Journal of Plant Nutrition
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/lpla20

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Available online: 14 Feb 2007

JOURNAL OF PLANT NUTRITION
Vol. 27, No. 7, pp. 1131–1148, 2004

Diagnosis of Nutrient Imbalance in Mango by DRIS and PCA Approaches

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ABSTRACT

Nutrient concentration in Totapuri cultivar of mango leaf as affected by application of varying levels of nitrogen (N), phosphorus (P), or potassium (K) was monitored in three field experiments for a period of nine years from 1991 to 1999. A data bank of nutrient concentration vs. fruit yield was established based on the mean nutrient concentration determined for different treatments. The data was further sub-divided into low and high yielding population based on yield performance. The Diagnosis and Recommendation Integrated System (DRIS) ratio norms were developed from high yielding population, while diagnosis of nutrient imbalance was made in low yielding plants. Forty-five nutrient expressions were chosen as

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DOI: 10.1081/PLN-120038540 0190-4167 (Print); 1532-4087 (Online)

diagnostic norms. Not withstanding application of a wide range of major nutrient doses, fruit yield was low in four to five cropping seasons. DRIS indices showed no signs of improvement nor there was a trend with application of N, P, or K at different levels. Some measures of total imbalance of nutrients in plant were reflected through sum of DRIS indices irrespective of sign. The greater imbalance of nutrients resulted in lower fruit yield. Principal Component Analysis (PCA) was applied to extract the correlation structure among the nutrient in low and high yielding plants and for DRIS indices. The first PC derived by PCA performed both on absolute nutrient concentration and DRIS indices was designated as (N−P + Mg−S + Fe + Cu+). Involvement of several nutrients in a single PC indicated that, it was not possible to diagnose nutrient imbalance of any particular nutrient in isolation in fruit crops like mango. The nutrient concentration variation in mango leaf appears to be an overall orchard phenomenon rather than individual tree phenomenon.

Key Words: Mango; DRIS; PLA.

INTRODUCTION

Attempts have been made in the past to improve the fruit yield potential in mango through nutrient application. However, consensus eludes regarding the magnitude of response or degree of deficiency of different nutrients in mango.[1] Both nutrient concentrations build up and depletion is very gradual in mango leaves due to perennial and deep-rooted nature of plant. The irregular bearing habit in mango is noticed withstanding maintaining the optimum nutrients in leaf. Also, the response in terms of increase in nutrient concentration in the leaf due to fertilizer application in mango is reported to be very mild. Sukthumrong et al.[2] observed from the leaf analysis from N, P, and K experiments in mango that the concentrations of plant nutrient were not affected by fertilizer treatment. Most of the studies relate the nutrient concentration in the mango leaves with the growth and fruit yield and standard nutritional values of the leaves are derived on that basis.

An improved knowledge of nutrient balance is necessary to comprehend the nature of nutrient interaction in plant and to facilitate interpretation of leaf analysis results. Diagnosis and Recommendation Integrated System (DRIS), as an interpretation technique for diagnosing nutrient concentration or equilibria in selected plant tissue, has been successfully used in variety of crops.[3–5] DRIS uses dual ratios of the original component that are first standardized as DRIS functions and further transformed into DRIS indices.[6] The aim of fertilizer management in mango crop is to use plant analysis information to attain the optimum nutrient balance with minimum nutrient application.

The response of mango plant to nutrient application in terms of nutrient levels in the plant is slow. Against the backdrop of this fact, the present investigation was carried out to find out whether or not application of N, P, and K in mango has any effect on nutrient concentration in mango leaf in the long run. The information on nutrient concentration vs. yield from field experiment was used to develop DRIS ratio norms from high yielding plants. The nutrient imbalance in low yielding population was explained using DRIS indices. The interrelationship among various nutrients was further explained by using Principal Component Analysis (PCA).

MATERIALS AND METHODS

Background

Mango under peninsular Indian conditions produces matured shoots that serves as fruiting wood only once by differentiating buds located terminally. Its function subsequent to bearing fruit is to serve as a base for developing new shoots. In case of regular bearing cultivars like *Totapuri*, fruited shoots have the tendency for developing new shoots laterally soon after the harvest of the fruits, which differentiate into fruit buds in the ensuring October–November period and therefore are able to bear crop in the following year also. However, not many such early produced shoots are observed to be potential for fruit bud differentiation. Therefore, the basic tendency of biennially in normal cropping exists even in regular bearers like Totapuri mango. In shoots, which are expected to flower, fluctuations in nutrient concentration especially during fruit bud differentiation were reported.

