Spatial variation features description of soil available P, K, Mg and soil pH by proportional effect

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ABSTRACT

This paper investigates the proportional effect of selected soil properties – how spatial variation changes are related to their local magnitudes (here standard deviations vs. mean). Content of available P, K, and Mg, and soil pH were analysed on nine agricultural fields of the Czech Republic. Firstly, strong direct within-field proportional effect based on Moving Window Statistics (MWS) was found for soil P and K, while Mg did not exhibit any clear proportionality. Soil pH showed indication of inverse proportional effect with high field-to-field fluctuations. The relationship strength of the effect was functionally related to the asymmetry (skewness) of distribution (r = 0.31 × skew 0.08). Secondly, between-field proportional effect of 9 surveyed fields, as a measure at different scale, showed generally parallel results with the MWS approach. Proportionality is therefore not scale dependent. However, slopes of linear relationships were different for the two scales. Finally, models for prediction of proportional variogram parameters were calculated. Correlation coefficients of relationship between semivariance parameters and mean proved that sill-nugget is more stable (r = 0.74 for P and 0.83 for K) than nugget (r = 0.30 for P and 0.53 for K).

Keywords: soil properties; spatial variation; proportional effect; moving window statistics

Most investigations of soil properties spatial variation are based on geostatistics with variogram as a central tool. Thus, it studies how the variation (semivariance) changes with separation distance of sampled points. Another approach that can be applied is based on Moving Window Statistics – MWS (Isaaks and Srivastava 1989). In the calculation of MWS, the area is divided into local neighbourhoods of equal size and within each local neighbourhood, or window, summary statistics is calculated (Isaaks and Srivastava 1989). It enables to explore how the local variation of the data changes across the study area. This feature is known as heteroscedascity (Goovaerts 1997). A particular form of heteroscedascity where the local variance of data is related to their local mean is called proportional effect. Isaaks and Srivastava (1989) note that such anomalies may have serious practical implications. Goovaerts (1997) describes that for positively skewed distributions the local variance increases with the local mean and calls it direct proportional effect. Inverse proportional effect, on the other hand, can be found when the distribution is negatively skewed.

Isaaks and Srivastava (1989) further note that the standard deviation of some soil properties increases in proportion to the mean, especially in log-normally distributed variables. From this McBratney and Pringle (1999) conclude that the greater is the magnitude of a property, the greater room for variation there is about the mean. They proposed a proportional variogram, if a relationship between the squared mean and variance exists. It needs to say that direct proportionality is here assumed. McBratney and Pringle (1999) therefore apply proportional variogram only on soil content of carbon, nitrate nitrogen, phosphorus and potassium. These variograms are potentially useful in optimisation of spatial sampling e.g. using Spatial Simulated Annealing published by van Groenigen (1999).

This paper explores the proportional effect of agronomically significant soil chemical properties (content of plant-available P, K, and Mg, and soil

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pH). In the first part, the proportional effect of within-field variation, based on Moving Window Statistics, was analysed. In the second part, the between-field proportionality of variation, standard deviation vs. mean, in a sense of broader scale was assumed. Finally, proportionality of nugget and sill-nugget parameters was used to construct prediction models for proportional variogram.

MATERIAL AND METHODS

In the first part of this study, four fields not far apart located in the region of Český Brod (Central Bohemia) were analysed for proportional effect based on MWS (Table 1). Two larger fields (I, II) were surveyed in 1999 and 2000 and two smaller fields (III, IV) were surveyed in 2001. Square grid pattern of 40 × 40 m sampling was applied on the fields I and II; triangle grid pattern of 30 × 30 m was applied on the fields III and IV. Mehlich III extraction method was used to determine the available P, K and Mg. Soil pH was determined in 0.2M KCl extract. A detailed description of the methodology of soil survey for the fields I and II is published in Brodský (2003).

In the calculation of summary statistics (mean and standard deviation) the square window of 100 × 100 m was employed with the condition of minimum 5 points within each moving window (along field borders). The maximum number of points used in a window was 9 for fields I and II, and 7 for fields III and IV. Overlapping of the windows was used as a compromise of large windows for reliable statistics and small windows for local detail and to receive higher number of points in the plots. In the second part of this study the same four fields (I, II, III, IV) and additional three (V, VI, VII) located in the same region were analysed to determine between-field proportionality. For a comparison of the results, other two surveyed fields (VIII, IX) from different regions were also considered.

