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Diagnosis and Recommendation Integrated System (DRIS) approach on Nutritional Diagnosis in Fruit crops- A Review

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Abstract: Diagnosis and Recommendation Integrated System (DRIS) is widely used statistical approach for interpretation of the plant tissue analysis data and to diagnose the plant nutreint needs much earlier than the reduction of crop yield with greater accuracy. It helps in simultaneous identifying imbalances, deficiencies and excesses of crop nutrients and ranks them in the order of their importance for their remedial steps. The DRIS norms based on foliar composition can developed in any crop and at any stage of its development. It provides a mathematical means of ordering large number of nutrient ratios into nutrient indices that can be easily interpreted. The nutrient ranges been established as deficient, low, optimum, high and excessive based on the mean of nutrient concentration and standard deviation from high yielding population to serve as a guide for a quick and routine diagnostic and advisory purpose. The major advantage of DRIS lies in its ability to minimize the effect of variation in tissue age on diagnosis, which allows a choice of wider range of tissues than permissible under the conventional critical value approach. Thus, DRIS is holistic in nature for identification of nutrient imbalance in crops and formulation of nutrient management strategies for achieving higher yields.

Keywords: DRIS indices, DRIS ratio norms, Fruit crops, Nutrient diagnosis

INTRODUCTION

The perennial fruit crops are distinct from seasonal crops in their nutritional requirement due to their plant size, density, root spread, growth pattern, phenomenon of bud differentiation and their relationship with the yield during the bearing and off-season. Major objectives of proper nutrient management in fruit orchards are to increase the net income through efficient fertilization. This requires a precise determination of the yield-limiting impact of a given nutrient. Determination of the nutritional needs of fruit crops must made prior to determination of potential yield. The best diagnostic tool is the one that recommends nutrients application based on direct economic response of crops. Suitable diagnostic tools were designed to avoid nutrient shortage or excess and with proper usage, there should not be any decrease in fruit production and quality. In additional to this, leaf analysis helps in accurate identification of the need for nutrient fertilization. Leaf analysis, is based on the assumption of positive relationship between the doses of nutrient supplied, leaf nutrient content and the yield. Leaf analysis is useful as it helps to prevent deficiency rather than correcting them after their development. Foliar analysis can be a useful tool for assessing plant nutrient status if, adequate procedures are available for diagnosis from the analytical data (Bhargava and Chadha, 1993). The foliar diagnosis is a complex exercise because of the dynamic nature of foliar composition, which has strongly influenced by leaf age and other interactions affecting nutrient uptake and distribution. Among several approaches adopted for interpretation of leaf analysis data, Diagnosis and Recommendation Integrated System (DRIS) is consider the best as it uses nutrient ratios and simultaneously identifies imbalances, deficiencies and excesses in crop nutrients, and, ranks them in the order of importance (Beaufils, 1973). The DRIS norms should be developed for specific conditions, in which all other factors to be correlated with yield or quality (or any other variable) are known: like cultivar, climate, soil and crop management, productivity *etc* for attaining the specific objectives (Bangroo *et al.*, 2010).

DIAGNOSIS AND RECOMMENDATION INTEGRATED SYSTEM (DRIS)

Normally, the concentration of N, P and K in leaves decreases with leaf age, while that of Ca and Mg in-

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creases. In order to overcome these problems in nutrient diagnosis the concept of DRIS was introduced. DRIS, developed by Beaufils (1973), is actually a dual ratio concept where mainly, the nutrient concentration ratios are considered rather than single nutrient value and are used for developing leaf/petiole nutrient norms/guides.

The main concept of DRIS envisages that the ratios N/P, N/K, P/K, Ca/Mg and their reciprocal should remain constant irrespective of leaf age. The product of NX Ca should be fairly constant. Further, DRIS act as alternative approach by using nutrient ratios rather than concentration themselves to interpret tissue analysis (Beaufils, 1971). DRIS received considerable attention since its introduction as it is described as a comprehensive system, which identifies all the nutritional factors limiting the crop production and helps in increasing the chances of obtaining high yields by improving fertilizer recommendation (Beaufils, 1973). DRIS index values measure how far specific nutrients in the leaf or plant are from optimum range.

