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CHANGES OF SOIL MICRORELIEF UNDER THE INFLUENCE OF SIMULATED RAINFALL

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Abstract

Soil microrelief is one of the factors affecting wind and water erosion process. Spatial variability of soil surface (microrelief) influences initiation of the surface runoff and water flow mainly through depressions, where the runoff is delayed and infiltration increases owing to the interception of the flowing water. The research was conducted to assess the changes of relief of two soils (sandy loam and fine sand) under the influence of rainfall in a model experiment. The soil microrelief was determined by means of a contactless 3D scanner using the effect of line distortion as light beam illuminating the object surface (so called Moire pattern). On the basis of obtained results, maps of the differences in the scanned surface elevations were plotted in ArcGIS programme and the soil losses volume was computed. RR indicator calculated for sandy loam was decreasing with increasing depth of simulated rainfall. No such dependence was observed for loose sand.

Keywords: soil microrelief, 3D scanner, DEM, soil erosion

INTRODUCTION

Soil microrelief is a spatial diversification of the soil surface relief, which plays a crucial role in physical processes occurring on the soil surface (Rejman *et al.* 1996). It controls many processes on the whole soil interface (Huang, Bradford 1990), such as soil infiltration (Steichen, 1984; Govers *et al.* 2000), out-flow, heat flux transfer, gaseous exchange or evaporation. It is one of the factors affecting the process of wind and water erosion (Huang *et al*. 1988), initiating surface runoff and water flow mainly through depressions, where owing to the interception of the flowing water, the runoff is delayed and infiltration increases, as well as surface flow resistance (Govers *et al.* 2000; Darboux *et al.* 2002; Darboux and Huang, 2005). Techniques used for soil microrelief measurement were developed at the beginning of the sixties of the previous century. At that time the contact measurement method was used (Saleh 1993). A pin meter (Wagner and Yu 1991) proved to be a popular method. Currently, the contactless methods, such as laser scanning (Huang *et al.* 1988; Helming *et al.* 1998; Arvidsson and Bölenius, 2006; Dąbek *et al.* 2014) or photogrametric methods (Jeschke, 1990; Taconet and Ciarletti, 2007) are preferred. Due to time saving and precision of measurements the tools mentioned above proved efficient. Presented research made use of 3D scanner using white light technique to determine the changes in the microrelief of two soils under the influence of simulated rainfall, maps of differences in the elevation of scanned areas were made, the volume of soil losses was computed and the roughness coefficient was determined.

MATERIAL AND METHODS

Measurements of soil surface relief were conducted on sandy loam and fine sand. Sandy loam reveled the following granulometric composition: 78% sand, 14% silt, 8% colloidal clay and 1.3% organic substance. The measurements were carried out on the soils devoid of vegetation, in laboratory conditions. A 25 x 30 cm cuvette filled with a 10 cm thick soil layer was placed in the S12-MkII hydrological system. Soil was compacted with use a 5 kg block of concrete. Precipitation was simulated at a height of 1 meter above the soil surface. It was subsequently subjected to a 30 minute sprinkling irrigation with the intensity of 19 mm h^{-1}. Kinetic energy of the rainfall, computed on the basis of Wischmeier and Smith equation (1978) was 69.5 J m^{-2}. The soil moisture was measured with a laboratory TDR probe. Initial moisture content of both soils was 6%, which after 30 minutes of sprinkling increased to 30% in sandy loam and to 28% in fine sand. Changes in the surface relief were determined prior to the sprinkling onset and after each 10 minutes of the experiment. The analyzed area was 0.088 m^2 for sandy loam and 0.051 m^2 for fine sand. The changes of the soil surface microrelief were determined using 3D contactless scanner for contactless measurement of absolute coordinates of three-dimensional objects (x, y, z) and gathering information about the object texture (R, G, B). The technique uses the effect of line distortion as light beam illuminating the object surface (so called Moire pattern). The obtained data (number of measurement dots – 93 per mm^2) was subjected to the analysis involving cleaning by means of 3D Mesh software.

