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Mapping of Variability in Major and Micro Nutrients for Site-Specific Nutrient Management

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Authors' contributions

This work was carried out in collaboration between all authors. Author MJK being Principal investigator of the project has designed the study and helped in manuscript correction and final evaluation. Author MR performed laboratory analytical analysis, statistical analysis and wrote the first draft of manuscript. Author SA managed intensive field sampling and computer analysis. Author IK conducted and manage all the agronomic and soil related activities. Author SN helped in conducting the lab work including soil testing and carried out proof reading of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Background: Spatial variation of soil physical and chemical properties influences soil and crop management efficiency causes uneven crop growth and decreases the effectiveness of uniformly applied fertilizers.
Purpose: Therefore, a comprehensive survey was made to determine the spatial variability of soil properties and their mapping in Charsadda district of Khyber Pakhtunkhwa Province (KP) of Pakistan to delineated area into low, medium and high level of plant nutrients for site-specific nutrient management using variable rate fertilizer technology.
Method: Soil sampling was done on a grid system using Global Position System (GPS) from two depths (0-15, and 15-45 cm) during 2004; and the samples were analyzed for soil physical (soil texture and saturation percentage), soil chemical (pH, ECe, SAR, lime,

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and organic matter) and soil fertility status (mineral N, AB-DTPA extractable P, K, Zn, Cu, Fe, Mn and HCl extractable B). Geostatistical techniques of semivariogram analysis and kriging were used to model the spatial variability and interpolation of data values at unsampled locations and mapping of the district. Semivariogram analyses of data showed some spatial patterns for soil properties. Silt (r2=0.48), clay (r2=0.71) contents and saturation percentage (r2=0.71) were described by linear model in both the depths (0-15, and 15-45 cm). Electrical conductivity was described by a linear model in both the depths with strong spatial structure in surface soil (r2=0.81). Calcium carbonate (CaCO3) in the surface soil had strong spatial structure (r2=0.59), organic matter content in the surface soil was described by a spherical model with a range of influence 6.65 km, while in the subsoil (15-45 cm) it was described by a linear model with moderate spatial structure (r2=0.41). Mineral N and P were described by linear models with strong spatial structure for P in both the depths (r2=0.77, 0.73) and moderate spatial structure (r2=0.36) for surface soil N. Potash content was described by a linear model in surface soil with moderate structure (r2=0.24), while in subsoil it was explained by a spherical model with strong spatial structure (r2=0.64) and a range of about 9 km. Zinc and Cu in the surface soil were randomly distributed, while they have strong spatial structure (r2=0.63 and 0.54, respectively) with a linear model in subsoil. Boron content in both the depths was described by a linear model with strong spatial structure in surface (r2=0.61) and moderate structure (r2=0.31) in subsoil.
Results: The maps of various measured soil properties showed that soil mineral N and boron (B) increases from north-east toward west-south, available P form south-east towards north-west and lime form northern towards southern parts of the district. Soil organic matter, sand and silt contents showed little spatial variation within sampled areas.
Conclusion: Texture of Charsadda district ranged from silt to sandy loam. Sand content in the east and silt in the whole area was higher, while clay was found low throughout the soil surveyed. All the soils were alkaline in reaction and calcareous in nature to different degrees as indicated in maps of surface soil pH and CaCO3. Organic matter content of both the depths was low. surface soils was deficient in N in all soils of district Charsadda while deficiencies of P, Zn and B were observed to a greater extent, while K, Cu and Mn are also appearing deficient in soil.

Keywords: Macro and Micro Nutrients, Charsadda, KP Province, Soil Properties, GPS.

1. INTRODUCTION

Crop production is affected by various factors that vary both in space (spatial variability) and time (temporal variability). Spatial variability of soil chemical and physical properties influences soil and crop management efficiency as well as the design and effectiveness of field research trials [1,2,3,4]. Spatial variability in soil properties causes uneven crop growth, confounds treatment effects in field experiments, and decreases the effectiveness of uniformly applied fertilizer or chemical amendments on field scale [5,6,7,8]. Understanding the magnitude and pattern in spatial variability of soil properties is necessary for improved management options relating to application of fertilizers and strategies for sampling and design of field research trials and mapping of fields on lower scale and districts on large scale [9,10,11,12,13,14].

Soil variability has been extensively studied in the past by soil scientists [14,15,16,17,18]. Geostatistical approaches involve analysis and modeling of spatial patterns using semivariograms and pattern interpolation and mapping using punctual kriging. Kriging method of interpolation has been successfully applied to regionalized variables in mining [19], hydrology [18], soil science [20,21,22,23,24,25], heavy metals in soils [26,27,28,29] and crop science [7,15,16,30].

Keeping in view the importance of spatial variability, this project was carried out to model the spatial variability of soil properties and their mapping in Charsadda district of Khyber Pakhtunkhwa sof Pakistan with the objective to assess the spatial variability and current nutritional status of the soils, delineate the area into different categories low, medium and high nutrients status for site-specific plant nutrients management.

Such information is needed for the best management of soil resources for enhancing agricultural production and provide as base for further research by the scientists.

2. MATERIALS AND METHODS

Intensive soil sampling from district Charsadda of Khyber Pakhtunkhwa of Pakistan was done on a grid system using Global Positioning System (GPS) during 2004. Stratified systematic unaligned sampling design [31] was used for sampling. Whole area was divided into different roads i.e. Peshawar-Charsadda road, Tangi-Charsadda road, Rajarh-Takhtbai road, Umarzai-Harichand road, Charsadda – Mardan road, and Charsadda – Nowshera road. Along each road, soil samples were collected at a regular interval of 5 km and their coordinates were recorded by GPS. Soil samples were collected from two depths i.e. 0-15 and 15-45 cm. In all, 79 soil samples were collected from each depth from agricultural fields growing wheat crop.

Soil samples thus collected were brought to the laboratory of Soil and Environmental Sciences, KP Agricultural University, Peshawar, Pakistan. Soil samples were air dried and sieved through a 2mm sieve. Soil samples thus prepared were analyzed for soil properties viz. texture [32], saturation percentage [33], pH [34], electrical conductivity [34], organic matter [35], CaCO3 content using acid neutralization method method [36], SAR [33], total mineral N [37], AB-DTPA extractable P, K, Cu, Zn, Fe and Mn [38] and boron by HCl acid method [39]. Phosphorus was read on spectrophotometer, K on flamephotometer, and Cu, Zn, Fe and Mn on atomic absorption spectrophotometer. Texture of the sampling locations is given in Table 1.

Table 1. Location and soil textural class at the sampling sites for 0-15 cm depth

S. No.	Road Location	GPS Reading	Textural Class	S. No	Road Location	GPS Reading	Textural Class
1	Arif abad	34-07-13N 71-39-34E	Loam	41	Mahmood abad	34-09-27N 71-52-56E	Silt loam
2	Station kalla	34-18-24N 71-38-04E	Loam	42	Malagi kalle	34-08-48N 71-53-20E	Silt loam
3	Tangi bazaar	34-17-37N 71-39-20E	Silt loam	43	Patwari kalle	34-08-16N 71-53-32E	Silt
4	Tangi	34-17-27N 71-39-46E	Silt loam	44	Dusahara kalle	34-08-36N 71-54-02E	Silt loam
5	Hoara	34-17-23N 71-40-44E	Silt loam	45	Nazo kale	34-08-04N 71-52-57E	Silt loam
6	Shoakano	34-17-26N	Silt loam	46	Aziz abad	34-07-47N	Silt loam

	kalle	71-41-28E				71-52-06E	
7	Karhi wal	34-17-20N 71-41-35E	Silt loam	47	Ahmad khan kale	34-07-34N 71-51-24E	Silt loam
8	Tani wal kalle	34-17-00N 71-40-55E	Silt loam	48	Captan kalle	34-07-42N 71-51-49E	Silt loam
9	Ummer zai	34-16-44N 71-41-24E	Loam	49	Sher bhadar kakke	34-07-12N 71-50-18E	Silt loam
10	Hagi Awaldin kalle	34-16-50N 71-41-26E	Sandy loam	50	Nisatta	34-07-30N 71-48-03E	Silt loam
11	Saifur kale	34-16-41N 71-41-53E	Silt loam	51	Khan zada kale	34-07-32N 71-46-57E	Silt loam
12	Noor Muhd kalle	34-17-05N 71-42-05E	Silt loam	52	Policeline	34-08-04N 71-46-17E	Silt loam
13	Chacha khan kale	34-17-25N 71-42-25E	Silt loam	53	Banda	34-07-58N 71-46-43E	Silt loam
14	Mamano dhari	34-17-38N 71-42-45E	Silt loam	54	Gulballa	34-07-13N 71-39-19E	Silt loam
15	Zarin abad	34-17-56N 71-43-10E	Silt loam	55	Sardhariab (mumtaz abad)	34-07-32N 71-41-01E	Silt loam
16	Zaim kalle	34-17-20N 71-42-32E	Silt loam	56	Allahabad	34-08-18N 71-41-49E	Silt loam
17	Masal korona	34-16-49N 71-42-15E	Silt loam	57	Shad abad kale	34-09-18N 71-43-05E	Silt loam
18	Aslam khan kalle	34-16-34N 71-42-12E	Silt loam	58		34-09-51N 71-42-58E	Silt loam
19	Sharpao kalle	34-16-17N 71-41-54E	Silt loam	59	Ghidhare kalle	34-09-44N 71-42-44E	Silt loam
20	Maih kalle	34-15-55N 71-41-46E	Silt loam	60	Sarki kalle	34-10-35N 71-42-03E	Silt loam
21	Maih jan kale	34-15-37N 71-42-37E	Silt loam	61	Ummar abad	34-08-37N 71-45-31E	Silt loam
22	Umar zai	34-13-42N 71-44-12E	Silt loam	62	Nisatta (tauhidabad)	34-06-48N 71-47-53E	Silt loam
23	Torang zai	34-12-22N 71-45-21E	Silt loam	63	Nisatta (dagai)	34-06-23N 71-48-18E	Silt loam
24	Uttaman zai	34-10-54N 71-45-43E	Silt loam	64	Shah pasand kale	34-05-53N 71-48-53E	Silt loam
25	Rajarh kalle	34-10-22N 71-44-02E	Silt loam	65	Tarlandi (bahram kale)	34-05-27N 71-49-30E	Silt loam
26	Muffti abad	34-11-04N 71-47-24E	Silt loam	66	Nawa kale	34-04-34N 71-50-39E	Silt loam
27	Khan mai	34-11-57N 71-48-55E	Silt loam	67	Hishgi (hisar kale)	34-03-55N 71-51-24E	Loam
28	Azam khan korona	34-13-02N 71-50-36E	Silt loam	68	Guggar abad	34-02-55N 71-52-29E	Sandy loam
29	Sadullah khan kalle	34-13-38N 71-50-29E	Silt loam	69	Nisatta (school korona)	34-05-47N 71-48-43E	Silt loam
30	Behlola	34-14-34N 71-50-46E	Silt	70	Nisatta (madni	34-06-15N 71-48-00E	Silt loam