Several advantages of this method over the conventional critical level approach have been reported (Walworth and Sumner, 1987) which are follows:

1. Identification of not only the most limiting element, but also the order in which the other elements would likely to become limiting.

2. The ability to diagnose the plant nutrient need to be much earlier in the life span of crop than the critical level approach thus, allowing one to take remedial measures earlier.

3. DRIS provides greater accuracy in diagnosis and offers relatively more freedom from the effect of some of the sampling variables such as the age of the plant part and geographical location *etc.*

The DRIS approach was designed to provide a valid diagnostic irrespective of plant age, tissue origin (Sumner, 1977, Meldal-Johnsen and Sumner 1980, Bailey *et al.,* 1997, Jones, 1993) 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 particularly in terms of differences caused by leaf position, tissue age, climate, soil conditions, and cultivar affect 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 for a given species, there has to be specific nutrient ratios for the maximum crop performance that transcend local conditions, such soil, climate and cultivars (Synder and Kretschmer, 1988). Thus, the DRIS had been successfully applied to many fruit crops like grapes (Bhargava and Raghupathi, 1995; Sharma *et al.,* 2005), 'Valencia' orange (Orlando *et al.,* 1997), pomegranate (Raghupathi and Bhargava, 1998), mango (Hundal *et al.,* 2005), apple (Singh *et al.,* 2000), peach (Awasthi *et al.,* 2000), papaya (Anjaneyulu, 2007), Ber (Kuldip *et al.,*2010), Aonla (Nayak *et al.,* 2011), Coorgmandarin (Raghupathi *et al.,* 2013) *etc.* The DRIS norms developed from data banks of observations of a particular cropping system, consisting of minimum tissue nutrient content and associated yields (Sumner, 1990). The norms, which are used as reference standards against which samples to be diagnosed are compared, can be calculated as the means of the various forms expressing the nutrients (N/P, N/K, and K/P *etc.*) for high yielding population of plants. The DRIS indices measure the deviations of various forms of expressions in the tissue under diagnosis from their respective norm values.

DRIS norm development: The first step in implementing DRIS is the establishment of standard values or norms. The DRIS utilizes a survey approach (Beaufils, 1973) for norms determination based on crop response model (Sumner and Farina, 1986). In DRIS, the populations of observations are divided into two subgroups *viz* low and high yielding groups based on cut-off yield and then mean values of high yielding groups that taken as estimates of tissue parameter optima. In addition, the coefficient of variation of high yielding data provides a measure of the relative spread or breadth of the yield response surface at upper yield levels (Walworth and Sumner, 1987).

The actual cut-off value used to divide low and high yield groups is not critical as long as the high yield data remain normally distributed (Fig. 1). In corn, when the cut-off value for dividing high and low corn yields varied from 7 to 9 Mg ha^{-1} than the normal value for average tissue N/P, N/K, and P/K ratios which varied 6.7, 4.8 and 2.4 per cent, respectively (Letzsch and Sumner, 1984). In practice, the chosen cut-off values are usually represented yields that farmers routinely obtain. For each pair of nutrients, there are three forms of expression that may be considered. For example, N and P can related as ratio of N/P, its inverse P/N or product N x P. In DRIS calculation, only one expression is used to relate each nutrient pair. The selection of is done by comparing the variation of low yielding group to that of high yielding segment of the population. The form of expression (N/P, P/N or N x P) selected for the use in DRIS computation is the one associated with the largest variance ratio and lower coefficient variation (Fig. 2) (Beaufils, 1973 and Walworth and Sumner, 1987).