Field Experiment

A field experiment was conducted at Indian Institute of Horticultural Research, Hessaraghatta, Bangalore (12° 58′′ N, 77° 30′′ E), involving application of N, P, and K at different levels under rainfed conditions to

Totapuri cultivar of mango. Three separate trials in randomized block design of N, P, and K were laid out with 10 replications each. The planting was done at a spacing of 10 m × 10 m during July 1985. The details of the treatments are shown below.

Location

The location of the experimental site experienced mild sub-tropical climate with near semi-arid condition with an average rainfall of 86 cm during the year. The soil was sandy loam with near neutral pH of 6.65 and had 250, 30, and 300 kg/ha available N, P, and K respectively at the start of the experiment.

Nutrient Application

A common dose of 20 g P_2O_5 + 70 g of K_2O in the N trial, 75 g N + 70 g K_2O in the P trial and 75 g N + 20 g P_2O_5 per plant per year of age in case of the K trial was applied (Table 1). The nutrient doses in all the trials were stabilized when the plants were 10-years old and the tenth year dose was continued in the subsequent years. Nitrogen was applied in the form of urea, P as single superphosphate and K as muriate of potash. Nutrients were applied through band application before the onset of monsoon and after harvest of fruits in July every year providing ½ N and full P and K. The remaining ½ N was applied during September–October months towards the end of rainy seasons.

Table 1. Details of nutrient application (g/plant/year of age).

Treatment	N trial	P trial	K trial
T1	0	0	0
T2	10	5	10
T3	25	10	20
T4	50	20	30
T5	100	50	100
T6	150	100	200
T7	200	—	—
T8	400	—	—

Leaf Sampling

The leaf samples were collected in the month of July every year before application of fertilizers and after the harvest of the crop. The leaf sampling was started in 1991 after the plant started giving stable fruit yield. The four- to seven-month-old leaf along with petiole from the vegetative shoots (nonfruiting terminal, in the middle of the whorl) was collected.[7] The fruit yield record was also maintained for all the years from the year 1988 up to 1999.

Analysis of Samples

The foliar samples were dried at 70°C, wet digested with H_2SO_4 and H_2O_2 and analyzed for N by Kjeldahl method. Another part of the sample was digested with HNO_3:$HClO_4$ (9:4 v/v) and P was estimated by vanado–molybdate method and S by turbidometric method. Atomic Absorption Spectrophotometer was used for determining calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), and zinc (Zn), and K in the emission mode.

Establishment of Data Bank

The first step in implementing DRIS is the establishment of the standard values or norms. A data bank of nutrient concentration vs. fruit yield was established based on these field experiments. The mean nutrient concentration and fruit yield of 10 replications were computed for each treatment for all the years. Therefore, from the N trial there were eight sets of data and six sets from each of P and K trials. There were 20 treatment combinations for which nutrient concentration vs. yield information was available every year. The data generated from 1991 to 1999 with total treatment combinations of 180 with unequivocal yield record were included in the data bank for the norms deriving exercise. Among 180 sets of data, 89 were classified as high yielders and 91 as low yielders. The treatments wherein the yield was higher than the average yield for that year were classified as high yielders.

Developments of DRIS Norms

The DRIS developed by Beaufils[8] was used for interpretation of results and for developing norms for leaves. The whole population was divided into two groups based on yield performance, as high and low yielding as stated earlier. The high yielding population was made use for norm deriving based on which the yield limiting nutrients in the low yielding plants were identified. Each parameter was expressed in as many forms as possible, e.g., N/P, P/N, etc. The mean of each sub-population was calculated for various forms of expressions. The variance ratio between yield of sub-population for all forms of expressions was calculated together with the coefficient of variation. All forms of expressions were taken for developing formulae for calculating the indices. Among different forms of expressions the one showing higher variance ratio (variance of low yielding/variance of high yielding population) was selected as diagnostic norm.

