FRACTAL ANALYSIS OF THE MODIFICATIONS INDUCED ON TOMATO PLANTS BY HEAVY METALS

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The fractal analysis is most useful in characterizing the structure of branching trees, root of plants, leaves, membrane surface of cells and so on. The fundamental underlying principle in fractal geometry is self-similarity and scale invariance which is a principle in the development and growth of biological forms. The exponent of these properties is the fractal dimension. The fractal dimension is a fractional quantity and it is a direct measure of the relative degree of complexity and roughness of the figure and it can never be greater than the Euclidian dimension of the space where the object is embedded. Fractal geometry has been applied to describe various aspects connected with the complexity of plant morphology. Many authors used the fractal analysis to study the form of the different kind of plants and tissue. The main objective of this study was to evaluate the impact of the treatment with zinc and cadmium on growth of tomato plants, using fractal analysis. In order to evaluate the change on tomato plants we determined the fractal dimension for untreated and treated tomato plant shoots. Our results showed that the average fractal dimension for untreated tomato plant is 1.4486, for treated tomato plants with zinc it is 1.3254 and for treated tomato plants with cadmium it is 1.2401. These results demonstrated that the fractal structure tomato leaves changed after the treatment with these heavy metals by comparison with the control ones. We suggest that these heavy metals diminished both the plant growth and their capacity to develop complex leaves.

***Keywords**: fractal dimension, self-similarity, heavy metal.*

Many biological objects like plants, leaves, roots, cells or sub cellular organelles display irregular shapes and discontinuous morphogenetic pattern in connection with their functional diversity and seem impossible to describe them rigorously or quantitatively using Euclidean geometry.

Fern leaf is the familiar example in this domain. A quantitative approach to the size and shape of fern leaves has never been formulated [2]. The study about fern leaves showed that the shapes and fronds have fractal properties and fern fronds differ from one species to another.

Then concepts of fractal geometry are most useful in characterizing the structure of some irregular objects. Many physiological processes are influenced by the size [14].

The concept of a fractal is most often associated with geometrical objects satisfying two criteria: self-similarity and fractional dimensionality. Self-similarity means that an object is composed of sub-units that (statistically) resemble the structure of the whole object. The fractal dimension is a fractional quantity and it is a direct measure of the relative degree of complexity and roughness of the figure and it can never be greater than the Euclidian dimension of the space where the object is embedded (Benoit Mandelbrot, *The Fractal Geometry of Nature,* New York, 1975). Many authors used the fractal analysis to study the form of the different kind of organs and tissue [3], [9], [10], [12], [15],[16]. Studies on the form for different kind of plants were reported in the literature [5], [6], [17].

The main objective of this study was to evaluate the impact of the treatment with zinc and cadmium on growth of tomato plants, using fractal analysis. In order to evaluate the change on tomato plants we determined the fractal dimension for untreated and treated tomato plant shoots.

MATERIAL AND METHOD

The tomato seeds (Buzau variety), were put into Petri dishes on double filter paper together with their treatment solution of different salts and 1% concentration where they were kept one week.

After that they were washed and they continued to germinate into Petri dishes water. Germinated seeds were planted in pots at the Biophysics Laboratory where they developed in low conditions of temperature (16-20^{0}C).

After two months measurements on fractal dimension of the tomato plants were performed. Then we sorted the following variants:

1 - untreated plants (control);
2 - treatment with $ZnSO_4*7H_2O$;
3 - treatment with $Cd(CH_3COO)_2*2\ H_2O$.

To determine the fractal dimensions the modified Box-Counting Method (BCM) method was used. HarFA soft from Institute of Physical and Applied Chemistry, Brno University of Technology, Czech Republic, was utilized to study images of tomato plants. In HarFA is used a modification of traditional Box Counting Method. By this modification on obtain three fractal dimensions, which characterise properties of black plane DB, black-white border of black object DBW (and this information is the most interesting) and properties of white background DW. The fractal dimension is the slope of the straight line „Black&White” [19].

This method is, in our opinion, very easy to use and more accurate and can be applied in plant physiology.

RESULTS AND DISCUSSION

Figure 1 show the untreated and treated tomato plants performed with a Canon camera. These photos were prepared with the COREL PHOTO-PAINT 1 in order to use the HarFA soft to show that these plants are fractals and to determine the fractal dimension of their contours [11].

