FRACTAL CHARACTERIZATION OF WHEAT CROP BASED ON DIGITAL IMAGES CAPTURED IN THE VISIBLE SPECTRUM

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Abstract

Fractal analysis was used as an instrument for the characterization of a winter wheat crop in different vegetation stages. The digital images captured in the visible spectrum were analyzed with the soft HarFA and ImageJ, and the data obtained facilitated the fractal characterization of the wheat crop. The fractal dimension (FD) varies in relation with the growth stages analyzed, between $1.896\pm0.019 - 1.931\pm0.017$ (with HarFA) and $1.898\pm0.015 - 1.933\pm0.064$ (with ImageJ), with a correlation $R^2 = 0.983 - 0.999$ for FD. The highest values of the fractal dimension were recorded in the stage of physiological maturity of plants. Particular values of the fractal parameters (fractal spectrum – FS, fractal dimension - FD) are specific for each vegetation stage and can represent stable elements for characterizing the wheat crop development.

Keywords: fractal analysis, fractal dimension, fractal spectrum, image processing, Triticum aestivum L.

INTRODUCTION

The vegetal cover of the earth is characterized by wide dynamics in space and time, depending on various factors, among which the climate and anthropic actions play a key role, (Vitousek et al., 1997; Karl and Trenberth, 2003).

Research on the spatial and temporal development of natural vegetation (grassy or woody) and of agricultural crops is of great interest, and the methods of investigation have developed, diversified and are intercorrelated in order to facilitate their parameterization and quantification for various purposes, with scientific and practical applications. In this direction, fractal analysis occupies a special place, (Walker and Kenkel, 1998; Li, 2000; Alados et al., 2005).

Fractal theory gives a qualitative and quantitative description of the irregularity inherent to any real object or phenomenon, in relation to the presence of complexity in variable dimensional scales. If the classic statistic theory describes irregularities of a limited number of parameters in a population with the other stable parameters, fractal analysis brings a quantitative measure in the case of structures of unlimited complexity, including the changing of the scale to which the analysis is made.

As a matter of fact, that is how all biological structures are, easily identifiable as approximate fractals (Mandelbrot, 1983; Zmeškal et al., 2001).

Eghball and Power (1995) used fractal method to analyse and characterize temporal variability for average yield in the United State of different crops with a wide range of yield levels and found with this method that crops were significantly different in terms of temporal variability. Eghball and Varfel (1997) observed different variability for crops under the influence of environmental factors and the management practices. They concluded in their research that temporal variability was much more dominant than spatial variability. Temporal variability may greatly influence how spatial variability is expressed in a given field.

Florin et al. (2009) studied the wheat yield variation across space and time. They said that is a serious need to further question how temporal variation of crop yield impacts one’s ability to manage spatial variation. With greater depth of temporal crop yield data this is a promising perspective from which to identify
optimal spatial management strategies. Numerous other studies have
used fractal methods for the study of land complexes (spontaneous
grassy or woody vegetation, cultivated areas, urban areas etc.) based
on satellite images or terrestrial images (Eghball et al., 1997; Green et
al., 2004; Hotař and Novotný, 2006; Linares et al., 2006; Zhu et al.,
2006; Ehsani et al., 2008).
The aim of the present research was to analyze
digital images captured in the visible spectrum
of a wheat crop, in different growth stages, for
obtaining a fractal characterization of the crop.

MATERIALS AND METHODS

The research focused on assessing the features
and obtaining a fractal characterization of a
wheat crop in different growth stages, based on
digital images captured in the visible spectrum.
Biologic material. The biologic material was
represented by species Triticum aestivum L.
ssp. vulgare "Ingenio" cultivar, in a uniform
crop condition. The assessment was made in
three growth stages: vegetative growth, booting
and full maturity.
Capture of digital images. Digital images were
captured with a Nikon D300 camera, 12 MP,
DX format, 24 mm focal lens, from a height of
1.5 m. Four digital images were taken for each
growth stage, for the purpose of work
uniformity.
Image processing and fractal analysis. Box-
Counting is the most important approximate
calculation method for assessing the fractal
dimension (Hausdorff). The Box-Counting
method was used for evaluating the fractal
properties of the wheat crop in different stages.
For this, the software used was HarFA lite
v5.5.30, which was developed at the Institute of
Physical and Applied Chemistry, Technical
University of Brno in the Czech Republic. The
software includes a procedure called Box-
Counting, which facilitates the evaluation of
the fractal dimension (Buchniček et al., 2000;
Nežádal et al., 2001).

