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ASSESSMENT OF SPATIAL VARIABILITY OF SOIL PROPERTIES IN AREAS UNDER DIFFERENT LAND USE

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Abstract

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Land conversion from native ecosystem to agricultural use may alter soil physical, chemical and biological properties depending on duration and the type of tillage. The objectives of this study were to evaluate effects of duration of intensive cultivation practices (5 and 20 years cultivation) on some soil chemical and physical properties and to characterize spatial variability of soil properties. The study area is located at Kaz Lake of Tokat, Turkey. Soil pH, electrical conductivity (EC), cation exchange capacity (CEC), soil organic matter (SOM), total N, plant available P and soil texture were analyzed soil samples collected from a 5- and 20-year cultivated field converted from a native grassland. In addition, spatial variability of the soil properties under each land use were defined using statistical and geostatistical analysis. Soil pH had the minimum variability compared to other soil properties. Soil tillage (5 and 20 years of cultivations) caused significant changes in soil properties. Soil organic matter, total N, available P, CEC, and EC, clay content and silt content decreased significantly ($p<0.01$) while K^+, Na^+, pH and sand content increased with cultivation. The range of spatial dependence is between 9.6 and 310 m.

Soil variables with low nugget effect were defined by spherical model. The variables of the cultivated soils generally had a lower nugget than the variables of the native grassland. The degree of spatial dependence for CEC, clay, silt, sand and pH was low. The variation of the soil variables was fairly homogenized in the cultivated fields compared to the native grassland.

Key words: duration of cultivation; soil properties; soil variation; spatial dependency; land use

Introduction

Soil management systems play an important role in sustainable agriculture and environmental quality. Management practices have greater effect on the direction and degree of changes in soil properties. Conversions of an area from native ecosystem to cultivated land may be the reason of soil degradation and decreases of quality.

Soil management systems such as soil tillage, fertilizers and extreme irrigation often create unsuitable changes in soil quality. Some researchers (Cambardella and Elliott, 1992; Lal et al., 1994; Jaiyeoba, 2003; Materechera and Mkhabela, 2001; Paz-Gonzalez et al., 2000; Dunjo et al., 2003) have studied the changes in the soil quality and its effects to the ecosystem. The most important effect of soil tillage is the decreases of cation exchange capacity (CEC) which is attributable to the reduction of SOM (Paz-Gonzalez et al., 2000). Soil tillage systems lead to increase of soil pH, base saturation, and extractable phosphorus (Paz-Gonzalez et al., 2000). Soil organic carbon (SOC) and total nitrogen decreased in cultivated soils compared to pasture (Chan and Hulugalle, 1999).

Soil physical and chemical properties are strongly influenced by soil management systems and changes in land use (Hulugalle et al., 1997). The greater percent of mechanically dispersible clay, lower pH and electrical conductivity were found in cultivated soils

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compared to pasture (Chan and Hulugalle, 1999). The mean gravel content is much higher for cultivated areas (Paz-Gonzalez et al., 2000).

Soil properties vary spatially from a field to a larger regional scale affected by both intrinsic (soil forming factors) and extrinsic factors (soil management practices, fertilization, and crop rotation) (Cambardella and Karlen, 1999). The variation is a gradual change in soil properties as a function of landforms, geomorphic elements, soil forming factors and soil management (Buol et al., 1997). The variation of soil properties should be monitored and quantified to understand the effects of land use and management systems on soils. Geostatistical methods have been used successfully for predicting spatial variability of soil properties (Trangmar et al., 1985; Gaston et al., 1990; Cambardella et al., 1994; Saldana et al., 1998; Zebarth et al., 2002; Lark, 2002; Dercon et al., 2003).

Conversion of native grassland to cultivated lands has been increased in the recent years in Turkey. The objectives of this study were to evaluate effects of the period of cultivation (5 and 20 years) on some soil chemical and physical properties and the spatial variability of these properties.

Materials and Methods

Study area

This study was conducted on the two contrasting land uses (grassland and cultivated land) with different duration of cultivation at Kaz Lake of Tokat Province in the middle Black sea region of Turkey. The area covers 700 ha. The experimental area was mainly native grassland, but some parts were converted to agricultural use during last 5 and 20 years. The native grassland and cultivated areas are located in a plain site of Kaz Lake with a slope of 0 to 2 %, and formed on an alluvial parent material. The soils are classified as Typic Ustifluvent (Soil Survey Staff, 1992) and usually shallow and moderately deep (30-65 cm depth), poor drained (the grassland) and well drained (the arable land), with a texture of clay loam (the grassland) to sandy clay loam (the arable land). Average elevation and annual precipitation are 580 m and 436 mm, respectively. Average air and soil temperature at 50 cm depth are 12^{o}C and 6.2^{o}C (State Water Works, 1999). Water and temperature regime of the study area are ustic and mesic, respectively.