					mahalla)		
31	Hafiz abad colony	34-09-20N 71-45-52E	Silt loam	71	Ummar zai (qaiam abad)	34-14-35N 71-43-54E	Silt loam
32	Pola dhair	34-09-27N 71-46-33E	Silt loam	72	Khan ghari	34-15-29N 71-44-44E	Silt loam
33	Malka dhair	34-09-49N 71-38-35E	Silt loam	73	Qamar abad	34-16-24N 71-45-44E	Silt loam
34	Sar dairy	34-10-06N 71-50-08E	Silt loam	74	Dakki	34-17-25N 71-46-36E	Silt loam
35	Shah jahan abad	34-10-29N 71-51-36E	Silt loam	75	Jahangir abad (mandarhi)	34-19-09N 71-46-51E	Silt loam
36	Dargai	34-10-47N 71-52-50E	Silt	76	Uzbako	33-20-09N 71-47-03E	Silt loam
37	Manga kalle	34-11-18N 71-54-34E	Silt	77	Harichan	34-21-44N 71-47-54E	Silt
38	mandaro kalle	34-11-38N 71-54-30E	Silt loam	78	Dahra kale	34-17-48N 71-46-17E	Silt loam
39	Dargai hafiz abad	34-10-52N 71-52-36E	Silt	79	Rajarh-sharsadda bypass	34-09-20N 71-44-36E	Silt loam
40	Dargai railway patak	34-10-16N 71-52-26E	Silt loam				

Location and soil textural class at the sampling sites for 15-45 cm depth

S. No.	Road Location	GPS Reading	Textural Class	S. No.	Road Location	GPS Reading	Textural Class
1	Arif abad	34-07-13N 71-39-34E	Silt loam	41	Mahmood abad	34-09-27N 71-52-56E	Silt
2	Station kalla	34-18-24N 71-38-04E	Sandy loam	42	Malagi kalle	34-08-48N 71-53-20E	Silt
3	Tangi bazaar	34-17-37N 71-39-20E	Silt loam	43	Patwari kalle	34-08-16N 71-53-32E	Silt
4	Tangi	34-17-27N 71-39-46E	Silt loam	44	Dusahara kalle	34-08-36N 71-54-02E	Silt loam
5	Hoara	34-17-23N 71-40-44E	Silt loam	45	Nazo kale	34-08-04N 71-52-57E	Silt loam
6	Shoakano kalle	34-17-26N 71-41-28E	Loam	46	Aziz abad	34-07-47N 71-52-06E	Silt
7	Karhi wal	34-17-20N 71-41-35E	Loam	47	Ahmad khan kalle	34-07-34N 71-51-24E	Silt loam
8	Taniwal kalle	34-17-00N 71-40-55E	Silt loam	48	Captan kalle	34-07-42N 71-51-49E	Silt loam
9	Ummer zai	34-16-44N 71-41-24E	Sandy loam	49	Sher bhadar kakke	34-07-12N 71-50-18E	Silt loam
10	Hagi Awaldin kale	34-16-50N 71-41-26E	Sandy loam	50	Nisatta	34-07-30N 71-48-03E	Silt loam
11	Saifur kale	34-16-41N 71-41-53E	Loam	51	Khan zada kalle	34-07-32N 71-46-57E	Silt loam

12	Noor Muhd kale	34-17-05N 71-42-05E	Silt loam	52	Policeline	34-08-04N 71-46-17E	Silt loam
13	Chacha khan kale	34-17-25N 71-42-25E	Silt loam	53	Banda	34-07-58N 71-46-43E	Silt loam
14	Mamano dhari	34-17-38N 71-42-45E	Silt loam	54	Gulballa	34-07-13N 71-39-19E	Silt loam
15	Zarin abad	34-17-56N 71-43-10E	Silt loam	55	Sardhariab (Mumtaz abad)	34-07-32N 71-41-01E	Silt loam
16	Zaim kale	34-17-20N 71-42-32E	Silt loam	56	Allahabad	34-08-18N 71-41-49E	Silt loam
17	Masal korona	34-16-49N 71-42-15E	Silt loam	57	Shad abad kalle	34-09-18N 71-43-05E	Silt loam
18	Aslam Khan Kale	34-16-34N 71-42-12E	Silt loam	58	Ahmad abad	34-09-51N 71-42-58E	Silt loam
19	Sharpao kalle	34-16-17N 71-41-54E	Silt loam	59	Ghidhare kalle	34-09-44N 71-42-44E	Silt loam
20	Maih kale	34-15-55N 71-41-46E	Silt loam	60	Sarki kalle	34-10-35N 71-42-03E	Silt loam
21	Maih jan kale	34-15-37N 71-42-37E	Silt loam	61	Ummar abad	34-08-37N 71-45-31E	Silt loam
22	Umar zai	34-13-42N 71-44-12E	Silt loam	62	Nisatta (tauhidabad)	34-06-48N 71-47-53E	Silt loam
23	Torang zai	34-12-22N 71-45-21E	Silt loam	63	Nisatta (dagai)	34-06-23N 71-48-18E	Silt loam
24	Uttaman zai	34-10-54N 71-45-43E	Silt loam	64	Shah pasand kalle	34-05-53N 71-48-53E	Silt loam
25	Rajarh kalle	34-10-22N 71-44-02E	Silt loam	65	Tarlandi (bahram kale)	34-05-27N 71-49-30E	Silt loam
26	Muffti abad	34-11-04N 71-47-24E	Silt loam	66	Nawa kalle	34-04-34N 71-50-39E	Silt loam
27	Khan mai	34-11-57N 71-48-55E	Silt loam	67	Hishgi (hisar kale)	34-03-55N 71-51-24E	Silt loam
28	Azam khan korona	34-13-02N 71-50-36E	Silt loam	68	Guggar abad	34-02-55N 71-52-29E	Sandy loam
29	Sadullah khan kale	34-13-38N 71-50-29E	Silt loam	69	Nisatta (school korona)	34-05-47N 71-48-43E	Silt loam
30	Behlola	34-14-34N 71-50-46E	Silt	70	Nisatta (madni mahalla)	34-06-15N 71-48-00E	Silt loam
31	Hafiz abad colony	34-09-20N 71-45-52E	Silt loam	71	Ummar zai (qaiam abad)	34-14-35N 71-43-54E	Silt loam
32	Pola dhair	34-09-27N 71-46-33E	Silt loam	72	Khan ghari	34-15-29N 71-44-44E	Silt loam
33	Malka dhair	34-09-49N 71-38-35E	Silt loam	73	Qamar abad	34-16-24N 71-45-44E	Silt loam
34	Sar dairy	34-10-06N 71-50-08E	Silt loam	74	Dakki	34-17-25N 71-46-36E	Silt loam
35	Shah	34-10-29N	Silt	75	Jahangir abad	34-19-09N	Silt

	jahan abad	71-51-36E			(mandarhi)	71-46-51E	
36	Dargai	34-10-47N 71-52-50E	Silt	76	Uzbako	33-20-09N 71-47-03E	Silt loam
37	Manga kalle	34-11-18N 71-54-34E	Silt	77	Harichan	34-21-44N 71-47-54E	Silt loam
38	mandaro kalle	34-11-38N 71-54-30E	Silt loam	78	Dahra kalle	34-17-48N 71-46-17E	Silt loam
39	Dargai hafiz abad	34-10-52N 71-52-36E	Silt	79	Rajarh-sharsadda bypass	34-09-20N 71-44-36E	Silt loam
40	Dargai railway patak	34-10-16N 71-52-26E	Silt loam				

The readings taken by GPS in degrees and minutes were changed to meters and kilometers using Arc view GIS3.2 version. The far most western edge of Charsadda was taken as zero point on X-axis, and the extreme southern end of the district map as zero on Y-axis. Graphic lines were drawn at regular intervals on the maps. Points were made on the map sheets from where the samples were collected and then x and y coordinates were noted from the map of the district for further analysis. Geostatistical technique of semivariogram analysis [7,21,40]. was used to determine spatial structure of various soil properties. Soil test values at unsampled locations were interpolated using geostatistical technique of punctual kriging [21] and detailed isarithmic maps were prepared at smaller gird spacing using Surfer 6.04.

Geostatistical analysis of semivariogram and kriging of the collected data on various soil properties was done using the Geo-Eas (US EPA). In case of punctual kriging the search neighborhood was 10 km radius. In this study, the linear and spherical models were the best fit using r2-values as a criterion to the data on different soil physical and chemical properties. Tentatively, a model with r2 < 0.20 was classified as poor, r2 of 0.20 to 0.50 as moderate and r2 >0.50 as strong spatial structure.

3. RESULTS AND DISCUSSION

3.1 Variability in Soil Properties

Considerable soil variation in various physical and chemical properties was observed. In case of soil physical properties, variation in sand content was higher in both the depths (41.4 and 44.1 %, respectively) than the other variables, while the lowest was observed for saturation percentage (Table 2). In case of soil chemical properties, pH had the lowest coefficient of variation (CV) in both the depths (4.80 and 6.30 %, respectively); while SAR was found with the highest CV in both the depths (Table 3). As regards plant nutrients, available P had the highest CV in both the depths (83.8 and 95.6 %, respectively) as against the lowest CV (46.9 %) for available K (Table 4) in the surface and available Zn (50.5 %) in the subsoil. It seems that there was a considerable magnitude of variation in various soil physical and chemical properties, and there is need to identify the spatial patterns in the distribution of these properties.

