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DIAGNOSIS AND RECOMMENDATION INTEGRATED SYSTEM APPROACH FOR NITROGEN, PHOSPHORUS, POTASSIUM, AND ZINC FOLIAR DIAGNOSTIC NORMS FOR AONLA IN CENTRAL INDO-GANGETIC PLAINS

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DIAGNOSIS AND RECOMMENDATION INTEGRATED SYSTEM APPROACH FOR NITROGEN, PHOSPHORUS, POTASSIUM, AND ZINC FOLIAR DIAGNOSTIC NORMS FOR AONLA IN CENTRAL INDO-GANGETIC PLAINS

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□ *A survey was conducted for the nutritional status of aonla orchards in the state of Uttar Pradesh lying in Central Indo-Gangetic plains. Preliminary diagnosis and recommendation integrated system (DRIS) norms were established for different nutrient ratios and used to compute the DRIS indices, which assessed the nutrient balance and order of limitations to yield. Maximum fruit yield of 40.2 kg plant^{-1} was recorded for the plants at the age group of 10–15 years and lowest yield was recorded 28.3 kg plant^{-1} in the age of above 20 years. Nutrient sufficiency ranges for aonla derived from DRIS norms were 1.30– 1.64, 0.054–0.092, 0.40–0.64%, and 32.4–45.9 ppm for nitrogen (N), phosphorus (P), potassium (K), and zinc (Zn), respectively. On the basis of these sufficiency ranges 33, 51, 47, and 46% of samples were found sufficient whereas 34, 22, 18 and 27% of samples were low and 26, 8, 1 and 17% deficient in N, P, K, and Zn, respectively. When compared age wise, a relative deficiency for N, P, and K corresponding to relative sufficiency for Zn was detected by DRIS technique for the plants above the age group of 15 onwards. For the younger orchards (5yrs old) a relative deficiency of N, Zn, and K corresponding to the relative sufficiency of P was detected. Nitrogen was found most limiting elements in all age group of plant. When the DRIS indices were compared on basis of soil pH, Zn and K was found to be relatively lesser in order of requirement than N and P.*

Keywords: DRIS, foliar diagnosis, leaf composition, aonla, fruit crop

INTRODUCTION

Aonla (*Emblica officinalis* Gaertn.) is an important fruit tree commonly grown in tropical and sub-tropica regions. It is a hardy tree belonging to the Euphorbiaceae family and has potential to grow in marginal soils and

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degraded lands, such as salt affected soils, ravines and dry area. Its fruit is acrid, refrigerant, diuretic, laxative in nature, and rich in vitamin C and pectin. Processed aonla is a main constituent of many Ayurvedic products. Naturally grown aonla is found in India, Srilanka, Cuba, Port Riko, Hawai, Florida, Iran, Iraq, Jawa, Trinidad, Pakistan, Malaya, China and Panama. In India, it occupies an area of 49,620 hectares with an annual production of 1,50,500 metric tons of which 42% comes from the state of Uttar Pradesh lying in the Central Indo- Gangetic plains (Pathak et al., 2003). Poor nutrition, marginal lands and senile orchards are some major factors contributing to declining yield and quality in this area, though no local guidelines are available. Locally, many trees in anola orchards appear unhealthy and pre-matured tree mortality is a wide spread problem. In tree plants, the selection of correct leaves, stages of sampling, age of plants and concentration of other nutrients have made it difficult to interpret the result of foliar analysis (Walworth and Sumner, 1987). The critical concentration concept addresses the issues of dificiency and sufficiency of a specific nutrient element and does not addresses the nutritional balance. The diagnosis and recommendation integrated system (DRIS) was developed by Beaufils (1973), used the nutrient ratio a stable criteria with respect to the age of plants and position of leaf tissues, has been proved useful in the interpretation of leaf tissue analysis. In addition, DRIS is based on nutrient balance and indicates not only the nutrient most likely to be limiting, but also the order, in which other nutrients are likely to become limiting and was able to diagnose plant nutrient needs early in the life of crops than sufficiency range method (Beverly et al., 1986; Mourao Filho, 2004). DRIS norms for fruit plants like guava (Hundal et al., 2007), apple (Nachtigall and Dechen, 2007), sapota (Appa Rao et al., 2006), Litchi (Hundal and Arora, 1996), and mango (Pimolaskar and Bhargava, 2003) have been developed for interpreting leaf tissue analysis.