The cultivated fields have been under conventional tillage system including moldboard plough (about 20 cm depth) in fall, fallowing cultivator (about 15 cm depths) and disc harrow (about 10 cm depths) subsequent to threshold soil tillage. Inorganic fertilizers (ammonium nitrate, diammonium phosphate and potassium sulphate) were applied to the cultivated fields at a rate of 120 kg N ha^{-1}, 100 kg P ha^{-1}, and 200 kg K ha^{-1} as subsequent with combination of animal manure (30 tone ha^{-1}) prior to the soil sampling. However, the native grassland did not expose to any fertilizer. The cultivated fields have been under production of cereals, watermelon, cucumber and tomato with sprinkler and furrow irrigations. The dominant vegetations in the grassland are mainly marshy plants such as *Pragmites australis, Carex silvata, Elymus repens L.* and *Plaris arundinaea*.

Soil Sampling and Laboratory Measurements

The soil samples were collected from 0 to 20 cm depth by a 20x20 m grid in each study area. In order to predicting variations in short distances, the soil samples were collected from the 46 locations for each study area with 4 m interval over the grid distance. The similar soil sampling were done on a regular grid spacing of 25 m by Ersahin and Brohi (2006) and on grid spacing of 15 m by Kilic et al. (2004) in an alluvial field near the studied area.

The collected soil samples were air-dried and passed through a 2-mm sieve. The particle-size distribution was determined by Bouyoucos hydrometer method (Gee and Bouder, 1986). Soil organic matter content was determined using the modified Walkley-Black wet oxidation procedure (Nelson and Sommers, 1982). Soil pH and electrical conductivity were measured with glass electrode in a 1:2.5 soil/water suspension. Total nitrogen was determined with Kjeldahl method. Soil available P was extracted with 0.5-mol L^{-1} $NaHCO_3$ at pH 8.5 using the method of Olsen et al. (1954). Cation exchange capacity (CEC), exchangeable sodium and potassium were measured after extraction with ammonium acetate (Rhoades, 1986).

Statistical and Geostatistical Methods

Mean, variance, and coefficient of variation (CV) were computed for each soil properties using Statmost 32 (1997). The Shapiro-Wilks normality test was performed to test the hypothesis assuming each property has a normal variable distribution and in the variables, and these variables without normal distribution subjected to log-transformation. Soil properties in each field were compared with Duncan's test. Linear correlations among soil properties were also determined.

Geostatistical software (GS+5.1, 2001; Gamma Design Software) was used to construct semivariograms and spatial structure analysis for the variables. The hypothesis and parities used to calculate semivariogram were described by Burgess and Webster (1980). Experimental semivariograms were obtained from omnidirectional semivariances, γ(h), of a set of spatial observations, z (x_i), which were calculated as

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

Where z is the regionalized variables, z (x_i) and z (x_i+h) are measured sample values at x_i and x_i+h points. N is the number of pairs separated with distances h (lag space).

Semi variance estimations may depend on the parameters such as lag intervals, number of lags, and anisotropy. In this study, the selection of lag intervals was made based on classical rules (Journel and Huijbregts, 1978; Trangmar et al., 1985; Webster and Oliver, 1990).

Experimental semivariograms were fitted by theoretical models with parameters: nugget (Co), sill (Co+C_1), and range of spatial dependence (a). Model selection for semivariograms was performed based on regression. Percentage of nugget ratio values show marked differences in the degrees of spatial dependence for variables.

Semivariograms were scaled according to Vieira (1997):

$$\gamma^{sc}(h) = \frac{\gamma(h)}{Var(z)}$$

Where γ^{sc} (h) is the scaled semivariogram, γ(h) is the original semivariogram, and Var (z) is the sample variance of the observations.