DRIS index/ indices and interpretations: DRIS provides a means of ordering nutrient ratios into meaningful expressions in the form of indices. The actual nutrient imbalance in plant is diagnosed through DRIS indices. Total sum of DRIS indices is zero. The DRIS indices were calculated as described by Walworth and Sumner (1987) by using the fol-

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

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

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

lowing formula, as an example for one nutrient as

$$f(A/B) = \frac{(A/B - 1)}{a/b} \quad X \quad \frac{1000}{CV}$$

given below

$$f(A/B) = \frac{(1 - A/B)}{a/b} \quad X \quad \frac{CV}{1000}$$

Where, when A/B is larger or equal to a/b,
when A/B is smaller than a/b,
In these equations, A/B is designated the tissue nutrient ratio of the plant to be diagnosed, a/b is the optimum value or norm for 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 also 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 weighted by the reciprocal of the CVs 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 and the contribution of each one to the calculation of this index will be function of the CV values (reference ratios) associated with them, which will reflect the relative influence of these two expressions in the fruit yield. It is important to remember that the composition of the formulae will depend on the situation and there is no fixed formula to use under all crops/situations. The investigator can attempt to work out the formulae for a given crop and use it. In a plant sample with optimal nutrient balance, all nutrient indices would equal to zero. However, it is important to recognize that an individual nutrient is not necessarily present in optimum concentration even if its index equals zero (Walworth and Sumner, 1987). For instance, if the results of a diagnosis were as follows:

Nutrient	N	P	K	Ca	Mg
Index	-14	0	+4	+4	+6

Among the nutrients tested, N had the most negative index and was likely to be yield limiting. Although the P index equaled zero, it was relatively less abundant than K and Ca or Mg and was the second most needed or limited nutrient in the diagnosis. Potassium, Ca and Mg levels were excessive relative to N and P. However, the recommendation from the above diagnosis index is supplementation of both the deficient N and to a lesser extent the P also (P index is zero) (Walworth and Sumner, 1987). Total nutrient balance in a plant may be indicated by the sum of the nutrient indices irrespective of the sign, which is called as Nutrient Balance Index (NBI). When the sums of the DRIS indices are large, one or more of the measured factors may limits the yield. Such relationship established between NBI and fruit yield of pineapple (Fig. 3). Moreover higher yields can result only when sum of indices are small, although high yields may still occur if other factors are limiting (Beaufils, 1973, Walworth and Sumner, 1987; Mourao- Filho, 2004).

Leaf nutrient ranges/standards: Bhargava and Chadha, (1993) developed five leaf/petiole nutrient ranges/standards which have been derived using mean and standard deviation as deficient, low, optimum, high and excess for each nutrient. The optimum nutrient ranges are the value derived from 'mean – 4/3 SD to mean + 4/3 SD'. The range 'low' was obtained by calculating 'mean – 4/3 SD to mean – 8/3 SD' and the value below 'mean – 8/3 SD' was considered as deficient. The value from 'mean + 4/3 SD to mean + 8/3 SD' was taken as high and the value above 'mean + 8/3 SD' was taken as excessive. Using these leaf nutrients range formulae developed into petiole nutrient ranges for Thompson seedless Grapes (*Vitis vinifera*) as deficient, low, optimum, high and excess as represented in Table 1 (Bhargava, 2002).

Specific application of DRIS method in fruit

Table 1. Petiole nutrient ranges for Thompson seedless grapes.

Element	Unit	Deficient	Low	Optimum/sufficient	High	Excess
N	%	<0.62	0.62-0.90	0.91-1.44	1.45-1.73	>1.73
P	%	<0.07	0.07-0.11	0.12-0.28	0.29-0.38	>0.38
K	%	<1.20	1.20-2.21	2.22-3.37	3.38-5.03	>5.03
Ca	%	<1.37	1.37-2.64	2.65-4.19	4.20-5.55	>5.55
Mg	%	<0.32	0.32-0.66	0.67-1.37	1.38-1.74	>1.74
S	%	<0.08	0.08-0.17	0.18-0.37	0.38-0.48	>0.48
Fe	$\mu g\ g^{-1}$	<24	24-32	33-92	93-124	>124
Mn	$\mu g\ g^{-1}$	<21	21-33	34-60	61-74	>74
Zn	$\mu g\ g^{-1}$	<10	10-16	17-40	41-54	>54
Cu	$\mu g\ g^{-1}$	<2	2-5	6-12	13-17	>17
Yield	(t ha^{-1})	<23.16	23.2-26.6	26.61.33.82	33.83-37.37	>38.00

(Source: Bhargava, 2002)

Table 2. 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
Nitrogen	3.04	1.81-4.00	3.03
Phosphorus	0.23	0.12-0.41	0.22
Potassium	4.49	1.66-5.40	3.40

(Source: Angeles *et al.,* 1993)

Table 3. Leaf nutrient composition and DRIS indices in aonla plants.

