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Fractal Dimensions of Preferential Flow Pathways in Field Soils

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Introduction

In the last two decades, preferential flow has been increasingly recognized as a process of great practical significance for the transport of water and contamination in field soils. Dyes have been frequently used to identify preferential pathways and recently fractals have been applied to characterize the geometry of stain patterns on digitized images of soil profiles. Fractals present the advantage of encapsulating the complex geometry of stain patterns into just two numbers, the so-called "mass" and "surface" fractal dimensions. Unfortunately, the evaluation of these dimensions requires a number of subjective choices to be made and the effect of which is unclear. The purpose of the present paper is to address directly this issue of subjective choices in the estimation of fractal dimensions.

Materials and Methods

Digitized images of stain patterns obtained in two separate infiltration experiments. In the first experiment, in an "orchard" soil, a vertical soil profile was carefully isolated and photographed (Figure 1). The resulting images, at different resolution, were thresholded using two separate algorithms, intermeans and minimum-error-method. Three fractal dimensions, capacity, information, and correlation dimensions, were evaluated for both mass and surface. The second field experiment involved the same "orchard" soil as in the first experiment, as well as sandy soil.

Results and Discussion

Of the various parameters subject to choice, image resolution seems to have the most pronounced influence on the value of the fractal dimension, with the latter increasing markedly at higher resolution (Figure 2). This dependence on image resolution suggests that the stain pattern is not a mass fractal. On the other hand, no such dependence on image resolution exists for the surface fractal dimensions, suggesting that the stain pattern is a surface fractal (Figure 3).

The sequence of images of horizontal cross-sections of the stain patterns in the two soils suggest that fingering occurred in the "orchard" soil, not in the sandy soil. However, the surface fractal dimensions of the stain patterns are very similar in both cases. This similarity suggests that these dimensions provide information not so much on the geometry of the stain patterns but more directly on the fractal properties of the pore network in the soil. This viewpoint is confirmed partially by the evidence of a good correlation between the surface fractal dimension and the exponent of a Van Genuchten-like expression applied to the particle size distribution of the soil (Figure 4 and 5).

References

Baveye, P., Ogawa, S., Boast, C.W., Parlange, J.-Y. and Steenhuis, T. Influence of image resolution and thresholding on the apparent mass fractal characteristics of preferential flow patterns in field soils. *Water Resources Research*, published, 1998.

Keywords: fractals, preferential flow, fingering, image processing

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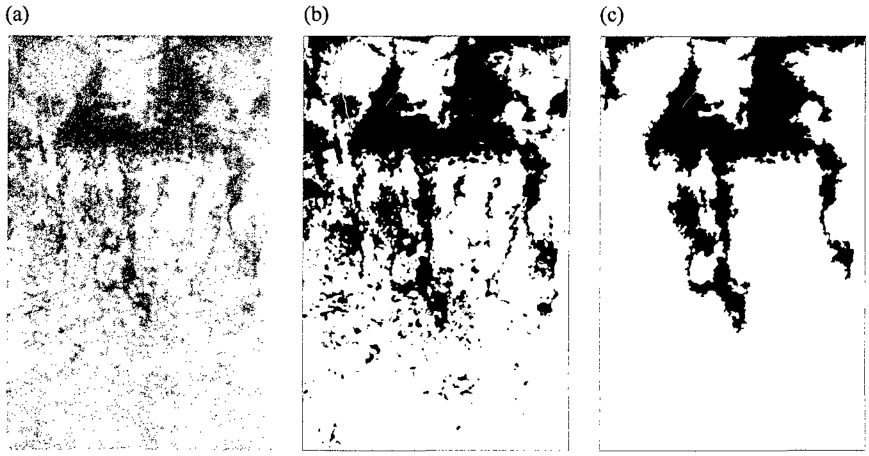

Figure 1 (a) Grayscale image, labeled 16-2, of the cyan layer of picture 16 retrieved at the second highest possible resolution, (b) black-and-white image obtained by thresholding image 16-2 with the intermeans algorithm, and (c) same image as in (b) but after removal of "islands" and filling of "lakes". (The frames around Figures (b) and (c) have been added here solely to indicate the limits of the digitized images.)

