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Spatial Variability of Organic Matter and Some Soil Properties of Mineral Topsoil in Cankiri Indagi Blackpine (*Pinus nigra*) Plantation Region

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Abstract: Determining spatial variations of important soil features in a forest system could be, to great extent, helpful for characterizing soils to take management and preventive measures for reforestration. This study investigated spatial variability of soil organic matter (SOM), bulk density (BD), texture, pH and hydraulic conductivity (HC) in Cankiri Indagi Blackpine (*Pinus nigra*) plantation. Additionally, soil USLE erodibility factors were determined from five soil and soil-profile parameters to examine the sensibility of soils to water erosion processes, which was thought to be useful in managing and caring forest soils. These parameters were measured in a total of 52 samples obtained from depth of 0-10 cm from a 400 by 600 m area. Soils of the research site were classified after the soil genetic horizons were described and placed into orders, 2 sub-orders and 2 subgroups. According to the spatial analysis, ranges of semivariograms, which indicated the maximum distances for spatial correlations of the soil properties measured, were 330, 137, 120, 130, 1, 340 and 250 m for the soil organic matter, bulk density, clay, sand, pH, hydraulic conductivity and soil erodibility factor, respectively. Spatial dependence of the soil properties for short distances was determined as moderate in general and kriging maps for each soil property showed similarity for the organic matter, bulk density, clay and sand contents, which was indicator that to similar extent forest management practices could successfully be applied in the area to optimize resource use.

Key words: Organic matter, soil properties, spatial variability, geostatistics, Turkey

INTRODUCTION

By knowing the distribution of soil properties in plantation site, one could refine the forestry management practices that are more suitable to the behaviour of the soils. Moreover, characterization of soil properties and their spatial variability are expected to determine forestry systems.

Most physical and chemical soil properties show spatial variations by the change in the composition of main soil material and physiographic land location. Also, species, age and frequency of the vegetation grown on the forested areas have great influence on the characterization of soil properties. Especially, type, age and frequency of the vegetation influence the amount and characteristics of the organic debris mixing with the soil. On the other hand, responsively, main material differences in the soils and the erosion intensity significantly affect the structural features.

Soil organic matter rate is related to the amount of organic debris mixing with soil, mineralization and the proportion of the fine soil grains. Studies showed that organic matter bound by the soil grains finer than 0.0053 mm was proportionally much more and well-protected during longer times than the organic materials of the particular structure[1]. Therefore, one can make generalizations about soil organic matter on the basis of the textural composition of soils[2].

Many studies have shown that the organic matter has great importance due to its effects and regulatory roles over numerous physical soil features as pH, bulk density, hydraulic conductivity, aggregate stability and erosion susceptibility. Loss of organic matter can cause soil aggregates to easily break down and accordingly to become more erodible[3]. Hajabbasi[4] found that decreases in the soil organic matter by the deforestration resulted in 20% increase in the soil bulk density. Celik[5] also linked a higher bulk density of the soils to the loss of the soil organic matter in the research of land-use effects on organic matter and physical properties of soil in a southern Mediterranean highland of Turkey. Parallel to the increases in soil organic matter, soil porosity increased and bulk density and soil erodibility decreased[6]. Baumhardt and Lascano[7] stated that

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litterfalls of the forest increased hydraulic conductivity when compared the those of the cultivated soils.

In recent years, procedures of the geostatistics with different kringing methods have been intensively used to understand the spatial variations and heterogeneities of the soil organic material and other soil features on small or large scale parcels[8-14]. Viera[15] and Lascano and Hartfield[16] indicated that soil properties frequently exhibited spatial dependence and samples collected closer to each other showed to be similar than those collected at greater distances, although the variation of soil properties within a field was often determined by classical statistical methods with the random distribution. Gonzalez and Zak[17] reported a direct influence of spatial variability of soil properties on forest growth in a tropical region. The aim of this study is to determine the spatial variations for important soil features of developing top mineral soil below blackpine plantation in Cankiri province, Turkey, where the distribution of main land uses are 301000 ha agriculture land, 304000 ha pasture and 220000 ha forest[18]. Considering the proportion of the forested land, which also includes the study site at the northern part of Cankiri province, it is easily recognizable that this land has great importance in relation to its economical or ecological features. Therefore, the refinement of forestry management practices that are specifically suitable to the characteristics of the soils is of very significance. It is our hope that with the help of kriging interpolation technique with geostatistical procedures, mapping spatial variations of soil organic matter, pH, bulk density, contents of clay and sand, hydraulic conductivity would highly contribute to the selection of management practices and soil erodibility factor to the determination of preventive measures in the area.

