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Multivariate diagnosis of nutrient imbalances in different yield categories of litchi in north Indian lower Himalayas

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ABSTRACT

In this study, multivariate compositional nutrient diagnosis (CND) norms were developed for diagnosis and identification of yield limiting nutrients in low yielding litchi orchards of Northern Himalayas of India. Data bank on leaf nutrient concentration *vs.* fruit yield was generated by conducting a regional survey in selected litchi orchards of Uttarakhand. Further, Principal component analysis (PCA) was used to study nutrient interactions in the Litchi plant.Results obtained indicate, in fruiting terminal (FT), CND norms for Nitrogen (V_N), Phosphorus (V_P) and Potassium (V_K) were 3.62, 2.41 and 3.40 respectively whereas CND norms for Calcium (V_{Ca}), Magnesium (V_{Mg}) and Sulphur (V_S) were 3.87, 2.82 and 1.51 respectively. Among micronutrients, Fe had higher norm value (V_{Fe} –0.45) in FT indicating higher Fe requirement as compared to Mn, Zn, Cu, B and Mo. Similarly, the CND norms in non-fruiting terminals (NFT) for V_N, V_P, V_K, V_{Ca}, V_{Mg} and V_s were 3.57, 2.40, 3.53, 3.93, 2.72 and 1.33 respectively. But, PCA performed on log transformed data of FT for P, S, Zn, Mn and B showed positive correlation whereas N, K, Ca and Fe have shown negative correlation whereas in NFT, P, K, Cu, B showed positive correlation compared to Ca, Mg, Mo which shown negative correlation in FT. Zn being a key micronutrient showed both positive and negative correlation in FT and NFT. Altogether, PCA indicated the existence of multi-nutrient interaction in litchi. The CND indices identified S, B, Zn and Mo as most common yield limiting nutrients in litchi.

Keywords: *Litchi chinensis*, nutrient interaction, yield limiting nutrients.

INTRODUCTION

Litchi, an important sub-tropical evergreen fruit crop, popularly known as 'queen of the fruits' with its attractive deep pink/red colour and fragrant aril (Singh *et al.,*1). India is the second largest producer of litchi in the world after China with an area of 93,300 hectare and annual production of 568,200 tonnes (Anon,2). The average productivity of litchi in the country is 6.1 tonnes per hectare in 2016-17, which is much lower than the potential productivity of the crop. It can be grown successfully on a wide range of soil types ranging from sandy loam, alluvial sand, and calcareous soils but it performs better in alluvial sandy loam soils with good drainage and access to the water table (Singh *et al.,*1). In Uttarakhand, a lower Himalayan state of India having hot summer months with dry, cool winter and free from frost are favourable for litchi.

The taxonomy, morphology and mycotrophic habit of mycorrhizal association with litchi have been described substantiating litchi - mycorrhizal interaction for optimum growth and higher production with better quality fruits. In addition, litchi plant requires adequate nutrients to sustain optimum vegetative growth and fruiting. When leaf nutrient concentration falls below critical levels, visible symptoms appear prior to reduction in growth and yield. Therefore, to avoid any yield penalty, continuous assessment and monitoring of the concentrations of nutrients in plant and soil within acceptable range is necessary. Lack of a suitable nutrient management practices, understanding of nutrient composition and their interactions in litchi are the major factors for limiting litchi production in lower Himalayas. The deficiency of major nutrients decrease plant growth significantly affecting flowering, and applications of N, P, and K have been found to promote growth, flowering and fruit yield.

