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Spatial variability of soil particle size distribution in Poland

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Abstract

Evaluation of soil spatial variability is an important issue in agrophysics and environmental research. Studies of spatial variability enable a better understanding of the physical processes that take place in the soil and their result can be useful in the elaboration of the best methods for the control of thermal-water-air relationship in plant environment and for the prevention of land degradation. The knowledge of spatial variability which is one of the fundamental soil physical properties, is of special importance for the modelling of energy and mass transportation processes.

The aims of the present study were to:

(1) recognise soil particle size distribution patterns in the territory of Poland and the features of its spatial variability,

(2) use semivariograms and fractal analysis to characterise and compare the spatial variability of soil particle distribution in three soil horizons (A, B, C).

Data collected on particle size distribution of the mineral soil representative for the territory of Poland, was used to describe its spatial variability by using geostatistic techniques and fractal theory. Based on data calculated for some points over the whole area and for selected directions, values of semivariance were determined. The slope of the regression line of log semivariance versus log distance was used to estimate a fractal dimension (D).

All variables studied, i.e. clay, silt and sand fractions, were space dependent. The range of spatial dependence for coarse and fine-textured soils decreased with depth. For medium-textured soils, the range of spatial dependence was higher in the B horizon than in the A and C horizons. Variogram surfaces showed anisotropy of all particle size fractions with a trend in the W to E directions.

Fractal analysis indicated the dominance of a short or long-range directional variation in the soil particle fractions for all three horizons. The smallest fractal dimensions were obtained for medium-textured soils, with intermediate values for coarse-textured soils and the highest values for fine-textured soils.

Keywords: spatial variability, particle size distribution, semivariogram, fractal dimension, Polish soils

Introduction

A collection of results that would be representative for the object studied both in relation to the space measured and variability in time, is the supreme goal in any research studies. Statistical methods widely applied to the soil object already at the beginning assume that the parameters observed are independent from one another. Such an independence of observation is a barrier to their accurate description and analysis. In Agrophysics we deal with observations which are dependent by nature. This dependence is interesting in itself from the cognitive point of view. In such a case, the methods of random field analysis on which, among others, the mathematical apparatus of the geostatistics is based, is of primary significance in studies of the variability of soil parameters. We are aware that our knowledge of a given phenomenon or feature studies is only fragmentary, since it is related to the areas or rather some points, from which samples were collected. We do not know what is happening in the area between the points of the measurement taken. The need to study these areas resulted in a new research discipline, i.e. geostatistics (Webster and Burgess, 1984; Perfect *et al.,* 1990; Hummatov *et al.,* 1992; Brus *et al.,* 1993; Papritz, 1993; Baranowski *et al.,* 1994; Bartoli *et al.,* 1995; kozal *et al.,* 1996; Usowicz *et al.,* 1996; Lipiec and Usowicz, 1997; Moreno *et al.,* 1997).

The geostatistic theory is based on an observation that besides a point of a determined value of a certain variable, i.e. humidity, there are points with similar values. In other words, humidity values located at some distance from one another, are correlated. The basis for the calculations of the above theory is a variogram function, or to be more accurate, half of the expected value of the difference in the values $Z(x)$ of the variable at the point x and the value $Z(x+h)$ located at a distance of the h vector from it. A semivariogram presents a behaviour or a given variable in space or time. The above variable is called a "regionalised" variable. The above variable shows a random aspect which takes into account local irregularities and a structural aspect which reflects multi-scale trends of the phenomenon. The function of a variogram with parameters determined (value of a nugget, sill, and dependency range) presents the behaviour of the variable studied in space and time, and at the same time allows us to draw conclusions about areas that are not represented by any measured data.

Courses in time or space obtained during agrophysical measurements are manifested by irregular shapes. Such irregularities (chaos) can be treated in two ways. Firstly, as a deviation from the ideal state-a classic statistical approach; and secondly, as a non-ordered course bound internally with indissoluble properties. It can be concluded that studying such a non-ordered course, we are able to obtain useful information not only on the course itself but also on the object from which the above course originated. Irrespective of the measuring scale, this type of course can be analysed by semivariograms. The above statement follows directly form the assumption of geostatistics. Another useful tool used in the analysis of irregularities can be the theory of fractals which by definition deals with such objects.