Results and Discussion

Soil properties were quite different in the two land uses. Mean organic matter (OM) was significantly higher in the native grassland (2.8 %) as compared to the cultivated fields (1.8% and 1.3%) (Table 1). Soil organic carbon was higher at no-tillage soils compared with minimum tillage with chisel plow and conventional tillage with mouldboard plow (López-Fando and Pardo, 2011). Some researchers reported that the highest OM content was found in grasslands compared to agricultural fields (Riezebos and Loerts, (1998); Chan and Hulugalle, 1999; Paz-Gonzalez et al., 2000; Jaiyeoba, 2003). The depletion of organic matter in the cultivated fields can be associated with the intensive tillage and the removal of plant residue.

The total N content of the cultivated fields decreased over the time in spite of fertilizer additions (Table 1). The difference between the native grassland and the 20-year cultivated soil was significant ($p<0.01$) (Table 1). The lower N content in the 20 year cultivated soil could be the result of intensive irrigation and lower OM. Paz-Gonzalez et al. (2000) reported that fertilizer application did not change total or inorganic N content. Jaiyeoba (2003) found that total nitrogen content of the topsoil was greater in 3-year cultivated soil compared to 20-year.

The available P significantly decreased ($p<0.01$) with cultivation compared to the grassland (Table 1). Some researchers revealed that available P increases with cultivation due to fertilizer application (Dick, 1982; Sarno et al., 2004).

The differences in K^+ and Na^+ concentrations between the sites of native grassland and cultivated field were significant ($p<0.01$).The content of K^+ increased with the time of cultivation period (Klimowicz and Uziak 2001). In a study conducted in an area close to the experimental field, it was reported that waters in the drainage canals could not be used for poor drained soils (Saltalı et al., 1999). However, in the study area, drainage waters have been used as irrigation water. The increases in K^+ and Na^+ contents in the cultivated fields could be the result of irrigation water.

The CEC in the native grassland was greater (44.41 cmol/kg) compared to the cultivated fields (35.73 and

Table 1
The Statistical summary and changes of the studied soil properties for the native grassland and 5- and 20-year cultivated soils (The different letter over the number indicates statistical difference at 0.01 levels)

Variable	Mean	Variance	C.V.	Minimum	Maximum
Native grassland					
N (%)	0.026[a]	0.0003	23.86	0.02	0.05
P (%)	3.52[a]	1.88	38.85	1.28	7.89
K (cmol/kg)	12.41[a]	0.35	21.33	1.68	3.97
Na (cmol/kg)	2.77[a]	2.93	13.79	9.53	15.47
OM (%)	2.82[a]	0.50	25.03	1.37	5.29
CEC (cmol/kg)	44.41[a]	29.19	12.16	30.91	53.20
pH	7.90[a]	0.02	2.03	7.55	8.30
EC (µS/cm)	507.67[a]	48547.15	43.40	277.00	1824.00
Clay (%)	29.75[a]	54.98	24.92	17.00	47.00
Silt (%)	44.74[a]	73.43	19.15	14.10	57.50
Sand (%)	25.50[a]	94.04	38.02	14.60	58.00
Cultivated field for 5 years					
N (%)	0.025[ab]	0.0001	49.08	0.01	0.07
P (%)	2.76[bc]	2.42	56.33	0.91	9.36
K (cmol/kg)	16.22[b]	0.30	13.94	2.62	4.78
Na (cmol/kg)	3.95[b]	4.11	12.50	11.15	19.52
OM (%)	1.80[b]	0.23	26.73	0.59	2.71
CEC (cmol/kg)	35.73[b]	25.47	14.12	27.03	45.43
pH	7.82[b]	0.05	2.97	7.18	8.34
EC (µS/cm)	965.43[b]	197201.6	45.99	231.00	2000.00
Clay (%)	21.67[b]	39.81	29.10	13.00	39.50
Silt (%)	44.77[a]	80.33	20.01	25.00	70.70
Sand (%)	33.54[b]	106.28	30.73	18.00	59.60
Cultivated field for 20 years					
N (%)	0.021[b]	0.0004	30.67	0.01	0.03
P (%)	2.63[c]	1.00	38.00	0.91	6.05
K (cmol/kg)	18.88[c]	0.27	11.22	3.16	5.52
Na (cmol/kg)	4.67[c]	3.12	9.36	14.39	21.14
OM (%)	1.25[c]	0.24	39.50	0.47	2.60
CEC (cmol/kg)	28.08[c]	20.90	16.27	21.28	41.41
pH	8.05[c]	0.03	2.27	7.58	8.46
EC (µS/cm)	290.08[c]	5776.70	26.20	182.00	570.00
Clay (%)	20.36[b]	27.22	25.61	12.00	39.50
Silt (%)	28.84[b]	41.50	22.33	5.00	50.90
Sand (%)	50.78[c]	62.49	15.56	23.00	64.60

28.08 cmol/kg), which could be attributed to the lower OM and clay content at the topsoil of the cultivated fields (Table 1). The soils under various types of agricultural uses had less CEC than the soils under native grassland (Jaiyeoba, 1995; Unger, 1997).