MATERIALS AND METHODS

Study site: The study area (Fig. 1) is located in northern part of Turkey, close to Cankiri, in an area called Indagi Mountain Pass at an altitude of about 1300 m above sea level. Long term means of annual precipitation (18.1-58.4 mm) and annual temperature (-0.5-21.1°C) were calculated from nearby weather station. The study site contains blackpine (*Pinus nigra*) plantation with a history of at least 40 years. Dominant soils in the study area were determined to be Lithic Exerorthents, Typic Haploxererts[19].

Soil sampling and analysis: An area of 400×600 m was selected within the Indagi Mountain Pass on August

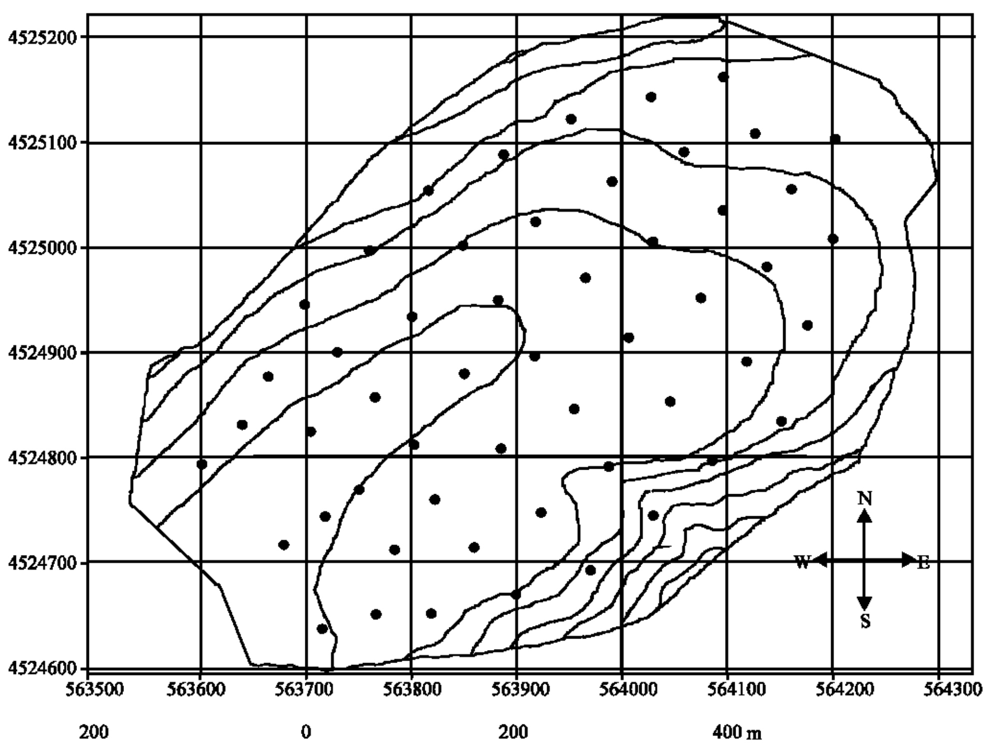

Fig. 1: Study site (Dots show sample area)

2004. Totally 52 distributed and undistributed soil samples from 0-10 cm depth were collected at 52 locations in irregular intervals. In addition 2 soil profiles were excavated to determine soil classification on different position.

The distributed soil samples were air-dried and ground to pass through 2 mm sieve. Soil pH was measured with glass electrode in a ½, 5 soil/water suspension. The SOM was determined by Walkley Black method and particle size distribution by the hydrometer method. The BD was determined by the core method. Saturated hydraulic conductivity was performed according to Klute and Dirksen[20].

