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Diagnosis of Nutrient Imbalances and Yield Limiting Nutrients in Low Yielding Orchards of Litchi (*Litchi chinensis* Sonn.) in Lower Himalayas through DRIS Approach

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ABSTRACT

The Diagnostic Recommendation and Integrated System (DRIS) is a unique statistical tool and dual ratio concept employed to diagnose nutrient imbalance and identify most yield limiting nutrients. In present study a reliable data bank of nutrient concentration versus fruit yield was developed from survey of litchi orchards grown in lower Himalayas (Uttarakhand, India). Firstly the DRIS norms were established for various nutrient ratios which obtained from the high-yield population (HYP) and then they were used to compute DRIS indices in low yielding population (LYP). Sixty-six nutrient expressions were selected as DRIS ratio norms from HYP and were found to provide statistically significant variance ratios and lower co-efficient of variations. The important nutrient ratio expressions identified in the backdrop of greater physiological significance in fruiting terminals (FT) of litchi are: P/N (0.292), Ca/N (1.274), Mg/N (0.438), P/Mg (0.667), Ca/S (10.08), Zn/S (116.7), Fe/Cu (17.13) and Cu/B (0.252) whereas for non-fruiting terminals (NFT) that expressions are N/P (3.185), K/N (0.942), Cu/N (13.60), P/Zn (0.017), K/Mg (2.250), Ca/Mg (3.417) and Cu/Zn (0.727). The nutrient element S followed by Zn, Mo and B in FT whereas in NFT, S followed by Mo, B and Zn are most common yield-limiting nutrients in LYP of litchi.

Key words: *DRIS, Litchi, Nutrient ratios, Nutrient imbalance index, Yield limiting nutreint.*

INTRODUCTION

Litchi (*Litchi chinensis* Sonn.), an important sub-tropical evergreen fruit crop belonging to family 'Sapindaceae', is popularly known as 'queen of the fruits' with its attractive deep pink/red colour and fragrant aril[1,2]. In Uttarakhand, litchi is widely cultivated for table purpose fruit crop after the mango. One of major limitation for litchi production in Uttarakhand is lack of suitable pertinent nutrient management strategies.

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The proper nutrient balance is majorly essential to maintain optimum growth and fruit quality of litchi[3]. The deficiency of major nutrients N, P, and K decreased plant growth significantly affecting flowering of litchi[4,5]. Optimum supply of same nutrients was found to promote growth, flowering and increased the fruit yield[6]. Deficiency of boron in litchi causes to dropping of flower and fruit[7,8]. Litchi being very sensitive to boron deficiency especially when high levels of nitrogen is applied or if trees undergo moisture stress which results in fruit cracking[9], constituting it as one of the major physiological disorder in litchi. In order to avoid yield loss from nutrient deficiency, analysis of leaf is most important as it indicate plant nutritional status directly than indirect evaluation by soil analysis, especially suitable for fruit crops, as they differ from seasonal crops in their nutrient requirement due to their size, population density, rate of growth and rooting pattern[10,11]. Therefore, nutrient management practices in litchi can be ascertained based on analysis and monitoring of leaf and soil nutrient levels which are very important for achieving higher yields[12,13]. Among several approaches adopted for interpretation of leaf analysis data, Diagnosis and Recommendation Integrated System (DRIS) is considered to be more effective and reliable method[11] as it employs nutrient ratios and simultaneously identifies imbalances, deficiencies and excesses of crop nutrients with ranks assigned in the order of importance[14].

According to Beaufils[14] and Walworth and Sumner[15], with the growth of leaf tissue the concentrations of nitrogen, phosphorus, potassium and sulphur decrease in older plants while the concentrations of calcium and magnesium increase in older plants. Since DRIS method uses the dual ratio and the values remain constant, minimizes the effect of biomass accumulation. The DRIS norms established from the nutrient-indexing survey of litchi were used to compute DRIS indices from the foliar mineral composition of samples from different sites to identify the most essential nutrient elements as well as their orders of requirement. The DRIS provides a mathematical means of ranking a large number of nutrient ratios into nutrient indices that can be easily interpreted. It can also detect causes of low yield due to nutrient imbalance, even when none of the nutrients is below the critical level through an imbalance index[16]. The DRIS indices are used in the calibration to classify yield factors in the order of limiting importance. This method is beneficial over the other conventional method of critical level approach[15] in many of leveraging issues entailing

a. Identification of not only the most limiting element, but the order in which the other elements would likely to become limiting.
b. The ability to diagnose the plant nutrient need much earlier in the life span of the crop than the critical level approach thus, allowing one to take remedial measures earlier.
c. DRIS provides greater accuracy in diagnosis and offers relatively more freedom from the effect of some of the sampling variables such as the age of the plant part and geographical location *etc.*