Age of plant (Years)	Yield (kg ha^{-1})	Leaf nutrient composition				DRIS indices				Requirement order
		N (%)	P (%)	K (%)	Zn (µg g^{-1})	N	P	K	Zn	
5	29.8	1.87	0.10	0.68	48.9	-924	1569	49	-695	N>Zn>K>P
10	34.6	1.84	0.089	0.798	50.2	-1491	-564	2479	-424	N>P>Zn>K
15	40.2	1.50	0.079	0.582	67.8	-5197	-1713	-1652	8562	N>P>K>Zn
20	30.0	1.47	0.070	0.527	45.4	-1249	-704	-413	2365	N>P>K>Zn
>20	28.3	1.34	0.079	0.692	36.5	-3719	1508	4463	-2252	N>P>K>Zn

(Source: Nayak *et al.,* 2011)

Table 4. Mean, range of nutrient concentrations in papaya and DRIS ratios norms for papaya.

Nutrient	Unit	Mean	Range	Selected ratio	Norms	Selected ratio	Norms
N	%	1.18	0.85 - 1.65	N/P	6.368	P/Zn	0.008
P	%	0.21	0.08 - 0.38	N/K	0.571	Cu/P	48.21
K	%	2.48	1.00 - 4.45	Ca/N	2.553	Ca/K	1.500
Ca	%	2.92	1.16 - 4.72	Mg/N	0.899	Mg/K	0.498
Mg	%	1.03	0.55 - 1.99	S/N	0.243	S/K	0.137
S	%	0.28	0.14 - 0.45	Fe/Mn	55.80	Fe/K	31.29
Fe	µg g^{-1}	64	31 – 139	N/Mn	0.025	Mn/K	23.25
Mn	µg g^{-1}	48	30 – 76	N/Zn	0.045	K/Zn	0.093
Zn	µg g^{-1}	29	8 – 56	N/Ca	0.138	Cu/K	4.280
Cu	µg g^{-1}	09	6 – 22	P/K	0.026	Ca/Mg	2.980

(Source: Anjaneyulu, 2007)

crops: In Vacaria, Brazil, Nachtigall and Dechen (2007) also evaluated the nutritional status of apple *(Malus domestica)* using the DRIS method. The DRIS indices and NBI for each nutrient were determined using three methods *viz.* Beaufils, Jones, and Elwali and Gascho. Results from their research showed that (i) the NBI, calculated from the generated norms, were negatively correlated with productivity and fruit coloration, and (ii) the DRIS method, described by Elwali and Gascho and using the F value, was the most suitable for apple tree orchards, because the NBI values obtained with this method best indicated the nutritional status of the plants and provided a more accurate nutritional diagnosis.

Angeles *et al.* (1993) developed DRIS norms for banana (*Musa spp.*) using 915 observations from 26 sources. The reference subpopulation was selected based on productivity of equal or higher than 70 t ha^{-1}. The indices originated from the developed norms were compared with the method of critical values and results of both methods were similar, except for K and K/ nutrient ratios (Table 2). The DRIS norms validity and their advantages over the method of critical values for providing correct nutritional diagnosis were partially confirmed through a fertilization experiment. In Eastern Africa, the experiments 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).

