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Indexing bioavailable and foliage boron content in apple orchards of Pishin district, Baluchistan, using GIS and geo-statistics as diagnostic tools

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Abstract

Poor nutrient management practices are the crucial factor in low yield in the country in addition to substandard root stock, insufficient use of horticultural/agronomic skills and lack of insect, pest/ disease control. Most Pakistani soils being alkaline in nature widespread boron deficiency is very likely. This research work was carried out to examine the boron status in the soils and foliage of apple orchards in one of the major apple growing district of Pakistan, the Pishin district of Baluchistan. Keeping in view the limitations of classical statistics in explaining spatial heterogeneity, a survey in the farmer grown apple orchards was conducted for indexing plant bioavailable boron. Geo-statistics and Geographical Information System (GIS) were used as diagnostic tools. Geo-referenced soil samples were collected from 90 apple orchards from different locations of the district. Recently matured leaves were also sampled from associated apple trees. Digital maps were prepared using ordinary kriging for classifying the whole area in to various zones on the basis of boron content levels for regional scale information. Results showed that physico-chemical soil properties and plant bioavailable boron contents were medium to strongly spatial dependent. Soils of the apple orchards were strongly alkaline calcareous. Sixty five percent of the surveyed orchards were deficient in organic matter content. Plant bioavailable B was deficient in 58 percent of upper arable and 61 percent lower arable soil layers. Foliage boron was found to be deficient in 62 percent of the total analyzed foliage samples. This research revealed widespread boron deficiency in the study area and emphasize the need of site specific B management in apple orchards.

Key words: GIS, Kriging, Spatial dependence, Boron, Physico-chemical properties

Introduction

Average production of Pakistani orchards is alarmingly low. The fruit yield and quality characteristics are not up to the standard compared to the produce of competing neighboring countries. Average yield of apple orchards is 5.76 tonnes per hectare in the country (MinNFSR, 2013-14). Optimum management of orchards especially the nutrient management is critical for obtaining maximum yield (Aziz *et al*., 2004). Nutrient deficiency, less or imbalanced use of fertilizers is one of the main reason for low average yield, and quality of apple produce (Ahmed *et al*., 2014).

Boron is involved in pollen tube development and hence plays a vital role in the fertilization and fruit setting (Bolaños*et al*., 2004). Boron is also essential in the meristimatic tissue development and cell division. Fruit development, root elongation, cell wall and tissue formation is indirectly influenced by boron as it is involved in hormone regulation (Rashid, 2006; Dell and Haung, 1997). In higher plants formation of boron sugar complex play an important role for the sugar transport under short and long period (Perica *et al*., 2001). Eighty countries and 132 plant species have been reported to be affected by boron deficiency. Tree fruit crops especially apple is more susceptible to boron deficiency (Alloway, 2008). Apple fruits of boron deficient trees are small, deformed, corked, sensitive to cracking and have yellow skin with a poor red color (Peryea *et al*., 2003).

Boron availability to plants is highly dependent on soil physico-chemical characteristics (Park and White, 1952). For sustainable management of plant nutrition in orchards, it is necessary that within field variability of the soil properties is taken into account because continual spatial

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variability is one of the important characteristic of the soil properties (Ahmed *et al*., 2014). Laborious soil sampling, analysis and usual statistical methods make it impossible to observe the nutrient content in the whole field. Application of modern techniques like GIS and geostatistics becomes in-evitable for efficient and site specific nutrient management (Ahmed *et al*., 2014; Attar *et al*., 2012). Geostatistics 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 (Ahmed *et al*., 2012; Jin *et al*., 2011).

Uniform application of fertilizer in larger geographical areas in 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). In Pakistan B deficiency is a widespread nutritional disorder affecting about 50 to 60 percent cultivated area of major crops like cotton, rice and wheat in Punjab, KP, Sindh and AJK (Rashid, 2006). Keeping in view the scarcity of information regarding plant available B content in the apple orchards of Baluchistan province of Pakistan, this research work was conducted to examine the B status in the soil and foliage of apple orchards.