The soil pH (8.0) was significantly higher in the 20-year cultivated land compared to the native grassland (7.9) (Table 1). The no-tillage soils had a higher soil pH values than plow tillage soils (Chatterjee and Lal, 2009). The soil pH in the cultivated lands was greater due to high salt concentration of the irrigation water. EC declined at the 20-year cultivated fields compared to the native grassland while EC increased at the 5-year cultivation. EC varies with the concentration of dissolved salts (Bohn et al., 1985), and usually pH decreases when the salt concentration increases (Seatz and Peterson, 1965).

Native grassland had the highest mean clay content (29.8%) (Table 1), whereas the 20-year cultivated soils had the lowest clay content (20.4%) (Table 1). The highest sand content (50.8%) was measured in the 20-year cultivated soils while the native grassland had the lowest sand content (25.5%). Although the particle size fractions were significantly different ($p<0.01$) in the contrasting management practices, clay and silt contents did not showed significant difference between the 5 and 20 years cultivated soils (Table 1). El Tahir et al. (2009) reported that coarse sand content and clay content were higher in soils under land management systems at pure crops compared to that soil under high-tree density. However, Paz-Gonzalez et al. (2000) found that particle size distribution were not significant under contrasting management systems (natural and cultivated soils). The increase in sand content can explain with vertical eluviations of clay with the dense irrigation. The coarseness of the surface soil increased with the increases of cultivation year. The increases could be the result of eluvial translocation from surface or removal of clay by runoff (Jaiyeoba, 2003).

The variation coefficient (CV) was the lowest for soil pH and the highest for EC among the soil properties. The CV for K, Na, and sand gradually decreased while the CV of OM increased. The CV of CEC and silt content continuously increased from the native grassland to the cultivated lands. Additionally, the CV of N, P, pH, EC, and clay declined in the 20-year cultivated land while they increased in the 5-year cultivated land. However, the CV of the other soil properties except K^+, Na^+, and sand increased with cultivation. The higher CV of the cultivated soils could be the consequence of agricultural practices such as soil tillage, fertilization, vertical eluviation of finer materials, the removal of nutrients by plants, and the changes of soil water balance.

Long-term agricultural practices revealed that soil properties such as K^+, Na^+, and sand had a tendency to homogenize. However, the native grassland exhibited a more diversity for soil properties. The difference and variation of chemical properties and texture are a clear indication of cultivation. Some researchers reported the differences of chemical (Fabrizzi et al., 2003), physical, and morphological soil properties (Bouma and Hole, 1971; Cattle et al., 1994) of the same soil type under different field management.

At the native grassland and 5-year cultivated soil, the correlation coefficients between K^+, Na^+ and CEC were significant ($p<0.01$). The correlation coefficient between K^+ and CEC at the 20-year cultivated soil was not significant (Table 2). On the contrary, a positive correlation between clay and sand content was found at the 20-year cultivated soil ($p<0.05$) while there was a negative correlation between clay and silt at the native grassland ($p<0.01$). For the all land uses, the correlation coefficients between sand and clay, and sand and silt were significant ($p<0.01$). Although the soil properties of the native grassland had much higher correlation coefficients than the 20-year cultivated soil, the soil properties of 5-year cultivated soil had the highest correlation coefficients (Table 2).

The spatial dependence of soil properties was determined by semi variance analysis (Table 3). Some of these variables were modeled with spherical and exponential semivariograms with a nugget effect. The range of spatial dependence was between 9.6 and 310 m. Paz-Gonzalez et al. (2000) reported a range from 6 to 7.5 m for 35 sample points of OM, N, P, CEC, and pH within a 10x10 m plot. The geostatistical range of soil properties were greater than the values reported by Paz-Gonzalez et al. (2000).