The leaf analysis is considered to be a more direct method of plant nutritional evaluation than soil analysis especially for fruit crops (Hallmark and Beverly,3). Several approaches have been adopted for interpretation of leaf analysis data, developing diagnostic norms and identification of nutrient imbalance in recent years. Of late, it is Compositional Nutrient Diagnosis (CND) (Parent and Dafir, 4). The CND uses log transformed multi-nutrient ratios (row centered log ratios), which are fully compatible with

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principal component analysis (PCA) to address the problem of multi-nutrient interaction in plant. The correlation structure among the nutrients can be extracted by PCA. Therefore, CND norms which are multivariate, with due weightage to all the essential nutrient elements including unmeasured factors have higher diagnostic sensitivity (Parent *et al.,*5). The CND technique further expanded the dual ratio concept of Diagnosis and Recommendation Integrated System (DRIS) to a multi-dimensional one. The CND recognizes high order interaction between nutrients which is only partially addressed by DRIS (Parent and Dafir, 4). There are no or little information in the literature on the use of multivariate nutrient diagnosis in litchi. Keeping in view, the present investigation was carried out to develop multivariate diagnostic norms using CND approach to improve the diagnostic precision and to identify the yield limiting nutrients in low yielding orchards of litchi through CND indices, most important is to understand the interaction among the nutrients which are governing the yields of the litchi by PCA under lower Himalayan region of India.

MATERIALS AND METHODS

The leaf nutrient concentration *vs* yield data bank was developed based on the survey carried out during 2012-13 in different litchi growing districts of Uttarakhand *viz.,*U. S. Nagar, Nainital, Champawat, Dehradun and Haridwar (Table 1) involving collection of soil and leaf samples. The present investigation was carried out on 20-30 years old litchi trees variety ‘Rose scented’. From each orchard, 25 to 30 trees were selected, and 50 leaves were collected randomly toform a composite sample. Leaf samples (one leaf sample per orchard, total=145) were collected by selecting 3rd to 5th position on the shoot appearing both on fruiting terminals (FT), which bear the fruits and vegetative flush in a balanced proportion for normal fruiting and non-fruiting terminals (NFT) of each orchard as out lined by Babita and Chadha (6) to develop nutrient diagnostic norms. The samples were taken to the laboratory on the same day for further processing and analysis.

The leaf samples were decontaminated, by washing and dried in an oven at 72°C for 48 h. After complete drying, the samples were powdered and stored in polycarbyl containers for further analysis (Bhargava and Raghupathi, 7). The leaf samples were analyzed for N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B and Mo. Except N, all other nutrients in leaf samples were analyzed in di-acid digests (9:4 ratios of nitric and perchloric acids) by following standard analytical methods (Jackson, 8).

After establishment of data bank of leaf nutrient concentration *vs* fruit yield of litchi, the whole population was divided into two sub-groups, namely low-and high-yielding orchards, taking 70 kg tree^{-1} as the cut-off yield. The orchard which is yields more than 70 kg tree^{-1} of litchi were considered as high yielding orchard and less than 70 kg tree^{-1} were constituted low yielding orchards. The cut-off yield was positioned in such a way that the high-yielding subpopulation reflected conditions that are deemed desirable. Out of 145 litchi orchards surveyed, 95 are considered as a high yielding orchards and 50 are low yielding orchards based on cut-off yield. High-yielding orchards was used for deriving CND norms, while the CND indices were developed for low yielding orchards for diagnosis of nutrient imbalance and identification of most yield limiting nutrient nutrients in litchi.

The CND norms were developed by adopting the procedure followed by Parent *et al.* (5). The full composition array for D nutrient proportions in plant tissues canbe described by the following simplex S^D contained to 100%.

S^D= [(N, P, K....R): N>0, P>0, K>0........R>0; N+P+K.....+R] = 100 %...................................(1)

Where, 100% was dry matter content; N, P, K were the nutrient concentrations and R was filling value between 100% and sum of the nutrients concentrations. Nutrient concentration was corrected by geometric mean, G of all components including R.

G= (N × P × K x.....x R)$^{1/D}$ ....(2)

The row centered log ratios were generated as follows:

V_N=ln (N/G) ....V_{Mo}=ln (Mo/G) ....(3)

Table 1. Geographical information of different districts of Uttarakhand in the surveyed region.