From the dot clouds obtained in this way, digital elevation models (DEM) were then interpolated with a resolution of 0.5mm by means of Nearest Neighbours method. The interpolation and further analyses were conducted using ArcGIS 10.3 programme. GIS tools were used because of their versatility and wide range of applications for spatial data processing, particularly for creating and analysis of DEM for various purposes (Bielska and Oberski 2014, Witzurki *et al.* 2016). On the basis of results obtained using ArcGIS 10.3 programme, maps of the differences in scanned surfaces elevations were plotted and the volumes of soil losses were computed. Compared were selected longitudinal cross-sections and the differences of the surface elevation before and after sprinkling were determined, indicating the sites of erosion and material deposition. The average relative elevation (AVG) referred to the minimum measured value and random roughness (RR) factor were determined. The random roughness factor was computed as a standard deviation of elevation points value (Allmaras *et al.* 1966):

$$RR = \left[\frac{1}{k} \sum_{i=1}^{k} \left(Z_i - \bar{Z} \right)^2 \right]^{1/2}$$

where: Z – readings at and location,
$\bar{Z}$ – mean readings at and location
k – number of readings

RESULTS

While analyzing obtained DEMs one may distinguish convex surfaces in various time intervals during the rainfall (Fig. 1 and 2). For sandy loam it was more visible that the surface was smoothed by the rainfall. Research conducted by Wesemael *et al.* (1996) revealed that soil surface roughness generally increases with tillage but decreases with growing rainfall depth. A lesser impact of rainfall on surface smoothing may depend on the soil granulometric composition and surface compactness, whereas the major factor affecting the changes of soil surface relief is the energy of raindrops impact. In the presented investigations kinetic energy of raindrops was the same, whereas the observed changes in both soil surfaces relief were different.

Changes of surface elevation of both soils surface as the main relief parameter were compiled in Table 1. Average values of Z [mm], both for sandy loam and fine sand, were decreasing with the time of sprinkling. Increases in average values (in 10 minute intervals) for sandy loam were 1.0 mm, 0.3 mm and 0.6 mm, respectively in the 10^{th}, 20^{th} and 30^{th} minute of sprinkling whereas for fine sand: 0.6mm, 0.8mm and 0.03mm. Changes in soil surface relief were assessed using a random roughness (RR) indicator (Tab.2). For sandy loam RR values showed a declining tendency in time. In other words, random roughness indicator decreased with increasing simulated rainfall depth. Many researchers have observed a decline in RR in the cumulative rainfall depth function (Magunda *et al.*, 1997; Linden, Van Doren 1986; Onstad *et al.*, 1984). In case of fine sand RR values did not change within the first 10 minutes, which does not evidence an unchanged soil surface relief. After 20 and 30 minutes of sprinkling RR indicator decreased by 0.01 mm. Obtained RR results for both soils are not compliant (increases in value) with the function suggested by Onstad *et al.* (1984) considering the relationship between RR and rainfall cumulation. It may be connected with the difference in the rainfall time and initial soil moisture content (Elbasid 2009). Wesemael *et al.* (1996) revealed that smoothing initially wet surface is very slow. Research conducted in this field demonstrated that in case of fine sand, smoothing of dry surface (initial soil moisture content 6%) was proceeding very slowly.

