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Mapping of leaf nutrient status of apple (*Malus domestica* Borkh.) plantations in northwestern Himalayas

Rakesh Sharma

Abstract
Spatial variability of leaf nutrients in apple (*Malus domestica* Borkh.) plantations in Nichar, Kalpa and Pooh region of Himachal Pradesh state of India were examined for implementation of site-specific fertilisation programs. Georeferenced leaf samples were collected randomly for the apple plantations. The leaf nutrient concentrations were assessed and analysed statistically and geostatistically. The concentrations of leaf nutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), boron (B), copper (Cu), manganese (Mn) and molybdenum (Mo) in apple plantations varied widely at different locations. Foliar nutrients like N, Ca, Mn, B and Zn in the apple plantations shows an increasing trend longitudinally. Leaf N concentration was positively and significantly correlated with Zn concentration at Nichar, Kalpa and Pooh and with Ca and B at Pooh and with Ca at Nichar and with B at Kalpa, only. Positive and significant correlation between leaf K and Ca was concentration was recorded at Nichar, Kalpa and Pooh. Geostatistical analysis of leaf nutrients showed different distribution patterns at different locations. This study revealed the need to determine spatial variability of nutrient status of apple plantations before planning a differential fertiliser program. Therefore, saving of nutrients could be achieved by adopting site-specific nutrient-management strategies.

Keywords: apple foliar nutrients, spatial variability, site-specific nutrient management, NW Himalayas

1. Introduction
Apple (*Malus domestica*, Borkh), the premiere table fruit is grown all over the world in temperate climate. In India, it is being cultivated in high reaches of Himalayan region mainly in the states of Jammu and Kashmir, Himachal Pradesh, Uttaranchal and Arunachal Pradesh but Jammu and Kashmir (J&K) and Himachal Pradesh are the only principal apple growing states. In Himachal Pradesh, apple is one of the most important fruit crops, since it occupies 49 percent of total area under fruit crops with an estimate production of 777 thousands tones over an area of 110.7 thousand hectares (Anonymous, 2016) [1]. There has been increasing interest among apple growers in expanding production, especially in Kinnaur region of North-Western India, the most important apple-growing district in India. Royal Delicious is the most popular cultivar of Himachal Pradesh as table fruit due to its shape, colour, quality and marketability but has the disadvantages of low yield per unit area alongwith high production cost. The low apple productivity as compared to international standards has been ascribed to various factors such as varietal, soil fertility and imbalanced nutrition etc. The keeping quality of fruits is highly dependent on the nutrition of apple tree (Faust, 1989) [7]. The productivity of apple (7.02 t/ha) in the country is, however, far below the international standards of (30 t/ha).
The climate of Kinnaur region of Himachal Pradesh provide congenial environment for growing high quality apple fruits due topographical variations and altitudinal differences. The apples of this region possess qualities at par with international standards for export purposes. In apple orchards, in general, the application of site-specific management has been unpopular because of slow adoption of new technology, lack of relevant technology for fruits, crop input subsidies and small farm size etc. The apple plantations are managed traditionally, applying fertilizers and other inputs at uniform rates without considering the field spatial variability. This management may result in under-application or over-application of inputs in some parts of the orchard giving rise to economic and environmental problems, such as increased production cost and environmental pollution from agrochemicals (Earl *et al*., 1996) [5].

Many research studies have been carried out on soil variability mostly in arable crops (Cambardella and Karlen, 1999; Shukla *et al*., 2004) [3, 15]. In horticultural crops, Zaman and Schuman (2006) [18] developed nutrient management zones for citrus based on variation in soil properties. In spite of increasing importance of apple as a commercial crop in this temperate region, no adequate scientific study concerning foliar diagnostic status had been made so far. Foliar nutrient constraints of commercial apple plantations of Kinnaur using global positioning system (GPS) will help in formulating site-specific balanced fertilizer recommendation. Therefore, the study was conducted to carry out the foliar nutritional survey of commercial apple plantations of Kinnaur district through foliar nutrient contents and to establish relationships, if any, between foliar nutrient contents with a view to using such knowledge in site-specific recommendations for better fruit yield and quality in the region.

