Eurasian J Soil Sci 2018, 7 (4) 355 - 364

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org

Spatial variability pattern and mapping of selected soil properties in hilly areas of Hindukush range northern, Pakistan

Munir Ahmad [a,*], Dost Muhammad [b], Maria Mussarat [b], Muhammad Naseer [c], Muhammad A. Khan [d], Abid A. Khan [b], Muhammad Izhar Shafi [b]

[a] School of Environmental Science and Technology, Dalian University of Technology, China
[b] Soil and Environmental Sciences, The University of Agriculture, Peshawar, Pakistan
[c] Agricultural Research Station, Seen Lasht, Chitral, Pakistan
[d] Department of Weed Sciences, The University of Agriculture, Peshawar, Pakistan

Article Info

Received : 23.02.2018
Accepted : 16.09.2018

Abstract

Soil samples at 0-20 cm depth were collected from major crop areas of Hindukush mountainous range, District Chitral, extreme Northwestern Pakistan, during April 2014 to assess their physico-chemical properties and spatial distribution pattern. 103 soil samples were analyzed and maps were created by geostatistical technique of inverse distance weighting and kriging techniques using GIS and GS win-7 computer software. The soil texture ranged from silt loam to dominantly sandy loam, slightly acidic to alkaline and moderate to highly calcareous but with no salinity indication. Soil organic matter was higher than 2 % in about 75 % of samples. Soil pH, EC and lime showed slight dependence on each other with r values from 0.4 to 0.5 while OM varied independently as indicated by their lower correlation values. Semivariogram analysis showed that soil pH, lime, OM had strong spatial dependence (nugget-sill ratio, <25%) while silt, sand, EC had moderately (nugget-sill ratio, 25-75%) and clay had weakly distributed in the area. Linear, Gaussian and exponential models were used for different soil parameter based on nugget, mean prediction error and root mean square standardize prediction error values and maps were developed through extension techniques to cover all the area outside the sampling points.

Keywords: Spatial variability, soil mapping, kriging, Chitral district, geostatistics.

Introduction

District Chitral is undoubtedly the most important and captivating place in the majestic Hindukush Range. It is a mountainous area in the extreme north of Pakistan about 330 kilometers away from Peshawar, the capital of Khyber Pakhtunkhwa province. The valley of Chitral lies at an elevation of 1494 m from the sea level. The total area of Chitral is 14,850 km^2 situated between 35.12 – 36.50^0 N latitude (North) and 71.20 – 74.55^0 E longitude (East). According to 2004 population census, the total population of district Chitral was about 320,000 and according to latest estimate it has reached the mark of 500,000 (Chitral today). Chitral has semi-arid climate with almost no rainfall during the very hot summers. The total cultivable land is 23000 ha which is only 4% of the total area. Farmers hold very limited farming land and hence reliance on food such as cereals and fodder crops for animal remains high. The common crops grown in district Chitral are maize, rice, wheat and potato.

Soil properties change temporally and spatially from field to large area. They are influenced by different soil forming factors like climate, parent materials, relief, time and organisms. Besides these natural process some other agronomic practices like fertilization, crop rotation also influences these properties at greater extent. Variation in soil properties affect crop growth though reduction in effectiveness of uniformly applied

* Corresponding author.
School of Environmental Science and Technology, Dalian University of Technology, Dalian City, Liaoning Province, China
Tel.: +86 18342260692 E-mail address: munirahmad089@yahoo.com
e-ISSN: 2147-4249 DOI: 10.18393/ejss.466424

fertilizer to the field as described by Mulla et al. (1990). In past, variation in properties of soil has been determined through field experiments such as Rothamsted Classical Experiments by Johnston et al. (1986) and Ecological Research Program by Risser (1991). But this method was very time-consuming and in most of the cases too much expensive to be affordable. Spatial variability of soil properties can be used for prediction the value of soil at un-sampled location by using experimentally analyzed data of sampled location. Geostatistics can be regarded as a collection of numerical techniques that deal with the characterization of spatial attributes, employing primarily random models in a manner similar to the way in which time series analysis characterizes temporal data by Olea (1999). Using geostatistics is not only related to soil physico-chemical properties, but it is also applicable for the determination of spatial pattern of soil microorganisms described by Wollum and Cassel (1984).

The present study was conducted to evaluate the soil physical and chemical properties of district Chitral collected randomly from various parts of the district. Arc GIS 9.3 and other statistical software were used for assessing variability, spatial pattern, mapping and classification of various soil properties determined in these soil samples. The prepared maps, chart and tables of various soil physico-chemical properties were thought to have good use for soil resource management, enhancing agriculture production and for as guide line for further research in the area. The main objective of this research was to determine various soil physico-chemical properties of district Chitral, to develop their maps and to delineate problem soil of district Chitral for future planning and management.

Material and Methods

Site description and sample collection

Soil samples were collected from different locations in district Chitral of Khyber Pakhtunkhwa province of Pakistan to determine the soil physico-chemical properties and their mapping by using geostatistical techniques and mapping tool (ArcGIS 9.3). For this purpose a total number of 103 soil samples were randomly collected from 0-20cm depth from different areas of the district (Figure 1). Samples were collected from major agricultural growing areas including Garam Chashma valley, Bumburate valley, upper Boni areas, Chitral Township, Agricultural Research Station, and Drosh valley lying in the south western part of the district. Extreme hilly area seldom used for patchy agricultural activities were excluded from the study. Extensive samples were collected from Chitral Agricultural Research Station and were analyzed separately. Each sampling location was recorded by using Global Positioning System (GPS). These soil samples were collected, labeled properly and then further analyzed.