Sl. No.	Name of district	Latitude	Longitude	Altitude (m)
1	U. S. Nagar	$28^0$88’78’’ to 28^0 99’84’’ N	79^o64’ 70’’ to 79^o 40’83’’E	250
2	Nainital	$29^0$01’25’’ to $29^0$17’38’’ N	$79^0$08’18’’ to $79^0$20’39’’ E	2,084
3	Champawat	$28^0$58’40’’ to $29^0$06’00’’ N	$80^0$03’26’’ to $80^0$07’41’’ E	1,610
4	Dehradun	$29^0$01’25’’ to $29^0$17’35’’ N	$77^0$46’32’’ to $77^0$54’14’’ E	450
5	Haridwar	$30^0$02’34’’ to $30^0$15’40’’ N	$78^0$05’29’’ to $78^0$11’24’’ E	314

Expressions such as N/G……. Mo/G are multi-nutrient ratios, since each nutrient is divided by geometric means of all the components (the determined nutrients and the filling value). The row-centered log-ratios are linearized (undistorted) estimates of the original components that are fully compatible with PCA (Parent and Dafir, 4; Parent *et al.,*5).

The PCA was performed on log transformed data of the original nutrient concentration prior to statistical computation that followed normal distribution. The correlation matrix in PCA generates a linear combination of standardized row centered log-ratios as follows:

$PC_j=a_{ij}(V_N-V^*_N)/SD^*_N+$...............+ $a(D-1)\ j(V_{Mo}-V^*_{Mo})/SD^*_{Mo}$...........(4)

WherePC_j is the jth principal component, and a_{ij} to $a_{(D-1)}$ [(D-1) components excluding R as specified above] are PC score coefficients of standardized row centered log-ratios. $V^*_N$to V^*_{Mo} and SD^*_N to SD^*_{Mo} were CND norms (indicated by asterisks) i.e. mean and standard deviation of each row centered log ratio in the high yielding orchards. Standardized variables $(V_N-V^*_N)/SD^*_N$ to $(V_{Mo}-V^*_{Mo})/SD^*_{Mo}$ were CND nutrient indices. The indices (I) for N to Mo are calculated in low yielding orchardby using the formula

$I_N=(V_N-V^*_N)/SD^*_N$,............,$I_{Mo}\ (V_{Mo}-V^*_{Mo})/SD^*_{Mo}$ .... (5)

Independent values of V_N to V_{Mo} were introduced in the equation (5) for diagnostic purpose.

The PC loading in eigen vector having values greater than the selection criterion (SC) only were considered significant. For a selection criterion to be declared as significant, PCs must have eigen values >100/P, where P is the total number of varieties under diagnosis. Alternatively, PCs showing eigen values <1 were considered to be not significant. Selection criterion would be computed as follows (Ovalles and Collins, 9):

SC = 0.50 / (PC eigen values) $^{0.5}$ ……........................…. (5)

The selection of high and low yielding orchard was carried out using Microsoft Office Excel- 2010. The calculation of norms, indices and PC analyses were carried out using GenStat 64-bit release 14.1 (VSN International Ltd. International Crop Research Institute for Semi -Arid Tropics -ICRISAT, Hyderabad, India).

RESULTS AND DISCUSSION

Mean of leaf nutrients concentration of in FTs and NFTs of high and low yielding orchards of litchi are presented in Table 2. The differences in concentrations of different nutrient elements in fruiting terminals of high and low yielding orchards were only marginal. Only the concentration of N, Mn, B and Cu were marginally lower while that of P and Fe were marginally higher in FT of low-yielding orchards as compared to high yielding orchards. The concentrations of different nutrient elements in NFT showed no large differences between high and low- yielding orchards. Only the concentration of N, Fe, and Mo were marginally lower in low- yielding orchards compared to high yielding orchards. The presence of higher concentration of most essential elements in the high yielding orchards indicated that these nutrients might have governed the yield and growth attributes of litchi to a greater extent.

Table 2. Mean of leaf nutrients concentration in fruiting and non-fruiting terminals of high and low yielding orchards of litchi.

