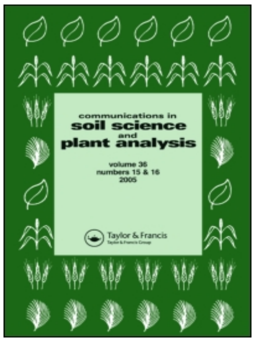

Taylor & Francis
Taylor & Francis Group

Communications in Soil Science and Plant Analysis

ISSN: 0010-3624 (Print) 1532-2416 (Online) Journal homepage: http://www.tandfonline.com/loi/lcss20

Nutrient Indexing in "'Kinnow" Mandarin (*Citrus deliciosia* Lour.× *Citrus nobilis* Tanaka) Grown in Indogangetic Plains

A. K. Srivastava & Prakash Patil

To cite this article: A. K. Srivastava & Prakash Patil (2016) Nutrient Indexing in "'Kinnow" Mandarin (*Citrus deliciosia* Lour.× *Citrus nobilis* Tanaka) Grown in Indogangetic Plains, Communications in Soil Science and Plant Analysis, 47:18, 2115-2125, DOI: 10.1080/00103624.2016.1228947

To link to this article: https://doi.org/10.1080/00103624.2016.1228947

Accepted author version posted online: 16 Sep 2016.
Published online: 16 Sep 2016.

Submit your article to this journal

Article views: 101

View Crossmark data

Full Terms & Conditions of access and use can be found at
http://www.tandfonline.com/action/journalInformation?journalCode=lcss20

COMMUNICATIONS IN SOIL SCIENCE AND PLANT ANALYSIS
2016, VOL. 47, NO. 18, 2115–2125
http://dx.doi.org/10.1080/00103624.2016.1228947

Taylor & Francis
Taylor & Francis Group

Nutrient Indexing in "'Kinnow" Mandarin (*Citrus deliciosia* Lour. × *Citrus nobilis* Tanaka) Grown in Indogangetic Plains

A. K. Srivastava[a] and Prakash Patil[b]

[a]Soil Science ICAR-Central Citrus Research Institute (Formerly National Research Center for Citrus), Nagpur, Maharashtra, India; [b]ICAR-Indian Institute of Horticultural Research, Bengaluru, Karnataka, India

ABSTRACT

Diagnosis and remediation of nutrient constraints in perennial fruit crop like citrus are the two important pillars of an effective nutrient management program. Efforts were made to develop nutrient indexing (NI) criteria based on generated leaf and soil analysis dataset for "Kinnow" mandarin (*Citrus deliciosia* Lour. × *Citrus nobilis* Tanaka) grown on illitic soils of Indogangetic plains (Entisol, Inceptisol, and Aridisol). NI through diagnosis and recommendation integrated system (DRIS) using leaf analysis data showed optimum value of leaf nutrient concentration as 2.22–2.32% nitrogen (N), 0.11–0.15% phosphorus (P), 1.10–1.41% potassium (K), 2.32–2.79% calcium (Ca), 0.38–0.61% magnesium (Mg), 22.4–58.3 ppm iron (Fe), 26.3–56.2 ppm manganese (Mn), 4.2–7.2 ppm copper (Cu), and 21.3–26.9 ppm zinc (Zn) vis-à-vis a fruit yield of 32.4–56.1 kg tree^{-1}. Using these NI criteria, Zn was observed as most deficient (64.7%) followed by Fe (61.5%), Mn (57.6%), N (96.1%), and P (38.5%) using percentage of orchards as basis. While, optimum NI (mg kg^{-1}) using soil analysis data was determined as 114.3–121.2 potassium permanganate ($KMnO_4$-N), 7.8–12.3 Olsen-P, 96.4–131.3 ammonium acetate (NH_4OAc)-K, 189.4–248.6 NH_4OAc-Ca, 72.3–89.9 NH_4OAc-Mg, 5.8–11.1, DTPA-Fe, 4.3–6.9 diethylenetriaminepentaacetic acid (DTPA)-Mn, 0.45–0.69 DTPA-Cu, and 21.3–26.9 DTPA-Zn for the optimum yield of 32.4–56.1 kg tree^{-1}. Soil analysis-based NIs displayed a good complementary with leaf analysis-based NIs evident from the diagnoses indicating Mn (52.2%) as most dominant constraint Zn (61.2%) followed by Mn (48.3%), N (41.2%), and P (35.6%). The recommended DRIS-based NIs would lay a scientific basis in formulating citrus fertilization program.

ARTICLE HISTORY
Received 16 December 2015
Accepted 23 June 2016

KEYWORDS
Diagnosis and recommendation integrated system; Indogangetic plain; "Kinnow"; leaf analysis; nutrient constraint; nutrient index; soil analysis

Introduction

"Kinnow," a F_1 generation hybrid between King mandarin (*Citrus deliciosia* Lour.) and Willow leaf (*Citrus nobilis* Tanaka), is a famous commercial citrus cultivar of northwestern Asia (Srivastava and Singh 2002). The cultivar is known for its excessive and precocious bearing through exceptionally higher annual flushes in comparison to other commercial citrus cultivars (Gururani and Singh 1983; Manivannan and Chadha 2011).Various studies (Dhatt et al. 1992; Embleton et al. 1973; Srivastava et al. 2009) in the past revealed that one ton of "Kinnow" fruits remove much higher nutrients (2.40 kg nitrogen (N)–0.27 kg phosphorus (P)–1.97 kg potassium (K)) compared to other two well-known mandarin cultivars viz., Nagpur mandarin (1.80 kg N–0.18 kg P–1.82 kg K) or Satsuma mandarin (2.06 kg N–0.16 kg P–1.41 kg K), displaying heavy nutrient foraging ability of former compared to other conventionally grown commercial mandarin cultivars.

CONTACT A. K. Srivastava aksrivas2007@gmail.com Principal Scientist, Soil Science ICAR-Central Citrus Research Institute (Formerly National Research Center for Citrus), Amravati Road, Nagpur, Maharashtra 440033, India; Prakash Patil pcfruits@gmail.com Project Coordinator, ICAR-Indian Institute of Horticultural Research, Hesaraghatta Lake post, Bengaluru, Karnataka 560089, India.