This methodology has been amply and aptly used to interpret results of foliar analysis in myriad of crops such as banana[17], apple[18], grape[19,20], pineapple[21] and Coorg mandarin[22]. Hence the objectives of the present investigation was framed in the similar line for developing DRIS diagnostic norms for different nutrients based on regional survey for the purpose of identifying constrained yield-limiting nutrients and nutrient imbalances in low yielding orchards of litchi through DRIS indices.

MATERIALS AND METHODS

A regional survey was conducted during 2012-13 in the litchi growing districts of Uttarakhand *viz.*, U.S. Nagar, Nainital, Champawat, Dehradun and Haridwar for collection of leaf samples. Location of sampling sites of litchi orchards along with geographical information of different districts of Uttarakhand in the surveyed region was presented in Figure 1 and Table 1. Appropriate quantities of leaf samples were collected by selecting 3rd to 5th position of the shoots both on fruiting terminals (FT) and non-fruiting terminals (NFT) as out lined by Babita and Chadha[23].The pertinent data on yield and amount of fertilizers and manures provided to the litchi orchards including other management practices have been collected from each owning farmers during the survey.

The leaf samples were first decontaminated by washing them in series of washing solution starting with tap water to remove the dirt or soil, then in 0.2% detergent solution and with N/10 HCl solution to remove residues of chemical spray drops deposited on the leaf followed by last rinsing in single and double distilled water. Excess water was removed by pressing leaves between the folds of blotting paper and later leaf samples would be dried in an oven at 75^0 C for 72 h. After complete drying, the samples was powdered and stored in polycarbyl containers for further analysis. The leaf samples were analyzed for N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B and Mo. Excluding N, all other nutrients in leaf samples were analyzed after di-acid digestion (9:4 ratio of nitric and perchloric acids) by following standard analytical methods[24]. Nitrogen was estimated by Nessler's reagent method, whereas P, K and S content were estimated by vanado-molybdate, flame-photometry and turbidimetric methods, respectively. Calcium and magnesium were quantified by titrimetric methods and the micronutrients *viz*. Fe, Mn, Cu and Zn were analyzed through atomic absorption spectrophotometric method. Boron and molybdenum were estimated by colourimetry in dry ashed samples. Thus, a leaf analysis data bank was established for the entire sample population.

Computation of DRIS norms

DRIS norms were calculated and derived as described by Beaufils[14]. The whole sample population was divided into two sub-groups, namely samples from low yielding population (LYP) -and high-yielding population (HYP), setting 70 kg fruits per tree as the cut-off criteria. The orchards that yielded more than 70 kg fruits per tree were considered as high yielding orchard and those yield less than 70 kg fruits per tree were constituted low yielding orchards. The cut-off yield was positioned in such a way that the HYP (95 orchards out of 145) reflected conditions that are deemed desirable[14]. Letzsch and Sumner[25] also indicated that the actual cut-off value should have little effect on developing norms as long as it tends not too low. Nutrient ratios which (variance of low yielding/variance of high yielding population) varied significantly with higher variance were selected as DRIS norms. Individual nutrients were also considered for computation of DRIS norms in the same way as the nutrient ratios. Altogether, sixty six ratios involving two nutrients were selected for the twelve nutrients.

Computation of DRIS indices and nutrient imbalance index (NII)

The DRIS provides a means of ordering nutrient ratios into meaningful expressions in the form of indices. The DRIS indices were calculated as described by Walworth and Sumner[15] by using the following formula:

For example, in case of N the indices are

$$N = 1/10[f\ (N/P)-f\ (K/N)+f\ (N/Ca)+f\ (N/Mg)+f\ (N/S)-f\ (Fe/N)+f\ (N/Mn)-f\ (Zn/N)+f\ (N/Cu)-f\ (B/N)-f\ (Mo/N)]$$

Where, when N/P is larger or equal to n/p,

$$f\,(N/P) = \frac{(N/P - 1)}{n/p} \times \frac{1000}{CV}$$

when N/P is smaller than n/p,

$$f\,(N/P) = \frac{(1 - n/p)}{N/P} \times \frac{CV}{1000}$$

Where, N/P was the actual ratio of N and P in the plant which is under diagnosis and n/p is the value of the norm (mean of the HYP) and CV was the co-efficient of variation for the population of n/p for the high yielding orchards. Similarly, the indices for other nutrients were calculated using appropriate formulae. The absolute sum of values of the nutrient indices (irrespective of signs) will give rise to an additional index called the "nutrient imbalance index" (NII) which implies an overall imbalance of nutrients in each low yielding orchard. The greater the sum, higher will be the imbalance of nutrients[26,27].

