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Diagnosis and Recommendation Integrated System for Monitoring Nutrient Status of Mango Trees in Submountainous Area of Punjab, India

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Abstract: The Diagnosis and Recommendation Integrated System (DRIS) was used to identify nutrient status of mango fruit trees in Punjab, India. Standard norms established from the nutrient survey of mango fruit trees were 1.144, 0.126, 0.327, 2.587, 0.263, 0.141% for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S), and 15, 3.5, 145, 155, and 30 mg kg^{-1}, respectively, for zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), and boron (B) in dry matter. On the basis of DRIS indices, 16, 15, 12, 17, and 16% of total samples collected during nutrients survey of mango trees 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. DRIS-derived sufficiency ranges from nutrient indexing survey were 0.92–1.37, 0.08–0.16, 0.21–0.44, 1.71–3.47, 0.15–0.37, and 0.09–0.19% for N, P, K, Ca, Mg, and S and 11–19, 1–6, 63–227, 87–223, and 16–44 mg kg^{-1} for Zn, Cu, Fe, Mn, and B, respectively.

Keywords: DRIS, mango, nutrient element and sufficiency ranges

INTRODUCTION

Mango (*Mangifera indica* L.) is grown extensively in the northern part of India. In Punjab, it ranks next to kinnow and occupies an area of

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5.6 thousand hectares with production of 5.6 thousand tons. Very little attention is given to nutritional program of mango trees by the orchardists, and this could be a major factor contributing to lower fruit yield and quality in Punjab. Actually, fruit nutrition is complex, and detection of nutritional limitation to yield among a host of other factors is also a major constraint. Environmental or other biological factors are often particularly limiting and fluctuating yield are observed even when there is no nutritional problem. Sometimes yield responses in nutritional orchard trials are also inconsistent. For these reasons, determining nutritional status of fruit trees is usually difficult, expensive, and time-consuming. The most common standard technique for interpreting leaf tissues mineral status is to compare observed concentrations with critical concentration or ranges (reference values). Nutritional concentrations substantially lower or higher than reference values are associated with decline in tree growth or its yield and quality. The critical concentration concept evaluates only a single nutrient element deficiency or toxicity at a time and could reflect nutritional balance when ratios between elements are calculated. The Diagnosis and Recommendation Integrated System (DRIS) technique deals with nutrient concentration ratios, rather than individual nutrient levels to interpret leaf tissues analysis. It also provides a mean of simultaneously identification of imbalances, deficiencies, and excesses of nutrients and ranking them in the order of importance (Walworth and Sumner 1986). Previously, DRIS was found reliable in diagnosing nutrient requirement for sugarcane (Beaufils and Sumner 1976), brinjal (Raghhupathi and Bhargava 1999), potato (Sharma 1991), lychee (Hundal and Arora 1995; Hundal and Arora 1996), and for kinnow (Hundal and Arora 2001) and other crops. DRIS norms could be established from a large number of independent leaf tissues mineral composition and their corresponded yield for a particular fruit trees rather than conducting the time-consuming and expensive orchard trials traditionally. However, it is required that data follow normal distribution and that the population has average of yields from high to low. In the present investigation, DRIS was used for monitoring nutrients status of Mango fruit trees (*Mangifera indica* L.) in northern submountainous area of Punjab, northwest India. An attempt was also made to derive sufficiency ranges from nutrient indexing survey of mango fruit trees.

MATERIALS AND METHODS

Three hundred forty-six leaf samples were collected from 2nd and 3rd positions of inflorescence panicles at full-bloom stage in the month of April from different orchards in submountainous areas of Punjab. To study the effect of leaf position, leaf samples were also taken separately from 2nd and 3rd positions of inflorescence and non-inflorescence-bearing panicles. Leaf sampling was also done to collect leaf pairs from top toward the base of inflorescence-bearing terminals and their position was referred to as zero (bud), 1st, 2nd, 3rd, 4th, and 5th, respectively. At maturity, fruits were counted to record yield per tree. Soil samples from 0- to 30-, 30- to 60-, and 60- to 90-cm depth were also collected from the corresponding sites and were analyzed for various physicochemical characteristics.

