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Micronutrient indexing in the apple orchards of Northern Punjab, Pakistan using geo-statistics and GIS as diagnostic tools

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Abstract

Micronutrient deficiencies of soil are causing wide spread nutritional disorder in horticultural crops, grown in the calcareous soils. Keeping in view the limitations of classical statistics for explaining spatial heterogeneity a survey in the farmer grown apple orchards was conducted for indexing micronutrient using geo-statistics and GIS as a diagnostic tools. Geo-referenced soil samples were collected from 30 apple orchards. Recently matured leaves were sampled from associated apple trees. Widespread deficiency of Zn existed in the foliage of apple orchards followed by site specific Mn, Fe and Cu, respectively. Bioavailable Zn in soil was deficient in 30, 33 and 50%, and marginal in 10, 15 and 30% of total analyzed samples collected from the surface (0-15 cm), subsurface (15-30 cm) and lower soil depth (30-45 cm). Moderate to strong spatial dependence of studied micronutrients in three soil depths provided an opportunity to prepare contour maps for classifying the whole area in to various zones on the basis of having differential micronutrient content levels for regional scale information.

Keywords: *Geo-statistics, GIS, bioavailability, correlation*

Introduction

Micronutrient deficiency in soil has become a widespread phenomenon that leads to decrease in yield and quality of many agronomic and horticultural crops**.** Zinc deficiency is reported over 30 to 49 percent of the total area of the world (Khan *et al*., 2006; Ahmed *et al*., 2010). It is estimated that 0.5 to 2 billion people are affected by Fe deficiency (Wojcick, 2007; Ahmad *et al*., 2012).

Average production of Pakistani orchards is alarmingly low (9 tonnes ha^{-1}) when compared at international level. Average yield of apple orchards is 6.1 tonnes ha^{-1} which is very low when compared with other apple producing countries (PARC, 2014).

Micronutrient deficiency is attributed to calcareousness, low organic matter content and alkaline pH of soils. Soil characteristics and climatic conditions are helpful to predict the nutrient deficiency but are not enough to make decisive recommendations. Soil testing and plant analysis for examining the nutrient deficiency play a key role in successful nutrient management (Moral *et al*., 2011).

One of the important characteristic features of the soil variables is to show a continual spatial variability. Observation of these changes from place to place and from each and every corner of the area is not possible by laborious soil sampling, analysis and usual statistical methods. Application of modern techniques like GIS and Geo-statistics becomes in-evitable for efficient and site specific nutrient management (Attar *et al*., 2012). Geo-statistics has been considered as an extensive tool for quantification of spatial variability of soil characteristics and bioavailable nutrients leading to estimate the values of un-sampled locations on the basis of sampled locations (Jin *et al*., 2011; Memon *et al*., 2011). Uniform application of fertilizer in each province of Pakistan leads to over or under fertilization and yield losses. Losses in yield can be minimized through site specific nutrient management (Shah *et al*., 2013).

A limited work is reported on the spatial variability of nutrients in various agronomic crops but no well documented work has been found for the orchard soils in Pakistan. Present research work was conducted for indexation and spatial variability of micronutrients (Zn, Cu, Fe and Mn) in the soils of apple producing region of Murree, Pakistan. The whole area was classified in to various categories on the basis of nutrient status for site specific nutrient management.

Materials and Methods

Soil sampling, processing and analyses

Murree area is located between the 33^0 54' 26.56" N and 73^0 23' 37.68" E on the north east of Islamabad (capital city of Pakistan) and spread over the 434 km^2 (Figure 1). Climatic conditions are congenial for growing apple orchards. Six composite soil samples (0-15, 15-30 and 30-

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45 cm) were collected at 6 m^2 from 30 apple orchards to cover the whole apple producing area of Murree. Associated foliage samples were also collected to examine the foliage micronutrient content. Coordinates were recorded with the help of GPS (Garmin e-trex). Soil samples were air dried, ground, and passed through a 2 mm sieve and were stocked in plastic bags for further analysis.