In the present investigation, DRIS approach was employed for interpreting leaf nutrient analysis data collected from different aonla orchards in the Central Indo-Gangetic plains. The sufficiency and deficiency ranges were derived with the DRIS technique, and these were used to monitor the nutrient status of aonla trees.

MATERIALS AND METHODS

Geographically the sampling area lies in semi-arid subtropical region of central Indo-Gangetic plains. This zone lies between the Saryu and Ganges Rivers in the Central Indo-Gangetic plains. It covers the districts of Sultanpur, Pratapgarh, Uttar Pradesh (Figure 1). It has an annual rainfall of 1000–1200 mm, of which 85–90% is received during the monsoon months of June–September/October and is also endowed with good soils. A total

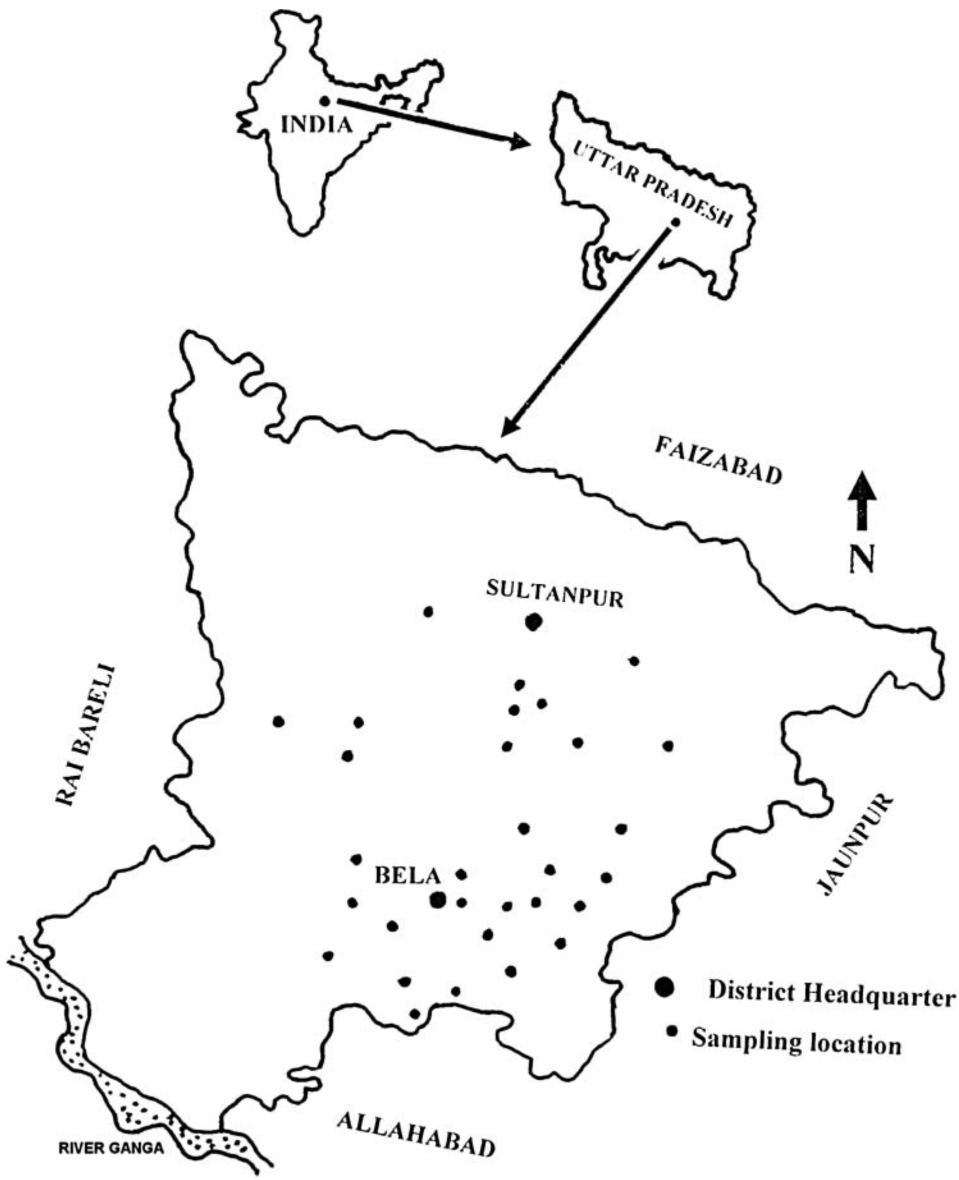

FIGURE 1 Location of the sampling sites (orchard) in Central Indo Gangetic plains.

110 mature leaf samples were collected from 30 orchards of different ages. Samples consisting of recently matured leaves from mid position of plants were collected at full bloom stage in the month of October. At maturity, the fruit yields of all the trees sampled were recorded in kg per plant.

Soil samples were also collected from the corresponding sites and were analyzed for pH, electrical conductivity (EC), organic carbon (Walkley and

Black, 1934), alkaline permanganate steam distilled available N (Subbiah and Asija, 1956), sodium bicarbonate ($NaHCO_3$) (pH 8.5) extractable P (Olsen et al., 1954), neutral 1 N ammonium acetate (NH_4OAc) extractable K (Chopra and Kanwar, 1986), and available Zn using (pH 7.3) diethylenetriaminepentaacetic acid (DTPA) extractable-Zn (Lindsay and Norvell, 1978).

The leaf samples were decontaminated by washing in sequence viz. 0.2% detergent solution, followed by 0.1 N hydrochloric acid (HCl), distilled water and finally in double distilled water (Bhargava and Raghupathi, 1993). Leaf samples were air dried at 70°C and ground using Wiley grinding machine to pass through a 60-mesh stainless steel sieve to obtain