Diagnostic Tools for Citrus: Their Use and Implications in India

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Constraint-based fertiliser scheduling is best achieved through using leaf nutrient DRIS indices supported by soil analysis and characteristic symptoms of nutrient deficiencies. A survey of citrus sites found multiple nutrient deficiencies – the most common being N, P, K, Mn, and Zn. Variations in soil types play an important role in regulating both production and quality. SSNM proved effective in achieving for high quality citrus production.

In India, citrus research to date has had little success in identifying cultivar-specific soil or plant nutrient diagnostics which can detect and monitor untimely declines in orchard longevity and productivity. Various diagnostic techniques – such as visual symptoms, leaf analysis, and soil testing – hold great importance in defining SSNM techniques that can be integrated into improved citrus fertilisation programs. Leaf nutrient standards developed in a number of countries (U.S.A., Brazil, Australia, etc.) and applied under Indian conditions have yet to provide a precise means to streamline citrus nutritional problems. This could be related to differences in cultivar nutrient requirement, growth habit, existing cultural practices, soil type variation, climate, and yield levels.

The absence of suitable diagnostic references has resulted in misinterpretation and diagnosis of nutritional problems within citrus orchards, improper fertilisation schedules, and reduced orchard productivity. Thus, existing diagnostics are failing to identify the real problems for commercial Indian citrus cultivars and are proving ineffective. This article highlights recent experiences in India to develop suitable diagnostic tools as part of more meaningful decision support systems.

Deficiency Symptoms

The development of visible symptoms is attributed to metabolic disorders which cause changes in micro-morphology of plants before the characteristic deficiency is identifiable. The way in which the symptoms develop and manifest on leaves or fruits gives a reliable indication of the cause of the nutritional disorders. Both deficiency and excess of nutrients can lead to reduced crop yield with inferior fruit quality. To view images of various nutrient conditions in citrus, visit the website at: **www.ipni.net/india/citrus**.

Abbreviations and notes for this article: DRIS = Diagnosis and Recommendation Integrated System; SSNM = site-specific nutrient management; N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; S = sulphur; Fe = iron; Mn = manganese; Cu = copper; Zn = zinc; C = carbon; B = boron; Mo = molybdenum; TSS = total soluble solids.

Table 1. Leaf nutrient indices for different commercial citrus cultivars of India.