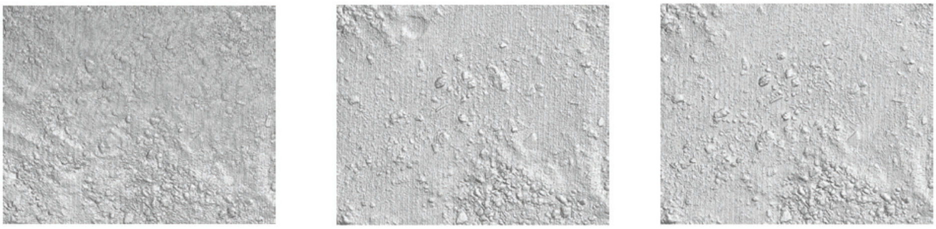

Figure 1. Maps of sandy loam surface relief – time step 0, 10 and 30 minutes

Figure 2. Maps of fine sand surface relief – time step 0, 10 and 30 minutes

Soil losses computed using ArcGIS 10.3 Programme were not increasing with the rainfall amount (Tab.2). For sandy loam the greatest soil losses were noted during the first time step of sprinkling (10 minutes). They decreased but then increased during the subsequent time step. It may be connected with initial low soil moisture content and settling of the soil surface. In case of fine sand, soil losses after 10 and 20 minutes were very similar. The Authors did not verify the values of soil loss computed by means of ArcGIS 10.3 Programme with real measurements in the respective time intervals.

Table 1. Changes of soil surface elevation in 10-minute time intervals

Time step [min.]	0/beginning	10	20	30/end
Parameter	Sandy loam			
Mean elevation [mm]	95.4	94.4	94.1	93.5
SD [mm]	10.6	10.3	10.1	9.9
	Fine sand			
Mean elevation [mm]	202.4	201.8	201.0	200.27
SD [mm]	9.9	9.9	9.8	9.9

SD – standard deviation

Table 2. Soil losses and mean erosion intensity in the individual time steps computed using ArcGIS Programme

	Time step [min.]	Soil loss from the previous scan [mm^3]	Soil los from the previous scan [m^3]	Mean erosion intensity from the previous scan [m^3/m^2]	RR
Sandy loam	0	0.00	0.00	0.00	10.6
	10	84 465.24	8.44652E-05	0.0009572	10.3
	20	32 623.44	3.26234E-05	0.0003697	10.1
	30	51 031.51	5.10315E-05	0.0005783	9.9
Total		174 103.20	0.000174103	0.001972953	
Fine sand	0	0.00	0.00	0.00	9.9
	10	32 107.38	3.21074E-05	0.000634634	9.9
	20	40 463.50	4.04635E-05	0.0007998	9.8
	30	36 162.00	3.6162E-05	0.000714763	9.9
Total		108 732.88	0.000108733	0.002149168	

Obtained results allowed to plot maps of the differences in the elevations of scanned surfaces. Figure 3 presents the difference between scans 0 and after 30 minutes of sprinkling. In case of loose sand uniform changes of the relief were observed almost on the whole surface. On a major part of the surface the changes were connected with soil loss. For sandy loam, erosion sites and apparent accumulation were spotted.

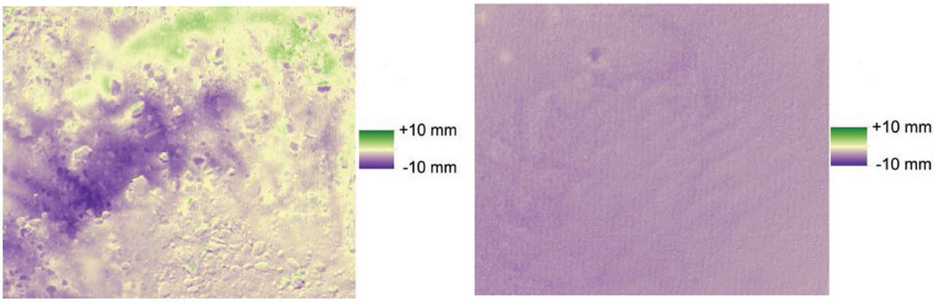

Figure 3. Maps of differences of the scanned surfaces in the 0 and 30th minute of sprinkling (left – sandy loam; right – fine sand)

