of importance (Walworth and Sumner, 1987). DRIS has been used successfully to interpret the results of foliar analysis for a wide range of crops such as sugarcane (Beaufils and Sumner, 1976, Elwali and Gascho, 1983, Elwali and Gascho 1984, Beverly, 1991, Reis, Hundal *et al*., 2005), potato (Meldal-Johnsen and Sumner 1980, Mackay *et al*, 1987), apple (Szu¨cs *et al*., 1990, Singh *et al*., 2000), peach Awasthi *et al* 2000), mango (Raj and Rao, 2006), sweetpotato (Ramakrishna *et al*., 2009), grassland swards (Bailey 1997), cauliflower (Hundal *et al*., 2003), rice (Singh and Agrawal, 2007), corn (Escano *et al*., 1981, Elwali *et al*, 1985, Soltanpour *et al*, 1995 and tomatoes (Hartz *et al*, 1998). DRIS is a system of calculations by which ratios of tissue nutrient concentrations in a sample are compared to the “optimum” values of the same ratios in a high-yielding or otherwise desirable population (Escano *et al.,* 1981). This system of calculation gives an index for each nutrient. Essentially, this nutrient index is a mean of the deviations of the ratios containing a given nutrient from their respective optimum or DRIS norms values (Bailey *et al*., 1997). Each relationship between nutrients in a high-yielding or desirable group constitutes a DRIS norm and it has its respective mean and coefficient of variation.

The DRIS formula (Beaufils, 1973) calculates relative index for nutrients that range from negative to positive values but always sum to zero (Elwali *et al*., 1985, Baldock and Schulte, 1996). Negative indexes indicate nutrient deficiency and positive indexes indicate adequacy (Escano *et al*., 1981, Baldock and Schulte, 1996). The DRIS also computes an overall index; which is the sum of the absolute values of the nutrient indices, called Nutrient Balance Index—NBI (Baldock and Schulte, 1996). NBI expresses the nutritional balance of a crop under evaluation. The smaller the absolute sum (NBI), the lesser imbalance among nutrients (Snyder and Kretschmer, 1988).

The DRIS approach was designed to provide a valid diagnostic irrespective of plant age, tissue origin (Sumner, 1977a, Meldal-Johnsen and Sumner 1980, Bailey 1997, Jones, 1993 Sumner, 1977) cultivar, local conditions (Payne *et al.,* 1990), or changes in the method of tissue sampling or the time of sampling (Moreno *et al*., 1996). The DRIS is sometimes less sensitive than the sufficiency range approach to differences caused by leaf position, tissues age, climate, soil conditions, and cultivar effect because it uses nutrient ratios (Sanchez *et al*., 1991). Once DRIS norms have been established and validated from a large population of randomly distributed observations, they should be universally applicable to that crop (Sumner 1977a & 1979) because of for a given species, there appear to be specific nutrient ratios for maximum crop performance that transcend local conditions, such soil, climate and cultivars (Snyder and Kretschmer, 1988, Snyder *et al*., 1989).

THE DRIS METHOD

The working premises for DRIS are based on: (a) the ratios among nutrients are frequently better indicators of nutrient deficiencies than isolated concentrations values; (b) some nutrient ratios are more important or significant than others; (c) maximum yields are only reached when important nutrient ratios are near the ideal or optimum values, which are obtained from high yielding-selected populations; (d) as a consequence of the stated in (c), the variance of an important nutrient ratio is smaller in a high yielding (reference population) than in a low yielding population, and to the relations between variances of high and low yielding populations can be used in the selection of significant nutrient ratios; (e) the DRIS indices can be calculated individually, for each nutrient, using the average nutrient ratio deviation obtained from the comparison with the optimum value of a given nutrient ratio, hence, as pointed by (Jones, 1981, Walworth and Sumner, 1987) the ideal value of the DRIS index for each nutrient should be zero.

In general, the DRIS has some advantages over other diagnosis methods: presents continuous scale and easy interpretation; allows nutrient classification (from the most deficient up to the most excessive); can detect cases of yield limiting due to nutrient unbalance, even when none of the nutrients is below the critical level; and finally, allows to diagnose the total plant nutritional balance, through an unbalance index (Baldock and Schulte, 1996). An additional advantage of DRIS, acknowledged by some authors but rebuted by others, is that, overall, it is less sensitive to tissue aging in comparison to others (Walworth and Sumner, 1987). Tissue aging influence the nutrient concentration (nutrient content/dry matter); several examples are reported in the literature, including studies in alfalfa, potato, corn, peach, and many other agricultural and horticultural crop species. Although some exceptions may occur, concentrations of nitrogen, phosphorus, potassium and sulfur tend to decrease with tissue aging. On the other hand, calcium and magnesium concentrations tend to increase in older tissues (low mobility), in spite of the opposite being reported in the very early or later stages for some crops. The dynamic nature of the plant tissue mineral composition tends to restrict the use of leaf analysis for nutritional diagnosis. As already stated, the criteria of critical levels or sufficiency ranges generally depend on norms for diagnosis derived from a specific plant tissue part and age, and classifies the plants based solely in the leaf nutrient concentration (leaf nutrient content/ leaf dry matter). Thus, the plant growth stage for leaf sampling is an essential factor for the application of both methods, and therefore, the diagnoses based on these criteria are usually applied in leaf samples obtained from a well-defined growth stage.

An important limitation of these methods is that, especially in some annual crops, the established standard sampling period many times occurs too late in the growing season, so that fertilizer application will not be effective to correct a nutritional problem, or may not match the sudden symptoms of a nutritional disorder, when the producer mostly need the information (Walworth and Sumner, 1987). To overcome this problem, it would be necessary to get nutritional reference values for several maturation stages. In addition to these limitations, little research has been developed to determine the influence of the cultivar in the nutrient concentration in a given maturation or development stage. Finally, factors that affect the tissue aging rate might also influence the relation between nutrient concentration and maturation.

An option for these diagnosis methods was proposed through the DRIS (Beaufils, 1973), which defined that, in general, nitrogen, phosphorus and potassium concentrations decrease with tissue maturation. Therefore, the ratios N/P, N/K, and P/K (or reciprocal ratios) should be kept constant. In the same way, because of concentrations of Ca and Mg generally increase with maturation; quotients between these nutrients (Ca/Mg or Mg/Ca) should result in constant values. Moreover, the product of two nutrients, with concentrations running in opposite directions with time (N × Ca, for example), also should remain constant.

Nevertheless, DRIS advantages have already been contested, because for some crops, it showed to be as sensitive as SRA to plant tissue maturation and plant age (Baldock and Schulte, 1996). Moreover, additional limitations to the method can be pointed, such as the need for extensive and advanced computational calculations and equipment, results expressed in non-independent indices, and frequent occurrence of false diagnosis for some nutrient excesses. Due to recent developments in both hardware and software resources, the difficulty in running the method turned to be of little importance. The non-independent indices are perhaps an advantage, because this might be the greater DRIS contribution in relation to the SRA. Other ten mistakes in the diagnosis through DRIS have also been identified, but many of them do not affects the method effectiveness in a relevant way (Hallmark *et al*, 1991).