RESULTS AND DISCUSSION

Concentrations of essential nutrients in litchi orchards

The differences in concentrations of different nutrient elements in FT of high and low yielding orchards were marginal. The concentration of N, Mn, B and Cu were slightly lower while that of P and Fe were marginally higher in FT of LYP as compared to HYP (Figure 2). The concentrations of different nutrient elements in NFT showed non-significant differences between HYP and LYP. Only the concentration of N, Fe, and Mo were lower in LYP compared to HYP (Figure 3). Significant differences between FT and NFT were noticed in the concentrations of all the nutrients except Ca, S, and Mo. The NFT showed significantly higher K, Zn and Cu concentrations as compared to FT. Conversely, the Mg, Fe, Mn, B and Mo concentrations in the leaves were significantly lower in the NFT as compared to FT. The presence of higher concentration of most essential elements in the HYP indicated that these nutrients might have governed or controlled the yield and growth attributes of litchi to a greater extent. Since the leaf samples were essentially collected from the orchards on soils rich in free Ca carbonate, the differences in Ca concentration between the two groups were more apparent and visible similar types of higher concentration of essential elements in HYP as compared to LYP had also reported by Hundal and Arora[28] in kinnow fruit, Raghupathi *et al*.[29] in mango and Anjaneyulu[30] for papaya.

DRIS ratio norms for fruiting terminals (FT) in litchi

A total of sixty- six nutrient ratio expressions used were developed and as diagnostic norms from HYP are presented in Table 2 along with their CV in FT. Ideally, it has been observed that a particular nutrient ratio to be chosen as a norm which have high variance ratio with lower CV for the purpose of higher diagnostic precision[22]. The important nutrient ratio expressions generated were : P/N (0.292), K/N (0.781), Ca/N (1.274), Mg/N (0.438), P/Mg (0.667), K/Mg (1.786), Ca/S (10.08), Zn/Ca (11.57), Zn/S (116.7), S/B (0.003), Fe/Cu (17.13) and Cu/B (0.252) etc. which showed lower CV compared to others. The ratios of Ca/Mg (2.881), Ca/B (0.031), Fe/Cu (17.13), Cu/B (0.252), and B/Mo (144.4) were also equally important from the physiological point of view. The CV ranged from the lowest of 17 percent for K/B to the highest of 49 percent for Fe/Mn indicating larger variation in their absolute concentrations in the HYP. The nutrient ratios which had lower CV but with high variance were more critically related to yield than the nutrient ratios which had a very high CV. These nutrient ratio norms that are worked out and used were in corroboration with values derived for grapes[31], banana[17] and mango[29].

DRIS ratio norms for non- fruiting terminals (NFT) in litchi

The DRIS ratio norms that are worked out for NFT in litchi are presented in Table 2. The important nutrient expressions involving N was: N/P (3.185), Ca/N (1.430) and N/Zn (0.053). The important nutrient ratios of P with other nutrients were: P/K (0.333), P/Ca (0.220), P/Mg (0.750) and P/Zn (0.017). The important ratios involving K were: Ca/K (1.519), K/Mg (2.250), K/Zn (0.050), and K/B (0.023). The ratios of Ca/Mg (3.417), Ca/B (0.035), B/Zn (2.161), and Mo/B (0.007) were also equally important from physiological point of view in NFT of litchi. The data indicated that the ratios of N/P (3.185), K/N (0.942), N/Zn (0.053), S/K (0.111), Ca/Zn (0.076), Cu/Mg (32.5), B/Zn (2.161), Zn/B (0.463) had lower CV values compared to others and were crucial for crop performance[29]. Among different expressions involving N, the norm N/P ratio was 3.185 indicating that the P concentration was much lower as compared to leaf N concentration. The DRIS ratio norm for Ca/ N was 1.430 indicating that both N and Ca were needed in almost equal proportion. The mean Ca concentration was, however, marginally higher than N concentration in the HYP. This was mainly attributed to the presence of high content of free Ca carbonate in the areas where the present survey was under taken. The ratio norm for Mg/N was 0.419 in which the mean Mg concentration was much lower as compared to that of Ca.

