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Soil-leaf nutrient relationships with fruit quality and yield of litchi (*Litchi chinensis*) in northern India

NAV PREM SINGH[1]*, JAGDISH SINGH[2], SARVPRIYA SINGH[3] and PARMPAL SINGH GILL[1]

Punjab Agricultural University, Ludhiana, Punjab 141 004, India

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ABSTRACT

In litchi (*Litchi chinensis* Sonner.) orchards of northern India, imbalanced nutrient applications and poor soil health status are the major constraints for lower orchard efficiency and poor fruit productivity. Soil and leaf nutrient indexing are considered supportive tools to recognize the nutritional status of litchi orchards and assess the relationship between nutrients, fruit yield and quality attributes. Hence a multi-location study was carried out at Hoshiarpur (S-I), Gurdaspur (S-II), and Pathankot (S-III) districts of Punjab during 2018–20 to study the soil-leaf nutrient relationships with fruit quality and yield of litchi. Nutritional analysis of leaf samples from litchi orchards demonstrated that Ca content was lower in 28.1% of orchards, followed by N (26.4%) and Mn (23.2%). Soil-leaf nutrient matrix was positively and significantly correlated with each other for K, Ca, and Mg content. A significant positive relationship between leaf N and K with fruit yield, size, weight, proportion of pulp (%) and pulp/stone ratio were observed. A significant and negative correlation was registered for colour value (hue angle, h^o) with leaf K and Ca contents depicted better pericarp red colour. It was observed that leaf N and K contents are primarily associated with the enhancement of fruit yield. Leaf Ca, Zn, Fe, and Cu content substantially influenced the fruit's physical and quality parameters of litchi.

Keywords: Fruit quality, Litchi, Nutritional survey, Yield levels

Litchi (*Litchi chinensis* Sonner.) is one of the excellent and delicious fruit, widely distributed in the tropical and warmer subtropical regions of the world due to the availability of specific climatic conditions. In Punjab (India), it is grown over an area of about 3057 ha (with 85% area confined to submontane zone in the foothills of Shivaliks mountains) with 50091 MT production and 16.4 Mt/ha productivity (Anonymous 2021).

Plant nutrition plays a significant role in litchi flowering, fruit set and sustainable fruit production. The variation in orchards productivity is also influenced by climatic factors, soil fertility, vegetative growth and plant health. Under north-western India, litchi plantations shows sub-optimal production potential due to inadequate scientific information on the role of leaf and soil fertility status on fruit yield related parameters. The litchi growers apply fertilizers arbitrarily based on their experience that ultimately affects fruit yield, quality attributes and pericarp colour coordinates. In litchi, the yield is significantly correlated with leaf N and K (Roy *et al.* 1984), available soil K content, while high leaf K concentration effectively improved photosynthesis rate, water use efficiency, stomatal conductance, fruit production, and quality characteristics (Pathak *et al.* 2012, Pandey and Singh 2018). The impact of adequate nutrient supply through manures and fertilizers on yield and quality of litchi are also well documented (Menzel and Simpson 1987, Menzel *et al.* 1992, Pathak *et al.* 2012, Yang *et al.* 2015).

However, the deficiencies of N and K; and to a lesser extent of B, Zn and Cu substantially restrict fruit set and development; and subsequently limit fruit yield (Menzel and Simpson 1987). The soil and leaf analyses are considered a beneficial diagnostic tool to check the availability of nutrients and quantify their impact on fruit yield and quality aspects (Singh *et al.* 2019). It was assumed that a significant relationship exists between soil and plant nutrient concentration, vegetative growth and fruit quality characteristics. Therefore, the present study was carried out to derive the interactions between soil and leaf nutrient content with yield-related attributes in litchi to optimize future nutrition management.

MATERIALS AND METHODS

The litchi orchards under study were situated at Hoshiarpur (S-I), Gurdaspur (S-II) and Pathankot (S-III) districts of Punjab, India. The soils and leaf samples were collected and analysed during 2018–20. The climatic conditions are characterized as sub-tropical regions with hot

[1]Punjab Agricultural University, Ludhiana, Punjab; [2]PAU-Regional Research Station Gurdaspur, Punjab; [3]Krishi Vigyan Kendra, Bathinda, Punjab. *Corresponding author email: navpremsingh@pau.edu

summer and frost-free cold winter. The area receives about 800–1100 mm rainfall annually in which 70–80% occurs during July–September. The crop was harvested during the second fortnight of June, the minimum and maximum temperature ranged from 21.1–27.8°C and 28.2–40.5°C, respectively during the harvesting period.