RESULTS AND DISCUSSION

A proportionality of the local standard deviation in relation to changes in the local mean exists for soil P and K (Figure 1). On the other hand, the plot of moving average means and standard deviations for Mg shows a cloud of points that is scattered without any clear trend. The generally increasing trend for P and K (fields I to IV) describe well the direct proportional effect. The graphs present results of the four fields together, which prove that this is rather a general feature. Results of proportionality for separate fields (I and II) are shown in Brodský (2003). The increase of standard deviations in proportion to mean is associated with positively skewed distribution in the data (Table 2), as stated by Goovaerts (1997). However, though the generally increasing trend displayed for P and K is clear, there is a difference in the relations at low values between the two elements. There are no low mean values for K, thus we cannot model the trend in this part of the graph.

Soil pH in Figure 1 exhibits rather scattered field of points with some indication of a decrease of standard deviation in proportion to the mean, which would be classified as the inverse proportional effect. The wide cloud is mainly caused by points of field II, where a strong trend in spatial variation was found (Brodský et al. 2004). Bimodal histogram is another indication of an inhomogeneity in the data set.

Table 1. Description of the fields included in the study

Field No.	Area (ha)	No. of samples	Soil unit WRB (ISSS-ISRIC-FAO 1998)
I	54.0	368	Haplic Luvisol
II	67.5	426	Luvic Chernozem
III	13.3	71	Chernozem
IV	15.4	88	Arenic Regosol/Chernozem
V	28.0	41	Cambisol
VI	11.0	26	Chernozem/Gleyic Fluvisol
VII	9.3	24	Chernozem/Gleyic Fluvisol
VIII	16.9	51	Phaeozem/Haplic Albeluvisol/Fluvic Gleysol
IX	38.0	101	Cambisol