homogeneous samples. Nitrogen in plant leaves was determined by Kjeldahl digestion and distillation (Jackson, 1973). Leaf samples were digested in di-acid mixture of perchloric acid ($HClO_4$): nitric acid (HNO_3) and P was determined spectrophotometrically using vanadomolybdophosphoric acid method, K by Flame photometrically as per methods described by Jackson (1973) and Zn by atomic absorption spectophotometer.

Using yield and plant tissue nutrient concentration from the survey data, DRIS norms and CVs were derived according to the procedure by Walworth and Sumner (1987). The statistical critical value approach (CVA) of Cate and Nelson (1971) was used to derive the cut off for high yielding and low yielding population. Mean values for each nutrient expression together with their associated CVs (coefficient of variances) and variances were then calculated for the two populations and presented in Table 1. The mean values (high yielding population) of nutrient expression were ultimately chosen as diagnostic norms. The selection of nutrient ratio expression values with relatively large variance ratio (variance of low yielding population/variance of high yielding population) were done.

TABLE 1 Differing statistical parameters for expressing leaf content of N, P, K and Zn in aonla fruit trees

Expression forms	Low yield Mean	Low yield Variance	Low yield Standard deviation	Low yield Coefficient of variation	High yield Mean	High yield Variance	High yield Standard deviation	High yield Coefficient of variation	S_A/S_B
N	1.70	0.045	0.211	0.124	1.468	0.017	0.129	0.088	2.68
P	0.080	0.000	0.019	0.241	0.073	0.000	0.014	0.196	1.80
K	0.589	0.014	0.117	0.198	0.518	0.008	0.091	0.176	1.64
Zn	43.9	58.5	7.65	0.174	39.0	27.2	5.22	0.134	2.15
N/P	22.1	20.4	4.55	0.204	20.6	12.8	3.57	0.174	1.60
N/K	2.99	0.406	0.637	0.213	2.90	0.173	0.416	0.144	2.35
K/P	7.73	5.52	2.35	0.304	7.21	2.15	1.47	0.204	2.56
Zn/N	26.0	21.9	4.68	0.180	26.7	11.8	3.44	0.129	1.85
Zn/p	570	17471	132	0.232	548	13346	115	0.211	1.19
Zn/K	77.4	388	19.8	0.255	77.3	237.9	15.42	0.200	1.63

