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SPATIAL DISTRIBUTION OF TOPSOIL WATER CONTENT ALONG A LOESS HILLSLOPE TRANSECT

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Abstract. The paper presents statistical, geostatistical and fractal analysis of variability of topsoil water content along a loess hillslope. Spatial dependence of topsoil water content was observed on studied sites. On a site with plants, the range of spatial dependence was smaller than on a site without plants. Fractal dimension showed that topsoil water on a site with plants was more randomized than on a site without it.

Keywords: soil water content, spatial variability, fractals, TDR method.

INTRODUCTION

Among different soil characteristics, water properties are the most variable [10]. However, knowledge of spatial variability of water content is of special importance for modeling of energy and mass transport processes. Studies of spatial variability enable better understanding of the processes that take place in the soil and their results can be useful for elaboration of optimal methods for control of thermal-water-air relationships in plant environment and for prevention of land degradation [6,7]. The topsoil water content is especially important for detachability of soil aggregates and the conditions of runoff development, the most important factor in transport of soil particles during the erosion process [4].

The aim of the study was to evaluate spatial variability of soil moisture content along a hillslope on a site with the crop cover and without it.

MATERIALS AND METHODS

The experiment was carried out on a silt soil developed from loess (*Orthic Luvisols*) in Bogucin (20 km north of Lublin, Poland) on the Nałęczów Plateau. The granular composition of the cultivated layer of the soil was following: 2, 65, 23, and 11% w/w, respectively for particle sizes: 1-0.1, 0.1-0.02, 0.02-0.002 and <0.002 mm. The content of organic matter was 1.8 % w/w, and pH 5.3. According to Turski *et al.* [7] this soil can be classified as slightly eroded soil.

Measurements of topsoil water content were made along runoff plots [11] situated on a northern hillslope of 12%, on two sites, with crop cover (mixture of oats and barley) and without plants (kept as a bare fallow). Soil water content was measured with reflectometric method (θ_{TDR}) [5] in the surface layer (0-5 cm) at 1 m intervals along the slope. Measurement points (84) were arranged in form of rectangular grid (Fig. 1) that covered an area of 20 x 24 m. The arrangement was forced by the size of runoff plots. Spatial variability of the water content data was evaluated on the basis of analysis of semivariograms and fractal dimension with GS+ and GeoEAS programs [2,3]. Number of collected data (40) enables a representative description of water content with statistical and geostatistical methods. Fractal dimension was calculated using the slope of lag-lag plotted semivariograms [1,7]. Values of fractal dimension was determined from the equation:

$$D = 2 - H/2 \qquad (1)$$

where H is the slope of the lag-lag plot as h approaches zero, and h is the lag.

Measurements were started from 8th May 1997 and were continued in weekly intervals (12 measurement periods). Additionally, on 16th June 1997, soil cores of 100 cm^3 were taken to determine bulk density (ρ) and gravimetric water content (θ_{grav}). Cores were taken at the same locations as TDR measurements.

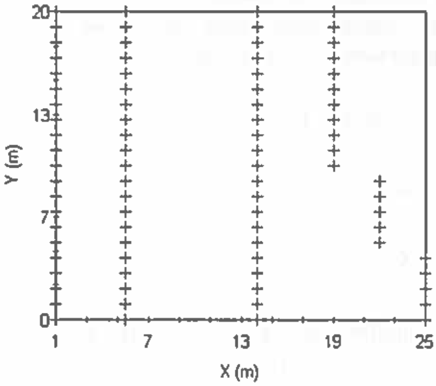


Fig. 1. Arrangement of measurement points.

RESULTS AND DISCUSSION

Rainfall and temperature characteristics

Total rainfall amount during the experiment (from 8th May to 21st July) was 169.7 mm. During the measurement periods there could be distinguished 4 periods in rainfall pattern, 7.3 mm from 8th May to 19th May, 53.5 mm from 19th May to 2nd June, 0.8 mm from 2nd June to 16th June, and 145.9 mm from 16th June to 21st July (Fig. 2). The average daily air temperature measured on 2 m above the ground surface during the measurement period was 14.8 °C, with minimum of 9.5 °C and maximum of 22.4 °C. The pattern of daily temperature is shown on Fig. 2.