The DRIS ratio norms indicated that the mean Fe concentration was almost 100 times higher to that of N whereas Mn was higher by twenty five times. Since the consideration of all the sixty -six nutrient expressions for interpretation of the leaf analysis data for diagnosis of nutrient imbalance is often difficult[10,32] only those expressions having higher physiological relevance need to be considered. Potassium is known to play a key role in N uptake and translocation whereas; Mg and N are vital constituents of chlorophyll. Hence, maintaining a correct ratio of these nutrients is inevitably very important for achieve quantum of yield anticipating in any crop[29]. However, the maintenance of the ratios of some expressions at optimum when they were with large CV was much less critical for performance of the crop. Further, it was also not practical to consider all the expressions for diagnosis of nutrient imbalance. The nutrients which are considered for yield building need to be kept in a state of relative balance for the maximum efficiency of dry matter production[32]. Similarly, the norms developed for other nutrients may help in identification of critical ratios for the normal growth and development of litchi. When a particular nutrient ratio is not in balance compared to the established norms, it becomes difficult to ascertain which nutrient element is deficient in the ratio. Therefore, it is essential to develop comprehensive indices for the diagnosis of yield limiting nutrients.

DRIS indices and nutrient imbalance index (NII) for fruiting terminals (FT) in litchi

The order in which different nutrients limit yields could be also derived depending on the magnitude of the indices. For example, in orchard no.1, NII was 970 where in N (-21), Ca (-70), Mg (-97), S (-22), Zn (-41), Cu (-40) and B (-194) (indices were having both negative sign and positive sign) the order of yield limiting nutrients were B>Mg>Ca>Zn (Table 3). As DRIS simultaneously identified imbalances, deficiencies and excesses in crop nutrients and ranked them in the order of importance[15], the nutrients were arranged in the order of their importance in which they were known to limit the yield. The order of yield limiting nutrients differed from orchard to orchard though some of the nutrients were more prominent. The diagnosis of nutrient imbalance through DRIS indices indicated that S was regarded as the most yield limiting nutrient among major nutrients in the low yielding orchards. The DRIS indices also implied that N and P were limiting yield to great extent only in certain orchards. Among the micronutrients, Zn, Mo and B were found to be the most yield-limiting nutrients in FT of different orchards. The low content of micronutrients in many orchards could be attributed to the high pH, presence of high Ca carbonate content resulting in low availability of micronutrients. The norms developed for sapota through DRIS by Savita and Anjaneyulu[33] indicated that Zn and B were the common deficient nutrient elements. In plum also the most limiting nutrients were B followed by Zn[34].

DRIS indices and nutrient imbalance index (NII) for non-fruiting terminals (NFT) in litchi

The DRIS indices developed for every individual low yielding orchard for the diagnosis of yield limiting nutrients which defers for every orchard depending on the soil fertility status and adoption of management practice. The order in which different nutrients were limiting yield was indicated depending on the magnitude of the indices. For example, in orchard no.1, NII was 884 where indices for B (-105), Cu (-91), Ca (-71), K (-59), N (-47), S (-33) and Mg (-30), Mo (-4), Zn (-2) were having negative sign and P (0), Fe (146) and Mn (296) indices were having positive sign (Table 4). The order of yield limiting nutrients was B>Cu>Ca >K>N> S> Mg>Mo >Zn. The P index was zero which showed that in that particular orchard P level was optimum. The indices of Fe and Mn were having positive values as these nutrients were in abundance in the soils of orchard. The nutrient indices near to zero indicated the optimum level, negative values as relative deficiency and positive value as relatively plenty of that particular nutrient[35]. Higher the NII, larger would be the plant nutritional imbalance and thus, lowers the yield.