DRIS indices as the quantitative evaluation of relative degree of imbalance of the nutrients in this study can be calculated for the following equations:

N index = [f(N/P) + f(N/K) + f(N/Zn)] / 3
P index = [−f(N/P) + f(P/K) + f(P/Zn)] / 3
K index = [−f (N/K) − f (P/K) + f(K/Zn)] / 3
Zn index = [−f (N/Zn) − f (P/Zn) − (K/Zn)] / 3

where

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

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

Similarly for the other functions, such as f (P/K) and f (K/Zn) were calculated in the same way, using appropriate norms and CV.

The leaf tissue optimum range for aonla plants were determined by using the DRIS technique. In fact DRIS norms as reference values of each element obtained from mineral composition of leaf tissues of the high yielding population constituted the mean of sufficiency. The optimum ranges are the values obtained from the mean ± 4/3 SD and mean ± 8/3 SD, respectively (Beaufils, 1971; Beaufils and Sumner, 1976; Bhargava, 2002). The nutrient values < (mean − 8/3 SD) measured deficient, whereas their low range falls including all value between > (mean − 8/3 SD) and < (mean − 4/3 SD). Values between > (mean − 4/3 SD) and < (mean + 4/3 SD) are considered as optimum. The range between > (mean + 4/3 SD) and < (mean + 8/3 SD) were expressed as high. The leaf concentration > mean + 8/3 SD were considered as toxic.

RESULTS AND DISCUSSION

The mostly soils of study area belong to three order (Inceptisol, Alfisol and Entisol). Mostly, the surface soil is fine loamy (55%), with small amount coarse loamy (32%) and fine silty loam (12%). The surface soils of aonla orchards are neutral (6.7 pH) to saline (9.3 pH) and range of electrical conductivity was 0.086 to 1.28 dS m^{-1}. Organic carbon content varied from 0.14–0.87% with mean value of 0.54% and calcium carbonate ($CaCO_3$) content varied from 3.24 to 11.4 g kg^{-1} with mean value of 8.52 g kg^{-1}. The available N, Olsen's P, and 1N NH_4OAc extractable K was ranged from 245–378 kg ha^{-1}, 16–28 kg ha^{-1}, and 58 to 251 kg ha^{-1} with mean value of 310, 19 and 167 kg ha^{-1}, respectively (Table 2).

Mean value of total N, P, K, and Zn content in leaves were found 1.87%, 1.84%, 1.50%, 1.47%, 1.34%, and 0.10, 0.089, 0.079, 0.07, 0.079% and 0.68,

TABLE 2 Soil properties of high yielding orchards of aonla plant of Central Indo-Gangetic plains of Uttar Pradesh

Soil property	Minimum	Maximum	Mean	CV (%)
pH (1:2)	7.65	9.52	8.76	18.5
EC (dSm^{-1})	0.12	0.56	0.38	21.2
Organic carbon (g kg^{-1})	0.14	0.57	0.34	16.2
$CaCO_3$ (g kg^{-1})	3.24	11.4	8.52	34.6
Available N (kg ha^{-1})	245	378	310	25.8
Olsen's P (kg ha^{-1})	16	28	19	21.2
Available K (kg ha^{-1})	58	251	167	13.2