	Indices				
	Deficient	Low	Optimum	High	Excess
'Nagpur' Mandarin (*Citrus reticulata* Blanco)					
N, %	< 1.1	1.1 - 1.7	1.7 - 2.8	2.8 - 3.4	> 3.4
P, %	< 0.06	0.06 - 0.08	0.08 - 0.15	0.15 - 0.19	> 0.19
K, %	< 0.22	0.22 - 1.01	1.01 - 2.59	2.59 - 3.38	> 3.38
Ca, %	< 1.1	1.1 - 1.79	1.79 - 3.28	3.28 - 4.02	> 4.02
Mg, %	< 0.31	0.31 - 0.42	0.42 - 0.92	0.92 - 1.38	> 1.38
Fe, ppm	< 55	55 - 75	75 - 113	113 - 133	> 133
Mn, ppm	< 40	40 - 55	55 - 85	85 - 99	> 99
Cu, ppm	< 5.9	5.9 - 9.7	9.8 - 18	18 - 22	> 22
Zn, ppm	< 5.5	5.5 – 14	14 - 30	30 - 38	> 38
Yield, kg/tree	< 13	13 - 48	48 - 117	117 - 152	> 152
'Mosambi' Sweet orange (*Citrus sinensis* Osbeck)					
N, %	< 1.28	1.28 - 1.97	1.97 - 2.57	2.57 - 2.68	> 2.68
P, %	< 0.05	0.05 - 0.09	0.09 - 0.17	0.17 - 0.21	> 0.21
K, %	< 1.12	1.12 - 1.32	1.32 - 1.72	1.72 - 1.92	> 1.92
Ca, %	< 1.09	1.09 - 1.72	1.72 - 2.98	2.98 - 3.62	> 3.62
Mg, %	< 0.13	0.13 - 0.31	0.31 - 0.69	0.69 - 0.87	> 0.87
Fe, mg/kg	< 26	26 - 69	69 - 137	137 - 200	> 200
Mn, mg/kg	< 30	30 - 42	42 - 87	87 - 160	> 160
Cu, mg/kg	< 2.0	2.0 - 6.5	6.5 - 16	16 - 20	> 20
Zn, mg/kg	< 9.0	9.0 - 12	12 - 29	29 - 37	> 37
B, mg/kg	< 7.8	7.8 - 13	13 - 23	23 - 44	> 44
Mo, mg/kg	< 0.3	0.3 - 0.4	0.4 - 1.1	1.1 - 1.5	> 1.5
Yield, kg/tree	< 46	46 - 76	76 - 138	138 - 168	> 168
'Khasi' Mandarin (*Citrus reticulata* Blanco)					
N, %	< 1.67	1.67 - 1.96	1.96 - 2.56	2.56 - 2.85	> 2.85
P, %	< 0.06	0.06 - 0.08	0.08 - 0.10	0.10 - 0.13	> 0.13
K, %	< 0.52	0.52 - 0.98	0.98 - 1.93	1.93 - 2.40	> 2.40
Ca, %	< 1.72	1.72 - 1.96	1.96 - 2.49	2.49 - 2.75	> 2.75
Mg, %	< 0.14	0.14 - 0.23	0.23 - 0.48	0.48 - 0.54	> 0.54
Fe, mg/kg	< 23	23 - 84	84 - 249	249 - 331	> 331
Mn, mg/kg	< 19	19 - 42	42 - 88	88 - 111	> 111
Cu, mg/kg	< 1.8	1.8 - 2.1	2.1 - 14	14 - 21	> 21
Zn, mg/kg	< 11	11 - 16	16 - 27	27 - 32	> 32
B, mg/kg	< 7.8	7.8 - 13	13 - 23	23 - 44	> 44
Mo, mg/kg	< 0.3	0.3 - 0.4	0.4 - 1.1	1.1 - 1.5	> 1.5
Yield, kg/tree	< 19	19 - 32	32 - 56	56 - 69	> 69

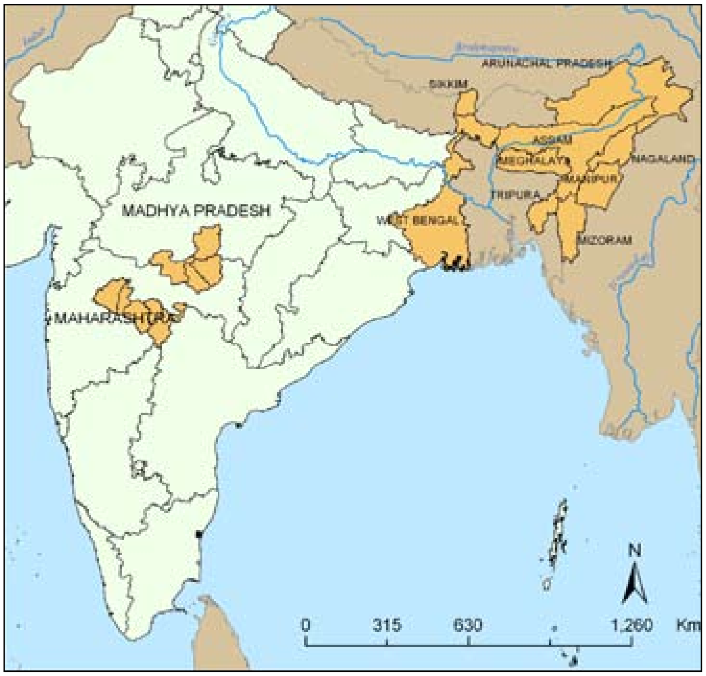

Figure 1. Citrus belts in India (shaded portion shows the areas of investigation).