Table 2. Descriptive statistics of soil physical properties (N = 79)

Property	Mean	Minimum	Maximum	CV (%)
	(0-15 cm depth)			
Sand (%)	22.9	12.0	60.0	41.4
Silt (%)	67.3	36.0	81.0	15.3
Clay (%)	97.4	7.00	21.0	33.4
Saturation (%)	22.7	22.0	34.0	14.3
	(15-45 cm depth)			
Sand (%)	23.7	12.0	60.0	44.1
Silt (%)	68.7	35.0	82.0	16.4
Clay (%)	7.89	5.00	20.0	33.1
Saturation (%)	20.8	18.0	33.0	12.5

Table 3. Descriptive statistics of soil chemical properties (N = 79)

Property	Mean	Minimum	Maximum	CV (%)
	(0-15 cm depth)			
pH	8.09	7.11	9.05	4.80
ECe (dS m^{-1})	9.42	3.10	22.7	63.6
Lime (%)	7.5	0.63	21.4	53.3
Organic matter (%)	1.37	0.40	4.23	55.2
SAR (meq $L^{-1})^{1/2}$	0.71	0.09	6.58	149
	(15-45 cm depth)			
pH	8.41	7.25	10.1	6.30
ECe (dS m^{-1})	6.82	1.80	25.5	56.8
Lime (%)	7.93	1.00	21.8	56.5
Organic matter (%)	1.05	0.15	2.58	58.8
SAR (meq $L^{-1})^{1/2}$	0.93	0.04	18.5	273

Table 4. Descriptive statistics of extractable plant nutrients (N = 79)

Property	Mean	Minimum	Maximum	CV (%)	% Samples Deficient	Marginal	Adequate
mg kg^{-1}	**(0-15 cm depth)**						
Mineral N	32.9	6.69	91.0	52.4	100	-	-
AB-DTPA ext. P	5.90	0.07	24.5	83.8	44	25	31
AB-DTPA ext. K	212	84.0	510	46.9	-	17	83
AB-DTPAext. Zn	12.7	4.65	44.0	53.4	-	-	100
AB-DTPA ext. Fe	0.47	0.05	1.77	66.2	92	-	8
AB-DTPA ext. Cu	3.60	0.01	7.48	50.5	5	4	91
AB-DTPA ext.Mn	4.45	0.24	10.5	47.4	8	-	92
Dil. HCl ext. B	0.65	0.03	3.34	83.6	41	39	20
	(15-45 cm depth)						
Mineral N	28.3	2.87	60.3	54.0	47	33	20
AB-DTPA ext. P	3.79	0.48	18.8	95.6	72	14	14
AB-DTPA ext. K	189	56.0	640	61.3	2	26	72
AB-DTPA ext. Zn	10.7	3.84	35.3	50.5	-	3	97
AB-DTPA ext. Fe	0.35	0.06	1.28	70.6	96	4	-
AB-DTPA ext. Cu	2.73	0.02	6.72	60.1	6	4	0
AB-DTPAext.Mn	4.28	0.50	12.7	51.1	9	-	91
Dil. HCl ext. B	0.61	0.03	2.56	76.4	46	39	15

3.2 Spatial Variability of Soil Properties

3.2.1 Soil physical properties

Semivariogram analysis of some of the soil physical properties (Table 5) showed that the physical parameters viz. sand, silt, clay content and saturation percentage showed some spatial patterns in the surface as well as in subsoil; and they were described by linear models for all these soil parameters (Figs. 1 - 3) except for sand content in both the depths and silt in subsoil. The r2-value for these models ranged from 0.44 to 0.71 being highest for surface soil clay content. It shows that spatial structure exists for these soil properties, except for sand in both the depths and silt in subsoil, which may be due to the parent material spatial distribution.

Table 5. Parameters of semivariogram models for soil physical properties in Charsadda District

Property	Nugget	Slope	r^2	Model
		(0-15 cm depth)		
Sand (%)	91.1	-0.106	0.001	Linear
Silt (%)	63.9	2.587	0.48	Linear
Clay (%)	5.51	0.450	0.71	Linear
Saturation %	5.50	0.451	0.70	Linear
		(15-45 cm depth)		
Sand (%)	91.0	-0.106	0.001	Linear
Silt (%)	98.1	0.871	0.06	Linear
Clay (%)	3.71	0.234	0.44	Linear
Saturation %	3.71	0.234	0.44	Linear

3.3 Soil Chemical Properties

Semivariogram analysis of the data on some soil chemical properties (Table 6) showed that soil pH had random variation in surface soil, while in subsoil it was described by a linear model with r2-value of 0.49, showing moderate spatial structure. Electrical conductivity (ECe) in the surface and subsurface soil were described by a linear model with strong spatial structure in the surface soil (Table 6, Fig. 4).

Table 6. Parameters of semivariogram models for soil chemical properties

Property	Nugget	Slope	Sill	Range (km)	r^2	Model
		(0-15 cm depth)				
pH	0.164	-0.002	-	-	0.17	Linear
ECe (dS m^{-1})	21.10	1.655			0.81	Linear
Lime (%)	12.06	0.399	-	-	0.59	Linear
Organic matter (%)	0.433	-	0.601	6.65	0.27	Spherical
SAR (meq $L^{-1})^{1/2}$	1.482	-0.04	-	-	0.30	Linear
		(15-45 cm depth)				
pH	0.207	0.0091	-	-	0.49	Linear
ECe (dS m^{-1})	15.49	0.097	-	-	0.03	Linear
Lime (%)	18.64	-0.035	-	-	0.06	Linear
Organic matter (%)	0.318	0.0073	-	-	0.41	Linear
SAR (meq $L^{-1})^{1/2}$	1.954	0.8419	-	-	0.69	Linear

$CaCO_3$ of the surface soil was described by a linear model with an r^2-value of 0.59, showing strong spatial structure of lime in the surface soil (Table 6, Fig. 5). Organic matter content in the surface soil was described by a spherical model with an r^2-value of 0.27 and a range of about 7 km, showing moderate spatial distribution of organic matter in surface soil (Table 6). Sodium absorption ratio (SAR) in the surface soil had random variation but subsoil SAR had strong spatial structure and was described by a linear model.

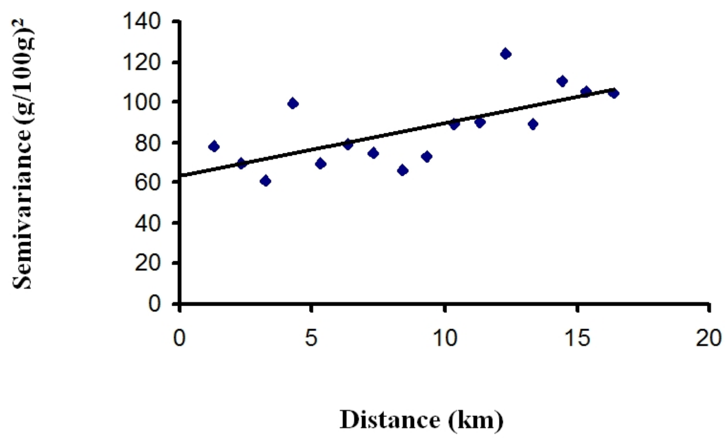

Fig. 1. emivariance and the best fitting model for surface soil silt, Charsadda district

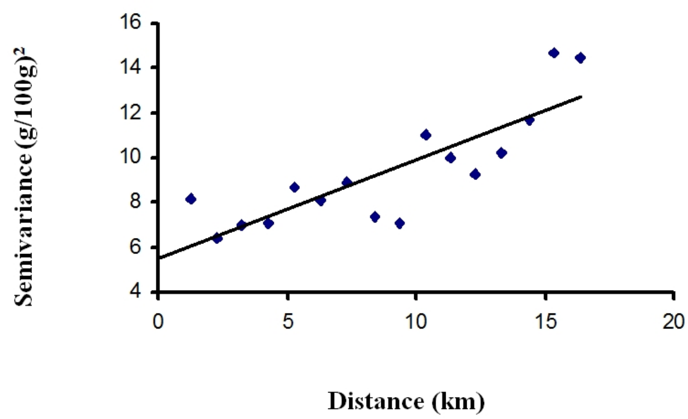

Fig. 2. Semivariance and the best fitting model for surface soil clay, Charsadda district

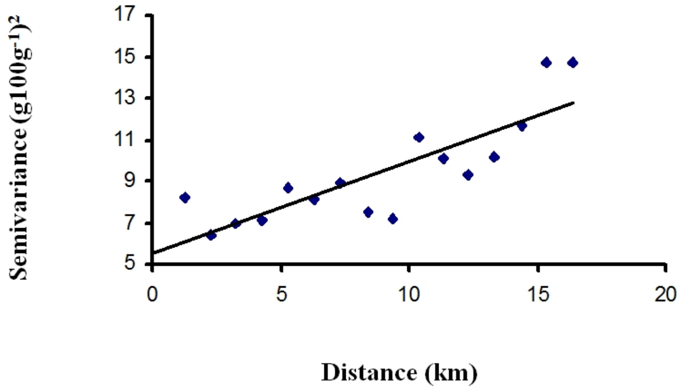

Fig. 3. Semivariance and the best fitting model for surface soil saturation percentage, Charsadda district

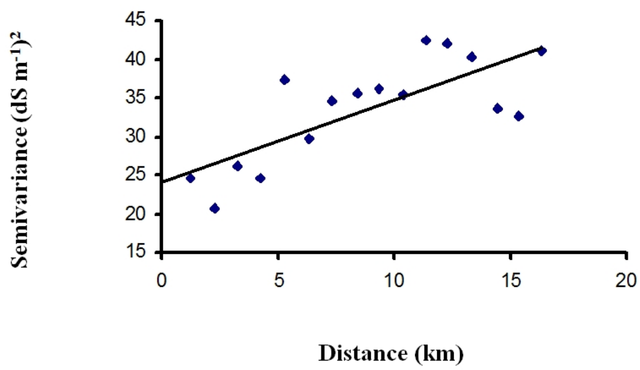

Fig. 4. Semivariance and the best fitting model for surface soil ECe, Charsadda district

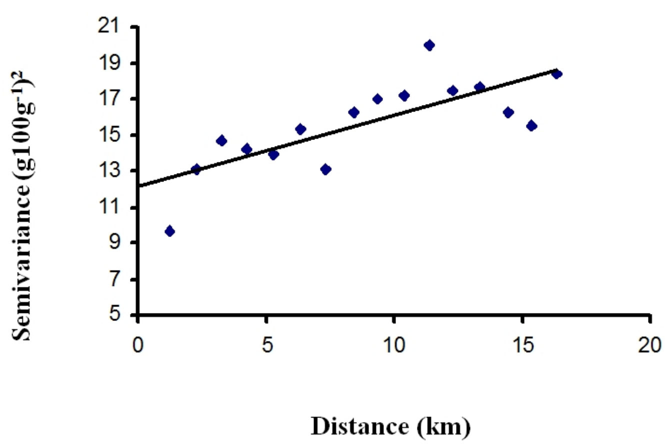

Fig. 5. Semivariance and the best fitting model for surface soil lime ($CaCO_3$), Charsadda district

3.4 Soil Fertility Status

Semivariogram analysis of the data on plant nutrients in the soils of Charsadda district (Table 7) showed that mineral nitrogen content of surface soil was described by a linear model with an r^2-value of 0.36 (Table 7, Fig. 6), showing moderate spatial structure. The data on extractable phosphorus content of the surface as will as subsoil were described by a linear model with a high r^2-value showing a strong spatial distribution of P (Table 7, Fig. 7).