Nutrient	Fruiting terminals		Non-fruiting terminals	
	High yielding orchards	Low yielding orchards	High yielding orchards	Low yielding orchards
N (%)	0.96	0.89	0.86	0.81
P (%)	0.28	0.32	0.27	0.28
K (%)	0.75	0.72	0.85	0.81
Ca (%)	1.21	1.20	1.23	1.28
Mg (%)	0.42	0.40	0.36	0.35
S (%)	0.12	0.11	0.09	0.10
Fe (µg g^{-1})	168.2	181.8	150.6	142.5
Mn (µg g^{-1})	30.0	27.3	25.0	24.6
Zn (µg g^{-1})	14.0	13.4	17.2	16.0
Cu (µg g^{-1})	9.82	8.98	11.7	11.2
B (µg g^{-1})	39.0	33.4	34.8	33.8
Mo (µg g^{-1})	0.28	0.26	0.25	0.22
Yield (kg tree^{-1})	102	49	102	49

N-Nitrogen; P-Phosphorous; K-Potassium; Ca-Calcium; Mg-Magnesium; S-Sulphur; Fe -Iron; Mn-Manganese; Zn-Zinc; Cu-Copper; B-Boron, Mo-Molybdenum.

Higher concentration of essential elements in high yielding population as compared to low yielding population had also reported by Hundal and Arora (10) in kinnow, and Anjaneyulu (11) in papaya. Large variations in nutrient concentrations of leaves of FT and NFT were recorded. The NFT showed significantly higher concentrations of K, Zn and Cu as compared to FT probably owing to their movement to the developing fruits. Conversely, the Mg, Fe, Mn, B and Mo concentrations in the leaves were significantly lower in the NFT. The results of the present investigation were in corroboration with the finding of Kotur and Singh (12) for K, Mg, Mn, B and Mo. The fruit yields in the high yielding orchards varied from 70 to 200 kg tree^{-1}with mean yield is 102 kg tree^{-1} whereas in the low yielding orchards the yields varied from 20 to 65 kg tree^{-1}with mean yield is 49 kg tree^{-1}.

The CND nutrient element norms (mean and standard deviation) used to solve equations 3 and 4 are presented in Table 3. In FT, the CND norms for

N (V_N), P (V_P) and K (V_K) were 3.62, 2.41 and 3.40, respectively. Among the macro nutrients, the CND norm derived for N indicated higher requirement of N as compared to K, which might be due to continuous and non-determinate type of vegetative growth in litchi. The Ca norm (V_{Ca} 3.87) was twice as high as that of Mg (V_{Mg}2.82). Among micronutrients, Fe had higher norm value (V_{Fe}0.45) indicating higher Fe requirement as compared to Mn, Zn, Cu B and Mo (Table 3).

For NFT (Table 3), the CND norm for V_N was3.57, V_P(2.40) and V_K(3.53). The Ca norm (V_{Ca} 3.93) was twice as high as that of Mg (V_{Mg} 2.72) norm. The CND norm for S (V_S 1.33) lies in between Ca and Mg norm. Among micronutrients, Fe had higher norm value (V_{Fe}-0.54) therefore its requirement was much higher as compared to Mn, Zn, Cu, B and Mo like in the case of FT. Similar type of classification was earlier reported in sapota (*Manilkara zapota* cv. Kalipatti) by Anjaneyulu and Raghupathi (13).

The CND norms for micronutrients showed the negative signs because the expressions such as N/GM..... Zn/GM were multi-nutrient ratios, where each nutrient was divided by geometric means (GM) of all the components. The row -centered log-ratios were linearized (undistorted) estimates of the original components. Since they were log transformed values it became negative especially, for nutrients which were present in small quantity. Therefore, for micronutrient negative CND norms were obtained in both FT and NFT in litchi.

The multivariate diagnostic norms generated higher values of N, P, Mg and S for FT as compared to those of the NFT. Such a trend suggested greater requirements of N, P, Mg and S for FT development. The differences in norms of FT and NFT were also recorded for Ca and Mg. The V_{Ca}norm values for FT and NFT were 3.87 and 3.93 and V_{Mg}norm values for FT and NFT were 2.82 and 2.72 respectively. The CND norm for Fe in FT (V_{Fe} -0.45) was marginally higher as compared to that of NFT (V_{Fe} -0.54). The norms for Mn, B and Mo were also higher for FT as compared to those of NFT. The norms for Zn and Cu were lower for FT as compared to that of NFT.