Soil and plant sampling, and analyses: About 10–20% uniform and vigour bearing trees of litchi cultivar Dehradun were selected for leaf and soil sampling based on yield performance. Leaf samples from the mid-portion of 4-5 months old leaves of autumn flush were collected during February-March from II^{nd} and III^{rd} pair of leaflets (Singh *et al.* 2019). The leaf samples were decontaminated, washed and dried at 70°C in a hot air oven for constant weight. The oven-dried samples were ground in a grinder with stainless steel blades to pass through 40 mesh sieves. Total leaf N content was determined by the micro-Kjeldahl method, phosphorus through the vanadomolybdate-phosphoric yellow colour method. The Potassium, Calcium, Magnesium, Copper, Zinc, Iron, and Manganese concentration of the digested leaf samples were estimated through atomic absorption spectrophotometer.

The composite soil samples from 0–15 depth were drawn 1.0–1.5 m away from the tree trunk with maximum concentrations of feeder roots with the help of a stainless-steel post hole auger. The soil samples were air-dried in the shade and analysed for available Phosphorus (Olsen's method) and available N (Subbiah and Asija 1956). Exchangeable Ca, Mg and K were extracted with neutral normal ammonium acetate and analysed through Flame photometer. Available Mn, Cu, Fe, and Zn were extracted from soil samples with DTPA using the atomic absorption spectrophotometer (model Perkin Elmer Analyst 200).

Fruit analysis: The total fruit yield per plant was estimated at the time of fruit harvest. The fruits for analyzing the quality parameters were harvested at physiological mature stage (deep red coloured pericarp fruit with flattened tubercles) in the second fortnight of June. The fruit size, fruit quality attributes, total soluble solids content and titratable acidity were recorded using standard procedure (AOAC 2005). Fruit colour coordinates (L*, a*, b*, C* and h*) were randomly measured on two opposite sites at fruit equator using Color Flex Spectrophotometer (Hunter Lab Color Flex, Hunter Associates Inc., Reston, VA, USA). The pulp/stone ratio and TSS/acidity ratio were also calculated.

Statistical analyses: The three-year pooled data on plant leaf nutrient concentrations were categorized as deficient, optimum and excess following the critical nutrient limits proposed by Menzel *et al.* (1992). Shapiro and Wilk Normality test was performed to test the normal distribution of the data. The leaf nutrient concentrations outliers in the data were identified using Box-and-whiskers diagram and Pearson correlation between soil-leaf nutrient contents, yield characteristics and tree size were worked out using R software (R-core team 2021).

RESULTS AND DISCUSSION

Soil nutrient status: The data from the Dehradun litchi

Table 1 Variability in soil nutrients content (0–15 cm) and leaf nutrient status of litchi orchards

Nutrient		S-I			S-II			S-III			Overall	
		Range	Mean	CV	Range	Mean	CV	Range	Mean	CV	Range	Mean
					Soil macro-nutrient (kg/ha) and leaf nutrients (%)							
N	Soil	336.0-403.2	373.3	11.9	313.6-436.8	359.4	12.5	336.0-436.8	370.4	13.2	313.6-436.8	373
	Leaf	1.13-2.06	1.44	14.7	1.38-1.86	1.6	13	1.1-1.98	1.56	11.8	1.13-2.06	1.55
P	Soil	15.7-22.6	19.03	8.4	14.1-24.3	19.6	9.6	15.4-23.8	20.9	9	14.1-24.3	19.7
	Leaf	0.10-0.26	0.16	6.4	0.08-0.35	0.2	7.4	0.10-0.35	0.18	5.9	0.08-0.35	0.18
K	Soil	102.5-365.1	232.7	25.8	88.9-269.0	176.7	23.6	97.5-270.0	185.7	24.7	88.9-365.1	198.3
	Leaf	1.0-1.40	1.17	10.4	0.60-1.10	0.88	13.7	0.60-1.50	1.11	24.6	0.60-1.50	1.05
Ca	Soil	84.7-301.6	173	30.5	43.5-94.2	67.7	20.6	46.8-47.2	47	2.9	43.5-301.6	95.9
	Leaf	2.39-5.08	3.18	8.2	1.32-3.53	2.2	7.17	0.33-3.53	1.8	5.15	0.33-5.08	2.3
Mg	Soil	26.9-209.0	94.6	21.7	7.1-30.6	16.7	8.9	10.2-13.1	11.7	2	7.1-209.0	41
	Leaf	0.29-0.79	0.48	6.4	0.22-0.74	0.54	13.4	0.12-0.89	0.53	8.1	0.12-0.89	0.52
					Micro-nutrient (ppm)							
Zn	Soil	1.6-8.3	3.4	2.7	0.3-7.3	2.1	4.6	1.5-1.9	1.7	1.9	0.3-8.3	2.4
	Leaf	17.30-161.0	63.6	32.3	20.7-187.0	60.3	44.3	13.6-77.7	25.0	24.4	13.6-187.0	46.8
Fe	Soil	38.6-105.4	74.8	14.6	12.7-75.0	33.3	13.9	19.0-45.7	32.3	10.9	19.0-105.4	46.8
	Leaf	76.6-238.0	122.6	46.2	77.4-280.0	140.7	50.1	50.4-174.0	103.2	35.4	50.4-280.4	120.2
Mn	Soil	2.6-15.2	8.4	3.8	3.5-12.4	8	3.5	4.8-10.9	7.9	2.9	2.6-15.2	8.1
	Leaf	27.6-62.0	41.5	10.5	47.4-125.8	87	24	11.0-68.2	43.6	14.3	11.0-125.8	56.4
Cu	Soil	0.9-2.6	1.8	1.8	0.6-1.8	0.6	0.9	0.2-0.8	0.4	0.2	0.0-2.6	0.8
	Leaf	10.0-33.6	19.85	6.2	11.6-35.4	19.6	6.8	9.6-16.0	12.18	11.8	9.6-35.4	16.6