Materials and Methods

Site description

District Pishin is located between 30°35'0N and 67°0'0E with an altitude of 5807 feet in eastern elevated plains of Baluchistan province (Figure 1). There are four types of soils in the area; lowland foothills, the Piedmont Basins, gravely piedmont fans and loess plains. The climate of district Pishin is arid, mean annual rainfall ranges from 250-500 mm and mostly occur in winter season especially in month of January and February. The water scarcity is compensated by artificial irrigation system including tube wells and karezes**.**

Soil and foliage sampling

Ninety representative apple orchards were selected in the Pishin district. Surface (0- 15cm) and subsurface (15-30 cm) soil samples were collected, labeled, air dried and were stored in sealed plastic bags for further analysis. Coordinates of the sampled sites were recorded by the GPS (Global Positioning System). Diagnostic plant samples, i.e., recently matured leaves from all around the canopy in the month of July and August, were collected from five trees in each orchard. Samples were brought to laboratory, dried using hot air oven and processed for analysis.

Soil and plant analysis

The soil samples were analyzed using standard methods for soil texture (Gee and Bauder, 1982), pH (Mclean, 1982), $CaCO_3$ contents (Leoppert *et al*., 1984), electrical conductivity (Mclean, 1982), organic matter (Nelson and Sommers, 1982) and dilute HCl bioavailable boron (Ponnamperuma *et al*., 1981). Foliage samples were analyzed for total boron following dry ashing procedure (Chapman and Pratt, 1961). Subsequent determination of B was done by colorometry technique using azomethine (Bingham, 1982). Critical values described by Gupta (1993) were used to classify the soil in to low, medium and high in plant available boron contents. Foliage boron contents were classified according to criteria suggested by Robinson *et al*. (1997).

Statistical and geostatistical analysis

Descriptive statistics including mean, standard deviation (SD), kurtosis and skewness were applied to the data set obtained for each physico-chemical property and bioavailable boron content. Impact of various physico-chemical characteristics on the availability of boron was estimated by correlation analysis. Co-efficient of variance was used to examine the variability of tested parameters 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. Semivariogram analysis was applied to examine the degree of spatial dependence of bioavailable boron in the soils at both soil depths (Bhatti *et al*., 1991). After the establishment of spatial dependence, ordinary kriging was applied to prepare the prediction maps (Isaaks and Srivastava, 1989). Nugget is considered as experimental error or the uncertainty due to the sampling error or small scale variability. Partial sill represents the variations due to parent material variability and vegetation. Semivariance indicates dispersion of all observations below the mean or target value of the data set. Range delineates the separation distance over which the spatial dependence is found apparent (Aishah *et al*., 2010). In this study nugget to sill ratio was used as an indicator for grouping the bioavailable boron and other 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 and Discussion

Physico-chemical characteristics and bioavailable boron content in the soils and foliage

Soil physico- chemical characteristics are summarized in the Table 1. Clay loam was the most dominant textural class (52 %) in the surveyed area. Other textural classes observed in the surveyed area were silty clay loam, sandy clay loam and clay (20, 12, and 11%). Sand, silt and clay content in the soils were found to be having medium heterogeneity as CV value of the data was between 15-35 percent. Surveyed soils were strongly alkaline as pH ranged from 7.49 to 8.26 with the mean value of 7.88±0.23 and 7.52 to 8.27 with the mean value of 7.90 ± 0.23 at surface and subsurface soils, respectively, with medium heterogeneity. Lime content in the surveyed soils ranged from 9.5 to 24.1 percent with the mean value 16.7±4.1 in the surface soils of surveyed apple orchard. In subsurface soils lime content ranged from 9.9 to 24.8 percent with the mean value of 16.9±4.1 which indicated these soils were strongly calcareous. Calcium carbonate content of soil samples revealed the medium heterogeneity having CV between (15-35 %). Climatic conditions and textural classes of surveyed area were favorable for growing apple orchards as recommended by Ahmed *et al.* (2014).