ESTABLISHMENT OF DRIS NORMS

The first step for the implementation of any nutritional diagnosis method is the establishment of standards or norms, and the same applies for the DRIS method. The following survey type approach is first employed in accumulating the basic data based on which DRIS norms are determined: (a) decide the area for which DRIS norms are to be developed (e.g. Region, district, state) (b) a large number of sites where crop is growing are selected at random in order to represent the whole production area (c) at each site, plant and soil samples are taken for all essential element analyses (d) other parameters likely to be related directly or indirectly to yields are also recorded (e) entire population of observation is divided into two subpopulation (high and low yielders) on the basis of vigour, quality and yields (f) each element in the plant is expressed in as many ways as possible (g) mean of each type of expression for each subpopulation is calculated (h) each form of expression which significantly discriminates between the high and low yielding subpopulation is retained as a useful diagnostic parameter (i) the mean values for each of these forms of expression (diagnostic parameters) of high yielding group constitutes the diagnostic norm. The chosen population or database for norms definition should be subdivided in two sub-populations or categories (Beaufils, 1973, Meldal-Johnsen and Sumner, 1980, Walworth and Sumner, 1987). These sub-populations are the following: a) Non-abnormal plants, or reference population, that are not influenced by adverse conditions and present yield significantly higher than an arbitrarily established level; b) Abnormal plants, or non-reference population, influenced by other factors, with lower yields than the established. DRIS norms are originated after the reference population definition, in other words, the relation between all the nutrients pairs and their respective standard deviations or coefficients of variation are obtained. The ratio between a pair of nutrients can be direct or inverse. The concentrations of nitrogen and phosphorus, for instance, can be related either as N/P or P/N ratio.

COMPUTATION OF DRIS INDICES

After norms definition, sample analysis results are ready to be submitted to the DRIS indices calculation (Walworth and Sumner, 1987), which are composed of each nutrient individual index, calculated in two steps: first, the functions for each nutrient pair ratio, and second, the sum of functions involving each nutrient. Hypothetical A to N nutrient indices can, therefore, be calculated as follows (Walworth and Sumner, 1987):

$$\text{Index A} = \frac{[f(A/B) + f(A/C) + f(A/D) \ldots + f(A/N)]}{Z}$$

$$\text{Index B} = \frac{[-f(A/B) + f(B/C) + f(B/D) \ldots + f(B/N)]}{Z}$$

$$\text{Index N} = \frac{[-f(A/N) - f(B/N) + f(C/N) \ldots - f(M/N)]}{Z}$$

where: When A/B is larger or equal to a/b,

$$F(A/B) = \left(\frac{A/B}{a/b} - 1\right)\frac{1000}{CV}$$

Or, when A/B is smaller than a/b,

$$F(A/B) = \left(1 - \frac{a/b}{A/B}\right)\frac{1000}{CV}$$

In these equations, A/B is the tissue nutrient ratio of the plant to be diagnosed; a/b is the optimum value or norm for that given ratio; CV is the coefficient of variation associated with the norm; and z is the number of functions in the nutrient index composition. Values for other functions, such as f(A/C) and f(A/D) are calculated in the same way, using appropriate norms and CV. In other words, one nutrient index is the average function of all the ratios containing a given nutrient. The components of this average value are pondered by the CV reciprocal of the high yielding populations (reference populations). Thus, if the A/B and A/C ratios are both used to generate an index for the A nutrient, the contribution of each one to the calculation of this index will be function of the CV values (reference ratios) associated to them, what will reflect the relative influence of these two expressions in the crop yield. The absolute sum values of the nutrients indices generate an additional index denominated Nutritional Balance Index (NBI). This index can be useful to the plant nutritional status indication, without however, hinting their causes. The higher the sum value, the larger will be the indication of plant nutritional unbalance and, therefore, the lower will be the yield.

INTERPRETATION OF THE DRIS NUTRITIONAL INDEXES

The value of each ratio function is added to the subtotal of one index and subtracted from another

[that is, the value *f (A/B)* is added to A index and subtracted from B index]; before the final ponderation, all the indexes are balanced around zero (Walworth and Sumner, 1987). Consequently, the sum of the nutritional indexes must be zero. When results are negative (lower than zero), that means deficiency, and the more negative the index, the higher the deficiency will be in relation to the other diagnosed nutrients. On the other hand, high index values (the more positive and distant from zero indexes) indicate excessive quantity of the considered nutrient relatively to the others. The following example may illustrate the DRIS method interpretation, and to make it simple, this example refers only to nitrogen (N), phosphorus (P) and potassium (K). Other nutrients may be incorporated to the calculations using the same procedure. For a nutritional diagnosis in maize, the interpretation norms are presented in Table 1. Considering a maize leaf sample with the following nutrient concentrations in the dry matter: N (3.30%), P (0.20%) and K (1.20 %), the calculations to be made are the ratios between the nutrients (represented in capital letters in the previous equations) that are: N/P = 3.3/0.20 = 16.5; N/K = 3.30/1.20 = 2.75; and K/P = 1.20/0.20 = 6.0.
Thus,

$$f(N/P) = \left(\frac{N/P}{n/p} - 1\right) \frac{1000}{CV}$$

because, N/P > n/p.

Applying the respective values, it will result:

f(N/P) = [(16.5/10.04) – 1] (1000/14) = 45.96.

In the same way,

$$f(N/K) = \left(\frac{N/K}{n/k} - 1\right) \frac{1000}{CV} = \left(\frac{2.75}{1.49} - 1\right) \frac{1000}{21} = 40.27$$

The equation for the f(K/P) is, however, 1 – [(k/p)/(K/P)] (1000/CV), because k/p > K/P and is equal to [1 – 6.74/6.00)] (1000/22) = -5.61. The other nutrient indexes are calculated:

N index = [f(N/P + f(N/K)]/2 = (45.96 + 40.27)/2 = 43

P index = [-f(N/P) – f(K/P)]/2 = (-45.96 + 5.61)/2 = -20
K index = [-f(N/K) + f(K/P)]/2 = (-40.27 – 5.61) = -23

The N index (43) >> P index (-20) > K index (-23); thus, this result may be interpreted as: for a high yielding corn, the K is being relatively more required than P, which is more required than N. A leaf sample with adequate nutritional balance will show all indexes equal to zero. However, it is possible to have a nutrient presenting an index equal to zero and not being at the adequate concentration. For example, supposing the following diagnosis results:

Nutrient:	N	P	K	Ca	Mg
Index:	-21	0	+7	+7	+7

It might be concluded that N index would indicate the most deficient nutrient, compared to the others, and would probably be the most limiting nutrient if the yields were entirely related to the nutrition. And the P index equal to zero would indicate a nutrient relatively less abundant than K and Ca or Mg and would be the second more deficient in this diagnosis. Nevertheless, in this case, because of nutrients may be added but not be removed from the soil, at least under ordinary conditions, the recommendations for this diagnosis would be addition of N, and addition of P in lower proportion, despite the P index equal to zero.