2. Materials and Methods
2.1. Study area, leaf sampling and laboratory analyses
The present studies were undertaken in commercial apple growing areas of Kinnaur region (30°22’40” to 33°12’40”N latitude and 75°47’55” to 79°04’20”E longitude) namely Nichar (24 locations), Kalpa (31 locations) and Pooh (27 locations) representing typical agro-microclimatic conditions (Figure 1). According to the Koppen’s climate classification, the valley area included the trans-Himalayan belt on the northern side of the west-ern Himalayas, which is cold, arid and windswept. There is less rain in the leeward side of the mountains, whereas, rainfall is received by the well exposed slopes. The experimental plantations/orchards are even grown on steep slopes. There was also a considerable loss of top soil due to erosion followed long snowy winter months. Winters are severe with heavy snowfall (5220 mm) causing glaciers and avalanches particularly in some parts of Kalpa and Pooh blocks. Summers are mild with rainy season in most of the Kalpa and Nichar blocks of the district with lighter snowfall. Pooh block of this district forms a part of the ‘Indian Cold Desert’ and receives less rain but as it falls in rain-shadow zone of Himalayas.

The field surveys were done on commercial apple plantations with cultivar Starking Delicious, which has a characteristic conical shape with deep red blush, is the main variety grown by farmers, hence was chosen for the study. Eighty-two locations spread over typical agro-microclimatic conditions (Nchar-24, Kalpa-31 and Pooh-27) were selected for collecting foliar samples and detail has been given in the table 1. Geo-referenced five foliar samples were collected from each location depending on the homogeneity of the area using a hand held GPS. Foliar samples (about fifty leaves per tree from middle of terminal shoot growth) were collected from tree/orchard between July 20 and end of the August months during the year 2011-12 as suggested by Kenworthy, 1964 and cleaning, drying, grinding and storage of samples was in accordance with Chapman, 1964. Foliar samples were washed with deionized water, dried at 65°C, weighed and milled to 20 mesh for mineral analysis.

Total N was determined by micro-Kjeldahl method, P by vanadomolybdate-phosphoric yellow colour method as suggested by Jackson (1973) [9]. The K, Ca, Mg, Cu, Zn, Fe and Mn in the digest were estimated on atomic absorption spectrophotometer. The foliar B and Mo was determined by carmine (Hatcher and Wilcox, 1950) [8] and thiocyanate stannous chloride (Johnson and Arkley, 1954) [10] methods, respectively. The foliar nutrient data were then categorized as deficient and sufficient in accordance with the working standards for apples as suggested by Shear and Faust (1980) [14]. About five to six trees per location was selected to record and calculate yield per tree and total fruit yield was estimated, accordingly.

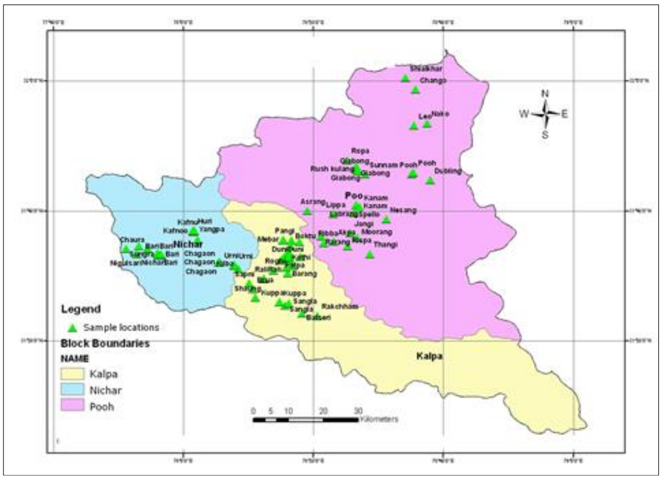

Fig 1: Geographical location of the study area.