DRIS Indices

The DRIS provides a means of ordering nutrient ratios or products into a meaningful expression called DRIS index. Essentially a nutrient index is mean of deviations of the ratios containing a given nutrient from their respective optimum or norm value. All indices were balanced around zero. Therefore, nutrient indices sum to zero. The more negative an index, the more lacking in the nutrient it represented relative to other nutrients used in the diagnosis. Alternatively, a large positive index indicated that the corresponding nutrients were present in relatively excessive quantity. An example for calculation of DRIS indices is illustrated below:

$$\begin{aligned} \mathrm{N} = 1/9[&f(\mathrm{N/P}) + f(\mathrm{N/K}) + f(\mathrm{N/Ca}) - f(\mathrm{Mg/N}) - f(\mathrm{S/N}) \\ &- f(\mathrm{Fe/N}) - f(\mathrm{Mn/N}) - f(\mathrm{Zn/N}) + f(\mathrm{N/Cu})] \end{aligned}$$

where

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

and

$$= \left(1 - \frac{n/p}{\mathrm{N/P}}\right)\left(\frac{1000}{\mathrm{CV}}\right) \quad \text{when N/P} < n/p \tag{2}$$

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

Nutrient Imbalance Index (NII)

Sum measure of total nutritional imbalance is indicted by sum of the nutrient indices irrespective of sign. The greater the sum, the more is the imbalance. When the sum of the indices is large, one or more of the measured nutrients limit the yield and therefore, large yield cannot occur.

Principal Component Analysis (PCA)

A reasoned application of PCA could lead to the greater understanding of the effect of fertilization treatments on leaf composition. PCA reduces the number of interdependent variables into smaller number of independent PCs that are linear combinations of original variates. A PCA was performed for nutrient concentration data for low and high yielding populations and for DRIS indices separately. According to distribution of data, all the measured concentration was transformed to their logarithms prior to statistical computation. It was shown that, the assumption of log normal distribution was reasonable. To be declared significant PCs must have eigen values $>100/P$, where P is the total number of varieties under diagnosis.[9] Alternatively, PCs showing eigen values <1 were considered nonsignificant. Only PC loading in eigen vectors having values greater than the selection criterion (SC) are given significance. The selection criterion was computed as follows:

$$SC = 0.50/(\text{PC eigen values})^{0.5}$$

RESULTS AND DISCUSSION

Concentration of Nutrients in Leaf Samples

The mean nutrient concentration in mango leaf for each year for high and low yielding groups is presented in Table 2. The observed ranges are very representative of the nutrient concentration prevailing in the region for mango. Only marginal difference was noticed in concentration of different nutrients between high and low yielding plants throughout the period of study. Calcium concentration was generally on the higher range both in high and low yielding plants. There was no difference in the concentration of nutrients with the advancing age of the plants although

Table 2. Leaf nutrient concentration variations during different years for low and high yielding populations of mango.

Nutrient		1991	1992	1993	1994	1995	1996	1997	1998	1999
N	Low	0.58	1.25	1.27	1.04	1.39	1.30	1.17	1.22	1.14
	High	0.54	1.22	1.14	1.04	1.30	1.39	1.21	1.29	1.15
P	Low	0.08	0.04	0.07	0.05	0.05	0.04	0.04	0.05	0.05
	High	0.09	0.04	0.05	0.06	0.04	0.04	0.05	0.04	0.03
K	Low	1.37	1.28	1.03	1.08	1.04	1.03	0.98	0.91	0.65
	High	0.91	1.31	1.09	1.10	0.92	0.97	1.09	0.91	0.70
Ca	Low	2.11	2.23	2.77	2.89	3.19	3.14	3.15	2.38	2.57
	High	2.61	2.35	2.37	2.88	2.68	2.82	2.77	2.56	2.52
Mg	Low	0.13	0.30	0.25	0.22	0.33	0.31	0.25	0.32	0.26
	High	0.16	0.28	0.24	0.20	0.26	0.28	0.24	0.31	0.37
S	Low	0.10	0.09	0.07	0.09	0.08	0.08	0.07	0.12	0.11
	High	0.11	0.09	0.09	0.09	0.09	0.09	0.07	0.10	0.11
Fe	Low	103	132	71	92	95	88	135	109	142
	High	158	133	160	95	61	73	135	131	114
Mn	Low	88	178	118	273	180	181	180	210	167
	High	58	175	223	257	300	277	203	191	211
Zn	Low	14	20	15	17	14	15	16	20	73
	High	13	17	14	18	13	13	17	20	39
Cu	Low	10	12	11	18	7	8	13	16	14
	High	8	12	9	18	11	10	12	19	15
Fruit	Low	0.66	4.68	2.50	4.21	3.46	3.41	5.90	1.60	6.22
yield	High	1.95	6.30	4.61	5.43	5.00	4.60	7.53	3.07	8.52

N, P, K, Ca, Mg, and S are in %, Fe, Mn, Zn, and Cu are in ppm and yield in t/ha.
Low, low yielding population.
High, high yielding population.

the yield potential increased as plants became older. Totapuri cultivar of mango is having a regular bearing habit.