Hundal *et al.* (2005) carried out DRIS studies on mango (*Mangifera indica.* L) trees in Punjab, India. Standard norms established from the nutrient survey of mango orchards were 1.144% N, 0.126% P, 0.327% K, 2.587% Ca, 0.263% Mg, 0.141% S and 15 mg Zn, 3.5 mg Cu, 145 mg Fe, 155 mg Mn and 30 mg B kg^{-1} dry matter. Based on DRIS indices, 16, 15, 12, 17, and 16% of total samples collected during nutrients survey

Table 5. Nutrient diagnosis norms for pomegranate with different techniques of interpretation.

Nutrients	Unit	CVA	DRIS	CND
N	%	1.46	1.59	1.61
P	%	0.18	0.17	0.18
K	%	1.19	1.17	1.09
Ca	%	2.35	1.81	1.33
Mg	%	0.40	0.30	0.37
S	%	0.40	0.30	0.37
Fe	μg g^{-1}	114	105	91
Mn	μg g^{-1}	53	47	44
Zn	μg g^{-1}	16	47	35

(Source: Raghupathi and Bhargava, 1999).

of mango orchards were low in N, P, K, Ca, and Mg, respectively. For micronutrients, 19, 18, 12, 20, and 6% samples were inadequate in Zn, Cu, Fe, Mn and B, respectively. Sharma *et al.* (2005) used data bank of nutrient concentration and yield for vines grafted on dog-ridge rootstock (*Vitischampini*) for developing DRIS ratio norms during bud differentiation and flowering stage. Sixty-six nutrient expressions were chosen as diagnostic norms. Among the nutrient ratios selected to form diagnostic parameters, P/N (0.260), K/N (1.761) P/Zn (0.0056) had greater physiological rationale during flowering stage. While, N/P (3.42) and N/K (0.68) were more critical during bud differentiation stage. Sodium followed by Mg, Ca, Fe, Cu and K were the most common yield limiting nutrients whereas, K, Mn and Fe at bud differentiation stage and Ca, N, and Mg at flowering stage were considered as excessive.

Raghupathi and Bhargava (1998) developed leaf nutrient diagnostic norms for pomegranate (*Punica granatum* L.) grown in Bijapur district of Northern Karnataka, India, found the optimum ranges of nutrients in leaf varying from 0.91 to 1.66% N, 0.12 to 0.18% P and 0.61 to 1.59% K. The evaluation of the individual low yielding orchards of pomegranate indicated that low levels of soil Zn and Cu were responsible for the low yields. 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, 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% peach orchards was Mg > N > P > K >Ca and remaining 40 % was in the order of requirement, Mg > P > N > K > Ca. In addition the study revealed that Mg was the most yield-limiting nutrient in peach orchards of Himachal Pradesh, followed by N and P. The Ca and K application were least required in these orchards.

The DRIS norms recognized from N, P, K, and Zn composition of aonla (*Emblica officinalis)* leaf samples were further employed to compute DRIS indices in orchards of Uttar Pradesh by Nayak *et al.* (2011). Specified nutrient requirements as per DRIS indices were in the order of N >P >K >Zn in most groups of plants. Nitrogen is the most limiting element in all age group of plant (Table 3). When compared age-wise among orchards, a relative deficiency for N, P, and K corresponding to relative sufficiency for Zn was detected by the DRIS technique for the plants above the age group of 15 years onwards. In younger orchards (5 years old), a relative deficiency of N, Zn, and K and a relative sufficiency of P was detected. Anjaneyulu (2007) has conducted studies using DRIS on papaya (*Carica papaya*) for development of petiole nutrient norms. A total of three hundred samples were collected

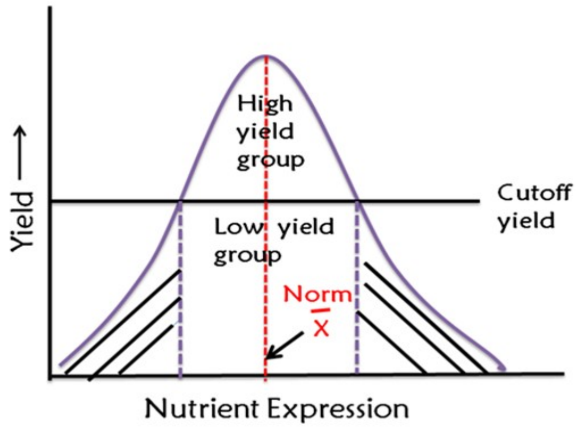

Fig. 1. *Schematic illustration of DRIS norms. (Source: Walworth and Sumner, 1987).*