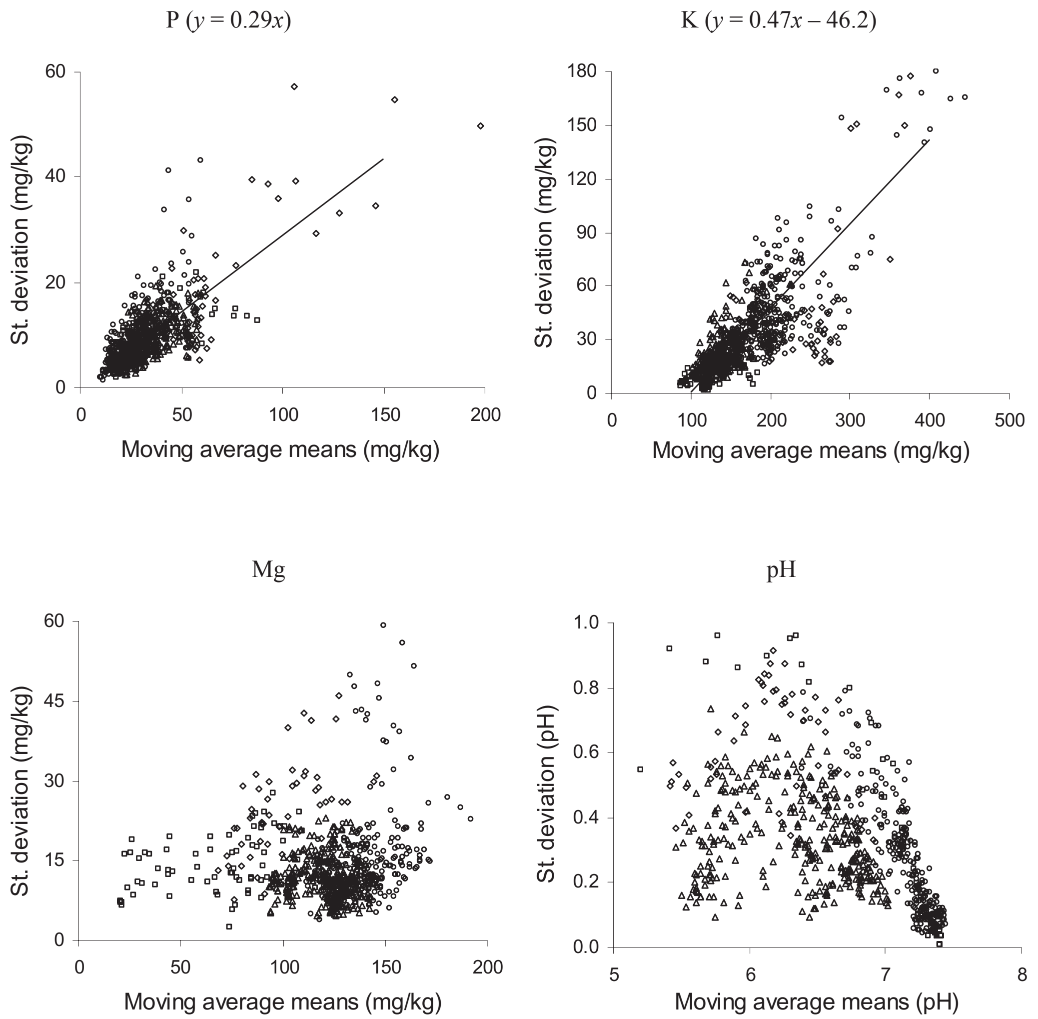

Figure 1. Plots of local standard deviation versus local means computed from MWS for fields I to IV (field I – circles; field II – triangles; field III – squares; field IV – diamonds)

Table 3 summarizes the strength of association between the two statistics. Measure of linear relation – correlation coefficient (r) and more robust rank correlation coefficient (r_{RANK}) were used. The coefficients prove a strong positive correlation for P and K, weak correlation for Mg and negative correlation for pH with high field-to-field fluctuation of the measure.

Asymmetry quantified by skewness in relation to correlation coefficients (r and r_{RANK}) shows a clear trend (Figure 2). This proves that the strength of proportional effect can be predicted from asymmetry of the distribution. The higher the asymmetry (i.e. the absolute value of skewness), the stronger the proportional effect. The points in Figure 2 are distributed in three separate clusters that describe different situations. The first and the biggest is a cluster of positive higher values of skewness and higher correlation coefficients that describes strong direct proportional effect of P and K data. The second cluster is located around the origin of the axes that describes poor proportional effect (mostly for Mg data). The third cluster describes inverse proportional effect; it consists mainly of pH data. The result in Figure 2 clearly proves the statement by Goovaerts (1997). Furthermore, it gives a clue where the proportional variogram can be constructed.

It seems that proportional effect is solely another measure of asymmetry (a third moment around the mean). There is a need to say that proportional effect based on MWS takes into account the effect of spatial distribution. It measures how well the spatial changes of the measured properties are related to their local magnitude.

In the second part, the between-field proportionality of variation (standard deviation) vs. mean was investigated (Figure 3). The analysed trend of proportionality expressed by a solid line was calculated from the results of the seven fields (black

Table 2. Summary statistics of the soil properties for the fields I to IV

Field	Parameter	P (mg/kg)	K (mg/kg)	Mg (mg/kg)	pH
I	mean	25.6	211.4	141.4	7.2
	SD	14.3	85.9	21.2	0.35
	skewness	1.69	3.49	1.48	–2.16
II	mean	34.1	141.3	121.1	6.4
	SD	13.5	35.8	16.9	0.55
	skewness	1.04	1.86	–0.28	–0.35
III	mean	70.7	241.4	105.4	6.3
	SD	49.1	101.5	32.9	0,76
	skewness	2.40	1.63	0.67	–0.47
IV	mean	36.4	123.8	60.7	7.0
	SD	22.9	34.7	29.6	0.76
	skewness	1.39	0.61	–0.03	–2.34

dots) located in the region around Český Brod. Asterisks denote the additional two fields from different locations. In spite of a limited number of points in the plots given by the number of surveyed fields, it is evident that there was also found the direct proportionality for P and K; unclear result for Mg is apparent. The increasing trend for P and K is consistent with the results presented in the first part. Linear regression model without intercept ($y = a \times x$) was applied for P, and a model with an intercept ($y = a \times x + b$) was used for K. Indication of the inverse proportionality for soil pH with some fluctuation is also similar to the results of the first part (Figure 1).