The mathematical concept of describing natural structures characterised by the geometric heterogeneity of linearity or surfaces, is called the theory of fractals (Bartoli *et al.,* 1991; Rieu and Sposito, 1991; Perfect and Kay, 1995; Anderson *et al.,* 1998; Lipiec *et al.,* 1998). The basic notion of the above theory is the notion of the fractal dimension D. It expresses an effective geometrical dimension of linearity or surface of the structure studied. According to the theory of fractals, the D value is a global value, and hence it characterises the whole object studied. The above value can assume values from the $1 \leq D \leq 2$ range for the linear sections and from the $2 \leq D \leq 3$ range for surfaces, and can be interpreted in the categories of spatial organisation of the property of process studied, i.e. it tells us how much the property studied is determined and to what extent its distribution is random.

Materials and Methods

The basic assumptions of geostatistics are as follows (Webster and Burgess, 1984; Webster, 1985; Pannatier, 1994): 1) k random variables $\{Z(x_1), Z(x_2), Z(x_3), Z(x_k)\}$ are assigned to each random function $Z(x)$, 2) knowledge of the first two statistical moments assigned to the random function of a given phenomenon is required, the first moment (mean), $E[Z(x)] = m(x)$ and the second (variance, co-variance, semivariogram) $Var\{Z(x)\} = E\{[Z(x) - m(x)]^2\}$. If the random variables $Z(x_1)$ $Z(x_2)$ have a variance, they also have a co-variance which is a function of location x_1, x_2: $C(x_1, x_2) = E\{[Z(x_1) - m(x_1)] \cdot [Z(x_2) - m(x_2)]\} = E\{Z(x_1) \cdot Z(x_2)\} - m(x_1) \cdot m(x_2)$. Semivariogram-$\gamma(x_1,x_2)$ is defined as half the variance from the difference between random variables $\{Z(x_1)\text{-}Z(x_2)\}$: $\gamma(x_1, x_2) = \frac{1}{2} Var\{Z(x_1) - Z(x_2)\}$.

It is also required for the phenomena or processes studied to be stationary, i.e. not to change their properties when the initial point of the spatial scale has been changed. Where being stationary is fulfilled for the random function $Z(x)$, it is determined as a stationary of the second order, moreover it is expected that (Webster, 1985; Pannatier, 1994):

- the expected value exists and does not depend on location x $E[Z(x)] = m$
- for each pair of the random variables $\{Z(x), Z(x+h)\}$ the covariance exists and depends only on the separation vector h $C(h) = E\{Z(x+h) \cdot Z(x)\} - m^2$,
- stationarity of the covariance implies stationarity of the variance and semivariance $Var\{Z(x)\} = E\{[Z(x) - m]^2\} = C(0)$ and $C(h) = C(0) - \gamma(h)$
- or all values of the vector h, the difference $\{Z(x+h)\text{-}Z(x)\}$ has a finite variance and does not depend on x. $\gamma(h) = \frac{1}{2} Var\{Z(x+h) - Z(x)\} = \frac{1}{2} E\{[Z(x+h) - Z(x)]^2\}$

When the vector h values equals zero, then the value of semivariance is also equal to zero. Moreover, the semivariogram is symmetric in relation to h: $\gamma(h)=\gamma(-h)$

The experimental semivariogram – $\gamma(h)$ for the distance h is calculated from the equation (Webster, R. 1985; Englund and Sparks, 1988; Pannatier, 1994; Gamma, 1998): $\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [v(x_i) - v(x_i + h)]^2$

where: $N(h)$ means a number of pairs of points at a h distance. The equation illustrates differentiation in the deviations of a given physical value-v from the trend equation in relation to the distance between the measuring points.