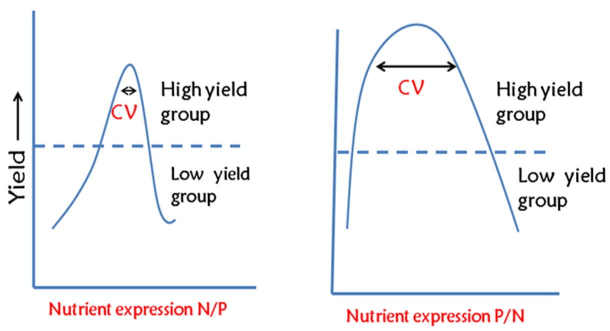

Fig. 2. *Schematic representations of relationship between nutrient expressions and yield.* (Source: Walworth and Sumner, 1987).

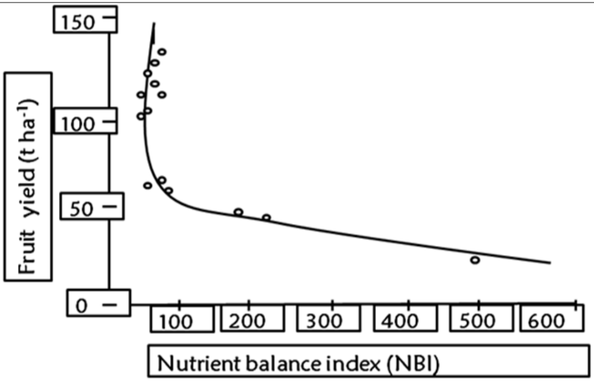

Fig. 3. *Relationship between nutrient balance index (NBI) and fruit yield of pineapple (Source- Angles et al. 1990).*

and analyzed for macro- and micro-nutrients for the data bank and forty-five nutrient expressions were selected as diagnostic norms (Table 4) *viz.,* N/P (6.368), N/K (0.571), Mg/N (0.899), N/Zn (0.045), Ca/Mn (0.062), Ca/Zn (0.0115), Mg/Zn (0.039) and S/Zn (0.010) etc. The diagnosis of nutrient imbalance through DRIS indices indicated that the most common yield-limiting nutrient was Zn followed by K. The optimum nutrient concentrations ranged from 0.91 to 1.44% N, 0.12 to 0.28% P, 2.22 to 3.75% K, 2.65 to 4.19% Ca, 0.67 to 1.37% Mg and 0.18 to 0.37% S. Among the micronutrients, the optimum ranges varied from 17 to 40 mg Zn, 33 to 92 mg Fe, 34 to 60 mg Mn and 6 to 12 Cu mg kg^{-1}tissues (Table 4). Anjaneyulu (2008) developed the DRIS norms for guava *(Psidium guajava).* Among the nutrient expressions selected as diagnostic norms, some expression such as P/N (0.105), N/K (1.375), P/Mg (0.485), P/Zn (0.006), K/ Zn (0.042), Mg/K (0.302), Mg/S (1.147), Fe/Zn (4.302) etc. had greater physiological rationale, as they showed lower coefficient of variation compared to other ratios. The DRIS indices indicated that Zn followed by K were the most common yield limiting nutrients in guava.