The mean nutrient concentration from N, P, and K trials showed no significant relationship with current year yield. However, K concentration in leaf showed significant negative correlation with the next year yield ($r = 0.616^*$) indicating that there was a considerable depletion in K levels in plant a season before heavy bearing (data not presented). With the exception of Mn ($r = 0.518^*$), there was no significant relationship between leaf nutrient concentrations with the previous year yield. The low yields recorded during some years of the study coincided with the low yield recorded in the region for that year.

Table 3. DRIS ratio norms for leaf nutrients developed from high yielding population of mango.

Ratios	Value	CV%	Ratios	Value	CV%
P/N	0.0434	29.94	K/Cu	0.085	49.60
K/N	0.840	31.76	Mg/Ca	0.111	39.25
Ca/N	2.02	19.65	Ca/S	26.38	20.61
Mg/N	0.217	36.21	Fe/Ca	60.39	20.85
S/N	0.079	28.95	Ca/Mn	0.0123	32.67
Fe/N	120.4	24.16	Zn/Ca	6.91	27.50
Mn/N	181.6	35.35	Cu/Ca	5.63	34.00
Zn/N	13.96	33.80	Mg/S	2.83	34.80
Cu/N	11.49	44.28	Fe/Mg	618.12	42.90
K/P	20.32	32.77	Mg/Mn	0.00137	55.07
P/Ca	0.0218	30.39	Zn/Mg	70.65	47.14
P/Mg	0.238	66.30	Mg/Cu	0.022	47.13
P/S	0.571	34.37	Fe/S	1572.5	23.85
P/Fe	0.0004	32.74	S/Mn	0.00049	39.97
P/Mn	0.0003	50.50	Zn/S	180.16	30.36
P/Zn	0.0033	40.83	S/Cu	0.0078	37.08
P/Cu	0.0042	42.35	Fe/Mn	0.727	31.75
K/Ca	0.42	32.50	Fe/Zn	9.31	31.05
K/Mg	4.344	50.78	Fe/Cu	12.02	40.30
K/S	11.12	37.10	Mn/Zn	0.0859	44.74
Fe/K	154.24	31.88	Cu/Mn	0.070	51.58
K/Mn	0.0051	44.79	Zn/Cu	1.315	30.26
Zn/K	17.81	40.15			

DRIS Ratio Norms for Mango

The mean values of high yielding population of 45 nutrient expressions chosen as diagnostic norms are presented in Table 3. Among the nutrient ratios selected to form diagnostic parameter, S/N (0.079), P/Zn (0.0033), K/Ca (0.42), and K/Mg (4.344) had greater physiological rationale. Potassium is known to play a key role in N uptake and translocation in mango. Wide variation in Ca followed by K and Mg levels in leaf was reported during fruit bud differentiation in mango.[10] The rationale for having some expressions were less obvious and those with large CVs indicated that maintaining their ratios at optimum values was much less critical for crop performance. Further, it is not practically possible to consider all the expressions for diagnosis of nutrient imbalance. The nutrients considered as yield building component, needs to be kept in

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a state of relative balance for maximum efficiency of dry matter production. It was established that a particular nutrient expression, to be chosen as diagnostic norm, should have high variance and small CV between high and low yielding population for higher diagnostic precision.

Diagnosis of Nutrient Imbalance

The diagnosis of nutrient imbalance in plant was made based on the DRIS indices. Each treatment combination was assumed as an independent sample and was substituted in Eq. (1) or (2) to find out DRIS indices. The overall imbalance of the nutrient in a particular treatment was assessed based on the sum of indices irrespective of sign.