Known mathematical functions (linear, exponential, Gauss', etc.) are fitted to the empirically determined semivariogram. These functions can then be used for the spatial analysis (analysis in time) of auto-correlation or visualisation by means of estimation of the physical value considered in space using the Kirging method.

Three characteristic parameters for the semivariogram are distinguished: effect of the nugget, sill and range. Where the semivariogram is a function increasing not from zero but from a certain value, this value is called the effect of a nugget (C_0); it expresses the variability of the physical variable studied with a scale lower than the sampling range or can be caused by a low measurement accuracy. The value reached at which the semivariogram function does not increase any further (approximately equal to the sample variance s^2) is called the sill, whereas the range of distances from zero to the point at which 95% of the constant value has been reached by the semivariograms, is called the *a* range. This latter value determines the border of spatial dependence of the observation. It is assumed that the semivariance beyond the range is equal to the variance from the sample-s^2, and is explained by the random variance. An increasing semivariogram from the nugget variance to the sill is determined by the structural variance (C). It is a true spatial component of the sample variance. It determines the part of the variance which results form the spatial dependence of the observation. Where the (C + C_0) determines the values at which variance stabilisation is observed-it corresponds approximately to the s^2 variance of the stationary data. When the C_0 threshold is equal to the s^2 variance, it determines the so-called pure nugget effect. Moreover, it describes the lack of spatial correlation of the variables $Z(x)$ i $Z(x+h)$, and the above fact can be interpreted as a spatial independence of the observation, with the best estimator-the mean value of the variable and s^2 variance for the whole object studied. What is more, the pure nugget effect and higher variance of the s^2 sample, pointed to the presence of a macro variance which can be observed, as a rule, for higher distances in conditions of the existing spatial dependence of the observation. With the missing C_0 component, the threshold is determined by the value of the structural C variance.

The studies conducted so-far showed that there are no direct methods for the determining or assessing fractality of the real objects. Properties of objects that may include features of fractals in their structure or which can be connected with the definition of fractals are looked for.

In recent years, fractal analysis was used not only for the geometrical descriptions of materials but also for the studies on the spatial variability of properties of a porous object, among others, granulometric composition, electric conductivity, penetrometric resistance, density, content of various salts in the soil or the influence of the colloid fraction on the soil erosion (Armstrong, 1986; Sokołowska *et al.,* 1989; Bartoli *et al.,* 1991; Rieu and Sposito, 1991; Bartoli *et al.,* 1995; Pachepsky *et al.,* 1995; Kozak *et al.,* 1996; Pachepsky *et al.,* 1996; Anderson *et al.,* 1998; Kravchenko and Zhang, 1998; Sokołowska *et al.,* 1998). The fractal dimension was determined by means of a semivariogram inclination coefficient in the logarithmic co-ordinate system.

In the present study, the fractal D dimension was determined on the basis of a semivariogram from the equation (Burrough, 1983; Perfect *et al.,* 1990; Gamma, 1998): $D = 2 - \frac{H}{2}$, where H is an inclination of the straight line of a semivariogram plotted in the logarithmic co-ordinate system.

The measuring data on the content of individual granulometric fractions in horizons A, B and C came from studies published in the “Soil Sciences Annual” in the period from 1952 to 2000, in the “Acta Agrophysica” and in the Bank of the Polish Mineral Soils Samples (Gliński *et al.,* 1991; Soil Sciences Annual, 1952-2000; Acta Agrophysica, 2001; Data Bank on Cultivated Mineral Soil of Poland BIGLEB-M). The quantitative contribution of the three granulometric fractions, i.e. clay (<0.002 mm), silt (0.002-0.02mm) and sand (0.02-1 mm) was considered. Spatial co-ordinates used for the calculations were expressed in degrees and degrees to the tenth part. The minute and second values were calculated to values of the tenth part of a degree as required by the software used for the analyses. In the geostatistic analysis, neither the height above sea-level, nor the fact that the area studied was a section of a ball, were taken into consideration. It was assumed that the surface was flat and the errors resulting from the above assumptions were insignificant.

