Morphology characterization of a plowed land through fractal analysis

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Abstract The present study aimed to evaluate the micro-morphology of a plowed land surface by fractal analysis based on aerial images taken at different heights. The soil in the study area is of chernozem type, it was plowed in autumn and partially leveled under the influence of climatic conditions in the winter period. The images were collected in March and at the altitudes of 1m, 5m, 10m, 15m and 20m using a drone DJI Phantom 3. Fractal analysis was done using box-counting method and the fractal values (D) and multifractal values (Dmf) have been determined by binarized images analysis, based on pixels BW (Dbw), B+BW (Dbw+B) and W+BW (Dwb+BW). In the case of fractal analysis based on low altitude (1m and 5m) large amplitudes of variations have been captured regarding the micro-morphology of the studied area, as a result of the varying terrain surface given by the roughness and irregularity degree, by the various glomerular structures regarding size and weight, by vegetation residue from the previous crops, by the weeds grown, by the furrows tilting and disposition on the ground, a number of variants being identified that are well separated based on fractal dimensions. There have been registered fractal and multifractal properties of the studied areas. Between the fractal values and the height of image acquiring, interdependency relations have been identified in conditions of statistical certainty. These relations have been described by polynomial equations of 2nd degree in the case of fractal dimension D (R² = 0.991; p= 0.009), fractal dimension Dbw (R² = 0.998; p = 0.002), and of the fractal dimension Dwb+BW (R² = 0.984; p = 0.016) and by a sigmoid function in the case of fractal dimension Dbw+B (R² = 0.994; p< 0.001). Fractal analysis facilitated the characterization of the studied area compared to the micro-morphology particularities of the plowed land and the altitude of image acquiring, the cluster grouping of the fractal dimension based on Euclidean distances being performed in conditions of statistical certainty (Cophenetic coeff. = 0.843).

Geomorphometry as a science that studies the digital terrain modelling for qualitative and quantitative characterization of the landscape, agricultural and non-agricultural areas, the plots and parcels, had benefited greatly from interdisciplinary applications and solutions. As a bland the sciences of soil, geography, engineering, computer science, math, and imaging based on satellite images, aerial or terrestrial, GIS, this field has been revolutionized and greatly powered with the help of applications and implications in earth sciences, precision agriculture, environmental monitoring, etc. Extensive studies have been made in this direction, emphasizing the different segments, or having an integrating character with the purpose of clarifying certain theoretical and practical aspects [17].

Agricultural lands surface and the soil in these cases, is very heterogeneous. Although smooth and apparently uniform at small-scale, soil surface presents a number of irregularities given by the roughness, inequalities and micro-irregularities as a result of the soil particles under the dimensional aspect and colour (colour is variable depending on: the type of soil, status of the soil - dry wet, excess salt content, etc.). Strong variations are given by soil work (the type of works), the degree of compaction, precipitations and other natural or human factors. If the soil is then covered with vegetation, the characteristics are given by the vegetation cover either spontaneous or cultivated plants [7, 8, 9]. The need to characterize the surface of the soil and agricultural land has been considered for a long time in relation to various factors, and fractal analysis is a method commonly used in the study, characterization and modelling of land and soil [35, 2].

Fractal analysis was used to characterize the rough surfaces of the different materials, based on fractal dimension [16, 14, 15], the soil being a culture
medium with varying degrees of textures and surface roughness [24, 26, 25]. The soil was studied with high certainty by fractal analysis, in order to be characterized in terms of microrelief and micro topography and other specific features [28] in relation to natural and technological influence factors such as: precipitation and ground water regime [11, 30], soil erosion and degradation [37, 3, 34], desertification [38], use of the land and mechanical works of the soil [32, 33, 13], crop plants and associations of natural vegetation [29, 12, 36].

This study aimed to characterize the morphology and fractal geometry of the surface of the plowed field by fractal analysis, and to evaluate the change in fractal dimension in relation the acquiring altitude of the sample images.

Material and Method

The study was conducted in the Didactic Station of BUSAMVB Timisoara, plot of land A519/1, topo coordinates 45°78'43"N 21°21' 26"E. The land was plowed in autumn, the soil type being chernozem. Climate condition in the period autumn -winter, by frost-thaw and precipitation have influenced the soil furrows resulted from the plowing, thus a partial levelling was resulted.

Acquiring digital images. Images were taken with the help of the drone DJI Phantom 3, from different heights: 1m (figure 1), 5m (figure 2), 10 m (figure 3), 15 m (figure 4) and 20 m (figure 5), using a resolution of 12 MP.