© 2016 Taylor & Francis

Occurrence of single or multiple nutrient deficiencies in citrus orchards is reported from all the six continents (Srivastava and Malhotra 2014). Nutrient deficiencies not only cut short the productive life span of citrus orchards, but disturb the economics of production cost as well. Malnutrition of citrus orchards in Asia is more or less a common feature, and often leads to a syndrome popularly known as citrus decline (Ghosh and Singh 1993; Srivastava and Singh 2006). The genesis of such syndrome is predominantly nutrient-mining induced, as a function of expanding gap accruing through comparatively lesser amount of nutrients replenished than annual nutrient requirement; with the result, citrus orchards over the time turn nutritionally poor to poorer, eventually culminating into sustained sub-optimum productivity, and cutting short the productive life of orchards as a cumulative effect (Srivastava, Singh, and Albrigo 2008). Such a situation is further complexed by the absence of application of cultivar-specific soil–plant nutrient diagnostics (Srivastava and Malhotra 2014), affecting the basis of formulating the balanced fertilization, and further jeopardizing the favorable impact of fertilizer additions for optimum soil fertility vis-à-vis plant nutrition. Our past experiences have ably demonstrated better precision in diagnosis of nutrient constraints through the use of cultivar-specific diagnostics (Srivastava and Malhotra 2014).

Researches on developing nutrient diagnostic tools viz., leaf analysis (Hernandez 1988; Plessis 1977, 2014; Srivastava et al. 1999), soil analysis (Jorgensen and Price 1978; Mylavarapu 2010; Srivastava and Singh 2002), deficiency symptomatology (Srivastava 2013a), juice analysis (Gallasch, Dalton, and Ziersch 1984; Moss and Higgins 1978), and to a lesser extent biochemical analysis using different metalloenzymes (Bar-Akiva 1965; Srivastava and Singh 2006) and floral analysis (Pestana et al. 2007) have shown varying amount of successes, but none of them alone is effective enough to precisely diagnose the nutrient constraints in citrus orchards (Srivastava, Singh, and Albrigo 2008), especially with regard to diagnosis and subsequent remediation in the current season standing crop (Srivastava 2013b, 2013c). Diagnosis and recommendation integrated system (DRIS), in this context, has displayed certain distinct advantages over other popularly used interpretation tools (Srivastava and Singh 2008; Beverly 1987; Hundal and Arora 2001; Li et al. 1999; Malavolta, Oliveika, and Vitti 1993). DRIS diagnoses, by and large, agree with the diagnoses made by the sufficiency range method, but with some additional advantages that DRIS reflects the nutrient balance (fluctuates narrowly across different crop developmental stages) and identifies the order of nutrients limiting the fruit yield, and its ability to make diagnosis at any stage of crop development. These merits impart DRIS to be able to identify nutrient constraint early in crop growth period and allow sufficient time for remediation of identified problem right in the same crop season (Walworth and Sumner 1987). The efforts in the past have successfully established the DRIS norms (Beverly et al. 1984; Hanlon et al. 2012; Srivastava and Prakash 2014; Srivastava and Singh 2005; Sumner 1977; Varalaxmi and Bhargava 1998) for world famous commercially popular citrus cultivars such as Valencia/Navel sweet orange (*Citrus sinensis* Osbeck), Kagzi lime (*Citrus aurantifolia* Swingle), Pera, sweet orange (*Citrus sinensis* Osbeck), Shamouti orange (*Citrus sinensis* Osbeck), Satsuma mandarin (*Citrus reticulata* Blanco), Nagpur mandarin (*Citrus reticulata* Blanco) etc. These DRIS-based nutrient norms when applied to "Kinnow" mandarin produced an erroneous diagnosis of different nutrient constraints. This was the basis of undertaking studies on nutrient indexing (NI) in "Kinnow" mandarin grown in Indogangetic plain bordering northwestern India, represented by typical arid sub-tropical climate.

Materials and methods

Experimental details

As many as 26 "Kinnow" mandarin orchards in Hoshirpur (locations: Chaksadhu, Mahalwali, Chauhal, Aimma, Daultpur, Gardinwala, Mahal), Ferozpur (locations: Fazilika and Abohar) districts of Punjab, and Sriganganagar (locations: Karanpur, Layilpur) districts of Rajasthan were surveyed. These orchards were geographically represented by 29.92°–31.53°N latitude and 72.92°–74.60°E longitude. All the orchards were predominantly developed on alluvial flood plains under arid sub-tropical climate. The soils were mineralogically illitic (2:1 non-expanding type) in nature. All the orchards used stionic combination of rough lemon as Jatti Khatti (*Citrus jambhiri* Lush) rootstock and "Kinnow" mandarin (*Citrus deliciosia* Lour. × *Citrus nobilis* Tanaka) as scion at row-to-row and plant-to-plant distance of 6 m apart with a planting density of 277 plants ha$^{-1.}$

The climate of study area in Punjab was characterized as sub-tropical semi-arid and monsoon type having mean summer and winter temperature of 31.6–32.1°C and 13.9–14.1°C, respectively, with an annual rainfall of 426–575 mm (5–8 dry months having rainfall of less than 30 mm). The soil moisture and temperature regimes were represented by ustic/udic/aridic and hyperthermic, respectively, with soils taxonomically classified as Typic Ustifluvents, Typic Ustochrepts, Typic Ustipsamments, Typic Haplustalfs, Udic Ustochrepts, Ustic Torripsamments, and Ustochreptic Camborthids represented by soil orders viz., Entisols, Inceptisols, Aridisols, and Alfisols. While, the climate of study area in Rajasthan was characterized by typical arid and monsoon type with mean summer and winter temperature varying between 44.5°C and 11.2°C, respectively, with an annual rainfall of 220–360 mm (6–10 dry months having rainfall of less than 30 mm). The soil moisture and temperature regimes were represented by aridic and hyperthermic, respectively. Soils taxonomically belonged to Typic Calciorthids, Typic Paleorthids, Typic Salorithids, Typic/Ustic, and Torripsamments belonging to soil orders predominantly Aridisols and Entisols.

Sampling and analysis

Six- to eight-month-old (August–October), spring cycle 2nd, 3rd, and 4th leaves from non-fruiting terminals were collected covering all four directions at a height of 1.5–1.8 m from the ground (Manivannan and Chadha 2011; Srivastava et al. 1999). The soil samples were simultaneously collected at 0–20 cm depth from beneath the perimeter of trees. The leaf samples were thoroughly washed (Chapman 1964), ground using Willey grinding machine to obtain homogenous samples, and subsequently digested in tri-acid mixture of perchloric acid:nitric acid:sulfuric acid ($HClO_4$:HNO_3:H_2SO_4) in 2:5:1 (Chapman and Pratt 1961). Analyses made consisted of N by auto-nitrogen analyzer (Model-Perkin Elmer-2410), P using vanadomolybdo-phosphoric acid method, K flame photometrically, and micronutrients (Fe, Mn, Cu, and Zn) by atomic absorption spectrophotometer (Model GBC-908) using the standard procedure (Page, Miller, and Keeney 1982).