Results and Discussion

Spatial differentiation of the granulometric composition in the soils was analysed by means of classical statistics, geostatistics and fractal dimension. The mean values showed that the sand content in the soils studied was the highest, irrespective of the genetic horizon, i.e. from 74 to 79%. The content of the silt fraction was considerably lower, i.e. from 13.6 to 16.3%, and the amount of the clay fraction was even lower, i.e. from 4.9 to 12.5%. The mean sand and clay content decreased slightly with depth, whereas the content of clay increased considerably, i.e. twice in horizon B and 2.5 times in horizon C when compared to the A horizon.

The highest values of the variability coefficient was observed for the clay in horizon A, and it decreased slightly with depth, from 117% in horizon A to 101% in horizon C. The variable silt and sand content increased with depth; for the silt from 67% to 87%, and for the sand from 17% to 30%.

The parameters characterising distribution of the individual granulometric fractions (skewness and kurtosis) showed a large right-sided asymmetry and a high concentration of values close to zero in the case of clay. The diagonal slant of kurtosis for the clay decreased with depth from 2.15 to 1.39 and from 9.2 to 5.8, respectively. Similarly, distribution of silt showed a right-sided asymmetry of 0.86 (A), 0.67 (B) and 0.71 (horizon C). Kurtosis was close to the values of the normal distribution, i.e. equal to 3 and decreased with depth from 3.75 to 2.88. The asymmetry of the sand distribution was left-sided and decreased slightly with depth from –0.71 to –0.6. Kurtosis was in that case close to the normal distribution; 3 (A), 2.73 (B) and 2.8 (horizon C).

The spatial variability of the granulometric fractions distribution in the soil profile was studied by means of semivariograms. The value nuggets, sills and ranges of spatial correlation were determined and the models of semivariograms were then fitted to the empirical values and the parameters of mode fitting were determined (Figure.1).

Spatial correlation was found in the case of all the fractions studied. The shape of spatial correlations was either exponential or spherical. The highest values from the range of spatial correlation in the case of the clay and sand fractions was noted in horizon A (1.2° and 2.5°, respectively), for the silt, in horizon B (3.18°), and the lowest, in horizon C; for clay (0.44°), silt (2.27°) and sand (1.48°).

The semivariance value for the individual fractions decreased with depth. The lowest values of the semivariance saturation values (silt) were observed in the horizon A. They were about 33 for clay, 125 for silt and 220 ($\%^2$) for sand. In horizons B and C, a four and a half to five times increase of the saturation semivariance for clay was noted. In the case of silt, semivariance increased to the maximum of about 17% in horizon C maximum when compared to horizon A. The semivariance relating to sand was more than twice higher in horizons B and C than in horizon A.