The DRIS indices also indicated that N, P and Mn were limiting the yields only in few orchards and S was found to be the most common yield-limiting nutrient followed by Mo, B and Zn which are mostly present in NFT of low yielding orchards. Similarly, the norms developed in plum through DRIS by Disha *et al.*[34] indicated that most limiting nutrient was B followed by Zn. The DRIS showed higher diagnostic sensitivity compared to the conventional critical values or optimum ranges. The relation between NII and yield was immediately and clearly evident as the yield tends to decrease with increase in sum of indices (NII value). However, yield cannot be predicted from sum of indices irrespective of sign because of the influence of unmeasured factors that might affect yield critically[15]. Simple correlations were worked out between NII and yield for the low yielding orchards for both FT and NFT (Data not shown). The linear correlation co-efficient indicated a weak negative correlation between yield and NII (r = -0.217). Similar results were reported Raghupathi *et al.*[22] in Coorg mandarin. Srivastava and Singh[36] also reported significant lowering of NII due to correction of yield limiting nutrients in Nagpur mandarin.

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

S. 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

Table 2: Diagnosis and recommendation integrated system (DRIS) ratio norms in fruiting terminals (FT) of litchi

Fruiting terminals (FT)						Non-fruiting terminals (NFT)					
Selected Ratio	DRIS norms	CV (%)	Selected Ratio	DRIS norms	CV (%)	Selected Ratio	DRIS norms	CV (%)	Selected Ratio	DRIS norms	CV (%)
P/N	0.292	28	K/Mg	1.786	19	N/P	3.185	20	Mo/Mg	0.694	34
K /N	0.781	24	K/S	2.333	26	K/N	0.942	21	S/Fe	0.001	40
Ca/N	1.274	28	Fe/K	224.3	35	Ca/N	1.430	25	S/Mn	0.004	46
Mg/N	0.438	21	K/Mn	0.025	31	Mg/N	0.419	19	S/Zn	0.006	25
N/S	8.000	33	Zn/K	18.67	30	S/N	0.105	29	S/Cu	0.008	22
Fe/N	175.2	33	K/Cu	0.076	27	N/Fe	0.006	29	S/B	0.003	24
N/Mn	0.032	39	K/B	0.019	17	Mn/N	29.07	38	S/Mo	0.360	42
Zn/N	14.58	29	K/Mo	2.778	42	N/Zn	0.053	20	Fe/Mn	6.024	34
N/Cu	0.098	35	Ca/Mg	2.881	23	Cu/N	13.60	14	Zn/Fe	0.107	35
N/B	0.025	43	Ca/S	10.08	27	B/N	40.47	32	Cu/Fe	0.078	26
N/Mo	3.556	44	Fe/Ca	139.0	39	N/Mo	3.440	45	B/Fe	0.231	37
P/K	0.373	25	Ca/Mn	0.040	49	P/K	0.333	33	Mo/Fe	0.002	41
P/Ca	0.231	30	Zn/Ca	11.57	26	P/Ca	0.220	38	Mn/Zn	1.553	33
P/Mg	0.667	25	Ca/Cu	0.123	37	P/Mg	0.750	45	Mn/Cu	2.137	31
P/S	2.333	33	Ca/B	0.031	25	S/P	0.333	39	Mn/B	0.718	36
Fe/P	600.7	48	Ca/Mo	4.481	46	P/Fe	0.002	44	Mn/Mo	100.0	48
P/Mn	0.009	40	S/Mg	0.286	20	Mn/Fe	0.166	36	Cu/Zn	0.727	22
P/Zn	0.020	32	Fe/Mg	400.5	40	P/Zn	0.017	28	B/Zn	2.161	26
P/Cu	0.029	45	Mg/Mn	0.014	47	Cu/P	43.33	17	Mo/Zn	0.016	37
P/B	0.007	38	Zn/Mg	33.33	22	P/B	0.008	26	Zn/B	0.463	21
P/Mo	1.037	42	Mg/Cu	0.043	29	P/Mo	1.080	46	Zn/Mo	64.40	41

N-Nitrogen; P-Phosphorous; K-Potassium; Ca-Calcium; Mg-Magnesium; S- Sulphur; Fe -Iron; Mn-Manganese; Zn-Zinc; Cu-Copper; B-Boron, Mo-Molybdenum, DRIS : Diagnosis Recommendation and Integrated System, CV is co-efficient of variation expressed in percent

Table 3: DRIS indices in fruiting terminals (FT), nutrient imbalance index, yields and order of nutrient requirement for low yielding litchi orchards