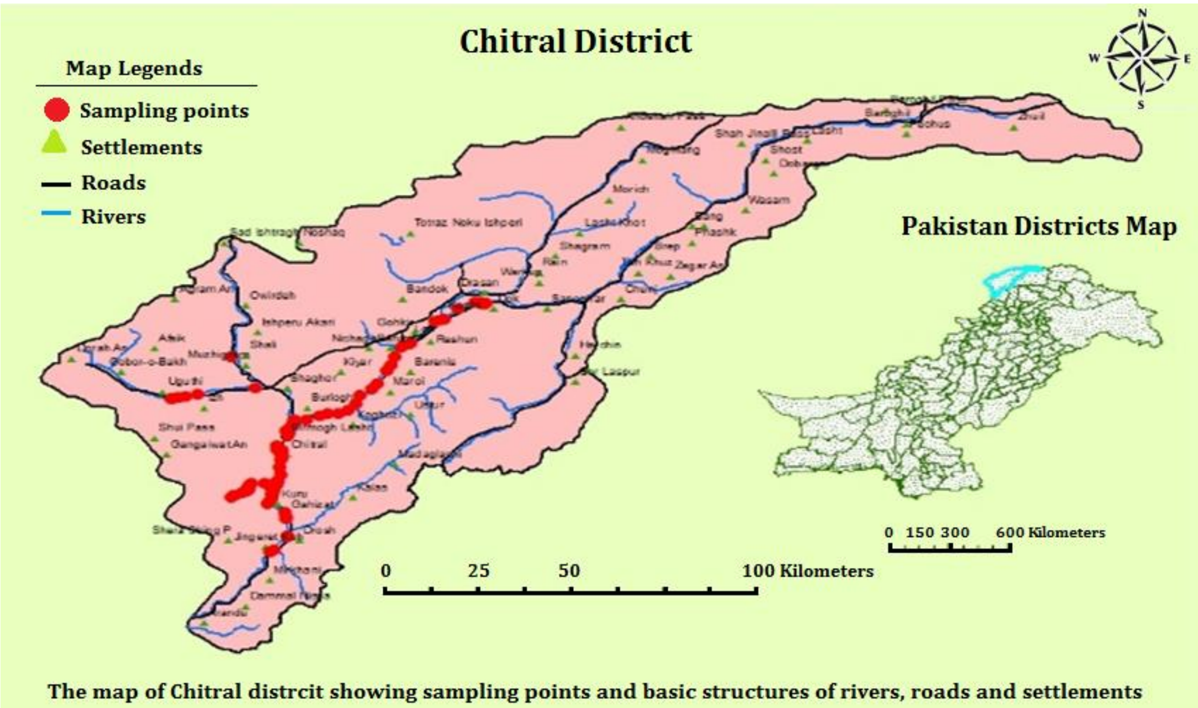

Figure 1. Boundaries of Pakistan and northern district Chitral showing sampling sites, settlements, roads and rivers

Sample analysis and data interpolation

Collected soil samples were ground and sieved with the help of 2 mm mesh after air drying and were analyzed in the laboratory for soil physico-chemical properties like soil pH by Mclean (1982), electrical conductivity by Richards (1954), soil texture by Bouyoucos (1936), organic matter by Nelson and Sommer (1982), lime content by Richards (1954). The reading of each location was taken by GPS in degrees and minutes and was then changed to decimal degrees. ArcGIS 9.3 and ArcGIS Geostatistical Analyst were used for mapping. To determine spatial structure of various soil properties, geostatistical techniques of semivariogram analysis by Bhatti et al. (1991) were used. Soil test of un-sampled location were analyzed by using geostatistical techniques (Kriging and Inverse Distance Weighting) and then map were prepared at smaller grid spacing by Rashid and Bhatti (2005). Inverse Distance Weighting (IDW) and Kriging were used to interpolate the values of unsampled locations as also suggested by Caers (2005). IDW can estimates or predict the values of unsampled location by using distance and the values of sampled location. It decreases the contribution of known values to predicted values. The weight of every sample point is an inversely proportional to the distance. Kriging is commonly used for interpolation or prediction of spatial data of unknown points through data from surrounding known points. The following formula was used for kriging:

$$Z\ (x_0) = \sum_{1=i}^{n(h)} \lambda_i\, Z\ (x_i)$$

Xo represent locations of un-sampled areas, λi are the weighting factors, Xi is the samples position and Z represent the measured value of soil property. Based on best fit, the IDW technique was used for district Chitral while kriging was used for interpolation of data acquired from Agricultural Research Station.

Variogram and semivariogram play an important role in kriging. It was used to produce spatial distribution and map of soil properties of Agriculture Research Station of district Chitral.

Semivariogram analysis

Semivariogram analysis is a key method to interpolate spatial variability. It was developed to interpolate the degree of spatial continuity among data points and to find a range of spatial dependence for soil physico-chemical property. It is used to measure the spatial correlation between two samples. It depends upon the distance between the samples points. Semivariance has a direct relationship to the distance. If the distance between the samples points are small then there will be smaller semivariance and if the distance is large then it yield larger semivariance. It was developed to evaluate and to analyze the degree of spatial continuity among sample points and to generate a range of spatial dependence for each soil parameters. Some of the characteristics of semivariogram are sill, range and nugget. Sill is the semivariance value at which the variogram levels off. Range is the lag distance at which the semivariogram or component of semivariogram reaches the sill value or it is the critical distance. Theoretically the value of semivariogram at the origin should be zero. It is very close to zero or different from zero then this semivariogram value is said to be nugget. Different variogram models were used for the quantitative description of soil properties. The most common and widely used variogram models include spherical, exponential and linear models and Gaussian.

Linear model : $\gamma\ (h) = Co + Bh$

Spherical model : $\gamma\ (h) = Co + [(\frac{3}{2})(\frac{h}{a}) - (\frac{1}{2})(\frac{h}{a3})]\quad 0<h<a$

Exponential model : $\gamma\ (h) = Co + C_1\ [1\text{-}\exp(-\frac{h}{ao})]$

Gaussian model : $\gamma(h) = C_0 + C\ [\ 1\text{-}\ \exp(\frac{h2}{a2})]\quad h>0$ and if $\gamma(0) = 0$

Results

Descriptive statistics

Soil separates showed that most of the soils in the Chitral district varied from silt loam to sandy loam. Sand fraction ranged from 36.40 to 78.40% with mean value of 59.04%, silt from 15.40 to 55.40% with mean value of 32.18% and clay from 4.20 to 14.20% with mean value of 8.76%, (Table 1). In hilly areas such coarse texture soils are common where most of fine materials prone to runoff losses. In contrast to low lying areas or flood plain, these areas are not expected to receive any soil depositions. The textural classes in the area are close to the reports of Nazif et al. (2006).

