Spatial Variability of Some Chemical and Physical Soil Properties in Nesho Mountainous Rangelands

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Abstract Soil is a suitable place for vegetation and plant growth, while this valuable investment is not preserved, shortage of food, erosion and damage natural resources will be respected. Soil is a heterogeneous, diverse and dynamic system and investigation of its temporal and spatial changes is essential. In this paper spatial variability of some chemical and physical soil properties were investigated in mountainous rangelands of Nesho, Mazandaran province, Iran. From the study area 110 soil samples were sampled by a systematic sampling strategy at 0 to 30 cm depth below the surface on a regular grid spacing of 30×30 m^2 with different vegetation cover and all the samples were transported to laboratory. Then soil chemical and physical parameters including Acidity (pH), Electrical conductivity, CaCO$_3$, Bulk density, Particle density, total phosphorus, total Nitrogen, available potassium, Organic matter, Saturation moisture, Soil texture (percentage of sand, silt and clay), Sodium, Calcium, magnesium were measured in laboratory. After data normalization, classical statistical analysis were used to describe soil properties and geo-statistical analysis were used to illustrate spatial correlation of soil characteristics and by using interpolating techniques of maps spatial distribution of these properties was prepared. Results indicated that in the study area saturation moisture and percentage of Sand had highest and lowest spatial correlation respectively.

Keywords SpatialVariability, Chemical And Physical Soil Properties, Nesho Rangeland

1. Introduction

The spatial variability and geographical heterogeneity of physical and chemical properties of rangeland ecosystems soils are under physical and biological factors impact including topography, vegetation cover, soil microclimate, various grazing systems and rangeland management (Chaneton and Avado, 1996). Soil properties change in time and space continuously (Rogerio et al., 2006). Heterogeneity may be occurred at large scale (region) or at small scale (community), even in the same type of soil or in the same community (Du Feng et al., 2008). Despite the temporal and spatial changes of soil characteristics in small and large scales, awareness of how are these changes for increasing profitability and sustainable agriculture management, is necessary (Ayoubi, 2008). Spatial changes and heterogeneous geographical distribution of chemical and physical properties of soils in rangeland ecosystem are influenced by a set of biological and physical factors including topography, vegetation, soil microclimate, different grazing systems andvarious rangeland Management(Chaneton and

Avado,1996). Distribution of Vegetation is related to soil moisture and other soil properties such as soil ventilation, soil texture, depth etc., and soil properties in relation tovegetation cover cause plant diversity and widespread geographical distribution of plants (Noy-Mire, 1973; Burke, 2001). Soil compaction following heavy grazing cause homogenous spatial distribution of soil properties and increase vulnerability of soil, water and soil loss, and consequently reduce available water for plants and production of rangeland (Ying Zhao et al., 2007). Cheng et al. (2007) reported that spatial variability of aboveground biomass in shrub lands is greater than grasslands. There is clear special spatial relationship between plant and soil (Etemaand Wardle, 2002; Covelo et al., 2008; Zhao et al., 2007). Determining soil variability is important for ecological modeling, environmental predictions, precise agriculture and management of natural resources (Hangsheng et al., 2005; Wang, 2009). For a long time, spatial changes of soil characteristics have been attended by soil scientists and also nowadays the access means to precise and quantitative information about these changes is essential for environmental assessment of soil quality, risk of soil pollution and retro gradation of soil characteristics and soil erosion studies as a part of environment and non-agricultural interpretations of soils has new challenges against soil scientists. Soil organic matter, nitrogen and phosphorus are the most important functions of

ecosystems because they play a direct role in ecosystem processes such as plant growth and carbon cycle (Roberston et al., 1988). Organic matter is one of the most indexes of soil quality, thus investigation of changes and spatial distribution of organic carbon can be useful for evaluation of soil function and understanding of soil carbon decomposition processes and determination of soil quality changes trends (Wood, 1998;Venteris et al., 2004). Temporal and spatial investigation of data is essential for understanding of soil spatial variability. Kersic (1997) knew geo-statistics technique as the most confident, strongest and widest method for interpolation and has acknowledged that geo-statistics is the strategy that considers spatial variance, location and distribution of samples. Geo-statistics is a powerful tool for determining the spatial variability (Sauer et al., 2006). Geo-statistical methods use mathematical and statistical functions for interpolation and their basis is statistical characteristics of data. This technique predicts unknown points based on autocorrelation and their spatial structure of measured points (Ghahroodi, 2006). Soil properties maps show their spatial changes well. Different methods exist for creating soil properties maps that one of them is gathering samples from soil depths and analyze the samples by using geo-statistics technique and regional theory (Hunter and et al, 1982). Since the part of variations are caused by a number of randomly occurring events and other part is related to the distance, geo-statistics lead us to more accurate estimations with less error (Adriana, 2007). In fact geo-statistics investigate the variables that have spatial structure (Hassani Pak, 2007) or continuous spatial distribution. Early principal of geo-statistics is that the similarity between near samples decreases when the distance increases (IsaakandSrivastava 1989;Goovaerts 1997). Many studies have shown the correlation between soil characteristics like organic matterand the results were illustrated in map (Jian-Bing et al., 2006; Zhang and McGrans, 2004; Fennessy and Mitsch, 2001; Anderson et al., 2005). Zhao (2007) reported that spatial variability of soil chemical and physical properties are affected by graze intensity and heavy grazing decreases soil water content (SWC) and soil organic carbon (SOC) but increases bulk density (BD) and shear strength (SS). Mohammadi and RaeisiGahrooei (2003) showed that spatial variation pattern of soil variables absolutely depends exactly on rangeland management history. Variogram of organic matter at grazing site has linear structure and does not access to threshold variance in attention to regional scale. While the spatial pattern of this variable at enclosure site has strong structure and determined threshold variance. Fennessy and Mitsch (2001) evaluated spatial distribution of soil properties in 2 year period. They found that the spatial variability of organic matter and total nutrient of soil had decreased in this period. Yong et al. (2006) investigated soil properties and their spatial pattern in a sandy grassland and reported that continuous grazing lead to decrease spatial dependence of soil organic carbon and total nitrogen at sandy hills. According to recent studies and confirmation of special spatial relation between soil properties and plant at different ecosystems like rangelands, knowledge of soil spatial variability for application purposes is necessary as well as model development (Søvik and Aagaard, 2003). This research was done to investigate spatial variability of some chemical and physical soil properties in mountainous rangelands.