The leaf samples were first washed with tap water while rubbing softly with hands to remove the dust and other contaminants if any and then rinsed in demineralized water acidified with HCl (0.01 *M*) before finally washing in demineralized water. After drying in hot air oven at 70°C to constant dry weight, the dried leaf samples were ground in a Wiley mill to pass through a 60-mesh stainless steel sieve. The ground leaf samples were digested in distilled concentrated nitric acid followed by H_2O_2 treatment. After digestion, the residue was brought to dryness and dissolved in 20% aqua regia solution (Jones 1984) and then analyzed simultaneously for P, K, Ca, Mg, S, Zn, Cu, Fe, Mn, and B on inductively coupled argon plasma atomic emission spectrophotometer (ICAP-AES). Nitrogen in dried leaf tissues was estimated on Technicon Auto analyzer after digesting in selenium dioxide–sulfuric acid mixture (Leece 1976).

The concentration of N, P, K, Ca, Mg, S, Zn, Cu, Fe, Mn, and B in leaf tissues and the corresponding fruit yields were used for establishing DRIS norms (reference values). The data were divided into two subpopulations on the basis of yield: subpopulation A in which fruit number lower than 300 per tree and subpopulation B in which fruit equal to or exceeded 300 per tree. Each nutrient element in leaf samples was expressed on the basis of concentration in dry matter. The mean values of 1.144, 0.126, 0.327, 2.587, 0.263, 0.141% for N, P, K, Ca, Mg, and S and 15, 3.50, 145, 155, and 30 mg kg^{-1} for Zn, Cu, Fe, Mn, and B, respectively, in leaf tissues of high-yield population were taken as the DRIS norms. These DRIS norms were than incorporated into a diagnostic computer DRISPB program (Letzsch and Sumner 1983) for calculating DRIS indices.

The sufficiency's range for leaf tissues of mango trees was also determined by DRIS technique. Actually, DRIS norms as reference values of each nutrient element obtained from mineral composition of leaf tissues of high yield population constituted the mean for sufficiency. The range of "sufficiency" is the value derived from the mean $-4/3 \times$ SD (standard deviation) to mean $+4/3 \times$ SD. The range of "low" was obtained by calculating to mean $-4/3 \times$ SD and the value below this was considered low. The value from excessive or toxic means $+4/3 \times$ SD to mean $+8/3 \times$ SD was taken as high, and the value above mean $+ 8/3 \times$ SD was considered as excessive and toxic.

RESULTS AND DISCUSSION

The soils of Punjab, northwest India are deep alluvium and illustrate varying degree of development due to different soil factors, such as climate and conditioned by topography over a period of time (Sidhu et al. 1995). The soils belong to four orders (Inceptisol, Entisol, Aridisol, and Alfisol). The subgroups of ustochrepts, camborthids, and ustifluvent are widely distributed in the area of Punjab. The surface soils are coarse loamy (52%) followed by fine loamy (32%) and sandy (12%). The soils are neutral to alkaline in pH from 6.30 to 8.40, with electrical conductivity 0.08–0.58 dSm^{-1} and generally deficient in organic carbon (0.05–0.66%). Available macronutrient status and depthwise physicochemical characteristics are listed in Table 1. The available Zn, Cu, Fe, and Mn determined by DTPA method (Lindsay and Norvell 1998) in the surface layer varied from 0.35 to 10.98, 0.37 to 3.10, 2.8 to 2.1, and 5 to 52 $mg\,kg^{-1}$ and with a mean value of 1.74, 1.17, 9.39, and 18 $mg\,kg^{-1}$ soil, respectively.

Elemental compositions of leaf tissues sampled from different locations related to inflorescence-bearing panicle differed from non-inflorescence-bearing panicle (Table 2). Therefore, the diagnosis of nutrient status of a particular element on the basis of optimum level may differ with position of leaf tissue sampled for analysis. However, DRIS indices computed from the mineral composition of leaf tissue collected from different panicles elucidate the consistent order for macro- or micronutrient requirement. On the basis of DRIS indices, P was the most required nutrient element among macronutrients. In micronutrients, consonance insufficiencies of Mn or B were observed, irrespective of panicle from where the leaf tissues were sampled. It is worthwhile to mention here that these orchards were not fertilized with macro- or micronutrient.