Fractal analysis. Digital images of the area have been subjected to the fractal analysis (box-counting method) in order to obtain fractal dimensions (D) and multifractal (Dmf). The analysis was done on binarized images based on pixels BW, B+BW and W+BW. In case of the image taken from the height of 1 m, they were analysed and segmented from the image (100 x 100 pixels) thus showing a great diversity of the land under the aspect of fragmentation degree, shading, crop residue content, weeds grown figure 1a, and as result we have 9 distinct case studies (representing the average of the 27 fragments), figure 1b. For the fractal analysis the software ImageJ [20] and HarFA [39] have been used.

Statistical processing of results. Experimental data has been analysed for highlighting the variation using the test ANOVA. Also, they were analysed to assess the level of correlations [22, 23] between fractal dimensions and height of image acquiring, in order to characterize the dynamic variation of the fractal properties in relation to the altitude of acquiring the digital images. Processing and statistical analysis of the data was done using for statistical calculation module from the application EXCEL, Office 2007, software SPSS and PAST.

Fig. 1. Study areas from the image take at 1m height: (a) location and shape of image samples (100 x 100 pixels) studied; (b) image segments representative for the description of particular distinct cases of micro morphology at ground level.
Results and Discussions

Soil furrows over the season, under the influence of alternating frost-thaw and precipitation became chopped, thus resulted a partial levelling/smoothing of the soil. The digital images have captured differently the micro morphology of the land, according to the altitude where they were taken. In the digital image from the altitude of 1 m (figure 1), it’s the best way to identify different particular aspects of the soil and land, such as: the degree of soil compaction, vegetation residue and weeds in the growing process, differentiated fragmentation of the soil, glomerular structures and microstructures, etc. These aspects have been examined differently by cutting equal sections (100 x 100 pixels) of the initial image (variants V_1 – V_9, which represents the average of 27 sections, each variant having 3 sections: V_1, 2, 3; V_2 – 4, 5, 6; V_3 – 7, 8, 9; V_4 – 10, 11, 12; V_5 – 13, 14, 15; V_6 – 16, 17, 18; V_7 – 19, 20, 21; V_8 – 22, 23, 24; V_9 – 25, 26, 27, figure 7) and they have been analysed by fractal and multifractal analysis for characterization purposes. From the individual analysis of the images 1 – 27, the medium fractal values have been obtained, table 1, under the conditions of statistic certainty ($R^2 = 0.989$). Based on the distribution diagrams, differentiated behaviours were observed fractal and multifractal properties, Figure 2.

<table>
<thead>
<tr>
<th>Variants</th>
<th>D</th>
<th>D mf</th>
<th>Slope</th>
<th>D_BW</th>
<th>D_B+BW</th>
<th>D_W+BW</th>
<th>R^2</th>
<th>SE</th>
<th>CV</th>
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</thead>
<tbody>
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<td>V_1</td>
<td>1.846</td>
<td>1.668</td>
<td>1.665</td>
<td>1.752</td>
<td>1.599</td>
<td>1.992</td>
<td>0.995</td>
<td>0.04</td>
<td>0.0057</td>
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<tr>
<td>V_2</td>
<td>1.794</td>
<td>1.702</td>
<td>1.903</td>
<td>1.886</td>
<td>1.883</td>
<td>1.939</td>
<td>0.980</td>
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<td>0.0110</td>
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<tr>
<td>V_3</td>
<td>1.696</td>
<td>1.693</td>
<td>1.908</td>
<td>1.883</td>
<td>1.933</td>
<td>1.895</td>
<td>0.983</td>
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<td>0.0148</td>
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<tr>
<td>V_4</td>
<td>1.838</td>
<td>1.656</td>
<td>1.750</td>
<td>1.928</td>
<td>1.936</td>
<td>1.932</td>
<td>0.994</td>
<td>0.03</td>
<td>0.0110</td>
</tr>
<tr>
<td>V_5</td>
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<td>1.656</td>
<td>1.720</td>
<td>1.915</td>
<td>1.943</td>
<td>1.891</td>
<td>0.990</td>
<td>0.03</td>
<td>0.0115</td>
</tr>
<tr>
<td>V_6</td>
<td>1.638</td>
<td>1.518</td>
<td>1.887</td>
<td>1.837</td>
<td>1.964</td>
<td>1.822</td>
<td>0.978</td>
<td>0.05</td>
<td>0.0170</td>
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<tr>
<td>V_7</td>
<td>1.808</td>
<td>1.656</td>
<td>1.780</td>
<td>1.923</td>
<td>1.943</td>
<td>1.903</td>
<td>0.993</td>
<td>0.03</td>
<td>0.0116</td>
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<tr>
<td>V_8</td>
<td>1.826</td>
<td>1.668</td>
<td>1.730</td>
<td>1.886</td>
<td>1.802</td>
<td>1.981</td>
<td>0.990</td>
<td>0.04</td>
<td>0.0128</td>
</tr>
<tr>
<td>V_9</td>
<td>1.838</td>
<td>1.668</td>
<td>1.771</td>
<td>1.936</td>
<td>1.869</td>
<td>1.969</td>
<td>0.994</td>
<td>0.03</td>
<td>0.0130</td>
</tr>
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</table>