Table 7. Parameters of semivariogram models for plant nutrients

Property mg kg^{-1}	**Nugget**	**Slope**	**Sill**	**Range (km)**	R^2	**Model**
		(0-15cm depth)				
N	245.8	4.795	-	-	0.36	Linear
P	18.13	0.382	-	-	0.77	Linear
K	8323	208.3	-	-	0.24	Linear
Zn	48.66	-0.1792	-	-	0.009	Linear
Fe	0.1088	-0.0005	-	-	0.02	Linear
Cu	3.071	0.0215	-	-	0.13	Linear
Mn	4.685	-0.0288	-	-	0.08	Linear
B	0.145	0.014	-	-	0.61	Linear
(15-45cm depth)						
N	226.5	0.553	-	-	0.009	Linear
P	7.834	0.642	-	-	0.73	Linear
K	6999	-	14925	9.084	0.64	Spherical
Zn	19.49	0.927	-	-	0.63	Linear
Fe	0.047	-	0.062	5.011	0.16	Spherical
Cu	1.967	0.067	-	-	0.54	Linear
Mn	1.997	-	4.876	3.966	0. 34	Spherical
B	0.154	0.0058	-	-	0.30	Linear

Available potash content of surface soil was described by a linear model having moderate spatial distribution of K (Table 7). In case of subsoil, available K was described by a spherical model with a high r^2-value and range of influence of about 9.0 km showing strong spatial variability. Zinc content had random variation in surface soil, while subsoil had strong linear spatial distribution. Copper content of both the depths were described by linear models (Table 7) with poor structure in the surface soil and strong spatial structure in subsoil. Extractable manganese content in subsoil was described by a spherical model (Table 7) with the range of influence of about 4 km though the spatial structure was moderate. The data on boron content was described by linear models in both the depths (Table 7). In surface soil, B had high r^2- value of 0.63, indicating a strong spatial distribution (Fig. 8). In subsoil, B has moderate spatial structure with an r^2 value of 0.30.

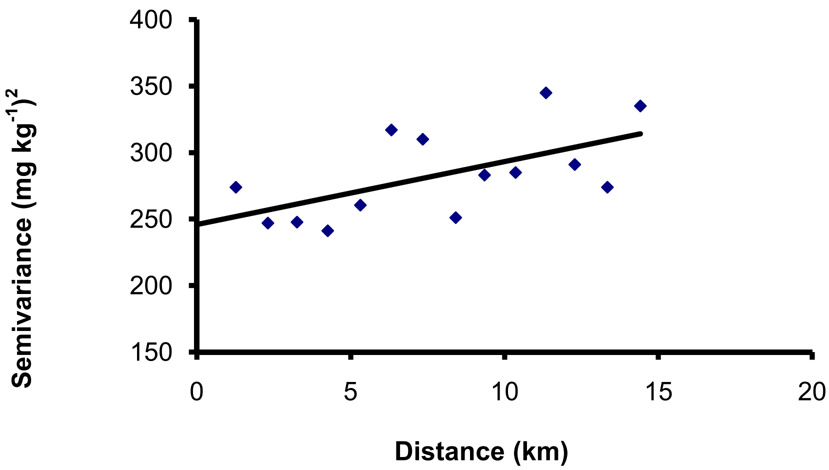

Fig. 6. Semivariance and the best fitting model for surface soil mineral-N, Charsadda district

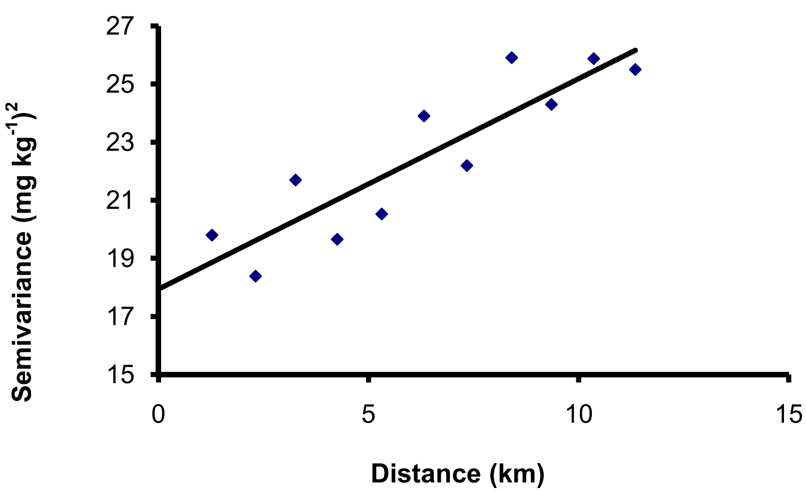

Fig. 7. Semivariance and the best fitting model for surface soil phosphorus, Charsadda district

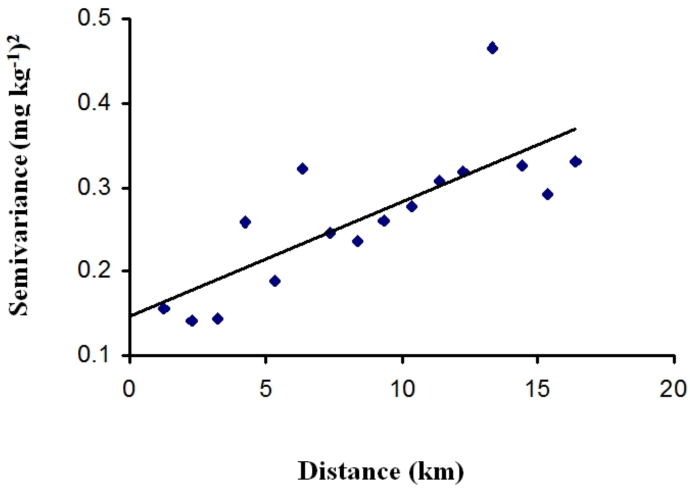

Fig. 8. Semivariance and the best fitting model for surface soil B, Charsadda district.

3.5 Interpolation and Mapping of Soil Properties

3.5.1 Physical soil properties

Map of sand content of the surface soils of Charsadda district (Fig. 9) shows some spatial patterns. The soils in the east are higher in sand content (≥ 40 %), rest of the area is medium in sand content (20-40 %). Silt content of the surface soils (Fig. 10) of the district was higher in the whole of the area (> 40 %). Clay content of the surface soils (Fig. 11) is low (≤ 30 %) in the whole area. Very weak variation is observed in clay content in the surface soil of the district.

3.5.2 Soil chemical properties

Map of pH of the surface soils (Fig. 12) showed that there was no considerable variation in the pH value of different parts of Charsadda district. However, the pH was alkaline (≥ 7.5). Map of $CaCO_3$ content of surface soils of Charsadda district (Fig. 13) shows that the soils are moderately calcareous (3-13%) in the whole area. Map of organic matter content of the surface soils (Fig. 14) shows that it is low in the north-west (< 1%) and medium in rest of the district (1-2%).

3.6 Soil Fertility

Available nitrogen content of the surface soil (Fig. 15) shows that the whole district is low (< 140 mg kg-1) in available N. Available phosphorus content of the surface soils (Fig. 16) shows that there are strong spatial patterns. Available phosphorus is deficient (< 4.0 mg kg-1) in the west and marginal (4.0-7.0 mg kg-1) in southern and central part, while rest of area is adequate (> 7.0 mg kg-1) in available P. Available boron content of the surface soils (Fig. 17) shows some spatial patterns. It is adequate (> 1.0 mg kg-1) in some parts of east- south, while rest of the area is marginal (0.45-1.0 mg kg-1) in available boron.