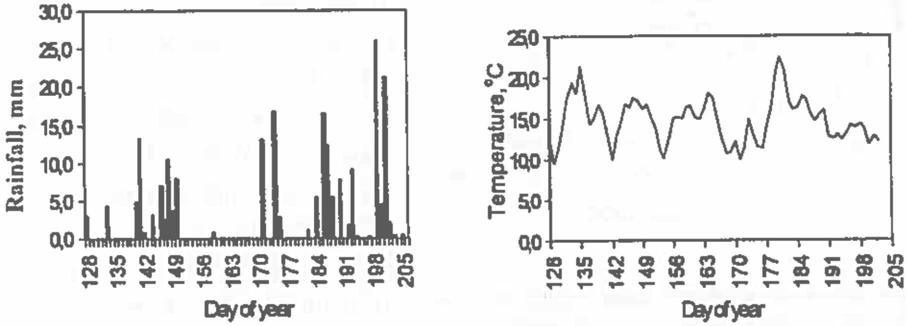


Fig. 2. Rainfall and average air temperature characteristics during the experiment.

Topsoil water content and bulk density

In order to determine conformity of data collected by two methods of water content determination, analysis of regression was performed. Values of soil water content obtained with reflectometric method were lower than values determined with gravimetric method. Nevertheless, the correlation between measurements made by these methods was in acceptable range with R=0.80. (Fig. 3). The similar relationship between both methods was observed by Usowicz and Kossowski [9].

Changes of water content during 12-week period and trend analysis were shown on Fig. 4a,b,c. A small decrease of water content with increasing slope position (height) was found on site with plants, whereas a small increase of water content with increasing slope position was found on site without plant. Topsoil water content on both sites analyzed together did not show any visible trend (Fig. 4c). Contrary to topsoil water content, analysis of bulk density data did not show any visible trend both on site with plants and on bare soil.

Statistics of water content and bulk density data, and fractal dimensions were shown in Table 1. Bulk density data were similar for both sites, and were in the

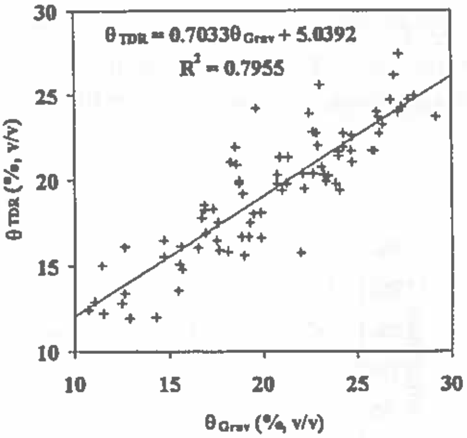


Fig. 3. Relationship between water content determined with reflectometric (θ_{TDR}) and gravimetric (θ_{Grav}) methods.

range 1.01-1.46 Mg m^{-3} on site with plants, and in the range 1.16-1.44 Mg m^{-3} on bare soil. Generally, topsoil water content was a little higher on a site without plants (22.1-31.6% v/v) than on a site with plants (17.1-30.1 % v/v). Bigger differences between both sites up to 7% were found only from 9th June to 30th June. This period was characterized by intensive growth of plant (from stage of second node to ear emergence), and additionally the period was followed by a week with no rain. Heavy rainfall period from 16th June to 21st July caused similar topsoil water content on both sites. The highest variability was observed on the site with plants at lower water content. An increase in water content resulted in decrease of the value of variability coefficient on both sites.

For the whole site (plant and without plant) and for sites with plants and without plants analyzed separately, semivariograms were calculated. Spatial autocorrelation was found both on the whole site and on separate sites. For the whole site, range of spatial autocorrelation was 23 m at lower water content and decreased to 3 m at higher water content. For separate sites, autocorrelation range were much smaller in comparison to the whole site at lower water content, and similar or higher at high water content.

At the beginning of measurements, values of fractal dimension were similar on both sites (Table 1). On a site without plants fractal dimension showed an increasing tendency with an increase of water content (r^2=0.34) and slight decreasing tendency with time, while on a site with plants fractal dimension showed slight increasing tendency with a water content and a decreasing tendency with time (r^2=0.53). The latter may be connected with development of plant, both in terms of canopy cover or plant height. This implies that plant growth caused an increase of randomization of water content, and the same, an increase of its spatial independence (Table 2). Fractal dimension of bulk density was high, with the values near the values of water content from 16th June.