Table 1. Statistical analysis of soil fractions

Parameters	%Clay	%Silt	%Sand
Minimum	4.20	15.40	36.40
Maximum	14.20	55.40	78.40
Mean	8.76	32.18	59.04
1st Quartile	8.20	27.40	54.40
Median	8.20	31.40	60.40
3rd Quartile	10.20	37.40	64.40
Sum	903.0	3315.4	6081.6
SD	1.76	8.29	8.82
C.V	20.15	25.76	14.94
Variance	3.12	68.76	77.89
SE Mean	0.17	0.81	0.86
Skewness	-0.08	0.53	-0.39
Kurtosis	0.31	0.44	0.01

Table 2. Valley wise analysis of soil fractions

Valleys Name	Clay (%) ± SD	Silt (%) ± SD	Sand (%) ± SD
Garam Chashma	7.80 ± 1.11	21.31 ± 5.83	71.02 ± 5.91
ARS, Chitral	7.41 ± 1.54	30.41 ± 4.73	62.30 ± 5.66
Chitral Town	9.58 ± 2.16	35.69 ± 8.29	54.99 ± 9.47
Kaari to Jenalikoch	8.96 ± 1.38	29.47 ± 6.91	61.48 ± 6.70
Boni Areas	9.69 ± 1.68	31.18 ± 3.47	58.92 ± 3.62
Chumurkone to Drosh	9.11 ± 1.11	39.10 ± 8.85	51.93 ± 8.94
Ayun	9.34 ± 1.96	38.40 ± 8.82	52.42 ± 9.09
Bumburate	7.80 ± 1.62	32.84 ± 5.74	59.27 ± 5.64

The soils in the area ranged from slightly acidic (6.12) to alkaline pH (8.35) with mean value of 7.59±0.36 in 1:5 soil water suspensions (Table 3). The alkaline pH could be associated to calcareousness of soil and low vegetation. About > 90 % samples were alkaline in soil reaction while only 10% samples had pH <7.0. Garam Chashma valley had comparatively lower soil pH with mean value of 6.91±0.51 while the higher pH value with mean value of 7.86±0.22 was noted in areas lying between Karri to Jenalikoch situated on Boni road. The upper lying Garam Chashma valley is cooler and at higher altitude with more vegetation than other areas that could be associated to its lower pH. This valley is commonly used for offseason potato production in summer due to its cooler climate and good soil conditions. The low lying areas have comparatively higher pH and higher lime content than upper areas.

Table 3. Statistical analysis of selected soil chemical properties

Parameters	pH (1:5)	EC (1:5) dSm^{-1}	Lime (%)	O.M (%)
Minimum	6.12	0.06	3.30	0.87
Maximum	8.35	0.30	22.48	3.98
Mean	7.59	0.16	10.79	2.44
1st Quartile	7.48	0.14	8.34	1.97
Median	7.70	0.17	9.88	2.42
3rd Quartile	7.81	0.19	13.24	2.94
Sum	782.17	17.49	1111.9	251.93
SD	0.36	0.04	3.77	0.68
C.V	4.83	24.18	34.98	28.15
Variance	0.13	1.68	14.26	0.47
SE Mean	0.03	4.04	0.37	0.06
Skewness	-1.58	0.50	0.84	0.03
Kurtosis	3.17	1.55	0.70	-0.37

Electrical conductivity (EC) as measured in 1:5 soil water suspension ranged from 0.06 to 0.30 dS m^{-1} with mean value of 0.16 dS m^{-1} (Table 3) indicating that the study area had no salinity problem (<4 dS m^{-1}). The northern hilly areas posing with frequent and extensive run off losses are rather low in basic salt requirements like Ca and S instead of any salinity problem. The values are in close consistency with Baber et al. (2004).

District Chitral ranged from moderate to strongly calcareous nature, ranged from 3.30 to 22.48% with mean value of 10.79% in the analyzed soil samples (Table 3). This range in % lime in the area was in agreement with reports of Wasiullah and Bhatti (2007). When averaged with reports of Rashid (1994) about >87% soil samples were moderately calcareous with lime 3-15% while 13% samples were strongly calcareous having lime >15%. Comparatively higher lime content with mean value of 14.69%±4.28 was observed in low lying Kaari to Jenalikoch areas than upper lying Garam Chashma areas with mean value of 6.25±1.43%. It includes all the materials of plants, animals or microbial origin produced in the soil or added to the soil.

Organic matter in soils of the area was comparatively more than other plain areas of Pakistan as discussed by Sarwar et al. (2008). It ranged from 0.87 to 3.98% with mean value of 2.44% in the whole soil samples (Table 3). When compared with standard values as described by Rashid et al. (1994), about >94% soil samples were high in organic matter with values above 1.29% while only <6% soil samples were low in organic matter. The higher organic matter in the areas could be attributed to colder weather conditions as compared to other parts of the country. Plant leaves and dry matter decomposition reduces significantly with decrease in soil temperature as reported by Hood (2001).

Table 4. Valley wise analysis of selected soil chemical properties

Valleys Name	pH ± SD	EC (dS m^{-1}) ± SD	Lime (%) ± SD	OM (%) ± SD
Garam Chashma	6.91 ± 0.51	0.13 ± 0.04	6.25 ± 1.43	2.41 ± 0.60
ARS, Chitral	7.58 ± 0.18	0.18 ± 0.03	9.64 ± 1.94	1.93 ± 0.46
Chitral Town	7.79 ± 0.10	0.18 ± 0.04	11.11 ± 2.44	2.31 ± 0.46
Kaari to Jenalikoch	7.86 ± 0.22	0.20 ± 0.03	14.69 ± 4.28	2.47 ± 0.57
Boni Areas	7.73 ± 0.10	0.20 ± 0.05	12.33 ± 3.40	2.51 ± 0.67
Chumurkone to Drosh	7.64 ± 0.24	0.16 ± 0.04	11.28 ± 3.58	2.27 ± 0.80
Ayun	7.46 ± 0.35	0.13 ± 0.03	9.18 ± 2.63	2.82 ± 0.43
Bumburate	7.41 ± 0.35	0.16 ± 0.02	8.90 ± 2.26	2.87 ± 1.01

Correlation analysis

Soil pH, EC and lime contents showed significant correlation with each other. Increasing the lime contents in soil, pH and EC increased with r2 values of 0.333 and 0.193. Similarly with increasing the EC the soil pH increased with r2 value of 0.285 (Figure 2). However, r2 values were lower and can suggest only the trends. Such weak correlations are not unusual in field conditions where any characteristics of soil could be influenced by many factors. For example, besides lime content and soluble salts, the pH of soil could be influenced by vegetation, parent materials, rainfall and soil texture. Soil sand and silt showed strong influence on each other advocating that these were the two main soil separates and that the increase of one decreased the other as revealed by their strong negative correlation with each other with r2 value of -0.98.