Leaf Analysis

Leaf analysis integrates the effect of orchard soil and climate, and can be used with great advantage within a citrus fertilisation program. The development of leaf sampling technique is a pre-requisite to a reliable leaf nutrient standard. The accuracy of foliar analysis depends on proper attention to standardising leaf age under a given set of growing conditions, position of leaves on the terminal shoot, type of terminal shoot, and time of leaf sampling.

Leaf nutrient norms for different citrus cultivars are developed through a combination of surveys, modeling, field response studies, and adoption of techniques and schedules implemented by elite orchards. This study employed a survey during 2002-05 of 11 citrus orchard-growing states including 55 sites in the north-eastern states of West Bengal, Sikkim, Arunachal Pradesh, Tripura, Mizoram, Nagaland, Manipur, Meghalaya, and Assam; and in west-central India, seven sites within the Chindwara District of Madhya Pradesh, plus 79 sites within Nagpur, Amravati, Aurangabad, Jalna, Parbhani, and Nanded of Maharashtra (**Figure 1**). The most important orchard selection criterion was orchard age within peak production efficiency. This varied from 15 to 25 years for 'Khasi' mandarin sites in northeast India to 12 to 20 years for 'Nagpur' mandarin sites in central India. The orchards were further selected to represent low, optimum, and high performance orchards within the representative physiographic positions of both citrus regions.

The climate in northeast India (mostly humid in nature) is characterised by a mean annual rainfall of 180 cm with mean summer and winter temperature varying from 25 to 33 ºC and 10 to 25 ºC, respectively. Central India has a hot, sub-humid tropical climate, characterised by hot and dry pre-monsoon summer months (March to May), followed by the well-expressed monsoon months of June to September. Mean summer and winter temperatures vary from 35 to 45 ºC and 15 to 22 ºC, respectively. Mean annual rainfall is 900 mm, of which 80 to 90% is received during the monsoon months. The soils of the northeast sites belong to the Alfisol and Ultisol orders and soils in the west-central region are mainly Vertisols.

The DRIS model was used for determining leaf nutrient norms. Results found a large variation in leaf nutrient standard values depending upon the type of cultivar (**Table 1**).

Examples of most suitable sampling of index leaves were observed at 6 to 8 months of leaf age during the Ambia flush (February bloom) on Typic Haplustert soils (deep black soil), and 5 to 7 months during the Mrig flush (July bloom) on Typic Ustochrept soils (shallow red soil). An appraisal of nutrient composition of 6 to 8-month-old leaves collected at the 2nd, 3rd, and 4th leaf positions on a shoot found no significant variation in the concentration of N, P, K, Ca, Mg, S, Fe, Mn, Cu, and Zn. Thus, all the leaf positions were equally effective as indexes for determination of the nutrient status of tree. Generally, leaves from fruiting terminals had lower N, P, K, Zn, Cu, Mn, Fe, and B, but higher Ca and Mg than those sampled from non-fruiting terminals. The basis for sampling of leaves from non-fruiting terminals is that such shoots are more numerous, can be sampled easily, and are less subject to stress from fruit production. These non-fruiting shoots are also likely to bear fruits in the following year so their nutrient composition is of more immediate interest.

Many studies across the world have recommended appropriate leaf sample size as low as 40 leaves and as high as 100 leaves. This study's lack of variation in leaf macro- and micronutrient status while using a leaf sample size varying from 30 to 70 leaves covering

Table 2. Leaf nutrient constraints in citrus orchards of India.