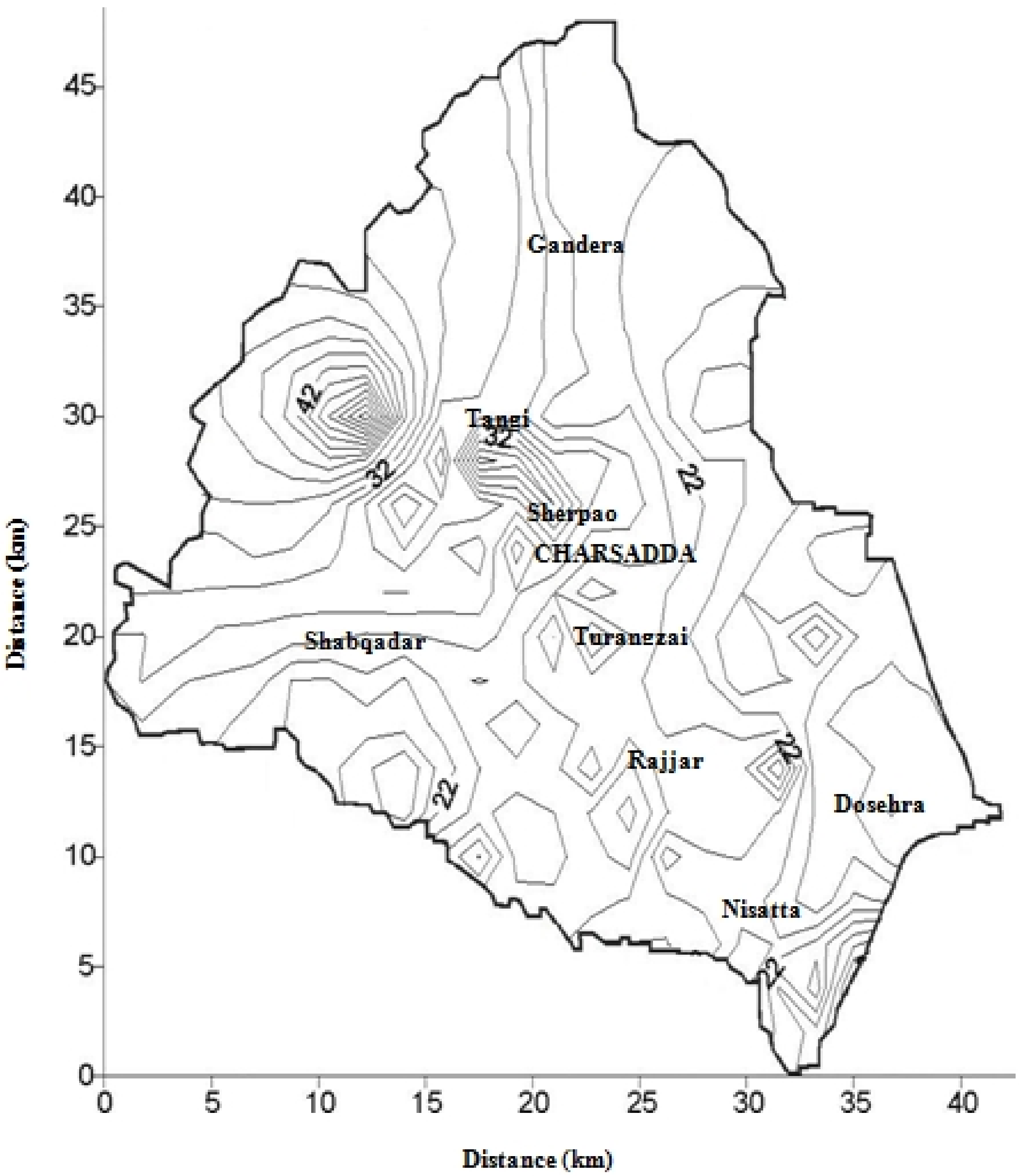

Fig. 9. Map of surface sand (%) by kriging, Charsadda district

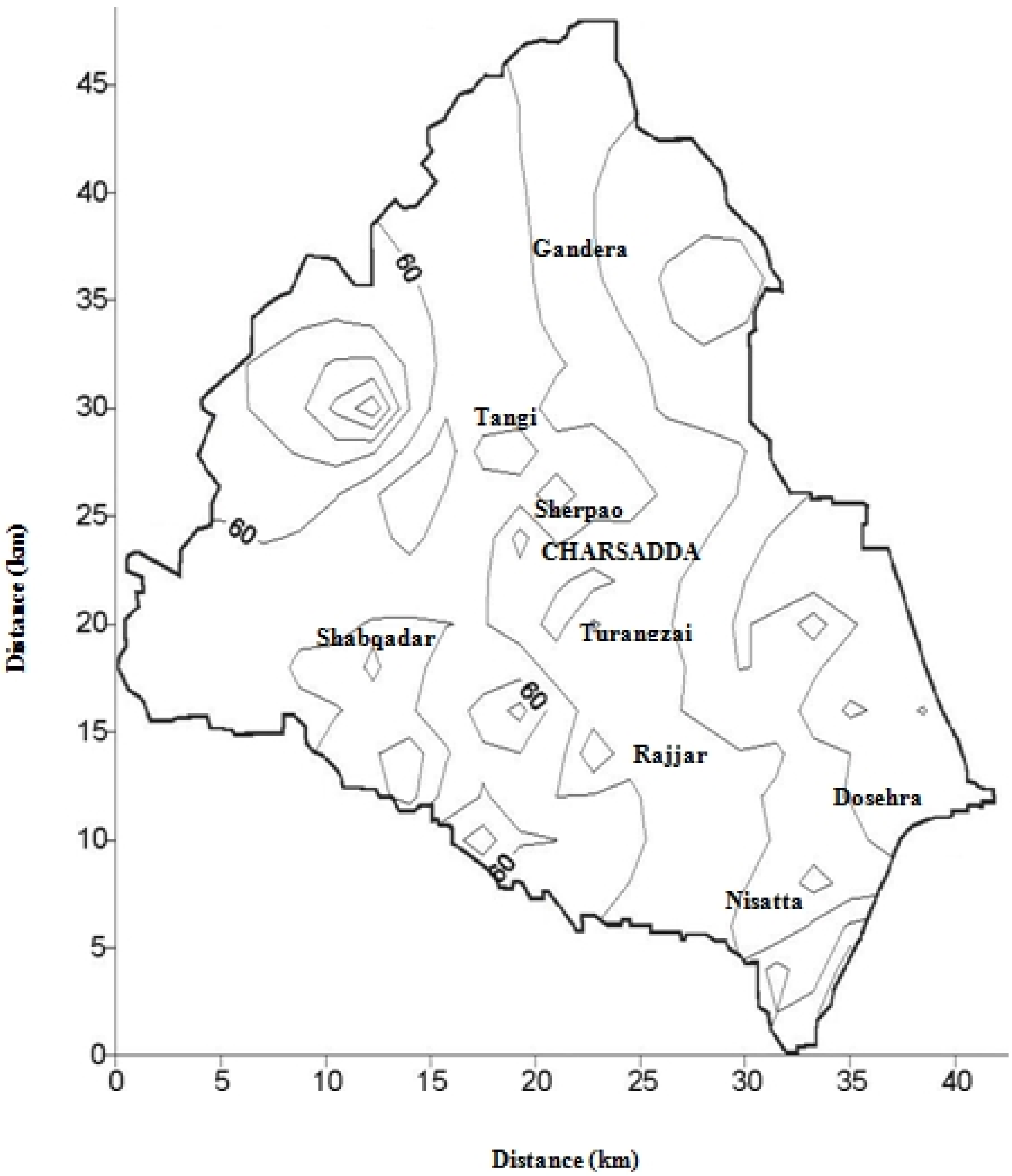

Fig. 10. Map of surface silt (%) by kriging, Charsadda district

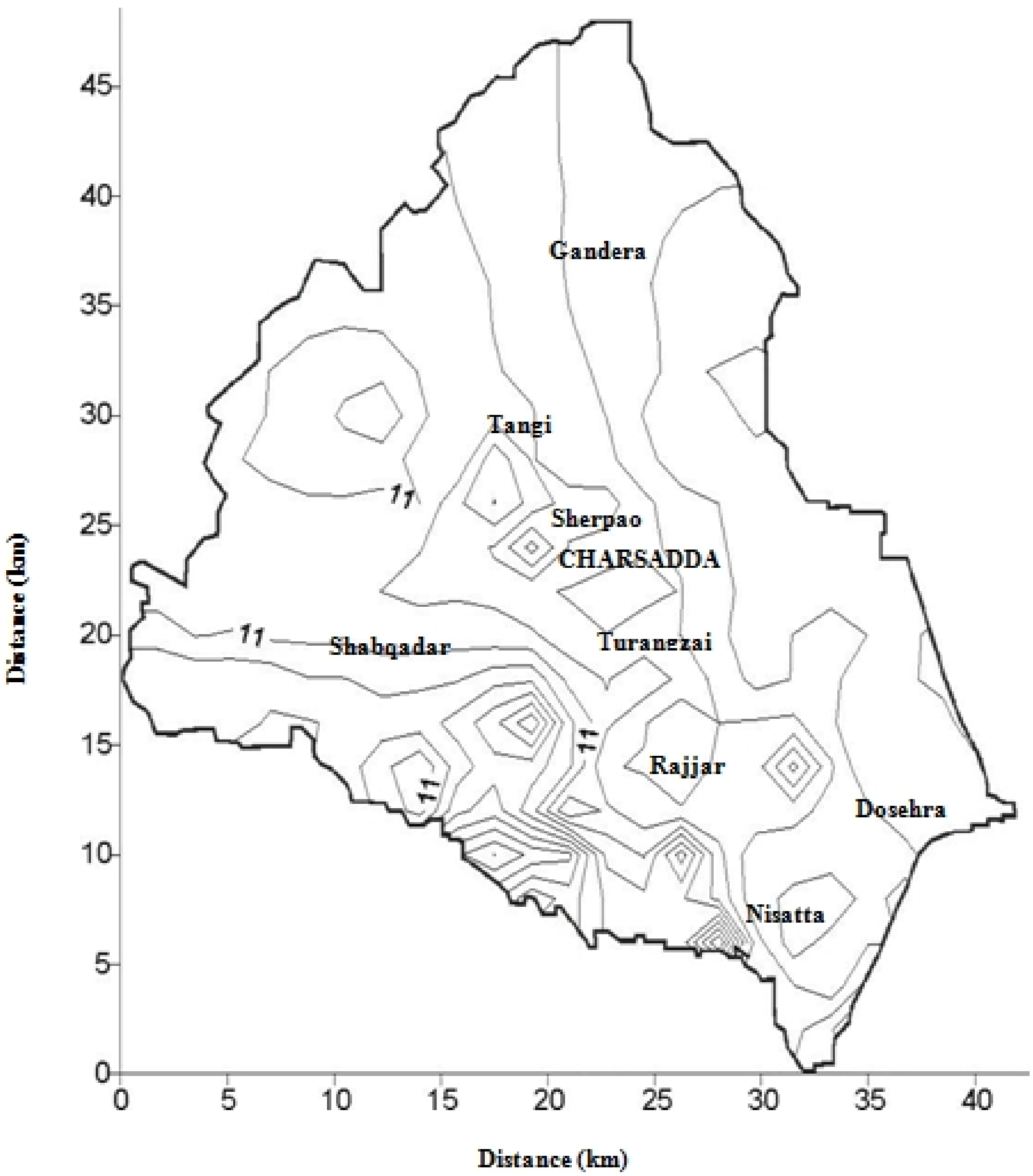

Fig. 11. Map of surface soil clay (%) by kriging, Charsadda district

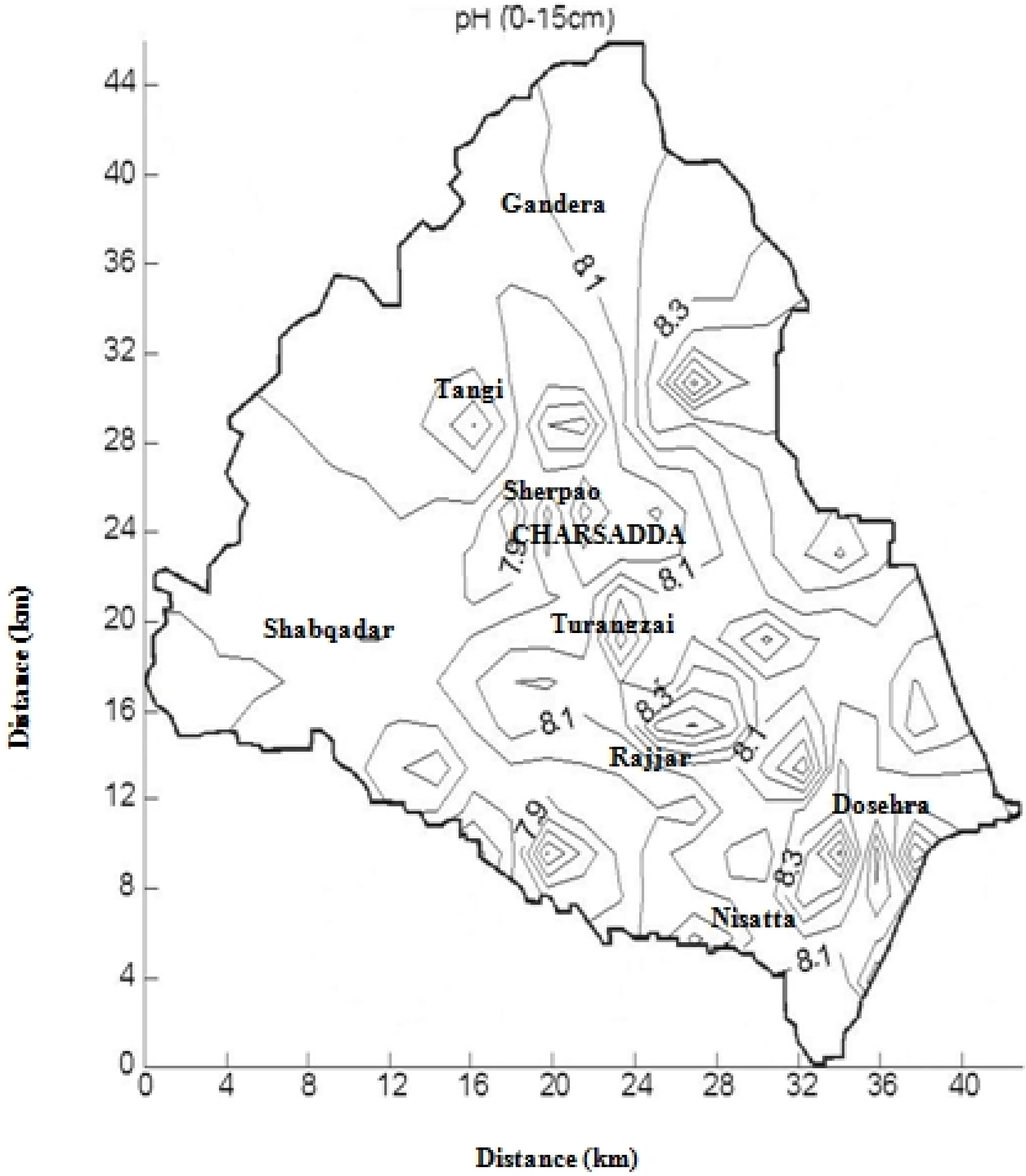

Fig. 12. Map of surface soil pH by kriging, Charsadda district

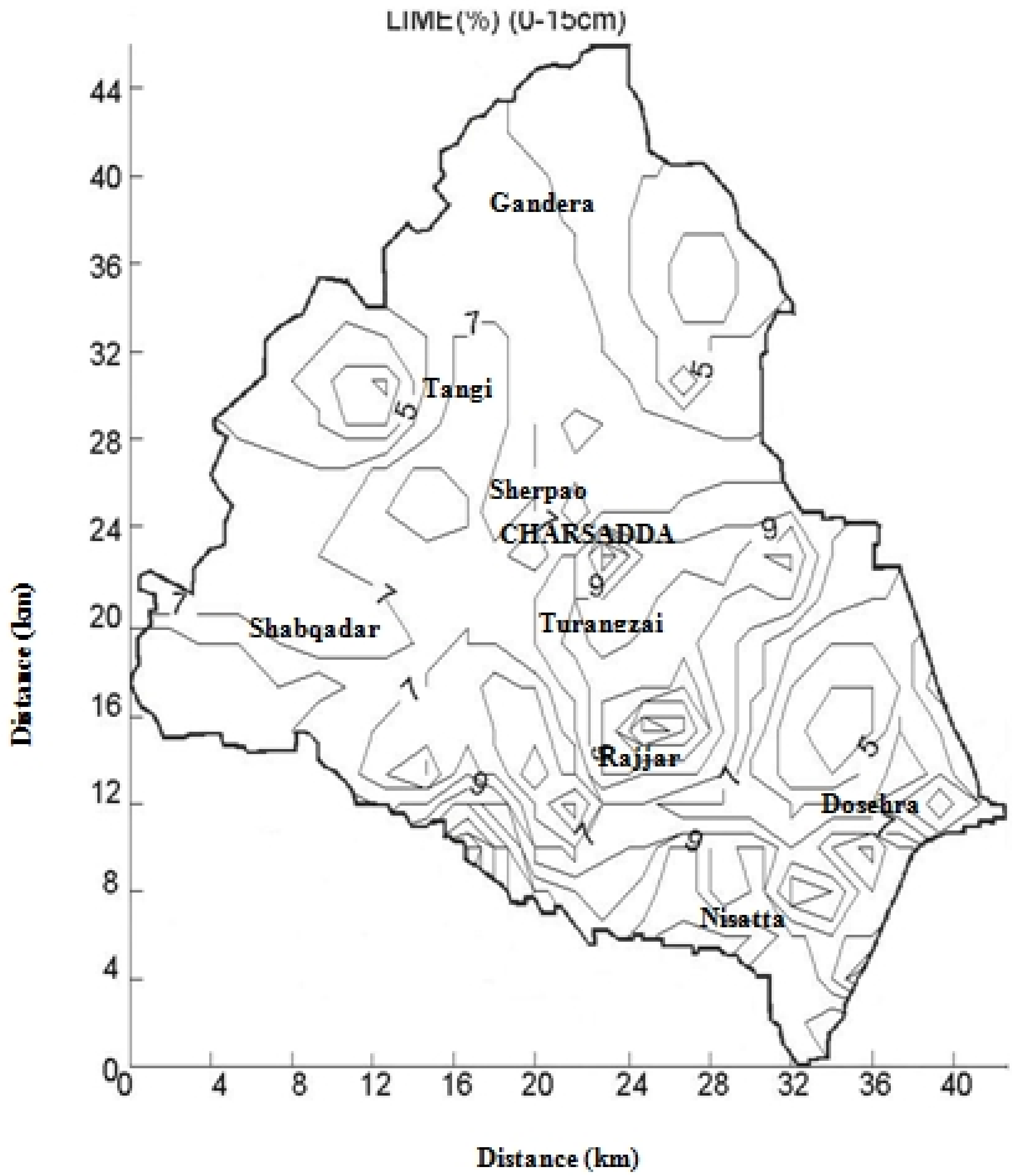

Fig. 13. Map of $CaCO_3$ in surface soil (%) by kriging, Charsadda district

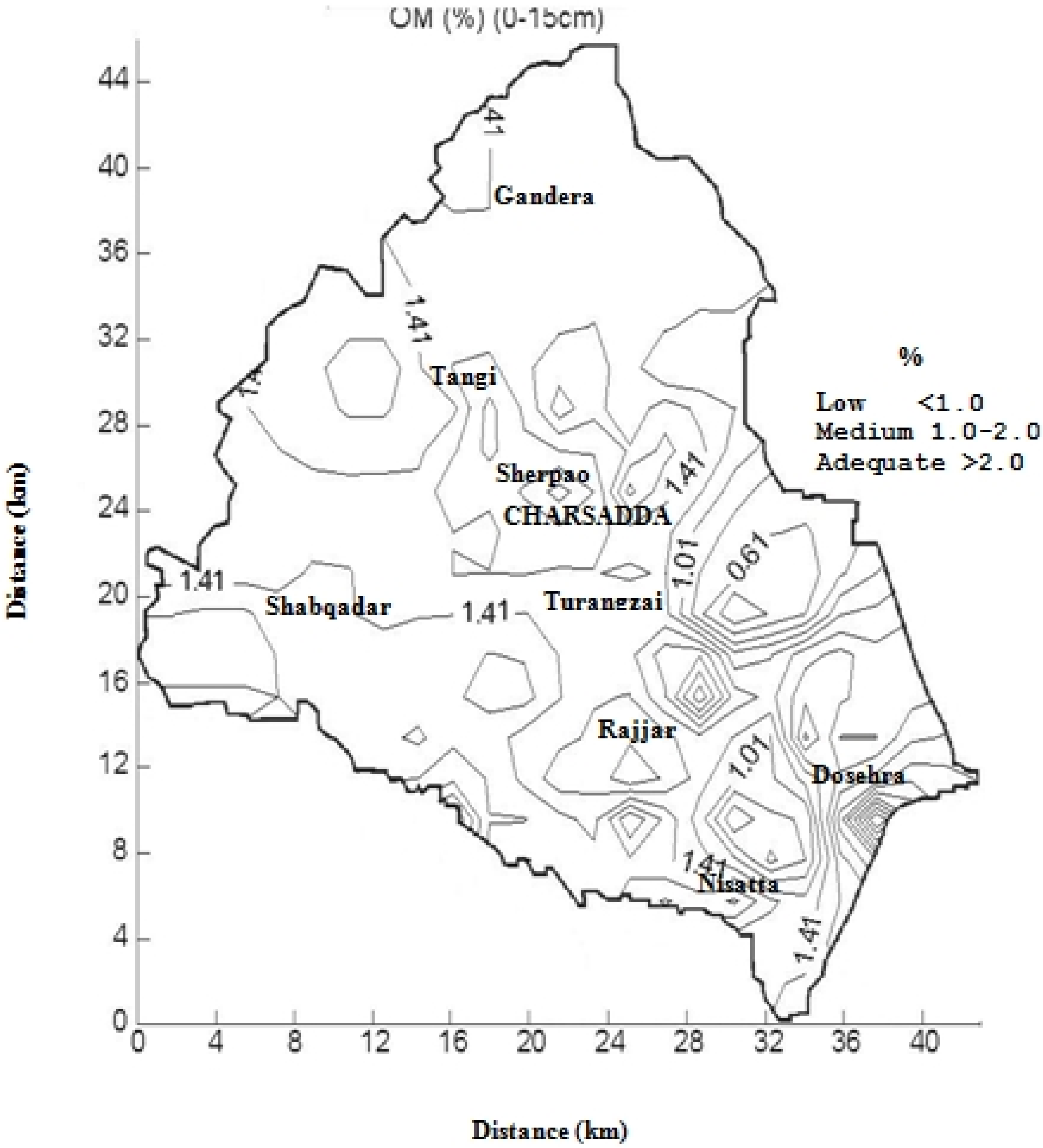

Fig. 14. Map of surface soil organic matter (%) by kriging, Charsadda district