Organic matter content in the soils ranged from 0.32 to 1.34 percent with the mean value of 0.77±0.22 and 0.30 to 1.38 percent with the mean value of 0.75±0.22 at surface and subsurface respectively. Sixty five percent of the soil samples were categorized deficient in organic matter content whereas 33% were found marginal. Data regarding organic matter content indicated medium heterogeneity (CV= 15-35%). The soil extractable boron ranged from 0.19 to 1.08 µg g^{-1} with mean value of 0.49±0.23 and 0.16 to 1.06 µg $g^{-1}$with the mean value of 0.47±0.23 in surface and subsurface soils respectively with high heterogeneity (CV > 35%). Plant bioavailable B was deficient in 58 and 61 percent of upper arable and lower arable soil layers of the surveyed apple orchards. Organic matter enhances 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). So organic matter deficiency in the soils of surveyed apple orchards was found to be one of the main reasons for boron nutrient deficiency. Total B content in the foliage of surveyed apple orchards ranged from 10.1 to 41.8 µg g^{-1} with the mean value of 18.45 ± 3.32. When comparing with the critical values established by Robinson *et al*. (1997) 62 percent of the total analyzed samples were classified deficient in foliage B content.

Relationship between Physico-chemical properties and bioavailable boron content in the soil

Pearson correlation at the probability level of <0.05 was used to examine the relationship between bioavailable boron and physico-chemical properties (Table 2). Positive significant correlation was observed between native soil B and organic matter (r = 0.39). Native humus of soil retained higher amount of adsorbed B and influenced significantly in B adsorption (Park and White, 1952). Sharma *et al*. (2006) concluded the positive effect of farm yard manure on retention of B in soil. The positive influence of organic matter on the available boron might be due to its decomposition which releases certain acids which solubilize B adsorbed on organic matter, clay and calcium carbonate. Mandal and De (1993) reported that boron form complexes with organic matter and on the organic matter decomposition, boron is released to the soil solution. Organic matter also acts as a leading source of reserve B after fertilization when present in soil at sufficient level (Marzadori *et al*., 1991). It is evident from different researches that native available B correlate significantly with organic matter and B is adsorbed more on organic matter than mineral soil (Gu and Lowe, 1990; Yermiyahu *et al*., 1995). The results regarding bioavailable B for soil texture represented that fine texture soil had greater amount of extractable B than sandy soil (Table 2). The results revealed that that clay had positive correlation (r = 0.34) with bioavailable B. These results are consistent with findings of various researchers in which they found that B adsorption increased on a fine texture and increased with the clay content (Communar and Keren, 2006; Evans, 1987; Bhatnagar *et al*., 1979).

Spatial variability of physico-chemical properties and bioavailable boron content

Skewness and kurtosis of the data set indicated normal distribution (Table 1). Semivariogram was calculated to examine the spatial structure of the physico-chemical properties and bioavailable boron at two depths. Results of the best fit semivariogram models for bioavailable boron, sand, silt, clay and are presented in Table 3.

In our case spherical model was best fit for the studied parameters. Soil separates like sand, silt, and clay at surface

Table 1: Soil physico-chemical characteristics of surveyed apple orchards

Characteristics	Depth (cm)	Mean	SD	Min	Max	C.V (%)	Skewness	Kurtosis
Sand	0-15	31.7	11.8	9.6	55.0	37.2	0.06	-1.04
	15-30	31.8	11.8	10.1	55.8	37.1	0.07	-1.05
Silt	0-15	35.1	13.4	11.2	63.7	37.9	0.21	-1.10
	15-30	35.3	13.2	11.4	63.4	37.4	0.20	-1.10
Clay	0-15	32.9	6.8	24.8	56.1	20.5	2.25	4.52
	15-30	32.8	6.6	24.6	52.9	20.3	2.23	4.49
pH	0-15	7.88	0.24	7.49	8.26	2.99	-.005	-1.19
	15-30	7.90	0.23	7.48	8.27	2.91	0.05	-1.14
$CaCO_3$	0-15	16.7	4.13	9.5	24.9	24.7	0.45	-0.87
	15-30	16.9	4.15	9.9	24.8	24.5	0.47	-0.92
Organic matter	0-15	0.77	0.22	0.32	1.34	28.5	0.12	0.006
	15-30	0.75	0.23	0.30	1.38	30.6	0.25	0.35
Bioavailable Boron	0-15	0.49	0.20	0.19	1.08	40.8	0.95	0.42
	15-30	0.47	0.19	0.16	1.06	40.4	0.98	0.73