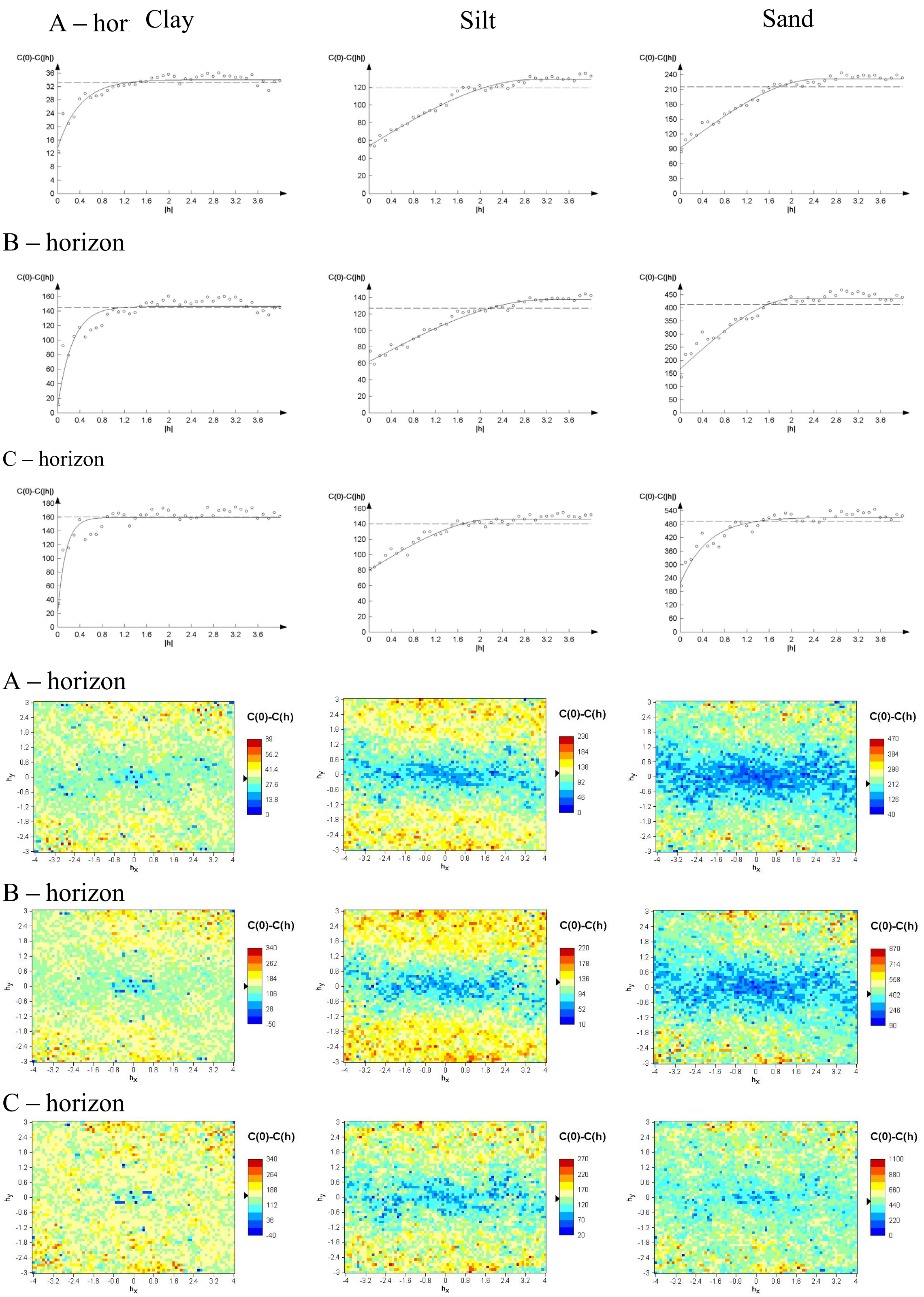

Figure 1 Omnidirectional and surface semivariograms of particle size distribution in Polish mineral soils. Horizon A, B, C with clay, silt and sand fractions.

Surface semivariograms presented in Figure.1 effectively allowed visualisation of anisotropy in the spatial distribution of the individual granulometric fractions. Anisotropy was clearest in the distribution of the sand and silt fractions in horizons A and B. Anisotropy was mainly directed in the W-E axis. In the horizon C of the same fractions, anisotropy was already considerably less visible. In the case of the clay fraction, a small anisotropy was also observed in horizon A in the W-E direction. The above anisotropy decreased with depth and became almost invisible in horizon C.

Fractal dimensions calculated on the basis of the inclination of the semivariogram straight line, were presented in Figure 2. Fractal dimensions were determined for the clay, silt and sand fractions from the soil genetic horizons A, B and C. In the calculations, isotropic semivariograms and directed semivariograms, i.e. with the angles of 0º, 45º, 90º and 135º, were taken into account. The 0º angle pointed to the W-E direction. The high values of the fractal dimensions, exceeding 1.8, pointed to the high randomness in the spatial distribution of the clay, silt and sand fractions. The clay fraction was characterised by the highest values of the fractal dimension, and the silt fraction had the lowest values. In the individual soil genetic horizons, fractal dimensions for the clay were slightly lower in the horizon B and almost identical in horizons A and C. In the case of silt, they were almost equal in most cases, whereas for the sand, the values of the fractal dimension increased with depth. Higher values of the fractal dimension in horizon C than in horizon A pointed to an increase in the differentiation of the sand fraction in horizon C. Clear decreases in the fractal dimensions were observed at an angle of 45º in the case of clay and sand. In the case of silt, an increase in dimensional values was observed at an angle of 90º.