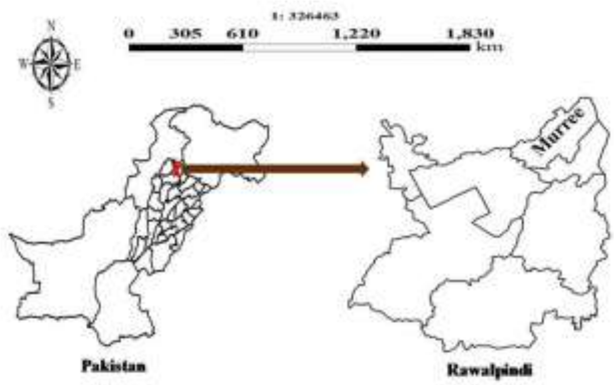

Figure 1: Geo-graphical location of surveyed area (Pakistan, Rawalpindi district indicating Murree tehsil)

The samples were analyzed for texture (Gee and Bauder, 1982), pH (Mclean, 1982), $CaCO_3$ contents (Leoppert *et al*., 1984), organic matter (Nelson and Sommers, 1982) and AB-DTPA extractable Zn, Cu, Fe and Mn (Soltanpour and Workman, 1979). Critical values described by Soltanpour (1985) were used to classify the soil in to low, medium and high in bioavailable micronutrient contents. Plant leaf samples were dry ashed and the digest was analysed for Zn by atomic absorption spectroscopy (Chapman and Pratt, 1961). Foliage micronutrient content were categorized in to low, medium and adequate using critical values established by Neubert *et al*. (1970).

Statistical and geo-statistical analyses

Descriptive statistics, including mean, standard deviation (SD), kurtosis and skewness were applied to the data set obtained for each micronutrient whereas the effect of various physico-chemical properties on the availability of micronutrients was estimated by correlation analysis. Distribution of bioavailable micronutrients were characterized using the Kolmogrov-Smirnov (K-S) test for goodness-of-fit (Sokal and Rohlf, 1981). Co-efficient of variance was used to examine the variability of micronutrients within the soils. Soil properties and nutrients having CV% values < 15% were grouped as least variable whereas those having CV between 15 to 35% were categorized as moderately variable. Co-efficient of variance value more than 35% indicated high variability (Wilding, 1985). Coordinates of each sampling location were used for mapping using Arc GIS 10.1 software, whereas geo-statistical analysis was performed by GS+ software. Semivariogram analysis was applied to examine the degree of spatial dependence of bioavailable micronutrients in the soils at three soil depths (Bhatti *et al*., 1991). Range of spatial dependence was established using the uniform interval of 2500 m. After the establishment of spatial dependence, ordinary kriging was applied to prepare the prediction maps (Isaaks and Srivastava, 1989). Nugget was considered as experimental error or the uncertainty due to the sampling error or small scale variability. Partial sill represented the variations due to parent material variability and vegetation. Semivariance indicated dispersion of all observations below the mean or target value of the data set. Range delineated the separation distance over which the spatial dependence was found apparent (Aishah *et al*., 2010). Nugget to sill ratio was used as an indicator for grouping the bioavailable micronutrients (variables) to determine the extent of spatial dependence. Ratio less than 25 represented the highest spatial dependence whereas ratio between 25 to 75 % indicated medium spatial dependency. Spatial ratio greater than 75 percent represented weak spatial dependence (Cambardella, 1994; Attar *et al*., 2012). Moreover, spatial dependence was considered weak if R^2 value less than 0.50 (Duffera *et al*., 2007; Liu *et al*., 2008). Ordinary kriging was used as a spatial interpolation technique because of its higher flexibility. Various models were compared by using cross validation indicators. Mean error (ME), root mean square error (RMSE), average standard error (ASE), mean standard error (MSE), and root mean squared standardized error (RMSSE) were used for comparing various models and to check the correctness of simulation (Robinson and Metternicht, 2006). Average standardized error close to RMSE was considered as prerequisite for correct prediction (Hani *et al*., 2010).

Results

Physico-chemical properties of soils in the surveyed apple orchards

Information related to soil physico- chemical properties is summarized in the Table 1. Dominant soil textural class found in the surface soils of surveyed area was clay loam as 46% of analyzed soil sample were categorized in this class. Clayey texture was prevalent over 35% of analyzed soil samples. Sandy clay loam and loam texture was observed in the 15 and 4 percent of soil samples. In sub-surface soils 46% of total samples were clay loam in texture where as clay, loam, sandy clay loam and sandy clay texture was observed in the 21, 5, 27 and 1% of analyzed soil samples, respectively. In the lower soil depth, clay loam texture was dominant with 37% of total samples followed by sandy clay loam textural class observed in 36% of total soil samples. Clay, loam, sandy clay and sandy loam texture was observed in the 14, 6, 3 and 4% samples, respectively. Sand, silt and clay were found to be having medium heterogeneity as the percent CV was found to be ≤ 25%. Generally an increasing trend in the sand and silt percentage was observed with the increase in depth. Soils of the surveyed area were non calcareous, slightly calcareous, moderately calcareous and strongly calcareous. Strongly calcareous soil dominated in the surface soils, sub-surface and lower soil depth as the 66, 68 and 68 percent of the total analyzed samples were characterized as strongly calcareous in three soil depths, respectively. Non calcareous soils were found least in the surveyed area as 17, 17 and 15 percent of the total analyzed soil samples with increasing depth. Moderately calcareous soils constituted 16, 10 and 11 percent of the total analyzed sample in three different depths (0-15, 15-30 and 30-45 cm), respectively. Slightly calcareous soils increased with the increase in depth as 5, 6 and 7 percent of analyzed soil samples fell in this category. Soil calcareousness was found to be highly heterogeneous as the CV percent value was more than 35.