The collected soil samples were air dried, ground, and passed through 2-mm sieve and subjected to various soil fertility analyses which consisted of: alkaline $KMNO_4$ distillation for available N (Subbiah and Asiza 1956), sodium bicarbonate ($NaHCO_3$) (pH 8.5) extractable-P as Olsen-P, 1 N neutral NH_4OAc extractable-K, and 1 N (pH 7.3), DTPA-calcium chloride ($CaCl_2$) extractable Fe, Mn, Cu, and Zn (Lindsay and Norvell 1978; Page, Miller, and Keeney 1982).

Procedure for DRIS analysis

The procedure as initially developed by Beaufils (1973) and modified by Bhargava (2002) was used through a personal computer (PC)-based program for the development of DRIS norms: (i) defining the parameters to be improved and the factors likely to affect them, (ii) Collection of all the reliable data available from the fields and experimental plots, (iii) Study the relationship between the yield and available nutrients in soil, (iv) establishment of relationship between the yield and leaf nutrient composition using the following steps: (a) each internal plant parameter is expressed in as many forms as possible, e.g., N/DM, N/P, P/N, N × P etc.; (b) the whole population is divided into a number of sub-groups based on the economic optimum; (c) the mean of each sub-population is calculated for the various forms of expressions; (d) if necessary, class interval limits between the average and the outstanding yields are re-adjusted, so that the means of below average populations remain comparable; (e) Chi-square test is performed to know that the population of orchards confirms a normal distribution; (f) the variance ratios between the yield of sub-populations (using

50 kg tree^{-1} as cut-off yield level (averaged yield level usually obtained at growers' field) to separate the sub-populations) for all the forms of expressions are calculated together with the coefficient of variation (CV); (g) the forms of expressions, for which significant variance ratios (S_A for low-yielding population/S_B for high-yielding population) were obtained, and essentially the same mean values for the population were selected in expression with common nutrient. The mean and CV values in the high-yield population for the selected ratios were used for calculating DRIS indices. The nutrient with the most negative index is considered the most deficient and most limiting to fruit yield and vice versa, and (h) The following equation was developed for the calculation of DRIS indices based on leaf /soil nutrient concentration:

$$N = 1/9[f(N/P)+f(N/K)+f(N/Ca)+f(N/Mg)+f(N/Fe)+f(N/Mn)+f(N/Cu)+f(N/Zn)]$$

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

$$\text{and } \left(1-\frac{n/p}{NP}\right)\left(\frac{1000}{CV}\right) \text{ when } N/P > n/p$$

where N/P is the actual value of the ratio of N and P in the plant under diagnosis, n/p is the value of the norm (the mean value of high-yielding orchards), and CV, the coefficient of variation for population of high-yielding orchards.

The following equations were developed for the calculation of DRIS indices based on leaf/soil analysis data:

(i) $N = 1/9[f(N/P)+f(N/K)+f(N/Ca)+f(N/Mg)+f(N/Fe)+f(N/Mn)+f(N/Cu)+f(N/Zn)]$

(ii) $P = 1/9[-f(N/P)+f(P/K)+f(P/Ca)+f(P/Mg)+(P/Fe)+f(P/Mn)+f(P/Cu)+f(P/Zn)]$

(iii) $K = 1/9[-f(N/K)+f(K/P)+f(K/Ca)+f(K/Mg)+f(K/Fe)+f(K/Mn)+f(K/Cu)+f(K/Zn)]$

(iv) $Ca = 1/9[-f(N/Ca)--f(P/Ca)--f(K/Ca)+f(Ca/Mg)+f(Ca/Fe)+f(Ca/Mn)+f(Ca/Cu)+f(Ca/Zn)]$

(v) $Mg = 1/9[-f(N/Mg)--f(P/Mg)--f(K/Mg)--f(Ca/Mg)+f(Mg/Fe)+f(Mg/Mn)+f(Mg/Cu)+f(Mg/Zn)]$

(vi) $Fe = 1/9[-f(N/Fe)--f(P/Fe)--f(K/Fe)--f(Ca/Fe)--f(Mg/Fe)+f(Fe/Mn)+f(Fe/Cu)+f(Fe/Zn)]$

(vii) $Mn = 1/9[-f(N/Mn)--f(P/Mn)--f(K/Mn)--f(Ca/Mn)--f(Mg/Mn)-f(Fe/Mn)+f(Mn/Cu)+f(Mn/Zn)]$

(viii) $Cu = 1/9[-f(N/Cu)--f(P/Cu)--f(K/Cu)--f(Ca/Cu)--f(Mg/Cu)--f(Fe/Cu)--f(Mn/Cu)+f(Cu/Zn)]$

(ix) $Zn = 1/9[-f(N/Zn)--f(P/Zn)--f(K/Zn)--f(Ca/Zn)--f(Mg/Zn)--f(Fe/Zn)--f(Mn/Zn)--f(Cu/Zn)]$

DRIS norms for soils and index leaves were calculated in a manner identical to that described for leaf tissue data. The norms for classification of nutrients in leaves were derived using them as mean of high-yielding orchards as the mean for optimum. The range of optimum was the value derived from mean −4/3 to +4/3 standard deviation. The range of low was obtained by calculating −4/3 to mean −8/3 standard deviation, and the value below mean −8/3 standard deviation was considered deficient. The value from mean +4.3 to mean +8.3 standard deviation was considered as an excess.

Correlation analysis

Linear coefficient of correlation ($r = \sigma xy)/\sigma x \times \sigma y$, where σx and σy are standard deviations of x and y, respectively, and σxy is the covariance) was used to test the relationship between soil available nutrients and leaf nutrient composition (Rangaswamy 1995).