S.No.	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo	NII	Yield (kg/tree)	Order of limiting nutrients
1	-21	106	46	-70	-97	-22	32	140	-41	-40	-194	161	970	65	B>Mg>Ca>Zn
1	-37	-92	-31	-74	-26	-50	142	-9	90	13	10	64	638	60	P>Ca>S>N
3	39	10	71	27	62	-120	-108	-70	30	19	-10	30	596	65	S> Fe>Mn>B
4	10	29	1	43	-3	-112	81	28	-266	-54	-26	269	922	50	Zn>S>Cu>B
5	100	132	-139	-20	-101	109	209	182	-235	-161	-65	-11	1464	60	Zn>Cu>K>Mg
6	-136	181	87	372	156	117	100	-102	-97	5	84	-767	2204	55	Mo>N>Mn>Zn
7	232	-37	332	-51	139	74	214	-241	-371	129	-208	-212	2240	40	Zn>Mn>Mo>B
8	95	63	-147	-29	-123	-298	698	50	82	-150	-172	-69	1976	40	S>B>Cu>K
9	24	33	12	-59	-80	-10	33	-1	260	-40	-151	-21	724	60	B>Mg>Ca>Cu
10	-94	56	-10	19	-68	30	147	-65	177	-41	-81	-70	858	50	N>B>Mo>Mn
11	-18	144	-13	35	8	34	140	-261	166	15	49	-299	1182	40	Mo>Mn>K>N
12	122	133	-121	-152	-25	74	-156	-129	27	-37	-9	273	1258	60	Fe>Ca>Mn>K
13	34	79	-27	128	11	10	-21	-111	-9	-94	-159	159	842	50	B>Mn>Cu>K
14	-5	118	-149	104	-6	110	83	19	-240	-175	28	113	1150	65	Zn>Cu>K>Mg
15	-71	-25	-38	110	-44	-7	-116	299	109	-61	-120	-36	1036	50	B>Fe>N>Cu
16	8	-17	51	272	77	-112	46	284	-7	46	-392	-256	1568	25	B>Mo>S>P
17	-2	92	-82	33	7	-296	-152	3	-122	125	16	378	1308	60	S>Fe>Zn>K
18	-97	64	29	166	-63	208	-207	84	94	-26	61	-313	1412	50	Mo>Fe>N>Mg
19	-36	88	35	74	52	-316	-229	80	87	108	-2	59	1166	20	S>Fe>N>B
20	-32	65	-18	25	64	-12	47	109	-39	118	-254	-73	856	65	B>Mo>Zn>N

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

Table 4: DRIS indices in non-fruiting terminals (NFT), nutrient imbalance index, yields and order of nutrient requirement for low yielding litchi orchards

S. No.	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo	NII	Yield (kg/tree)	Order of limiting nutrients
1	-47	0	-59	-71	-30	-33	146	296	-2	-91	-105	-4	884	60	B>Cu>Ca>K
2	-41	-16	345	-21	34	-211	15	198	-312	103	-87	-7	1390	65	Zn>S>B>N
3	-61	88	-27	-23	-89	-12	65	-19	-26	-68	46	126	650	65	Mg>Cu>N>K
4	-207	-104	60	60	-24	82	100	39	-24	-86	128	-24	938	50	N>P>Cu>Zn
5	16	-19	128	4	77	33	121	29	-166	-141	58	-140	932	60	Zn>Cu>Mo>N
6	-1	-70	28	93	234	-187	142	-111	33	-48	74	-187	1208	55	S>Mo>Mn>P
7	122	149	79	-144	-73	86	117	-78	-253	-79	51	23	1254	40	Zn>Ca>Cu>Mn
8	126	-18	-5	-80	-13	24	248	89	108	-76	-90	-313	1190	40	Mo>B>Ca>Cu
9	-98	-27	25	1	-34	56	44	-84	142	-9	45	-61	626	60	N>Mn>Mo>Mg
10	-104	75	4	126	76	55	-22	-18	-167	-117	81	11	856	50	Zn>Cu>N>Fe
11	-119	43	21	-64	32	66	34	13	96	78	-70	-130	766	40	Mo>N>B>Ca
12	61	38	136	-24	-130	47	-55	-88	-200	56	126	33	994	60	Zn>Mg>Mn>Fe
13	-59	24	73	233	229	-144	337	-247	-136	-56	-320	66	1924	50	B>Mn>S>Zn
14	14	-89	-102	45	126	100	191	-43	-10	-95	-74	-63	952	65	K>Cu>P>B
15	41	-124	-68	123	47	43	-122	212	103	-110	-68	-77	1138	50	P>Fe>Cu>Mo
16	228	-116	-14	28	-27	13	110	96	11	-107	95	-317	1162	40	Mo>P>Cu>MG
17	30	-35	-79	74	25	-132	19	55	262	224	-456	13	1404	65	B>S>K>P
18	66	131	-45	36	43	-134	-21	5	-10	-63	99	-107	760	45	S>Mo>Cu>Fe
19	-9	48	60	114	-74	-47	-25	-84	158	2	59	-202	882	50	Mo>Mn>Mg>S
20	20	-34	-64	-61	88	-89	62	30	26	18	58	-54	604	40	S>K>Ca>Mo