Soil pH was slightly alkaline to strongly alkaline in nature having least heterogeneity as the CV value was less than 20%. Organic matter content ranged from 0.92 to 5.77% in the surface soils whereas sub-surface soils contained organic matter ranging from 0.72 to 5.45%. In the lower soil depth organic matter ranged from 0.55 to 3.77%.

Table 1: Physico-chemical properties of orchard soils

Soil Property	Soil Depth cm	Mean	S.D.	Min.	Max.	CV%	Skewness	Kurtosis
Sand	0-15	36.35	7.89	21.00	56.00	21.70	0.25	-0.94
	15-30	40.11	7.54	25.00	58.00	19.00	0.22	-0.83
	30-45	44.05	7.14	31.00	59.00	16.20	0.30	-1.01
Silt	0-15	26.16	5.51	14.00	40.00	21.06	0.44	-0.27
	15-30	24.55	5.45	13.50	38.00	22.19	0.47	-0.29
	30-45	23.08	5.22	13.00	36.00	22.61	0.44	-0.44
Clay	0-15	37.48	8.49	17.00	59.50	22.65	0.39	-0.15
	15-30	35.38	8.18	16.00	55.50	23.18	0.39	-0.13
	30-45	32.86	7.83	15.00	54.50	24.00	0.46	-0.23
$CaCO_3$	0-15	13.61	7.84	0.25	23.40	57.60	-0.84	-0.99
	15-30	13.94	7.88	0.52	23.50	56.52	-0.85	-0.97
	30-45	14.28	7.94	0.56	24.15	55.60	-0.89	-0.93
pH	0-15	7.51	0.49	6.35	8.36	6.52	-0.07	-0.83
	15-30	7.54	0.58	6.47	8.40	6.35	-0.10	-0.74
	30-45	7.60	0.51	6.45	8.60	6.71	-0.07	-0.72
Organic Matter	0-15	2.65	1.15	0.92	5.77	43.39	0.41	-0.58
	15-30	2.20	1.03	0.72	5.45	47.07	0.69	-0.04
	30-45	1.43	0.69	0.55	3.70	45.36	1.05	0.74

(n = 540); S.D. = Standard Deviation

Descriptive statistical analyses and micronutrient indexation

Data regarding the micronutrient content in the surveyed area is represented in Table 2. In the surface soil layer bioavailable Zn content ranged from 0.39 to 5.35 µg g^{-1} with the mean value of 1.78 ± 0.98 and was deficient (< 0.9 µg g^{-1}) in 33% of total analyzed samples. Soil samples categorized as marginal (0.9 - 1.5 µg g^{-1}) constituted about 10 % of total analyzed soil samples. Sub-surface soil contained Zn content ranging from 0.35 to 3.52 µg g^{-1} with the mean value of 1.48 ± 0.72. Deficient soil samples constituted 33% of total analyzed samples whereas 9% of the analyzed soil samples were found marginal in bioavailable Zn content. In the lower soil depth (30-45 cm) the Zn content ranged from 0.31 to 2.85 µg g^{-1} with the mean value of 1.08 ± 0.50. Deficiency of Zn was more pronounced at lower depth as 50 and 12 percent soil samples were categorized as deficient and marginal in bioavailable Zn content. When compared with critical values, none of the soil sample was found deficient in the bioavailable Cu (<0.2 µg g^{-1}) and Fe (< 3 µg g^{-1}) content. Bioavailable Cu was marginal in 4, 11 and 17 percent of total analysed samples at three soil depths. Mn content also exhibited a decreasing trend with the increasing depth and 7, 9 and 12 percent of the total analyzed samples were categorized as marginal in three depths. Moreover, bioavailable micronutrients exhibited moderate to strong heterogeneity as the coefficient of variance was more than 15%.