2.2 Exploratory statistical analysis
Foliar nutrient data were analysed statistically for descriptive statistics such as mean, maximum, minimum, standard deviation (SD), coefficient of variation (CV), skewness and kurtosis of data distribution. For the variables where skewness >1, log-transformation was used to stabilize variance. The ArcGIS software (ArcGIS v.10.1; ESRI Co, Redlands, USA) program was used to manage the data. Geostatistical tools contained in the ArcGIS program were used for the analysis and interpolation of the spatial information. Specifically, the geostatistical tool called Kriging, using the procedure called Universal Kriging (ESRI Inc., 2003) [6]. This method considers both the distribution of the data as well as spatial trends in the data in any direction, which can then be validated. Once the data were analyzed and the information was incorporated into a geostatistic model, it was then possible to do the interpolation. The distribution of the continuous values of leaf nutrients was done using the krigging method, which is included in the ArcGIS software. Different classes were established for various leaf nutrients in order to permit visualization of the wide variation in the values of the variables.

3. Results and Discussion
3.1 Exploratory statistical analysis
The descriptive statistics of leaf nutrients are given in Table 2. There was a wide range of concentrations (min.–max.) for all the nutrients across all three locations. For individual leaf nutrients N, P, K, Ca, Mg, Fe, Zn, B, Cu, Mn and Mo, the mean values of concentration were different across all locations. The concentration of foliar N varied between 1.60 to 2.40, 1.80 to 2.50 and 2.10 to 2.60 per cent; phosphorus 0.20 to 0.32, 0.18 to 0.26 and 0.21 to 0.33 per cent; potassium 0.90 to 1.70, 1.30 to 1.70 and 1.20 to 1.80 per cent; calcium 0.90 to 1.80, 1.30 to 1.70 and 1.20 to 2.10 per cent and magnesium 0.24 to 0.45, 0.24 to 0.36 and 0.24 to 0.40 per cent in plantations of Nichar, Kalpa and Pooh blocks, respectively (Table 2). N, K and Ca, Mn, B, Cu and Zn concentrations were lower in Nichar than in Kalpa and Pooh region plantations/orchards. Mean concentration of P, Mg and Mo were lower for Kalpa than for other places. In apple

plantation of Pooh region only mean Fe concentration was lower than Nichar and Kalpa region (Table 2). This is in line with of the findings of Singh (1987) [16] and Sharma and Bhandari (1992) [13], who also observed wide a range of N, P, K, Ca, Mg Fe, Mn, Mo, B, Cu and Zn concentrations in apple plantations of Kinnaur and Himachal Pradesh. The distribution of the foliar N, Ca, Mn, B and Zn in the apple plantations/orchards shows an increasing trend longitudinally (Figure 2.1 – 2.5 and 3.1-3.6). Wide variations in leaf nutrient concentrations in other fruit crops such as grape (*Vitis vinifera*) and mango (*Mangifera indica*) have been reported in orchards developed on different soil types of India (Raghupathi and Bhargava 1999; Bhargava 2002) [12, 2].

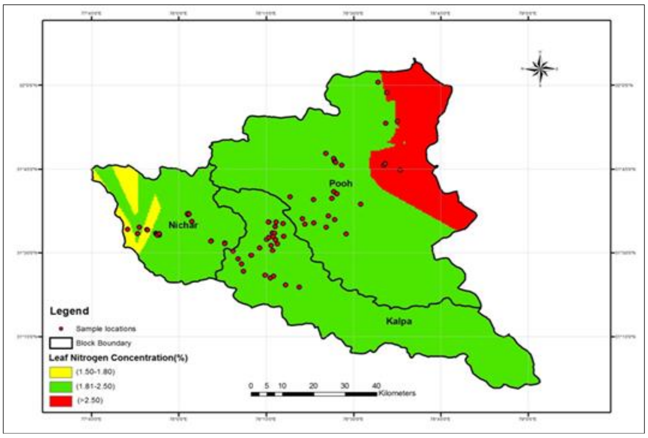

Fig 2.1: Ordinary krigged interpolation maps of leaf macronutrients (N) in apple plantations

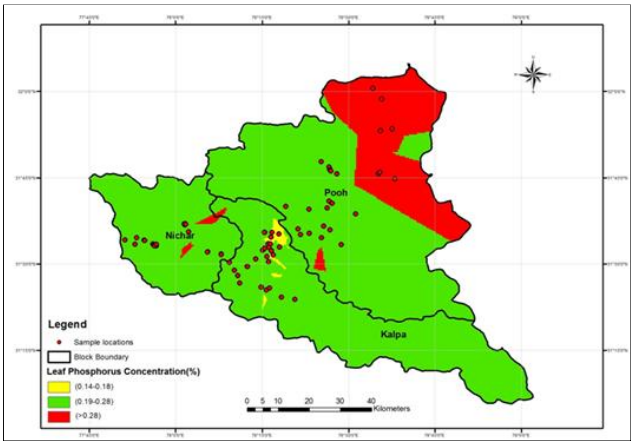

Fig 2.2: Ordinary krigged interpolation maps of leaf macronutrients (P) in apple plantations