APPLICATION OF DRIS METHOD

Since the inception of DRIS approach in nutrient diagnosis, it has been developed for several cereal, horticultural, ornamental, forest, and fruit species. Among the main horticultural, cereal, and fruit crops diagnosed by this method include sugarcane (Beaufils and Sumner, 1976, Elwali and Gascho, 1983, Elwali and Gascho 1984, Beverly, 1991, Reis, Hundal *et al*, 2005), potato (Meldal-Johnsen and Sumner 1980, Mackay *et al.*, 1987), sweet potato (Ramakrishna *et al*, 2009), grassland swards (Bailey 1997), cauliflower (Hundal *et al.*, 2003), tomatoes (Hartz *et al.*, 1998) (Mayfield *et al.*, 2002), lettuce (Sanchez *et al.*, 1991), cucumber (Mayfield *et al.*, 2002), onion (Caldwell *et al.*, 1994), apple (Szu¨cs *et al.,* 1990, Singh *et al.*, 2000), peach (Awasthi *et al.,* 2000), mango (Raj and Rao, 2006), banana (Memon *et a.,l*, 2005), hazelnuts (Alkoshab *et al.*, 1988), pecan (Sanz *et al.*, 1992), rice (Singh and Agrawal, 2007), corn (Escano *et al.*, 1981, Elwali *et al.*, 1985, Soltanpour *et al.*, 1995).

Table 1. Maize DRIS norms for nitrogen, phosphorus and potassium [(a)]

Representation	Low yielding population (A)			High yielding population (B)			Variance ratio (SA /SB)
	Means	CV (%)	Variance (SA)	Means	CV (%)	Variance (SA)	
N(%dm[b])	2.86	20	0.326	3.06	18	0.303	1.075
P(%dm[b])	0.30	20	0.0036	0.32	22	0.0050	0.720
K(%dm[b])	2.32	27	0.392	2.12	23	0.238	1.647[c]
N/P	9.88	18	3.158	10.04	14	1.996	1.582[c]
N/K	1.39	28	0.150	1.49	21	0.101	1.485[c]
K/P	6.94	29	4.000	6.74	22	2.222	1.800[c]
P/K	0.13	26	0.0011	0.15	24	0.0013	0.846
P/N	0.10	18	0.00032	0.10	16	0.00026	1.231
K/N	0.81	24	0.0380	0.72	22	0.0259	1.467[c]
NP	0.85	33	0.0792	0.98	32	0.096	0.824
NK	6.59	34	5.040	5.45	34	4.910	1.026
PK	0.71	37	0.0675	0.68	36	0.0611	1.105

[a] Data from Sumner (1982), *apud* Walworth & Sumner (1987)[1]; [b] dm = dry matter; [c] Variances obtained for low and high yielding populations are significantly different at $P < 0.01$.

[1]SUMNER, M.E. The Diagnosis and Recommendation Integrated System (DRIS). Soil/Plant Analysis Workshop, Council on Soil Testing and Plant Analysis. Anaheim, CA, USA. 1982.

Table 2. Classification of plant samples based on limiting nutrients as indicated by DRIS and critical nutrient concentration concepts. (No. of samples)

Stage of sampling	DRIS concept				Critical concentration			
	N	P	K	S	N	P	K	S
Low yield group								
Tillering	24	13	12	14	5	43	63	6
Booting	11	00	9	43	39	00	00	00
High yield group								
Tillering	13	15	21	13	00	46	00	00
Booting	13	17	12	20	4	00	00	00
All samples								
Tillering	37	28	33	27	5	89	63	6
Booting	24	17	21	63	43	00	00	00

source: Singh and Agrawal, 2007

Table 3. Diagnosis and Recommendation Integrated System Norms (Mean and Coefficients of Variation) for Corn Crop

Ratio	Mean	Coefficient of Variation (%)
N/P	10.04	15.0
N/K	1.49	22.0
Ca/N	0.184	47.0
Mg/N	0.097	45.0
K/P	6.74	25.0
Ca/P	1.88	50.0
P/Mg	1.074	48.0
Ca/K	0.32	59.0
Mg/K	0.14	67.0
Mg/Ca	0.527	36.0

N, P, K, Ca, Mg (g kg^{-1})

source: Sumner, 1977

There are few research works in the literature about the application of DRIS method in ornamental forest plants. Some of them refer to the Christmas pine (*Abies fraseri*) (Rathon & Bunger, 1991a & 1991b, Arnold *et al*., 1992) and Eucalpypt (*Eucalyptus grandis*) (Silva *et al*., 2004). There are reports on DRIS application to cereals crops and some DRIS norms were developed for application in rice, in the state of Uttar Pradesh, India (Singh and Agrawal, 2007). Nutrient concentration ratios in rice leaves collected at different growth stages (tillering and booting stage) and plant yield were also determined. Data were collected from 125 rice fields in Ghazipur district of U.P. Two youngest but fully blown leaves were sampled at tillering and booting stages from fifty plants at each of the location and were analyzed for nutrient concentrations. The DRIS indexes for each nutrient were calculated. The summarized data (Table-2) indicated that on the DRIS platform nitrogen is most limiting (37 locations) at tillering stage followed by potassium (33 locations), phosphorus (28 locations) and sulphur (27 locations) where as sulphur was most limiting at booting stage (63 locations).

The DRIS method was used to identify mineral deficiencies in corn. (Sumner, 1977) (Table 3.), Escano *et al*., 1981, Elwali *et al.,*1985 and Dara *et al.,*1992 developed DRIS norms for corn crop. Studies accompanied by Sumner (1977a and 1977) suggested that the universal applicability of DRIS norms in corn, but Escano *et al*., 1981 and Dara *et al.,* 1992, suggested that locally developed DRIS norms are more accurate than broad based norms in the corn diagnosis. Nziguheba *et al*., 2009, identified nutrient limitations to maize production in on-farm Trialsin Togo and in several long-term experiments in Nigeria and Benin. Maize ear leaf samples were analyzed for macro and micro-nutrients, and the Diagnosis and Recommendation Integrated Systems (DRIS) was applied to rank nutrients according to their degree of limitation to maize. In the on-farm trials, both yield and DRIS results indicated that, when N is supplied, P limited maize production in all fields, reducing yields by 31% on average. Sulfur was limiting in 81% of the fields and was responsible for an average yield reduction of 20%. In the long-term experiments where N, P, and K had been annually applied, Ca and Mg indices were strongly negative, indicative of deficiency. Zn indices were negative in all trials. Despite N-fertilizer additions, N indices remained negative in some of the long-term experiments, pointing to low efficiency of applied fertilizers. There was a direct link between DRIS indices and the management imposed in the different experiments, indicating that DRIS is a useful approach to reveal nutrient deficiencies or imbalances in maize in the region. The foliar diagnostic norms (Grove and Sumner, 2005) for Sunflower were developed through the application of DRIS and the prognostic value of these norms was tested using the low fertility experiment. In 32 of the 37 cases where the DRIS analysis could be checked against actual experimental yield results, application of the nutrient diagnosed as the most yield limiting resulted in a positive yield response.