0.798, 0.582, 0.527, 0.692% and 48.9, 50.2, 67.9, 45.4 and 36.5 ppm in the orchards of 5 yrs, 10 yrs, 15 yrs, 20 yrs and more than 20 yrs, respectively (Table 3). N, P and K and Zn contents in leaf samples were considerably reduced with increasing the age of aonla tree where as no specific trend was found in Zn concentration. The decreased nutrient concentration in older plants was partly due to increases in total biomass of plant and partly due to poor nutritional management of the old nursery by the farmers. However, with increases in the pH of the orchard soils (Table 4) there were decreases in the nutrient contents in the aonla leaves. The N contents in leaves were 1.77, 1.49, 1.48, 1.45, and 1.36% at pH <7, 7.5, 8.0, 8.5, and > 9.0, respectively. Similar trends were observed in respect to P, K and Zn concentration. Rao and Singh (2006) reported a decreased in nutrient content in aonla leaves with increases in the soil sodicity. Maximum fruit yield of 40.2 kg $plant^{-1}$ was recorded for the plans at the age group of 10–15 years and lowest yield was recorded 28.3 kg $plant^{-1}$ in the age of above 20 years (Table 3). Similar reducing trends of yield of aonla fruits were recorded with increase in soil pH and lowest yield of 19.5 kg $plant^{-1}$ yield was found at pH > 9 (Table 4).

The DRIS norms recognized from N, P, K, and Zn composition of aonla leaf samples were further employed to compute DRIS indices from the foliar composition of declining anola plants of orchards in the plains of Uttar Pradesh. As per DRIS indices obtained, the next of kin deficiencies for

TABLE 3 Mineral composition and DRIS indices of leaf samples of aonla plants collected from Central Indo-Gangetic plains of Uttar Pradesh

Orchard age	Leaf composition				DRIS indices				Requirement order	Yield kg $plant^{-1}$
	N (%)	P (%)	K (%)	Zn ppm	N	P	K	Zn		
5 yrs	1.87	0.10	0.68	48.92	−924	1569	49	−695	N >Zn>K>P	29.8
10 yrs	1.84	0.089	0.798	50.2	−1491	−564	2479	−424	N>P>Zn>K	34.6
15 yrs	1.50	0.079	0.582	67.86	−5197	−1713	−1652	8562	N>P>K>Zn	40.2
20 yrs	1.47	0.07	0.527	45.43	−1249	−704	−413	2365	N>P>K>Zn	30.0
>20yrs	1.34	0.079	0.692	36.54	−3719	1508	4463	−2252	N>P>K>Zn	28.3

TABLE 4 Effect pH on Mineral composition and DRIS indices of leaf samples of aonla plants collected from Central Indo-Gangetic plains of Uttar Pradesh

pH Range	Leaf composition				DRIS indices				Requirement order	Yield kg plant^{-1}
	N (%)	P (%)	K (%)	Zn ppm	N	P	K	Zn		
7.5–8.0	1.77	0.085	0.623	52.21	−75	−12	−0.93	87	N>P>K>Zn	38.5
8.0–8.5	1.49	0.072	0.69	51.43	−224	−106	189	140	N>P>Zn>K	34.4
8.5–9.0	1.48	0.065	0.625	45.87	−1661	−2441	1969	2132	P>N> K>Zn	26.5
>−9.0	1.45	0.048	0.703	42.98	−460	−7784	5766	2477	P>N>Zn>K	22.3

each nutrient was identified, DRIS indices specified requirements orders as N>P>K>Zn in mostly all age groups of plants. Nitrogen was found the most limiting elements in all age group of plant (Table 3). In the soil pH range 8.5–9 and >9, P was found to be the most limiting element (Table 4); whereas N was limited at soil pH < 8.5. In addition to the diagnosis of deficient nutrients in the old senile aonla orchards of Uttar Pradesh, the DRIS technique also gave the order of necessity for nutrients; however it was difficult to determine if a relative nutrient toxic or deficient of greater concern. When compared age wise, 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 onwards. For the younger orchards (5 yrs old) a relative deficiency of N, Zn, and K corresponding to the relative sufficiency of P was detected. When the DRIS indices were compared on basis of soil pH, Zn and K was found to be relatively less than N and P in regards to the order of requirement.

The DRIS approach can also be employed to compute deficient, low, sufficient, high and toxic ranges for nutrients. Sufficiency ranges of nutrients derived from a nutrient indexing survey of aonla fruit trees are shown in Table 5. The leaf composition interpretations of deficient, low, sufficient, high and toxic level of each nutrient are defined (Bhargava, 2002) as follows:

> Deficient: This indicates that the effective supply of the nutrient is so low that there is a reduction in growth, yield, and quality. Clearly visible deficiency symptoms, if they appear, indicate an acute shortage and imbalances of the nutrient in the plant.