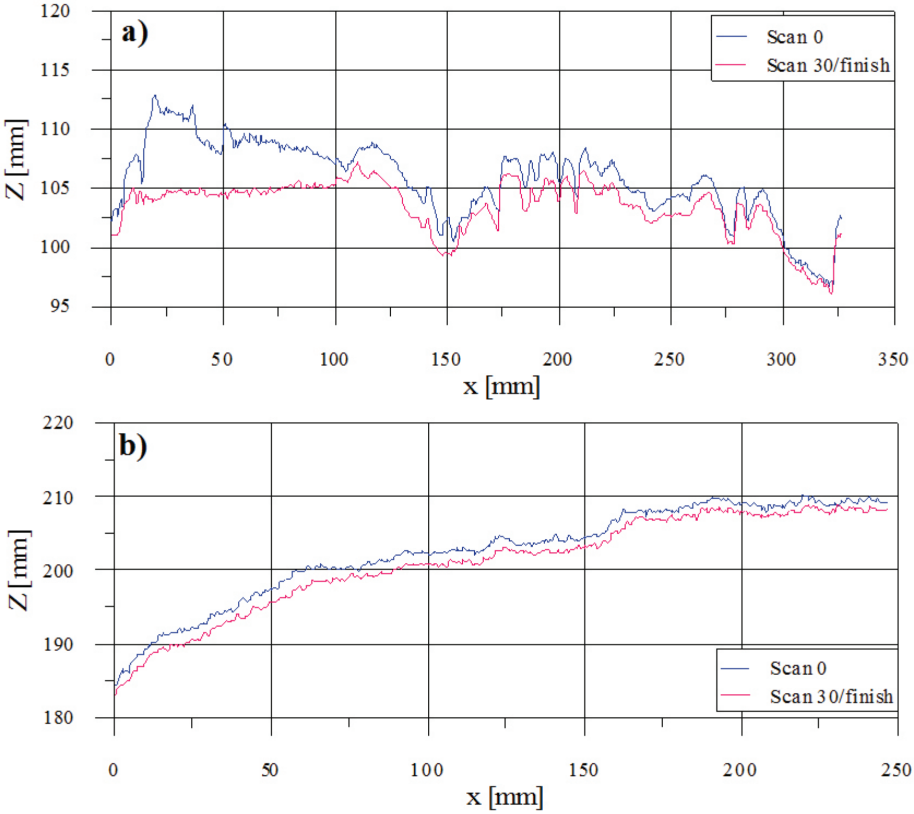

Figure 4. Sandy loam (a) and fine sand (b) cross section in 0 and 30th minute of sprinkling

Subsequently, cross sections were drawn along the analyzed surfaces of both soils (Fig.4). Maximum difference between 0 and the 30^{th} minute of sprinkling in sandy loam was – 9.0 mm, minimum +1.2 mm. Standard deviation of the elevation difference Z [mm] was 3.3 mm. Greater changes of relief were observed in the upper part, where soil washout with settling was maximum 9.0 mm. A lesser variability was observed for fine sand, where the minimum value of differences between the scans was – 2.9 mm, the maximum 0.04 mm and the standard deviation 0.46 mm. While analyzing changes in surface relief in a selected cross section of fine sand it may be seen that the changes were greatly uniform along the whole length of the cross section.

SUMMING UP AND CONCLUSIONS

The main aim of presented research was a comparison of changes in relief of two soils under the influence of simulated rainfall. 3D scanner using white light was applied as a measuring device. It is a very fast method, allowing to measure millions of coordinates of points describing shapes forming so called dot cloud during a very short time. Owing to this fact, a fast and precise mapping of even a very complicated geometry proved possible. Undoubtedly, this technique is not without flaws, as digitalization of object surfaces may involve a loss or misshaping of some of the information about the scanned surface (Szal, Herma 2011). Initially conducted research allowed for a most precise determining of the accumulation and erosion sites of the analyzed soil surfaces. Computed random roughness (RR) indicator for sandy loam decreased with an increase in simulated rainfall depth. On the other hand, for fine sand it did not change in the first 10 minutes, but decreased after 20 and 30 minutes. Soil losses computed following the ArcGIS 10.3 Programme were not increasing with the rainfall amount. For sandy loam the greatest soil losses were obtained after 10 minutes of sprinkling, whereas for fine sand soil losses after 10 and 20 minutes were approximate.

The choice of parameters, which would most precisely reflect the dynamics of physical processes occurring on the soil surface, remains a problem. Further research should be conducted to analyze the impact of various factors on the changes of soil microrelief, such as: variable rainfall intensity, the amount of runoff or initial moisture content.

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