Nevertheless, there are differences between the two approaches. In the first, local variation on a chosen fixed area is analysed, while in the second, the whole fields that can comprise widely different parts are considered. Technically, proportional effect at two different scales with different number of points involved in the calculation of the statistics is compared. This explains why the slopes of the trends are different. Despite the difference, the results in Figures 1 and 3 appear parallel, which means that the feature is not scale dependent generally.

McBratney and Pringle (1999) proposed proportional variogram based on a relationship between squared mean and variance, e.g. exponential model:

$$\gamma(h) = (\text{mean}^2 \times b_1) + (\text{mean}^2 \times b_2)\ \{1 - \exp(-h/r)\}$$

where: b_1 and b_2 are the gradients of the linear relationship. Linear model without the intercept ($y = a \times x$) was only employed. McBratney and Pringle (1999) suggest that the variance increases

Table 3. Correlation coefficients of local standard deviations versus local means computed from MWS for fields I to IV separately

Field	Parameter	P	K	Mg	pH
I	r	0.74	0.81	0.33	–0.86
	r_{RANK}	0.75	0.53	0.44	–0.86
II	r	0.58	0.54	–0.10	–0.20
	r_{RANK}	0.63	0.47	–0.20	–0.27
III	r	0.80	0.26	–0.39	–0.20
	r_{RANK}	0.49	0.58	–0.40	–0.14
IV	r	0.80	0.36	–0.34	–0.93
	r_{RANK}	0.72	0.41	–0.30	–0.88

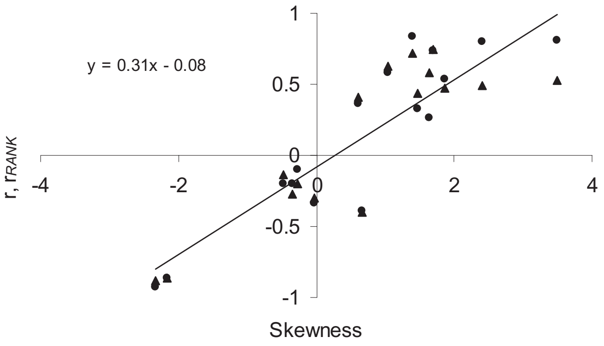

Figure 2. Relationship between correlation coefficients of the trend in the proportionality and skewness of the statistical frequency distribution (correlation coefficient r – black dots; rank correlation coefficient r_{RANK} – triangles); regression was calculated using only the r values

in proportion to the mean squared similarly as the standard deviation in proportion to mean. This is functionally true for the linear regression model without intercept.

Proportionality of nugget and sill-nugget variance for P and K as another parallel feature was used to calculate prediction models of proportional variogram parameters. Only the fields with more than 40 samples were used (fields I to V, VIII, and IX). Square roots of nugget and sill-nugget were initially calculated to keep comparability with the previous findings. The increasing trend was again described functionally by linear regression model without intercept ($y = a \times x$) for P and with an intercept ($y = a \times x + b$) for K. Table 4 summarizes the prediction models of variogram parameters based on the proportionality. Correlation coef-