2. Material and Methods

Study area

The study area is located at central Alborz zone, Mazandaran province Northern Iran and 40 km south of Ruyan county (50° 08'00" E to 50° 08'17" and 36° 21'49" N to 36° 22'04"). It has 1700 m altitude above sea surface and 6 ha area (Figures 1 and 2). The land use of this area was forest that was transformed to rangeland about 30 year ago. The climate is cold-mountain based on Embergermethod with mean annual precipitation of 253 mm, mostly falling in the winter, autumn and spring. Minimum and maximum monthly mean temperatures were -4.1 and 28.4 in January and August respectively. The annual mean temperature is 12.17 ◦C. Nesho village is surrounded by forest from each side.

Sampling

A sampling site was selected in Nesho rangelands. Soil samples were sampled by a systematic sampling strategy at 0 to 30 cm depth below the surface on a regular grid spacing of 30×30 m² from 0-30 cm depth. 96 points were selected and also 14 marginal points were added to increase the accuracy of research (110 soil samples in total). The UTM coordinates of soil samples were recorded for using in spatial analysis of soil characteristics.

Laboratory analysis

The samples were air-dried and passed through a 2 mm sieve to prepare them for experiments. The methods that were applied were: hydrometer method for soil texture (Jacob and Clark, 2002), Kjeldahl method for total nitrogen (Bremner and Mulvaney, 1982), and the modified Walkley-Black wet oxidation procedure for organic carbon content. Multiplying the soil organiccarbon by 1.72 resulted in soil organic matter (Nelson and Sommers, 1982). Titration method with EDTA solution were used for measuring Calcium and Magnesium (Lanyon and Heald, 1982), Pycnometer method for Particle density (Jacob and Clark, 2002), sampling cylinder method for Bulk density (Jacob and Clark, 2002) and also soil pH and electrical conductivity (EC) were measured in saturated mud and saturated extract, respectively (McLean, 1982). Saturated moisture was determined from saturated mud and weighing method (McLean, 1982). CaCO₃ was measured by Titration method with I N NAOH (Nelson, 1982). The amount of Phosphorus that exists in extracts of soil was determined by Spectrophotometer (Olsen and Sommers, 1982). Absorbable K and Na after extraction were measured using 1 N ammonium acetate (pH= 7) (Knudsen, Peterson, and Pratt 1982). Apparent density and soil actual density were measured applying sampling cy-

linders and Pichnometer respectively (Jacob and Clarke, 2002), also calcium and magnesium were measured using titration method with EDTA solution (Lanyon and Heald, 1982).

Spatial analysis of data

At first in order to recognize how data is distributed and accessing to statistical information summary, each soil characteristics were investigated using descriptive statistics. Geo-statistics was used to investigate spatial variability of soil properties. In geo-statistical studies, abnormal distribution of data have such effects that may lead to high fluctuations in variograms and reduces the reliability of analytical results, thus normalization of data is necessary. Normal distribution of data was estimated based on their skew ness, to this case that the data with a range of -1 to +1 skew ness were considered as normally distributed data (Virgilio et al., 2007;PazGonzales et al., 2000). This method is widely used in the analysis of soil ecological heterogeneity (Schlesinger et al., 1996). Since nitrogen and phosphorus had skew ness coefficient greater than 1, after elimination of imperfect data, Logarithmic conversion was chosen as the best method (Webster and Oliver, 2001). For every variable before implementing geo-statistics analysis, with drawing of different directions variograms, isotropy and anisotropy of each soil variable were controlled. Geo-statistics is based on spatial correlation between observations or samples and this correlation can be expressed with mathematical model which called "variogram". In fact, variogram is defined as functions which describe spatial variations of one variable (Hassani Pak, 2007) and is defined by following formula:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i + h) - Z(x_i)]^2 \qquad (1)$$