Results and discussion

Leaf NI

Leaf analysis as a method of assessing the crop nutrient requirement is based on the assumption that within certain limit, there exists a positive relation between doses of the nutrient supplied, leaf nutrient content, and fruit yield (Srivastava, Singh, and Albrigo 2008). However, the concentration of nutrients determined in leaf is dynamic in nature and undergoes a large variation as evident from the concentration ranges of different nutrients in index leaves (Srivastava et al. 2001). There was a contrasting difference (Table 1) between mean values of low-yielding and high-yielding "Kinnow" mandarin orchards. The mean values of concentration of different nutrients in low-yielding orchards were observed as 1.78% N (CV 8.40%), 0.08% P (CV 17.32%), 0.80% K (CV 22.32%), 1.80% Ca (CV 8.40%), 0.28% Mg (CV 9.30%), 19.32 ppm Fe (CV 14.23%), 18.10 ppm Mn (CV 16.40%), and 19.20 ppm Zn (CV 8.90%) with a mean fruit yield of 20.30 kg tree^{-1} (CV 17.18%). While, high-yielding orchards showed a significantly higher mean concentration of different nutrients in high-yielding orchards as 2.46% N (CV 11.23%), 0.16% P (CV 14.10%), 1.52% K (CV 18.40%), 2.91% Ca (CV 7.32%), 0.71% Mg (CV 6.10%), 69.32 ppm Fe (CV 10.94%), 64.40 ppm Fe (CV 18.14%), 8.90 ppm Cu (CV 6.89%), and 29.32 ppm Zn (CV 26.49%) with a fruit yield of 68.21 kg tree^{-1} (CV 10.20%).

Bataglia (1989) was probably the first researcher to report the application of DRIS technique for diagnosis of nutritional constraints in citrus. He indicated DRIS as an alternative diagnostic method, pointing out the need of using it together with other diagnostic criteria. The developed DRIS norms in our studies predicted optimum value of different nutrients as 2.22–2.32% N, 0.11–0.15% P, 1.10–1.41% K, 2.32–2.79% Ca, 0.38–0.61% Mg, 22.4–58.3 ppm Fe, 26.9–56.2 ppm Mn, 4.2–7.2 ppm Cu, and 21.3–26.9 ppm Zn in relation to fruit yield of 32.4–56.1 kg tree^{-1} (Table 2). A proportionately higher leaf nutrients levels were suggested to be maintained to obtain the fruit yield of up to or beyond 72.9 kg tree^{-1}. These values (2.32–2.78% N, 0.15–0.20% P, 1.41–1.61% K, 2.79–3.12% Ca, 0.61–0.83% Mg, 58.3–92.2 ppm, Fe, 56.2–81.9 ppm Mn, 7.2–10.3 ppm Cu, and 26.9–31.3 ppm Zn) changed considerably at such higher fruit yield levels. DRIS norms developed for different citrus cultivars in India demonstrated optimum value of different nutrients as 1.70–2.81% N, 0.09–0.17% P, 0.96–2.59% K, 1.73–3.43% Ca, 0.24–0.92% Mg, 69.5–249.0 ppm Fe, 21.0–87.6 ppm Mn, 2.13–17.6 ppm Cu, and 11.6–50.0 ppm Zn in relation to fruit yield of 31.6–37.9 kg tree^{-1} and 15.7–19.4 kg tree^{-1} for mandarins and acid

Table 1. Mean leaf nutrient values between low- and high-yielding "Kinnow" mandarin orchards of northwest India.

	Low-yielding orchards (*n* = 10)			High-yielding orchards (B) (*n* = 16)			
Leaf nutrients	$\bar{X}$	CV (%)	S_A	$\bar{X}$	CV (%)	S_B	S_A/S_B*
Nitrogen (%)	1.78	8.40	9.10	2.46	11.23	14.20	0.64
Phosphorus (%)	0.08	17.32	8.69	0.16	14.10	18.40	0.47
Potassium (%)	0.80	22.32	12.32	1.52	18.40	16.90	0.73
Calcium (%)	1.80	8.40	6.32	2.91	7.32	12.41	0.51
Magnesium (%)	0.28	9.30	7.32	0.71	6.10	24.82	0.29
Iron (ppm)	19.32	14.23	8.10	69.32	10.94	19.30	0.42
Manganese(ppm)	18.10	22.10	11.60	64.40	18.14	23.20	0.50
Copper (ppm)	2.81	10.32	16.40	8.90	6.89	30.270	0.54
Zinc (ppm)	19.20	18.12	8.92	29.32	26.49	20.30	0.43
Fruit yield (kg tree^{-1})	20.30	17.18	9.32	68.21	10.20	15.89	0.59

*Variance of low-yielding and high-yielding orchards population was significantly different (p = 0.01).
$\bar{X}$ and CV stand for mean and coefficient of variation, respectively.
S_A and S_B stand for variance of low- and high-yielding orchards, respectively.

Table 2. Leaf nutrient norms (derived from DRIS-based analysis) for "Kinnow" mandarin grown in northwest India.

	DRIS norms				
Leaf nutrients	Deficient	Low	Optimum	High	Excess
Nitrogen (%)	<1.72	1.72–2.22	2.22–2.32	2.32–2.78	>2.78
Phosphorus (%)	<0.07	0.07–0.11	0.11–0.15	0.15–0.20	>0.20
Potassium (%)	<0.74	0.74–1.10	1.10–1.41	1.41–1.61	>1.61
Calcium (%)	<1.78	1.78–2.32	2.32–2.79	2.79–3.12	>3.12
Magnesium (%)	<0.20	0.20–0.38	0.38–0.61	0.61–0.83	>0.83
Iron (ppm)	<18.3	18.3–22.4	22.4–58.3	58.3–92.2	>92.2
Manganese (ppm)	<17.1	17.1–26.3	26.3–56.2	56.2–81.9	>81.9
Copper (ppm)	<2.1	2.1–4.2	4.2–7.2	7.2–10.3	>10.3
Zinc (ppm)	<18.4	18.4–21.3	21.3–26.9	26.9–31.3	>31.3
Fruits yield (kg tree^{1})	<19.6	19.6–32.4	32.4–56.1	56.1–72.9	>72.9

lime, respectively (Srivastava, Singh, and Albrigo 2008). While, Gallasch and Pfeiler (1988) developed a comprehensive leaf nutrient standard for Riverland district of Victoria and Sunraysia districts of New South Wales (Australia), which suggested optimum limit comprising of 2.4–2.7% N, 0.14–0.17% P, 0.70–1.49% K, 50–129 ppm Fe, 6–15 ppm Cu, and 25–60 Zn ppm. These limits turned out to be different in China, suggesting optimum values measuring 3.0–3.5% N, 0.15–0.18% P, 1.0–1.6% K, 2.5–5.0% Ca, 0.30–0.60% Mg, 50–120 ppm Fe, 25–100 ppm Mn, 4–100 ppm Cu, and 25–100 ppm Zn for Satsuma mandarin grown on quaternary red earth (Alfisols) using 3rd leaf from vegetative terminals (Wang 1985). On the other hand, different leaf nutrient standards have been suggested for citrus belts (concentrated in seven provinces) of contrasting climates (the cool and warm regions separately) and fruit sizes (small and large) in South Africa (Plessis and Koen 1992). These observations further advocated for the use of leaf nutrient standards of varying dimensions to take into account the regional differences in climate and soil-site characteristics (Srivastava, Singh, and Albrigo 2008).

