Consistency of spatial dependence of soil chemical properties in two fields: a geostatistical study

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ABSTRACT

This study examined consistency of spatial variation of plant-available soil nutrients P, K, Mg and soil pH in two fields of an area of 54 and 67.5 ha (haplic Luvisol and luvic Chernozem) in the region of Český Brod (Central Bohemia). Computed variograms showed a spatial dependence extending to 150 m on an average with small fluctuations for most analysed data sets. These results of two different fields indicate that soil spatial variation is rather a general feature than specific to every field. However, soil available Mg in one field showed a shorter-range (89 m) and soil pH in the other showed considerably longer-range (375 m). Consistency of spatial variation features makes it possible to construct regional average and proportional variograms with great precision. This can bring further practical opportunities.

Keywords: soil properties; spatial variation; geostatistics; variogram; spatial dependence

Soil properties are continuous variables; their values at various points differ according to changes in direction and distance from nearby samples (Burgess and Webster 1980). It is caused by a number of factors and processes acting at different spatial and temporal scales (Borůvka et al. 2002).

When dealing with site-specific management (nowadays mostly named as Precision Farming), soil variation in terms of space and time is a key element. If there were no variation, production through traditional practices with proper adjustment for actual field conditions would be sufficient (Goderya 1998). Castrignano et al. (1998) describe that spatial characterization of soil properties is necessary in order to locate homogenous areas to be carefully managed for agricultural sustainable development. Borůvka et al. (2002) remark that the task is to reveal at least some of the factors influencing soil variation and use this knowledge to design agricultural management practices that would be both environment friendly and highly productive.

Geostatistics provides us with the tools to explore the structure of spatial variation in soil (Oliver 1999). The variogram is a critical input to geostatistical studies (Gringarten and Deutsch 2001). It is a tool to investigate and quantify the spatial variation of the phenomenon under study. The variogram measures the spatial dependence of soil properties using semivariance. Computation of average semivariance between any pair of sampling points is widely presented by many authors, e.g. Webster and Oliver (2000):

$$\hat{\gamma}(h) = \frac{1}{2m} \sum_{i=1}^{m(\boldsymbol{h})} \{z(\boldsymbol{x}_i) - z(\boldsymbol{x}_i + \boldsymbol{h})\}^2 \qquad (1)$$

where the $z(\boldsymbol{x}_i)$ and $z(\boldsymbol{x}_i+\boldsymbol{h})$ represent actual values of Z (soil variable) at places separated by $\boldsymbol{h}$ (lag distance), m is the number of pairs of data points separated by $\boldsymbol{h}$. Plotting average semivariance against the lag generates experimental variogram which can be fitted by a continuous model. The most common are exponential and spherical models. The exponential model with nugget is given by the formula (Webster and Oliver 2000):

$$\gamma(h) = Co + C\left\{1 - \exp(-\frac{h}{r})\right\} \qquad (2)$$

where Co is a nugget variance, C is the sill variance, h is the scalar of $\boldsymbol{h}$ in equation (1) and r (r_{exp}) is a distance parameter that defines the spatial extent of the model (effective range a is then about $3r_{exp}$). The spherical model with nugget is given by the formula (Webster and Oliver 2000):

$$\gamma(h) = Co + C\left\{\frac{3h}{2a} - \frac{1}{2}\left(\frac{h}{a}\right)^3\right\} \qquad h \le a \qquad (3)$$

$$\gamma(h) = C \qquad h > a$$

where a is the range (a_{sph}).

As many authors (e.g. McBratney and Pringle 1997, Cambardela and Karlen 1999) suggest, there is a need to develop a database identifying spa-

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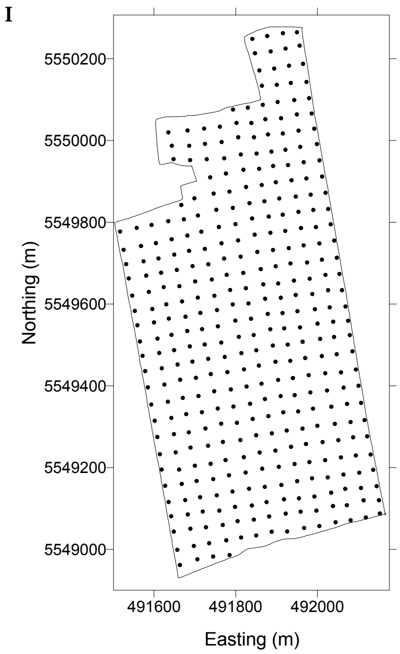