N (h) is the number of sample pairs that are located by a particular distance (h) from each other. Z (xi) and Z (xi+ h) are the values of regionalized variable at location xi and xi+ h respectively.
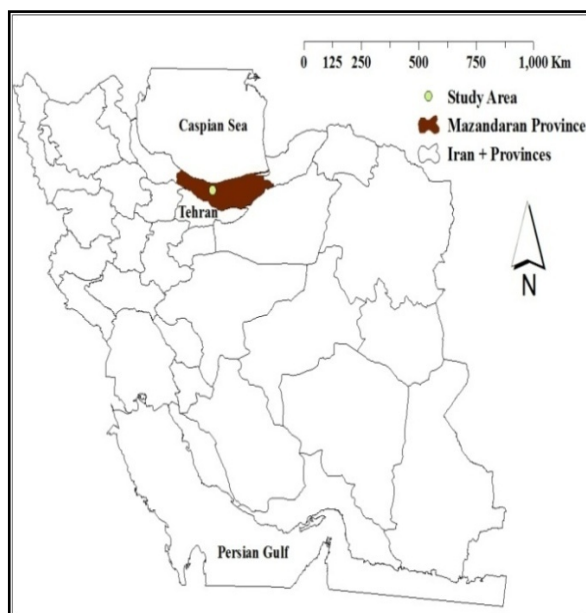
After calculating the experienced variogram, fitting a theoretical model is necessary to generalization of deductionand estimation of variables in points where not have been sampled. In the next spatial interpolation and spatial map ping of soil characteristics Kriging method was used. Overall Kriging method is a statistical estimator that gives statistical weight to each observation so their linear structure's has been unbiased and has minimum estimation variance (Kumke et al., 2005). This estimator has high application due to minimizing of error variance with unbiased estimation (Polhaman, 1993).
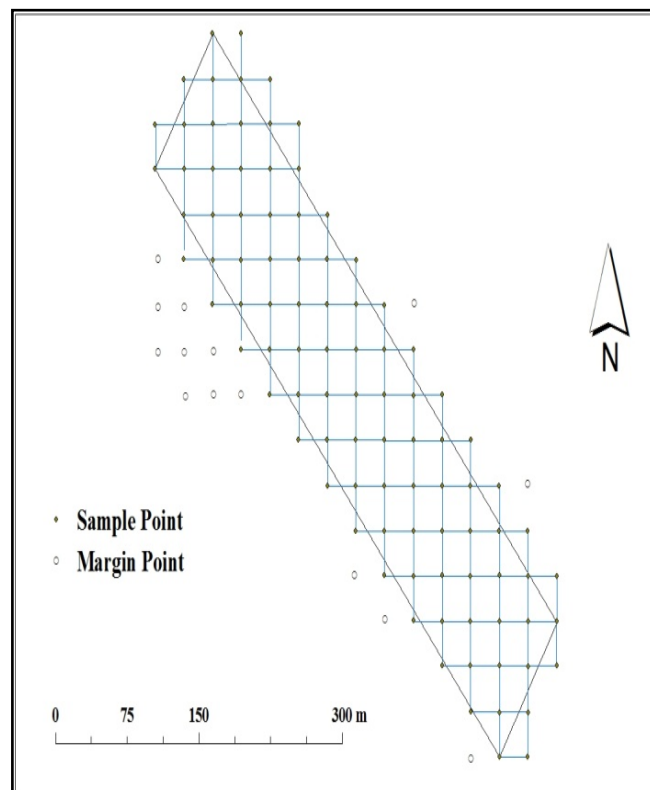

Figure 2.   Used regulars sampling pattern in this study

$$Z^*(X_O) = \sum_{i=1}^{N} \lambda_i Z(X_i) \qquad (2)$$

Where, Z*(XO) is, estimated variable at XO location and Z*(XO) is values of investigated variable at Xi location and λi is the statistical weight that is given to Z (Xi) sample located near XO. N is the number of observations in the neighborhood of estimated point. Accuracy assessment of interpolation was done by using Cross-validation methods (Goovaerts, 1997). The software package GS+ version 5.1 was also used for geo-statistical analysis (Gamma Design Software, MI, USA).

3. Results

Table 1 shows the summary statistics of soil characteristics. Coefficient variation is used to show total changes. According to Table 1, pH and $CaCO_3$ had lowest and highest coefficient variation respectively.

Figure 1.   Geographical position of study area

Table 1. Summary statistics of soil properties in the study area

Soil properties	Units	Min	Max	Mean	SD	CV%	Skewness
CaCO₃	**%**	0.100	12.100	4.0036	2.9788	74.40304	0.67
OM	**%**	1.070	3.190	2.3125	0.4244	18.35243	-0.37
N	**%**	0.010	0.200	0.0525	0.0348	66.28571	1.43
P	ppm	4.160	19.650	8.5287	3.8325	44.93651	1.52
K	ppm	182.030	595.510	322.5292	81.4001	25.23806	0.87
Bd	g/cm3	1.450	2.390	1.8814	0.1899	10.09355	0.03
Pd	g/cm3	1.920	2.970	2.4538	0.2074	8.452197	-0.06
pH	-log [H+]	5.620	7.800	6.8127	0.5744	8.431312	-0.32
EC	µs/cm	303	952	574.5429	146.8971	25.56765	0.42
Na	ppm	106.900	376.040	209.1447	74.9754	35.84858	0.14
Ca	m.e./litr	1.400	8.800	4.3903	1.9374	44.1291	0.23
Mg	m.e./litr	0.800	10.000	3.7624	1.7855	47.45641	0.88
Sand	**%**	39.760	65.760	53.8153	4.6664	8.67114	0.07
Silt	**%**	16.200	36.200	25.2782	3.8050	15.0525	0.18
Clay	**%**	10.240	32.240	20.9064	4.3494	20.80416	0.13
SM	**%**	31.370	69.020	52.4387	8.7417	16.67032	-0.11