The difficulty in producing uniform leaf nutrient norms that would cover the range of orchard conditions throughout region, state, or district or even as province is, therefore, increasingly realized, because few orchards are established on replant sites having preferential accumulation of some nutrients, and others are on virgin soils of typical low soil fertility (Hanlon et al. 2012). It remains to be seen that the diagnostic norms derived from specific index leaves and orchards, categorized into deficient or optimum in different nutrients on the basis of nutrient concentration, has the same utility to that of norms developed through leaves sampled at other crop developmental stages (leaving the index sampling period) in order to make DRIS a more flexible monitoring tool without affecting the production at any stage of crop (Srivastava and Singh 2008). Irrespective of such physiographical divergence, DRIS norms developed in one specific region, if applied to another region, the elemental composition of high-yielding orchards need to be nearly identical with skewness free normal distribution of data according to Gualiya and Zonn (1990).

Soil fertility indexing

A soil test becomes the first step in any nutrient best treatment practice development, implementation, and monitoring activity (Mylavarapu 2010). Use of DRIS with soil data provides an advantage of taking into account the nutrient balance and ranking nutrients in terms of abundance relative to optimal levels (Bhargava 2002). Optimizing soil fertility has slowly emerged as a new field of investigation which ensures maximum yield under a wide range of soil conditions (Srivastava and Singh 2002). The range of values for different soil fertility test values between low-yielding and high-yielding orchards was observed (Table 3). The soil test values in low-yielding orchards were observed as 92.83 mg kg^{-1} $KMnO_4$-N (12.33% CV), 6.48% Olsen-P (18.41% CV), 89.27 mg kg^{-1} NH_4OAc-K (22.10% CV), 126.91 mg kg^{-1} NH_4OAc-Ca (19.32% CV), 41.30 mg kg^{-1} NH_4OAc-Mg (17.10% CV), 3.10 mg kg^{-1} DTPA-Fe (17.92% CV), 1.29 mg kg^{-1} DTPA-Mn (11.32% CV), 0.30 mg kg^{-1} DTPA-Cu (8.20% CV), and 0.48 mg kg^{-1} DTPA-Zn (24.32% CV) with 20.30 kg tree^{-1} fruit yield (17.18% CV). These values were contrastingly different in high-yielding orchards reading as 128.14 mg kg^{-1} $KMnO_4$-N (19.21% CV), 12.82 mg kg^{-1} Olsen-P (14.20% CV), 130.91 mg kg^{-1} NH_4OAc-K (18.41% CV), 212.42 mg kg^{-1} NH_4OAc-Ca (9.23%

Table 3. Mean soil test values between low- and high-yielding "Kinnow" mandarin orchards of northwest India.

Soil available nutrients (mg kg^{-1})	Low-yielding orchards (A) (n = 10)			High-yielding orchards (B) (n = 16)			
	$\bar{X}$	CV (%)	S_A	$\bar{X}$	CV (%)	S_B	S_A/S_B*
$KMnO_4$-N	92.83	12.33	14.38	128.14	19.21	24.30	0.60
Olsen-P	6.48	18.41	8.20	12.82	14.20	17.39	0.47
NH_4OAc-K	89.27	22.10	16.69	130.91	18.41	46.31	0.36
NH_4OAc-Ca	126.91	19.32	6.81	212.42	9.23	10.32	0.66
NH_4OAc-Mg	41.30	17.10	11.20	76.18	11.23	20.11	0.55
DTPA-Fe	3.10	17.92	9.32	14.21	21.32	21.32	0.44
DTPA-Mn	1.29	11.32	14.20	7.30	16.42	29.31	0.48
DTPA-Cu	0.30	8.20	9.23	0.82	11.49	20.23	0.46
DTPA-Zn	0.48	29.32	16.40	0.80	20.32	28.10	0.58
Fruit yield (kg $tree^{-1}$)	20.30	17.18	9.32	68.21	21.32	15.89	0.59

*Variance of low-yielding and high-yielding orchards population was significantly different (p = 0.01).
$\bar{X}$ and CV stand for mean and coefficient of variation, respectively.
S_A and S_B stand for variance of low- and high-yielding orchards, respectively.

CV), 76.18 mg kg^{-1} NH_4OAc-Mg (11.23% CV), 14.21 mg kg^{-1} DTPA-Fe (14.21% CV), 7.30 mg kg^{-1} DTPA-Mn (7.30% CV), 0.82 mg kg^{-1} DTPA-Cu (11.41% CV), and 0.80 mg kg^{-1} DTPA-Zn (20.32% CV) for the fruit yield of 68.21 kg $tree^{-1}$ (21.32% CV).

DRIS-based soil available nutrient norms suggested the optimum values of $KMnO_4$-N 114.3–121.2 mg kg^{-1}, Olsen-P 7.8–12.3 mg kg^{-1}, NH_4OAc-K 96.4–31.3 mg kg^{-1}, NH_4OAc-Ca 189.4–248.6 mg kg-$^{-1}$, NH_4OAc-Mg 72.3–89.6 mg kg^{-1}, DTPA-Fe 5.8–11.1 mg kg^{-1}, DTPA-Mn 4.3–6.9 mg kg^{-1}, DTPA-Cu 0.45–0.69 mg kg^{-1}, and DTPA-Zn 0.62–0.78 mg kg^{-1} in relation to optimum fruit yield of 32.0–56.2 kg $tree^{-1}$. These values at much higher fruit yield level of 56.2–72.3 kg $tree^{-1}$ as high yield, a different soil test values would be required to be maintained. These values comprise of: 121.2–141.6 mg kg^{-1} $KMnO_4$-N, 12.3–16.3 mg kg^{-1} Olsen-P, 131.3–169.4 mg kg^{-1} NH_4OAc-K, 248.1–380.4 mg kg^{-1} NH_4OAc-Ca, 89.6–112.3 mg kg^{-1} NH_4OAc-Mg, 11.1–16.9 mg kg^{-1} DTPA-Fe, 6.9–9.2 mg kg^{-1} DTPA-Mn, 0.69–1.84 mg kg^{-1} DTPA-Cu, and 0.78–0.92 mg kg^{-1} DTPA-Zn (Table 4). A soil testing program, thus, can identify areas which are either under- or over-fertilized to enable more efficient use of fertilizers. Of late, soil test-based fertilizer recommendations on "Nagpur" mandarin using geocoded soil sampling-based spatial variogram was suggested (Srivastava et al. 2014) to make soil testing more practical, reliable, and predictive in perennial crops. Mylavarapu (2010) reported nutrient loss assessment tools such as Florida phosphorus index and bahia (*Paspalum notatum*) and citrus (Citrus spp.) tests for P are not being made possible in Florida through integration of soil and tissue testing methods.