Table 2: Micronutrient content in the soils of surveyed apple orchards

Micronutrient	Depth (cm)	Mean	S.D.	Min.	Max.	Skewness	Kurtosis	CV %
Zn	0-15	1.78	0.98	0.39	5.35	0.76	-0.28	56.97
	15-30	1.48	0.72	0.35	3.52	0.56	-0.35	48.64
	30-45	1.08	0.50	0.31	2.85	0.62	-0.24	46.29
Cu	0-15	1.48	0.49	0.35	2.91	0.34	-0.35	33.10
	15-30	1.02	0.37	0.21	2.11	0.18	-0.44	36.27
	30-45	0.27	0.18	0.20	1.67	0.69	-0.31	36.00
Fe	0-15	56.49	14.15	21.63	98.38	0.85	0.40	25.07
	15-30	49.94	14.93	20.33	91.93	0.31	0.12	29.89
	30-45	47.89	13.60	19.92	84.58	0.40	0.21	28.39
Mn	0-15	3.13	1.43	0.39	7.24	0.25	-0.33	45.68
	15-30	2.46	1.16	0.37	5.98	0.43	0.22	47.15
	30-45	1.89	0.84	0.26	3.82	0.48	0.36	44.44

(n = 540); S.D. = Standard Deviation

Prediction of micronutrient in the soil profile (0-45 cm) from surface analysis

Establishment of significant positive relationship (Figure 2) between the bioavailable micronutrient content in the surface and the soil profile up to depth of 45 cm provide a clue that micronutrient analysis for surface soils can serve as an acceptable indicator for bioavailable micronutrient content in the soil profile up to 45 cm. Regression analysis between the micronutrient content in the surface soils and in the soil profile up to 45 cm indicated R^2 approaching to unity (Table 3). Predicting bioavailable micronutrient up to depth of 45 cm by analyzing surface micronutrient content will save the time, labor and chemicals in the future studies.

Table 3: Slope, intercept and regression coefficient of regression equations enabling to predict the micronutrient content in the soil profile (0-45 cm)

Micronutrients (µg g^{-1})	a (intercept)	b (slope)	R^2
Zn	0.67	0.27	0.91
Cu	0.56	0.24	0.71
Fe	0.85	3.40	0.80
Mn	0.76	0.10	0.97

Micronutrient content in the foliage

Zn concentration in the diagnostic apple leaves ranged from 12.89 to 32.56 µg g^{-1} with the mean value of 21.59 ± 4.30. When compared with the critical values established by Neubert *et al*. (1970), about 80% of the collected samples were categorized as deficient. Foliage Cu content ranged from 3.27 to 20.39 µg g^{-1} with the mean value of 12.76 ± 3.27. Fourteen percent of the total collected samples were categorized as deficient. Foliage Mn content ranged from 6.34 to 47.25 with the mean value of 31.22 ±10.78. Fe content in the diagnostic apple leaves ranged from 40.23 to 107.25 µg g^{-1} with the mean value of 65.42 ± 14.04. Plant analysis indicated an acute Zn deficiency regardless of less deficiency in the soils of apple orchards. A significant positive relationship (r = 0.66 $P \leq 0.05$) was established between the bioavailable Zn and foliage Zn concentration. Foliage Fe content was also found in good agreement (r = 0.47 $p \leq 0.05$) with the bioavailable Fe concentration in the foliage (Figure 3).

Spatial variability of micronutrients in the soils

Semivariogram was calculated to examine the spatial structure of the bioavailable micronutrients in the soils at three depths. Results of the best fit Semivariogram models for bioavailable micronutrients (Zn, Cu, Fe and Mn) are presented in Table 4.

The best fit model for bioavailable Zn was spherical at the surface and lower soil depth whereas exponential model fitted well for bioavailable Zn content in the surface soils. Bioavailable Zn was categorized as medium spatial dependent in the surface and strongly spatial dependent at the subsurface and lower soil depth. The range for three depths was 13.5, 8.64 and 12.28 km, respectively, (Table 4). Regression co-efficient (r^2) values calculated for bioavailable Zn at three soil depths were 0.58, 0.92 and 0.75, respectively (Table 4).