From the data of nutrient concentration vs. yield available from 1991 to 1999 in N experiment, it was observed that nearly 64% of the plants were low yielding. Notwithstanding application of 400 g N/plant/year of age, yield was low during many cropping seasons as a result of imbalance of Mg, sulfur (S), Fe, Mn, Zn, and copper (Cu). Therefore, DRIS ratio norms were instrumental in diagnosis of incipient multinutrient imbalance in as often as four to five cropping seasons. The zero level application of N resulted in fewer imbalances of N and K, where as there was an accompanying imbalance of S, Fe, Mn, Zn, and Cu as well as with increasing levels of N application during different cropping seasons. The DRIS indices showed no signs of improvement nor were there any trend with application of N at different levels (Table 4).

The percent of low yielding trees under P trial was fewer compared to N experiment. Among low yielding plants of P experiment in different years, P was diagnosed as yield limiting in nearly 43% of plants and appear to be independent of P application rate. The potassium imbalance in P experiment was less frequent compared to N imbalance. Nitrogen was the most common yield-limiting nutrient due to P application (Table 5). The earlier results indicated that P was the most interactive although in a negative manner, followed in importance by K, Mg, and Fe.[11]

Almost 50% of the plants under K trial were observed to be low yielding. However, it was difficult to assign a particular nutrient as a cause for low yield. Potassium was found yield limiting in five continuous cropping seasons from 1994 although at different levels of K applications. The K concentration of different nutrients determined were in agreement with the previously suggested desirable ranges,[12] however, they were still identified as yield limiting. Phosphorous was the most common yield-limiting nutrient due to K application. Nitrogen was also found to have negative index mainly due to its imbalance with S as all

Table 4. Diagnosis of leaf nutrient imbalance by DRIS indices in N experiment plots.

Year	T	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Sum	Yield (t/ha)
1991	1	−415	305	−110	123	−94	240	48	−79	−85	67	1566	0.56
	6	−688	437	−299	1	−276	348	236	45	−138	333	2801	0.97
	8	−297	189	−477	156	−167	443	226	28	−161	60	2204	0.29
1992	1	170	102	95	−10	37	−116	−86	4	−6	−37	510	3.53
	2	71	2	−59	−16	91	−38	−3	−145	196	2	623	5.02
	7	66	−39	89	−8	54	−82	−43	−43	33	−28	485	4.65
	8	94	−9	−88	−36	59	−113	−1	46	83	−36	565	4.40
1993	1	−20	213	29	100	36	−143	65	−252	−15	−13	886	1.67
	2	−4	141	−14	101	36	−148	28	−25	−91	−23	611	2.32
	3	34	148	16	97	−1	−230	55	−143	16	7	747	2.21
	4	47	181	4	12	−3	−163	46	−136	3	8	603	2.54
	5	50	126	6	5	33	−172	51	−4	−28	−67	542	2.85
	6	102	123	−11	123	7	−187	78	−95	−86	−54	859	2.84
	7	77	52	−29	79	21	−113	53	16	−77	−79	596	2.96
	8	64	54	37	35	−22	−105	82	3	−56	−92	550	1.88
1994	2	−192	25	38	52	−271	−28	108	−38	52	254	1058	4.61
	3	−180	64	53	−34	−271	17	200	−209	74	287	1389	4.22
	7	−130	−17	34	102	−343	11	−176	218	−12	312	1355	4.51
	8	−81	−46	22	12	−277	18	81	83	6	182	808	2.80
1995	1	93	23	90	61	135	−4	−35	−29	−105	−233	813	1.10
	2	21	70	60	88	122	−116	173	−32	25	−409	1116	3.53
	3	156	23	119	13	252	−159	−119	−72	45	−257	1215	3.39
	4	215	83	167	−18	160	−24	−115	−189	−92	−184	1247	3.70
	5	135	88	22	148	207	−95	−72	−32	−18	−384	1201	4.34
	6	176	26	105	76	161	−71	−38	−87	−110	−228	1078	3.18
	7	210	17	95	2	162	−77	−131	−181	−82	−115	1072	3.97
	8	159	41	143	100	128	10	−111	−120	−20	−330	1162	2.23
1996	1	85	22	83	52	128	−11	−40	−33	−95	−191	740	3.05
	2	26	4	61	91	124	−110	178	−29	27	−372	1022	3.55
	3	156	23	118	13	251	−160	−117	−72	45	−258	1213	3.60
	5	127	80	17	137	198	−100	−78	−37	−26	−316	1110	3.40
	8	151	35	136	92	121	4	−114	−122	−13	−290	1078	3.10
1997	3	24	−57	63	4	28	−12	−8	1	−27	−17	241	6.04
	5	57	16	−71	−97	−8	34	4	−43	100	8	438	6.09
	6	99	12	36	−285	−25	40	−7	−1	125	6	636	5.92
	7	90	−1	−72	−327	34	−37	−52	−14	141	238	1006	6.23
	8	80	−27	−23	72	−21	27	−55	−102	−67	116	590	4.75
1998	1	42	41	−113	−59	−31	−14	−93	22	17	188	620	1.39
	2	174	184	−13	−533	81	2	−77	−165	116	229	1574	1.85
	3	57	85	−85	−101	47	−35	−147	−51	174	57	839	1.56
	4	116	92	−142	−26	−1	22	−201	5	24	111	740	1.96
1999	1	−37	−30	−461	77	41	63	1	24	173	149	1056	6.50
	3	−113	−93	−291	115	89	−62	88	25	103	138	1117	6.55
	6	−41	34	−74	117	−35	52	−72	14	67	−61	567	6.60
	7	18	22	−81	92	66	−16	−31	60	−17	−114	517	6.70
	8	−1	−10	−142	62	47	126	−68	−135	35	85	517	6.25
				r (overall) = −0.565**						r = −0.411**			