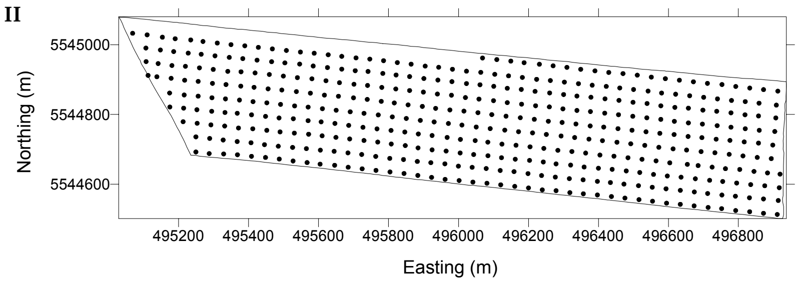

Figure 1. Boundaries of the field I and II with point sampling design

tial distributions of soil properties, there is also a need to implement management regimes in different regions. The cataloguing of the spatial variation of soil properties also needs a uniform set of methods to allow effective comparisons. McBratney and Pringle (1997) constructed average and proportional variograms of soil properties based on a vast literature search. The variograms show fairly high fluctuation as they are gathered from many different studies.

In this paper we investigated soil spatial variation of two larger fields not far apart (~ 10 km) in the region of Český Brod (Central Bohemia). Variogram of regionalized variable theory as a principal tool was used to identify the magnitude of spatial variation. As the two fields may be well representative of the region, we compared them for consistency or differences in spatial variation features.

MATERIAL AND METHODS

Two field sites were examined, field I (near Klučov village) with an area of 54 ha was sampled in 1999 and field II (near Třebovle village) with an area of a 67.5 ha was sampled in 2000. The field I was classified according to WRB (ISSS-ISRIC-FAO 1998) as haplic Luvisol and the field II as luvic Chernozem with a contribution of haplic Chernozem in the central part.

Soil samples were collected from topsoil (0 to 30 cm) using the point sampling method with regular grid square pattern of 40 × 40 m across the whole fields. 14 individual core samples were taken from each point (sampling area) from a circle area with a radius of 3 m from the centre point. The total number of soil samples collected from field I was 368 and from field II 426 (Figure 1). The coordinate system is in UTM projection, WGS-84 datum. Mehlich III extraction procedure was applied to release available P, K and Mg for their determination. Soil pH was determined in 0.2 M KCl extract. See details of the methodology in Brodský et al. (2001) and Brodský (2003). Geostatistics, using GS+ (Robertson 2000), was used to explore spatial variation of soil in the field.

Table 1. Summary statistics of determined soil properties

	Characteristic	P	K	Mg	pH
		(mg/kg)			
Field I	mean	25.6	211.4	141.4	7.2
	variance	204.5	7375	448.2	0.13
	min	4.0	101.2	89.9	5.7
	max	105.0	953.4	258.1	7.6
Field II	mean	34.1	141.3	121.1	6.4
	variance	181.5	1284	287.7	0.31
	min	10.4	58.9	68.4	5.0
	max	90.9	351.0	162.5	7.3

RESULTS AND DISCUSSION

Summary statistics

Table 1 gives the summary statistics of the determined soil properties. According to classification of soil test levels for Mehlich III solution extraction method average values of P show a very low level for both fields with values up to medium level. Average values of K show medium levels for field I and low levels for field II ranged from low to very high level. The average values of Mg show low levels for both fields, which range from very low to high level for field I and medium level for field II. Soil pH_{KCl} average values show a neutral level for field I and a slightly acidic level for field II. The range in the data cover intervals of soil acidity from slightly acidic to alkaline for field I and from acidic to alkaline for field II.

Basic geostatistical analysis

Experimental variograms were calculated from all available data from the examined fields and mathematical models were applied to them (Figures 2 and 3). Exponential model with nugget (2) was used in most cases (for soil P, K, and Mg). However, a spherical model with nugget (3) was used for soil pH data for both fields. Since the semivariance analysis in different axis orientation did not show any significant changes, all the presented variograms (Figures 2 and 3) are isotropic.