Table 1

| a. Slope for fractal dimension ($V_1$) | b. Fractal distribution ($V_1$) |
c. Slope for multifractal dimension ($V_8$)

Figure 2. Graphic representation on fractal properties in the micromorphy of the studied land

By analysing the obtained data (fractal dimensions) based on Euclidean distances, the cluster grouping of the variants was done according to the reality from the field, with a high degree of confidence (Cophenetic coefficient = 0.843). In the present study conditions, the most realistic cluster grouping has been done based on the values $D_{W+BW}$. For the overview images, acquired from the variable heights between 1m and 20m, fractal analysis led to the fractal and multifractal variables, shown in Table 2. Binarized images and interactive 3D surface plot are presented in Figure 3.

### Table 2

<table>
<thead>
<tr>
<th>H (m)</th>
<th>D</th>
<th>$D_{mf}$</th>
<th>Slope</th>
<th>BW</th>
<th>B+BW</th>
<th>W+BW</th>
<th>$R^2$</th>
<th>SE</th>
<th>CV</th>
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<tbody>
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<td>1</td>
<td>1.8872</td>
<td>1.9362</td>
<td>1.9905</td>
<td>1.8744</td>
<td>1.9188</td>
<td>1.9499</td>
<td>0.999</td>
<td>0.025</td>
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<td>5</td>
<td>1.8885</td>
<td>1.7925</td>
<td>1.8247</td>
<td>1.8661</td>
<td>1.9775</td>
<td>1.8017</td>
<td>0.998</td>
<td>0.023</td>
<td>0.0107</td>
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<td>10</td>
<td>1.8947</td>
<td>1.7931</td>
<td>1.8473</td>
<td>1.812</td>
<td>1.9873</td>
<td>1.7283</td>
<td>0.999</td>
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<td>15</td>
<td>1.8988</td>
<td>1.9819</td>
<td>2.0757</td>
<td>1.7415</td>
<td>1.9931</td>
<td>1.641</td>
<td>0.999</td>
<td>0.023</td>
<td>0.0103</td>
</tr>
<tr>
<td>20</td>
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<td>1.9888</td>
<td>2.0707</td>
<td>1.6497</td>
<td>1.9961</td>
<td>1.5408</td>
<td>0.999</td>
<td>0.024</td>
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</table>

Statistical correlation between the fractal dimensions and height of acquiring the images was carried out based on the correlation coefficient of Spearman’s rho, Table 3. It was observed that the height $H$ was correlated closely with all of the variables examined (the correlation is statistically significant, $p < 0.001$), excepting $D_{mf}$ and Slope. In relation to the last two variables, coefficients indicate an average correlation but not statistically accurate.

Analysing the interdependency relations between the height of the image acquiring and the fractal values, these have been described by 2nd degree polynomial functions under conditions of statistical certainty. Thus, variation of the fractal dimension $D$ according to the height of the images acquiring has been described in the equation (1), under conditions of statistical certainty ($R^2 = 0.991; p = 0.009$), graphical distribution of the particular values being represented in figure 4a.

### Variation of the fractal dimension

Variation of the fractal dimension $D_{BW}$ determined based on pixels BW have been described by 2nd degree polynomial function, equation (2), under very high conditions of correlation ($R^2 = 0.998$) and statistical certainty ($p = 0.002$), particular distribution of the data being shown in Figure 4b. In the case of fractal dimension $D_{W+BW}$, interdependency relation to the height of images acquiring has been described by a sigmoid function, expression of the function being shown by equation (3), under conditions of statistical certainty ($R^2 = 0.994; p < 0.001$), and graphical distribution in figure 4c. In the case of fractal dimension $D_{W+BW}$, interdependency relation to the height of images acquiring has been described by a 2nd degree polynomial function, equation (4), under conditions of statistical certainty ($R^2 = 0.984; p = 0.016$), and graphical distribution in figure 4d.
The table of correlations between the parameters studied