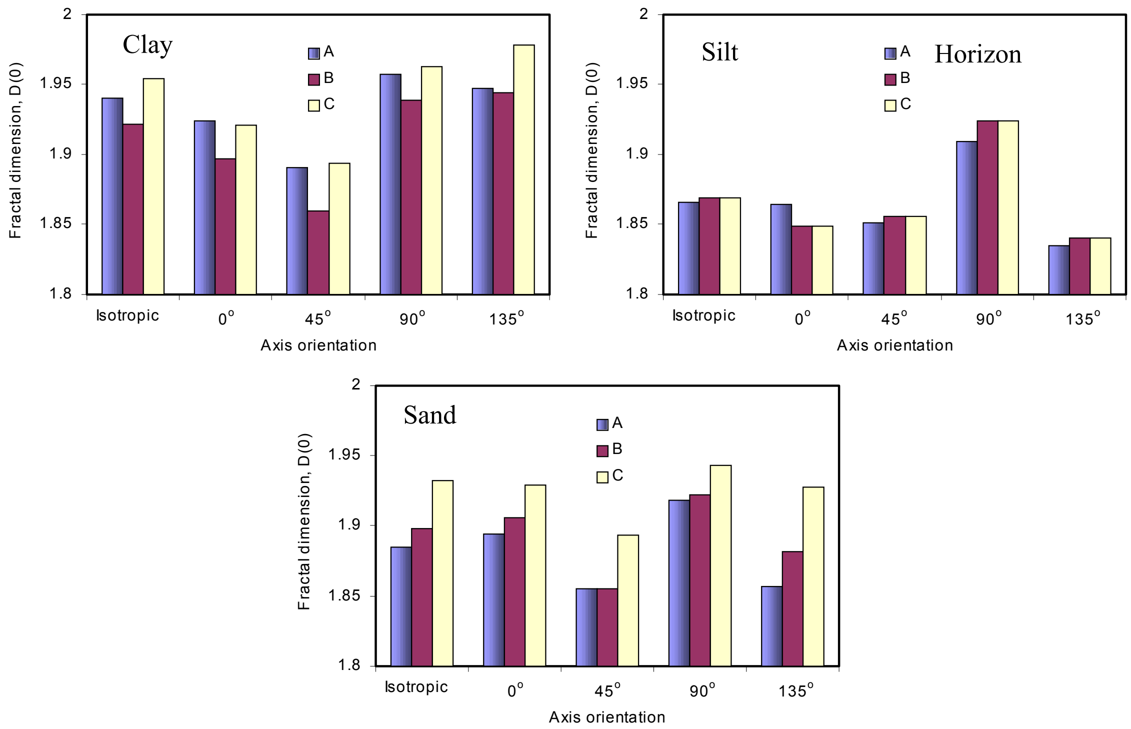

Figure 2 Fractal dimension for particle size distribution in Polish mineral soils. □- horizons A, B and C.

Conclusion

The present study evaluates spatial variability in the content of clay, silt and sand in Polish mineral soils from genetic horizons A, B and C. The data measured was analysed using the methods of classical statistics, geostatistics and the theory of fractals.

Basic statistical parameters were calculated and it was found that the content of sand in the whole profile studied was the highest, and the amount of clay in the surface soil layer was the lowest. The highest variability was observed for the clay fraction, and the lowest for the sand fraction.