Beverly *et al*., 1986, applied DRIS for the foliar diagnosis of soybean. Using a data bank in excess of 35,000 tissue samples, reference values for evaluating the status of soybean with respect to N, P, K, Ca, Mg, Mn, Fe, Cu, Zn, Mo, B, and Al were derived. A comparison with the sufficiency approach was also made and treatments indicated by DRIS to be needed gave greater yield increases than those indicated by the sufficiency range approach. Bethlenfalvay *et al.,* 1990, evaluated the nutritional affects of VAM on soybean through DRIS. The plants were grown either colonized by one of three geographical isolates of the VAM fungus *Glomus mosseae* (Nicole and Gerd). Analysis of DRIS confirmed that N, P, and K were limiting and established different ranking in the degree of deficiency for each nutrient. N was limiting in all four treatments and K or P was most limiting in each of two treatments.

Hundal *et al.,* 2005, carried out studies to monitor the N, P and K status of sugarcane plants cultivated in different areas of Punjab (India) through DRIS. Two hundred leaf samples were collected from the middle bud (zero) of top towards the lower base of sugarcane plant and their position were mentioned as zero, 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th}, and 6^{th} leaf, respectively. The DRIS indicated that 9, 14 and 77% of the total sugarcane samples collected were suffering from the inadequacy of N, P, and K, respectively. Diagnosis of sugarcane

Table4. Effect of position of leaf sampled on N, P, and K concentration in leaf of sugarcane, DRIS indices and on their order of requirement.

Leaf position	Leaf composition (%)			DRIS Indices			Order of Requirement
	N	P	K	N	P	K	
Site I							
Zero (Middle Bud)	1.00	0.241	1.146	-20	23	-3	N>K>P
1^{st} (Two leaves)	1.18	0.241	0.896	-5	16	-12	K>N>P
2^{nd} leaf	1.24	0.249	0.848	-6	27	-21	K>N>P
3^{rd} leaf	1.22	0.240	0.794	-5	28	-23	K>N>P
4^{th} leaf	1.22	0.216	0.768	-1	23	-21	K>N>P
5^{th} leaf	1.16	0.191	0.735	0	19	-19	K>N>P
6^{th} leaf	1.12	0.203	0.645	0	27	-27	K>N>P
Site II							
Zero (Middle Bud)	1.00	0.218	1.085	-16	19	-3	N>K>P
1^{st} leaf	1.40	0.277	1.148	-9	21	-12	K>N>P
2^{nd} leaf	1.26	0.242	1.039	-8	19	-11	K>N>P
3^{rd} leaf	1.22	0.235	1.035	-9	19	-10	K>N>P
4^{th} leaf	1.22	0.227	0.854	-5	22	-18	K>N>P
5^{th} leaf	1.22	0.212	0.834	-3	19	-17	K>N>P
6^{th} leaf	1.16	0.192	0.692	1	21	-22	K>N>P
Site III							
Zero (Middle Bud)	1.04	0.278	0.883	-18	38	-20	K>N>P
1^{st} leaf	1.32	0.224	0.847	-1	20	-19	K>N>P
2^{nd} leaf	1.12	0.221	0.868	-8	22	-15	K>N>P
3^{rd} leaf	1.12	0.226	0.900	-9	23	-14	K>N>P
4^{th} leaf	1.16	0.199	0.831	-3	18	-14	K>N>P
5^{th} leaf	1.32	0.210	0.721	4	22	-26	K>N>P
6^{th} leaf	1.12	0.199	0.725	-2	22	-204	K>N>P

*source: Hundal *et al.,* 2005

Table 5. Effect of soil available nutrient status on leaf composition, DRIS indices and curd yield of cauliflower.

Soil status code	Leaf composition (%)				DRIS indices				Order of requirement	Curd yield (g $plant^{-1}$)
	N	P	K	S	N	P	K	S		
N_1PKS	3.3	0.678	2.794	0.668	-8	1	3	4	N>P>K>S	652
N_2PKS	4.9	0.687	2.783	0.760	4	-4	-3	3	P>K>S>N	798
NP_1KS	4.2	0.543	2.251	0.608	7	-6	-4	3	P>K>S>N	713
NP_2KS	4.2	0.854	2.643	0.652	-1	7	-4	-2	K>S>N>P	852
NPK_1S	4.3	0.691	2.385	0.680	3	0	-6	3	K>P>S>N	592
NPK_2S	4.3	0.688	3.383	0.667	-1	-3	6	-2	P>S>N>K	925
NPKS_1	4.1	0.786	2.849	0.562	0	5	1	-7	S>N>K>P	688
NPKS_2	3.9	0.774	2.895	0.830	-6	1	-2	7	N>K>S>P	890

N_1< 120mg N kg^{-1} soil, N_2> 240 mg N kg^{-1} soil; P_1< 5 mg P kg^{-1} soil, P_2> 10 mg P kg^{-1} soil; K_1< 60 mg K kg^{-1} soil, K_2> 120 mg K kg^{-1} soil; S_1,10 mg S kg^{-1} soil, s_2>10 mg S kg^{-1} soil. The N, P, K, and S status was within sufficient range for each element.

Source: Hundal *et al.,* 2003

Table 6. The DRIS diagnosis of the effects of N, P, and K application on fruit yield and leaf N, P, and K status of Starking Delicious apple and its comparison with diagnosis made by critical value approach during 1994.

Treatment (g/tree)			Leaf nutrient composition (%)			DRIS indices (%)			Nutrient Imbalance Index (NII)	Yield (kg/tree)	
N	P	K	N	P	K	N	P	K			DRIS
350	0	0	1.77	0.153	1.55	-4.1	-2.7	+6.8	13.6	45.6	N>P>K
700	0	0	1.78	0.145	1.46	-0.9	-3.4	+4.3	8.6	59.1	P>N>K
1050	0	0	2.06	0.147	1.37	+7.5	-5.5	-1.9	15.0	53.9	P>K>N
350	350	0	1.79	0.160	1.47	-2.9	+0.6	+2.2	5.8	44.6	N>P>K
700	350	0	1.88	1.167	1.41	-1.0	+2.3	-1.3	4.6	75.9	K>N>P
1050	350	0	1.88	0.167	1.41	-1.0	+2.3	-1.3	4.6	75.9	K>P>N
350	0	700	1.99	0.149	1.22	+8.0	-1.3	-6.7	15.0	58.5	K>P>N
700	0	700	2.03	0.151	1.40	+5.5	-4.2	-1.3	11.0	86.0	P>K>N
1050	0	700	1.93	0.145	1.52	+2.3	-6.6	+4.3	13.3	70.6	P>N>K
350	350	700	1.85	0.147	1.55	-0.9	-4.9	+5.8	11.6	77.7	P>N>K
700	350	700	1.86	0.159	1.48	-1.0	-1.0	+2.0	4.0	91.3	P=N>K
1050	350	700	2.01	0.159	1.40	+3.6	-1.3	-2.3	7.2	90.4	K>P>N
$CD_{0.05}$			0.09	NS	0.14					9.8	

'-', '+' and '0' indicate relative nutrient insufficiency, excess and balance respectively. 'a' is based on sufficiency range given by Shear and Faust(1980). '0' indicate optimum and 'L' low nutrient status.

