Use of Fractals to Model Soil Structure and Structurally-Mediated Processes

Ed Perfect

Department of Agronomy
University of Kentucky
Lexington, KY 40546-0091
e-mail: eperfect@ca.uky.edu

Soil structure refers to the form or internal geometry of natural porous media. Structural form is both spatially and temporally variable, and is the product of many different biochemical, physical and mechanical processes including soil aggregation, compaction, cracking and fragmentation. Fractals are hierarchical, often highly complex, spatial or temporal systems generated using iterative algorithms with simple scaling rules. The patterns within such systems repeat themselves over a defined range of scales (self similarity). As a result, no matter how intricate a particular pattern might be, its statistical properties can be reproduced at other length or time scales. Fractals offer new opportunities for modeling hierarchical structures and the processes that take place within such structures. Because of their complexity at any given scale, they are particularly applicable to heterogeneous media such as soils.

This presentation will cover the introductory principles of statistical self-similarity and survey recent developments on spatial fractals as applied to soil structure, with emphasis on the fields of soil physics and soil mechanics. Applications of fractals in these areas can be grouped into five broad categories:

(i) characterization of the geometry of structured porous media,
(ii) prediction of soil water retention and transport processes,
(iii) adsorption phenomena on irregular surfaces,
(iv) crack growth and fragmentation, and
(v) quantification of soil spatial variability.

In terms of structural characterization, fractal geometry has been used to model ped shape, changes in aggregate density with size, and pore-size distribution. In terms of water retention and transport processes, fractals have been used to develop physically-based models to predict the soil water characteristic curve and saturated hydraulic conductivity based on structural characteristics, and to model diffusion and hydrodynamic dispersion within tortuous porous media. Investigations of physio-chemical adsorption phenomena have focussed on the irregular surfaces of pore walls. The area of such surfaces changes when measured with molecular probes of different diameters, which has implications for exchange reactions, adsorption isotherms and solute transport. Advances have also been made in fracture mechanics based on the propagation of fractal cracking patterns within homogeneous solid materials. This work needs to be extended to heterogeneous porous media. Multiple fractures result in fragmentation, and several models are available for the prediction of fragment-size distribution from knowledge of structural form characteristics, assuming the same probability of failure for different-sized structural units under a given applied stress. In terms of spatial variability, fractal techniques, including semi-variograms, power spectra and multifractal spectra, have been employed to analyze large data sets collected at different length scales within the landscape.

Further research is needed to investigate the physical support for different fractal models, to collect data sets specifically for testing these models, and to move from the current descriptive paradigm towards a more predictive one. Fractal models offer the opportunity of not only quantifying the geometry of structured porous media under static conditions, but of using this information to predict physio-chemical and mechanical processes within these media under dynamic conditions.