The geostatistic parameters determined showed a spatial dependence in the distribution of clay, silt and sand in the individual genetic soil horizons. In the case of the clay and sand fractions, the radius of spatial correlation decreased with depth. In the case of silt, it reached the maximum value in horizon B. Its highest values were observed in horizon A for clay and sand and in horizon B for silt, and the lowest in horizon C. Moreover, distribution of the clay and sand content in the soils studied was characterised by high anisotropy, and the clay fraction had only slight anisotropy.

Among the granulometric fractions considered, the highest values of the fractal dimension were observed for clay and somewhat lower for silt. It was found out that in the distribution of the clay content in the soil, randomness (fortuitousness) is the highest. A slightly lower randomness was found in the sand content, and was considerably lower in the silt content. Anisotropy was observed in the distribution of the fractal dimension in the WS-NE direction in the case of clay and sand, and in the S-N direction in the case of silt.

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References

Acta Agrophysica. The Period from 1993 to 2001.

Anderson, A.N., A.B. McBratney and J.W. Crawford. 1998. Applications of Fractals to Soil Science. Advences in Agronomy 63:2-76. (D.L. Sparks Editor, Academic Press)

Armstrong, A.C. 1986. On the fractal dimensions of some transient soil properties. J. Soil Sci. 37:641-652.

Baranowski, P., J. Kossowski and B. Usowicz. 1994. Spatial variability of soil water content in cultivated fields. Zesz. Prob. Post. Nauk Rol. 405:9-19.

Bartoli, F., G. Burtin, J.J. Royer, M. Gury , V.Gomendy, R. Phylippy, T.H. Leviandier and R. Gafrej. 1995. Spatial variability of topsoil characteristics within one silty soil type effects on clay migration. Geoderma 68:279-300.

Bartoli, F., R. Philippy and G. Burtin. 1992. Influence of organic matter aggregation in Oxisols rich in gibbsite or in goethite: I. structures the fractal approach. Geoderma 54:231-257.

Bartoli, F., R. Philippy, M. Doirisse, S. Niquet and M. Dubuit. 1991. Structure and self-similarity in silty and sandy soils: the fractal approach. J. Soil Sci. 42:167-185.

Brus, D.J. 1993. Incorporating models of spatial variation in sampling strategies for soil. Ph.D. Thesis, Wageningen Agricultural University, The Netherlands. 211 p.

Burrough, P.A. 1983. Multiscale sources of spatial variability in soil: I. the application of fractal concepts to tested levels of soil variation. J. Soil Sci. 34:577-626.

Data Bank on Cultivated Mineral Soil of Poland BIGLEB-M. Institute of Agrophysics, Polish Academy of Sciences.

Englund, E. and A. Sparks. 1988.Geostatistical Environmental Assessment Software. Environmental Monitoring Systems. Laboratory Office of Research and Development, U.S. Environmental Protection Agency, Las Vegas, NV 89193-3478.

Gamma Design Software. 1998. GS^+ v. 3.06.5 beta. Geostatistics for the environmental Sciences.

Gliński, J., J. Ostrowski, Z. Stępniewska and W. Stępniewski. 1991. Bank Próbek Glebowych Reprezentujących Gleby Mineralne Polski. Problemy Agrofizyki 66.

Hummatov, N.G., S.V. Zheromskiy, Ye.V. Mironenko, Ya.A. Pachepskiy and R.A. Shcherbakov. 1992. Geostatistical analysis of water retention capacity spatial variability for a grey forest soil. Pochvoviedenie 6:52-62.

Kozak, E., Y.A. Pachepsky, S.Sokołowski, Z. Sokołowska and W.Stępniewski. 1996. A modified number-based method for estimatig fragmentation fractal dimensions of soils. Soil Sci. Am. J. 60:1291-1297.

Kozak, E., Z. Sokołowska, S. Sokołowski and J. Wierzchoś. 1995. Surface fractal dimension of soil materials from pore size distribution data: I. a comparison of two methods of determination. Polish J. Soil Sci. 28:77-85.

Kravchenko, A. and R. Zhang. 1998. Estimating the soil water retention from particle-size distributions: a fractal approach. Soil Sci. 163:171-179.