Source: Singh *et al*., 2000

Table 7. Sensitivity of DRIS indices to long-term fertilizer application of N, P, and K

Treatment no.a	Treatmentsb N	P	K	Order of nutrient deficiencies	Fruit yield (kg plant^{-1})
1	1	1	1	K > Fe > Ca > Mg > S	280.0
2	3	1	1	K > Ca > Mg > Mn > S	163.0
3	1	3	1	Mg > Ca > Zn > K > S > Fe	490.0
7	1	3	3	Ca > Fe > Mg > Zn > S > Cu	694.0
8	3	3	3	Fe > Ca > S > Mg > Zn > Cu	302.2
10	4	2	2	Mg > Zn > Ca > K > Cu > Mn > Fe	270.2
12	2	4	2	Zn > Ca > Mg > S > K > Mn	212.5
13	2	2	0	K > Ca > Mg > Zn > S	247.5

aSelective treatmental combinations were taken for comparison.
bN: 1, 2, 3, and 4 doses are 405, 1000, 1595 and 2000 g N tree^{-1}. P: 1, 2, 3, and 4 doses are 405, 1000, 1595 and 2000 g P_2O_5 tree^{-1}. K: 1, 2, 3, and 4 doses are 405, 1000, 1595 and 2000 g K_2O tree^{-1}.
Source: Raj and Rao, 2006

Table 8. DRIS norms for peach

Nutrient expression	Norm value	CV (%)	F value
N	3.01	6.32	*
P	0.31	11.13	*
K	2.15	8.21	NS
Ca	1.71	18.21	*
Mg	0.27	22.60	*
N/P	9.71	11.34	*
N/K	4.51	9.36	*
N*Ca	5.15	18.13	*
N*Mg	0.81	24.61	*
K/P	6.93	12.26	*
P*Ca	0.67	20.18	*
P*Mg	0.08	17.23	NS
K/Ca	1.22	14.12	*
Mg/K	0.12	21.13	*
Mg/Ca	6.33	21.62	*

Source: Awasthi *et al*., 2000

Table 9. DRIS norms and critical nutrient levels in the 3rd lamina of banana established from published sources

Nutrient expression (%)	DRIS	Critical value range	Av. of published critical values
N	3.04	1.81-4.00	3.03
P	0.23	0.12-0.41	0.22
K	4.49	1.66-5.40	3.40

Source: Angeles *et al*., 1993

leaves varying in their position on the plant or sampled at various stages of growth irrespective of cultivar or planted or ratoon crops carried out with DRIS approach showed that only minor variation in the nutrient order occurred. The nutrient diagnosis was largely independent of type of leaf tissue sampled (Table 4).

DRIS norms were derived for processing tomato (Lycopersicon esculentum Mill.) by Hartz *el al*., 1998, from a 1993-94 survey of greater than100 fields in the Sacramento and San Joaquin Valleys of California. Relative foliar N, P, K, Ca, Mg, and S concentrations were expressed in ratio form, with DRIS norms calculated as the means of fields with fruit yield greater than or equal to 90 Mgha^{-1}. Norms were developed for three growth stages: first bloom, full bloom, and 10% of fruits ripe. Optimum foliar nutrient concentration ranges were calculated by regression analysis from DRIS nutrient indices of high-yield fields. These optimum ranges were in general agreement with existing empirically derived sufficiency ranges for N and P, higher for Ca, Mg, and S, and much lower for K. The relatively low foliar K levels observed were attributed primarily to the strongly determinate growth habit of currently used cultivars. In the fields sampled, yield-limiting nutrient deficiency appeared to be rare.

To develop DRIS norms for sweet potato (*Ipomoea batatas*), the sweet potato garden survey was conducted in four highland provinces in Papua New Guinea (PNG): Eastern Highlands, Simbu, Western Highlands and Enga. One hundred and forty sweet potato gardens were selected. At each planting station, four dominant active shoot tips were selected on each plant present and the youngest or first fully opened leaf identified. The seventh to ninth leaf blades (minus petioles) along each vine numbered from this first leaf were than collected. Investigating several nutrient ratios, the author (Ramakrishna *et al*., 2009) confirmed six nutrient ratios expressions viz., P/N, K/N, N/S, K/P, S/P, and K/S with norm values 0.075, 0.728, 12.7, 10.5, 1.17, and 9.22 respectively as a suitable DRIS norm.

Hundal *et al.,* 2003, evaluated DRIS for monitoring status of N, P, K, and S of cauliflower. Two hundred and ninety-two recently matured leaf samples were collected from cauliflower-growing areas of alkaline soils of Punjab, India. Curd yield was also recorded from the sampling sites. The DRIS indices show that in the first available soil status code (N_1PKS), N was the most limiting element followed by P, K, and S in order of N>P>K>S and yielding 652g of curd per plant. In the second soil available status code (N_2PKS), DRIS indices indicated the least requirement of N by cauliflower plant with sufficient level of P, K, & S, similar to first soil status code elucidating the order of requirement P>K>S>N with 798g of curd per plant. Likewise for the other soil status codes (Table5). The DRIS indices inferred that 24, 23, 1, and 22 per cent of total samples were showing inadequacy of N, P, K, and S, respectively. Thus these results conclusively elucidate that DRIS is capable of making meaningful diagnosis, which when followed by appropriate treatment could lead to higher yield of cauliflower.