orchards (Table 1) established in sub mountainous agro-climatic zone, viz. Hoshiarpur (S-I), Gurdaspur (S-II) and Pathankot (S-III) districts in Punjab, India revealed overall variability in soil available N (313.6–436.8 kg/ha), available P (14.1–24.3 kg/ha), available K (88.9–365.1 kg/ha), Ca (43.5–301.6 kg/ha) and Mg (7.1–209.0 kg/ha) with mean values of 373.0, 19.7, 198.3, 95.9 and 41.0 kg/ha, respectively. Some orchards in Hoshiarpur (S-I), Gurdaspur (S-II) and Pathankot (S-III) were found deficient in soil available potassium (available K<137 kg/ha), similar results were also reported by Kumar and Hundal (2002), that the districts Gurdaspur, Jalandhar and Hoshiarpur were low in soil K concentration. On average, orchards belonged to location S-III were lower (1.7 ppm) in available Zn content, followed by at S-II (2.1 ppm) and highest in S-I (3.4 ppm). Dhaliwal *et al.* (2020) also reported that 36.2% soil samples of Hoshiarpur and 33.1% soil samples of Gurdaspur were Zinc deficient (available Zn < 0.6 ppm). The soil available Fe was not deficient in any of the orchard at three locations. Chahal *et al.* (2005) further reported that the Zn content is an anticipated constraint to crop production in semi-arid coarse texture soils with low organic carbon, high *p*H and calcium carbonate. The few orchards at S-I and S-II locations were deficient in available Mn (available Mn <4.5 ppm). The DTPA extractable Cu was not deficient (<0.2 ppm) at any of orchards at all the locations.

Leaf nutrients content: The leaf nutrients concentration of Dehradun litchi orchards established at three locations (S-I, S-II and S-III districts) in north-western India showed overall wide variability in leaf N (1.13–2.06%), P (0.08–0.35%), K (0.60–1.50%), Ca (0.33–5.08%) and Mg (0.12–0.89%) with mean values of 1.55, 0.18, 1.05, 2.30 and 0.52%, respectively (Table 1). On the basis of critical leaf nutrient standards and categorization suggested by Menzel *et al.* (1992), it was observed that about 26.4% of orchards were deficient in leaf N content (66.6%, 6.3% and 6.3% at S-I, S-II and S-III, respectively), overall, 57.8% were in optimum range (33.4%, 68.7% and 71.2% at S-I, S-II and S-III, respectively) and overall, 15.8% orchards were in excess limits (0.0%, 25.0% and 22.5% at S-I, S-II and S-III, respectively) (Table 2). At location S-II, none of the leaf samples were found deficient in Mg, Zn, Fe, Mn and Cu nutrients, however, 45.5% were deficient in leaf Ca content (Table 2). At site-S III, about 6.3%, 6.3%, 18.8%, 38.8%, 18.8% and 36.4% of orchards were deficient in N, P, K, Ca, Mg, and Mn content, respectively. The data from three locations revealed that leaf samples were deficient in N (26.4%), P (9.9%), K (8.5), Ca (28.1%), Mg (9.9), Fe (11.1%) and Mn (23.2%); however, maximum orchards were deficient in leaf Ca, N and Mn content (Table 2). Kumar and Hundal (2002) reported that soils of agricultural lands of mid-hill soil zone were medium to high in available N, low to medium in available P and low to high in available K content. Under alluvial plains of West Bengal, Bombai litchi produced maximum yield when soil N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn concentrations were 0.001645%, 0.00290%, 0.0086%, 0.2630%, 0.0565%, 0.0039%, 0.17 ppm, 3.25 ppm, 66.5 ppm, 63.6 ppm, 1.36 ppm, respectively and leaf N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn concentrations of 1.61%, 0.16%, 0.81%, 0.69%, 0.32%, 0.13%, 13.0 ppm, 18.5 ppm, 284 ppm, 31.0 ppm and 42.0 ppm, respectively (Pathak *et al.* 2012).