Exponential was a best fit model for bioavailable Cu in the surface and sub-surface soils while spatial structure of the bioavailable Cu content at lower soil depth was best described by spherical model. Bioavailable Cu content were moderately spatial dependent at the surface whereas strongly spatial dependant at the subsurface and lower soil depth with the ranges of 10.89, 10.80 and 14.5 km. Spatial structure of bioavailable Fe was best described by exponential model at the surface and spherical model at the

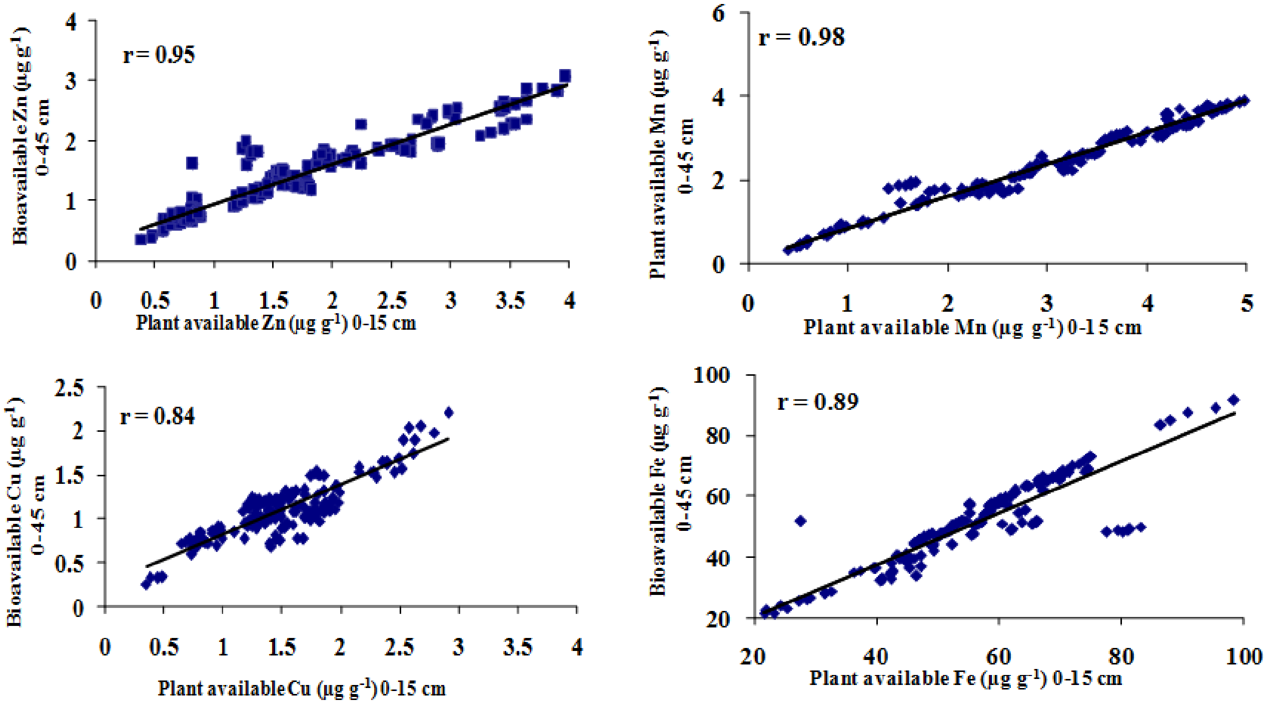

Figure 2: Relationship between the bioavailable micronutrients in the surface and cumulative soil profile (0-45 cm)

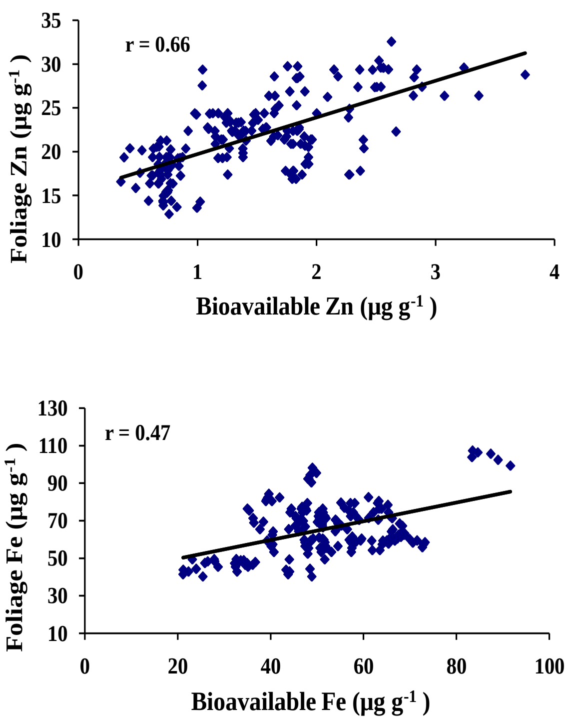

Figure 3: Relationship between the foliage and bioavailable micronutrients (Zn and Fe)

subsurface and lower soil depth. Bioavailable Fe content showed moderate spatial dependency at three soil depths with the range of 15.57, 19.63 and 20.93 km, respectively, (Table 4).