Table 1. Characteristics of soils under mango orchards in submountainous area of Punjab, northwest India

Soil characteristics	0–30 cm		30–60 cm		60–90 cm	
	Range	Mean	Range	Mean	Range	Mean
pH (1 : 2 ratio)	6.30–8.4	7.2	6.3–8.3	7.3	6.3–8.3	7.3
EC (dSm^{-1}) (1 : 2 ratio)	0.08–0.58	0.35	0.07–0.59	0.36	0.06–0.64	0.37
Organic carbon (%)	0.05–0.66	0.35	0.08–0.79	0.31	0.08–0.47	0.26
Amm.AC.K. ($mg\,kg^{-1}$)	42.5–200.0	86.5	37.5–132.5	74.5	27.5–122.5	68.7
Olsen's – P ($mg\,kg^{-1}$)	8.9–40.9	18.5	8.9–30.0	17.2	8.9–28.2	15.1
0.01M $CaCl_2$ S ($mg\,kg^{-1}$)	10–49.0	20.7	8.5–27.5	17.4	9.5–29.5	18.5
Available N ($mg\,kg^{-1}$)	27.8–160.0	104	57–184.9	100.9	57.0–132.8	92.9

Table 2. Leaf composition/DRIS indices of leaf sampled from florescence and non-inflorescence-bearing panicles of mango fruit trees collected from orchards at different location in simultaneous area of Punjab

Location/position of leaf sampled		Leaf composition/DRIS indices											Order of requirement	
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn (mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	B (mg kg^{-1})	Macronutrient	Micronutrient
Budabarh	A	1.62	0.113	0.372	1.149	0.146	0.076	10	3.24	236	154	14	P > K > N>	B > Zn >
(Hoshiarpur)	B	1.46	0.104	0.376	1.175	0.116	0.069	9.76	2.05	182	116	12	Ca > Mg > S	Mn > Cu > Fe
DRIS indices	A	22	8	14	−47	−31	−5	0	13	28	10	−11	P > K > N >	B > Zn >
	B	26	13	22	−57	−60	3	8	9	26	11	−2	Mg > Ca > S	Cu > Mn > Fe
Nethapur	A	1.62	0.137	0.389	1.089	0.124	0.076	13	3.66	228	114	21	P > K > N >	B > Mn >
(Hoshiarpur)	B	1.58	0.112	0.359	1.147	0.142	0.075	11.60	2.47	185	74	21	Ca > Mg > S	Zn > Cu > Fe
DRIS indices	A	18	11	13	−43	−35	−6	5	14	22	2	0	P > K > N >	Mn > B >
	B	24	11	16	−52	−37	0	7	9	21	−3	5	Ca > Mg > S	Zn > Cu > Fe
Dasua	A	1.46	0.171	0.436	1.173	0.174	0.076	15	3.87	174	106	34	N > P > K >	Mn > Zn >
	B	1.75	0.144	0.476	1.156	0.173	0.079	14.6	3.43	145	96	32	Ca > Mg > S	B > Fe > Cu
DRIS indices	A	5	13	13	−36	−14	−11	5	12	10	−4	8	P > K > N >	Mn > Zn >
	B	18	9	16	−39	−15	−10	5	9	6	−7	7	Ca > Mg > S	Fe > B > Cu
Dasua	A	1.66	0.140	0.634	1.003	0.263	0.094	17	6.13	173	35	19	P > N > K >	Mn > B >
	B	1.62	0.096	0.608	1.152	0.164	0.077	12.4	4.42	402	37	22	Ca > S > Mg	Zn > Fe > Cu
DRIS indices	A	25	14	41	−71	0	−6	15	44	17	−71	−9	P > N > K >	Mn > B >
	B	26	−1	41	−57	−30	−14	2	28	73	−65	−3	Ca> Mg > S	Zn > Cu > Fe
Gatora	A	1.58	0.103	0.620	0.922	0.217	0.069	13	4.55	254	25	21	P > N > K >	Mn > B >
	B	1.62	0.111	0.548	1.169	0.251	0.086	14	4.23	192	31	23	Ca > Mg > S	Zn > Cu > Fe
DRIS indices	A	36	12	56	−101	−21	−9	14	42	51	−84	4	P > N > K >	Mn > B >
	B	29	9	38	−63	−9	−4	11	29	26	−69	3	Ca > Mg > S	Zn > Fe > Cu