Nagpur Mandarin	Nutrients found deficient and low (n = 27)					Nutrients found high and excess (n = 30)					Yield, kg/tree
	Zn	P	N	Fe	Cu	Mn	Mg	K	Ca		
Conc., mg/kg[1]	9.2	0.06	1.56	68.3	19.2	91.6	0.92	2.62	3.34		32
DRIS indices	-166	-60	-28	-20	16	42	55	63	98		
Mosambi Sweet orange	Nutrients found deficient and low (n = 32)					Nutrients found high and excess (n = 28)					Yield, kg/tree
	N	Zn	K	P	Mg	B	Ca	Mo	Fe	Cu	
Conc., mg/kg[1]	1.28	9.1	1.14	0.08	0.70	28.2	3.01	1.1	138.1	18.1	39
DRIS indices	-185	-111	-82	-58	38	40	48	74	92	144	
Khasi Mandarin	Nutrients found deficient and low (n = 68)						Nutrients found high and excess (n = 40)				Yield, kg/tree
	Zn	P	Ca	N	Mg	Cu	K	Mn	Fe		
Conc., mg/kg[1]	10.5	0.06	1.66	1.60	0.18	1.9	–	–	–		22
DRIS indices	-201	-101	-91	-86	-78	-42	104	219	276		

[1]Values of N, P, K, Ca, and Mg are given in %.

Table 3. Soil fertility standards for different commercial citrus cultivars of India.

	Indices				
	Deficient	Low	Optimum	High	Excess
Nagpur Mandarin (*Citrus reticulata* Blanco)					
Organic C, g/kg	< 2.6	2.6 - 3.8	3.8 - 6.2	6.2 - 7.4	> 7.4
N, mg/kg	< 65	65 - 95	95 - 155	155 - 185	> 185
P, mg/kg	< 4.8	4.8 - 6.5	6.5 - 16	16 - 21	> 21
K, mg/kg	< 64	64 - 147	147 - 312	312 -395	> 395
Ca, mg/kg	< 306	306 - 408	408 - 616	616 - 718	> 718
Mg, mg/kg	< 43	43 - 85	85 - 163	163 - 203	> 203
Fe, mg/kg	< 4.6	4.6 -11	11 - 25	25 - 41	> 41
Mn, mg/kg	< 4.7	4.7 - 7.4	7.5 - 23	23 - 31	> 31
Cu, mg/kg	< 1.1	1.1 - 2.4	2.4 - 5.1	5.1 - 6.5	> 6.5
Zn, mg/kg	< 0.3	0.3 - 0.6	0.6 -1.3	1.3 -1.7	> 1.7
Yield, kg/tree	< 13	13 - 48	48 - 117	117 - 152	> 152
Mosambi Sweet Orange (*Citrus sinensis* Osbeck)					
Organic C, g/kg	< 3.0	3.0 - 4.9	4.9 - 6.9	7.0 - 8.2	> 8.2
N, mg/kg	< 62	62 - 107	107 - 197	197 - 242	> 242
P, mg/kg	< 4.9	4.9 - 8.5	8.5 - 16	16 - 20	> 20
K, mg/kg	< 85	85 - 186	186 - 389	389 - 491	> 491
Fe, mg/kg	< 1.6	1.6 - 4.7	4.7 - 17	17 - 24	> 24
Mn, mg/kg	< 3.7	3.7 - 7.6	7.6 - 16	16 - 20	> 20
Cu, mg/kg	< 0.3	0.3 - 1.8	1.8 - 4.7	4.7 - 6.2	> 6.2
Zn, mg/kg	< 0.1	0.1 - 0.4	0.4 - 1.0	1.0 - 1.3	> 1.3
B, mg/kg	< 0.2	0.2 - 0.3	0.3 - 0.6	0.6 - 0.7	> 0.7
Mo, mg/kg	< 0.05	0.05 - 0.1	0.1 - 0.16	0.17 - 0.19	> 0.2
Yield, kg/tree	< 46	46 - 76	77 - 138	138 - 168	>168
Khasi Mandarin (*Citrus reticulata* Blanco)					
Organic C, g/kg	< 8.6	8.6 - 15.6	15.6 - 32.5	32.5 - 50.2	> 50.2
N, mg/kg	< 82	82 - 161	161 - 419	419 - 548	> 548
P, mg/kg	< 2.3	2.3 - 4.4	4.5 - 8.7	8.8 - 11	> 11
K, mg/kg	< 20	20 - 82	82 - 288	288 - 390	> 390
Ca, mg/kg	< 80	80 - 149	149 - 285	285 - 354	> 354
Mg, mg/kg	< 4.7	4.7 - 31	31 - 84	84 - 111	> 111
Fe, mg/kg	< 31	31 - 39	39 - 181	181 - 252	> 252
Mn, mg/kg	< 8.9	8.9 - 27	27 - 80	80 - 116	> 116
Cu, mg/kg	< 0.5	0.5 - 0.7	0.7 - 2.9	2.9 - 4.1	> 4.1
Zn, mg/kg	< 2.2	2.2 - 2.8	2.8 - 5.1	5.1 - 8.7	> 8.7
Yield, kg/tree	< 19	19 - 31	31 - 56	56 - 69	> 69