Table 2. Calculated semi-variograms properties of soil factors

Soil properties	Model	Range A0 (m)	Nugget (C0)	Sill (C0+C)	Nugget /Sill ratios C0/(C0+C), %	R²	RSS	Spatial dependence level
CaCO₃	Spherical	910.90	4.52	18.310	24.68596	0.970	1.82	strong
OM	Exponential	910.90	0.144	0.29000	49.65517	0.688	8.702E-04	moderate
N	Gaussian	910.90	0.4810	0.9630	49.948	0.087	7.883E-03	weak
P	Spherical	11320	0.1390	0.37427	37.1389	0.238	0.021601	weak
K	Spherical	360.40	1530.000	9610.000	15.92092	0.965	2.222E+06	strong
Bd	Exponential	874.20	0.02912	0.05834	49.9143	0.686	3.937E-05	moderate
Pd	Exponential	910.90	0.03420	0.06850	49.92701	0.689	4.951E-05	moderate
pH	Exponential	889.10	0.01400	1.58300	0.884397	0.996	9.859E-04	strong
EC	Spherical	273.80	8270.000	26740.000	30.92745	0.909	3.018E+07	moderate
Na	Spherical	910.90	4260	8521	49.994	0.232	8.654E+06	weak
Ca	Spherical	562.00	0.16000	7.32900	2.183108	0.979	0.868	strong
Mg	Gaussian	910.90	2.8800	5.7610	49.991	0.211	1.10	weak
Sand	Exponential	910.90	17.690	35.390	49.98587	0.239	73.2	weak
Silt	Spherical	688.30	4.300	28.590	15.04022	0.951	15.9	strong
Clay	Exponential	157.00	9.210	23.0100	40.02608	0.821	23.4	moderate
SM	Spherical	710.90	1.5000	154.400	0.97150	0.929	409	strong

Table 3. Results of assessment using cross validation

Soil properties	Regression coefficient	Standard error	R²	Y intercept	SE prediction
CaCO₃	0.900	0.135	0.292	0.391	2.506
OM	0.852	0.197	0.148	0.335	0.392
N	0.017	0.025	0.004	0.11	0.035
P	2.579	2.943	0.007	3.20	3.819
K	0.905	0.105	0.416	30.610	62.204
Bd	0.841	0.231	0.109	0.304	0.179
Pd	0.547	0.359	0.021	1.112	0.205
pH	0.977	0.050	0.778	0.156	0.270
EC	0.995	0.117	0.413	2.567	112.572
Na	0.503	0.342	0.020	104.307	74.235
Ca	0.951	0.060	0.703	0.196	1.057
Mg	0.669	0.248	0.063	1.187	1.728
Sand	1.098	0.250	0.152	-5.264	4.298
Silt	0.896	0.109	0.386	2.624	2.982
Clay	1.212	0.151	0.374	-4.458	3.440
SM	0.919	0.063	0.668	4.183	5.037

Presented models in Table 2 were selected from fitted models to soil characteristics because had less residual sum of squares and better structure. Suitable model for soil characteristics was isotropic. Results showed that $CaCO_3$, organic matter, nitrogen, phosphorus, particle density, magnesium and sand had highest effective range with 910.900 meter and clay, with 157 meter had minimum effective range between the studied characteristics of soils.

In the study area the spatial dependence of soil characteristics was different. Nitrogen, phosphorus, sodium, magnesium, and sand had weak, organic matter, bulk density, particle density, electrical conductivity and clay had moderate, and $CaCO_3$, available potassium, pH, calcium, silt and saturated moistures had strong spatial dependence in the study area.

Assessment of fitted models showed that models of phosphorus, clay and sand content had a higher regression coefficient and thus more accuracy (Table 3).