The parameters of the modelled variograms are presented in Tables 2 and 3. Based on the formula (1), the variogram gives an estimate of half the average squared difference between all pairs of observations separated by the lag. The sill for P data equals 170 (field I) and 174 (field II). This means that pairs of P values would be expected to differ on an average by ±18.4 and ±18.6 mg/kg at the separation distance greater than the range. The values of range parameter for P in the two fields are also very close (174 m for field I and 182 m for field II). The pairs of K values would be expected to differ at the separation distance greater than the range on average by ±116.8 and ±50.1 mg/kg, respectively. However, though there was found a substantial difference in the sill of K variogram between the two fields, the magnitude of the range parameter showed great consistency (144 for field I and 146 m for field II). The pairs of Mg values would be expected to differ at the separation distance greater than the range on average by ±30.2 and ±23.3 mg/kg, respectively. The range parameters were, however, slightly different: 89 m

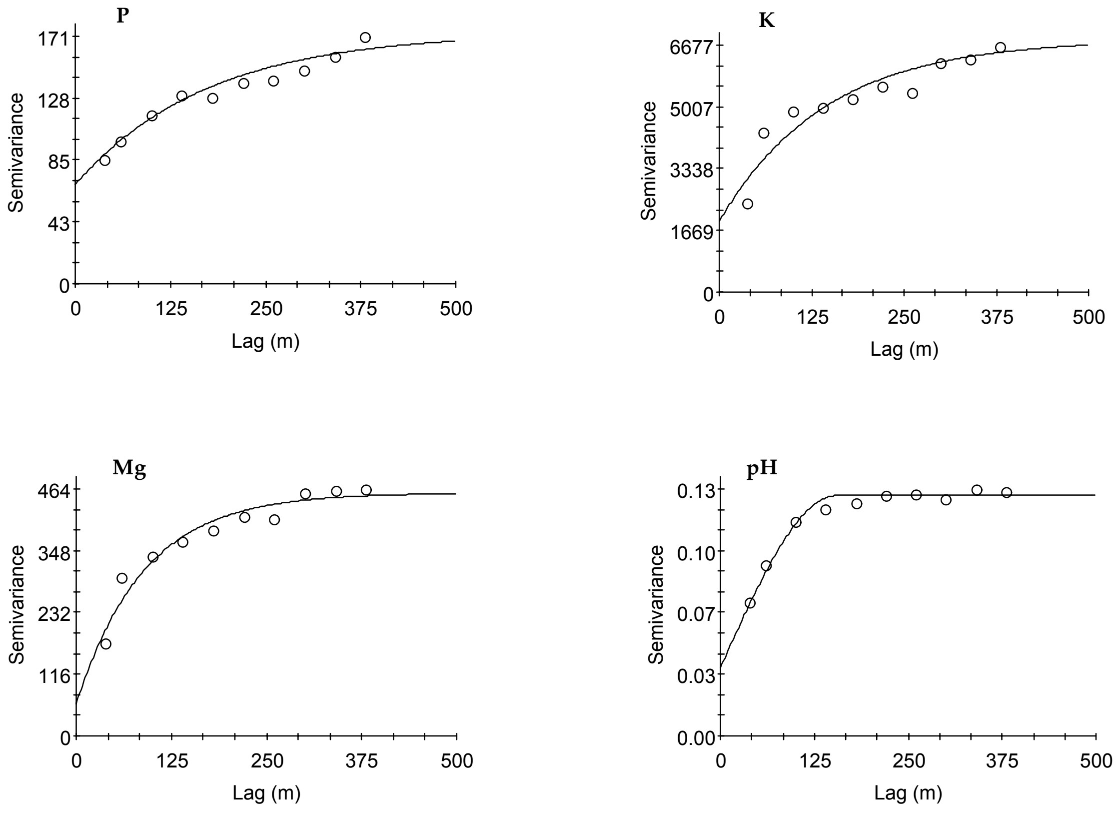

Figure 2. Variograms of determined soil P, K, Mg and pH (field I)