Note: r is the correlation between sum of indices irrespective of sign and yield. *T*, treatment as detailed in Table 1.

Table 5. Diagnosis of nutrient imbalance by DRIS indices in P experiment plots.

Year	T	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Sum	Yield (t/ha)
1991	1	−420	251	−212	116	−235	104	269	−2	102	28	1739	0.98
	2	−598	638	−249	42	−166	−35	252	−15	106	25	2126	0.45
	3	−557	403	84	−9	−129	69	107	−250	216	65	1889	0.40
	5	−422	399	285	53	−186	−51	214	−225	−36	−32	1903	0.64
1992	3	−82	−83	142	−135	57	196	−117	−11	−13	46	882	5.42
1993	3	−22	106	24	4	−6	82	−42	1	23	−171	477	3.25
1994	1	9	59	32	35	−311	−31	−153	115	54	192	991	4.40
	2	−18	63	40	89	−213	27	−138	96	−77	131	892	4.61
1995	Nil												
1996	1	30	−74	32	6	17	−33	88	17	−57	−27	381	3.46
	2	33	−34	−67	76	8	−32	42	110	−89	−47	538	3.70
	3	−16	−108	0	62	33	−23	32	93	−55	−19	441	3.14
1997	1	−18	−100	63	88	−38	−120	−33	11	−40	188	699	6.09
	2	20	41	1	−291	176	−50	63	33	79	−73	827	5.41
	3	−30	11	50	123	38	−22	4	−68	−68	−38	452	5.80
	4	74	−30	7	−255	77	−32	96	47	−11	27	656	5.90
	5	24	52	60	−272	45	−24	37	62	−28	44	468	6.51
1998	4	28	−101	−103	−57	132	81	−144	54	30	80	810	1.84
	6	35	159	80	−567	216	40	−31	−154	−80	303	1665	1.55
1999	1	−30	−37	−184	−69	−8	179	−97	−45	129	−61	739	6.60
	4	31	−121	−113	65	−57	279	−91	−166	146	27	1096	6.30
	5	−12	128	−137	−45	−50	82	−82	−60	148	26	770	6.10
							$r = -0.709^{**}$						

other forms of N expression often had value more than the norm value. The K application also affected to a certain extent the content of secondary and micronutrients in mango leaves (Table 6).

Nutrient Imbalance Index (NII)

The sum of the indices irrespective of sign showed significant negative relationship with yield for data obtained from three experiments ($r = -0.565^{**}$). The imbalance in individual experiments also had negative relationship with yield ($r = -0.411^{*}$ in N experiment, $r = -0.709^{**}$ in P experiment, $r = -0.700^{**}$ in K experiment). When imbalance of nutrients was more, the yield was also low as it is not the absolute nutrient concentration that is important, rather their relative balance. However, yield cannot be predicted from sum of indices

Table 6. Diagnosis of nutrient imbalance by DRIS indices in K experimental plot.