Nutrient interactions were investigated using PCA. The PCA conducted on log-transformed data produced five significant PCs(Principal components) and five eigen values added up to 7.67 explaining about 63.9 percent of the total variance (Table 4). The interaction of as many as five nutrients was evident in PC1. The first PC was positively correlated with S, Zn and B but negatively correlated with Fe and Cu indicating that S, Zn and B behaved in one direction and the rest of the nutrients in the opposite direction and its structure suggested that S+ Zn+ B+ Fe- Cu-. The second PC was negatively correlated with K, Ca and Mg. In PC3, antagonistic effect of N and Mo with Mn was evident. In PC4, P was isolated. The PC5was positively correlated with S, negatively correlated with Zn and Cu indicating that S behaved in one direction and the rest of the nutrients in an opposite direction and explained only 9.86 percent of variance which was of minor significance. In the similar studies Raghupathi and Bhargava (14) applied PCA approach in pomegranate (*Punica granatum*) for explaining nutrient interactions. These nutrient interactions need to be considered for the correction of nutrient deficiencies and for evolving nutrient management strategies for litchi to obtain higher yield and better quality.

Table 3. Compositional nutrient diagnosis norms of fruiting and non-fruiting terminals for high yielding orchards of litchi.

CND Variate	Fruiting terminals		Non-fruiting terminals	
	CND norms	Standard deviation	CND norms	Standard deviation
V_N	3.62	0.28	3.57	0.30
V_P	2.44	0.27	2.32	0.28
V_K	3.40	0.20	3.53	0.20
V_{Ca}	3.87	0.22	3.93	0.27
V_{Mg}	2.82	0.17	2.70	0.23
V_S	1.51	0.27	1.33	0.38
V_{Fe}	-0.45	0.36	-0.54	0.38
V_{Mn}	-2.24	0.48	-2.36	0.42
V_{Zn}	-2.91	0.31	-2.70	0.21
V_{Cu}	-3.26	0.30	-3.02	0.24
V_B	-1.87	0.29	-1.94	0.30
V_{Mo}	-6.92	0.42	-6.94	0.46

V_N-Nitrogen, V_P-Phosphorus, V_K -Potassium, V_{Ca}-Calcium, V_{Mg}-Magnesium, V_S-Sulphur, V_{Fe}-Iron, V_{Mn}-Manganese, V_{Zn}-Zinc; V_{Cu}-Copper; V_B-Boron, V_{Mo}-Molybdenum.

Similarly, PCA was also conducted on log-transformed data of NFT which is produced in five significant PCs and five eigen values are added up to 7.90 explaining about 65.8% of the total variance (Table 4). In first PC, a negative correlation with Ca and Mg but a positive correlation with K was observed and its structure suggested K+Ca- and K+Mg-. In the second PC, the antagonistic effect of P and Zn was evident and its structure suggested P+Zn-. In PC3, positive correlation with Zn and Cu but negative correlation with Fe and Mo was noticed indicating that Zn and Cu behaved in one direction and Fe and Mo were in opposite direction. In PC4, B was isolated. The PC5, explained only 9.27% of variance and had a minor significance. Wairegi and Van-Asten (15) and Raghupathi *et al.* (16); used PCA approach for explaining nutrient interactions in banana (*Musa* spp. A)

Table 4. Principal component analysis (PCA) loading performed on log-transformed data of fruiting terminals.