Nutrient constraints and their frequency distribution

"Kinnow" mandarin is considered highly nutrient responsive citrus cultivar. The range of nutrient deficiencies such as Zn, Fe, Mn, N, and P due to their negative values in decreasing order (121→32) was observed (Table 5) through soil or leaf analysis-based DRIS indices. While, other nutrients viz., Cu, Ca, Mg, and K were observed in high to excess limit due to increasing positive indices (58→180). A large positive nutrient index (more negative an index, the more lacking is the nutrient) indicated the presence of corresponding nutrient in relatively excessive quantity. Using the progressive nutrient diagnosis, if the first limiting factor Zn is corrected by its supply, the next nutrient that will limit the yield is Fe. Further, if Zn and Fe are satisfied, the next limiting nutrient is Mn followed by N and P. Hence, various nutrients in the order of decreasing influence on fruit yield were rated as Zn< Fe < Mn < N < P < Cu < Ca < Mg < K.

Worldwide, Zn is claimed to be the single-most frequently limiting nutrient impairing with the sustainable citrus production (Srivastava and Singh 2004). These nutrient constraints laid the basis for fertilization to maximize the yield and subsequently verify the ability of DRIS indices in identifying the nutritional problems existing actually under the field conditions. The frequency

Table 4. Soil fertility norms (derived from DRIS based analysis) for "Kinnow" mandarin grown in northwest India.

Available nutrients	DRIS norms				
	Deficient*	Low	Optimum	High	Excess**
$KMnO_4$-N (mg kg^{-1})	<92.1	92.1–114.3	114.3–121.2	121.2–141.6	>141.6
Olsen-P (mg kg^{-1})	<2.8	2.8–7.8	7.8–12.3	12.3–16.3	>16.3
NH_4OAc-K (mg kg^{-1})	<72.3	72.3–96.4	96.4–131.3	131.3–169.4	>169.4
NH_4OAc-Ca (mg kg^{1})	<124.3	124.3–189.4	189.4–248.6	248.6–380.4	>380.4
NH_4OAc-Mg(mgkg^{1})	< 34.1	34.1–72.3	72.3–89.6	89.6–112.3	>112.3
DTPA-Fe (mg kg^{-1})	<2.4	2.4–5.8	5.8–11.1	11.1–16.9	>16.9
DTPA-Mn (mg kg^{-1})	<1.20	1.20–4.3	4.3–6.9	6.9–9.2	>9.2
DTPA-Cu (mg kg^{-1})	<0.16	0.16–0.45	0.45–0.69	0.69–1.84	>0.84
DTPA-Zn (mg kg^{-1})	<0.32	0.32–0.62	0.62–0.78	0.78–0.92	>0.92
Fruits yield (kg $tree^{1}$)	<19.6	19.6–32.8	32.4–56.1	56.1–72.3	>72.3

*Very low, ** Very high.

Table 5. Soil fertility constraints in "Kinnow" mandarin orchards of northwest India.

	Nutrients found deficient and low (*n* = 10)					Nutrients found high and excess (*n* = 16)			
"Kinnow" mandarin (*n* = 26)	Zn	Fe	Mn	N	P	Cu	Ca	Mg	K
Soil analysis-based constraints									
Concentration (mg kg^{-1})	0.48	2.6	3.2	96.2	3.9	1.12	312.3	91.3	162.7
DRIS indices	−121	−110	−82	−62	−32	56	61	110	180
Leaf analysis-based constraints									
Concentrations	16.41	18.01	16.72	1.58	0.07	3.69	0.89	10.10	1.73
DRIS indices	−161	−140	−82	−70	−58	71	90	148	212

Higher is the value of negative indices, higher is the magnitude of nutrient deficiency and vice versa.

distribution of soil fertility constraints were diagnosed (Table 6) which revealed 61.2% orchards were deficient in DTPA-Zn followed by 52.2% orchards deficient in DTPA-Fe, 48.3% orchards deficient in DTPA-Mn, 41.2% orchards deficient in $KMnO_4$-N, and 35.6% orchards deficient in Olsen-P. On the other hand, 74.4% orchards displayed optimum level of NH_4OAc-K followed by 62.3% orchards optimum in DTPA-Cu, 58.4% orchards optimum in NH_4OAc-Ca, 54.3% orchards optimum in Olsen-P, 52.4% orchards optimum in NH_4OAc-Mg, and 44.6% orchards optimum in $KMnO_4$-N. Leaf analysis-based diagnosis of nutrient constraints revealed almost similar results. Zinc (64.7%) was observed to be the most deficient nutrient followed by Fe (61.5%), Mn (57.6%), N (46.1%), P (38.5%), and K (15.4%) DRIS norms computed from 471 sets of data on leaf mineral composition and corresponding fruit yield collected from 87 "Kinnow" fruit orchards of submontaneous areas of northwest India showed deficiency symptoms of nutrients like N, P, K, Zn, Co, and Mn which could form the basis of formulating fertilizer recommendation in "Kinnow" mandarin (Hundal and Arora 2001). Singh Vinay and Tripathi (1985) observed large-scale Zn deficiency in "Kinnow" mandarin orchards established on old alluvial plains of Indogangetic plains (Typic Ustochrepts) and suggested critical limit of leaf Zn content as 20 ppm for delineating the healthy orchards from declining chlorotic orchards.

The frequency distribution of nutrient constraints as diagnosed through DRIS-based plant–soil nutrient diagnostics demonstrated a good complementarily between leaf nutrient composition and available nutrients in soil with reference to nutrients like N ($r = 0.624$, $p = 0.01$), P ($r = 0.412$, $p = 0.01$), K ($r = 0.212$, $p = 0.05$), Ca ($r = 0.123$, non-significant), Mg ($r = 0.181$, non-significant), Fe ($r = 0.416$, $p = 0.01$), Mn ($r = 0.512$, $p = 0.01$), Cu ($r = 0.458$, $p = 0.01$), and Zn ($r = 0.583$, $p = 0.01$). The earlier studies have shown that nutritional problems of citrus orchards are better identified with the combined use of leaf and soil analysis than either of the two alone (Jorgensen and Price 1978; Srivastava et al. 2001). The nutrient Zn was estimated low to deficient (63.4–72.8%) followed by N (52.3–66.3%), K (28.3–35.3%), P (28.1–31.3%), and Fe (28.2–29.8%) irrespective of test methods used.