Year	T	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Sum	Yield (t/ha)
1991	1	−597	380	282	−54	−106	198	88	−111	−62	−17	1895	0.67
	2	−483	203	298	−134	−144	194	154	−114	−61	89	1874	0.44
	3	−74	−59	360	−301	−307	−127	153	18	152	184	1735	0.92
	4	−221	407	418	−277	−251	−148	195	−13	−133	23	2086	0.63
	5	−78	−87	446	−370	−60	−84	133	−34	105	30	1427	0.66
	6	−230	31	576	−361	−38	−56	193	−35	−64	−17	1601	1.03
1992	2	−9	−31	270	−68	54	−16	−75	−158	212	−179	1072	4.06
	3	−4	−35	132	−101	97	−26	−76	−39	79	−28	617	5.47
	4	26	−91	1	48	−31	−50	−57	16	119	18	457	4.91
1993	Nil												
1994	2	−34	−6	−63	−63	120	−32	40	77	−26	−13	474	4.53
	4	−18	10	−3	−30	123	31	62	−131	−49	5	462	3.81
	5	−21	−10	−5	−115	107	8	26	50	−27	−14	383	4.40
1995	1	51	−239	−126	31	30	35	39	178	−12	15	756	4.48
	2	24	−35	−166	84	5	9	22	239	−86	−96	766	3.83
	6	97	−96	−129	74	−37	40	18	96	−58	−6	651	4.31
1996	3	121	4	−122	−45	−9	105	60	−86	−3	−25	580	3.74
1997	2	81	−107	74	−59	−3	−127	40	155	13	−68	727	6.20
1998	1	−47	−104	42	−19	165	207	−85	−144	29	−44	886	1.08
	2	4	−11	−98	−42	76	125	−68	−44	68	−11	547	1.80
	3	−106	−144	15	17	112	236	−217	19	90	−22	978	1.36
	5	−78	−62	−89	−119	−19	343	−113	4	116	18	961	1.84
	6	−23	−104	−11	−58	26	113	−63	31	101	−20	550	1.59
1999	1	31	−37	−334	16	16	87	61	−50	198	11	841	5.35
	2	79	−60	−180	19	76	101	123	−204	48	0	890	5.30
						$r = -0.700^{**}$							

irrespective sign because of the influence of unmeasured factors that affect the yield but not included in calculation of DRIS indices.[13] The nutrient concentration variation in mango leaf appears to be an overall orchard phenomenon rather than individual tree phenomenon.

Principal Component Analysis

Several options were available to conduct PCA, however, PCA was performed using nutrient concentration data from low and high yielding populations and for DRIS indices.

The first PC of the low yielding population was positively correlated with P, S, Fe, and Cu and negatively with N and Mg and was designated as (N−P+Mg−S−Fe−Cu+). The contrast indicates inverse relationship between foliage N and Mg on the one hand and P, S, Fe, and Cu on the other hand due to concentration changes in opposite directions with time. The first component had a very high correlation ($r = -0.844$) with N followed in importance by Mg ($r = -0.747$). The second PC was designated as (K−Ca+S+Mn+Zn+Cu+). The PC2 formed however, effective in separating chemical elements into two groups based on their mobility. Potassium behaved in one direction while Ca, S, Mn, Zn, and Cu in the opposite direction (Table 7). The PC3 (K−Ca+S+) performed on the high yielding population also appear to pick up the contrast between K and (Ca+S+). The involvement of several nutrients both in first and second PC indicates that, the diagnosis of nutrient imbalance of any single nutrient is not possible in isolation. The third PC was designated as PC (Mn−) and therefore, in contrast to other elements the build or depletion of Mn in leaf occurred independently.

The three eigen values added up to 5.79 explaining about 58% of the total variance. The varimax rotation of the PCs redistributes the eigen values (with out loosing any original variance) in order to maximize the relationships among the standardized variables. The rotation itself does not modify the interpretation of result.[14] The three PCs with eigen values 5.79 before rotation showed eigen value 3.68 after varimax rotation (data not shown) explaining only 36.8% of total variance, therefore, the idea of varimax rotation was abandoned.