SD = Standard deviation CV =Co-efficient of variance

Table 2: Relationship between soil physico-chemical characteristics of surveyed area

Characteristics	Sand	Silt	Clay	pH	$CaCO_3$	Organic matter	Bioavailable Boron
Silt	-0.46*						
Clay	-0.04^{NS}	-0.32^{NS}					
pH	-0.07^{NS}	0.19^{NS}	0.16^{NS}				
$CaCO_3$	0.16^{NS}	-0.14^{NS}	0.18^{NS}	0.21^{NS}			
O.M	-0.07^{NS}	-0.03^{NS}	0.28^{NS}	-0.13^{NS}	-0.13^{NS}		
Bioavailable Boron	0.13^{NS}	-0.06^{NS}	0.34*	-0.29^{NS}	-0.04^{NS}	0.39*	

* $P < 0.05$ ^{NS} Non significant

Table 3. Characteristics of Semivariogram model for soil physico-chemical properties at surface and subsurface using ordinary kriging for map generation.

Characteristics	Depth (cm)	Model	Range (A_o)	Nugget/Sill (%)	RMSSE	ASE	RMSE
Sand	0-15	Spherical	0.76	29.0	0.92	8.60	7.79
	15-30	-----------	0.77	28.9	0.93	8.51	7.69
Silt	0-15	Spherical	0.64	47.5	0.87	10.6	9.08
	15-30	-----------	0.64	47.2	0.88	10.5	9.98
Clay	0-15	Spherical	0.17	3.07	1.46	4.89	7.41
	15-30	-----------	0.17	0.7	1.51	4.73	7.37
pH	0-15	Spherical	1.77	43.0	1.04	0.19	0.21
	15-30	-----------	1.80	48.2	1.04	0.19	0.21
Calcium carbonate	0-15	Spherical	0.22	70.4	1.00	3.67	3.66
	15-30	-----------	0.20	67.4	1.00	3.71	3.66
Organic matter	0-15	Spherical	3.25	72.0	1.12	0.18	0.20
	15-30	-----------	3.26	85.6	1.19	0.18	0.21
Bioavailable B	0-15	Spherical	29.8	25.8	1.13	0.18	0.21
	15-30	-----------	29.8	21.6	1.18	0.17	0.20
Foliage B	-	Spherical	-	168	-	-	-

with range (0.77, 0.64, 0.17 km) and subsurface (0.76, 0.64, 0.17 km) showed medium spatial dependence for sand and silt while strong spatial dependence for clay. Medium to strong spatial dependence in soil separates indicated that texture in the soil is maintained by parent material which is the most prominent property of soils. The spatial structure of pH indicated medium spatial dependence at surface and subsurface with range of 1.77 and 1.80 km respectively. The best fit model for calcium carbonate content was spherical at surface and subsurface representing medium spatial distribution pattern with range of 0.22 to 0.20 km respectively. Spatial structure of soil organic matter showed moderate spatial dependence at surface with range 3.25 km while weak spatial dependence at subsurface was found with range 3.26 km. Spatial structure of bioavailable boron was described by moderate spatial dependence at surface and subsurface with range of 29.8 and 29.8 km respectively. Moderate spatial dependence for pH, calcium carbonate and organic matter content at surface and subsurface might be due to orchard management activities like cultivation, farm yard manure application and intercropping of agronomic crops in the orchards. Parent material is also one of the important factors maintaining the spatial variability of different soil characteristics (Liu *et al*., 2004; Spiker *et al*., 2005). Rahal, (2015) revealed that soil physico-chemical properties including soil separates, calcium carbonate and organic matter were strongly spatial dependent while pH was moderately spatial dependent. Zhang *et al.* (2014) explored the spatial heterogeneity of soil properties and nutrients and reported that soil separates and N, P, K and pH were moderately spatial dependent while organic matter was weakly spatially dependent. Our results were in line with different researchers (Kavianpoor *et al*., 2012; Vasques *et al*., 2010). Foliage boron was weakly spatial dependent as nugget to sill ratio was more than 75%.