The nugget effect can be defined as an indicator of the continuity at close distances. Soil properties with lower nugget effect were generally defined by spherical semivariogram model (Table 3). The models are in concordance with selected ones reported by Cerri et al. (2004) that used data from several studies to estimate proportional variograms for pH, N, C, clay and sand. McBratney and Pringle (1999) shown that pH, clay and sand contents were the best fitted by the spherical model. The consistent between the selected models from McBratney and Pringle (1999) and from the present study was related to pH. K^+ exhibited the lowest nugget effect, although P and OM showed the highest nugget effect. Nevertheless, the variables of the native grassland and 5-year cultivated soil had higher nugget effect than the 20-year cultivated soil. The decrease of the nugget effect of the semivariograms for soil properties in the 20-year cultivated soil compared with native grassland and 5-year cultivated soil reflected the influence of land use. Sun et al. (2003) reported that the nugget effect was decreased with land use alteration and soil management practices. P and OM indicated approximate a zero nugget effect in the 20-year cultivated soil while they had a pure nugget effect in the native grassland. The reason of decreasing nugget effect in the cultivated soil could be the result of management applications. The low nugget effect at the cultivated soils

Table 2
Spearman's correlation matrix for soil properties

Variable	N	P	K	Na	OM	CEC	pH	EC	Clay	Silt	Sand
Native grassland											
N, %	1.000	-0.097	0.267	0.065	0.168	-0.128	0.161	-0.161	-0.081	0.095	0.038
P, %		1.000	0.023	-0.029	0.139	-0.033	0.000	0.334**	0.207	-0.098	-0.204
K, cmol/kg			1.000	0.756**	0.105	0.564**	0.139	0.139	0.189	0.263	-0.423**
Na, cmol/kg				1.000	0.160	0.588**	0.040	0.200	0.161	0.196	-0.318*
OM, %					1.000	0.084	0.298*	0.122	0.378**	0.077	-0.274
CEC, cmol/kg						1.000	-0.087	0.302*	0.000	0.100	-0.134
pH							1.000	-0.572**	-0.034	0.349**	-0.230
EC, µS/cm								1.000	0.384**	-0.331**	-0.097
Clay, %)									1.000	-0.329**	-0.575**
Silt, %)										1.000	-0.482**
Sand, %)											1.000
Cultivated field for 5 years											
N, %	1.000	0.044	0.388**	0.149	0.353**	0.229	-0.146	0.160	0.226	0.112	-0.300*
P, %		1.000	-0.092	-0.076	0.082	-0.050	-0.019	-0.086	0.055	0.056	0.029
K, cmol/kg			1.000	0.768**	0.073	0.878**	-0.223	0.299*	-0.041	0.192	-0.124
Na, cmol/kg				1.000	0.126	0.813**	-0.143	0.308*	0.049	0.251	-0.245
OM, %					1.000	-0.022	-0.104	0.224	0.250	0.284*	-0.250
CEC, cmol/kg						1.000	-0.029	0.206	-0.111	0.166	-0.077
pH							1.000	-0.418**	0.116	-0.256	0.128
EC, µS/cm								1.000	-0.123	0.171	-0.058
Clay, %									1.000	0.069	-0.611**
Silt, %										1.000	-0.746**
Sand, %											1.000
Cultivated field for 20 years											
N, %	1.000	-0.131	0.052	-0.165	-0.132	-0.206	-0.077	-0.001	-0.010	-0.220	0.161
P, %		1.000	0.056	0.235	0.065	0.063	-0.052	0.014	0.029	-0.033	-0.023
K, cmol/kg			1.000	0.785**	0.102	0.119	-0.158	-0.094	-0.098	-0.161	0.206
Na, cmol/kg				1.000	-0.005	0.282*	-0.266	-0.244	-0.164	-0.146	0.237
OM, %					1.000	-0.172	0.451**	0.431**	-0.028	-0.260	0.217
CEC, cmol/kg						1.000	-0.016	-0.246	0.007	0.233	-0.175
pH							1.000	0.027	-0.121	-0.257	0.214
EC, µS/cm								1.000	0.318*	-0.097	-0.172
Clay, %									1.000	0.289*	-0.717**
Silt, %										1.000	-0.820**
Sand, %											1.000

* Significant at the 0.05 probability level, ** Significant at the 0.01 probability level

showed the homogeneous of soil properties. However, the higher nugget effect at the native grassland can be related to the diversity of natural vegetation and the presence of micro heterogeneity on the sampling grids.

The variables had a range and did not randomly distributed (Table 3). However, generally, P and OM at the native grassland, pH and silt at the 5-year cultivated land, and clay, silt, sand and pH at the 20-year cultivated land had the lowest correlation coefficients. The degree of spatial dependence for clay, silt, sand, pH and CEC decreased as related to the duration of soil cultivation.