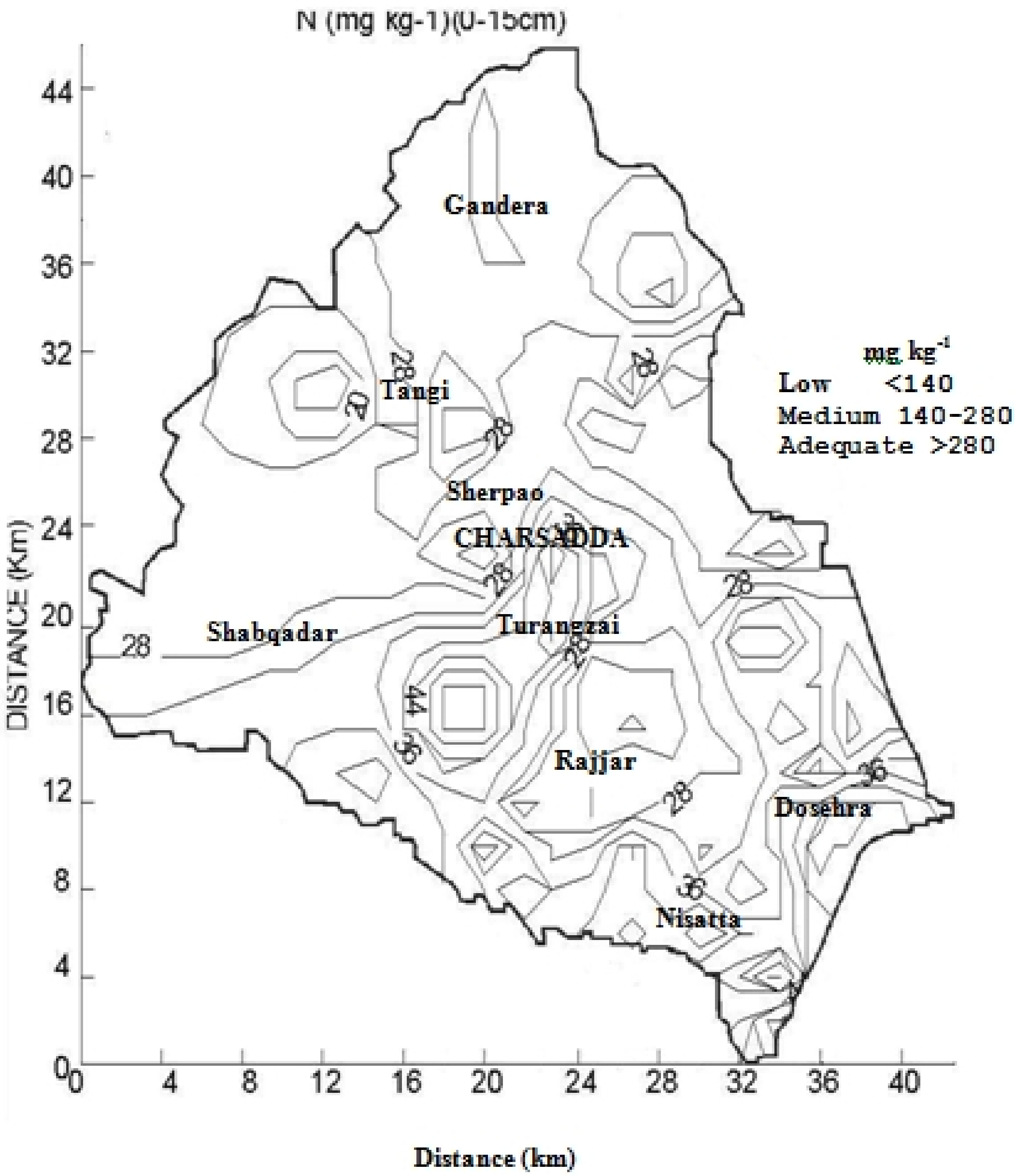

Fig. 15. Map of surface soil mineral N (mg kg^{-1}) by kriging, Charsadda district

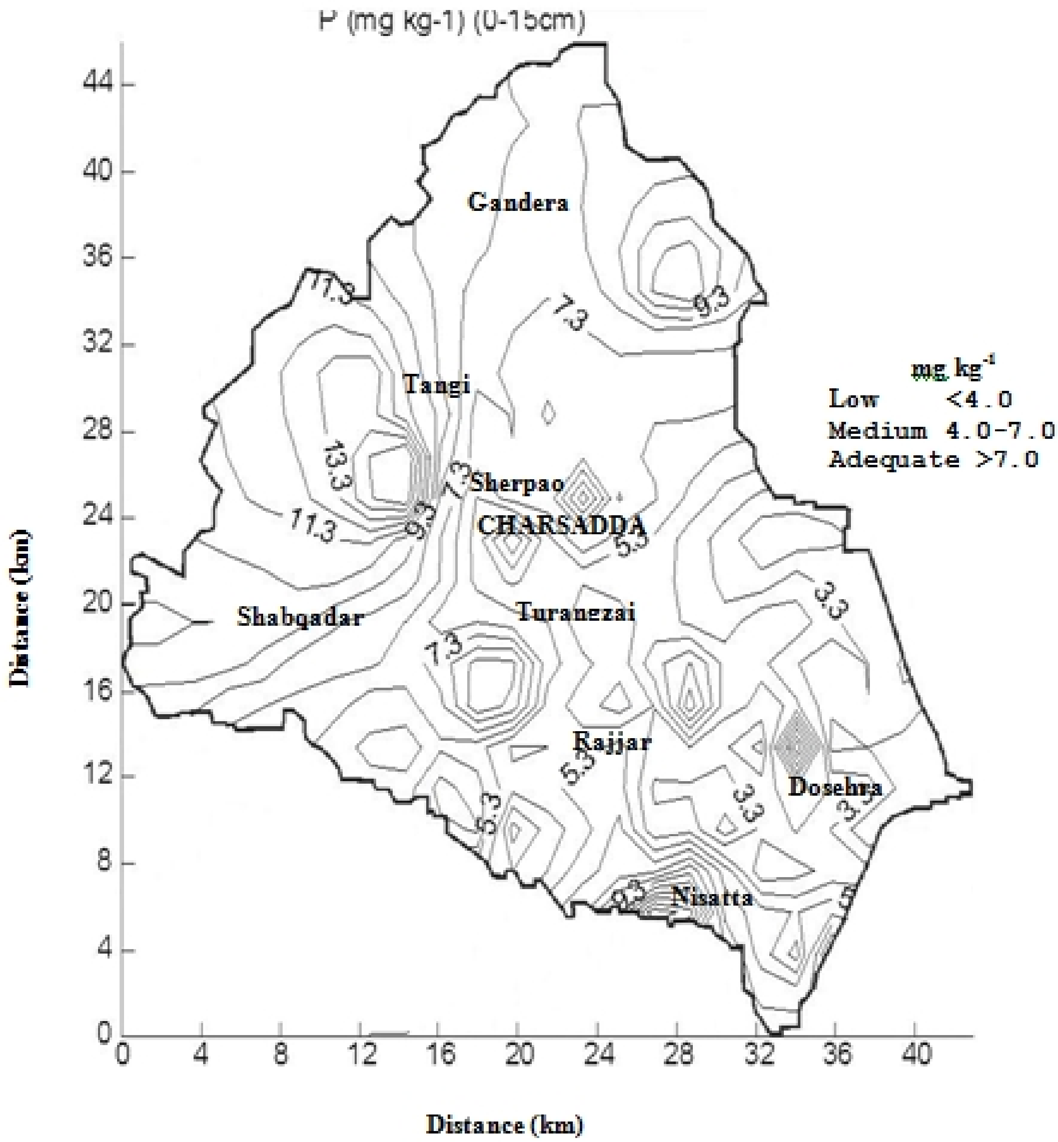

Fig. 16. Map of surface soil extractable P (mg kg^{-1}) by kriging, Charsadda district

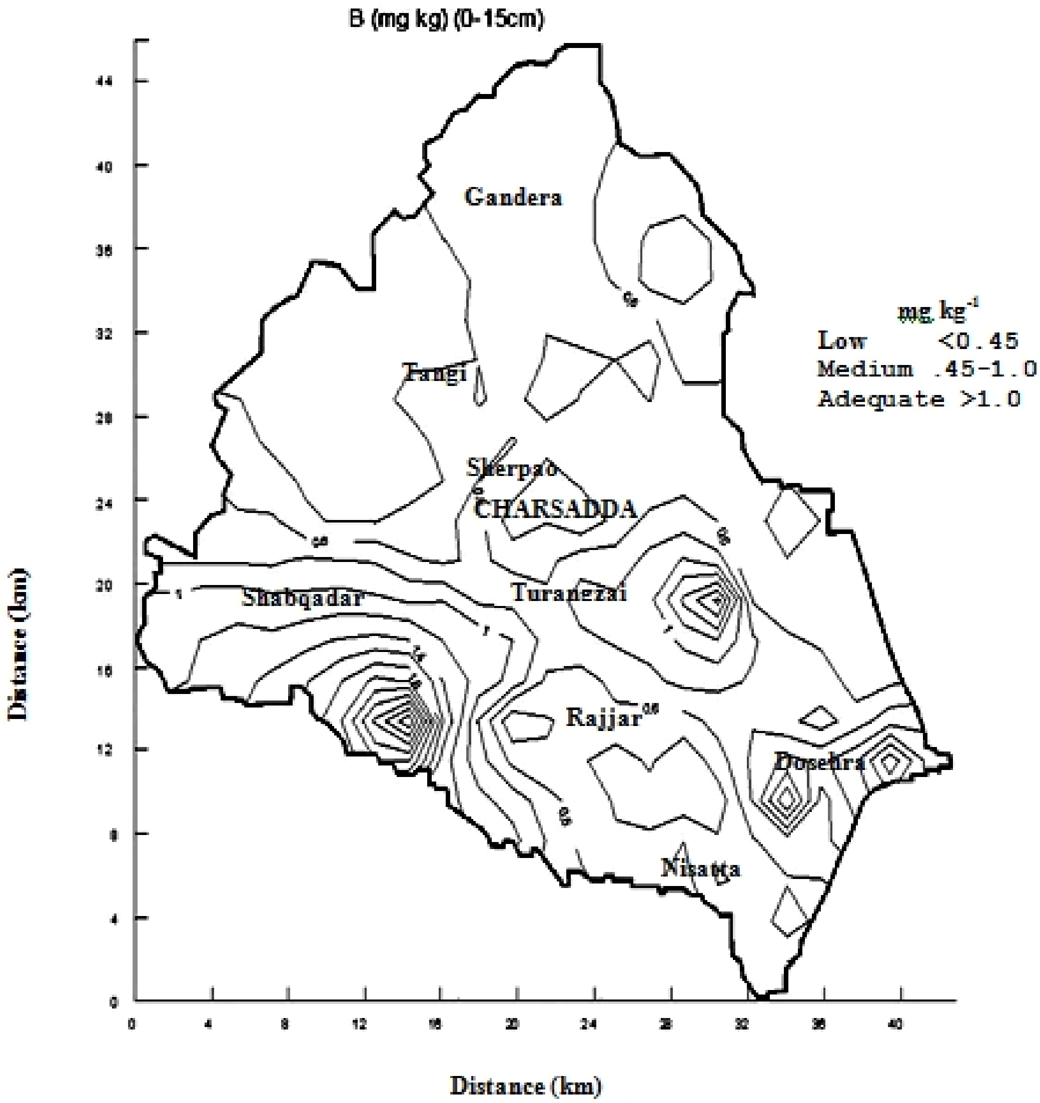

Fig. 17. Map of surface soil extractable B (mg kg^{-1}) by kriging, Charsadda district.

Spatial variability of various soil properties in the study area was evident as indicated by the semivariogram models. Spatial dependence of soil properties can be attributed to extrinsic as well as inherent factors [1,7,15,27].

Maps of various soil properties especially soil fertility showed spatial patterns in their distribution. These maps will be useful in delineating the area into low, medium and high nutrients contents and managed accordingly. Such regional variability is determined using geostatistical technique of semivariogram analysis and kriging, which has been successfully used by different workers at field level [7,11,17,18] or at larger unit such as district level [5,41] for the site-specific management of soil fertility. These techniques have also been used to prepare contour maps of soil properties [28,41,42,43,44,45] and the use of geostatistics and elaboration of contour maps of heavy metals proved useful to identify hotspots of contamination for remediation purposes[28].