GIS based digital mapping of physico-chemical properties and bioavailable boron content in soils

After the establishment of spatial dependence, ordinary kriging was applied to prepare the maps and for 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 3. Digital maps for soil separates (sand, silt and clay), pH, $CaCO_3$ and organic matter content were also produced and are presented in Figure 2 and 3. Whole district was also delineated in to various areas having differential

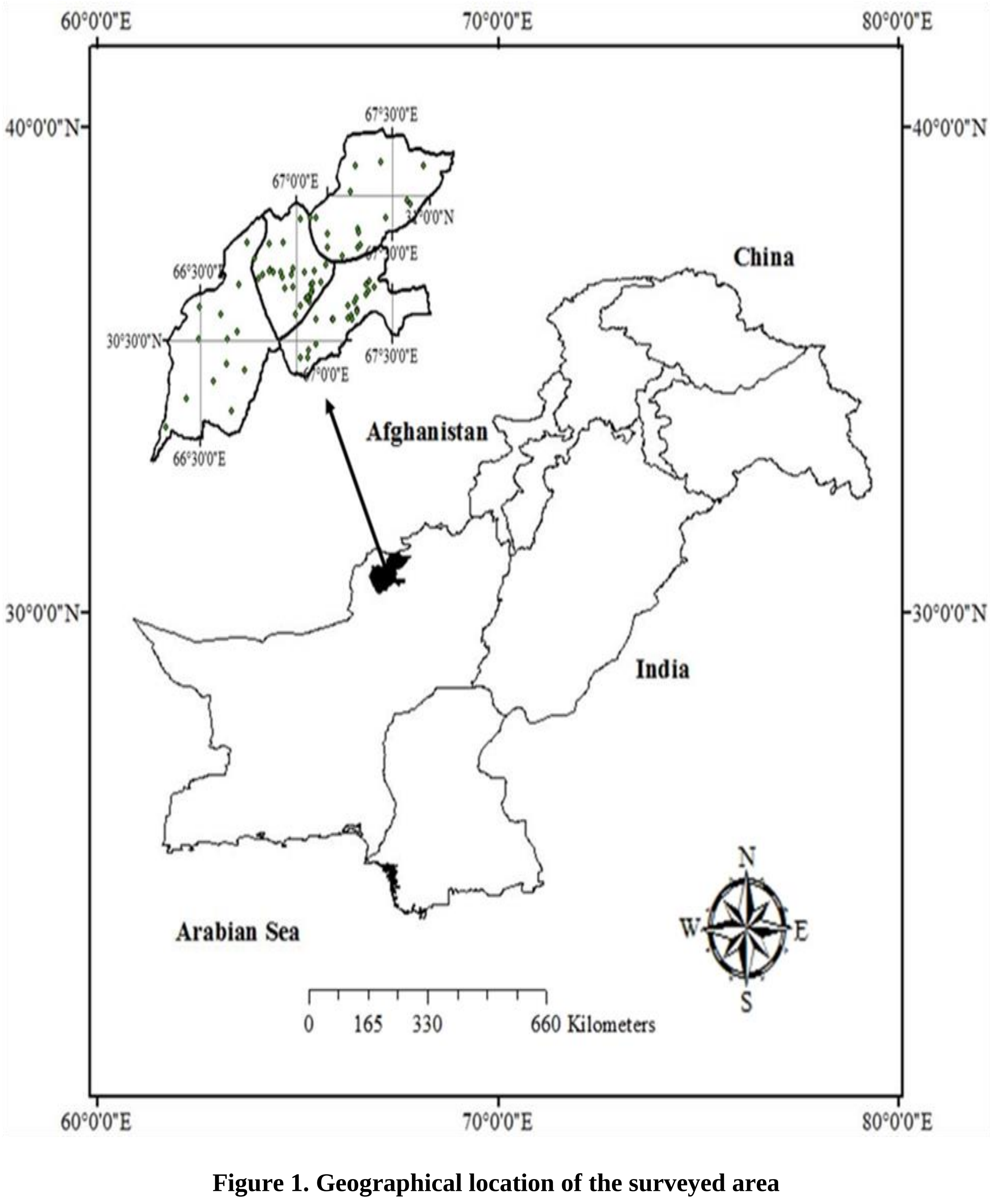

Figure 1. Geographical location of the surveyed area

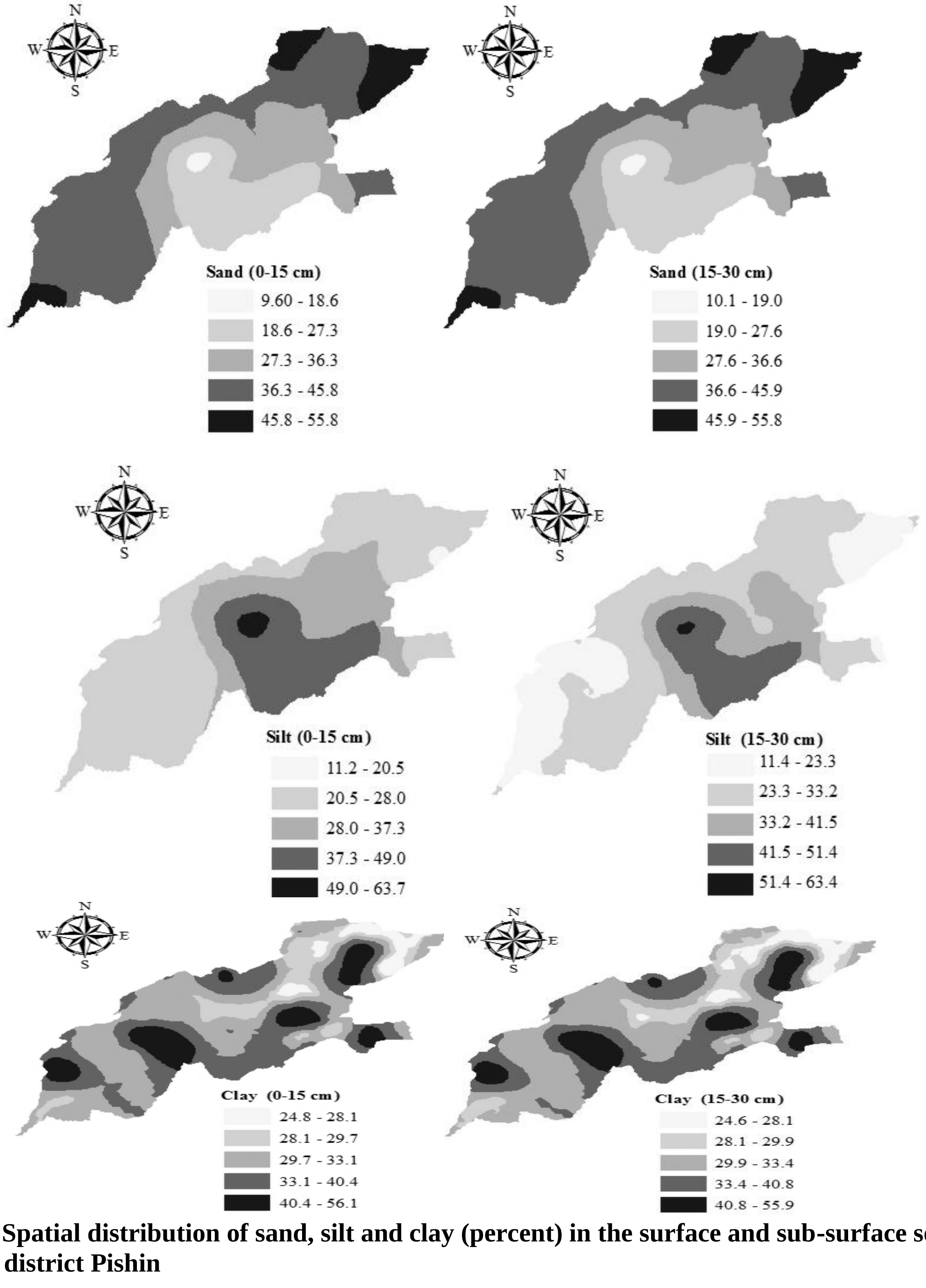

Figure 2: Spatial distribution of sand, silt and clay (percent) in the surface and sub-surface soils of district Pishin