Soil erodibility factor (K): The soil erodibility factor determined by using nomograph[21], comprises five soil and soil-profile parameters: percent modified silt (0.002-0.1 mm), percent modified sand (0.1-2 mm), percent organic matter (SOM) and classes for structure (s) and permeability (p)[22]. Algebraic approximation[23] of the nomograph where the silt fraction does not exceed 70% is,

$$K = \left[2.1*10^{-4}(12\text{-OM})M^{1.14}+3.25(s\text{-}2)+2.5(p\text{-}3)\right]/100 \quad (1)$$

Where, M is the product of the primary particle size fractions: (% modified silt or the 0.002-0.1 mm size fraction) (% silt + % sand).

Geostatistical analysis: Descriptive statistics were used to express the overall variability within the study area. Spatial variability of soil properties was defined using geostatistical methods. Experimental semivariograms were developed to determine the spatial dependence of soil properties using the following equation given by Journel and Huijbregts[24] and reviewed Trangmar[25].

$$\gamma^*(h) = \frac{1}{2N(h)}\sum_{i=1}^{N(h)}\left[z(x_i) - z(x_i + h)\right]^2 \quad (2)$$

Where, $\gamma(h)$ is the semivariance; N(h) the number of experimental pairs separated by a distance h; $z(x_i)$ the measured sample value at point, x_i and $z(x_i + h)$ measured sample value at point $x_i + h$.

The spherical and the Gaussian models are the most commonly used theoretical models and these models are described by:

$$\gamma(h) = 0 \qquad h = 0 \quad (3)$$

$$\gamma(h) = C_0 + C\left[1.5\frac{h}{a} - 0.5\left(\frac{h}{a}\right)^3\right] \qquad h \le a \quad (4)$$

$$\gamma(h) = C_0 + C \qquad h > a \quad (5)$$

and

$$\gamma(h) = 0 \qquad h = 0 \quad (6)$$

$$\gamma(h) = C_0 + C\left[1 - e^{-3(h/a)^2}\right] \qquad h \le a \quad (7)$$

$$\gamma(h) = C_0 + C \qquad h > a \quad (8)$$

Where C_0 and C are the nugget variance and sill value, respectively and a is the range of influence for the spherical model[26]. The range a for the Gaussian model is described as practical range at which the semivariogram reaches 95% of its sill value[27]. The model parameters are estimated visually as suggested by Vieira[28], Cuenca and Amegee[29].

Kriged estimate $z^*(x_0)$ and error estimation variance $\sigma_k^2(x_0)$ at any point x_0 are calculated as follows:

$$z^*(x_0) = \sum_{i=1}^{n}\lambda_i z(x_i) \quad (9)$$

$$\sigma_k^2(x_0) = \mu + \sum_{i=1}^{n}\lambda_i\gamma(x_0 - x_i) \quad (10)$$

Respectively, where λ is weights; μ, LaGrange constant and $\gamma(x_0\text{-}x_i)$ the variogram value corresponding to the distance between x_0 and x_i[30,31].

RESULTS AND DISCUSSION

Descriptive statistics: Descriptive statistics about examined soil features are given in Table 1. The lowest Variance Coefficient (VC) was determined for sand content. It was estimated that study area had exposed to severe erosion prior to establishment of plantation. It may be thought that removal of finest soil grains and persistency of sands would be efficient for low VC result. The other soil feature for which VC was determined so low was pH. Also other investigators reported low VC for pH[8,12,32,33]. The highest VC was determined for hydraulic

Table 1: Descriptive statistics of soil properties

	Descriptive statistics				
Soil properties	Depth (cm)	Mean	SD	Variance	Variation cofficient (VC)
SOM (%)	0-10	5.1	1.94	3.760	38
BD (mg m^3)	0-10	1.27	0.15	0.024	12
Clay (%)	0-10	29.8	10.00	101.000	33
Sand (%)	0-10	49.1	10.60	113.000	2
pH (1/2.5 water)	0-10	6.6	0.48	0.231	7
HC (cm h^{-1})	0-10	7.5	7.37	54.400	98
K	0-10	0.103	0.05	0.003	48