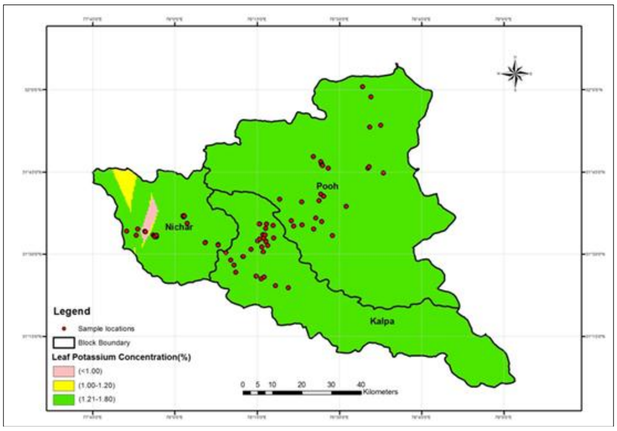

Fig 2.3: Ordinary krigged interpolation maps of leaf macronutrients (K) in apple plantations

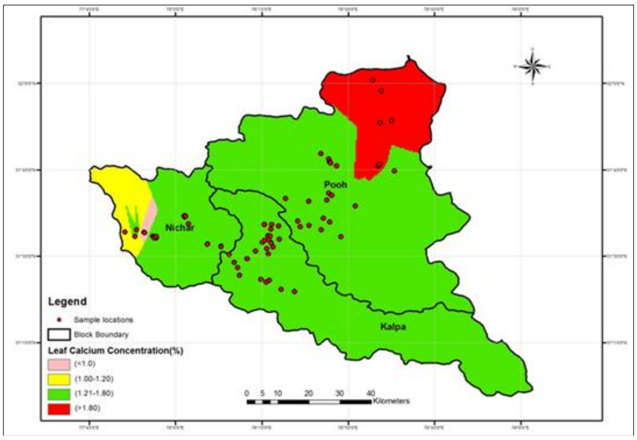

Fig 2.4: Ordinary krigged interpolation maps of leaf macronutrients (Ca) in apple plantations

3.2 Spatial distribution maps of apple foliar nutrients

According to the sufficiency ranges prescribed by Shear and Faust (1980) [14], 3.2-33.2% of leaf samples were deficient in various macro-nutrients (N, P, K, Ca and Mg) and 3.7-41.7% in various micro-nutrients (Fe, Mn, Mo, B, Cu and Zn). Among macro-nutrients, the deficiencies of K, Ca and Mg were more pronounced (>10%) in leaf samples of Nichar as compared to Kalpa and Pooh thereby suggesting a need to incorporate/include their fertilizers in fertilizer schedule. Widespread deficiencies of B, Zn and Mo were distinguishable (>10%) in leaf samples of all the three regions. However, the deficiencies of Fe and Mn (>10%) were noticed only in leaf samples of Pooh and Nichar. This may be partially because orchardists of area are not well aware of the usefulness of applications of micronutrients, whereas it is a common practice in other districts of the state. Leaf Cu concentration was almost sufficient at Nichar, Kalpa and Pooh and may be attributed to enhanced solubility and availability under slightly acidic soil reaction prevalent in these areas alongwith abundant use of Cu based pesticides (Singh, 1987) [16] in the region by the orchardists.