2 to 10% of tree area validates the minimum in both cases, as an effective protocol for foliar analysis.

Data on proper height of sampling is also rather conflicting. However, the authors found that most positional effects can be avoided by ensuring that leaves are collected from around the entire periphery of the tree.

Multiple nutrient deficiencies were common to all orchards surveyed. Example plant sample data for Nagpur mandarin orchards found Zn, P, N, and Fe deficiencies (**Table 2**). Higher negative DRIS indices provide an indication of the proportionate scale of nutrient deficiency. Alternatively, a large positive index would be indicative of above optimal nutrient concentrations. Data from the group of sweet orange orchards indicated deficiencies for N, Zn, K, and P. The Khasi mandarin orchards had significant deficiencies for Zn, P, Ca, N, Mg, and Cu.

Soil Analysis

Soil analysis-based guidelines for this study were comprised of skirt belt sampling, or sampling at 0 to 15 cm depth around the tree perimeter (**Table 3**). The soil test method is based on the assumptions that roots would extract nutrients from the soil in a manner comparable to chemical soil extractants, and that there is a simple, direct relationship between the extractable concentration of nutrients in the soil and uptake by plants. Often, the analysis has to be significantly modified in relation to soil type, particularly for calcareous and non-calcareous soils, and recommendations require adjustment in relation to a targeted yield.

Comparative DRIS analysis of soil data determined a much wider range of index values among the different commercial citrus cultivars (**Table 4**). DRIS-based analysis of soil fertility data from Nagpur mandarin found deficiencies for N, organic C, Zn, P, Fe, and K. Thus, if the first limiting factor was met by adequate soil amendment with organic manures, the remaining deficiencies could be addressed with fertiliser. In sweet orange, shortages were noted for organic C, N, Zn, P, Mn, and K. In Khasi mandarin, orchards were deficient in P, Ca, N, Mg, and Zn.

Implications for Fruit Quality

Past studies have shown that quality of citrus fruit is governed by the nature and properties of soil. This relationship was verified in this study which found quite different fruit quality characteristics between the two dominant orchard soil types. Fruits from red soil types, especially those located at higher elevations, had characteristically tighter skins and better TSS levels than fruits harvested from orchards under deeper, black soil types. Data from Nagpur mandarin sites invariably showed better fruit quality characters, with the exception of fruit size, within red clay loam orchards compared to those from deeper black clay orchards (**Table 5**). This can be primarily related to differences in available water capacity and nutrient availability, particularly K. Water soluble K (24 to 53 mg/kg) and exchangeable K (188 to 291 mg/kg) were much higher in black soils than in red soils (i.e., water soluble K:3 to 13 mg/kg and exchangeable K:82 to 268 mg/kg) – the reverse being true for non-exchangeable K.

Higher availability of K coupled and good water holding capacity in black soils does provide for better hydration capacity of fruits, which is relatively weak in red soil sites and is a common reason for sub-optimum fruit size and a major limitation for Nagpur mandarin orchards located on red soils. Higher availability of K in black soils also induces higher fruit

Table 4. Soil fertility constraints in citrus orchards of India.