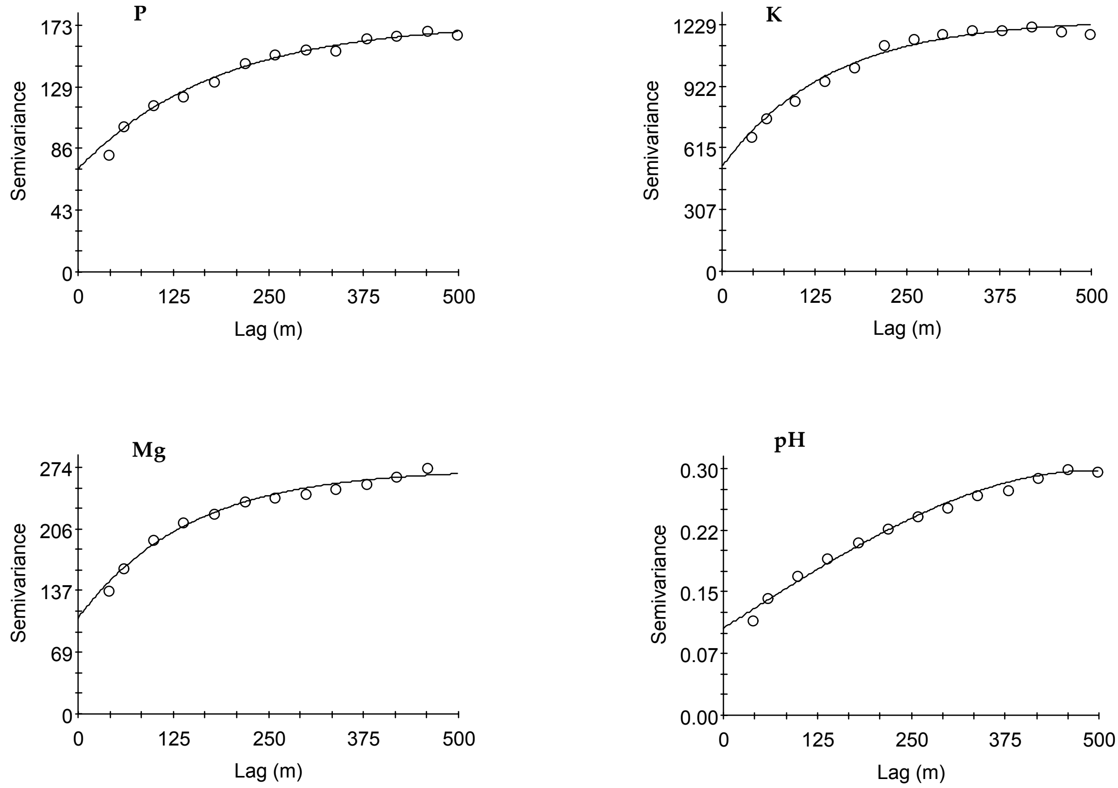

Figure 3. Variograms of determined soil P, K, Mg and pH (field II)

(field I) and 145 m (field II). For pH data sets and the separation distances greater than the range (155 m for field I and 375 m for field II), the pairs of pH values would be expected to differ on average by ±0.5 and ±0.7 units, respectively.

The results show that variogram range parameters fluctuate on average around 150 m for most of the determined soil properties in both fields. There is also a need to say that the results represent a sampling of similar domain size (54 and 67.5 ha) and the same field sampling methodology. These results of the two fields show that soil spatial variation is rather a more general feature than only a specific to every field.

All the resulting ranges accord with the expected results shown in Wollenthaupt et al. (1995). Cambardella et al. (1994), Frogbrook (1999), and Cambardella and Karlen (1999) also showed similar results. However, soil available Mg in the field I showed shorter range parameter (89 m) and soil pH in the field II showed considerably longer range (375 m). The long-range structure is an indication of a trend in the data. When the exponential model was applied to the experimental variogram of soil pH in the field II, the resulting parameters (Co = 0.107, $Co + C$ = 0.413, r_{exp} = 457 m) showed even longer range of the variogram. This finding also justified the comparability between the range parameters (r_{exp}) of exponential variogram models and the range (a_{sph}) of the spherical variogram models in this study.

Field variation in soil properties is caused by interaction of several independent soil forming processes, such as geology, relief, climate, etc., and also by agricultural management practices. The result of shorter range for Mg in the field I was associated with parent material rather than with management practices. The result of soil pH in the field II should be further investigated.