The 3672 values estimated by kriging contour maps for CEC, OM, clay content and sand content were constructed to show variability in the soil properties depending on the land uses. The spatial variability of these properties was completely different between the native grassland and the cultivated lands. The 5-year cultivated field had four different micro-regions ranging from 25 to 45 cmol/kg for CEC, as for the 20-year cultivated field ranging from 20 to 40 cmol/kg (Figure 1). CEC had five different micro-regions at the native grassland ranging from 30 to 55 cmol/kg.

The spatial variability of OM was the similar to the results obtain for CEC by kriging. The maps of CEC

Table 3
Semivariance parameters for soil properties

Variable	Model	Nugget	Sill	Range, m	R^2	RSS	Nugget ratio, %
Native grassland							
N, %	Spherical	0.27	1.07	43.40	0.76	3.25E-4	25
P, %	Linear	1.05	1.05	85.66	0.50	7.18E-3	100
K, cmol/kg	Spherical	0.00	1.06	43.00	0.80	5.86E-4	0
Na, cmol/kg	Spherical	0.08	3.03	245.30	0.93	4.31E-5	2
OM, %	Linear	0.98	0.98	85.66	0.24	8.43E-4	100
CEC, cmol/kg	Spherical	0.30	1.06	54.40	0.69	5.29E-5	28
pH	Exponential	0.80	1.62	209.60	0.25	2.45E-8	49
EC, µS/cm	Exponential	0.79	1.59	201	0.10	5.91E-4	49
Clay, %	Spherical	0.69	1.50	207.80	0.73	2.80E-4	46
Silt, %	Spherical	0.00	1.07	23.10	0.72	1.46E-3	0
Sand, %	Exponential	0.75	1.88	200.40	0.24	4.26E-3	39
Cultivated field for 5 years							
N, %	Spherical	0.65	1.52	214	0.47	4.61E-9	65
P, %	Exponential	0.77	1.68	198.20	0.18	1.95	45
K, cmol/kg	Spherical	0.02	1.16	61.60	0.89	0.01	1
Na, cmol/kg	Spherical	0.28	1.09	59.30	0.78	2.39	25
OM, %	Exponential	0.26	3.90	224.50	0.85	9.93E-3	6
CEC, cmol/kg	Spherical	0.00	1.25	69	0.97	32.1	0
pH	Linear	1.01	1.01	85.66	0.31	5.95E-4	100
EC, µS/cm	Exponential	0.47	1.12	24.40	0.80	1.93E-9	41
Clay, %	Spherical	0.65	2.06	310.90	0.72	96.1	31
Silt, %	Linear	1.01	1.01	85.66	0.44	1098	100
Sand, %	Exponential	0.87	1.74	306	0.20	1594	50
Cultivated field for 20 years							
N, %	Exponential	0.56	2.51	207.20	0.93	3.49E-4	22
P, %	Spherical	0.11	1.06	42.10	0.80	3.85E-3	10
K, cmol/kg	Spherical	0.00	1.34	76.40	0.95	1.40E-5	0
Na, cmol/kg	Spherical	0.00	1.34	75	0.95	8.45E-6	1
OM, %	Exponential	0.00	1.04	9.60	0.69	4.36E-3	0
CEC, cmol/kg	Exponential	0.76	1.74	195.50	0.47	5.97E-5	43
pH	Linear	1.03	1.03	85.66	0.08	3.62E-8	100
EC, µS/cm	Exponential	0.35	1.14	22.90	0.78	2.30E-4	30
Clay, %	Linear	0.99	0.99	85.66	0.05	1.89E-3	100
Silt, %	Linear	0.95	0.95	85.66	0.00	0.01	100
Sand, %	Linear	1.02	1.02	85.66	0.22	6.84E-4	100

and OM values exhibited a close correspondence for the native grassland and 20-year cultivated land (Figure 1). These similarities were not explained for the 5-year cultivated land. However, the high values of CEC coincided with those of high OM.

The clay content ranged from 10 to 50% with the highest variability at the eight different micro-regions of the native grassland (Figure 2). The variability of clay content decreased gradually from the native grassland to 20-year cultivated land. There was an important change in the spatial variability of sand content associated with soil tillage (Figure 2).

Finally, the important changes occurred in soil properties with cultivation. Soil degradation increased at fifth year of soil tillage, and rapidly deteriorated soil fertility by decreasing clay content, OM and CEC. Therefore, a sustainable soil management system should be applied to decrease soil degradation. Kriging maps could be used as a reference for comparing different types of soil management and determining the best soil management practices for sustainable land use.