Raghupathi *et al.* (2013) surveyed Coorg mandarin *(Citrus reticulate)* in Kodagu region of Karnataka, India to develop data bank of nutrient concentration and yield. Twenty-eight nutrient expressions were derived for identification of nutrient imbalance in Coorg mandarin. Among the nutrient expressions selected as diagnostic norms, some expressions such as N/P (6.427), N/K (1.703) and P/Zn (0.0134) were found to have greater physiological rationale in seedling plants. The ratio of N/P (7.17), N/K (1.395) and Zn/P (77.80) and Ca /Mg (5.92) were found important in budded plants. DRIS identified Zn and Mg as the most yield-limiting nutrients in Coorg mandarin. MouraoFilho and Azevedo (2003) established DRIS norms for the 'Valencia' sweet orange (*Citrus sinensis* L.) budded on Rangpur lime, Caipira sweet orange and *Poncirus trifoliate* rootstocks. The nutritional balance indexes calculated by the derived norms were highly correlated with yield for the rootstock/scion combinations. They inferred that DRIS norms might be for leaves sampled from non-bearing fruit branches of irrigated-plant groves. Nutrient sufficiency ranges derived from DRIS norms were 0.688–1.648 % N, 0.184–0.339% P, 1.178 –1.855% K, 1.064–1.768% Ca, 0.234–0.391% Mg, 0.124–0.180% S, 55–205 mg Fe, 26–80 mg Mn, 17–33 mg Zn, and 5–11 mg Cu kg^{-1}using DRIS norms in ber (*Zizyphus mauritiana*) (Kuldip *et al.* 2011).

Savita and Anjaneyulu (2008) surveyed 106 orchards growing sapota (*Manilkara zapota* cv. Kalipatti) in Northern Karnataka, India for developing leaf nutrient norms using DRIS showed that K, B and Zn were the most common yield-limiting nutrients. Optimum leaf nutrient content ranged from 1.51 to 2.09% N, 0.06 to 0.15% P, 0.83 to 1.44% K, 1.36 to 2.34% Ca, 0.54 to 0.68% Mg and 0.48 to 0.80% S. Among the micronutrients, optimum concentrations ranged from 109 to 206 mg Fe, 49 to 99 mg Mn, 13.3 to 21.9 mg Zn, 3.76 to 9.10 mg Cu and 34.8 to 66.8 mg B kg^{-1}. Hundal and Arora, (1996) used DRIS for foliar diagnosis of micronutrients in litchi (*Litchi chinensis* Sonn.). They concluded that DRIS norms can be used irrespective of variety and position of leaf sampled from the floral or non-floral panicleswith inadequacy levels for Zn, Cu, Fe and Mn are 14, 10, 190 and 20 mg kg^{-1} leaf tissues, respectively. Further, Disha *et al.* (2012) carried out a survey on leaf sampling in plum (*Prunus domestica* ssp. Domestica cv. Santa Rosa) orchards of Kullu district of Himachal Pradesh, India. Their study revealed the deficiency of N, P, K, Mg, Zn, Mn and B were diagnosed in 4, 12, 20, 12, 24, 8 and 32 % orchards, respectively, while an excess of N, Fe and Cu were diagnosed in 8, 36 and 12 % orchards respectively. The order of nutrients limiting in different orchards indicated that B was the most limiting nutrient as 32 % orchards showed its deficiency, while 24 % orchards showed Zn deficiency.

A COMPARISON OF DRIS AND OTHER DIAGNOSTIC SYSTEMS

Sumner (1979) critically evaluated the precision and flexibility of different foliar diagnostic techniques in making a valid diagnosis of nutrient imbalances in crops. A comparison of diagnostic precision between critical level and DRIS approach was made using data from various field crop experiments with corn, soybean sugarcane, and potatoes and it was opined that DRIS was superior to critical value approach. In most comparisons of diagnostic capabilities of critical value or sufficiency range systems and DRIS, the tissue sampling had been done at a specific stage of growth. Even under these conditions, DRIS usually maintains slightly a higher diagnostic precision. According to Sumner (1979), the DRIS based treatment resulted in 39 successes with 12 failures whereas, treatment based on critical values resulted in 22 successes with 11 failures in the case of potato crop. Similarly, in corn 166 successes and 24 failures were recorded with DRIS, whereas these were 133 successes and 34 failures with critical value systems (Walworth and Sumner, 1987). Research works carried out in Hungary investigated on the DRIS standard ratios for apple (*Malus domestica* Borkh) orchards (Szucs *et al.,* 1990). The data on yield and leaf nutrient concentration from 18 representative orchards were collected during three consecutive years. With the conventional DRIS method based calculations, the indices 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. It was concluded that the norms obtained by regression analysis might possibly point out more extreme nutrient ratios than the traditional method.