Lipiec, J., R. Hatano and A. Słowińska-Jurkiewicz. 1998.The fractal dimension of pore distribution patterns in variously-compacted soil. Soil Tillage Res. 47:61-66.

Lipiec, J. and B.Usowicz. 1997. Spatial variability of penetration resistance of soil at different compaction level. Bibliotheca Fragmenta Agronomica t.2b:423-426.

McBratney, A.B. and R. Webster. 1983. How many observations are needed for regional estimation of soil properties. Soil Sci. 135(3):177-183.

Moreno, F., B. Usowicz, J.E. Fernandez and L. Andreu. 1997. Spatial distribution of salinity and water content in the reclaimed salt-affected soils of south-western Spain, pp. 83-93. *In* Proc Int. Conf. on Wastewater Re-Use in Irrigated Agriculture, Vol. IV. Valenzano (Bari), Italy.

Pachepsky, Y.A., L.P. Korsumskaja and M. Hajnos. 1996. Fractal parameters of soil pore surface area under a developing crop. Fractals 4:97-104.

Pachepsky, Y.A., T.A. Polubesova, M. Hajnos, Z. Sokołowska and G. Józefaciuk. 1995. Fractal parameters of pore surface area as influenced by simulated soil degradation. Soil Sci. Soc. Am. J. 59:68-75.

Pannatier, Y. 1994. Variowin 2.1. Program for Geostatistical Analysis. University of Lausanne.

Papritz, A.J. 1993. Estimating temporal change of soil properties. Ph.D. Thesis, Swiss Federal Institute of Technology, Zurich. 166 p.

Perfect, E., P.H. Groenevelt, B.D. Kay and C.D. Grant. 1990. Spatial variability of soil penetrometer measurements at the mesoscopic scale. Soil Tillage Res. 16:257-291.

Perfect, E. and B.D. Kay. 1995. Application of fractals in soil and tillage research: a review. Soil Tillage Res. 36:1-20.

Rasiah, V. and A.G. Alymore. 1998. Characterizing the changes in soil porosity by computed tomography and fractal dimension. Soil Sci. 163:203-211.

Rieu, M. and G. Sposito. 1991. Fractal fragmentation, soil porosity, and soil water properties. Soil Sci. Soc. Am. J. 55:1231-1244.

Soil Sciences Annual. The Period from 1952 to 2000.

Sokołowska, Z., M. Hajnos and S. Sokołowski. 1998. Effect of leaching of dissolved organic carbon on fractal dimension of soils, pp. 231-239. *In* M.M. Novak (ed.). W: Fractals and Beyond: Complexities in the Science. World Sci. Pub. Co. Pte. Ltd., Singapore, New Jersey, London, Hong Kong.

Sokołowska, Z. and S. Sokołowski. 1999. Influence of humic acid on surface fractal dimension of kaolin: analysis of mercury porosimetry and water adsorption data. Geoderma 88:233-249.

Sokołowska, Z., J. Stawiński, A. Patrykiejew and S. Sokołowski. 1989. A note on fractal analysis of adsorption process by soils and soil minerals. Int. Agrophysics 5:3-12.

Usowicz, B., J. Kossowski and P.Baranowski. 1996. Spatial variability of soil thermal properties in cultivated fields. Soil Tillage Res. 39:85-100.

Usowicz, B. 1998. Time and space variability of soil thermal properties in cultivated fields. Proc. 16th World Congress of Soil Science, Montpellier, France. 20-26 August, CD 253-t.pdf, 1-9.

Walczak, R. and B. Usowicz. 1994. Variability of moisture, temperature and thermal properties in bare soil and in crop field. Int. Agrophysics 8:161-168.

Webster, R. 1985. Quantitative spatial analysis of soil in the field. Advances in Soil Science 3:1-70.

Webster, R. and T.M. Burgess. 1984. Sampling and bulking strategies for estimating soil properties in small regions. J. Soil Sci. 35:127-140.