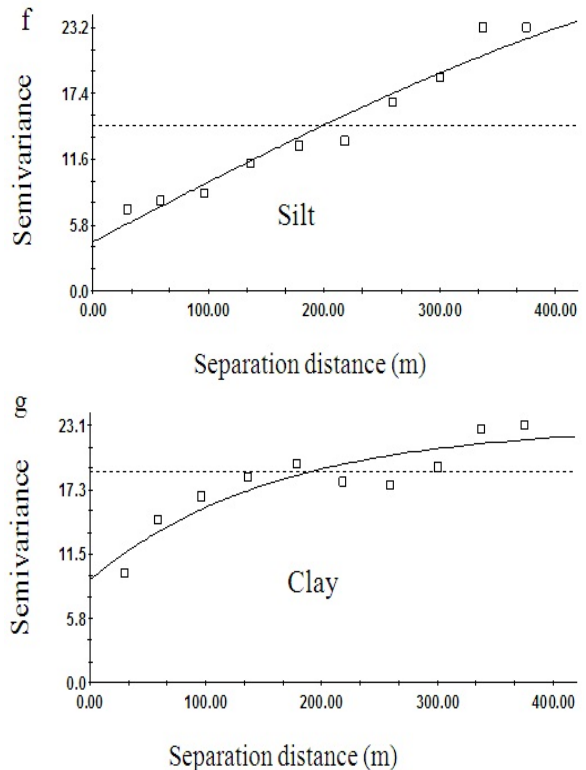Semi-variograms and maps of soil characteristics presented in figures 3 and 4.
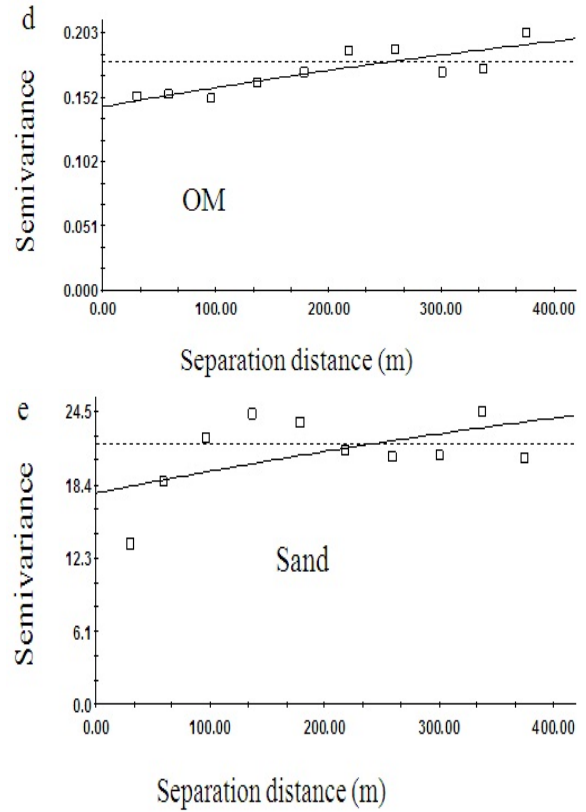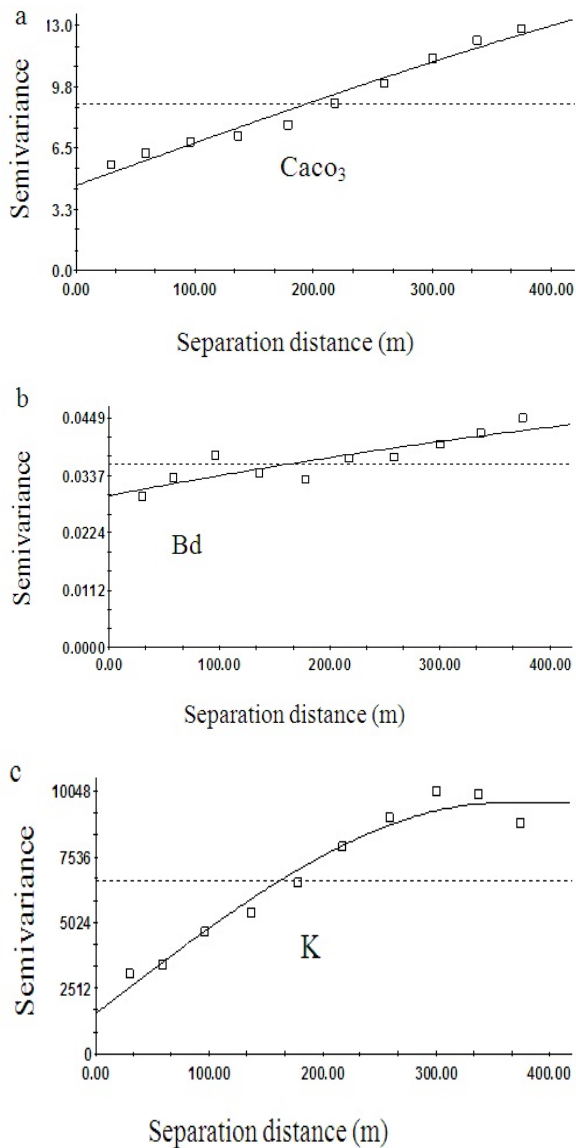
Figure 3. Semi-variograms of (a) $CaCO_3$, (b) Bd, (c) K, (d) OM, (e) Sand, (f) Silt, (g) Clay, (h) Ca, (i) EC, (j) pH, (k) SM, (l) N, (m) Na, (n) Pd, (o) Mg, and (p) P. Described parameters are Bd, Bulk density; K, Potassium; OM, Organic matter and Sand, Sand content; Silt, Silt content; Clay, Clay