Nutrients	Fruiting terminals					Non- fruiting terminals				
	PC1	PC2	PC3	PC4	PC5	PC1	PC2	PC3	PC4	PC5
N	-0.196	0.151	-0.457*	-0.238	-0.329	0.076	0.110	-0.060	-0.374	-0.443
P	0.131	0.207	-0.275	0.556*	-0.077	0.038	0.522*	-0.064	0.042	0.256
K	-0.039	-0.493*	-0.222	0.210	-0.131	0.439*	0.196	0.178	0.109	-0.333
Ca	0.027	-0.420*	0.126	0.025	-0.249	-0.537*	0.252	0.094	0.149	-0.189
Mg	0.155	-0.469*	-0.170	-0.146	0.077	-0.511*	0.268	0.103	0.165	-0.170
S	0.351*	0.081	0.232	0.254	-0.511*	0.149	-0.295	0.197	0.357	-0.408
Fe	-0.508*	0.093	0.089	0.137	-0.192	-0.144	-0.226	-0.483*	-0.252	0.013
Mn	-0.257	0.201	0.543*	-0.232	0.039	-0.192	0.018	0.047	-0.111	0.087
Zn	0.362*	0.143	0.120	0.336	0.510*	-0.070	-0.384*	0.483*	-0.276	0.500*
Cu	-0.425*	-0.265	-0.086	0.144	0.481*	0.231	0.077	0.434*	-0.398	-0.043
B	0.366*	-0.240	0.228	-0.372	0.012	0.178	-0.106	0.079	0.599*	0.328
Mo	0.210	0.301	-0.437*	-0.398	0.143	0.284	0.212	-0.488*	-0.004	0.168
Eigen Value	2.043	1.585	1.539	1.321	1.183	1.953	1.792	1.701	1.340	1.113
%Variation	17.02	13.21	12.82	11.01	9.86	16.28	14.93	14.17	11.17	9.27
Selection criteria*	0.349	0.397	0.403	0.435	0.459	0.358	0.374	0.383	0.432	0.474

N -Nitrogen; P -Phosphorous; K -Potassium; Ca -Calcium; Mg -Magnesium; S -Sulphur;Fe -Iron; Mn -Manganese; Zn -Zinc; Cu -Copper; B-Boron, Mo-Molybdenum, *Significant over selection criteria, Fruiting terminals, PC1 (S+Fe-Zn+Cu-B+); PC2 (K-Ca-Mg); PC3 (N-Mn+Mo-); PC4 (P+); PC5 (S-Zn-Cu-). Non-fruiting terminals, PC1 (K+Ca-Mg-); PC2 (P+Zn-); PC3 (Fe-Zn+Cu+Mo-); PC4 (B+); PC5 (Zn-).

Therefore, using PCA and CND discards the random information and retains only significant factors. Each varimax-rotated factor contains interpretable information on nutrient interactions, discharge, dilution, or accumulation and can be diagnosed independently with respect to a multivariate critical sphere (Parent *et al.*,5). Since CND was related to PCA (Parent *et al.*,5), PCA had been applied to CND derived row-centered log ratios to explore nutrient relationships in studies by Parent *et al.* (17) in potato and also by Raghupathi *et al.* (16) in banana (*Musa spp.*). Therefore, the PCA indicated the existence of multi-nutrient interaction in litchi and correction of nutrient imbalance could not done in isolation and therefore, multi-nutrient diagnostic norms were required for identification of nutrient deficiency or excess in particular soil type.

Independent values were introduced from low yielding orchards for the purpose of diagnosis of a nutrient that limits the yield. The nutrient indices near to zero indicated the optimum level, negative values as relative deficiency and positive value as relative excess of that particular nutrient (Mourao Filho, 18). Out off of fifty low yielding orchards only fifteen selected low-yielding orchards presented in Table 5. Yield-limiting nutrients differed from orchard to orchard, though some nutrients were more prominent in low yielding orchards of FT. The S, Zn, B and Mo were common yield limiting nutrients in FT of litchi through CND indices. However, Ca Mg, Cu and Mn were also found to be low in some of the orchards as reflected from CND indices. Similarly, Zn and B were identified most common yield limiting nutrient in sapota (*Manilkara zapota* cv. Kalipatti) using CND indices by Anjaneyulu and Raghupathi (13).

Thus, the yield limiting nutrients were differing from orchard to orchard with different CND indices were more prominent. Hence, the CND simultaneously identified imbalances, deficiencies and excesses in crop nutrients and ranked them in order of importance. The correlations among indices indicated that N indices correlated with none of the nutrient indices whereas there was an overwhelming negative correlation between Fe and Zn indices, indicating their antagonism. Indices for K were also negatively correlated with Mn and positively correlated with Mg and Cu. Among the secondary nutrients, indices of Cawere positively correlated with Mg and Cu whereas indices of Mg were negatively correlated with Mn. The correlations among indices of micronutrients indicated that Fe indices were negatively correlated with B in FT of litchi (Table 5).