Table 5. Correlation analysis among soil parameters

	EC	Lime	OM	Clay	Silt	Sand
pH	0.45	0.54	0.00	0.11	0.22	-0.23
EC	1.00	0.41	-0.07	0.20	0.03	-0.07
Lime	-	-	0.10	0.27	0.12	-0.17
OM	-	-	-	0.05	0.08	-0.09
Clay	-	-	-	-	0.20	-0.39
Silt	-	-	-	-	-	-0.98

Spatial variability and geostatistical analysis

The strength of spatial variability is measured by semivariogram analysis. In this the data is analyzed and fit into different models like Linear, Exponential and Gaussian. For best fit model and measuring the strength, different geostatistical results are made as criteria such as the mean prediction error close to 0, root mean square standardize prediction error close to 1 and smallest nugget value. Similarly, the nugget-sill ratio of <25% is considered as strong spatial dependence, 25-75% is considered as moderate spatial dependence and >75% is considered as weak spatial dependence as described by Cambardella et al. (1994).

Table 6. Models and parameters of spatial distribution of soil physico-chemical properties

Soil parameters	C_0 (Nugget)	C_0+C (Sill)	C_0/C+C_0 Nugget-Sill ratio (%)	A_0(m) (Range)	Models	r^2	RSS
%Clay	3.01575	3.01	100.0	46463	Linear	0.284	3.41
%Silt	51.4	103.7	49.57	31470	Gaussian	0.663	1963
%Sand	53.8	134.8	39.91	46080	Exponential	0.622	2089
Soil pH	0.047	0.196	24.0	32071	Gaussian	0.631	0.0237
Soil EC	0.00117	0.003	44.49	40250	Gaussian	0.640	1.135
Lime	5.12	36.34	14.08	101100	Exponential	0.302	412
OM	0.094	0.48	19.58	1320	Gaussian	0.160	0.106