The correlation matrix between soil and leaf contents showed significant and positive correlation relationship for K, Ca and Mg contents. The soil N showed a positive but non-significant relationship with leaf P, K, Mg, Mn and Cu. Available soil P showed positive and non-significant correlation with leaf N, P, K, Mg, Zn, Fe, Mn and Cu content. The litchi trees applied with N, P and K considerably enhanced their leaf N, P and K contents, fruit yield and biomass production (Nath *et al.* 2021). A statistically significant positive relationship was observed between leaf K content and soil K (0.62**), Ca (0.64**), Mg (0.61*), Zn (0.51*), Fe (0.60*) and Cu content (0.78**). The leaf Ca content was significantly correlated to soil Ca (0.73**), Zn (0.53*), Fe (0.52*) and Cu content (0.75**). The leaf Mg content was also significantly correlated to the soil Ca (0.76**), Mg (0.68**), Fe (0.62*) and Cu

Table 2 Distribution of leaf nutrient status of litchi orchards under different categories at different sites

Nutrient	Nutritional level (per cent samples)											
	S-I			S-II			S-III			Overall		
	D	O	E	D	O	E	D	O	E	D	O	E
N	66.6	33.4	0.0	6.3	68.7	25.0	6.3	71.2	22.5	26.4	57.8	15.8
P	16.7	83.3	0.0	6.8	84.4	8.8	6.3	45.9	47.8	9.9	71.2	18.9
K	0.0	75.0	25.0	6.6	49.6	43.8	18.8	56.2	25.0	8.5	60.3	31.3
Ca	0.0	75.0	25.0	45.5	54.5	0.0	38.8	42.5	18.7	28.1	57.3	14.6
Mg	8.3	66.7	25.0	0.0	74.0	26.0	18.8	25.0	56.2	9.0	55.2	35.7
Zn	0.0	8.4	91.6	0.0	36.3	63.7	0.0	81.3	18.7	0.0	42.0	58.0
Fe	33.4	66.6	0.0	0.0	27.3	72.7	0.0	0.0	100.0	11.1	31.3	57.6
Mn	33.3	66.7	0.0	0.0	100.0	0.0	36.4	63.6	0.0	23.2	76.8	0.0
Cu	0.0	25.0	75.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0	75.0	25.0

D, Deficient; 0, Optimum; E, Excess.

Table 3 Correlations studies between leaf and soil nutrients concentration with vegetative growth, and fruit physico-chemical characteristics

Nutrient	Soil				Leaf									
	Pericarp colour coordinate								Fruit yield	Fruit breath	Fruit weight	TSS	Pulp stone ratio	Tree volume
	L*	a*	b*	h°	L*	a*	b*	h°						
N	-0.19	-0.41*	0.23	-0.28	0.75*	0.45*	0.47*	0.57**	0.72**	0.59**	0.48*	0.13	0.47*	0.60**
P	0.12	0.11	0.39*	0.29	0.295	0.2	0.43*	0.63**	0.2	0.24	0.23	0.1	-0.19	-0.3
K	-0.40*	0.59*	0.17	0.40*	0.51*	0.46*	0.33	-0.47*	0.43*	0.52*	0.59**	0.67**	0.74**	0.15
Ca	0.14	0.13	0.19	0.07	0.02	0.22	0.07	-0.49*	0.19	0.28	0.13	0.14	0.27	-0.08
Mg	-0.09	-0.24	0.27	0.56**	0.11	0.06	0.04	0.32*	-0.27	0.27	-0.21	-0.09	0.17	0.2
Zn	0.21	0.17	0.05	0.05	0.47*	0.26	0.28	-0.052	0.22	0.36*	0.28	0.48*	0.42*	0.29
Fe	0.18	0.07	0.2	0.11	0.28	0.01	0.04	0.052	0.1	0.11	0.11	0.2	-0.14	0.15
Mn	-0.12	-0.40*	0.22	0.17	0.26	0.04	0.03	0.39*	0.45*	0.38*	-0.07	0.35*	0.38*	0.23
Cu	0.16	0.06	-0.12	0.31	0.23	0.19	0.12	-0.094	0.17	0.41*	0.13	0.38*	0.42*	-0.17