content; EC, Electrical conductivity; SM, Saturation moisture; N, Nitrogen; Na, Sodium; Pd, Particle density; Mg, Magnesium and P, Phosphorus
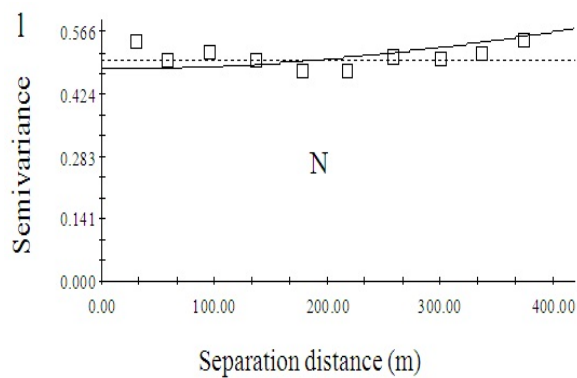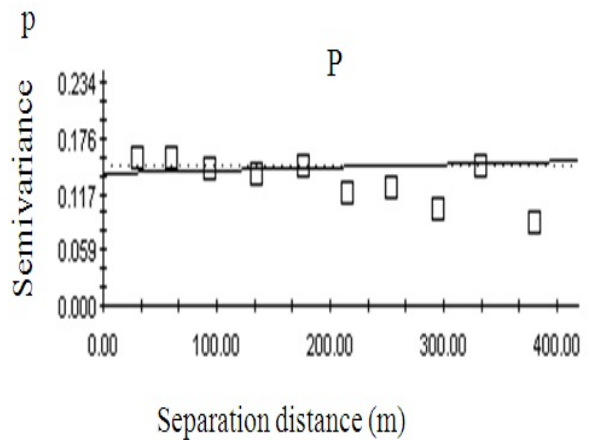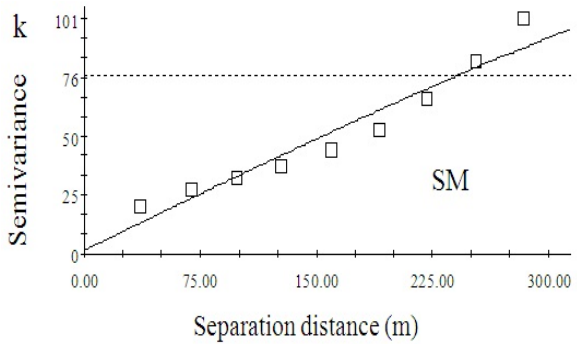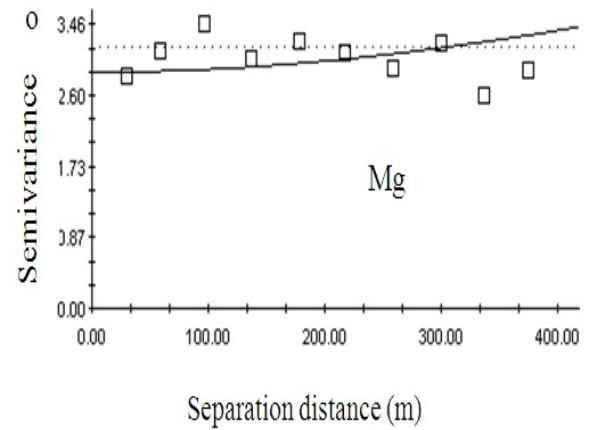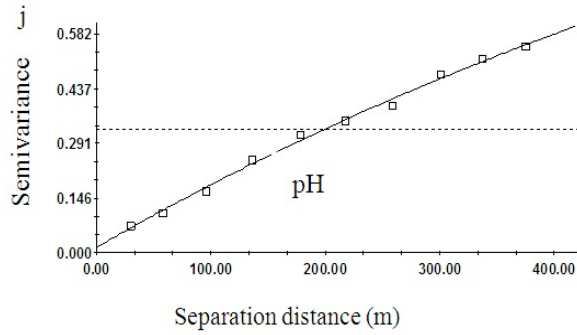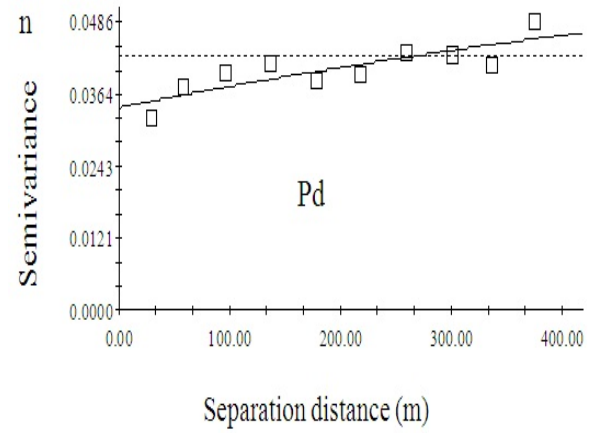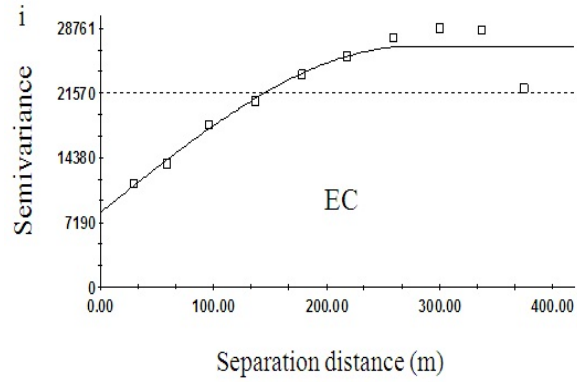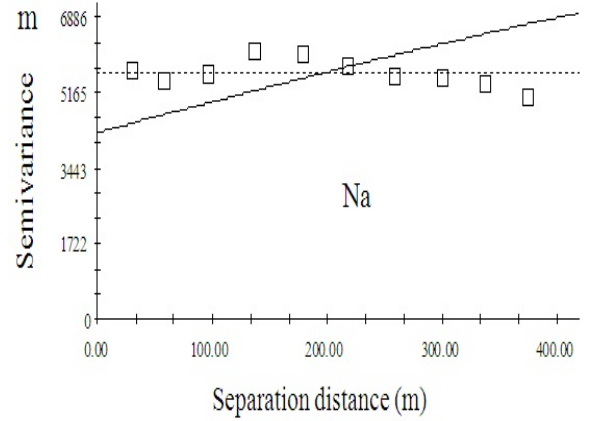
Figure 3. Continued