Spatial correlation of bioavailable Mn was described by the exponential model in the surface and sub-surface soils and by spherical model in the lower soil depths. Spatial dependence in case of Mn was categorized as medium at the surface soils whereas strong at subsurface and lower soil depth (Table 4).

After the establishment of spatial dependence, ordinary kriging was applied to prepare the maps, estimating the nutrient content of the un-sampled sites. Root mean square standardized error, average standardized error and root mean square error are given in Table 4. Whole area was classified in to five predicted zones for each micronutrient, presented in Figure 4 and 5.

Influence of physico-chemical properties on the micronutrient availability

Sand negatively influenced the availability of micronutrients as a negative relationship was established between the sand and analysed bioavailable nutrients. This relationship was significant for Cu (r = -0.177, $p \leq 0.01$) and Zn (r = - 0.144, $p \leq 0.01$). A negative but non significant relationship was established between sand and bioavailable Fe (r = -0.0742) and Mn (r = - 0.0797).

(Liu *et al*., 2004; Spiker *et al*., 2005). Moderate spatial dependence of bioavailable Cu, Mn and Fe were maintained by extrinsic and intrinsic factors at three soil depths (Chunfa *et al*., 2010; Banerjee *et al*., 2011).

Table 4: Parameters related to Semivariogram models and interpolation of plant available micronutrients at various soil depths

Micronutrient	Depth (cm)	Model	Range (A_0)	Nugget/Sill (%)	R^2 Value	RMSSE[a]	ASE[b]	RMSE[c]
Zn	0-15	Spherical	13.5	36.44	0.85	0.97	0.39	0.31
	15-30	Exponential	10.64	7.19	0.92	1.03	0.71	0.79
	30-45	Spherical	12.28	24.25	0.74	1.02	0.31	0.33
Cu	0-15	Exponential	10.89	25.39	0.59	0.98	0.28	0.30
	15-30	Exponential	10.80	18.78	0.63	0.97	0.30	0.33
	30-45	Spherical	14.5	22.5	0.85	0.99	0.24	0.21
Fe	0-15	Exponential	15.57	44.85	0.55	1.11	11	12.27
	15-30	Spherical	19.63	26.92	0.94	1.06	12.59	13.53
	30-45	Spherical	20.93	30.16	0.92	1.04	16.36	17.13
Mn	0-15	Exponential	14.16	37.23	0.69	1.18	1.03	1.23
	15-30	Spherical	11.70	13.21	0.86	1.15	0.81	0.95
	30-45	Spherical	14.96	23.00	0.53	1.12	0.63	0.72

[a] Root mean square standardized error; [b] Average standardize error; [c] Root mean square error

A positive relation was observed between the bioavailable micronutrients and silt. This relationship was significant for bioavailable Cu (r = 0.198, $p \leq 0.01$) and Mn (r = 0.148, $p \leq 0.01$) whereas non significant for bioavailable Fe (r = 0.055) and Zn (r = 0.054). Positive significant relationship was observed between the organic matter and bioavailable micronutrients. Correlation coefficient values observed were Zn (0.450, $p \leq 0.01$), Cu (0.463, $p \leq 0.01$), Fe (0.334, $p \leq 0.01$) and Mn (0.431, $p \leq 0.01$). A significant negative relationship was observed between the bioavailable micronutrients and soil pH. Correlation coefficient values observed were as Zn (r = -0.225, $p \leq 0.01$), Cu (r = - 0.164, $p \leq 0.01$), Fe (r = -0.316, $p \leq 0.01$) and Mn (r = -0.170, $p \leq 0.01$).

Significant negative relationship was observed between the bioavailable micronutrients and $CaCO_3$ content. Correlation coefficient values calculated were as Zn (r = -0.123, $p \leq 0.01$), Cu (r = -0.108, $p \leq 0.01$) and Fe (r = -0.327, $p \leq 0.01$).