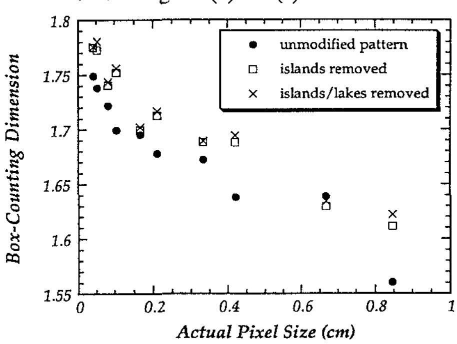

Figure 2 Influence of the removal of islands, and of islands and lakes, on the values of the box-counting dimension in images thresholded with the intermeans algorithm.

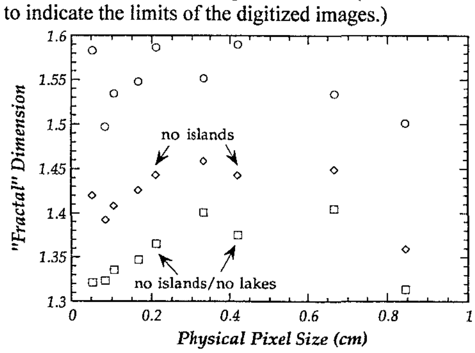

Figure 3 Influence of the removal of islands, and of islands and lakes, on the values of the surface box-counting dimension in images thresholded with the Intermeans algorithm. The circles correspond to the original images, whereas the diamonds and squares represent the dimensions obtained after removal of the islands, and islands and lakes, respectively.

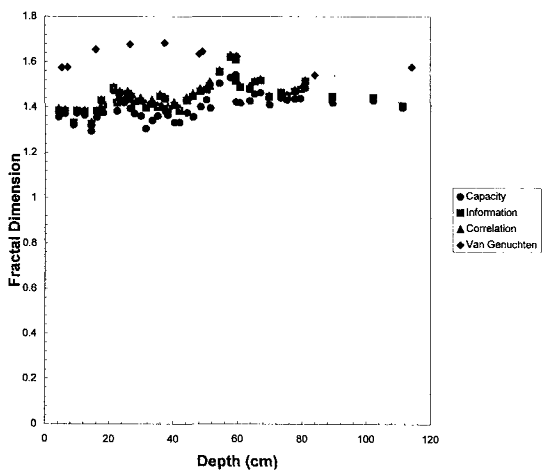

Figure 4 Fractal dimensions and soil size distribution for Orchard 2. Three surface fractal dimensions are capacity, information, and correlation dimensions. The notation $2\text{-}\lambda$ is the fractal dimension calculated from the exponent of a Van Genuchten-type distribution.

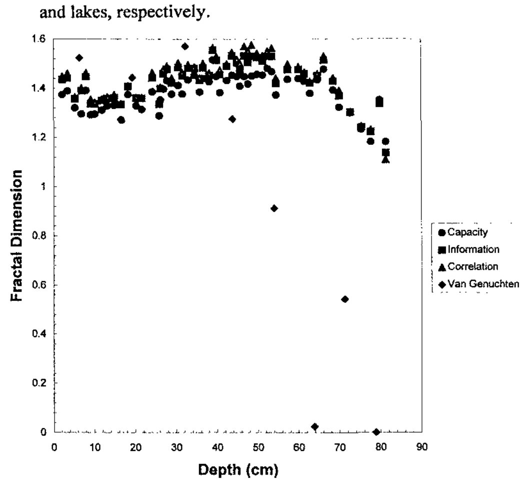

Figure 5 Fractal Dimensions and Soil Size Distribution for Pasture 2. Three surface fractal dimensions are capacity, information, and correlation dimensions. The notation $2\text{-}\lambda$ is the fractal dimension calculated from the exponent of a Van Genuchten-type distribution.