Table 1. Statistics of topsoil water content and bulk density

Parameter	Water content, θ (%, ϖ/ϖ)											Bulk density, σ (Mg m^{-3})
Date 1997	8.05	12.05	19.05	26.05	2.06	9.06	16.06	30.06	7.07	14.07	21.07	16.06
						All data						
Mean	22.1	23.3	23.7	24.7	30.7	24.3	19.6	19.3	30.0	25.3	29.9	1.274
Coef. Var.	13.4	14.5	13.6	11.3	8.8	12.6	20.7	22.6	7.1	11.1	7.0	7.34
Fractal Dim.	1.913	1.922	1.942	1.935	1.934	1.912	1.832	1.608	1.966	1.950	1.944	1.995
						Plants						
Mean	22.3	24.6	23.2	23.8	30.1	23.0	17.1	15.6	29.4	24.9	29.1	1.244
Coef. Var.	13.3	13.6	14.6	12.0	8.1	13.0	22.5	13.3	6.4	10.3	7.7	7.45
Fractal Dim.	1.854	1.876	1.869	1.971	2.000	1.931	1.949	1.966	1.987	1.937	2.000	1.912
						Bare soil						
Mean	21.9	22.1	24.2	25.6	31.3	25.6	22.1	23.0	30.5	25.4	30.7	1.304
Coef. Var.	13.5	13.5	12.3	9.6	9.2	9.9	10.6	11.1	7.3	11.8	5.1	5.36
Fractal Dim.	1.846	1.956	1.976	1.920	1.779	1.931	1.930	1.914	1.892	1.863	1.854	1.946

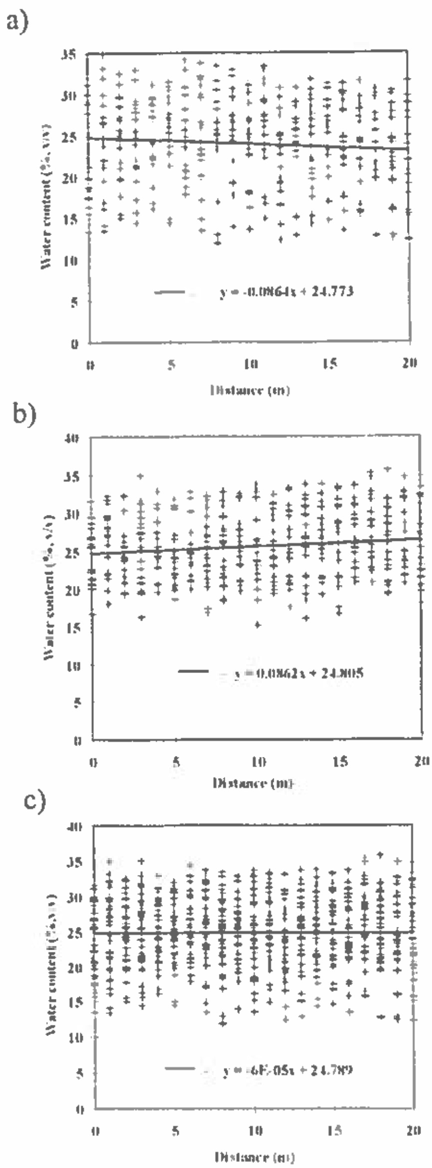


Fig. 4. Water content and trend functions on a site with plants (4a), without plants (4b), and for both sites together (4c).

Models of semivariograms were applied to create maps of spatial distribution of water content (Fig. 5) and bulk density (Fig. 6). To create the maps an ordinary kriging method was used. To present distribution of water during different weather conditions, there were chosen the following periods: 8th May (initial stage), 2nd June, 16th June, and 21st July. The maps showed that changes of water content were related to the stage of plant growth, to the periods of heavy rainfall, and to local changes of soil physical properties inside the experimental site.

CONCLUSIONS

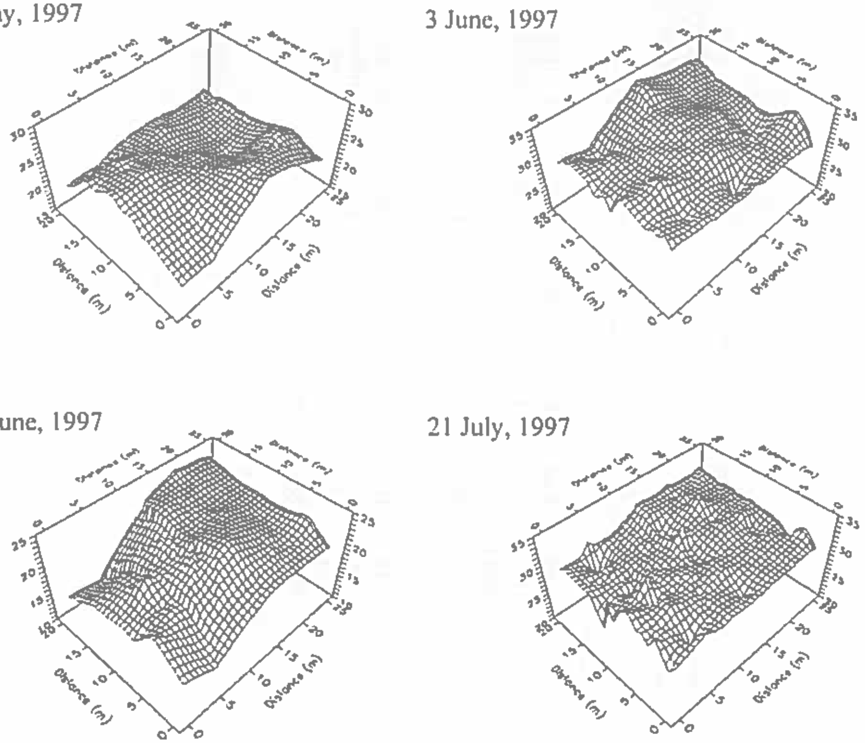
An approach applied in this study to characterize a spatial distribution of soil water content take into account a random character of physical status of porous media both in time and space. The experimental results showed that variability of water content was related to the level of soil water content and stage of plant growth. The highest variability was observed on the site with plants at lower water content. An increase in water content resulted in decrease of the value of variability coefficient on both sites.