SOM: Soil Organic Matter, BD: Bulk density, HC: Hydraulic conductivity

Table 2: Models and parameters of soil properties

	Models and parametrs						
Soil properties	Depth (cm)	Model	Nugget effects (Co)	Sill (Co+C1)	C-Co/C (%)	a	R^2
SOM (%)	0-10	Spherical	2.15	3.9	44	330	0.961
BD (Mg m^3)	0-10	Spherical	0.011	0.025	56	137	0.892
Clay (%)	0-10	Spherical	53	88	51	120	0.818
Sand (%)	0-10	Spherical	48	99	51	130	0.740
pH (1/2.5 water)	0-10	Pure Nugget effect	0.23	0.23	-	-	-
HC (cm h^{-1})	0-10	Gausian	39.9	96.8	58	340	0.995
K	0-10	Spherical	0.0016	0.0037	56	250	0.997

SOM : Soil Organic Matter, BD: Bulk density, HC: Hydraulic conductivity

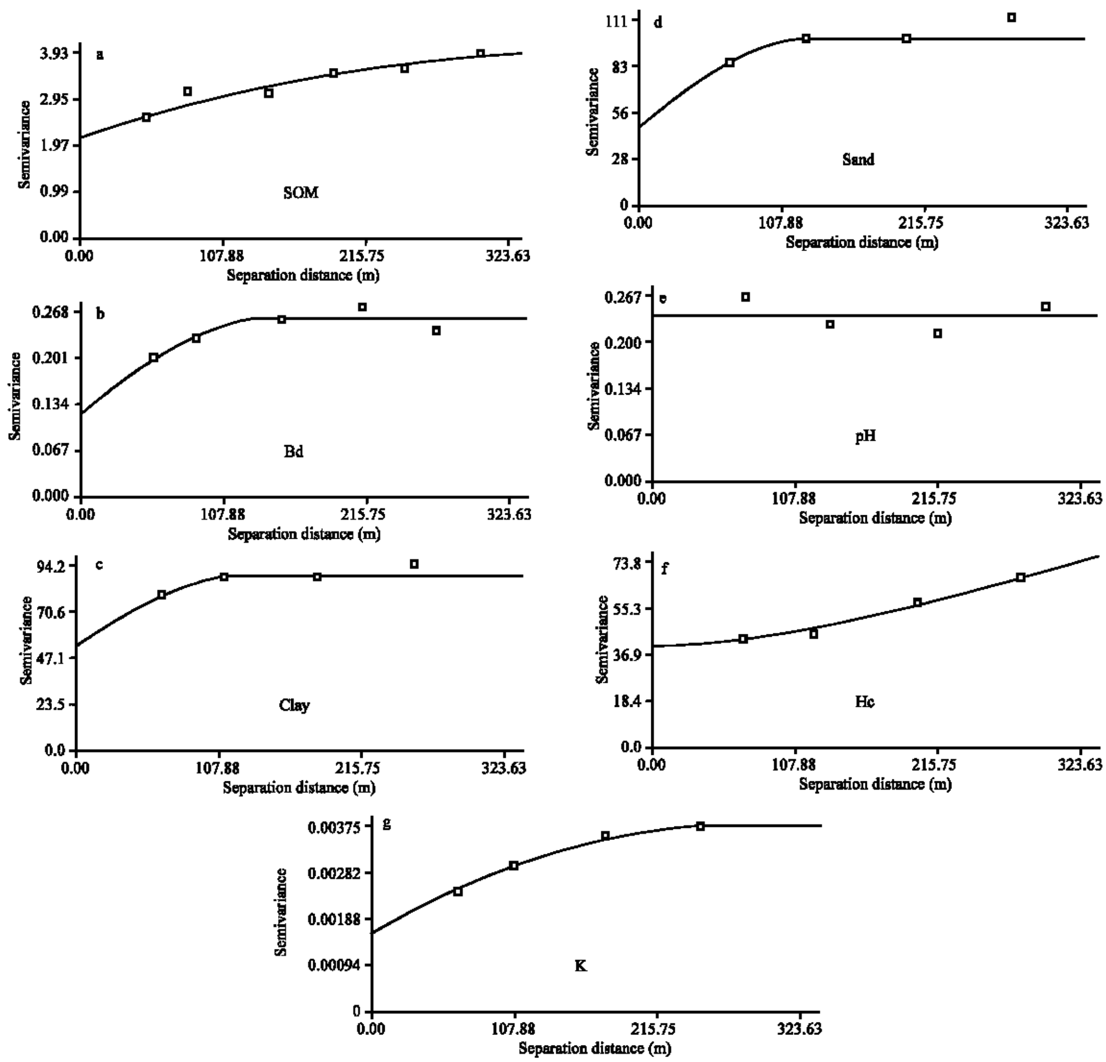

Fig. 2: Experimental and theoretical semi-variogram models of soil properties. (a) SOM (b) BD (c) Clay (d) Sand (e) pH (f) HC (g) K

conductivity. Generally it was accepted that hydraulic conductivity does not show normal distribution and changes significantly on short distances[5].