RESULTS AND DISCUSSIONS

The canopy of wheat crop in a wheat crop is
very complex, due to its constitutive elements:
plants, stems, leaves, spikes with different
distribution angles in a three-dimensional plan.
The vegetative mass of the crop displays wide
dynamics in space and time, given by the
individual morphology, by plant density and
the morphologic specificity of each growth
stage.
Digital images of a wheat crop, Ingenio
cultivar, captured 1.5 m high, underwent
analysis for fractal characterization of the
respective crop in various growth stages, as
shown in Figure 1.

![Figure 1. Original images of wheat crop in different stages of vegetation, Ingenio cultivar](image)

HarFA software analyses black & white
images. The Box-Counting method utilizes the
covering fractal pattern with raster of boxes
(squares) and then evaluates how many boxes

$N_B$, $N_W$ or $N_{BW}$ of the raster are needed to
cover fractal completely (Kubík, 2005), where:

$N_B$ - number of black squares; $N_W$ - number of
white squares; $N_{BW}$ - number of black&white
squares; $N_{BBW}$ - number of black and
black&white squares; $N_{WWW}$ - number of white
and black&white squares.
These aspects are important, because for different values of Mask Intensity on a scale from 0 to 255 pixels (black & white), different values of the fractal parameters are obtained for the same image. Repeating this measurement with different sizes of boxes \( r = 1/c \) will result in logarithmical function of box size \( r \) and number of boxes \( N(r) \) needed to completely cover fractal. The slopes of the linear functions (1), (2), (3):

\[
\ln N_{BW}(r) = \ln(K_{BW}) + D_{BW} \ln(r), \quad (1)
\]
\[
\ln N_{BBW}(r) = \ln(K_{BBW}) + D_{BBW} \ln(r), \quad (2)
\]
\[
\ln N_{WBW}(r) = \ln(K_{WBW}) + D_{WBW} \ln(r). \quad (3)
\]

give \( D_{BW} \), \( D_{BBW} \) and \( D_{WBW} \) the fractal dimensions. \( D_{BW} \) characterizes the properties of border of the fractal pattern, \( D_{BBW} \) characterizes the fractal pattern on the white background and \( D_{WBW} \) characterizes the fractal pattern on the black background. This procedure was used for analyzing all digital images for the three growth stages of the wheat crop under research. The box counting dimension was computed over a black and white representation of the image area (4288 x 2848 pixels). Based on the analysis of the B&W histogram of the images captured, for every image we obtained a total number of 12212224 pixels, with intensity variation specific for each growth stage analyzed, as shown in Figures 2-4.

Taking into account the 0 to 255 variation interval for Mask Intensity and consequently the range of thresholding conditions (fractal analysis interval), a fractal dimension analysis was made on the interval minim value - maxim value for every image and the fractal spectra were obtained, Figures 2-4, where: a - binary image for fractal analysis, b - histogram distribution of pixels in B&W image, c - fractal spectra.

From the analysis of fractal spectra and of histogram distributions, the thresholding intervals were established for each digital image. For these particular cases in the entire fractal spectrum, Table 1 presents the thresholding functions and the correlation values (R) corresponding to the growth stages under analysis, while Figure 5 shows the regression functions.

The fractal dimensions obtained on the analyzed interval, when both categories of boxes are taken into consideration (fully covered and partially covered), are: 1.896-for stage 1; 1.904-for stage 2 and 1.931-for stage 3.
After processing the digital images with the software ImageJ on the three growth stages of the wheat crop, equation (13), the results show an increase in the average value of the fractal dimension (FD) together with the morphological and physiological changes in plants brought about by different phenophases, similarly with the values determined with HarFA.

\[ FD = \text{regression slopes} \left( \frac{\ln(F)}{\ln(a)} \right) \]  
(13)

where:
FD = fractal dimension
F = boxes containing foreground pixels
\( a \) = Box size/Image dimension

The highest value of the fractal dimension was recorded at physiological maturity of the wheat crop, as shown in Table 2. Anova statistical analysis indicates reliability of the results obtained by fractal analysis of wheat crop, Ingenio cultivar (F>F crit, p<0.01), Table 3.