Not only the results of ranges, describing spatial dependence within the fields, but also the fluctuations of measured soil properties at the determined separation distances were found to show remarkable similarity. The exception in the results is the K data set for field I and II. The expected fluctuation of K in the field I was found to be more than two times higher than in the field II, at corresponding distances. The higher variance and semivariance values of K data in the field I might be explained by irregular fertilizer application on the field in the past. The field practitioners have revealed this, but no written evidence from that time (about 15 years ago) has been found yet.

The semivariances of some soil properties showed a further increase above calculated sill in the distance much longer than the range. This increase

Table 2. Parameters of variogram models (field I)

Characteristic	P	K	Mg	pH
Nugget *Co*	68.5	1 910	60.0	0.037
Sill *Co* + *C*	169.5	6 829	456.0	0.132
Range a_{sph}/r_{exp} (m)	173.5	143.9	88.7	154.5
Co/(*Co* + *C*)	0.40	0.28	0.13	0.28
Model	exponential	exponential	exponential	spherical

Table 3. Parameters of variogram models (field II)

Characteristic	P	K	Mg	pH
Nugget *Co*	72.7	522.0	106.6	0.091
Sill *Co* + *C*	174.2	1 253	272.3	0.268
Range a_{sph}/r_{exp} (m)	182.0	146.0	145.0	374.7
Co/(*Co* + *C*)	0.42	0.42	0.39	0.34
Model	exponential	exponential	exponential	spherical

was considered as wide-range spatial dependence, on the separation distances of a bigger sampling area. Another spatial structure of the variogram could be modelled if there were more data in a broader region.

Relative value *Co*/(*Co* + *C*) was used to compare spatial dependence of the determined soil properties. Cambardella et al. (1994), and Cambardella and Karlen (1999) presented the classification of spatial dependence in three categories (weak < 0.25, moderate 0.25–0.75, and strong > 0.75) according to the share of the nugget on the total sill. Most of the determined soil properties showed moderate spatial dependence. The only strong spatial dependence was classified for soil available Mg in the field I.

Spatially uncorrelated structure of the variogram (nugget *Co*) is usually associated with sampling and analytical errors, and variation on shorter distance than applied sampling grid. The statistical results of the quality assurance of analytical data, shown in Brodský et al. (2001) and Brodský (2003), revealed very low deviation of repeated measures. Thus, the contribution of the analytical error in the nugget value must be small.

Geostatistical analysis of soil spatial variation proved to be an effective method to investigate spatial features, which are not analysed by traditional basic summary statistics. Identification of spatially dependent component of variogram revealed that most determined soil properties have very consistent magnitude of spatial variation in the two fields. The variogram ranges showed spatial dependence to 150 m on average. This indicates that the spatial processes worked at the same spatial level.

These results suggest that it is possible to calculate an average and proportional variograms for a region, which would exhibit only within region fluctuations. This variogram is potentially beneficial, for instance, in optimal sampling design for investigation of the other fields in the region. It is also possible to suggest that data with a considerable trend should not be applied to the calculation of the average and proportional variograms.

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ABSTRAKT

Shoda prostorových závislostí chemických vlastností půd na dvou pozemcích: geostatistická studie

Práce porovnává shodu prostorové variability půdních živin P, K, Mg a pH půdy na dvou pozemcích o rozloze 54 a 67,5 ha (hnědozem modální a černozem luvická) v oblasti Českého Brodu. Ukázalo se, že rozsah (*range*) sestrojených variogramů zkoumaných dat vykazuje prostorovou závislost do hodnot okolo 150 m s vysokou shodou. Tyto výsledky dvou pozemků poukazují na fakt, že zákonitost půdní prostorové variability je obecnější záležitostí než jen vlastností specifickou pro každý pozemek. Přesto výsledky vykazují jisté odchylky: rozsah variogramu pro Mg na jednom pozemku byl kratší (89 m) a rozsah pro pH půdy na druhém pozemku byl podstatně delší (375 m). Jestliže existuje shoda vlastností prostorové variability, je možné sestrojit průměrný a proporcionální variogram pro daný region s vysokou přesností. Tento variogram přináší řadu možností praktického využití.

Klíčová slova: půdní vlastnosti; prostorová variabilita; geostatistika; variogram; prostorové závislosti

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