Leaf nutrients at different locations exhibited medium coefficients of variation (i.e. in the range 10–100%) except N concentration in Kalpa and Pooh and for P in Kalpa only, which had a low coefficient of variation (<10%). Among three locations, Nichar showed highest variability in respect of leaf macronutrients (N, P, K, Ca and Mg) and micro-nutrients (Cu, B and Mo) on the basis of coefficients of variation and this may be because of application of various fertilizers from time to time to apple plantations in the region by the orchardists. Table 3 presents a correlation matrix for leaf nutrients. Leaf N concentration was positively and significantly correlated with Zn at Nichar, Kalpa and Pooh and with Ca and B at Pooh and with Ca at Nichar and with B at Kalpa, only. Similarly, leaf K concentration was positively and significantly correlated with Ca at Nichar, Kalpa and Pooh. However, leaf Zn concentration was positively and significantly correlated with Pat Kalpa and with B at Pooh only. The concentration of leaf Zn was negatively, significantly correlated with Fe at Pooh only.

Kriged distribution maps of leaf nutrients (N, P, K, Ca, Mg, S and B) revealed that the apple plantations in the region could be divided into homogenous, small zones depending upon the different nutrient ranges (Figures 2.1-2.5 and 3.1-3.6). Lower concentrations of N, K, Ca, B and Zn were recorded in western Nichar. Similarly, the distribution patterns of P, Mg, Fe, Mn, and Mo were different at different locations. Phosphorus deficiency was observed in north-eastern pockets of Kalpa region only. An irregular Fe and B distribution pattern was recorded in all locations. These maps are of great use for planning appropriate strategies for efficient nutrient management. Efforts must be made to apply the required nutrient in the area, where the nutrient is deficient. Application of the nutrient is not necessary when leaf nutrient concentration is at optimum level. This will help the apple orchardists to reduce their inputs, mostly N, P K, Fe and Cu and make apple production more profitable and environmentally sound.

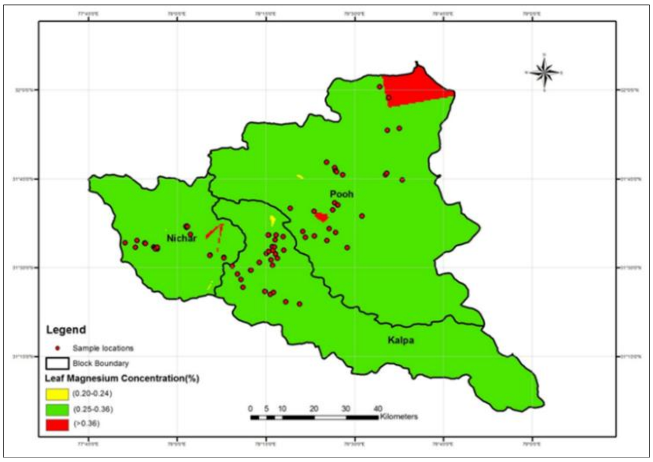

Fig 2.5: Ordinary krigged interpolation maps of leaf macronutrients (Mg) in apple plantations

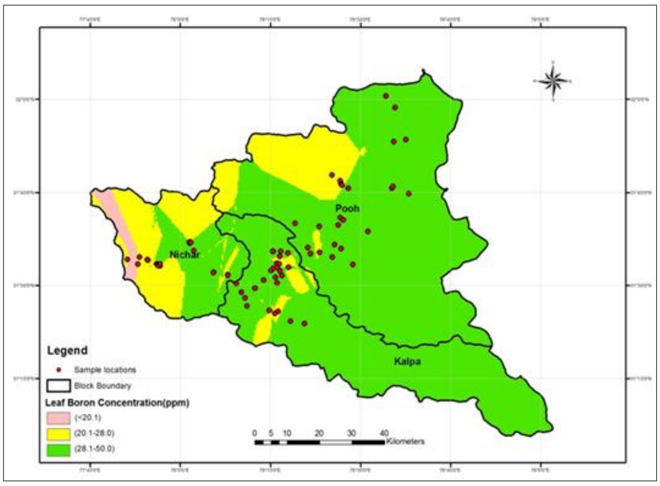

Fig 3.1: Ordinary krigged interpolation maps of leaf micronutrients (B) in apple plantations