When averages were examined it was seen that organic matter level was high. K factor averages pointed out that soil were moderately sensitive to erosion[34]. Soil reaction was slightly acidic. When sand and clay averages were considered soils may be said as slightly textured. Soil permeability was medium[22].

Geostatic analysis: Models and parameters soil features of study area are given in Table 2. Empirical

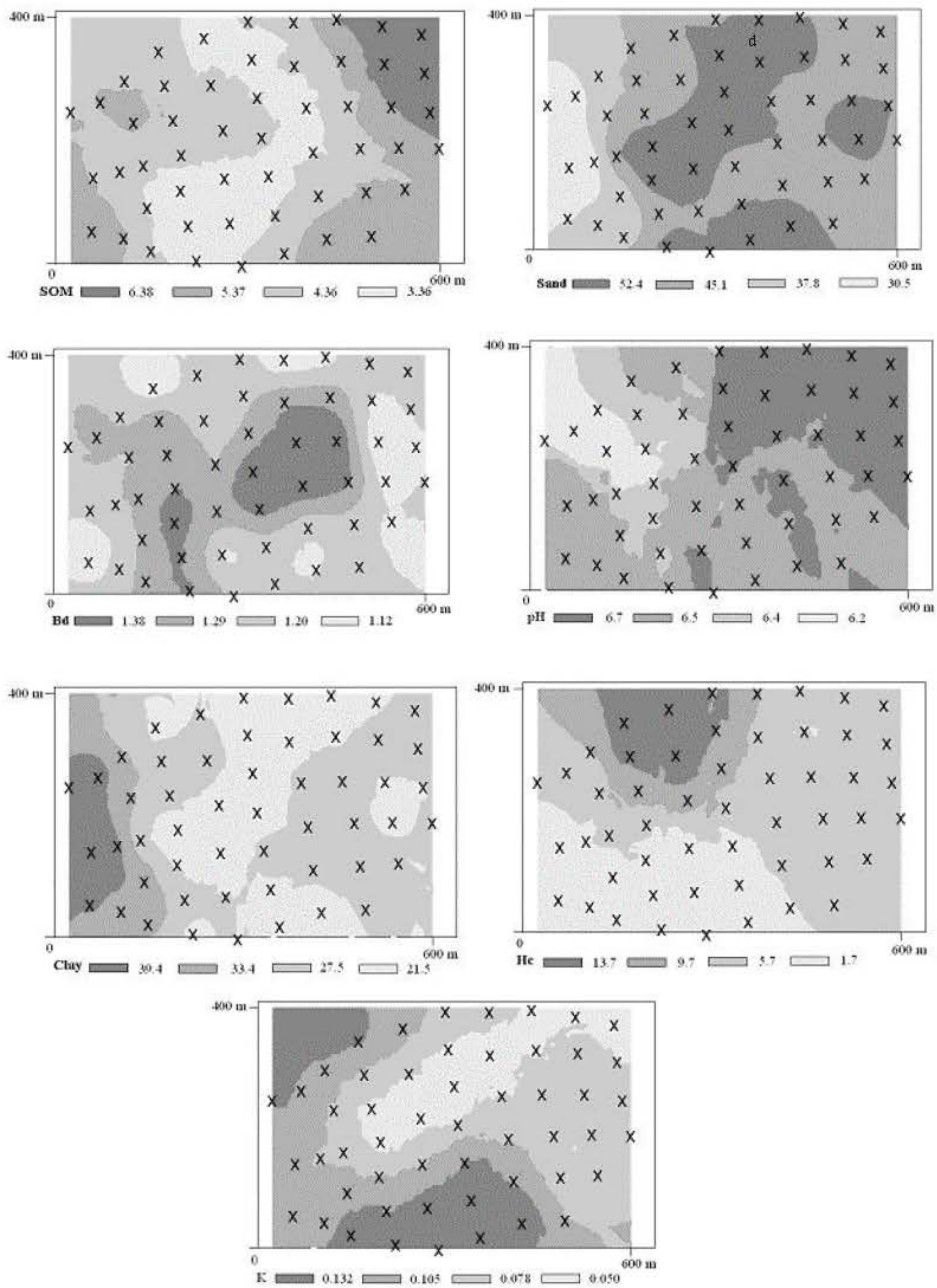

Fig. 3: Kriging maps (a) SOM (b) Bd (c) Clay (d) Sand (e) pH (f) Hc (g) K

semivariograms are calculated in four different direction of 0°(north-south), 45° (north east-south west), 90° (east-west) and 135° (south east-north west).

Soil properties were isotropic in all ways and there was no variation in the soil features in relation to direction. Nugget effect appeared in all soil features. This situation may be related to short distance variation of soil properties, analysis and sampling errors.

Experimental and model variograms of soil features are shown in Fig. 2.

Modeling was made by the spherical model for organic matter content (Fig. 2a), bulk density (Fig. 2b), clay content (Fig. 2c), sand content (Fig. 2d) and K factor (Fig. 2g) and by the pure nugget effect (Fig. 2e) for pH and finally by the Gaussian model for hydraulic conductivity (Fig. 2f).

Spatial dependencies of soil features may be determined by nugget effect-sill ratio. Strong, medium and weak location dependency for short distances are considered when nugget effect-sill ratio is, respectively, smaller than 25%, between 25-75% and greater than 75%[14,35]. It was seen that all of the soil features examined in this manner had spatial dependency of medium level. Related distances of soil features changed between 120 and 340 m. A stronger relation (a) was determined with the organic matter and hydraulic conductivity in relation to others even though the weakest relation was obtained with the clay content.

Kriging maps for different soil features were formed with GS^+ 7 geostatistics packet program [36] in 8395 point grid system (115x73) by using variogram models and raw data (Fig. 3). When Kriging map of the soil organic matter (Fig. 3a) was examined, there were important similarities with maps of bulk density (Fig. 3b), clay content (Fig. 3c) and sand content (Fig. 3d). In middle part of study area where low clay content and high sand content existed, there was distribution of low organic matter and high bulk density. In that part of study