Conclusions

Soil properties changed as related to the duration of soil tillage. The maximum variability was observed for EC while the minimum variability was in pH for the three land uses. The correlation coefficients among

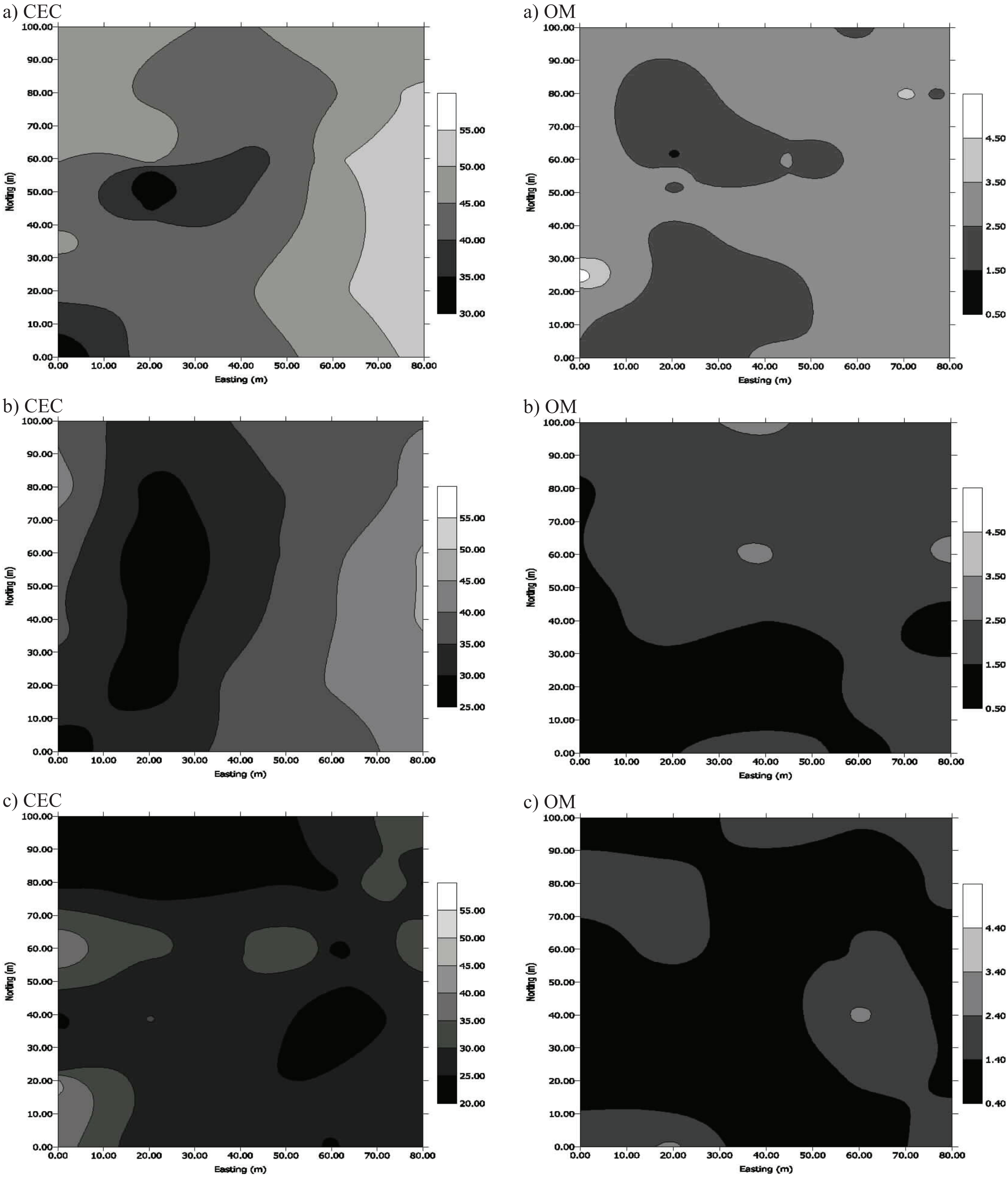

Fig. 1. Map for cation exchange capacity (CEC, me/100 g) and organic matter (OM, %): a) native grassland, b) 5-year cultivated land, and c) 20-year cultivated land.