(continued)

Table 2. Continued

Location/position of leaf sampled		Leaf composition/DRIS indices N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn ($mg\,kg^{-1}$)	Cu ($mg\,kg^{-1}$)	Fe ($mg\,kg^{-1}$)	Mn ($mg\,kg^{-1}$)	B ($mg\,kg^{-1}$)	Order of requirement Macronutrient	Micronutrient
Dasua	A	1.28	0.097	0.439	1.012	0.160	0.094	14	3.51	205	50	24	P > N > K >	Mn > B >
	B	1.31	0.097	0.346	1.131	0.198	0.124	17	3.44	170	56	28	Ca > Mg > S	Zn > Cu > Fe
DRIS indices	A	17	7	23	−63	−28	3	12	18	25	−20	7	P > K > N >	Mn > B >
	B	14	4	11	−49	−14	7	14	14	14	−21	7	Ca > Mg > S	Zn > Cu > Fe
Etti	A	1.51	0.126	0.399	1.178	0.263	0.075	20	3.90	155	69	16	P > K > N	Mn > B >
(Gurdaspur)	B	1.53	0.078	0.290	0.888	0.180	0.070	15	3.19	280	81	13	Ca > S > Mg	Fe > Zn > Cu
DRIS indices	A	18	10	15	−50	−2	−10	21	21	11	−17	−11	P > K > N	B > Mn >
	B	26	3	12	−85	−24	−2	17	17	45	−1	−6	Ca > Mg > S	Zn > Cu > Fe
Chani	A	1.46	0.136	0.446	0.988	0.302	0.079	15	3.60	211	71	21	P > N > K >	Mn > B >
(Gurdaspur)	B	1.16	0.104	0.367	1.138	0.149	0.078	13.8	2.49	267	69	22	Ca > S > Mg	Zn > Cu > Fe
DRIS indices	A	14	9	17	−61	9	−10	7	16	19	−17	−3	P > N > K >	Mn > B >
	B	13	7	16	−52	−33	−2	10	8	37	−8	4	Ca > Mg > S	Cu > Zn > Fe
Neelma	A	1.50	0.160	0.655	1.172	0.197	0.086	17	4	200	54	25	P > N > K >	Mn > B >
	B	1.50	0.105	0.349	0.843	0.126	0.074	13	2.86	209	59	20	Ca > Mg > S	Zn > Cu > Fe
DRIS indices	A	15	14	33	−43	−11	−11	10	15	17	−37	−1	P > K > N >	Mn > B >
	B	26	13	19	−84	−46	5	14	18	29	−2	9	Ca > Mg > S	Zn > Cu > Fe
Duffer	A	1.16	0.122	0.374	0.874	0.142	0.088	10	4	110	53	23	P > N > K >	Mn > Zn >
	B	1.50	0.116	0.323	1.079	0.139	0.080	9	3	187	62	27	Ca > Mg > S	Fe > B > Cu
DRIS indices	A	19	18	22	−85	−40	9	10	28	12	−4	12	P > K > N >	Mn > Zn >
	B	23	13	14	−59	−39	2	3	15	23	−7	11	Ca > Mg > S	B > Cu > Fe