<table>
<thead>
<tr>
<th>Spearman's rho Correlation Coefficient</th>
<th>B+BW</th>
<th>BW</th>
<th>CV</th>
<th>D</th>
<th>DMF</th>
<th>H</th>
<th>SLOPE</th>
<th>W+BW</th>
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<td>1.000**</td>
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<td>Sig. (2-tailed)</td>
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**. Correlation is significant at the .01 level (2-tailed).
*. Correlation is significant at the .05 level (2-tailed).
Fig. 3. Binary image and interactive 3D surface plot resulted from the analysis of the digital images of the studied area, acquired from different heights (H 1m, H 5m, H 10m, H 15m, H 20m).

\[
D = 1.8865 + 0.0004H + 3 \cdot 10^{-5}H^2 \tag{1}
\]

\[
D_{BW} = 1.8795 - 0.0015H - 5 \cdot 10^{-4}H^2 \tag{2}
\]

\[
D_{B+BW} = e^{0.6916 - 0.0403H} \tag{3}
\]

\[
D_{W+BW} = 1.9618 - 0.0278H + 4 \cdot 10^{-3}H^2 \tag{4}
\]
The variation coefficient (CV) of the fractal dimensions is reduced along with the height, as a result of the reduction/blurring of the irregularities revealed from the details of the soil, captured in the images acquired at lower heights, especially 1 m. The CV behaviour in relation with the height was described by equation (5), under conditions of statistical certainty ($R^2 = 0.968; \ p = 0.032$), graphical distribution being shown in figure 5.

$$CV = 0.0108 - 2 \cdot 10^{-5} H - 4 \cdot 10^{-7} H^2$$

(5)

Fractal geometry parameters, such as the fractal dimension $D$, were used in creating some estimation models for the change in soil roughness, under simulated conditions of precipitation [1].

Rieu and Sposito (1990) [21] conducted soil description structured in the form of a fractal pattern. The model presented in the form of a porous medium, fractal fragmented, assumed a mathematical partitioning of a volume of soil in terms of specific components, spatially distributed. Variation of some parameters facilitated the estimation for the change in the structure and degree of behaviour of the soil based on the model developed. Tyler and Wheatcraft (1990) [27] studied the distribution of ground particles based on fractal dimensions and they have considered fractal analysis as a useful tool in assessing the relationship between the porosity of the soil (soil particle size and density) and water retaining capacity. The soil structure has been approached by fractal analysis also by Zribi et al. (2000) [40], who studied three types of soil: plowed...
soil, compacted soil as result of precipitation, and planted soil. Similar studies were conducted in other research [18, 10, 31, 19, 5] in order to characterize the different types of soil in the natural or cultivated areas.

Vázquez et al. (2007) [29] studied the microrelief from the surface of the soil according to the precipitations and six different systems of soil works using fractal analysis. The fractal dimension D was used to describe the way irregularities have changed according to the scale. They found that the fractal value D has changed according to the type and number of soil works, as well as according to the quantity of rainfall, the value of D is decreasing in relation to the increase of precipitation quantity regardless of the type of soil works. Fractal dimension D was found to be a very good indicator for describing the variation of horizontal and vertical roughness of soil. Dathe et al. (2001) [4] studied based on fractal and image analysis, aspects of soil porosity, in the context of increased interest for quantification of soil structure according to different influence factors. By fractal analysis, they highlighted aspects of complexity and heterogeneity of soil structure. The study was conducted on a microscopic digital images of a luvisol (Bt horizon), Gottingen, Germany, and found interdependencies between fractal dimensions and image resolution and respectively soil properties. Ersahin et al. (2006) [6] used fractal analysis for the study of specific size and particle distribution of 22 types of soil with different textures. The comparative analysis of fractal dimension with other parameters of soil led to the polynomial regression function which accurately estimated the specific surface area of the cation exchange capacity ($R^2 = 0.740 – 0.760$).

In this study, fractal analysis (according to the fractal dimensions obtained) was used to describe the morphology variation of the land in relation to the specific particularities and height of the image acquiring.

Conclusions

Fractal analysis facilitated the accurate analysis of the surface geomorphology for a plowed land, partially levelled by weather conditions, based on digital images acquired at varied altitudes. Based on the low altitude images (1m and 5m), large amplitudes of variation were captured regarding the micro-geomorphology of the plowed field and fractal and multifractal properties have been identified.

Between the fractal dimensions and altitude of the images acquiring, there has been recorded a high correlation described using 2nd degree polynomial functions and sigmoidal functions, under conditions of statistical certainty.

Along with the altitude increase for the images acquiring in the range studied, there is a decrease of fractal dimension variation coefficient as a result of the limitation of irregularities due to land micro morphology, more obvious in images of low altitude (1 m).

References

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