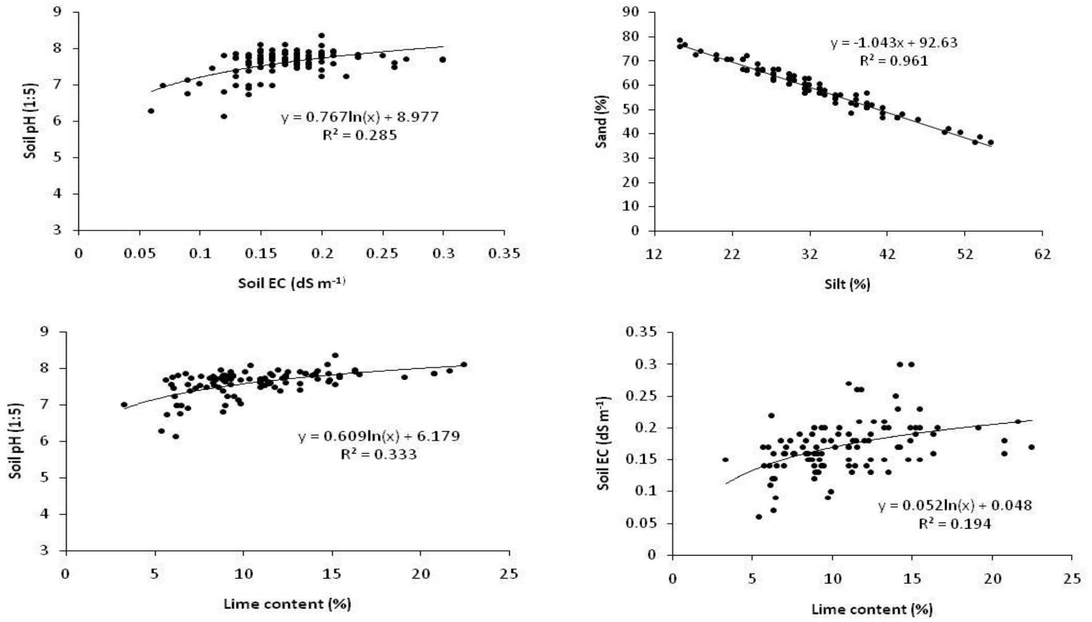

Figure 2. Correlation among soil parameters

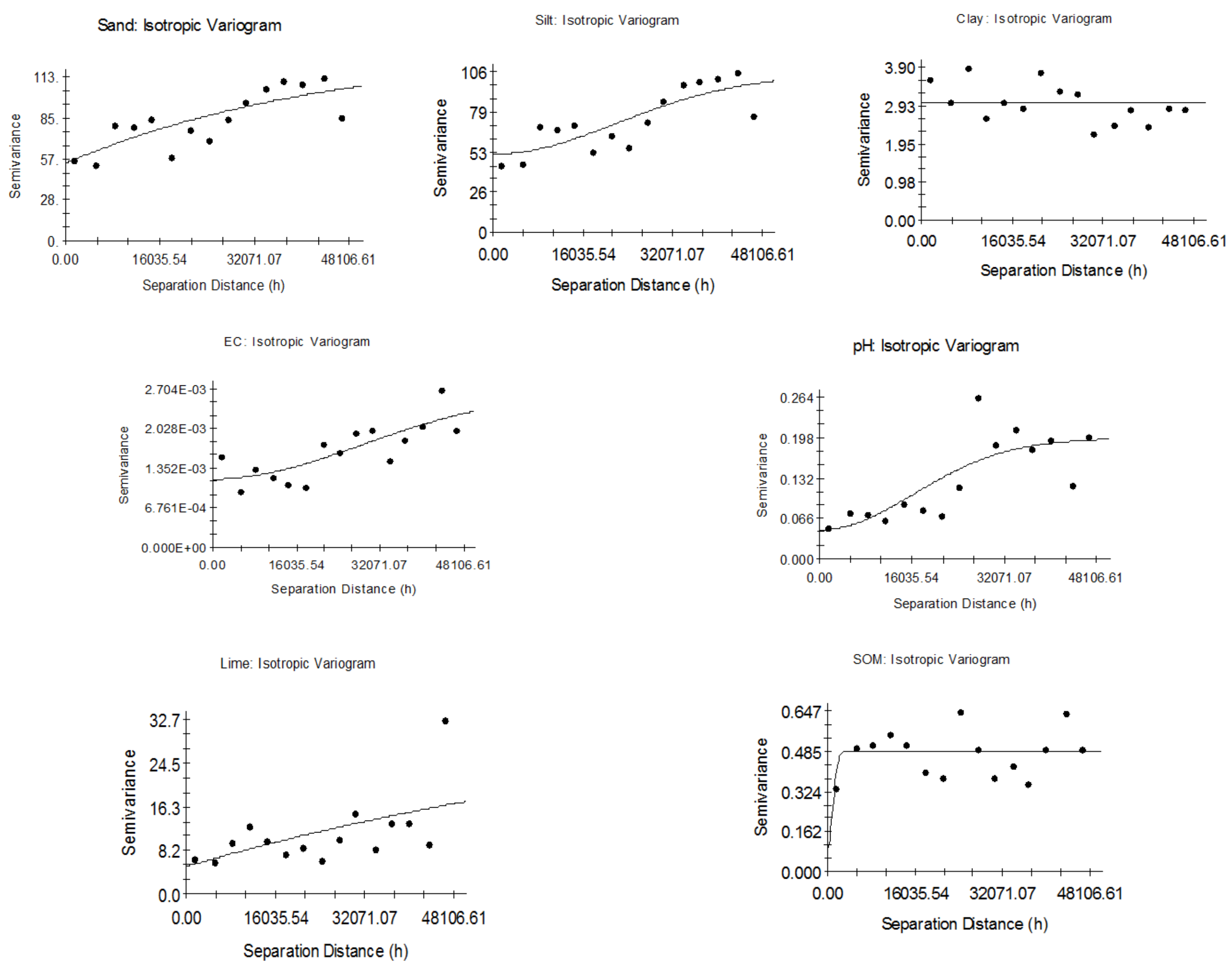

Figure 3. Spatial distribution pattern of soil properties across the sampling sites

Interpolation and mapping of selected soil properties

The following maps shows sampling points of the whole district and Agriculture Research Station, Chitral (Figure 4). Soil sample were collected from 103 selected areas started from April to May 2014. Arc GIS 9.3 and other necessary statistical software were used for evaluating spatial variability pattern, mapping and classification of various soil parameters.

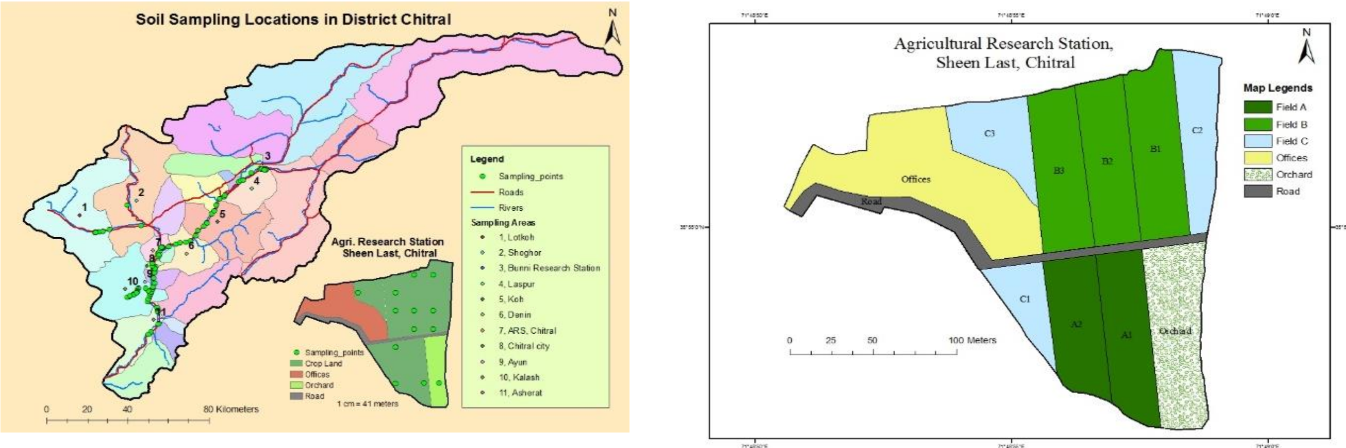

Figure 4. Maps showing sampling points in Agriculture Research Station and whole district including various rivers, settlement and roads

Map distribution regarding soil fractions in the areas shows that comparatively high clay was found in northern and north eastern parts of the district while low were found in northwestern parts (Figure 5). Sands contents was comparatively high in northwestern parts while comparatively low northeastern parts which could be associated to high altitude and slope lands.