** Significant $P<0.01$, * Significant $P<0.05$.

(0.91**). The leaf Zn content had negative and significant correlation with soil Ca (-0.52*), Mg (-0.55*), Zn (-0.52*), Fe (-0.70**) and Cu (-0.78**). Micronutrient (Zn, B, Fe, Cu, Mn) plays a significant role in vegetative growth, plant metabolism processes and uptake of nutrients (Arora *et al.* 2017). The potential of these can be exploited on litchi crop during growth period and improvement of fruit yield and quality traits. The results are corroborated with the findings of Bettelli and Renzi (1990) who reported positive and significant correlation between soil Ca and leaf Cu, while significant negative correlation between soil Mn and leaf Fe content.

Yield and fruit quality relations with leaf and soil nutrients: The overall mean for various physico-chemical parameters of Dehradun litchi cultivar at three locations was 94.9 kg/tree for fruit yield, fruit length (3.60 cm), fruit breadth (3.24), fruit weight (18.5 g), pulp percentage (66.3), TSS (18.1 %), juice acidity (0.64 %), TSS/acid ratio (46.1) and pulp/stone ratio (3.69). Correlation matrix of pericarp colour coordinates with soil nutrient content (Table 3) revealed soil K had significant relationship with L*(-0.40*), *a** (0.59*) and *h*° (0.40). Pericarp colour coordinate *a** significantly and negatively correlated with soil N 0.41* and -0.45*, respectively indicating that biosynthesis of red anthocyanin content was less due to higher N soil level. The colour coordinate *b** had significant positive relationship with soil P and values were 0.39* and 0.32*, respectively. Soil Mg had significant positive correlation with *h*° (0.56*). The soil Mn has significant and negative correlation with *a** (-0.40*). The leaf nutrient content had significant effect on the pericarp colour coordinates (Table 3). The pericarp colour coordinate *a** had significant positive correlation with leaf N (0.45*) and leaf K (0.46*) and intensity of red colour (a*) as also observed by Pandey and Singh (2018), however, colour coordinate *b** was related to leaf N (0.47*) and leaf P (0.43*). The pericarp colour (*h*°) had significant positive relationship with leaf P (0.63**), Mg (0.32*) and Mn (0.39*), while significant and negatively with K (-0.47*) and leaf Ca (0.32*). Correlation studies between leaf nutrients with fruit quality attributes in Mauritius litchi were investigated by Sivakumar and Korsten (2007) who reported significant associated between leaf P and K with proportion of pericarp anthocyanin and hue angle, respectively.

Leaf N content was positive and significantly correlated with fruit yield (0.72**), fruit breadth (0.59**), fruit weight (0.48*) and pulp/stone ratio (0.47*) (Table 3) due to proper development of tree canopy as also depicts from positive and significant relationship between leaf N and tree volume. Similarly, leaf K (0.43*) and Mn (0.45*) content was significantly and positively correlated with fruit yield. The fruit pulp (%) was positively correlated with leaf N (0.48*) and leaf K (0.52*). The soluble solid content was positively correlated to leaf K content (0.67**), Zn (0.48*), Mn (0.35*) and Cu (0.38*), however, titratable acid was negatively related with leaf N (-0.38*) and positive with leaf K (0.46*) (Table 3). Significant positive correlation of leaf K with fruit weight, fruit size and fruit yield was also recorded. These findings are corroborated with the findings of Pandey and Singh (2018) that plants treated with foliar feeding of K considerably enhanced fruit size, pulp (%), marketable fruit yield and biochemical attributes. The correlation between different plant leaf nutrient concentrations and yield revealed that the best fruit yield and quality should be observed if leaf nutrient status is maintained at leaf N (%): 1.38–1.71, P (%): 0.12–0.20, K (%): 0.90–1.20 and Ca (%): 1.59–3.02, Mg (%): 0.37–0.63; Zn (ppm): 21.1–49.9, Fe (ppm): 83.6–155.2, Cu (ppm): 12.2–20.4 and Mn (ppm): 35.8–72 for mature Dehradun litchi plants under north western India.