area, high sand content resulted in insufficient growth of trees. Also, the organic matter content decreased because of the low clay content, dominancy of oxidation and mineralization conditions. Consequently, the organic matter was not well-protected in the soil. The fact that the bulk density had a distribution with the high value could easily be explained by low content of organic matter and high content of the sand.

Kriging maps that formed for hydraulic conductivity and pH, did not show important degree similarity in relation to itself and other examined soil features (Fig. 2). A partial similarity between K factors and the organic matter, bulk density, clay and sand maps (Fig. 2) were found in middle portion of the study area. And another important finding was the similarity between kriging map produced for K factor and topographic map. This situation suggests that examined soil features and K factor were affected by the topographical changes greatly.

CONCLUSIONS

Soil properties that were examined greatly varied. VC was the higest for hydraulic conductivity although it was the lowest for both sand and pH. The data suggested that a sufficient amount of the organic matter accumulated in the soil of the study area over time beginning from the establishment of plantation. Bulk densities of soils were slightly higher due to their sand contents. The hydraulic conductivities were moderate and the soils were moderately sensitive to the erosion.

Nugget effect/sill ratio of the examined soil features indicated moderate dependency for short distances. In fact, nugget effect was influenced by the sudden changes of soil properties in the short distances, sampling errors and analysis. The related distances varied from 120 to 340 m. Although the weakest spatial relation was obtained with the clay content (120 m) strongerst relations with the organic matter (330 m) and hydraulıc conductivity (340 m). Especially, there were significant similarities in the kriging maps of the organic matter, bulk density, clay and sand distributions.

Geostatistical techniques led to important ideas about spatial changes of the soil properties.

Before forestation, geostatistical evaluations of some soil properties supplied preliminary information in order to determine inappropriate areas and to take preventive measures. Conclusively, this method has capability of easily observing the post-forestation changes in the soil properties.

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