Mineral composition of leaf tissues sampled from top bud toward the base of mango tree panicle varied inconsistently at both sites (Chintpurni and Chohal) in Hoshiarpur district (Table 3). Inconsistent variation in concentration occurred in leaf tissues sampled from different position of the mango tree panicle at both locations. Among micronutrients, DRIS indices inferred consistent inadequacy of Fe or B and likely least requirement for Cu or Mn at all time of sampling. The optimum ranges (Reuter and Robinson 1986) of N, P, K, Ca, and Mg were 1.0–1.5, 0.08–0.18, 0.30–1.2, 3.0–5.0, and 0.20–0.40% and Zn, Cu, Fe, Mn, and B were 20–150, 10–20, 70–200, 60–500, and 50–100 mg kg^{-1}, respectively, in dry matter leaf. On the basis of these optimum levels, leaf tissues collected from different positions of same panicle illustrate consistently similar nutrient status for the same fruit tree. However, DRIS indices on the basis of order of requirement referred the inadequacy of K and Fe among macro- and micronutrient, at Chintpurni location. The insufficiency of N and Fe or B was observed in the orchard at Chohal. Sufficiency of P was recorded by DRIS approach and validated by higher soil P status at both sites. According to the sufficiency level approach, orchards at both sites were adequate in Zn, Fe, and Mn but low in Cu and B, respectively.

To investigate the effect of time of sampling, DRIS indices were computed from the leaf mineral composition collected at bimonthly intervals from the same mango fruit tree (Dashaheri cv) grown in an orchard located at Punjab Agricultural University, Ludhiana (Table 4). The sampling was commenced in the 1st week of December and terminated in the 1st week of October. Declining trend of P and K while increasing trend of Ca, Mg, and S contents in leaf tissues were recorded within the sampling period. DRIS indices illustrate similar order of requirement for macronutrients ($P > N > K > Ca > Mg > S$) irrespective of time of sampling. Among micronutrients, DRIS indices elucidate consistent insufficiencies of Mn and least requirement of Cu at all time of samplings. DRIS approach suggested the soil application of phosphatic fertilizers along with spray of Mn could enhance fruit trees' vigor, yield, and quality of fruit at that particular site.

The DRIS norms established from the nutrient indexing survey of mango tree was further used to compute DRIS indices from the foliar mineral composition of problematic trees located at different locations of Punjab. On the basis of DRIS indices (Table 5), the relative deficiencies for each of 10 nutrient elements were identified and compared with the diagnosis of already published critical limits (Reuter and Robinson 1986). The already published critical limits of N, P, K, Ca, Mg, and S were 1.00, 0.08, 0.30, 3.0, 0.20, and 0.52%, whereas for Zn, Cu, Fe, Mn, and B were 20, 10, 70, 60, and 50 mg kg^{-1}, respectively, in leaf tissues on oven-dried weight basis. The computed DRIS indices from foliar nutrient concentrations and the foliar nutrient concentrations evaluated by already published critical limits in the literature consistently identified N, K, Ca, Mg, Zn, Cu, Fe, Mn, and B deficiencies at different locations. In addition to diagnosis of deficient

Table 3. Mineral elemental composition and DRIS indices of leaf tissues sampled from top bud toward the base of mango fruit trees terminals collected from two sites at Chintpurni and Chohal in Hoshiarpur district, in submountainous area of Punjab

	Leaf composition/DRIS indices											Order of requirement	
Position of leaf sampled	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn (mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	B (mg kg^{-1})	Macronutrients	Micronutrients
								Chintpurni					
0	2.46	0.262	0.420	3.858	0.256	0.182	23	6	154	363	27		
	3	2	−10	40	14	−10	−5	1	−16	5	−24	K > P > N > S > Mg > Ca	B > Fe > Zn > Cu > Mn
1st	2.16	0.296	0.383	3.834	0.233	0.181	20	6	129	396	33		
	1	4	−12	39	9	−9	−8	3	−21	9	−15	K > N > P > S > Mg > Ca	Fe > B > Zn > Cu > Mn
2nd	1.96	0.296	0.436	3.914	0.216	0.166	24	5	107	386	29		
	1	10	−6	39	4	−10	−1	0	−29	11	−18	K > N > P > S > Mg > Ca	Fe > B > Zn > Cu > Mn
3rd	1.64	0.290	0.483	3.980	0.231	0.179	24	5	97	383	32		
	4	9	−4	40	7	−8	−1	0	−34	11	−14	K > N > P > S > Mg > Ca	Fe > B > Zn > Cu > Mn
4th	1.56	0.271	0.430	3.237	0.222	0.161	22	5	−118	341	29		
	−3	10	−4	24	4	−8	−1	2	−20	10	−15	K > N > P > S > Mg > Ca	Fe > B > Zn > Cu > Mn