Discussion

Soil analysis indicated the deficiency of bioavailable Zn while Cu and Mn content were marginal in some places of the surveyed area. These results were in line with the previous work indicating the micro-element deficiency in the soils of apple producing region Murree (Ahmad *et al*., 2010; Ahmed *et al*., 2012). Spatial dependence of bioavailable Zn was found to be disturbed by anthropogenic activities at surface and sub-surface soils. This might be due to intercropping of exhaustive crops like potatoes and wheat in the orchards. Spatial dependence in the lower soil depth was maintained by inherent soil factors like parent material

Maps prepared for the micronutrients using ordinary kriging also indicated the spatial dependence. Similar techniques were successfully used by the researchers to delineate various areas in to low, medium and high nutrient content for site specific nutrient management (Rafique *et al*., 2006; Shah *et al*., 2013). Maps indicated an acute Zn deficiency in the south eastern surveyed area that increased with depth while marginal Zn content were found in the north eastern surveyed region. All other micronutrients were found marginal to adequate in the whole area.

Climatic conditions and textural classes of surveyed area were suitable for growing apple orchards as recommended by Ahmed *et al.* (2010). Bioavailability of micronutrients was influenced by physico-chemical properties like organic matter, silt and clay. Results were in line with the findings of Chinchmalatapure *et al*. (2000) and Nazif *et al*. (2006). Positive relationship between bioavailable micronutrients and organic matter might be due to enhanced ability of soil to retain and supply nutrients to plants because of higher cation exchange capacity of organic matter. Moreover, mineralization of organic matter releases substantial amount of nutrients (Rahman *et al*., 2013). Factors negatively influencing the availability of micronutrients were pH, $CaCO_3$ and sand. Availability of micronutrients is mostly diminished in calcareous soils due to sorption to clays and carbonates, co-precipitation with carbonates or formation of insoluble compounds. Similar results were reported by Rashid *et al*. (1997) and Gupta *et al*. (2000). Negative relationship between sand and bioavailable nutrients might be due to low cation exchange