Figure 4. Ordinary kriged maps of (a) Bd, (b) CaCO₃, (c) N, (d) Pd, (e) K, (f) P, (g) Sand content, (h) OM,(i) Clay, (j) Silt, (k) Ca, (l) Na, (m) pH, (n) Mg, (o) SM, and (p) EC. Described parameters are Bd, bulk density; Pd, Particle density; N, Nitrogen; P, Phosphorus; K, Potassium; OM, Organic matter; Sand, Sand content. Silt, Silt content.; Clay, Clay content; Na, Sodium; Ca, Calcium; Mg, magnesium; EC, Electrical conductivity and SM, Saturation moisture
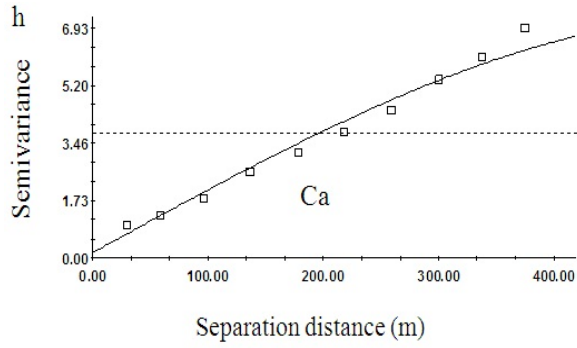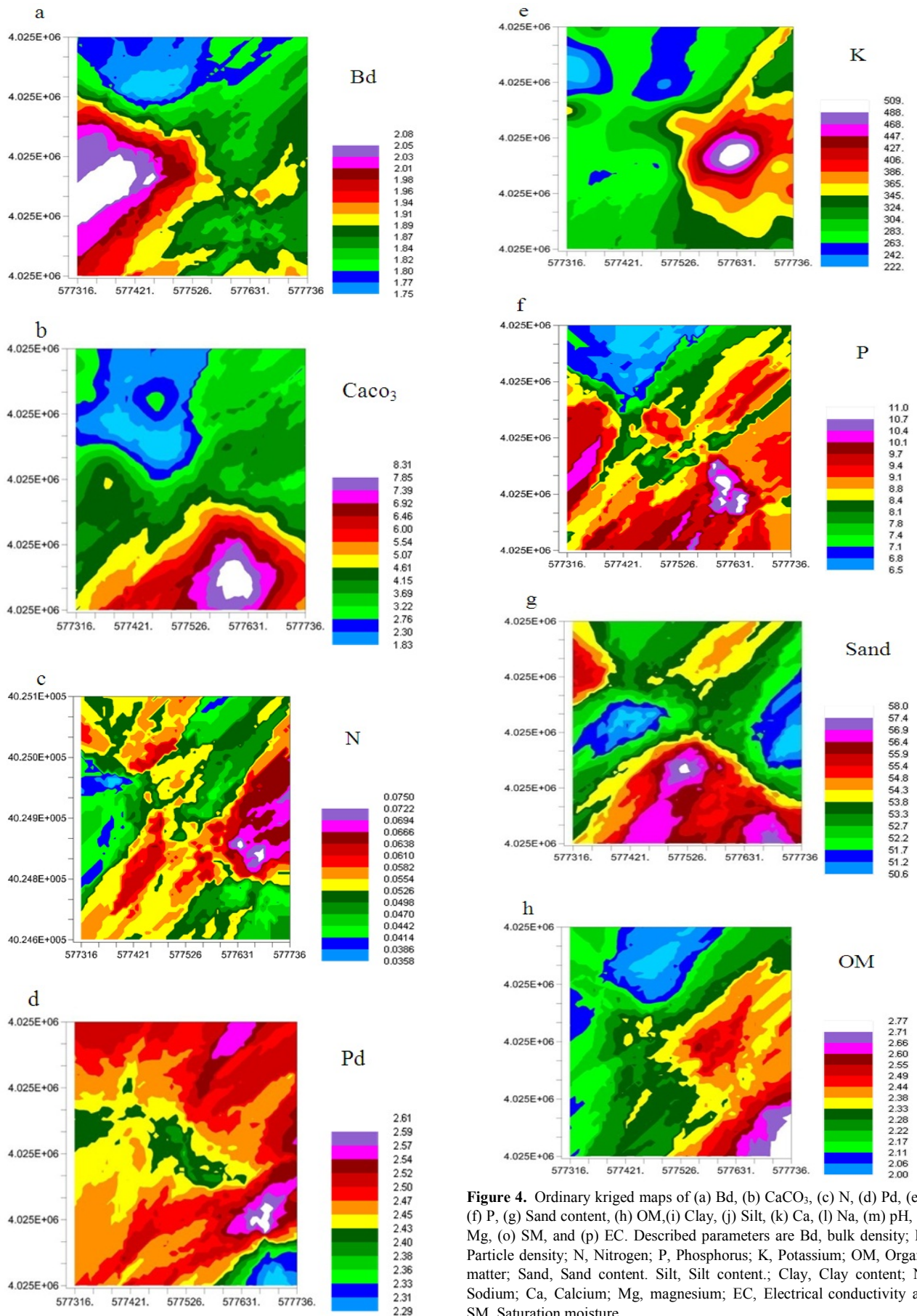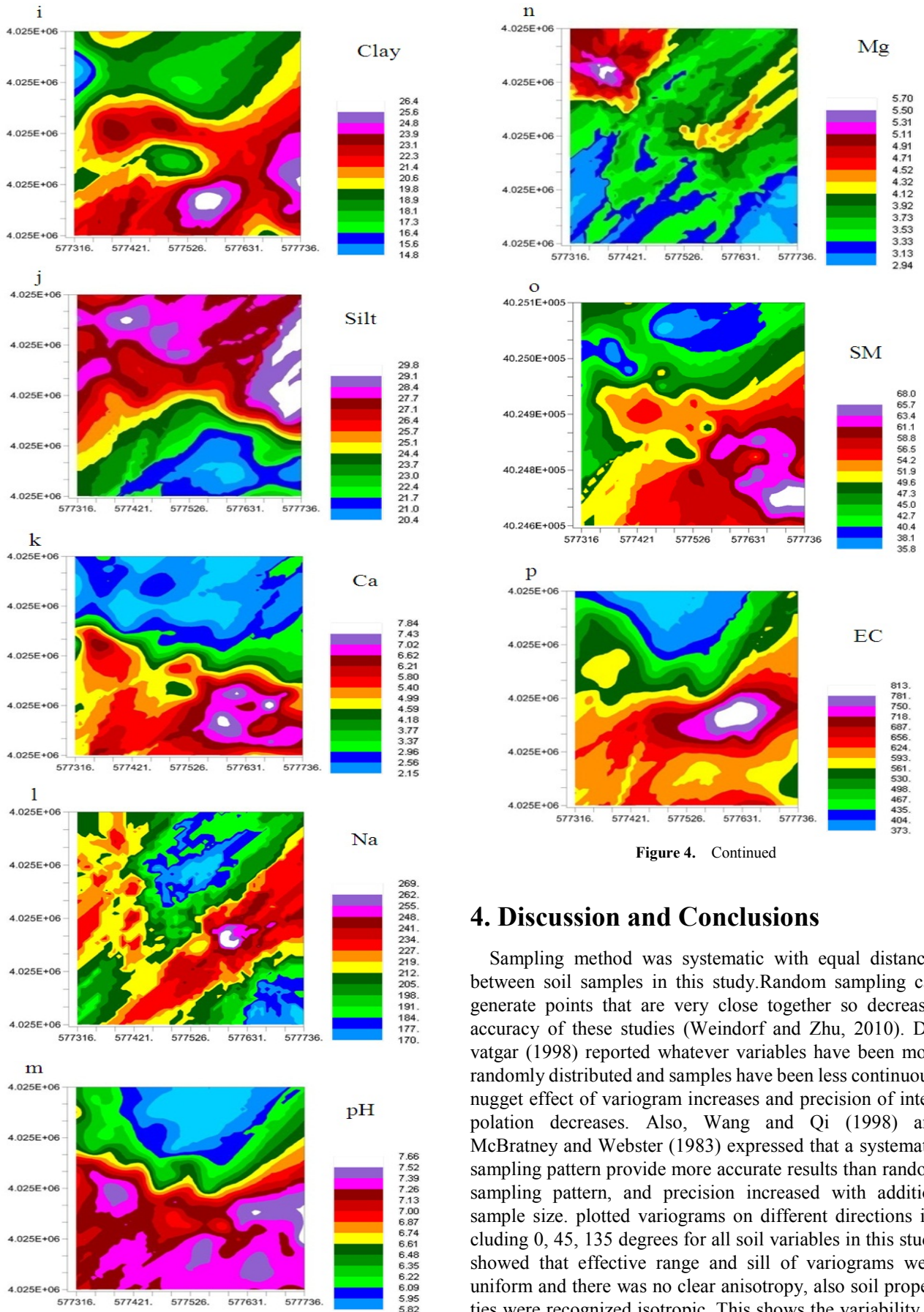
Figure 4. Continued