On a site with plants, the range of spatial dependence was smaller than on a site without plants. It means that for representative description of topsoil water content distribution both on a site with plants and without plants, apart

T a b l e 2. Parameters of semivariograms

Parameter	Water content, θ (%, ϖ/ϖ)											Bulk density,σ (Mg m^{-3})
Date 1997	8.05	12.05	19.05	26.05	2.06	9.06	16.06	30.06	7.07	14.07	21.07	16.06
						All data						
Nugget (% v/v)2	3.59	5.98	5.3	5.85	2.68	4.9	6.41	0.01	0.42	1.27	0.27	1.71E-03
Sill (% v/v)2	9.12	12.01	10.61	9.22	7.48	9.81	19.18	26.35	4.44	7.70	4.28	7.67E-03
Range (m)	9.58	11.3	6.26	23.41	8.82	11.68	20.13	23.27	3.42	3.09	3.63	5.22
Models	Sph	Sph	Sph	Li	Li	Sph	Sph	Sph	Ex	Ex	Ex	Ex
						Plants						
Nugget (% v/v)2	3.42	3.07	7.24	6.82	4.85	7.06	2.18	0.39	0.65	5.27	0.81	6.76E-03
Sill (% v/v)2	11.31	11.7	16.22	9.37	6.66	11.03	15.9	4.38	3.55	7.56	4.49	1.06E-02
Range (m)	11.09	5.73	61.02	15.33	15.3	15.3	2.91	1.89	1.38	15.3	1.35	15.33
Models	Sph	Sph	Li	Li	Li	Li	Sph	Sph	Sph	Li	Ex	Li
						Bare soil						
Nugget (% v/v)2	3.17	7.17	0.01	4.2	2.96	0.89	0.32	0.67	0.21	4.93	1.54	3.91E-03
Sill (% v/v)2	10.05	10.82	8.83	7.45	13.93	6.92	5.50	7.07	5.28	13.85	3.39	5.83E-03
Range (m)	11.83	17.31	2.43	17.31	17.31	4.53	3.1	3.1	3.6	17.31	17.31	17.31
Models	Sph	Li	Ex	Li	Li	Ex	Sph	Sph	Sph	Li	Li	Li

Abbreviation: sph - spherical model; Li-linear model; ex - exponential model.



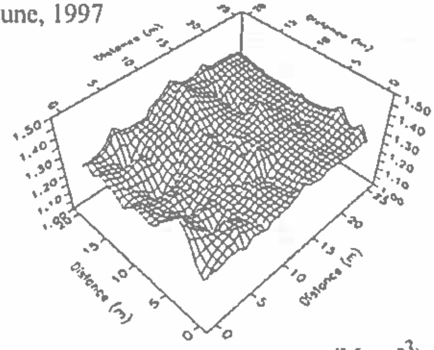
8 May, 1997

3 June, 1997

16 June, 1997

21 July, 1997

Fig. 5. Maps of soil moisture content estimated with kriging method for some measurement periods on the whole site (θ(%, v/v)).



16 June, 1997

ρ(Mg m^{-3})

Fig. 6. Map of bulk density estimated with kriging method for 16th June.

of statistical characteristics, geostatistical parameters are necessary.

Degree of spatial arrangement evaluated on the basis of fractal dimension showed an increasing tendency with an increase of water content and slight decreasing tendency with time on a site without plants, whereas on a site with plants it showed the opposite tendency. Plant development caused the increase in randomization (noise) of the topsoil water content.

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