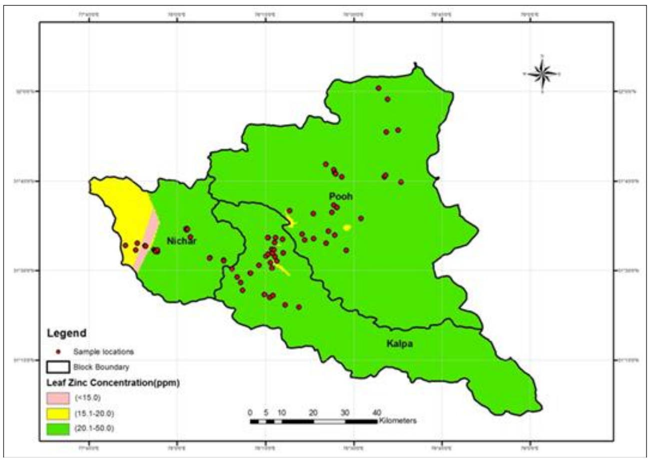

Fig 3.2: Ordinary krigged interpolation maps of leaf micronutrients (Zn) in apple plantations

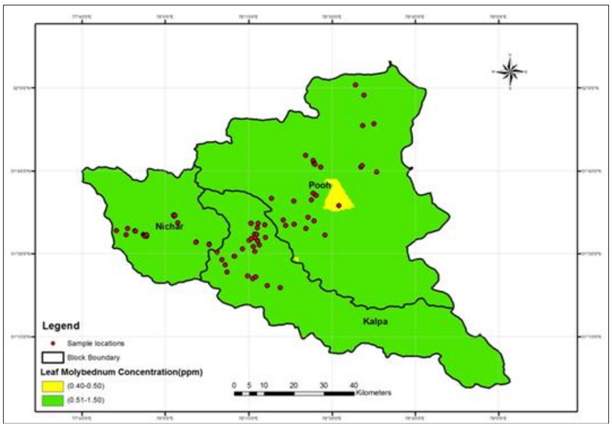

Fig 3.3: Ordinary krigged interpolation maps of leaf micronutrients (Mo) in apple plantations

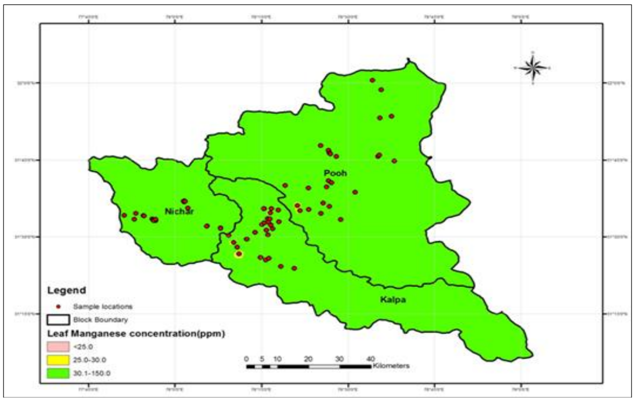

Fig 3.4: Ordinary krigged interpolation maps of leaf micronutrients (Mn) in apple plantations

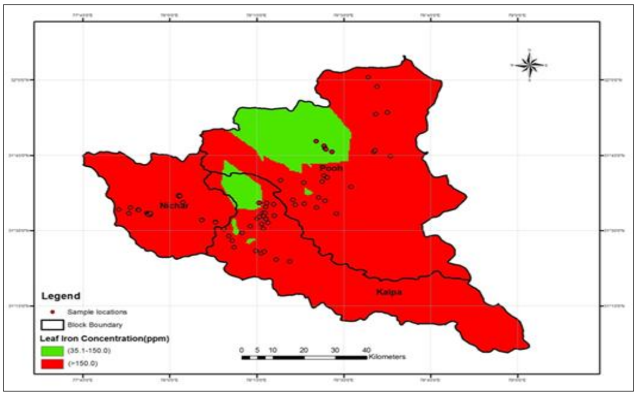

Fig 3.5: Ordinary krigged interpolation maps of leaf micronutrients (Fe) in apple plantations

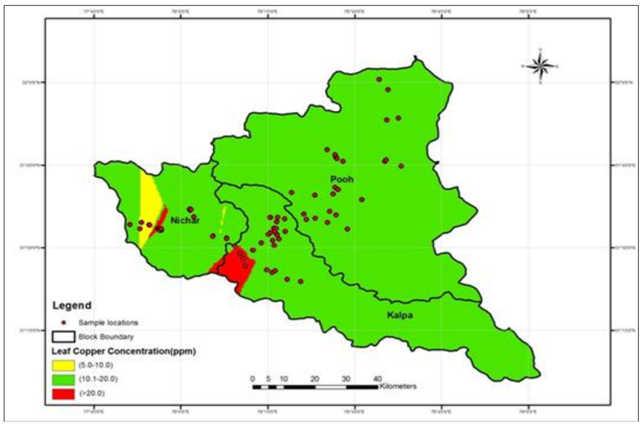

Fig 3.6: Ordinary krigged interpolation maps of leaf micronutrients (Cu) in apple plantations

Table 1: Details of the locations, soil types, age and average yield of apple plantations.