In figures 2 and 3 the fractal dimension for untreated plants and for treated plants with Cd are given. For treated plants with Zn the diagrams are not given in this paper.

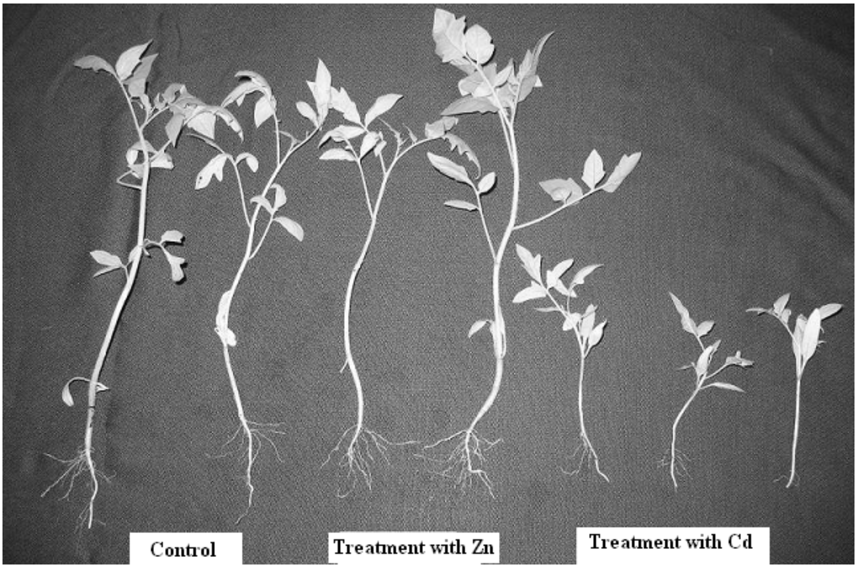

Figure 1. **Tomato plants**

Our results showed that the average fractal dimension for untreated tomato plant is 1.4486, for treated tomato plants with zinc it is 1.3254 and for treated tomato plants with cadmium it is 1.2401. Then these results showed that the treatment of the tomato plants with zinc and cadmium influences the responses of the plants to these stress factors.