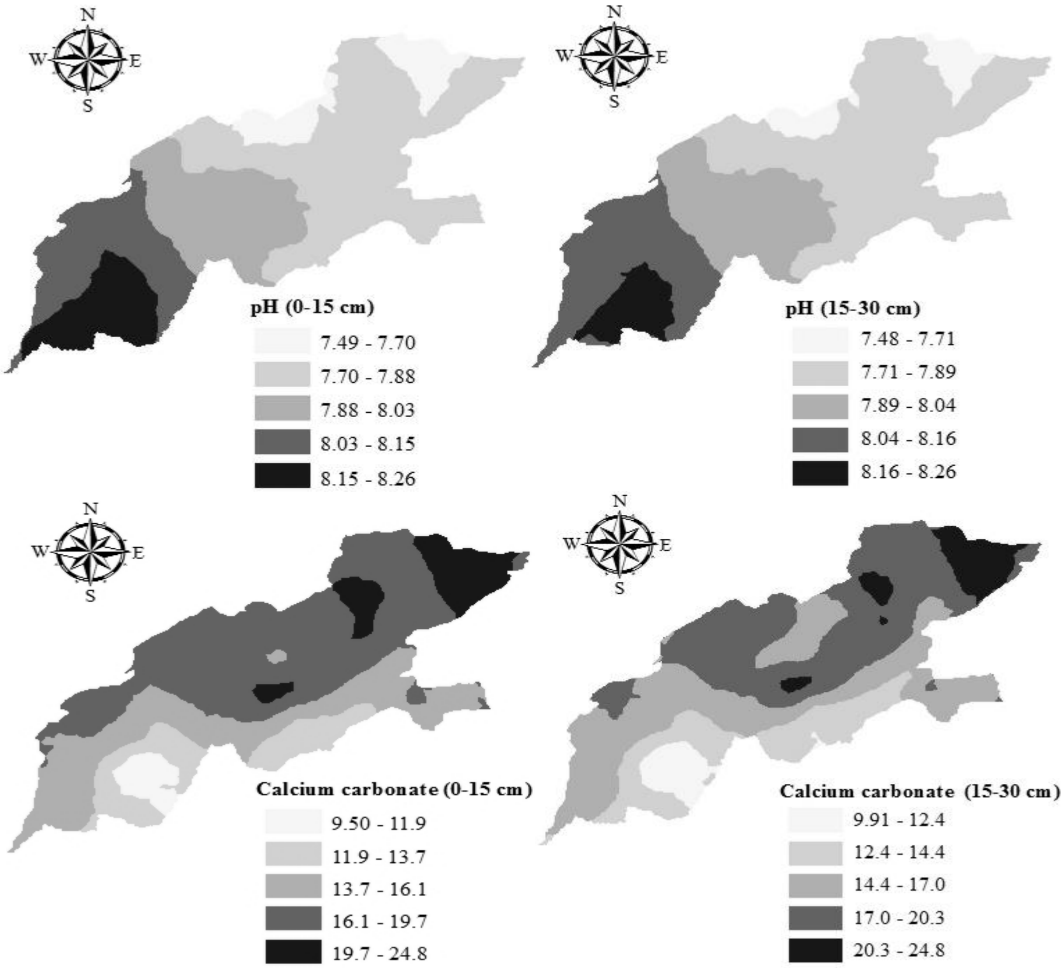

Figure 3: Spatial distribution of pH and $CaCO_3$(%) in the surface and subsurface soils

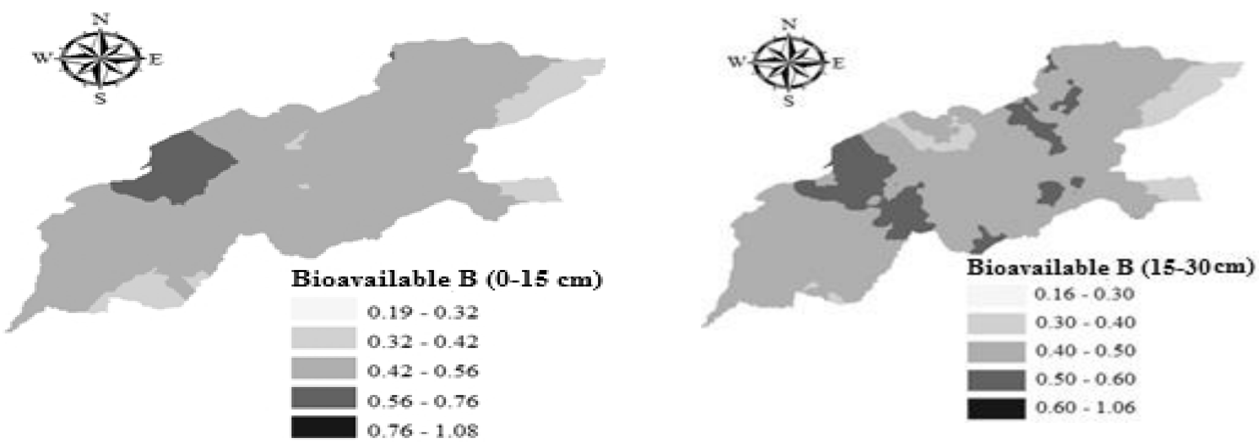

Figure 4: Spatial distribution of bio-available B (µg g^{-1}) in the surface and subsurface soils

bioavailable boron content (Figure 4) at surface and sub-surface soils.

Conclusion

Boron deficiency is an impediment to sustainable fruit production. Diagnosis of site specific bioavailable and foliage boron is, therefore, a prerequisite for better orchard nutrition management for profitable fruit farming. The study highlighted the importance of digital soil information and the geostatistical techniques in the diagnosis of soil nutrient status and its sustainable management. It revealed that most of the parameters related to soil physico-chemical properties and boron availability status are spatially dependent in the study area. Bioavailability of B was positively influenced by clay and organic matter while a negative relationship was observed between the pH and $CaCO_3$. Soil separates like sand silt and clay were found moderately spatial dependent. Similarly bioavailable boron was found moderately spatially dependent at the surface soils while moderately spatial dependent in the subsurface soils. Strong to moderate spatial dependence in the surface and subsurface soils provided an opportunity to prepare isarthmic maps of the surveyed area. Isarthmic maps are of prime utility by the farming community for prediction of the boron content of apple orchards of their area. Digital soil information can be used by the scientific community to plan their future research. Digital maps prepared will be a torch bearing guideline for the government and policy making agencies. Deficiency of bioavailable and foliage boron implied a dire need of site specific boron nutrition management in the apple orchards of surveyed area. Future research work is required for situation analysis and long term nutrition management recommendations.

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