Similarly, for NFT also CND indices developed for fifty low-yielding orchards but only fifteen selected are presented in Table 6. Both macro-micronutrients were also found to be either low or deficient in low yielding orchards of NFT. The CND indices identified S, Mo, Zn and B in NFT as the most common yield limiting nutrients. However, most often more than two or four nutrients were found to be yield limiting nutrients and therefore, it can be anticipated that the larger the number of diagnosed nutrients, the higher the precision of diagnosis on tissue components (Raghupathi and Bhargava, 14). The correlation among indices indicated that N indices correlated with none of the nutrient indices in NFT of litchi. The

Table 5. Compositional nutrient diagnosis indices along with order of yield limiting nutrients in fruiting terminals of selected low yielding orchards of litchi.

Orchard No.	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo	Order of yield limiting nutrients
1	1.15	0.99	-1.12	0.08	-1.23	-2.26	2.60	0.56	0.99	-0.94	-1.60	-0.75	S>B> Mg>K>Mo
2	-0.43	0.06	-0.33	-0.92	-0.48	-0.65	1.70	-0.79	0.97	0.06	-0.12	0.31	Ca>Mn>S>Mg>N
3	0.71	1.07	0.84	-0.16	-1.45	-0.26	0.98	0.25	-1.78	0.20	-0.72	-0.22	Zn> Mg >B > Mo>Ca
4	0.23	1.77	-1.32	1.56	0.27	1.38	1.19	0.29	-2.82	-2.10	-1.64	0.86	Zn> Cu >B > K>Ca
5	1.41	0.30	1.38	0.20	-0.54	-3.27	0.90	1.40	-3.14	-0.78	-0.69	1.44	S>Zn> Cu >B > Mg
6	0.14	-0.04	0.64	2.63	0.90	-1.13	0.80	1.79	-0.51	0.32	-3.20	-2.17	B>Zn>Mo>Mn>P
7	0.01	1.55	0.88	-0.65	-1.22	-0.14	0.76	1.17	-2.67	-0.42	-1.97	1.17	Zn>B>Mg>Ca>Cu
8	0.54	1.03	0.94	1.13	0.89	-2.31	0.64	0.62	2.09	0.45	0.75	-1.48	S> Mo >Cu >N>Mn
9	0.47	0.41	0.57	1.92	0.31	0.24	0.54	-0.76	-1.77	1.07	-0.26	-0.78	Zn>Mo>Mn>B>S
10	-1.07	0.86	0.19	-0.31	-0.17	-1.16	1.86	0.45	-0.19	0.83	-3.00	0.29	B>S>N>Mn>Ca>Zn
11	0.46	1.58	1.29	0.32	0.70	-2.62	-1.11	-0.60	0.92	0.48	-2.11	1.33	S> B >Fe >Mn>Ca
12	0.38	-0.62	0.92	-0.41	0.36	0.27	0.68	-0.82	-0.91	0.65	-0.90	-0.85	B>Zn>Mo>Mn>P
13	-1.36	1.51	0.86	3.21	1.63	-0.82	1.05	-0.91	-0.85	-0.29	0.39	-2.66	Mo>N>Mn>Zn>S
14	-0.38	1.48	-0.27	0.28	0.17	0.05	1.42	-1.83	1.29	0.19	0.07	-0.65	Mn>Mo>N>K>B
15	0.90	0.85	0.52	1.96	-0.71	-1.97	-1.44	0.62	0.99	-0.47	0.48	-2.45	Mo>S>Fe >Mg>Cu

N-Nitrogen; P-Phosphorous; K-Potassium; Ca-Calcium; Mg-Magnesium; S-Sulphur; Fe -Iron; Mn-Manganese; Zn-Zinc; Cu-Copper; B-Boron, Mo-Molybdenum.