There are reports on DRIS application to fruit crops and some DRIS norms were developed for application on apple. Research works carried out in Hungary investigated the DRIS standard ratios for apple orchards (Szucs *et al*., 1990). Data on yield and leaf nutrient concentration from 18 representative orchards were collected during three consecutive years. By means of conventional DRIS method calculations, the indexes indicated K-excess and P-deficiency, while the N concentrations were adequate. The norms estimated by quadratic regression analyses for N/P, N/K and K/P indicated K excess and relative N- and P-deficiency, suggesting that the norms obtained by regression analysis might possibly point out more extreme nutrient ratios than the traditional method. In Himachal Pradesh, India, DRIS norms for apple (*Malus* x *Domestica* Borkh. L. CV. Starking Delicious) were developed by Singh *et al*., 2000. A data bank comprising 1,800 observations of leaf nutrient concentrations and yield were recorded during 1994 & 1995 from six important apple growing areas, ranging from 1500 to 2450m a.m.s.l. Out of 36 nutrients expressions selected N/K, N x Ca, N x Mg, P/N, P x Ca, P x Mg, K x Ca, K x Mg, and Mg/Ca expressions obtained by rationing macro-nutrients with norm values 1.3, 3.6, 0.69, 0.09, 0.11, 0.30, 0.006, 2.08, 0.53 and 0.19 respectively, produced significantly variance ratio, thus revealed that these expressions have a significant contribution for high yields in apple. The validity of norms involving N, P, and K nutrients only viz., P/N, N/K and P/K from a factorial fertilizer experiment in which 12 NPK combinations were applied and significant response to leaf N, P, and K concentrations and yield was obtained . DRIS approach correctly diagnosed relative nutrient insufficiencies even where critical value approach (CVA) failed to make any diagnosis (Table 6). DRIS norms and indexes involving N, P, K, Ca and Mg were established for apple orchards in New Zealand (Goh & Malakouti, 1992). DRIS was compared to the SRA and the conclusion was that both methods presented similar efficacy. Unbalances referred to the N-excess and Ca-deficiency were detected. The best sampling period for diagnosis purposes was 3 to 5 months after blooming. DRIS norms were developed for mango orchards, Alphonso cultivar, using a plant population from the Maharashtra district, India (Raghupathi & Bhargava, 1999). The reference population was defined within the productivity range of 5.4 and 7.4 t ha^{-1}. Low yield was associated to low Mg concentrations. The same authors developed another similar research work with pomegranate (*Punica granatum*, L.) (Raghupathi & Bhargava, 1998).

Raj and Rao, 2006. applied DRIS for the identification of yield-limiting nutrients in mango (cv. Baneshan) in Andhra Pradesh, India. The nutrients identified as yield limiting by DRIS indices were observed to be not totally independent of age of sampled tissue. The validity of the newly developed DRIS indices was tested by applying two of the most yield-limiting nutrients in 88 and 46 cases of young and aged trees. The yield-limitation due to individual nutrients was either totally eliminated or changed in ranking in 96.0 and 93.5% of the young and aged trees, respectively, after the application of yield-limiting nutrients, as indicated by the newly developed DRIS indices. The increase in the fruit yield with the application of yield-limiting nutrients identified by the DRIS indices varied from 11.5 to 45.9% in young trees and from 15.2 to 34.0% in aged trees over the control (Table 7).

Awasthi *et al*., 2000, developed DRIS norms for peach (*Prunus persica* L.) Cv. July Elberta in Rajgarh (Himachal Pradesh, India) from the data base of 1,200 observations (Table 8). The diagnosis of peach orchard, using DRIS approach revealed that DRIS indices for N, P, K, Ca, and Mg varied from -58 to -1, -66 to 8, 15 to 89, 305 to 577 and -314 to -601 respectively. The order of requirement in 60% orchards was Mg>N>P>K>Ca and rest of the 40% in the order of requirement was Mg>P>N>K>Ca. It revealed that Mg is most yield limiting nutrient in peach orchards of Himachal Pradesh, followed by N and P. In 60% orchards, N was at second rank and in 40% orchard P was at second rank of nutrient requirement. The Ca and K application were least required in these orchards.

Srivastava and Singh, 2008, studied the DRIS norms and their field validation in Nagpur Mandarin (budded on *Citrus jambhiri* Lush). A total of 57 mandarin orchards of central India were surveyed. The DRIS norms derived primarily from spring-cycle index leaves from non-fruiting terminals sampled during August to October (6-8 months old) suggested optimum leaf macronutrient concentration (%) as: 1.70-2.81 N, 0.09-0.15 P, 1.02-2.59 K, 1.8-.28 Ca, and 0.4-0.92Mg. while, optimum level of micronutrient (ppm) was determined as 74.9-11.4 Fe, 54.8-84.6 Mn, 9.8-17.6 Cu, and 13.6-29.6 Zn in relation to fruit yield of 47.7-117.2 kg tree^{-1}. Primary DRIS indices developed on the basis of leaf and soil analysis revealed deficiency of N<P< K< Fe< and Zn.

Mourao Filho & Azevedo, 2003, established DRIS norms for the ‘Valencia’ sweet orange budded on Rangpur lime, Caipira sweet orange, and *Poncirus trifoliata* rootstocks. The nutritional balance indexes calculated by the derived norms were highly correlated with yield for the rootstock/scion combinations, from what it was inferred that DRIS norms might be applicable always that leaf sampling is collected from non-bearing fruit branches of irrigated-plant groves. Angeles *et al*., 1993, developed DRIS norms for banana, based on 915 observations from 26 sources (published and unpublished data). The reference subpopulation was selected according to productivity equal or superior to 70 t ha^{-1}. The indexes originated from the developed norms were compared with the method of critical values and the results of both methods were similar, except for K and K/nutrient ratios (Table 9). The DRIS norms validity and their advantages over the method of critical values, by providing correct nutritional diagnosis, were partially confirmed through a fertilization experiment. In Eastern Africa, experiments and research carried out in 45 farms in the region of Kagera, Tanzania, also derived new norms to estimate the nutritional status of the banana plantation, using both DRIS and the critical value method (Wortmann *et al*., 1994).

CONCLUSIONS

From review of scientific literature it is evident that DRIS is an authoritative tool for the nutritional diagnosis in several crops. Most of the developed research works turns clear that DRIS is as effective as the conventional methods of nutritional diagnosis (critical values and sufficiency range) with the additional advantage of establishing a nutrient deficiency or excess ranking, according to its importance, and a strong relation among them, quantifying the plant nutrient balance. Further study is needed to answer the controversies regarding calculation procedures, method of validation and criteria for the reference sub-population definition. In this way, DRIS norms should be developed for specific conditions, in which all other factors to be correlated with yield or quality (or any other variable) be known and isolated: cultivar, climate, soil and crop management, productivity etc., attaining the specific objectives.

REFERENCES

Alkoshab, O., Righettii, T.L. and Dixon, A.R. 1988. Evaluation of DRIS for judging the nutritional status of hazelnuts. *Journal of the American Society for Horticultural Science,* 113: 643-647.

Angeles, D.E., Sumner, M.E. and Lahav, E. 1993. Preliminary DRIS norms for banana. *Journal of Plant Nutrition,* 16: 1059-1070.

Arnold, R.J., Jett, J.B. and Allen, H.L. 1994. Identification of nutritional influences on cone production in fraser fir. *Soil Science Society of America Journal,* 56:586-591.

Awasthi, R.P., Sharma, S.K. and Bhutani, V.P. 2000. Diagnosis And Recommendation Integrated System (DRIS) norms for peach (*Prunus persica* L.) CV. July Elberta in Himachal Pradesh. *Indian Journal of Horticulture* 57(4): 277-280.

Bailey, J.S. 1989. Potassium-sparing effect of calcium in perennial ryegrass. *Journal of Plant Nutrition,* 12:1019–1027.

Bailey, J.S. 1991. A re-examination of phosphorus-lime interactions in perennial ryegrass. *Plant and Soil,* 135:185–196.

