Multifractal-Based Characteristics of Soil Particle Size Distribution in Abandoned Farmland in Semi-arid Regions (Postprint)

Authors: Wang Yan, Siqing Bilige, Jia Xu, Meng Zhongju, Lü Shijie 2

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Abstract

To elucidate the evolution characteristics of soil quality following farmland abandonment, five land use types were selected in the mid-section of the northern Yinshan Mountain agro-pastoral ecotone: currently cultivated land and land abandoned for 1, 2, 3, and 4 years. Soil particle characteristics and organic matter content in the 0–80 cm layer of abandoned farmland were measured, and the relationship between soil particle size distribution and organic matter content was investigated based on multifractal theory analysis. The results showed that sand content exhibited a positive correlation with multifractal parameters (D0, D1, $ $0) and a highly significant negative correlation with organic matter. In the study area, as sand content increased, the range of soil particle size distribution gradually widened, the distribution became more discrete, and soil evolved toward coarsening. With the extension of abandonment duration, the surface layer (0–10 cm) soil showed a consistent decreasing trend in both clay and organic matter contents, and clay content was highly significantly positively correlated with soil organic matter. Therefore, clay content could be considered as an indicator to reflect the trend of soil organic matter changes.

Full Text

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1.2 Materials and Methods

1.2.3 Study Area The study site is located in the midland region of the Yinshan Mountains at coordinates 41°23 16.96 N, 111°23 02.55 E, with an elevation of 1,675 m. The area experiences a temperate semi-arid climate with an annual

precipitation of 1,839.0 mm, concentrated in July–September. The mean annual temperature is 3.3°C, with 100 frost-free days per year. The average wind speed is 4.5 $m \cdot s^{-1}$, and the soil freezing period lasts 65 days. The dominant vegetation communities include *Leymus chinensis*, *Artemisia frigida*, and *Stipa breviflora*. The soil type is classified as chestnut soil.

1.2.1 Multifractal Analysis of Soil Particle Size Distribution Soil particle size distribution (PSD) was analyzed using the mass distribution method. For a normalized PSD dataset where the mass of soil particles with diameter $\leq \lambda$ is defined as the measure , the partition function (q,) is calculated as:

$$\chi(q,\varepsilon) = \sum_{i=1}^{N(\varepsilon)} \mu_i(\varepsilon)^q$$

where represents the scale, q is the moment order ($-10 \leq q \leq 10$), and _i( ) is the measure within the i-th interval. The generalized dimension D(q) is derived from:

$$\chi(q,\varepsilon) \propto \varepsilon^{\tau(q)}$$

$$D(q) = \frac{\tau(q)}{q-1}$$

For q = 0, 1, and 2, we obtain three key multifractal parameters: D_0 (capacity dimension), D_1 (information dimension), and D_2 (correlation dimension). D_0 characterizes the capacity dimension of PSD, D_1 reflects the information dimension dominated by high particle concentrations, and D_2 represents the correlation dimension influenced by low particle concentrations. The ratio D_1/D_0 indicates the uniformity of PSD, while the multifractal spectrum width $\Delta\alpha$ and the difference in fractal dimensions Δf quantify the heterogeneity and asymmetry of the distribution, respectively.

2.2 Relationship Between Soil Organic Matter and Particle Size Distribution

The soil organic matter (SOM) content in the 10–20 cm layer showed significant variation across abandonment chronosequences, decreasing in the order: 1-year > 2-year > 3-year > 4-year abandoned plots. The SOM content in the 0–3 cm surface layer ranged from 5.04% to 15.37%, while the 30–80 cm layer exhibited relatively stable SOM levels. The PSD was primarily influenced by sand content, which increased with abandonment duration, leading to a coarsening succession trajectory. As sand content increased, the PSD range widened, local particle concentration decreased, and the distribution became more discrete.

2.3 Multifractal Spectrum Characteristics

The multifractal spectrum parameters (Table 3) revealed that D_2 values remained relatively stable across abandonment years, while Δf showed an increasing trend, indicating enhanced heterogeneity in fine particle distribution. The Δf values ranged from 0.178 (1-year) to 0.354 (4-year), demonstrating that long-term abandonment intensified the non-uniformity of PSD. The correlation analysis (Table 4) showed that sand content was positively correlated with D_0, D_1, and α_0 ($P < 0.01$), but negatively correlated with SOM content. Conversely, SOM exhibited significant negative correlations with D_1/D_0 ($r = -0.716$, $P < 0.01$) and positive correlations with Δf ($r = 0.939$, $P < 0.01$).

[Figure 1: see original paper] Generalized dimension spectrum of soil particle size distribution in different years of abandonment

[Figure 2: see original paper] PSD multifractal spectrum with different years of abandonment

Different shifts of PSD multifractal spectrum parameters

Correlation analysis of soil texture, SOM content and multifractal parameters

The multifractal analysis demonstrated that with increasing abandonment duration, the PSD shifted toward coarser fractions, accompanied by decreased SOM content in surface soils. The parameter Δf effectively captured the evolving heterogeneity of PSD, suggesting its utility as an indicator for monitoring soil degradation processes in abandoned farmlands. The strong correlations between sand content, SOM, and multifractal parameters indicate that the coarsening of PSD can serve as a reliable predictor of SOM loss in semiarid abandoned agricultural lands.

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Note: Figure translations are in progress. See original paper for figures.