Table 6. Compositional nutrient diagnosis indices along with order of yield limiting nutrients in non-fruiting terminals of selected low yielding orchards of litchi.

Orchard No.	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo	Order of yield limiting nutrients
1	0.41	0.11	0.47	0.47	-1.52	-1.71	-0.45	-1.10	-0.32	0.97	1.04	1.39	S>Mg>Mn>Fe>Zn
2	1.08	0.35	0.75	2.13	2.17	-0.78	2.14	-1.60	-1.58	-0.36	-2.70	0.53	B>Mn>Zn>S>Cu
3	0.66	0.75	0.59	0.83	-0.32	0.73	0.11	-0.02	-0.15	0.16	-0.17	-0.65	Mo>Mg>B>Zn>Mn
4	-0.83	0.64	1.74	-0.09	0.89	-1.34	-0.80	-0.59	-0.94	1.03	1.21	0.04	S>Zn>N>Fe>Mn
5	0.76	0.15	-0.55	1.00	0.94	-0.37	-0.70	0.58	1.86	1.00	-2.11	-0.47	B>Fe>K>Mo>S
6	0.38	0.43	1.27	0.60	1.75	-0.86	1.16	0.24	-0.99	-0.76	1.99	-0.17	Zn>S>Cu>Mo>N
7	-0.47	-0.14	-0.22	-0.75	-0.36	-0.83	1.72	1.10	0.86	-0.49	-1.03	-2.30	Mo>B>S>Ca>Cu
8	-0.56	-0.35	0.56	-0.19	-0.90	-0.23	-0.64	-0.24	-3.83	0.78	-0.91	2.05	Zn>B>Fe>N>P
9	1.09	0.49	0.58	2.07	0.82	-0.68	0.29	1.19	1.08	0.21	-2.72	-0.74	B>Mo>S>Cu>Zn
10	0.53	0.84	-0.07	1.42	0.86	0.84	-0.57	-1.32	-0.48	-1.11	0.70	0.37	Mn>Cu>Fe>Zn>K>
11	0.15	-0.14	1.43	0.19	0.78	0.67	0.96	0.56	-3.44	-1.42	0.49	-0.99	Zn>Cu>Mo>P>N
12	-0.64	1.41	0.72	1.49	-1.02	-1.42	0.85	-0.63	-1.28	-2.20	0.32	0.12	Cu>S>Zn>N>Mn
13	0.13	-1.01	0.60	0.67	-0.38	-1.06	0.76	0.67	-0.56	-0.79	0.70	-0.33	S>P>Cu>Zn>Mo
14	-1.19	-0.21	3.67	0.07	0.57	-1.12	0.01	0.17	-2.82	1.52	-1.36	0.25	Zn>B>N>S>P
15	0.14	2.07	-0.69	0.54	0.42	-0.70	-0.54	0.22	-0.66	-0.53	0.86	-1.22	Mo>S>Mg>Zn>K

N-Nitrogen; P-Phosphorous; K-Potassium; Ca-Calcium; Mg-Magnesium; S-Sulphur; Fe -Iron; Mn-Manganese; Zn-Zinc; Cu-Copper; B-Boron, Mo-Molybdenum.

indices for P and K were highly negatively related with Mn. Among the secondary nutrients, index of Ca was positively correlated with Mg whereas, index of Mg was negatively correlated with Mo. The correlation among indices of micronutrients indicated that Fe index negatively correlated with B in fruiting terminals of litchi. The index for Zn was negatively correlated with Mo.

From the present investigation it can be concluded that the CND is the multivariate expansion of CVA and DRIS and it is fully compatible with PCA. The CND approachcan be suitably used as an important and holistic diagnostic tool for identifying the hidden hunger of various nutrient elements, to rectify the nutrient imbalance and to evolveproper nutrient management strategies for realizing higher and better quality fruit yield in litchi. Therefore, the CND indices identified S, B, Zn and Mo as the most common yield limiting nutrients in litchi under lower Northern Himalayas of India.

DECLARATION

The authors declare no conflict of interest.

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