5th	1.22	0.290	0.471	3.405	0.250	0.166	22	5	104	337	26		
	−10	14	−1	25	8	−7	0	3	−25	11	−19	N > K > P > S > Mg > Ca	Fe > B > Zn > Cu > Mn
Chohal													
0	2.06	0.238	0.489	3.327	0.184	0.163	20	5	104	262	29		
	3	8	1	25	5	−6	2	4	−23	4	−13	K > N > P > S > Mg > Ca	Fe > B > Zn > Mn > Cu
Ist	1.64	0.266	0.543	3.366	0.217	0.184	23	5	137	244	25		
	−2	8	2	26	3	−4	0	2	−14	0	−20	N > K > P > S > Mg > Ca	B > Fe > Zn > Mn > Cu
2nd	1.90	0.256	0.553	3.309	0.193	0.176	24	5	114	198	26		
	4	8	4	25	−3	−4	3	4	−20	−4	−17	N > K > P > S > Mg > Ca	Fe > B > Zn > Mn > Cu
3rd	2.06	0.276	0.579	3.390	0.219	0.181	26	6	137	226	24		
	2	8	2	30	5	−7	1	5	−17	−3	−26	N > K > P > S > Mg > Ca	Fe > B > Zn > Mn > Cu
4th	1.86	0.321	0.680	3.300	0.230	0.185	29	6	102	204	25		
	0	14	7	29	8	−6	5	6	−32	−6	−25	N > K > P > S > Mg > Ca	Fe > B > Zn > Mn > Cu
5th	1.72	0.283	0.605	3.031	0.215	0.184	24	5	116	196	23		
	1	13	7	20	2	−3	3	4	−20	−4	−23	N > K > P > S > Mg > Ca	Fe > B > Zn > Mn > Cu

Table 4. Effect of time of sampling on leaf mineral composition/DRIS indices and order of nutrient requirement on mango fruit trees (Dashehari)

	Leaf mineral composition/DRIS indices											Order of requirement	
Sampling time	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn (mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	B (mg kg^{-1})	Macronutrient	Micronutrient
1 December	1.630	0.144	0.610	0.892	0.166	0.086	16	5	173	62	32		
DRIS indices	17	11	28	−60	−16	−8	9	23	13	−24	8	P > N > K > Ca > Mg > S	Mn > B > Zn > Fe > Cu
2 February DRIS	1.582	0.112	0.546	1.134	0.177	0.092	13	3	159	49	25		
	23	8	31	−54	−23	0	8	12	4	−26	6	P > N > K > Ca > Mg > S	Mn > B > Zn > Fe > Cu
3 April DRIS	1.464	0.088	0.476	1.136	0.200	0.099	13	5	176	68	26		
	15	−2	20	−47	−12	−2	4	25	13	−17	3	P > N > K > Ca > Mg > S	Mn > B > Zn > Fe > Cu
4 June DRIS	1.485	0.081	0.378	1.156	0.170	0.106	11	4	185	90	27		
	16	−2	13	−44	−20	2	1	17	15	−4	5	P > K > N > Ca > Mg > S	Mn > Zn > B > Fe > Cu
5 August DRIS	1.663	0.078	0.359	1.173	0.175	0.110	15	7	137	96	33		
	16	−9	7	−38	−14	−3	4	38	3	−9	6	P > K > N > Ca > Mg > S	Mn > Zn > B > Fe > Cu
6 October DRIS	1.721	0.097	0.346	1.179	0.253	0.115	17	6	208	35	29		
	26	0	12	−54	−4	2	14	41	24	−68	7	P > K > N > Ca > Mg > S	Mn > B > Zn > Fe > Cu

Table 5. Leaf mineral composition, DRIS indices for macro and secondary nutrient as the most required elements of mango fruit tree recorded at different locations of submontainous area of Punjab