4. Discussion and Conclusions

Sampling method was systematic with equal distances between soil samples in this study. Random sampling can generate points that are very close together so decreases accuracy of these studies (Weindorf and Zhu, 2010). Davatgar (1998) reported whatever variables have been more randomly distributed and samples have been less continuous, nugget effect of variogram increases and precision of interpolation decreases. Also, Wang and Qi (1998) and McBratney and Webster (1983) expressed that a systematic sampling pattern provide more accurate results than random sampling pattern, and precision increased with addition sample size. plotted variograms on different directions including 0, 45, 135 degrees for all soil variables in this study showed that effective range and sill of variograms were uniform and there was no clear anisotropy, also soil properties were recognized isotropic. This shows the variability of

variables is equal in different directions and changes depend on distance between samples (Mohammadzamani et al., 2007). The ratio of nugget to sill (C0/C0+C) reflects the spatial autocorrelation generally (Li and Reynolds, 1995). If it is less than or equal to 25%, spatial dependent of variable is strong, if the ratio is between 25 and 75%, spatial dependent of variable is moderate and if it is greater than 75%, spatial dependent of variable is weak (Cambardella et al., 1994). Among the investigated variables in this study, $CaCO_3$ had highest Coefficient of variation with % 74.40. This result is consistent with the research of Jafarian et al. (2009). pH had lowest coefficient variation with % 8.43, which could be because of the uniform conditions in the region such as small changes in slope and its direction that led to uniformity of soil in this region. Cambardella et al. (1994), Kamare et al. (2010), Afshar et al. (2009) and Yi-chang et al. (2009) found similar results. Nitrogen, phosphorus, sodium, magnesium and sand had a weak spatial dependence because the fitted R2 was less than 0.50(Emadi, 2008). Silt percentage, available potassium and acidity (pH) had strong spatial dependence according to results of Cambardella et al. (1994), Lopez-granados et al. (2002) and Weindorf and Zhu(2010). Bulk density had moderate spatial dependence similar to what had been illustrated in research of Cambardella et al. (1994) and Jafarian et al. (2009) also organic matter had moderate spatial dependence according to results of Yi-chang et al. (2009). Variables with strong spatial structure and very low nugget effect have high continuous distribution in this area. Strong spatial dependence can be controlled through the inherent variability of soil properties such as soil texture, mineralogy and less spatial dependence by non-intrinsic factors such as grazing (Cambardella et al., 1994). Semivariograms have difference forms depending on the quality of data and the distance between samples (Davatgar et al., 2000). The results showed spatial distribution of clay content can be described with spherical model according to results of Vasques et al. (2010),Weindorf and Zhu (2010),Jian-Bing Wei et al. (2008)and Jafarian et al. (2009).Organic matter can be described with exponential model according to results of Jian-Bing et al. (2006). Available potassium can be expressed with spherical method as had been showed in research of Yi-chang, et al. (2009), Mohammadi and RaeisiGahrooei(2003). The value of nugget effect for pH, bulk density and saturated moisture is small which suggest that the random variance of variables is low in the study area.This means that near and away samples have similar and different values respectively. In other words, a small nugget effect and close to zero indicates a spatial continuity between the neighboring points. Results of Vieira and Paz Gonzalez (2003), Mohammad Zamani et al. (2007) showed that variogram of nitrogen had very small nugget effect equal to 0.006. Kamare et al. (2010), Afshar et al. (2009) and Jian-Bing Wei et al. (2008) reported that nugget effect of clay content; electrical conductivity and bulk density were 0.01, 0.0008 and 0.00308 respectively. The larger effective range has more widespread spatial structure and this expansion will increase the virtual range which can be used to estimate the amount of regional variable at unknown points (HasaniPak, 2007). Effective range of some soil properties including $CaCO_3$, organic matter, nitrogen, phosphorus, bulk density, magnesium and sand content were higher than others which probably is due to same impact of intrinsic processes on these soil characteristics. Spatial structure of these parameters have been more widespread rather than others and also in sampling design, one can extend sampling interval up to effective range. The effective ranges were 157- 911 meters in this study which represents an increase in soil heterogeneity or potential of retrospection processes. The results of this study can be used to make recommendations of best management and modeling of soil and plant relationships in future studies.

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