4. CONCLUSIONS

Soil texture of Charsadda district ranged from silt to sandy loam. Sand content in the east and silt in the whole area was higher, while clay was found low throughout the soil surveyed. All the soils were alkaline in reaction and calcareous in nature to different degrees as indicated in maps of surface soil pH and CaCO3. Salinity problem was found in most of the soils surveyed. SAR of soils at both the depths was normal and no sodium hazard was found in the soils studied. Organic matter content of both the depths was low. Total mineral N of surface soils was deficient in all soils of district Charsadda, while in subsoil it was deficient to moderate level in different soils. Deficiencies of P, Zn and B were observed to a greater extent, while those of K, Cu and Mn are also appearing. Silt, clay content, saturation percentage, soil pH, ECe, organic matter and SAR, lime, N, P, K, Fe, Mn, Cu and B either in the surface soil, subsoil or both have spatial patterns. Maps of various soil properties showed variation in different areas and can be managed accordingly. Currently, a blanket recommendation is made for the whole district. Whole area can be divided into different categories on the basis of each plant nutrient as shown in the maps. Variable rate fertilizer management strategy can be developed for different zones, which will increase the efficiency of fertilizers; and this will avoid over or under-fertilization and will be economical, and environmentally safe.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Van Es HM, Van Es CL, Cassel DK. Application of regionalized variable theory to large-plot field experiments. Soil Sci. Soc. Am. J. 1989;53:1178–1183.
2. Bhatti AU, Mulla DJ, Frazier BE. Estimation of soil properties and wheat yields on complex eroded hills using geostatistics and thematic mapper images. Remote Sens. Environ. 1991;37:181-191.
3. Fagroud M, Meirvenne MV, Accounting for soil spatial autocorrelation in the design of experimental trials. Soil Sci Soc Am J. 2002;66:1134–1142.
4. Bhatti AU, Rashid M. Shape and size of plots in field experiments and spatial variability. Sarhad J. Agric. 2005;21(2):33-41.
5. Mulla DJ, Bhatti AU, Kunkel R. Methods for removing spatial variability from field research trials. Adv. in Soil Sci. 1990;13:201-213.
6. Bhatti AU, Mulla DJ. Spatial variability of soil properties and wheat yields on complex hills and their fertility management. J. Ind. Soc. Soil Sci. 1995;43(1):53-58.

7. Bhatti AU, Bakhsh A, Afzal M, Gurmani AH. Mapping of major plant nutrients and crop productivity using geostatistical techniques for fertilizer management. Pak. J. Soil Sci. 1999;16:129-136.
8. Mzuku M, Khosla R, Reich R, Inman D, Smith F, MacDonald L. Spatial Variability of Measured Soil Properties across Site-Specific Management Zones. Soil Sci. Soc. Am. J. 2005;69:1572-1579.
9. Bhatti AU, Bakhsh A. Management strategy of using gypsum for reclamation of salt affected soils. J. Ind. Soc. Soil Sci. 1995;43(4):657-659.
10. Bhatti A U, Ali, Khan RF, khan MJ. Comparison of wheat yield under uniform and variable rates of fertilizer on spatially eroded land. Commun. Soil Sci. Plant Anal. 1998a;29:2855-2864.
11. Bhatti AU, Khan M, Khurshid KS, Farmanullah. Site-specific determination of N rates for irrigated wheat based on soil properties. In: Proceedings of Symposium on Nutrient Management for Sustainable Agricultural Growth at NFDC Islamabad, 1998b. Dec. 8-9;1997:131-137.
12. Wendroth OP, JuÈrschikb, Kersebaumc KC, Reutera H, Kesseld CV, Nielsene DR. Identifying, understanding, and describing spatial processes in agricultural landscapes. Soil & Till. Res. 2001;58:113-127.
13. Wasiullah, Bhatti AU, Khan F, Akmal M. Spatial variability and geo-statistics application for mapping of soil properties and nutrients in semi arid district Kohat of Khyber Pakhtunkhwa (Pakistan). Soil & Environ. 2010;29(2):159-166.
14. Adhikari, Paradip, Shukla, Kumar M, Mexal, John G. Spatial variability of soil properties in an arid ecosystem irrigated with treated municipal and industrial wastewater. Soil Sci. 2012;177(7):458-469.
15. Vieira SR, Nielsen DR, Biggar JW. Spatial variability of field-measured infiltration rate. Soil Sci. Soc. Am. J. 1981;45:1040–1048.
16. Trangmar BB, Yost RS, Wade MK, Uehara G, Sudjadi M. Spatial variation of soil properties and rice yield in recently cleared land. SSSAJ. 1987;51:668–674.
17. Zuo X, Zhao H, Zhao X, Zhang T, Guo Y, Wang S, Drake S. Spatial pattern and heterogeneity of soil properties of soil properties in sand dunes under grazing and restoration in Horgin Sandy Land, Northern China. Soil & Till. Res. 2008;99(2):202-212.
18. Strudley MW, Green TR. Ascough II JC. Tillage effects on soil hydraulic properties in space and time: State of the science. Soil & Till. Res. 2008;99(1):4-48.
19. David M. Geostatistics area reserve estimation. Elsevier Sci. Publ., Amsterdam; 1977.
20. Hajrasuliha S, Baniabbassi N, Metthey J, Nielsen DR. Spatial variability of soil sampling for salinity studies in southwest Iran. Irrig Sci. 1980;1:197–208.
21. Trangmar BB, Yost RS, Uehara G. Application of geo- statistics to spatial studies of soil properties. Adv. Agron. 1985;38:45–93.
22. Boruvka L, Donátová H Nemecek K. Spatial distribution and correlation of soil properties in a field: a case study. Rostl. Výr. 2002;48:425-432.
23. Anuar AR, Goh KJ, Heoh TB, Ahmed OH. Spatial variability of soil inorganic N in a mature oil palm plantation in Sabah, Malaysia. Am. J. App. Sci. 2008;5:1239-1246.
24. Amado TJC, Pes LZ, Lemainski CL, Schenato RB. Chemical and physical attributes of oxisols and their relation with irrigated corn and common bean yields. Revista Brasileira de Ciência do Solo. 2009;33:831-843.

25. Afshar FA, Ayoubi S, Jalalian A. Soil redistribution rate and its relationship with soil organic carbon and total nitrogen using 137Cs technique in a cultivated complex hillslope in western Iran. J. Environ.Radioactivity. 2010;101:606-614.
26. Andronikov SV, Davidson DA, Spiers RB. Variability in contamination by heavy metals: sampling implications. Water, Air, and Soil Pollution. 2000;120:29-45.
27. Navas A, Machin J. Spatial distribution of heavy metals and arsenic in soils of Aragon (northeast Spain): Controlling factors and environmental implications. Appl. Geochem. 2002;17:961–973.
28. Burgos P, Medejon E, Perez-de-Mora A, Cabrera F. Spatial variability of chemical characteristics of a trace-elements-contaminated soil before and after remediation. Geoderma. 2006;130:157-175.
29. Kabala C, Bojko O, Madynyska A, Szczepaniak A. Spatial variability and temporal changes in the heavy metal content of soils with a deep furrow-and-ridge microrelief formed by an afforestation plowing. Environ Monit Assess. 2012;185(6):5141–5150.
30. Sadler EJ, Evans RG, Stone KC, Camp CR. Opportunities for conservation with precision irrigation. J. Soil Water Conserv. 2005;60(6):371–379.
31. Webster R, Oliver MA. Statistical methods in soil and land resource survey. Oxford University Press; 1990.
32. Gee GW, Bauder JW. Particle size analysis. In: A. Klute, A. (ed.) Methods of Soil Analysis. Part 1. Physical and Minerological Methods. 2nd Edition. Agron. Monogram. 9.ASA and SSSA, Madison, WI. 1986;383-411.
33. Richards LA. Diagnosis and Improvement of Saline and Alkali Soils. Agri. Handbook No.60. U.S.A. Washington, D.C. 1954;102-129.
34. Mclean EO. Soil pH and lime requirement. In: Page AL, Miller RH, Keeney DR. (eds.), Methods of Soil Analysis. Part 2. Agron. 9. ASA. Madison, WI. pp. 209-223; 1982.
35. Nelson D W, Sommers LE. Total carbon, organic carbon and organic matter. In: A.L. Page, R.H. Miller, and D.R. Keeney (eds.). Methods of Soil Analysis. Part 2. Agronomy 9. Amer. Soc. of Agron, Madison, WI. 1982;539-577.
36. Nelson RE. Carbonate and gypsum. In: A.L. Page, Miller RH, Keeney DR, (eds.). Methods of Soil Analysis. Part 2. Agron.9. ASA, Madison, WI. 1982;181-198.
37. Keeney DR, Nelson DW. Nirogen-Inorganic forms. pp.643-693. In: Page AL, Miller RH, Keeney DR. (eds.), Methods of Soil Analysis. Part 2. Agron. 9. ASA. Madison, WI. 1982;643-698.
38. Soltanpour PN. Use of AB-DTPA soil test to evaluate elemental availability and toxicity. Commun. Soil Sci. Plant Anal. 1985;16:323-338.
39. Ryan J, Estefan G, Rashid A. Soil and plant analysis laboratory manual. Jointly published by Int. Center Agric. Res. In Dry Areas (ICARDA), Aleppo, Syria and National Agric. Res. Center (NARC) Islamabad, Pakistan; 2001.
40. Journal AG, Huijbregts CH. Mining Geostatistics. Acadmics Prss, New York; 1978.
41. Rafique E, Rashid A, Ryan J, Bhatti AU. Zinc deficiency in rainfed wheat in Pakistan: Magnitude, spatial variability, management, and plant analysis diagnostic norms. Commun. Soil Sci. & Plant Anal. 2006;37:181-197.
42. Lark RM, Bellamy PH, Rawlins BG. Spatio-temporal variability of some metal concentrations in the soil of eastern England, and implications for soil monitoring. Geoderma. 2006;133:363–379.
43. Liu D, Wang Z, Zhang B, Song K, Li X, Li J, Li F, Duan H. Spatial distribution of soil organic carbon and analysis of related factors in croplands of the black soil region Northeast China. Agric. Ecosyst. Environ. 2006;113:73-81.

44. Bai Y, Wang Y. Spatial variability of soil chemical properties in a Jujube Slope on the Loess Plateau of China. Soil Sci. 2011;176:550-558.
45. Sharma P, Shulka MK, Mexal JG. Spatial variability of soil properties in agricultural fields of South New Mexico. Soil Sci. 2011;176:288-302.

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