Table 6. Frequency distribution of nutrient constraints (expressed in % distribution) in "Kinnow" mandarin orchards of northwest India.

	Percentage frequency distribution				
Nutrients	Deficient	Low	Optimum	High	Excess
Soil analysis-based constraints					
$KMnO_4$-N	41.2	14.2	44.6	–	–
Olsen-P	35.6	10.1	54.3	–	–
NH_4OAc-K	10.2	15.4	74.4	–	–
NH_4OAc-Ca	10.2	10.2	58.4	21.2	–
NH_4OAc-Mg	14.2	5.8	52.4	27.6	–
DTPA-Fe	52.2	11.4	36.4	–	–
DTPA-Mn	48.3	10.9	40.8	–	–
DTPA-Cu	10.2	12.3	62.3	15.2	–
DTPA-Zn	61.2	14.3	21.1	3.4	–
Leaf analysis-based constraints					
Total N	46.1	15.3	38.6	–	–
Total P	38.5	19.2	42.3	–	–
Total K	15.4	19.3	53.8	11.5	–
Total Ca	–	–	84.6	15.4	–
Total Mg	–	–	76.9	23.1	–
Total Fe	61.5	15.4	23.1	–	–
Total Mn	57.6	23.1	19.3	–	–
Total Cu	7.6	11.5	73.1	7.8	–
Total Zn	64.7	23.8	11.5	–	–

Funding

The authors are thankful to All India Research Project on Tropical Fruits, Indian Council of Agricultural Research, New Delhi, for financial help for conducting this project.

References

Srivastava, A K, and S. Singh. 2006. Citrus nutrition and biochemical markers. *Journal of Plant Nutrition* 29:827–55. doi:10.1080/01904160600651688.

Srivastava, A K, and S. Singh. 2008. DRIS norms and their field evaluation in Nagpur Mandarin (Citrus reticulata Blanco). *Journal of Plant Nutrition* 31:1091–107. doi:10.1080/01904160802115359.

Bar-Akiva, A. 1965. Pentose accumulation and peroxidase activity in manganese deficient and normal citrus leaves. *Phyton Journal* 22:131–36.

Bataglia, O. C. 1989. DRIS-Citros: Uma alternativa pera avaliar a nutrição das plantas. *Laranja* 10:565–76.

Beaufils, E. R. 1973. *Diagnosis and recommendation integrated system (DRIS)*. South Africa: Soil Science Bulletin I. Univ. of Natal, Pietermaritzburg.

Beverly, R. B. 1987. Modified DRIS method for simplified nutrient diagnosis of valencia oranges. *Journal of Plant Nutrition* 10:1401–08. doi:10.1080/01904168709363672.

Beverly, R. B., J. C. Stark, J. C. Ojala, and T. W. Embleton. 1984. Nutrient diagnosis of valencia oranges by DRIS. *American Society for Horticultural Science* 109:649–54.

Bhargava, B. S. 2002. Leaf analysis for nutrient diagnosis, recommendation and management in fruit crops. *Journal of the Indian Society of Soil Science* 50:352–73.

Chapman, H. D. 1964. Suggested foliar sampling and handling techniques for determining the nutrient status of some field, horticultural and planting crops. *Indian Journal of Horticulture* 21:97–119.

Chapman, H. D., and P. F. Pratt. 1961. *Methods of analysis for soil, plant and water*, 182–86. Berkley, USA: Division of Agricultural Science, University of California.

Dhatt, A. S., G. P. S. Grewal, B. S. Chahill, and D. Dhillon. 1992. Removal of NPK by Kinnow mandarin and umran ber. *Acta Horticulturae* 321:541–44.

Embleton, T. W., W. W. Jones, C. K. Labanauskas, and W. Reuther. 1973. Leaf analysis as a diagnostic tool and guide to fertilization. In *The Citrus Industry Rev*, ed. W. Reuther, Vol. 1, 183–210. Berkeley, CA, USA: Div. Agri. Sci.

Gallasch, P. T., G. S. Dalton, and J. Ziersch. 1984. The use of juice analysis to define fertilizer requirements of citrus. In *Proceedings of the International Society of Citriculture*, Vol. 2, eds. W. Heitor, C. Studart Montenegro, and S. Moreira, 140–42. Sao Paulo, Brazil. July 15–20. Sao Paulo, Brazil: International Society of Citriculture, Escola Superior de Agricultura Luiz de Queiroz.

Gallasch, P. T., and G. R. Pfeiler. 1988. Developing a unique leaf analysis service, including a computer programme. In *Proceedings of 6th International Citrus Congress*, ed. R. Goren, and K. Mendel, Vol. 2, 689–97. Rehovot, Israel: International Society of Citriculture, Balaban Publications.

Ghosh, S. P., and R. B. Singh, ed. 1993. *Citrus in South Asia*, 21. Bangkok, Thailand: RAPA Publication, FAO, Regional Office Bangkok.

Gualiya, M. V., and S. V. Zonn. 1990. Genetic differences and productivity of red and yellow earths in relation to relief. *Soviet Soil Science* 22:16–27.

Gururani, A. K., and R. Singh. 1983. Variation in mineral composition of leaves from different flushes of Kinnow mandarin under Tarai conditions. *Punjab Horticultural Journal* 23:141–48.

Hanlon, E. A., K. T. Morgan, T. A. Obreza, and R. Mylavarapu. 2012. Leaf analysis in citrus: Developments in analytical techniques. In *Advances in citrus nutrition*, ed. A. K. Srivastava, 81–87. The Netherlands: Springer Verlag.

Hernandez, J. 1988. Results of leaf analysis for nitrogen in citrus. *Cultivos Tropicales* 10 (2):92–94.

Hundal, H. S., and C. L. Arora. 2001. Diagnosis and recommendation integrated system (DRIS) approach for diagnosing the nutrient status of Kinnow fruit trees. *Indian Society of Soil Science* 49:703–9.

Jorgensen, K. R., and G. H. Price. 1978. The citrus leaf and soil analysis system in Queensland. In *Proceedings of the International Society of Citriculture*, Vol. 1, ed. P. R. Cary, 297–99. Sydney, Australia. August 15–23. Sydney, Australia: International Society of Citriculture, University of Sydney.