The present study showed relationship between soil-plant nutrients with fruit yield and quality parameters of Dehradun litchi. The leaf K and Mn content was significantly and positively correlated with fruit yield, whereas soil K was significantly related to fruit quality parameters L*, a*, and h° coordinates. The optimal leaf nutrient levels are to be maintained to achieve sustainable yield and quality of litchi. Thus, the integration of suggested nutrient norms along with soil nutrient status may be beneficial to fulfill the nutritional requirement of fruit trees for quantitative and qualitative production as well as also sustaining soil physical and chemical properties.

REFERENCES

Anonymous. 2021. *Package of Practices for Cultivation of Fruits,* pp. 75–80. Punjab Agricultural University, Ludhiana, India.

AOAC. 2005. Official Methods of Analysis. *Van Nostrand's Encyclopedia of Chemistry*. G D Considine (Ed.). Association of Official Analytical Chemists (AOAC). Washington, D.C.

Arora R, Singh N P and Kaur S. 2017. Micro nutrients for yield and quality enhancement in litchi (*Litchi chinensis* L.) - A review. *Indian Journal of Ecology* **44**: 586–90.

Bettelli G and Renzi G. 1990. A nutritional survey of kiwifruit orchards in northern Italy. *Acta Horticulture* **282**: 173–81.

Chahal D S, Sharma B D and Singh P K. 2005. Distribution of forms of Zinc and their association with soil properties and uptake in different soil orders in semi-arid soils of Punjab, India. *Communications in Soil Science and Plant Analysis* **36**: 19–20.

Dhaliwal S S, Shukla A K, Sharma V, Behera S K, Choudhary O P, Chaudhari S K, Kumar A, Patra A K, Parkash C, Sikaniya C and Tripathi A. 2020. Atlas on status of micronutrients in soils of Punjab. AICRP on micro and secondary nutrients and pollutant elements in soils and plants, Department of Soil Science, Punjab Agricultural University, Ludhiana, pp. 8–9.

Kumar R and Hundal H S. 2002. Stability of potassium minerals in Punjab soils. *Journal of Nuclear Agriculture and Biology* **31**: 71–78.

Menzel C M and Simpson D R. 1987. Lychee nutrition: a review. *Scientia Horticulture* **31**: 195–225.

Menzel C M, Haydon G F and Simpson D R. 1992. Mineral nutrient reserves in bearing litchi trees (*Litchi chinensis* Sonn.). *Journal of Horticulture Science* **67**: 149–60.

Nath V, Pandey S D, Singh N P and Pandey S. 2021. *Litchi Production and Post-harvest Management*. IBPSS, New Delhi.

Pandey D and Singh N P. 2018. Influence of foliar application of KNO_3 on fruit pericarp colour development and yield of litchi cv Dehradun. *Environment and Ecology* **36**(2): 370–76.

Pathak P K, Majumder K and Mitra S K. 2012. Levels and time of potassium fertilization influence soil and leaf nutrient composition and its relation with yield of litchi. *Indian Journal of Horticulture* **69**: 33–38.

R Core Team. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Roy R N, Rao D P and Mukherjee S K. 1984. Orchards efficiency analysis of the litchi. *Indian Journal of Horticulture* **41**: 16–21.

Singh J, Singh N P, Sangwan A K, Gill P P S, Gill B S, Kaur S, Singh N, Singh D and Singh S. 2019. Standardization of litchi leaf nutrient composition for tissue analysis in sub tropics of India. *Communications in Soil Science and Plant Analysis* **50**(22): 2889–98.

Sivakumar D and Korsten L. 2007. Relating Leaf nutrient status to fruit quality attributes in litchi cv. Mauritius. *Journal of Plant Nutrition* **30**: 1727–35.

Subbiah BW and Asija G L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Current Science* **25**: 259–60.

Yang B M, Yao L X, Li G L, He Z H and Zhou C M. 2015. Dynamic changes of nutrition in litchi foliar and effects of potassium–nitrogen fertilization ratio. *Journal of Soil Science and Plant Nutrition* **15**(1): 98–110.