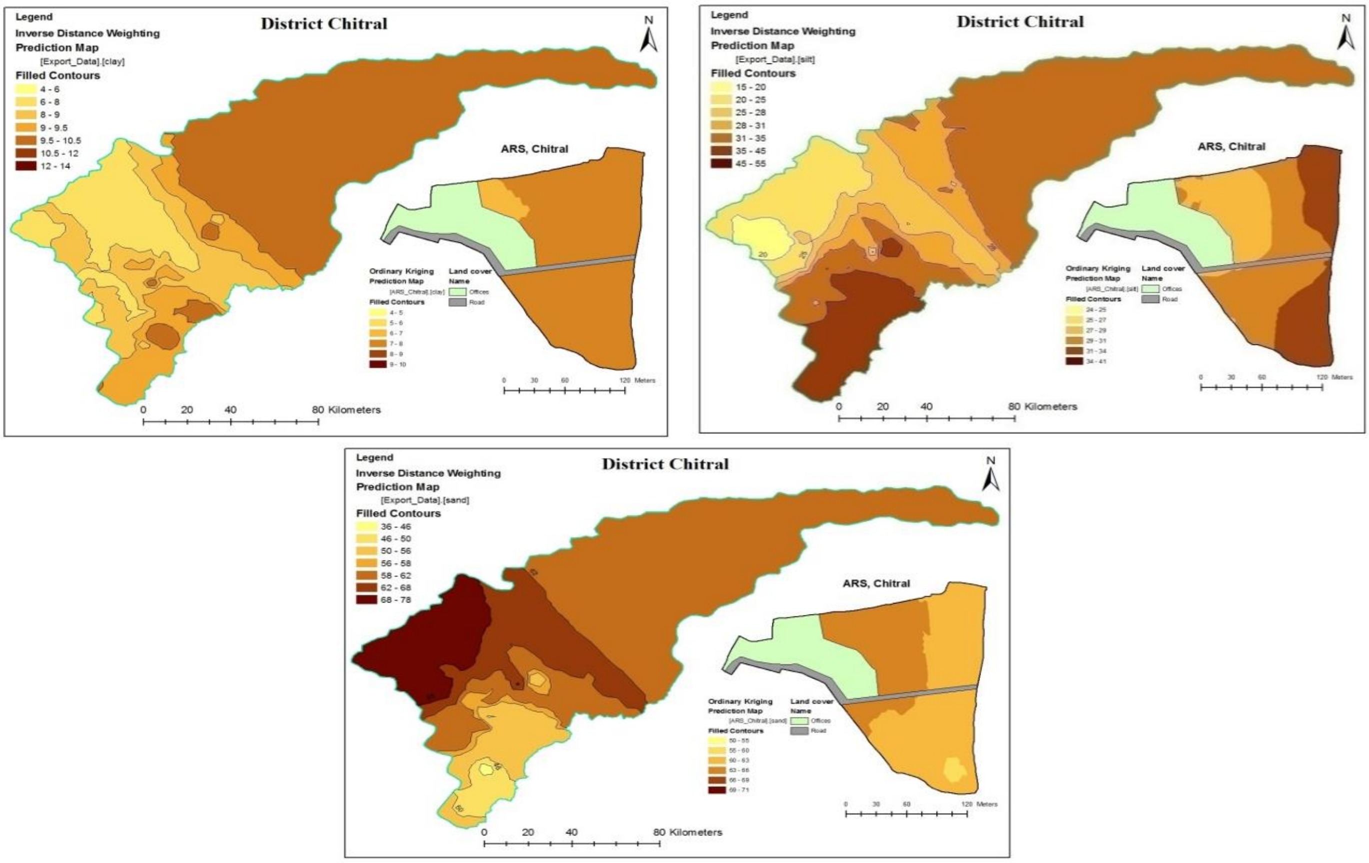

Figure 5. Map showing of soil fractions (clay, silt and sand)

Town and central areas are mostly alkaline in nature. On basis of valleys, Garam Chashma and south-western parts had low pH comparatively to the lower lands, which could be attributed to higher rainfall at higher altitude. The higher pH in a range of > 8.0 was found in the across the mid line and near to the city. Similarly, Orchard field in ARS, shows comparatively higher pH than the other fields. Most of the areas did not show salinity problem but comparatively higher values were found in central and north-eastern parts of the districts while minimum in extreme north-western side (Figure 6).

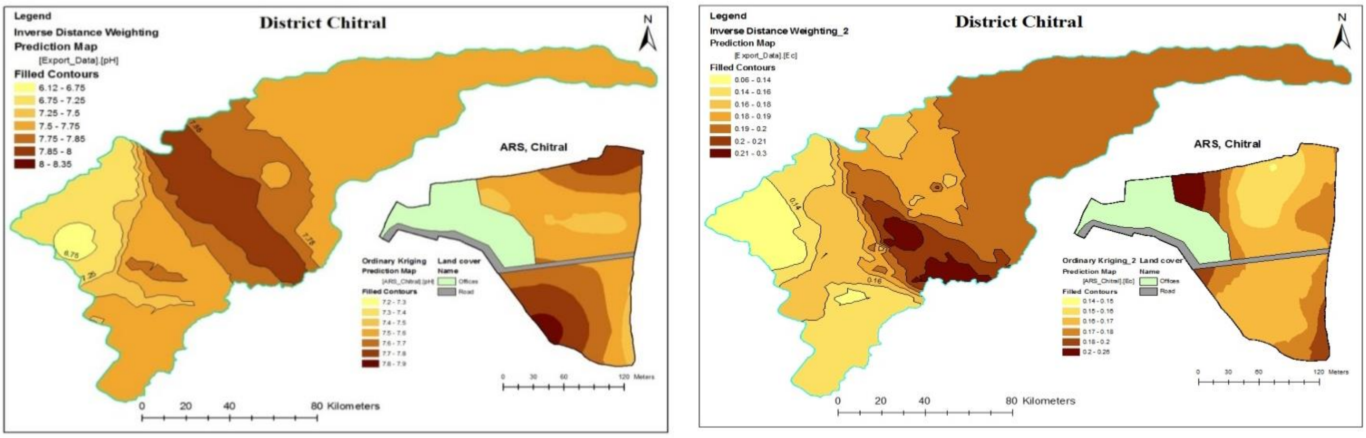

Figure 6. Map showing soil pH and EC (dSm^{-1})

Lime and organic matter content are comparatively high in central parts and northern areas than the other sitess (Figure 7). Lime content was low in north-western areas of district Chitral. In ARS the lime was higher in central areas while the soil organic matter was high in orchard while low in crop land area.