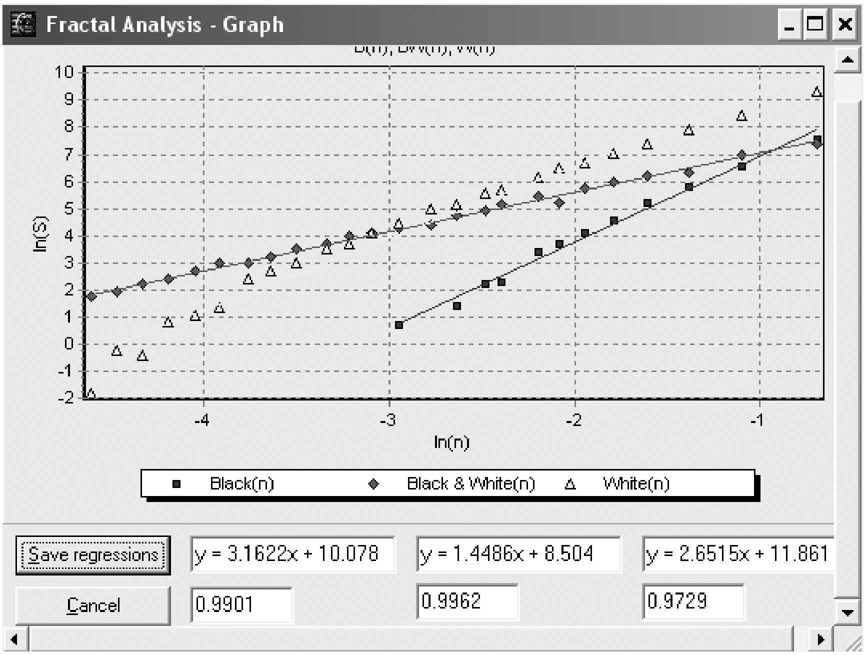

Figure 2. **Fractal dimension for untreated plant**

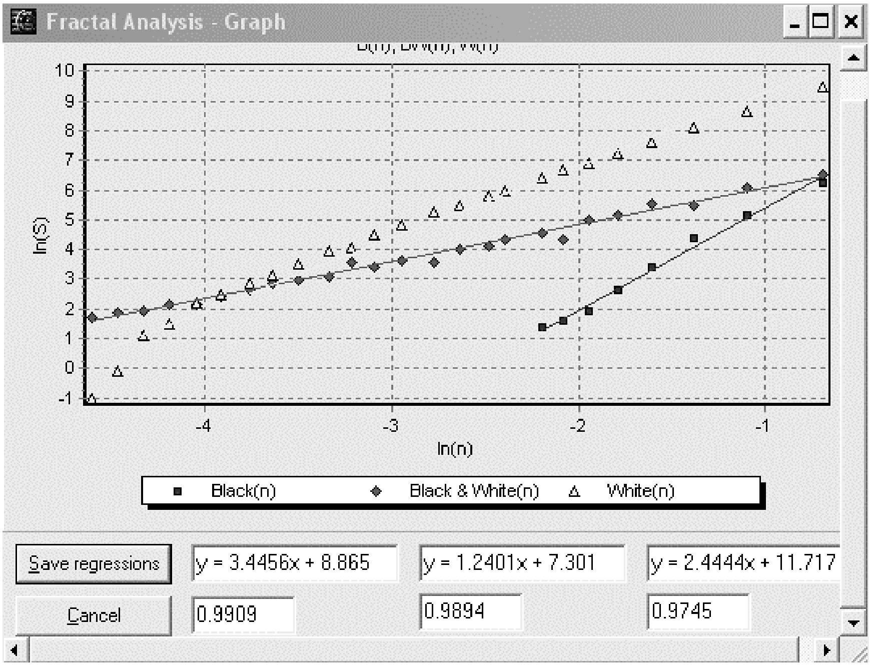

Figure 3. **Fractal dimension for treated tomato plants with Cd**

We also showed in a quantitative way that our specie is a fractal and the fractal analysis is adequate to determine the response of plants to the different stresses.

Our opinion is sustained by J. R. Castrehon Pita and coworkers [13] who used Box Counting Method to measure the fractal dimension of an African plant that is widely cultivated as an ornamental, *Asparagus plumosus*. The leaves of this plant consist of repeated bifurcations from the main stem, showing a high degree of both symmetry and scaling. Although the branches may be dramatically different in shape the authors show that their fractal dimension is the same.

Borkowski [1] demonstrated that fractal dimension may be used to discriminate between species with more than 90% accuracy, especially when used with other measures. Then it may be utilized for purely taxonomical purposes.

We also studied the fractal properties of the tree leaves in order to describe the leaf complexity [4]. Fractal dimension, which determines the complexity level of an object, indirectly provide some information about its shape as well.

To study the role of the root systems in soil-based resources acquisition by plants, root system complexity must be quantified, in addition to other morphometric traits. In [8] authors developed a new method using computed tomography (CT) in order to study the complexity of root systems. The fractal dimension of each root system was estimated on a skeletonized 3D image reconstructed from CT scan data.

G.B. West and coworkers [18] showed that the existence of fractal-like network endows life with an additional fourth spatial dimension. Natural selection has tended to maximize both metabolic capacity, by maximizing the scaling of exchange surface areas, and internal efficiency, by minimizing the scaling of transport distances and times.

CONCLUSIONS

We pointed out the importance of concept of fractal structure in physiological characterization of plant morphology in this paper. Heavy metals induce a number of toxicity symptoms in plants e.g. choroids and blackening of root system it inhibits photosynthesis, upsets mineral nutrition and water balance [7].

We demonstrated that these heavy metals diminished the fractal dimension of the tomato plants. This means that heavy metals diminished both the plant growth and their capacity to develop complex leaves.

This work presents a morphological effect of Zn and Cd toxicity using a quantitative method of study, fractal analysis, with the scope to develop a strategy for heavy metal detoxification. In this work we determined the planar fractal dimension (2D) of the plants, with the aid of the above mentioned photos, but for better results we will use the 3D fractal dimension in the future and we will connect it with the morphological change in plant system.

We suggest that some other possibilities, e.g., measures based on multifractal dimension or nonlinear approximation are worthy of study.

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