TABLE 5 Nutrient status of aonla fruit trees orchards in orchards from Central Indo-Gangetic plains of Uttar Pradesh (%)

Elements	Deficient	Low	Sufficient	High	Toxic
N (%)	26	34	33	7	—
P (%)	8	22	51	19	—
K (%)	1	18	47	31	3
Zn (ppm)	17	27	46	9	1

TABLE 6 Optimum ranges of elements derived DRIS technique of aonla tree orchards from Central Indo-Gangetic plains of Uttar Pradesh

Element	Mean	S D	Deficiet	Low	Sufficient	High	Toxic
N (%)	1.468	0.129	<1.13	1.13–1.30	1.30–1.64	1.64–1.81	>1.81
P (%)	0.073	0.014	<0.036	0.036–0.054	0.054–0.092	0.092–0.11	>0.11
K (%)	0.518	0.091	<0.28	0.28–0.40	0.40–0.64	0.64–0.76	>0.76
Zn (ppm)	39	5.219	<25.0	25.0–32.4	32.4–45.9	45.9–52.9	>52.9

Low: The supply of nutrient is inadequate for the optimum productivity. It induces malnutrition symptoms and reduction in growth, yield and quality, which is some times referred to as hidden hunger.

Adequate: The growth, yield and quality of the tree are satisfactory, and there is no need to make any changes in the schedule of manures and fertilizers. Changes in the nutrient concentration in the specified plant part do not increase or decrease growth or production.

High: Usually it represents the concentration in the leaf tissues between adequate and excessive range, which is more than necessary, leading to its luxury consumption, nutrient imbalance, or deterioration in quality. The nutrient application may be reduced.

Excessive/toxic: when the concentration in the leaves reaches this level, serious abnormality in mineral metabolism is expressed. Definite toxicity symptoms may occur for some nutrients and cause reduction in vigor, yield and/or quality.

The sufficiency range for nitrogen vary from 1.30–1.64% with an average value of 1.47%. In the present study, it was observed that optimum values of P, K, and Zn ranged from 0.054–0.092%, 0.40– 0.64% and 32.4– 45.9 ppm with mean values of 0.073%, 0.52%, and 39.1 ppm, respectively (Table 6).

Thus, when interpreted with respect to sufficient nutrient concentration ranges, on the basis of leaf N-content in aonla tree, among all surveyed orchards 18%, 35%, 37%, 10%, and 0% plants were found Deficient, low, sufficient, high and toxic respectively. Whereas in case of P (8, 22, 51, 19 and 0%), K (1, 18, 47, 31%), and Zn (3; 17, 27, 46, 9, and 1%) plants were found deficient, low, sufficient, high, and toxic ranges, respectively (Table 5). Accordingly, 53% of plants were found below sufficiency level of N. But in the case of K, only 19% of plants were below sufficiency level.

CONCLUSIONS

It is apparent from this study that leaf tissue analysis of aonla fruit trees can be interpreted by DRIS approach to generate positive or negative indices for each of the nutrients. A positive index indicates adequate and above levels of the nutrient under consideration, whereas a negative index indicates below a sufficiency level; thus the nutrient requirement can be ordered relative to one another. On the basis of DRIS derived sufficiency ranges, 34, 22, 18 and 27% of samples were low in N, P, K, and Zn, respectively. More than 25, 8, and 17% of aonla tree showed to deficient in N, P, and Zn, respectively. Based on the indices obtained, the fertility status of the soil, and the management levels of the orchards, the kind and quantity of fertilizer to be applied can be determined and formulated. With the DRIS approach, each nutrient can be proficiently applied.

REFERENCES

Appa Rao, V. V., S. Singh, B. D. Sharma, and D. T. Mesh Ram. 2006. DRIS norms for sapota in western plains of India. DRIS. *Indian Journal of Horticulture* 63: 145–147.