	Leaf mineral composition/DRIS indices												
Location	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	B (ppm)	Critical limits	Order of requirement
Gangian	0.94 −15	0.180 −1	0.324 −12	3.08 26	0.334 17	0.188 0	18 −5	5 1	250 −2	190 −8	35 −1	1.00	N > K > Mn > Zn > Fe > P > B > S > Cu > Ca
Dharmpur	1.10 −4	0.116 −6	0.447 5	2.69 5	0.262 3	0.140 −4	14 −5	3 −4	245 11	191 2	31 −4	0.08	P > Zn > N > S > Cu > B > Mn > Mg > K > Ca > Fe
Dasua	0.94 −10	0.150 0	0.222 −18	3.21 11	0.344 13	0.169 0	16 −3	4 2	217 5	207 2	33 −3	0.30	K > N > Zn > B > P > S > Cu > Mn > Fe > Ca > Mg
Budabarh	1.00 8	0.108 8	0.480 27	1.35 −44	0.200 −19	0.093 1	12 6	3 12	56 −15	192 19	17 −3	1.0	Ca > Mg > Fe > B > S > Zn > N > P > Cu > Mn > K
Khurd	1.10 6	0.097 0	0.344 8	2.55 −3	0.152 −30	0.131 5	13 3	3 7	118 2	203 15	15 −13	0.20	Mg > B > Ca > P > Fe > Zn > S > N > Cu > K > Mn
Musapur	1.20 −2	0.117 −6	0.319 −4	2.37 2	0.229 0	0.121 −8	14 −6	7 25	181 2	164 −2	35 0	0.52	S > P > Zn > K > N > Mn > Mg > B > Ca > Fe > Cu

(continued)

Table 5. Continued

Location	Leaf mineral composition/DRIS indices											Critical limits	Order of requirement
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	B (ppm)		
Gangian	0.84	0.188	0.495	2.96	0.425	0.208	2	3	263	150	36	20	Zn > Ca > N > Mn > Cu >
	−4	31	32	−7	16	30	−179	11	42	9	18		Mg > B > S > P > K > Fe
Duffer	1.36	0.119	0.283	2.94	0.246	0.135	14	1	205	123	37	10	Cu > Mg > Mn > Ca > K >
	11	4	1	0	−9	4	3	−39	17	−2	11		Zn > P > S > N > B > Fe
Barabarh	1.20	0.124	0.283	1.93	0.244	0.130	13	5	60	208	19	70	Fe > Ca > B > Mg > K >
	5	3	0	−16	−5	1	0	42	−21	2	−11		Zn > S > Mn > P > N > Cu
Gangian	0.84	0.182	0.458	3.79	0.334	0.184	17	2	88	176	34		Fe > Cu > N > B > Zn >
	−12	8	7	15	9	5	1	−15	−19	1	0		Mn > S > K > P > Mg > Ca
Hoshiarpur	1.10	0.202	0.310	4.51	0.510	0.244	23	5	240	140	49	60	Mn > N > K > P > Zn > B >
	−17	−6	−17	39	47	−4	−6	−5	−5	−19	−6		Cu > Fe > S > Ca > Mg
Phagwara	1.30	0.098	0.254	2.25	0.307	0.113	12	1	161	47	46		Mn > Cu > Ca > Mg > P >
	−19	5	5	−22	−6	6	6	−29	18	−34	32		K > S > Zn > Fe > N > B
Barabarh	1.52	0.171	0.405	2.69	0.375	0.178	21	6	155	210	29	50	B > Fe > K > S > Zn > N >
	−3	−3	−5	9	25	−4	−2	7	−8	−3	−12		P > Mn > Cu > Ca > Mg

element, DRIS technique also gave the order of requirement for other elements followed by the least required one. It is difficult to tell if a relative excessive or the accompanying relative deficiency is of greater concern. Nevertheless, it could be emphasized that the application of deficient one or the most required element through fertilizer or spray could eventually enhance yield and/or quality of mango fruit. In contrast to this option, the application of excessive or least required nutrient element could exaggerate the requirement of deficient one and hamper tree growth or yield and fruit quality. The relative excessive values derived by DRIS approach from nutrient indexing survey of mango fruit trees in the present investigation (Table 6) are not very high. A large portion of this inconsistency is due to symmetry of DRIS. This is because an equal number of ratios for each of 10 nutrients were selected in calculating indices for each individual element, because this was an absolute (orthogonal) requirement of the mathematic model. Relative deficiencies for N, P, K, Ca, Mg, S, Zn, Fe, and Mn and corresponding relative excesses for Ca, Fe, Mg, K, Mn, Cu, Fe, and B were detected by DRIS evaluations in the leaf tissues of mango trees (Table 5). Comparing DRIS diagnosis with critical limits approaches on trees identified by DRIS as having nutritional disorders is informative. Critical concentrations and DRIS approaches both consistently identified deficiencies of N, K, Mg, S, Zn, Cu, and Fe, respectively, in mango trees at different sites. However, the inadequacy of Ca at