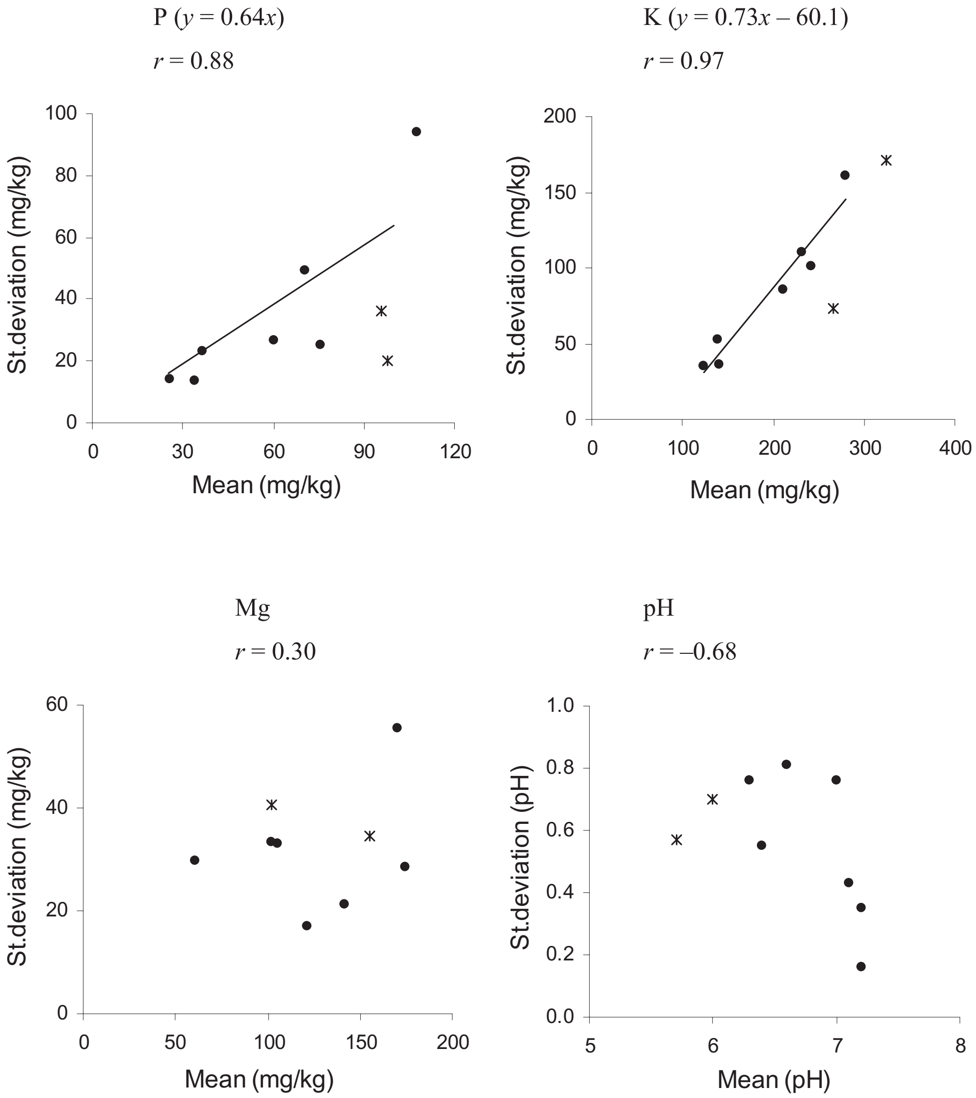

Figure 3. Plots of between-field proportionality of standard deviation to the mean of P, K, Mg and pH (fields I to VI – black dots; fields VIII and IX – asterisks)

Table 4. Prediction models for proportional variogram parameters of P and K

Parameter	Prediction for P	Prediction for K
Nugget	$(0.14 \times \text{mean})^2$	$(0.12 \times \text{mean} + 13.3)^2$
Sill-nugget	$(0.60 \times \text{mean})^2$	$(0.79 \times \text{mean} - 79.1)^2$
R_{nugget}	0.30	0.53
$r_{sill-nugget}$	0.74	0.83

ficients as additional measure of the strength of the linear relationships are presented. The coefficients proved that sill-nugget is a more stable (r = 0.74 for P and 0.83 for K) parameter than nugget (r = 0.30 for P and 0.53 for K). It can be expected that prediction of sill-nugget is more reliable than prediction of nugget. The reason is that the nugget represents uncorrelated spatial variation related to measurement error and spatial variation at distances smaller than shortest sampling interval. Slopes of the linear relationship for prediction of sill-nugget were found similar to those in Figure 3 of the between-field proportionality. This infers the comparability of the parameters. Range parameter was not functionally described, as there is no reason to see proportionality with the statistics used here. McBratney and Pringle (1999) note that the range is less likely related to the distribution and more likely is a function of the sampling scheme applied.

To conclude, it is clear that different soil chemical properties exhibit different features of proportional effect with good consistency. Generally, proportional effect is not scale dependent. The question is whether the spatial features of soil properties, quantified e.g. by proportional effect, are only soil property dependent or are also related to some other features of the landscape (soil units, relief, etc.). If there were found any quantifiable dependency, then this knowledge would bring not only great practical advantages in dealing with soil variation, but also better understanding of the phenomenon. One of the examples can be an improvement of the optimal sampling design for mapping field variation. An approach based on MWS could be applied when there are already measured related data with high density (e.g. from soil sensors and scanners). Another approach is applicable rather for multistage sampling where initial survey was done.

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