Location	Latitude	Longitude	Elevation (m above mean sea level)	Soil order[A]	Age of plantations (years)	Average fruit Yield (t ha^{-1})
Nichar	31°31’37.2”-31°36’59.8”N	77°51’10.7”-78°07’52.2”E	1700-2546	Entisols, Inceptisols	12-35	2.5-28
Kalpa	31°23’51”-31° 35’31”N	78°08’11.7”-78°20’40.7”E	1836-3000	Entisols, Inceptisols	10-40	8-37
Pooh	31°33’23.3”-31°58’42.7”N	78°19’06”-78°38’01.6”E	2447-3459	Entisols, Inceptisols	15-40	10-37.5

[A]Soil Taxonomy (Soil Survey Staff 2014)

Table 2: Summary statistics of foliar nutrient concentrations of apple plantations.

Variable	Min.	Max.	Mean	s.d*.	CV (%)*	Skewness	Kurtosis	% Samples with deficiency
	Nichar (n=24)							
N (%)	1.60	2.40	2.07	0.25	12.3	-0.44	-0.76	20.8
P (%)	0.20	0.32	0.25	0.03	13.16	0.81	-0.10	-
K (%)	0.90	1.70	1.42	0.21	14.82	-1.1	0.68	16.7
Ca (%)	0.90	1.80	1.40	0.29	20.9	-0.07	-1.3	33.2
Mg (%)	0.24	0.45	0.32	0.06	18.15	0.38	-0.58	12.5
Fe (mg/kg)	164.0	390.0	279.0	70.1	25.16	0.01	-0.79	-
Mn (mg/kg)	23.0	71.0	46.7	13.3	28.61	-0.14	-0.48	16.7
Mo (mg/kg)	0.48	0.78	0.61	0.09	17.20	0.33	-0.81	12.5
B (mg/kg)	17.7	36.5	27.2	4.9	25.67	-0.14	-0.17	41.7
Cu (mg/kg)	10.0	28.0	14.0	4.1	29.41	2.1	4.9	4.2
Zn (mg/kg)	11.0	35.0	23.4	6.7	28.8	-0.22	-0.80	37.4
	Kalpa (n=31)							
N (%)	1.80	2.50	2.30	0.15	6.42	-1.2	2.60	3.2
P (%)	0.18	0.26	0.22	0.02	9.2	-0.32	-0.15	6.5
K (%)	1.30	1.70	1.55	0.10	6.43	-0.28	0.01	-
Ca (%)	1.30	1.70	1.52	0.10	6.62	-0.13	-0.72	-
Mg (%)	0.24	0.36	0.29	0.03	12	0.04	-0.79	16.1
Fe (mg/kg)	98.0	337.0	216.0	59.4	27.44	-0.24	-0.42	-
Mn (mg/kg)	24.0	78.0	47.1	14.9	31.75	0.54	-0.41	9.7
Mo (mg/kg)	0.48	0.84	0.59	0.09	15.1	1.2	1.31	16.1
B (mg/kg)	24.0	38.0	29.9	3.3	11.0	0.73	0.84	25.8
Cu (mg/kg)	8.50	25.0	16.1	4.2	26.06	0.95	0.15	3.20
Zn (mg/kg)	15.0	45.0	26.9	7.4	27.45	0.43	0.03	19.4
	Pooh (n=27)							
N (%)	2.10	2.60	2.37	0.15	6.5	-0.28	-0.88	-
P (%)	0.21	0.33	0.26	0.03	12	0.26	-0.47	-
K (%)	1.2	1.80	1.53	0.17	11	-0.24	-0.71	7.4
Ca (%)	1.2	2.10	1.62	0.25	15.51	0.09	-0.79	7.4
Mg (%)	0.24	0.40	0.32	0.05	15.54	0.05	-0.96	11.1
Fe (mg/kg)	98.0	358.0	209.0	83.4	39.8	0.29	-1.3	37.1
Mn (mg/kg)	29.0	80.0	52.0	14.4	27.64	0.09	-1.1	3.7
Mo (mg/kg)	0.44	0.85	0.63	0.11	18.1	0.12	-0.96	14.8
B (mg/kg)	18.0	45.0	31.1	5.9	19.05	0.80	1.3	25.9
Cu (mg/kg)	12.4	24.6	14.4	3.1	21.4	2.9	7.6	-
Zn (mg/kg)	15.0	46.0	29.0	8.4	28.85	0.09	-0.56	25.9