Bailey, J.S. 1993. Sustainable fertilizer use. *Proc Fert Soc,* 343

Bailey, J.S., Beattie, J.A. and Kilpatrick, D.J. 1997. The Diagnosis and Recommendation Integrated System (DRIS) for Diagnosing the Nutrient Status of Grassland Swards. I. Model Establishment. *Plant and Soil,*197: 127–135.

Baldock, J.O. and Schulte, E.E. 1996. Plant Analysis with Standardized Scores Combines DRIS and Sufficiency Range Approaches for Corn. *Agronomy Journal,* 88: 448–456.

Beaufils, E.R. 1973a. Diagnosis and Recommendation Integrated System (DRIS); *Soil Science Buletin No.* 1 University of Natal: Pietzemburg, South Africa.

Beaufils, E.R. 1973. Diagnosis and Recommendation Integrated System (DRIS). A general scheme for experimentation and calibration based on principles developed from research in plant nutrition. *Soil Science Buletin No.* 1 University of Natal, pp 1–132

Beaufils, E.R. and Sumner, M.E. 1976. Application of the DRIS Approach for Calibrating Soil and Plant Factors in Their Effects on Yield of Sugarcane. *Proceedings of the South Africa Sugar Technology Association,* 50: 118–124.

Beverly, R.B., Sumner, M.E. and Plank, C.O. 1986. Foliar diagnosis of soybean by DRIS. *Communications in Soil Science and Plant Analysis,* 17(3): 237-256

Beverly, R.B. 1991. *A Practical Guide to the Diagnosis and Recommendation Integrated System (DRIS)*; Micro-Macro Publishing, Inc.: Athens, GA, 385.

Bethlenfalvay, G.J., Franson, R.L. and Brown, M.S. 1990. Nutrition of Mycorrhizal Soybean Evaluated by the Diagnosis and Recommendation System (DRIS). *Agronomy Journal,* 82: 302-304.

Caldwell, J.O., Sumner, M.E. and Vavrina, C.S. 1994. Development and testing of preliminary foliar DRIS norms for onions. *Hort Science,* 29: 1501-1504.

Dampney, P.M.R. 1992. The effect of timing and rate of potash application on the yield and herbage composition of grass grown for silage. *Grass and Forage Science* 47:280–289.

Dara, S.T., Fixen, P.E. and Gelderman, R.H. 1992. Sufficiency Level and Diagnosis and Recommendation Integrated System Approaches for Evaluating the Nitrogen Status of Corn. *Agronomy Journal,* 84:1006–1010.

Elwali, A.M.O. and Gascho, G.J. 1983. Sugarcane Response to P, K and DRIS Corrective Treatments on Florida Histosols. *Agronomy Journal,* 75: 79–83.

Elwali, A.M.O. and Gascho, G.J. 1984. Soil Testing, Foliar Analysis and DRIS as a Guide for Sugarcane Fertilization. *Agronomy Journal,* 76: 466–470.

Elwali, A.M.O., Gascho, G.J. and Sumner, M.E. 1985. DRIS Norms for 11 Nutrients in Corn Leaves. *Agronomy Journal*,77: 506–508.

Escano, C.R., Jones, C.A. and Uehara, G. 1981. Nutrient diagnosis in corn grown on Hydric Dystrandepts: II. Comparison of two systems of tissue diagnosis. *Soil Science Society of America Journal,* 45:1140–1144

Goh, K.M. and Malakouti, M.J. 1992. Preliminary nitrogen, phosphorous, potassium, calcium and magnesium DRIS norms and indexes for apple orchards in Canterbury, New Zealand. *Communications in Soil Science and Plant Analysis,* 23:1371-1385.

Grove, J.L. and Sumner, M.E. 2005. Yield and leaf composition of Sunflower in relation to N, P, K and lime treatments. *Nutrient Cycling in Agro ecosystem,* 3 (4): 367-378.

Hallmark, W.B. and Beverly, R.B. 1991. Review – An update in the use of the Diagnosis and Recommendation Integrated System. *Journal of Fertilizer Issues,* 8: 74-88.

Hartz, T.K., Miyao, E.M. and Valencia, J.G. 1998. DRIS Evaluation of the Nutritional Status of Processing Tomato. *HortScience,* 33: 830–832.

Hundal, H.S., Arora, C.L., and Brar, J.S. 2003. The Diagnosis and Recommendation Integrated System for Monitoring Status of N, P, K and S of cauliflower. *Journal of the Indian Society of Soil Science,* 51(1): 80-82.

Hundal, H.S., Singh, D. and Brar, J.S. 2005. The Diagnosis And Recommendation Integrated System for Monitoring N, P and K Status of Sugarcane in Punjab. *Journal of the Indian Society of soil Science,* 53(2). 198-202

Jones, J.B. 1993. Jr. Modern Interpretation System for Soil and Plant Analysis in the USA. *Aust. J. Exp. Agric,* 33: 1039–1043.

Jones, J.B., Eck, H.V. and Voss, R. 1990. Plant analysis as an aid in fertilizing corn and grain sorghum. In: Westerman RL (ed) Soil testing and plant analysis. 3rd edn. Soil Science Society of America, Madison, WI, USA, pp 521–547.

Jones, W.W. 1981. Proposed modifications of the diagnosis and recommendation integrated system (DRIS) for interpreting plant analyses. *Communications in Soil Science and Plant Analysis,* 12: 785-794.

Katyal, J.C., Randhawa, N.S. 1985. Micronutrients. FAO *Fertilizer and Plant Nutrition Bulletin* 7

Kelling, K.A. and Matocha, J.E. 1990. Plant analysis as an aid in fertilising forage crops. In: Westerman RL (ed) Soil testing and plant analysis. 3rd edn. Soil Science Society of America, Madison, WI, USA, pp 603–643.

Mackay, D.C., Carefoot, J.M. and Entz, T. 1987. Evaluation of the DRIS Procedure for Assessing the Nutritional Status of Potato (*Solanum tuberosum* L.). *Communications in Soil Science and Plant Analysis,* 18: 1331–1353.

Mayfield, J.L., Simonne, E.H., Mitchell, C.C., Sibley, J.L., Boozer, R.T. and Vinson, E.L. 2002 Effect of current fertilization practices on nutritional status of double-cropped tomato and cucumber produced with plasticulture. *Journal of Plant Nutrition,* 25: 1-15.

Meldal-Johnsen, A. and Sumner, M.E. 1980. Foliar Diagnostic Norms for Potatoes. *Journal of Plant Nutrition,*2: 569–576.

Memon, N., Memon, K.S., and Hassan, Z. 2005. Plant Analysis as a Diagnostic Tool for Evaluating Nutritional Requirement of Banana. *International Journal of Agriculture & Biology,* 7 (5): 824-831.

Munson, R.D. and Nelson, W.L. 1990. Principles and practices in plant analysis. In: Westerman RL (ed) Soil testing and plant analysis. 3rd edn. Soil Science Society of America, Madison, WI, USA, pp 359–387.