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

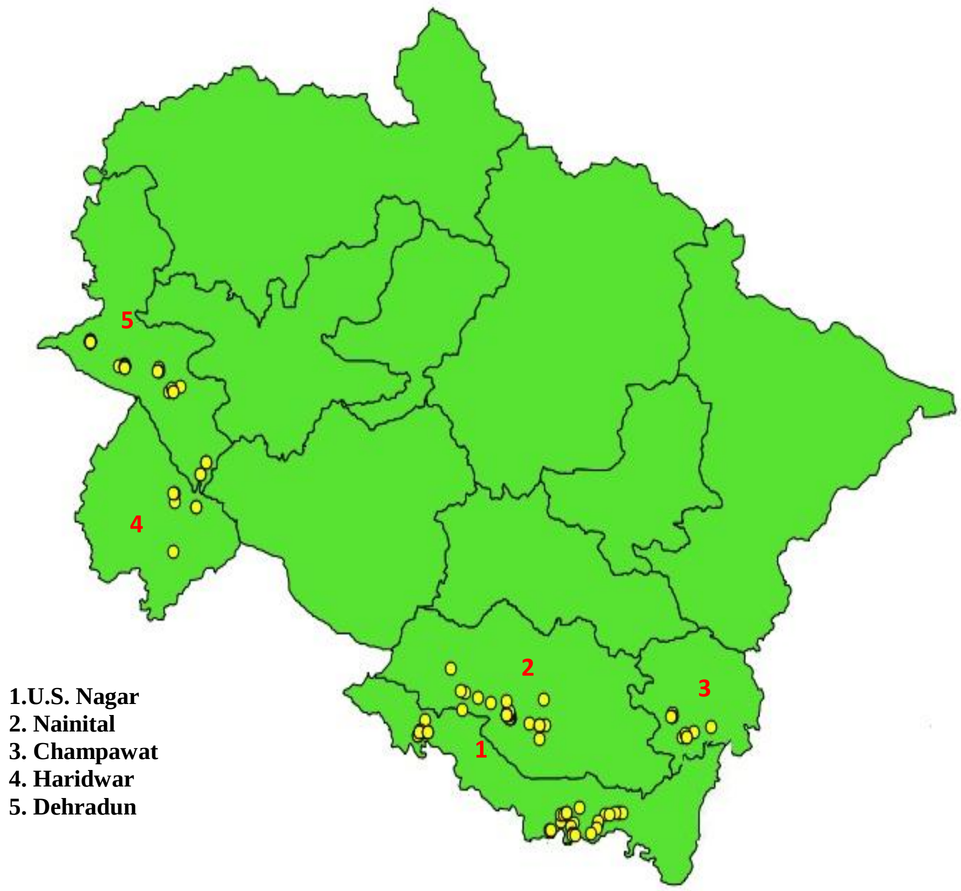

Fig. 1: Location of sampling sites (Litchi orchards) of Uttarakhand state

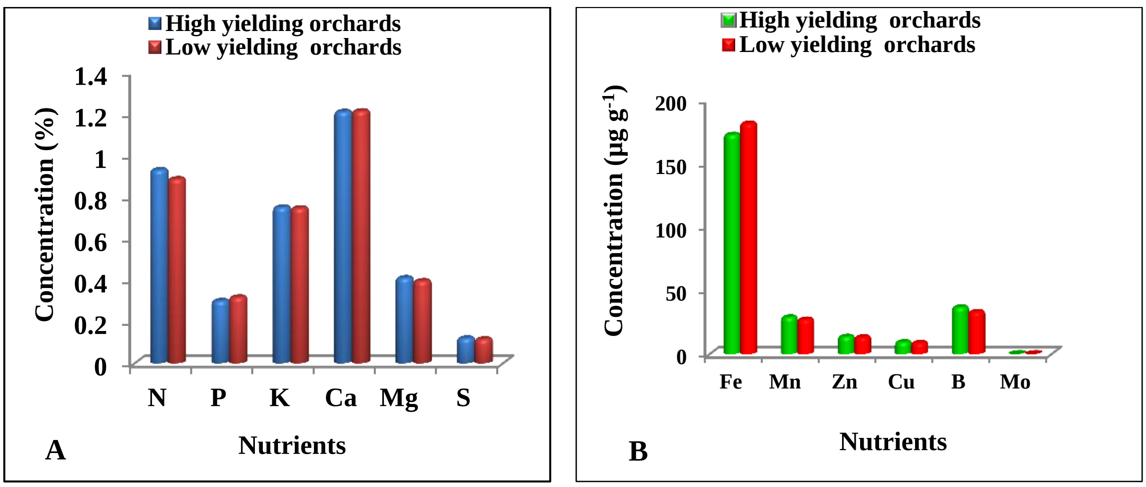

Fig. 2: A). Mean N, P, K, Ca, Mg and S concentration B). Mean Fe, Mn, Zn, Cu, B and Mo in litchi leaves of fruiting terminals (FT) of high and low yielding orchards

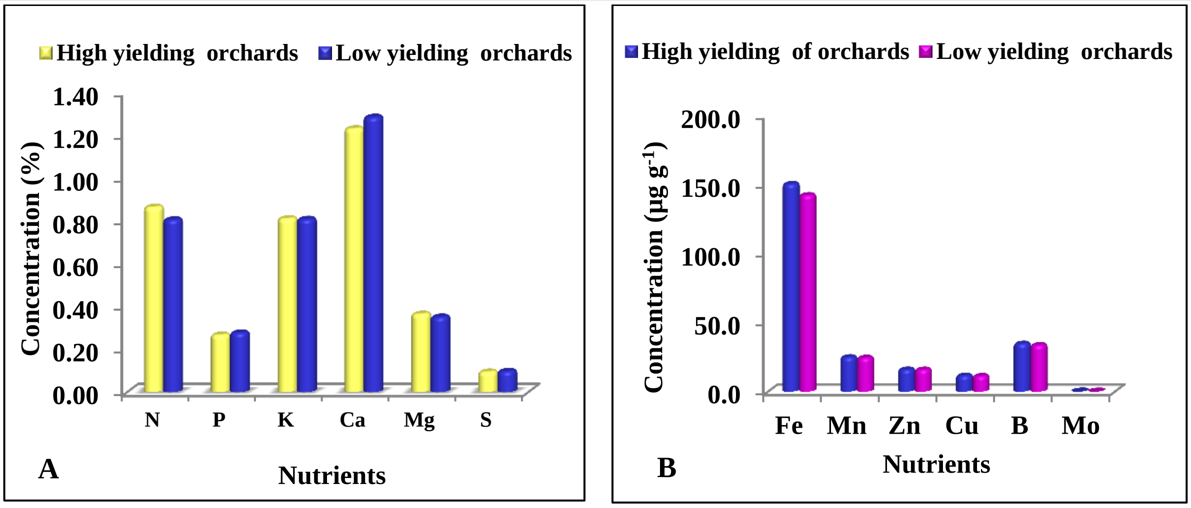

Fig. 3: A) Mean N, P, K, Ca, Mg and S concentration B) Mean Fe, Mn, Zn, Cu, B and Mo concentration in litchi leaves of non-fruiting terminals (NFT) of high and low yielding orchards

CONCLUSION

The present investigation clearly demonstrated that DRIS approach is holistic for identifying nutrient imbalances in litchi crop and thereby emphasizing DRIS as important and ideal technique for evolving nutrient management strategies to realize higher fruit yields. The diagnosis of nutrient imbalance through DRIS indices indicated that S followed by Zn, Mo and B were found to be the most yield-limiting nutrients in FT whereas in case of NFT also, S was found to be the most common yield-limiting nutrient followed by Mo, B and Zn which operate in of low yielding orchards. In addition, the DRIS ratio diagnostic norms are useful for assessing the nutrient status of litchi crop grown under similar soil type and climatic conditions. Nutrient interactions showed that the DRIS approach was far better in diagnosis of nutrient imbalances in litchi than the single nutrient approaches.

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