*s.d., Standard deviation; **CV, coefficient of variation

Table 3: Pearson correlation coefficients demonstrating relationships among leaf nutrient concentrations in apple plantations.

Variable	N	P	K	Ca	Mg	Fe	Mn	Mo	B	Cu	Zn
Nichar (n=24)											
N	1.00										
P	0.359	1									
K	0.888**	0.206	1								
Ca	0.813**	0.277	0.785**	1							
Mg	0.132	0.303	0.082	-0.01	1						
Fe	0.099	0.315	0.135	0.141	0.171	1					
Mn	0.447*	0.515**	0.34	0.367	0.193	0.230	1				
Mo	0.194	-0.034	0.082	0.219	-0.213	0.097	-0.170	1			
B	-0.008	0.311	-0.041	-0.021	0.163	-0.122	0.261	0.081	1		
Cu	0.151	0.026	0.028	0.222	0.015	-0.260	-0.059	0.308	0.173	1	
Zn	0.940**	0.349	0.827**	0.747**	0.102	0.093	0.495**	0.179	-0.074	0.172	1
Kalpa (n=31)											
N	1										

P	0.416*	1									
K	0.180	0.377*	1								
Ca	0.007	0.366*	0.453*	1							
Mg	0.077	0.082	0.381*	0.358	1						
Fe	0.26	-0.003	0.006	-0.108	0.018	1					
Mn	0.238	0.039	0.065	0.448*	0.271	0.056	1				
Mo	0.00	-0.140	-0.002	0.038	0.232	0.265	0.081	1			
B	0.440*	0.297	0.123	0.078	-0.167	-0.018	0.006	0.093	1		
Cu	0.155	0.121	-0.082	-0.333	-0.235	0.230	-0.256	0.305	0.305	1	
Zn	0.536**	0.540**	0.222	0.231	0.226	0.138	0.303	0.209	0.432*	0.019	1
Pooh (n=27)											
N	1										
P	0.251	1									
K	-0.024	0.177	1								
Ca	0.425*	0.354	0.574**	1							
Mg	0.632**	0.179	0.030	0.291	1						
Fe	-0.054	0.241	0.033	-0.145	0.020	1					
Mn	-0.045	0.046	-0.017	-0.128	-0.359	-0.019	1				
Mo	0.367	-0.224	-0.218	0.230	0.141	-0.151	0.104	1			
B	0.382*	0.486*	0.189	0.255	0.448*	0.216	0.047	-0.033	1		
Cu	0.130	-0.047	0.491**	-0.304	0.233	-0.032	-0.316	-0.153	-0.026	1	
Zn	0.693**	0.381*	0.142	0.444*	0.545**	-0.419*	0.162	0.266	0.515**	-0.239	1

*$P<0.05$; **$P<0.01$

4. Conclusions

Hence, the information generated on spatial variability of leaf nutrients in apple plantations could be used to design site-specific application strategies. Moreover, intermittent leaf analysis provides an appropriate guide for formulating a possible precision fertilization program of N, P K, Fe, Cu, Zn and B to avoid economic and potential environmental problems arising from homogenous fertilization schemes. The different distribution patterns of leaf nutrients have demonstrated that the apple plantations should be divided into small zones depending on different nutrient ranges and these zones will have a more reliable base for site-specific fertilization program for precision farming, which will involve a consistent reduction in fertilizers.

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