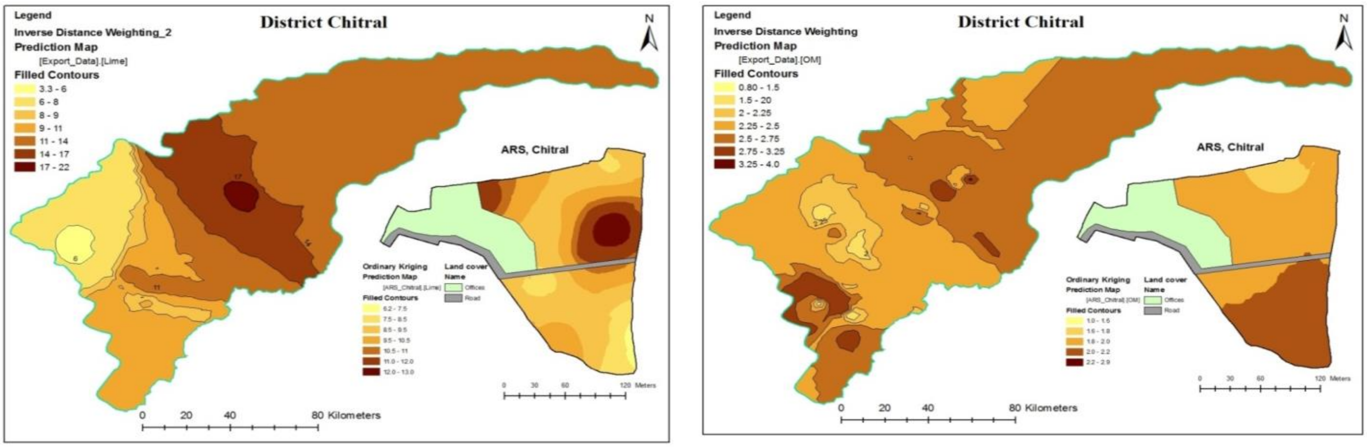

Figure 7. Map showing soil lime and organic matter (%) contents

Discussion

Descriptive statistical analysis of soil properties

Comparing the variation in different valleys of the area, upper areas like Garam Chashma valley had coarser soils than the lower areas like Chitral Town, Ayun and Drosh. The drift from coarser to fineness in soil separate toward down the slope in hilly areas was reported by Charan et al. (2013) whereby the clay and silt fraction showed negative while sand showed positive correlation with altitude. However, this variation between the upper and lower areas in the valley was smaller and all the soils in the area irrespective of location were coarser in nature. Such soils are prone to runoff losses and hence measures should be taken to control both water and wind erosion.

The soil pH may vary with soil organic matter, lime content, precipitation and natures of parent soil materials as discussed by Mellbye (1988) and Rastija (2007), which are influenced by the elevation and climatic conditions of the area and as such not a single factor could be responsible for pH changes in the given area. For examples, Boni which is also at higher altitude but still have alkaline pH which could be associated to higher lime and low rainfall in the area as compare to Garam Chashma or Bumburate areas.

Low electrical conductivity in the area would be due to sandy soil and high leaching process that removed the salts from surface soil. Low saline soil would also be due to irrigation of field with good quality of water that could wash away the surface salts into deeper zones as discussed by Friedman (2005). Again the Garam Chashma had lower EC than low lying areas that showed close correlation with soil fraction. However other factors like irrigation water and precipitation could also affect. The Ayun area which is finer in texture than other areas and also is low lying area but because of frequent irrigation with good quality water most of salts leach down from root zone and hence had lower EC than upper lying Boni area in contrast. It is common phenomenon that, high temperature and dry regions lead to accumulation of salts in surface soil.

The natural factors governing variation in soil lime content include evaporation, precipitation, runoff and leaching losses and parent material (Ou et al., 2017; McLean., 1982) and as such a single pattern could not assign to its variation in the study areas. The high lime content is useful to maintain basic salts concentration in these areas and also may act as cementing agent to coagulate soil materials and help them to resist losses with runoff water. However on other hand, this high lime content is responsible for alkaline pH in the area.

The decrease in temperature reduces the oxidation rate and as a result whatever the organic materials added to soils stays in the soil for longer periods and hence shows comparatively more organic matter than other similar but hot areas. This was corroborated by the fact that organic matter increased with altitude. Comparing the different valleys, Bumburate valley showed higher organic matter content with mean value of 2.87%. This valley is at high altitude with cooler climate and more vegetation than other parts of the district. However only the altitude could not be responsible for higher organic matter other factors like addition of organic fertilizers to soils and agronomic practice also largely influence the organic matter content of soil. For example Ayun area which is comparatively plain and is down hill area but had higher organic matter contents than Boni and Garam Chashma valleys that might be associated with agricultural practices.

Spatial variability and geostatistical analysis

Soil separates showed weak to moderate spatial pattern indicating that they varied independently at each location. The weakest was among the clay contents with nugget-sill ratio of 100 % whereas the sand and silt showed moderate spatial distribution with nugget-sill ratio of 39.91 and 49.57% and r^2 of 0.622 and 0.663, respectively. Clay, silt and sand were best expressed by linear, Gaussian and Exponential models, respectively. Soil pH was best fit by Gaussian model and it was strongly spatially distributed with nugget-sill ratio of 24%. EC was also expressed by best fit of Gaussian model but it was moderately spatially distributed with nugget-sill ration of 44.49 %. Lime showed strong spatial distribution among the sites in district Chitral having nugget-sill ratio of 14.08%. Such strong spatial distribution of lime could be associated with soil formation factors and parent materials that remain comparatively similar for adjoining sampling sites. Organic matter also showed strong spatial distribution with best fit to Gaussian model and nugget-sill ratio of 19.58 %. The range for spatial distribution for lime was comparatively higher than organic matter.

Interpolation and mapping

The prepared maps, classified tables and figures for various physico-chemical properties were thought to have a good use for soil resource management, enhancing agriculture production and for as guide line for further research in the area.

Higher amount of sand contents in higher altitude could be attributed to rapid weathering and disintegration of rocks such as shale, granite and limestone etc. The rainwater might run away the surface soils to the lower lands. Continuous cultivation and application of fertilizer in ARS, farm made the soil very productive. Moderate calcareous and low pH in higher altitude like Garam Chashma valley could be associated with climatic condition like high rainfall, low temperature and high organic matter contents. As shown in the map that low electrical conductivity in most of the area would be due to sandy soil and high leaching process that removed the salts from surface soil. In plain areas, low saline soil would also be due to irrigation of field with good quality of water that could wash away the surface salts into deeper zones. It was further confirmed that areas at higher altitude were low EC than lower lands due to coarse texture soil. It is common phenomenon that, high temperature and dry regions lead to accumulation of salts in surface soil. Maps were prepared that visually described the distribution of each parameter that could be easily understood and used by researcher, farming community and policy makers and other stack holders.