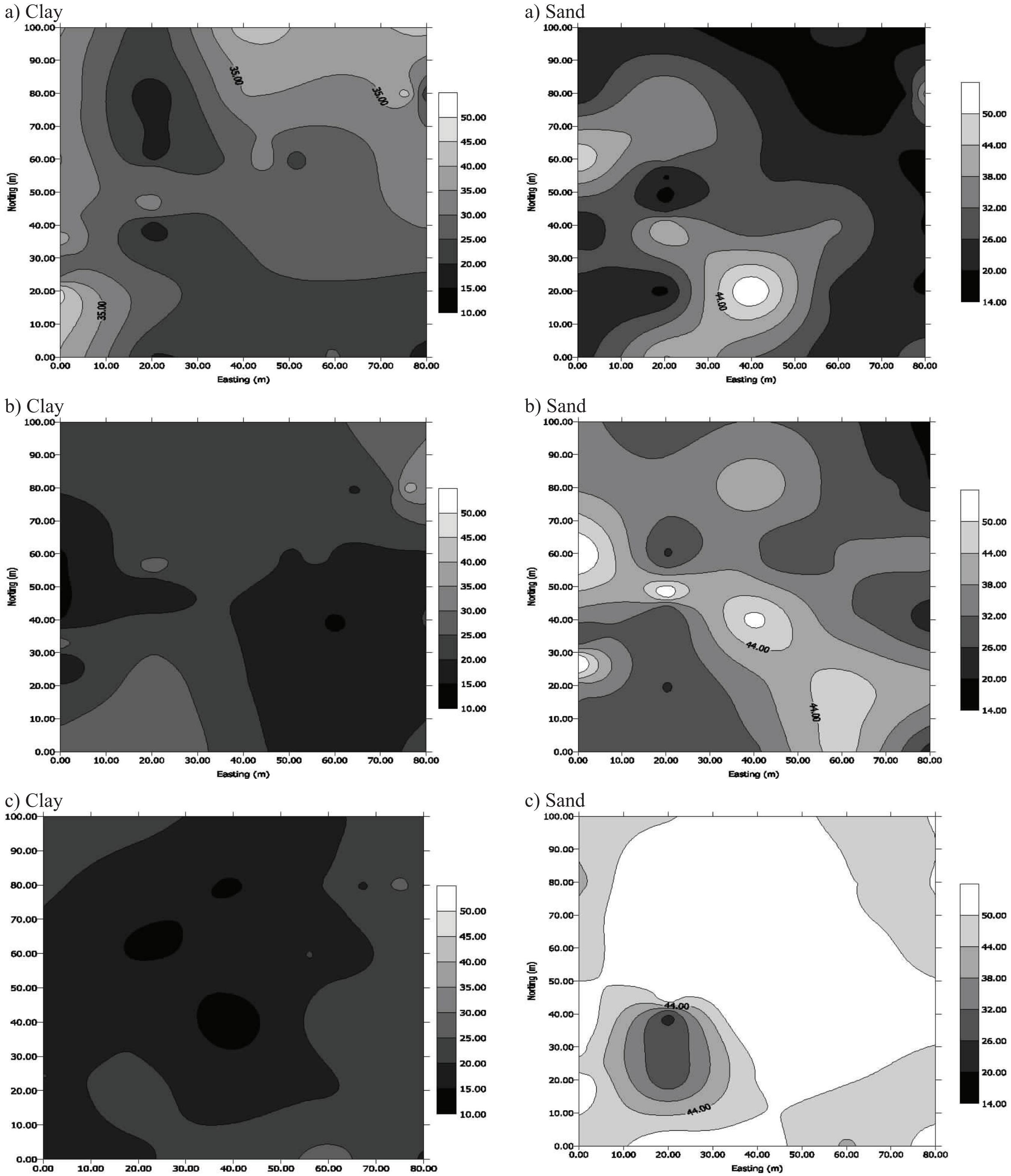

Fig. 2. Map for Clay (%) and Sand (%): a) native grassland, b) 5-year cultivated land, and c) 20-year cultivated

clay, silt and sand contents and between K^+ and Na^+ gradually increased with disturbance from the native grassland to the cultivated lands. However, the range of spatial dependence generally decreased from the native grassland to cultivated lands. The lower nugget effect for the soil variables were generally observed in the native ecosystem. The soil variables of cultivated lands were homogenous while the variables of native grassland were heterogeneous.

The methodology used in this study can characterize and acquire quantitative information for detecting and monitoring variability of soil properties. These results would provide further knowledge for crop design, management strategies and precision farming.

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