Moreno, J.J., Lucena, J.J. and Carpena, O. 1996. Effect of the Iron Supply on the Nutrition of Different Citrus Variety/Rootstock Combinations Using DRIS. *Journal of Plant Nutrition,* 19: 698–704.

Mourão Filho, F.A.A. and Azevedo, J.C. 2003. DRIS norms for Valencia sweet orange on three rootstocks. *Pesquisa Agropecuária Brasileira,* 38: 85-93.

Nziguheba, G., Tossah, B.K., Diels, J., Franke, A.C., Aihou, K., Iwaufor, E.N.O., Nwoke, C., and Merckx, R. 2009. Assessment of nutrient deficiencies in maize in nutrient omission trails and long-term field experiments in the West African Savana. *Plant and Soil,* 314:143-157.

O'Sullivan, J.N., Asher, C.J. and Blamey, F.P.C. 1997. Nutrient disorders of sweet potato. ACIAR Monograph Series, ACIAR, Canberra, Australia, p 136

Payne, G.G., Rechcigl, J.E. and Stepherson, R.L. 1990. Development of Diagnosis and Recommendation Integrated System Norms for Bahia grass. *Agronomy Journal,* 82: 930–934.

Raghupathi, H.B. and Bhargava, B.S. 1998. Diagnosis of nutrient imbalance in pomegranate by diagnosis and recommendation integrated system and compositional nutrient diagnosis. *Communications in Soil Science and Plant Analysis,* 29: 2881-2892.

Raghupathi, H.B. and Bhargava, B.S. 1999. Preliminary nutrient norms for Alphonso' mango using diagnosis and recommendation integrated system. *Indian Journal of Agricultural Sciences,* 69:648-650.

Raj, G.B., and Rao A.P. 2006. Identification of Yield-Limiting Nutrients in Mango through DRIS Indices. *Communications in Soil Science and Plant Analysis,* 37(11): 1761 — 1774.

Ramakrishna, A., Bailey, J.S., and Kirchhof, G. 2009. A preliminary diagnosis and recommendation integrated system (DRIS) model for diagnosing the nutrient status of sweet potato (*Ipomoea batatas*). *Plant and Soil,* 16:107-116.

Rathfon, R.A. and Burger, J.A. 1991a. Diagnosis and Recommendation Integrated System (DRIS) nutrient norms for Fraser Fir Christmas trees. *Forest Science,* 37:.998-1010.

Rathfon, R.A. and Burger, J.A. 1991b. Diagnosis and Recommendation Integrated System modifications for Fraser Fir Christmas trees. *Soil Science Society of American Journal,* 55:1031-1037.

Reis, R.A. Jr. Diagnose Nutricional da Cana-de-ac¸u´car Com o Uso do Sistema Integrado de Diagnose e Recomendac¸a˜o (DRIS). D.Sc. Thesis, Universidade Estadual do Norte Fluminense, Campos dos Goytacazes, Brazil.

Sanchez, C.A., Sera, G.H. and Burdine, H.W. 1991. DRIS Evaluation of the Nutritional Status of Crisphead Lettuce. *Hort Science,* 26:274–276.

Sanz, M., Heras, L. and Montanes, L. 1992. Relationships between yield and leaf nutrient contents in peach-trees – early nutritional-status diagnosis. *Journal of Plant Nutrition,* 15: 1457-1466.

Silva, G.G.C., Neves, J.C.L., Alvarez, V.H. and Leite, F.P. 2004. Nutritional Diagnosis for Eucalypt by DRIS, M-DRIS, and CND. *Scientia Agricola,* 61 (5) 507-515.

Singh, N.P, Awasthi,R.P. and Sud A. 2000. Diagnosis And Recommendation Integrated System (DRIS) norms for apple (Malus x Domestica Borkh. L. CV. Starking Delicious) in Himachal Pradesh .*The Indian Journal Horticulture,* 57(3): 196-204

Singh, V.K. and Agrawal, H.P. 2007. Development of DRIS norms for Evaluating Nitrogen, Phosphorus, Potassium and Sulphur Requirements of Rice Crop. *Journal of the Indian Society of Soil Science,* 55(3): 294-303.

Shear, C.B. and Faust, M. (1980). Nutritional ranges in deciduous tree fruits and nuts. *Horticultural Reviews* 2: 142.

Soltanpour, P.N., Malakouti, M.J. and Ronaghi, A. 1995. Comparison of Diagnosis and Recommendation Integrated System and Nutrient Sufficient Range of Corn. *Soil Science Society of American Journal,* 59: 133–139.

Snyder, G.H. and Kretschmer, A.E. 1988. DRIS Analysis for Bahia grass Pastures. *Soil & Crop Science Society of Florida – Proceedings,* 47: 56–59.

Snyder, G.H., Sanchez, C.A. and Alrights, J.S. 1989. DRIS Evaluation of the Nutrient Status of Bahia and St. Augustine Turf grasses. *Proceedings of the Florida State Horticultural Society,* 102: 133–137.

Srivastava, A.K. and Singh, S. 2008. DRIS Norms and their Field Validation in Nagpur Mandarin. *Journal of Plant Nutrition,* 31:1091-1107.

Stevens, R.J. and Watson, C.J. 1986. The response of grass for silage to sulphur application at 20 sites in Northern Ireland. *The Journal of Agricultural Science Cambridge,* 63:209–219.

Sumner, M.E. 1977. Effect of Corn Leaf Sampled on N, P, K, Ca and Mg Content and Calculated DRIS Indices. *Communications in Soil Science and Plant Analysis,* 8: 269–280.

Sumner, M.E. 1977a. Application of Beaufil's Diagnostic Indices to Maize Data Published in the Literature Irrespective of Age and conditions. *Plant and Soil*,46: 359-369.

Sumner, M.E. 1979. Interpretation of Foliar Analysis For Diagnostic Purposes. *Agronomy Journal,* 71: 343-348

Szu¨cs, E., Ka´llay, T. and Szenci, G. 1990 Determination of DRIS Indices for Apple (Malus domestica Borkh). *Acta Horticulturae* ,274: 443–721.

Walworth, J.L. and Sumner, M.E. 1986. Foliar diagnosis – a review. *In* Adv. Plant Nutr., vol III. Ed. B P Tinker. pp 193–241. Elsevier, New York.

Walworth, J.L. and Sumner, M.E. 1987. The diagnosis and recommendation integrated system (DRIS). In: Stewart BA (ed) Advances in soil science. vol. 6. Springer, New York, pp 149–188.

Westfall, D.G., Whitney, D.A. and Brandon, D.M. 1990. Plant analysis as an aid in fertilising small grains. In: Westerman RL (ed) Soil testing and plant analysis. 3rd edn. Soil Science Society of America, Madison, WI, USA, pp 495–519.

Wortmann, C.S., Bosch, C.H. and Mukandala, L. 1994. Foliar nutrient analyses in bananas grown in the highlands of East-Africa. *Journal of Agronomy and Crop Science,* 172: 223-226.

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