The PCA conducted on high yielding population also indicated involvement of several nutrients in a single PC and PC1 was designated as (N+P+Fe+Mn+Zn−Cu−). The positive loading for N (0.497) and a high score for Zn (−0.802) in PC2 indicate interaction between these two elements in high yielding population. It is commonly held view that P has a positive significant interaction with N absorption and that of Mn as well. The increase in ratio of P to Zn due to lowering of Zn concentration because of heavy P application has been reported earlier in some other crops.[15,16] However, the interaction between P and Fe is difficult to explain. Although some studies have been reported earlier, the micronutrient interaction is not fully characterized in mango.

In the third option, PCA was conducted on DRIS indices derived for low yielding population. The DRIS indices are standardized at the steps of computing DRIS functions and are amicable for conducting PCA.[17] The first PC derived from indices was identical as that of PC1 derived

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Table 7. Principal component analysis of log transformed nutrient concentration and for DRIS indices.

	Low			DRIS indices			High		
	PC1	PC2	PC3	PC1	PC2	PC3	PC1	PC2	PC3
N	−0.844*	0.186	0.075	−0.912*	0.082	0.105	0.497*	0.178	0.183
P	0.623*	−0.341	0.367	0.661*	−0.465*	−0.198	0.350*	−0.622*	0.205
K	0.108	−0.698*	−0.088	−0.098	−0.749*	0.323	0.216	−0.194	−0.694*
Ca	−0.051	0.374*	0.187	−0.066	0.224	−0.840*	0.153	−0.320	0.685*
Mg	−0.747*	0.054	0.382	−0.804*	−0.153	−0.076	−0.342	0.781*	−0.0018
S	0.344	0.583*	0.353	0.414*	0.528*	−0.028	−0.303	0.365	0.515*
Fe	0.639*	−0.138	0.102	0.653*	−0.353	−0.176	0.505*	0.148	0.037
Mn	0.047	0.527*	−0.674*	−0.032	0.517*	−0.163	0.391*	0.299	0.373
Zn	0.240	0.507*	0.418	−0.045	0.274	0.569*	−0.802*	−0.196	−0.072
Cu	0.578*	0.443*	−0.203	0.592*	0.409*	0.486*	−0.579*	−0.431*	0.319
Eigen value	2.587	1.871	1.340	2.880	1.771	1.484	2.035	1.636	1.540
% Variance	25.86	18.71	13.40	28.8	17.7	14.80	20.35	16.36	15.39
Selection criteria	0.310	0.365	0.431	0.294	0.375	0.410	0.350	0.390	0.402
	PC1 = N − P + Mg − S + Fe + Cu+ PC2 = K − Ca + S + Mn + Zn + Cu+ PC3 = Mn −			PC1 = N − P + Mg − S + Fe + Cu+ PC2 = P − K − S + Mn + Cu+ PC3 = Ca − Zn + Cu+			PC1 = N + P + Fe + Mn + Zn + Cu − PC2 = P − Mg + Cu+ PC3 = K − Ca + S+		

Significant loading.
Low, low yielding population.
High, high yielding population.

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from nutrient concentrations and was found to explain nearly 28.8% of the variance. However, the PC2 derived from indices were slightly different from the one that was explained by nutrient concentration. The loading for P was significant both in PC1 and PC2 indicating that the variance in P was not fully explained by PC1 alone.

CONCLUSIONS

From the foregoing discussion, it becomes evident that nine years of continuous fertilizer application to mango at different levels produced no specific effect either on leaf nutrient concentration or on fruit yield. It appears that soil may not have been sufficiently deficient in any of the nutrients studied to allow for significant differences in yield and consequently difference in the DRIS indices. It is also apparent that, it is impossible to diagnose imbalance of any particular nutrient in isolation since large number of nutrients either increase or decrease together. Therefore, to improve the nutrient concentration levels in leaf through external application, it is necessary to go in for multinutrient correction. The correction of N imbalance is possible only at the cost of resulting imbalance in P, Mg, S, Fe, and Cu. Similarly, the correction in K level in leaf is likely to result in imbalance of as many as five nutrient elements viz., Ca, S, Mn, Zn, and Cu. The realization of higher yield is possible only when multinutrient interaction is addressed to. Therefore, it is important, in addition to developing norms, to diagnose the multinutrient interaction to isolate the elements that behave in opposite direction. When long-term fertilizer application is planned in mango, nutrient management strategies can be planned taking in to account the multinutrient interactions.

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