Beaufils, E.R. 1971. Physiological diagnosis: A guide for improving maize production based on principles developed for rubber trees. *Fertilizer Society of South Africa Journal* 1: 1–28,

Beaufils, E. R. 1973. Diagnosis and Recommendation Integrated System (DRIS): A general scheme for experimentation and calibration based on principals developed from research in plant nutrition. *University of Natal Soil Science Bulletin* 1: 1–132

Beaufils, E. R., and M. E. Sumner 1976. Application of DRIS approach for calibrating soil, plant yield and plant quality factors of sugarcane. *Proceedings of the South Africa Sugar Technology Association* 50: 118–124

Beverly, R. B., M. E. Sumner, W. S. Letzch, and C. O. Plank. 1986. Foliar diagnosis of soybean by DRIS. *Communications in Soil Science and Plant Analysis* 17: 237–256.

Bhargava, B. S. 2002. Leaf analysis for nutrient diagnosis, recommendation and management in fruit crops. *Journal of Indian Society of Soil Science* 50: 352–373.

Bhargava, B. S., and H. B. Raghupathi. 1993. Analysis of plant material for macro- and micro-nutrients. In: *Methods of Analysis of Soils, Plants, Waters and Fertilizers*, ed. H. L. S. Tandon, pp. 48–82. New Delhi, India: Fertilizer Development and Consultation Organization.

Cate, R., and L. A. Nelson. 1971. A simple statistical procedure for partitioning soil test correlation data into two classes. *Soil Science Society of America Journal* 35: 658–660.

Chopra, S. L., and J. S. Kanwar. 1986. *Analytical Agricultural Chemistry*. Ludhiyana, India: Kalyani Publishers.

Hundal, H. S., and C. L. Arora. 1996. Preliminary micronutrients foliar diagnostic norms for litchi (*Litchi chinensis* Sonn) using DRIS. *Journal of Indian Society of Soil Science* 44: 294–298.

Hundal, H. S., D. Singh, and K. Singh. 2007. Monitoring nutrient status of guava fruit trees in Punjab, northwest India through the diagnostic and recommendation integrated system approach. *Communications in Soil Science and Plant Analysis* 38: 2117–2130.

Jackson, M. L. 1973. *Soil Chemical Analysis, Indian Edition*. New Delhi, India:Prentice Hall of India.

Lindsay, W. L., and W. A. Norvell. 1978. Development of DTPA soil test for zinc, manganese and copper. *Soil Science Society of America Journal* 42: 421–428.

Mourao Filho, F. A. A. 2004. DRIS: Concepts and applications on nutritional diagnosis in fruits crops. *Science Agriculture (Piracicaba, Brazil)* 61: 550–560.

Nachtigall, G. R., and A. R. Dechen. 2007. DRIS use on apple orchard nutritional evaluation in response to potassium fertilization. *Communications in Soil Science and Plant Analysis* 38: 2557–2566.

Olsen, S. R., C. V. Cole, F. S. Watanabe, and L. A. Dean. 1954. Estimation of available phosphorus in soil by extraction with sodium bicarbonate. U. S. Department of Agriculture Circular 939. Washington, DC: U.S. Government Printing Office.

Pathak, R. K., D. Pandey, A. K. Mishra, M. Hasib, and D.K. Tandan. 2003. Aonla production. In: *Extension Bulletin 16*, pp. 1–32. Lucknow, India: Central Institute of Sub-Tropical Horticulture.

Pimolaskar, M., and B. S. Bhargava. 2003. Leaf and soil nutrient norms in mango (*Mangifera indica* L.) grown in tribal belt of southern Gujarat. *Journal of Indian Society of Soil Science* 51: 268–272.

Rao, V. K., and H. K. Singh. 2006. Response of sodicity and salinity levels on vegetative growth and nutrient uptake of anola genotypes. *Indian Journal of Horticulture* 63: 359–364.

Subbiah, B. V., and G. L. Asija. 1956. A rapid procedure for the determination of available nitrogen in soils. *Current Science* 25: 259–260.

Walkley, A., and I. A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science* 34: 29–38.

Walworth, J. L., and M. E. Sumner. 1987. The diagnosis and recommendation integrated system (DRIS). *Advances in Soil Science* 6: 149–188.