Li, J. L., X. X. Li, J. C. Peng, and G. Q. Zhuang. 1999. Effect of five mineral elements on nutritional status of navel orange tree. *Journal Hunan Agricultural University* 25:36–39.

Lindsay, W. L., and W. A. Norvell. 1978. Development of DTPA Test for Zinc, Iron, Manganese and Copper. *Soil Science Society of America Journal* 42:421–28. doi:10.2136/sssaj1978.03615995004200030009x.

Malavolta, E., S. A. Oliveika, and G. C. Vitti 1993. The use of diagnosis recommendation integrated system (DRIS) to evaluate the nutritional status of healthy and blight affected citrus trees. In *Proceedings of 8th International Colloquium of optimization plant nutrition*, eds. M. A. C. Fragosa, and M. L. Van Beusichem, 157–59. August 31–September 8, 1992. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Manivannan, S., and K. L. Chadha. 2011. Standardization of time of sampling for leaf nutrient diagnosis on Kinnow mandarin in North-West India. *Journal of Plant Nutrition* 34:1820–27. doi:10.1080/01904167.2011.600409.

Moss, G. I., and M. L. Higgins. 1978. Analysis of orange juice for mineral content as a diagnostic tool to fertilizer practice with special reference to fruit juice quality. In *Proceedings of International Society of citriculture*, ed. P. R. Cary, 300–2. Sydney, Australia. August15–23. Sydney, Australia: International Society of Citriculture, University of Sydney.

Mylavarapu, R. S. 2010. Diagnostic nutrient testing. *HortTechnology* 20 (1):19–22.

Page, A. L., R. H. Miller, and D. R. Keeney. 1982. *Methods of soil analysis, Part 2*, 159–64. Madison, Wisconsin, USA: American Society of Agronomy and Soil Science Society of America.

Pestana, M., C. P J, A. De Varennes, J. Abadia, and E. A. Faria. 2007. The use of floral analysis to diagnose the nutritional status of orange trees. *Journal of Plant Nutrition* 24:1913–1323. doi:10.1081/PLN-00107603.

Plessis, D. S. F. 1977. Soil analysis as a necessary complement to leaf analysis for fertilizer advisory purposes. In *Proceedings of International Society of citriculture* Vol. 1, ed. W. Grierson, 15–19. Orlando, Florida, USA. May 1–8. Orlando, FL: International Society of Citriculture, University of Florida.

Plessis, D. S. F., and T. J. Koen. 1992. Leaf analysis norms. In *Proceedings of Seventh International Citrus Congress*, ed. E. Tribulato, A. Gentile, and G. Refergiato, Vol. 2, 551–52. Acireale, Italy: International Society of Citriculture.

Rangaswamy, R. A. 1995. *Text Book of Agricultural Statistics*, 142–201. New Delhi, India: Wiley Eastern Limited.

Singh Vinay, and B. R. Tripathi. 1985. Studies on chlorosis in sweet orange in Agra region of Uttar Pradesh. *Journal of the Indian Society of Soil Science* 33:333–38.

Srivastava, A. K. 2013a. Nutrient deficiency symptomology in citrus: An effective diagnostic tool or just an aid for post–mortem analysis. *Journal of Agricultural Science* 2:177–94.

Srivastava, A. K. 2013b. Nutrient diagnostics in citrus: Are they applicable to current season crop. *Agrotechnology* 2:2. e104. doi:10.4172/2168-9881.1000e104.

Srivastava, A. K. 2013c. Early warning system for plant nutrient deficiency: Future toolbox. *Agrotechnology* 2:3. doi:10.4172/2168-9881.1000e106.

Srivastava, A. K., S. N. Das, S. K. Malhotra, and K. Majumdar. 2014. SSNM-based rationale of fertilizer use in perennial crops: A review. *Indian Journal of Agricultural Sciences* 84:3–17.

Srivastava, A. K., R. R. Kohli, H. C. Dass, A. D. Huchche, and L. Ram. 1999. Evaluation of the nutritional status of Nagpur mandarin (*Citrus reticulata* Blanco) by foliar sampling. *Tropical Agriculture (Trinidad)* 72:93–98.

Srivastava, A. K., and S. K. Malhotra. 2014. Nutrient management in fruit crops: Issues and strategies. *Indian Journal of Fertilisers* 10:72–88.

Srivastava, A. K., and P. Prakash. 2014. Fertility indexing for acid lime growing smectite soils. *Annals of Plant and Soil Research* 16:25–28.

Srivastava, A. K., S. Shyam, H. A D, and L. Ram. 2001. Yield based leaf and soil test interpretations for Nagpur mandarin in central India. *Communications in Soil Science and Plant Analysis USA* 32:585–99. doi:10.1081/CSS-100103030.

Srivastava, A. K., and S. Singh. 2002. Soil analysis based diagnostic norms for Indian citrus cultivars. *Communications in Soil Science and Plant Analysis* 33:1689–706. doi:10.1081/CSS-120004816.

Srivastava, A. K., and S. Singh. 2004. Zinc nutrition, a global concern for sustainable citrus production. *Journal of Sustainable Agriculture and the Environment* 25:1–20.

Srivastava, A. K., and S. Singh. 2005. Diagnosis of nutrient constraints in citrus orchards of humid tropical India. *Journal of Plant Nutrition* 29:1061–76. doi:10.1080/01904160600689183.

Srivastava, A. K., S. Singh, and L. G. Albrigo. 2008. Diagnosis and remediation of nutrient constraints in citrus. *Horticultural Reviews* 34:277–363.

Srivastava, A. K., S. Singh, V. S. Diware, and H. Singh. 2009. Site specific nutrient management in 'Mosambi' sweet orange. *Better Crops–India* 3:10–11.

Subbiah, B. V., and G. L. Asiza. 1956. A rapid procedure for determination of available nitrogen in soils. *Current Science* 25:259–60.

Sumner, M. E. 1977. Use of the DRIS system in foliar diagnosis of crops at high yield levels. *Communications in Soil Science and Plant Analysis* 6:269–80. doi:10.1080/00103627709366719.

Varalaxmi, L. R., and B. S. Bhargava. 1998. Plant nutrient status and leaf diagnostic norms for acid lime (*Citrus aurantifolia*). *Indian Journal of Agricultural Sciences* 68:375–76.

Walworth, J. L., and M. W. Sumner. 1987. The diagnosis and recommendation integrated system (DRIS). *Advances in Soil Science* 6:150–88.

Wang, T. 1985. Application of fertilizers to Satsuma based on leaf analysis. *Journal of Soil Science, (Turang Tongbo)* 16:275–77.