Table 6. Sufficiency ranges of nutrient elements derived by DRIS technique from nutrient survey of mango tree orchards in submountainous area of Punjab, northwest India

					Percent	
Element	Low	Sufficient	High value	Excessive	Low	Toxic
Nitrogen (%)	<0.92	0.92–1.37	1.37–1.59	>1.59	16	—
Phosphorus (%)	<0.08	0.08–0.16	0.16–0.21	>0.21	15	—
Potassium (%)	<0.21	0.21–0.44	0.44–0.55	>0.55	12	1
Calcium (%)	<1.71	1.71–3.47	3.47–4.35	>4.35	17	1
Magnesium (%)	<0.15	0.15–0.38	0.38–0.49	>0.49	16	—
Sulphur (%)	<0.09	0.09–0.19	0.19–0.24	>0.24	16	2
Zinc (mg kg^{-1})	<11	11–19	19–24	>24	19	1
Copper (mg kg^{-1})	<1	1–6	6–8	>8	18	4
Iron (mg kg^{-1})	<63	63–227	227–309	>309	12	6
Manganese (mg kg^{-1})	<87	87–223	223–290	>290	20	6
Boron (mg kg^{-1})	<16	16–44	44–59	>59	6	2

Budabarh recorded in the leaf tissues of the mango trees, but according to the critical limits these nutrient levels comes within the optimum range.

Sometimes, more than one nutrient element could be found deficient or excessive with sufficiency's range approach. However, DRIS recommends the application of most required nutrient element. To interpret data of mineral leaf composition by sufficiency range approach, plant tissues must be sampled at a definite stage of growth and from specific plants parts to compare the concentration of test samples for each element with their respective standard reference values.

The DRIS has the advantages of placing any deficiency or excess in order of importance, and results are not affected by general dilution or concentration due to variation in type position of leaf tissue and time of sampling. DRIS approach can also be used to compute low, sufficient, high, and excessive ranges for different nutrient elements to be used for foliar diagnostic of mango fruit trees. Sufficiency ranges of macro- and micronutrients derived from nutrient indexing survey of mango fruit trees in Punjab, northwest part of India were 0.92–1.37, 0.08–0.16, 0.21–0.44, 1.71–3.47, 0.15–0.37, and 0.09–0.19% for N, P, K, Ca, Mg, and S and were 11–19, 1–6, 63–227, 87–223, and 16–44 $mg\,kg^{-1}$, for Zn, Cu, Fe, Mn, and B, respectively.

The leaf composition as series of low, sufficient, high, and excessive level of each nutrient is defined (Leece 1976) as follows:

- Low: No visual deficiency symptoms; level is below normal and may be insufficient for optimum performance.
- Sufficient: Level is normal and should be adequate for optimum performance.
- High: Level is above normal and may be causing nutrient imbalance.
- Excess: Toxicity symptoms may or may not be present; level is too high for optimum performance.

According to these sufficiency ranges (Table 6), 16, 15, 12, 17, 16, and 16% of total samples of mango trees collected were found to be low in N, P, K, Ca, Mg, and S, respectively, whereas 1% each were found to be excessive in Ca and Mg. In micronutrients, 19, 18, 12, 20, and 6% samples were identified in low range for Zn, Cu, Fe, Mn, and B, respectively. Only 1, 2, 6, 6, and 2% leaf tissues samples were found to be in toxic range for Zn, Cu, Fe, Mn, and B, respectively. The already published sufficiency ranges (Jones 1984), especially for the micronutrients, were very wide and high compared with the sufficiency ranges derived by DRIS technique from the nutrient-indexing survey of mango trees in Punjab.

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