Conclusion

From the analysis it is concluded that soils of district Chitral were dominantly coarse in texture, alkaline in reaction, non-saline, moderate to highly calcareous and contained comparatively highly higher organic matter than other low lying areas of the country. Clay had poor but silt and sand had moderate spatial dependence (nugget-sill ratio, 25-75%). Soil lime, organic matter content, pH and EC had strong spatial dependence (nugget-sill ratio, <25%). These distributions were fit into different models including linear, exponential and Gaussian based on smallest nugget value, MPE close to 0 and RMSSPE close to 1. Maps were developed that visually described the distribution of each parameter that could be easily understood and used by researcher, farming community and policy makers and other stack holders. Such maps should be developed for other areas of the country with focus on more other parameters to manage and safeguard food and environment security.

Acknowledgment

The assistance of Agricultural Research System especially the Agricultural Research Station, Seen Lasht, Chitral is highly appreciated in collection of data and soil samples.

References

Baber, K., Khattak, R.H., Hakeem., 2004. Physico-chemical characteristics and fertility status of Gilgit soils. *Journal of Agricultural Research* 42 (3-4): 305-312.

Bhatti, A.U., Mulla, D.J., Frazier, B.E., 1991. Estimation of soil properties and wheat yields on complex eroded hills using geostatistics and thematic mapper images. *Remote Sensing of Environment* 37(3): 181-191.

Bouyoucos, G.J., 1936. Directions for making mechanical analysis of soils by the hydrometer method. Soil Science 42(3): 225–230.

Caers, J., 2005, Petroleum Geostatistics, Society of Petroleum Engineers. 88p.

Cambardella, C.A., Moorman, T.B., Parkin, D.L., Karlen, J.M., Novak, Turco, R.F., Konopka, A.E., 1994. Field-scale variability of soil properties in central Iowa soils. *Soil Science Society American Journal* 58 (5): 1501–1511.

Charan, G., Bharti, V.K., Jadhav, S.E., Kumar, S., Acharya., Kumar, P., Gogoi, D., Srivastava, R.B., 2013. Altitudinal variations in soil physico-chemical properties at cold desert high altitude. *Journal Soil Science and Plant Nutrition* 13(2): 267-277.

Friedman, S.P., 2005. Soil properties influencing apparent electrical conductivity: a review. *Computers and Electronics in Agriculture* 46(1-3): 45-70.

Hood, R.C., 2001. The effect of soil temperature and moisture on organic matter decomposition and plant growth. *Isotopes in Environmental and Health Studies* 37(1): 25-41.

Johnston, A.E., Goulding, K.W.T., Poulton. P.R., 1986. Soil acidification during more than 100 years under permanent grassland and woodland at Rothamsted. *Journal of Soil Use Management* 2 (1): 3-10.

McLean, E.O., 1982. Soil pH and lime requirement. In: Methods of Soil Analysis, Part 2, Chemical and microbiological properties, Second Edition. Number 9, Page, A.L., Keeney, D. R., Baker, D.E., Miller, R.H., Ellis, R. Jr., Rhoades, J.D. (Eds.). ASA-SSSA, Madison, Wisconsin, USA. pp.199-224.

Mellbye, M., 1988. The effect of surface liming on soil pH and calcium. Handout, Soil Acidity and Liming Symposium, Oregon State University, Corvallis, USA.

Mulla, D.J., Bhatti, A.U., Kunkel, R., 1990. Methods for removing spatial variability from field research trials. In: Advances in Soil Science, Singh R.P., Parr J.F., Stewart B.A. (Eds.). Vol 13, Springer, New York, USA. pp. 201-213.

Nazif, W., Perveen, S., Saleem, I., 2006. Status of micronutrients in soils of district Bhimber (Azad Jammu and Kashmir). *Journal of Agriculture and Biological Science* 1(2): 35-40.

Nelson, D.W., Sommers, L.E., 1982. Total carbon, organic carbon, and organic matter. In: Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, A.L. Page, R.H. Miller, D.R. Keeney (Eds.), 2nd Ed. Agronomy Monograph No. 9, ASA-SSSA, Madison, Wisconsin, USA. pp.539–573.

Olea, R.A., 1999. Geostatistics for Engineers and Earth Scientists. Kluwer Academic Publishers 324p.

Ou, Y., Rousseau, N.A., Wang, L., Yan, B., 2017. Spatio-temporal patterns of soil organic carbon and pH in relation to environmental factors—A case study of the Black Soil Region of Northeastern China. *Agriculture, Ecosystem and Environment* 245: 22-31.

Rashid, A., Rafique, E., Bughio, N., 1994. Diagnosing boron deficiency in rapeseed and mustard by plant analysis and soil testing. *Communication in Soil Science and Plant Analysis* 25(17-18): 2883-2897.

Rashid, M., Bhatti, A.U., 2005. Mapping of spatial variability of macro and micronutrients for site specific management. *Soil and Environment* 24 (1): 34-52.

Rastija, M., Banaj, D., Markoviš, M., 2007. Influences of liming on nutritional status of soil. *Cereal Research Communications* 35 (2): 981-984.

Richards, L.A., 1954. Diagnosis and improvement of saline and alkali soil. U.S. Salinity Lab. Staff, U.S. Department of Agriculture, Agricultural Research Service, Handbook 60. Washington D.C. USA. 160p.

Risser, P.G., 1991. Long-term Ecological Research: An International Perspective. Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions (ICSU). Wiley, New York. USA. 294p.

Sarwar, G., Schmeisky, H., Hussain, N., Muhammad, S., Ibrahim, M., Safdar, E., 2008. Improvement of soil physical and chemical properties with compost application in rice-wheat cropping system. *Pakistan Journal of Botany* 40 (1): 275-282.

Wasiullah, Bhatii, A.U., 2007. Physico-chemical properties of soils of Kohat and Bannu Districts NWFP Pakistan. *Journal of the Chemical Society of Pakistan* 29(1): 20-25

Wollum, A.G., Cassel, D.K., 1984. Spatial variability of Rhizobium japonicum in two North Carolina soils. *Soil Science Society of American Journal* 48(5): 1082-1086.