Nagpur Mandarin	Nutrients found deficient and low (n = 27)					Nutrients found high and excess (n = 30)					Yield, kg/tree
	Organic C	Zn	P	Fe	K	Mg	Ca	Cu	pH	Mn	
Conc., mg/kg[1]	3.2	0.31	5.0	4.8	143	172	678	5.8	7.9	22.8	32
DRIS indices	-116	-104	-98	-92	-52	61	72	81	108	155	
Mosambi Sweet Orange	**Nutrients found deficient and low (n = 32)**						**Nutrients found high and excess (n = 28)**				**Yield, kg/tree**
	Organic C	N	Zn	P	Mn	K	Fe	Cu	Mo	B	
Conc., mg/kg[1]	4.1	106.8	0.38	7.8	6.2	183	22.8	5.8	0.19	0.60	39
DRIS indices	-181	-106	-90	-72	-51	-21	61	89	162	209	
Khasi Mandarin	**Nutrients found deficient and low (n = 68)**					**Nutrients found high and excess (n = 40)**					**Yield, kg/tree**
	P	Ca	N	Mg	Zn	Org. C	K	Cu	Mn	Fe	
Conc., mg/kg[1]	3.1	78	152	4.7	2.1	38.6	289	0.9	91	249	22
DRIS indices	-110	-82	-78	-58	-49	58	62	70	78	109	

[1]Values of N, P, K, Ca, and Mg are given in % and Org. C in g/kg.

Table 5. Comparison of quality of Nagpur mandarin grown in two soil types (red versus black soil).

	Fruit quality parameters, %		
	Juice	TSS	Acidity
Red soil	43.2	10.8	0.64
Black soil	42.4	9.2	0.78
LSD (p = 0.05)	0.6	0.4	0.08

Table 6. SSNM fertiliser rates meeting targeted orchard productivity.

	Fruit yield, t/ha	SSNM application rate, g/tree						
		N	P	K	$ZnSO_4$	B (borax)	$FeSO_4$	$MnSO_4$
Red soil	14.7	1,200	600	600	300	100	300	300
Black soil	19.0	600	400	300	300	100	300	300

acidity (0.78%) compared to red soil (0.64%), impairs the fruit sugar conversion process, and hampers the formation of a desired TSS: acid ratio. As a consequence, fruit maturity under black soils is delayed compared to that under red soils. Such an implication can be compensated by comparatively longer on-the-tree life for fruits on black soil orchards, and can be very well exploited to adjust the time of fruit harvesting to suit market demand/supply trends.

Implications for Site-Specific Nutrient Management

Fertiliser rates traditionally considered as "optimum" are increasingly being proven to be suboptimal as they fail to match soil nutrient depletion rates and high crop productivity levels. Under such circumstances, SSNM operates as a systematic approach to rationalising fertiliser use under orchards of increased productivity.

The authors' experiments on SSNM in central India have shown wide differences in optimum fertilisation to match the targeted orchard productivity of 14.7 t/ha in shallow soil and 19 t/ha in deep soil (**Table 6**). SSNM will not only help tailor fertiliser applications for individual orchards but will begin to address a more complex problem of wide differences in fruit yield within orchards.

India has 320,000 ha of mandarin orchards presently producing 2.07 million metric tons of fruit annually. Although orchard productivity is highly variable within space and time, an average productivity per planted area of 6.5 t/ha is obviously low if compared to the international average of 30 to 35 t/ha. A major constraint is inadequate and imbalanced nutrient use. Proper diagnosis through soil and plant analysis and nutrient management in accordance with these diagnostic tools can improve crop productivity. BC-INDIA

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Note: A photo gallery of images showing nutrient deficiency symptoms in citrus is available at the IPNI India Programme website: **www.ipni.net/india/citrus**.