Wairegi and Van-Asten (2011) compared the norms for banana (Musa spp. AAA) using CND, DRIS and a DRIS that includes a filling value (DRIS-Rd) in East African highland. The data on foliar N, P, K, Ca and Mg concentrations and plant performance were obtained from 300 plots in Uganda. CND indices were closely related to DRIS and DRIS-Rd indices (R^2>0.965). Four nutrient interactions were common in both low and high bunch weight sub-populations. Although the three approaches could be used to diagnose nutrient imbalances in AAA- bananas, the CND was recommended because of the ease in use.

Raghupathi and Bhargava (1999) compared the diagnostic norms using univariable critical value approach (CVA), bivariate DRIS and CND in 112 selected commercial orchards of pomegranate (*Punicagranatum* cv. Ganesh) in India. Among CVA, DRIS and CND, the differences in the norm values were also noticed for N, Ca, Fe and Zn. The norms values and identification of yield limiting nutrients were close to each other with DRIS and CND, while there was no consensus with CVA norms and the diagnosis. When several nutrients are likely to limit yield simultaneously, the diagnosis of mineral disorder by multivariate CND approach is better for higher diagnostic precision (Table 5). Therefore, CND approach provides a better theoretical basis for further improvement in foliar diagnosis as compared to CVA and DRIS (Raghupathi and Bhargava, 1999).Santos (1997) evaluated the DRIS method using results of leaf analysis derived from a series of field experiments with N, P and K fertilization in commercial citrus groves of the São Paulo State. He obtained superior results with the DRIS for detecting yield limitation by nutrient deficiency as compared to the SRA. Among the three available procedures for the DRIS indices calculations, the one proposed by Jones (1981) was found to be the most advantageous. Creste (1996) reported that the first DRIS evaluation by comparison with the sufficiency range approach (SRA) in 'Siciliano' lemon (*Citrus limonium*) groves of Brazil. The data was obtained from the analysis of leaves of fruiting branches of different plant ages and rootstocks in several harvesting years. The reference population was derived from plants with productivity greater than 80 t ha^{-1}. After the DRIS norms calculations, the method was evaluated under field conditions. The DRIS was shown to be more advantageous over the SRA, as it was able to mainly discriminate the nutrient importance in the order of their deficiency or excess. The diagnosis of nutritional status of bananas (*Musa spp.*) through plant analysis not only provided the basis of correct fertilizer requirement of the crop but also guided towards the nutritional requirements of the future crops. The DRIS is also used for interpreting plant analysis data, based on a comparison of calculated elemental ratio indices with established norms. The plant analysis with standardized scores (PASS), the most efficient diagnosis systems, has not been effectively utilized for bananas. The accurate plant sampling, handling, and analysis of the sample coupled with a thorough knowledge of cropping history, sampling techniques, soil test data, environmental influences, and nutrient concentrations favour the efficient diagnosis and interpretation system (Memon *et al.*, 2005).

Conclusion

Comprehensive review of scientific literature reveals that DRIS is a promising, effective auxiliary tool for the nutritional diagnosis in fruit crops. Except for a few studies, most of the developed research works amply clarify that DRIS is more efficient than conventional methods of nutritional diagnosis (critical values and sufficiency range) with the additional advantage of establishing a nutrient deficiency or excess ranking, according to their importance and quantifying the plant nutrient balance. The cutting edge advantage of this approach lies in its ability to minimize the effect of tissue age on diagnosis, thus enabling interested researchers to sample over a wider range of tissue age than permissible under the conventional critical value approach. Myriad of scientific groups have opined 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. Therefore, DRIS approach is holistic in nature, helps in identification of nutrient imbalance in crops and formulation of nutrient management strategies for achieving higher crops yields. The DRIS approach represents a step forward to strengthen our abilities to diagnose nutritional status of crops and has significant implications on nutrient management practices in horticultural and field crops.

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