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Multifractal characterization of saprolite particle-size distributions after topsoil removal

J.G.V. Miranda [a], E. Montero [b], M.C. Alves [c], A. Paz González [d,*], E. Vidal Vázquez [e]

[a] Instituto de Física, Universidade Federal da Bahia, Brazil
[b] Dept. de Matemática y Física Aplicada, Universidad Alfonso X el Sabio, Spain
[c] Faculdade de Engenharia de Ilha Solteira, Universidade Estadual Paulista, Brazil
[d] Facultad de Ciencias, Universidade da Coruña, Spain
[e] Escuela Politécnica Superior, Universidade de Santiago de Compostela, Spain

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Abstract

Multifractal analysis is now increasingly used to characterize soil properties as it may provide more information than a single fractal model. During the building of a large reservoir on the Parana River (Brazil), a highly weathered soil profile was excavated to a depth between 5 and 8 m. Excavation resulted in an abandoned area with saprolite materials and, in this area, an experimental field was established to assess the effectiveness of different soil rehabilitation treatments. The experimental design consisted of randomized blocks. The aim of this work was to characterize particle-size distributions of the saprolite material and use the information obtained to assess between-block variability. Particle-size distributions of the experimental plots were characterized by multifractal techniques. Ninety-six soil samples were analyzed routinely for particle-size distribution by laser diffractometry in a range of scales, varying from 0.390 to 2000 μm. Six different textural classes (USDA) were identified with a clay content ranging from 16.9% to 58.4%. Multifractal models described reasonably well the scaling properties of particle-size distributions of the saprolite material. This material exhibits a high entropy dimension, D_1. Parameters derived from the left side ($q>0$) of the $f(\alpha)$ spectra, D_1, the correlation dimension (D_2) and the range ($\alpha_0-\alpha_{q+}$), as well as the total width of the spectra ($\alpha_{max}-\alpha_{min}$), all showed dependence on the clay content. Sand, silt and clay contents were significantly different among treatments as a consequence of soil intrinsic variability. The D_1 and the Holder exponent of order zero, α_0, were not significantly different between treatments; in contrast, D_2 and several fractal attributes describing the width of the $f(\alpha)$ spectra were significantly different between treatments. The only parameter showing significant differences between sampling depths was ($\alpha_0-\alpha_{q+}$). Scale independent fractal attributes may be useful for characterizing intrinsic particle-size distribution variability.

Keywords: Multifractal analysis; Soil restoration; Particle-size distribution; Oxisol; Saprolite

1. Introduction

Natural soils are the result of pedogenetic processes that are governed by soil-forming factors, namely parent material, climate, relief, biosphere, water and time. Land use by man can have an effect on all the above soil-forming factors and, in some cases, can severely change or even destroy natural soil profiles.

* Corresponding author. Tel.: +34 981 167000; fax: +34 981 167065.
E-mail addresses: vivas@ufba.br (J.G.V. Miranda), elomont@terra.es (E. Montero), mcalves@agr.feis.unesp.br (M.C. Alves), tucho@udc.es (A. Paz González), evavidal@lugo.usc.es (E. Vidal Vázquez).

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Soil is now viewed as a multifunctional medium. It is a substrate for agricultural production; it forms an essential part of the landscape, provides raw materials and conserves the remains of our past. However, soil is a limited and non-renewable resource so damage to soil is not easily repaired.

Soil use, as a structural and foundation material for engineering purposes, is widespread and results in artificially disturbed landscapes. Unless reclamation measures are undertaken (such as soil replacement, landscaping or establishment of vegetation cover), at many construction sites, soil disturbances may continue for years. Construction of reservoirs and associated facilities in São Paulo State (Brazil), such as roads, buildings and earthworks, was achieved by engineering practices which included the manipulation and disturbance of deep soil profiles with highly weathered soil horizons. Natural soil profiles were excavated and 5–8 m of topsoil removed, exposing an underlying saprolitic material (Alves, 2001). This profile decapitation caused a drastic reduction in soil biota, which resulted in loss of stability of both the above ground plant community and the soil community itself with loss of ecosystem function. As a consequence, this soil, with a long natural history and influenced by agricultural activities, was not only degraded but also consumed so that it was no longer productive.

Disturbed areas left after surface and subsurface soil removal are not necessarily lost to agriculture or alternative land uses. Current interest in improving soil quality (an issue which is also linked to sustainable development) should not only focus on agricultural and natural soils but also on degraded soils and raw materials exposed at the earth surface (EEA, 2000). Land use and soil management systems are sustainable only if they maintain or improve soil quality and do not compromise environmental quality (Doran and Parkin, 1994; Carter et al., 1997; Gregorich, 2002). Improved soil quality increases the ability of a soil to fulfil its functions, including crop productivity, water and nutrient storage, and filtering and buffering of pollutants, thereby reducing contamination of surface and groundwater bodies by erosion or leaching processes.

During the building of a large reservoir on the Parana River, a highly weathered soil profile was excavated at Selvíria, Brazil. The saprolitic material exposed at the site was less resilient and that motivated this study. There was no pioneer vegetation growth after the abandonment and also further degradation by erosion was apparent. This motivated the installation of field trials to test the efficiency of different revegetation strategies.

The experimental design consisted of randomized blocks. In field trials, it is currently assumed without further testing that basic soil properties and parameters influencing fertility status and plant production are randomly distributed; hence, they do not significantly differ between plots with different treatments. This assumption has been strongly criticized, since, on the one hand, structured horizontal spatial variability has been often reported using geostatistical techniques (Vieira et al., 1983; Solie et al., 1999; Paz González et al., 2000) and, on the other hand, local or global trends may produce a bias in soil attributes involving blocks of a specific treatment. Structured variation in soil spatial properties between and within blocks may obscure the results of field trials.

Soil texture is one of the main properties characterizing a soil. The particle-size distribution of a given horizon is the result of the interaction between soil-forming processes and factors. Proper characterization of particle-size distribution is needed to quantify the various processes it influences. Soil mechanical composition is commonly expressed as percentage of clay, silt and sand contents and represented in a textural triangle, but a textural class contains limited information for assessing particle-size distributions (Martín and Taguas, 1998; Martín and Rey, 2000; Martín et al., 2001; Posadas et al., 2001). In spite of this, a number of different approaches have been developed to model and characterize particle-size distributions (see Montero, 2005 for a review). It has been stated that the main objective in characterizing soil particle-size distributions should be to find quantities or parameters that capture the essence of the phenomena and also that new concepts are required for this purpose (Martín and Taguas, 1998; Martín and Rey, 2000; Martín et al., 2005).

Over the last few decades, much attention has been paid to quantitative studies of soil texture and other physical parameters using the concept of fractal geometry. Fractal models were recognized as valuable tools in the description, quantification and modeling of soil properties varying as a function of observation scale. Scaling effects have been frequently observed in soil properties and attributes, so they are thought to be more the rule than the exception. Within this framework, a measure no longer appears to be a single number or a mean value with a confidence interval, but rather a function of the scale. In the simplest case, when self-similarity at every measurement scale is evidenced, the function of scale is a power law and the exponent of the power law depends only on the so-called fractal dimension, D. This single scaling exponent has been