![Image](image.png)

Table 1. Functions for calculating the fractal dimensions \( D_{BW} \), \( D_{BBW} \) and \( D_{WBB} \) and the values of the correlation coefficients particularized for the thresholding condition

<table>
<thead>
<tr>
<th>Growth stage</th>
<th>Equations</th>
<th>Equation number</th>
<th>Correlation (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>( \ln N_{BW} = 1.7162 \ln(a) (\pm 0.3800) + 14.9420 (\pm 0.3121) )</td>
<td>(4)</td>
<td>0.985</td>
</tr>
<tr>
<td></td>
<td>( \ln N_{BBW} = 1.8966 \ln(a) (\pm 0.0191) + 15.8138 (\pm 0.0706) )</td>
<td>(5)</td>
<td>0.999</td>
</tr>
<tr>
<td></td>
<td>( \ln N_{WBB} = 1.8800 \ln(a) (\pm 0.0218) + 15.7427 (\pm 0.0806) )</td>
<td>(6)</td>
<td>0.998</td>
</tr>
<tr>
<td>Stage 2</td>
<td>( \ln N_{BW} = 1.6933 \ln(a) (\pm 0.3800) + 14.9420 (\pm 0.3121) )</td>
<td>(7)</td>
<td>0.983</td>
</tr>
<tr>
<td></td>
<td>( \ln N_{BBW} = 1.9086 \ln(a) (\pm 0.0191) + 15.8138 (\pm 0.0706) )</td>
<td>(8)</td>
<td>0.999</td>
</tr>
<tr>
<td></td>
<td>( \ln N_{WBB} = 1.8597 \ln(a) (\pm 0.0218) + 15.6001 (\pm 0.0806) )</td>
<td>(9)</td>
<td>0.999</td>
</tr>
<tr>
<td>Stage 3</td>
<td>( \ln N_{BW} = 1.7993 \ln(a) (\pm 0.0670) + 15.3584 (\pm 0.2693) )</td>
<td>(10)</td>
<td>0.990</td>
</tr>
<tr>
<td></td>
<td>( \ln N_{BBW} = 1.9314 \ln(a) (\pm 0.0170) + 15.9974 (\pm 0.0630) )</td>
<td>(11)</td>
<td>0.999</td>
</tr>
<tr>
<td></td>
<td>( \ln N_{WBB} = 1.8047 \ln(a) (\pm 0.0310) + 15.0803 (\pm 0.1148) )</td>
<td>(12)</td>
<td>0.998</td>
</tr>
</tbody>
</table>

The correlation coefficients resulting from the calculation of the fractal dimension (FD) with two applications, HarFA and ImageJ, have values of 0.983-0.999, which also has high safety results.

Fractal dimension values obtained (FD) are between 1-2 and topological aspect of wheat crop can be considered, as fractal properties, between segment and square after general formulas:

\[ N(a) = \left(\frac{a}{2}\right)^2 \] for segment (value 1)

and

\[ N(a) = \left(\frac{a}{2}\right)^2 \] for square (value 2).
**CONCLUSIONS**

The results obtained through this study facilitated the parameterization and fractal characterization of the wheat crop, Ingenio cultivar, based on digital images captured in different growth stages.

The fractal spectrum (FS) has particular distributions and offers information that is specific for each growth stage of the wheat crop under analysis. The values of the average fractal dimension varied depending on the growth stage analyzed. One particularity observed through the present study was that the fractal dimension increased as the wheat crop developed from one growth stage to another. Fractal dimension can be associated with other wheat crop parameters in order to provide more information about the growth stage.

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**REFERENCES**


***ImageJ 1.47t, Image Processing and Analysis in Java, Wayne Rasband developer, National Institute of Health, USA.