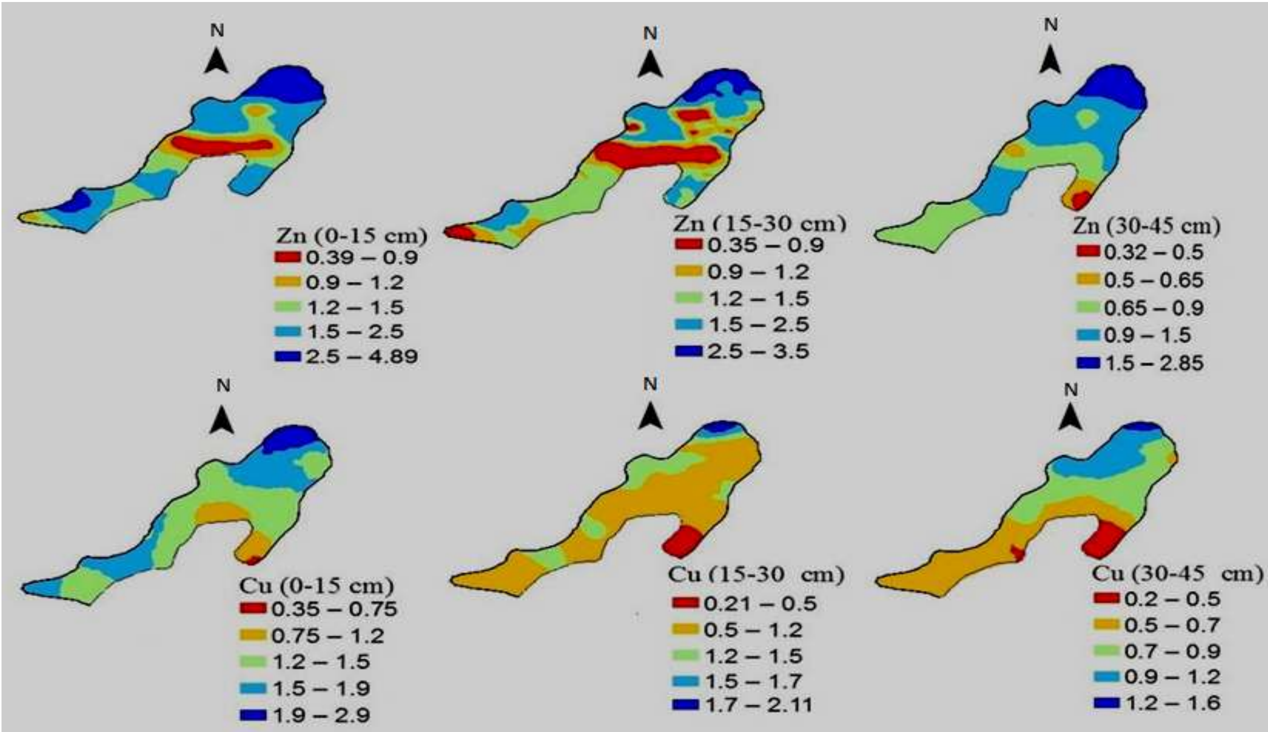

Figure 4: Spatial distribution of Zn and Cu (µg g^{-1}) in the soils

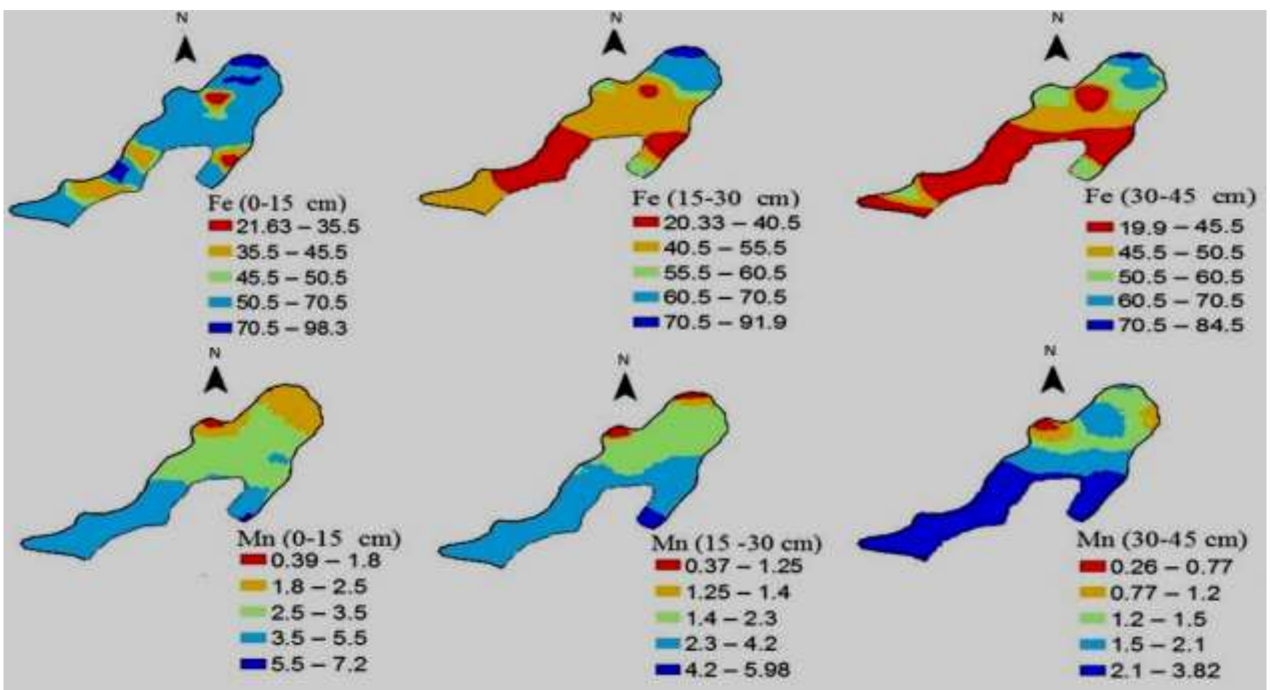

Figure 5: Spatial distribution of Fe and Mn (µg g^{-1}) in the soils

capacity of sand. Similar relationship was observed by Nazif *et al*. (2006). A positive correlation established between the silt and bioavailable micronutrients signified that increase in silt enhances the availability of nutrients. These results were in line with Sharma *et al*. (1996) and Perveen *et al*. (1993).

Conclusion

Bioavailable Zn was the only deficient micronutrient in soils of apple orchards. Availability of micronutrients was positively influenced by organic matter, silt and clay and negatively influenced by sand, pH and $CaCO_3$ content. Bioavailable Zn, Cu and Mn were moderately spatial dependant in the surface soils whereas strongly spatially dependent in the subsurface and lower soil depth. Bioavailable Fe was moderately spatial dependent at all soil depths. Presence of medium to strong spatial dependence of micronutrients in the soils indicated a need for the development of site specific recommendation for the management of Zn nutrition to improve yield and quality of apple.

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