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RESEARCH ARTICLE

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Soil fractal features of subalpine coniferous forests in western Sichuan under different anthropogenic disturbances

Abstract Fractal theory, used to study natural figures and images with self-similarity but without characteristic lengths, offers an effective tool to investigate quantitatively the complex systems such as soil. In this paper, we have discussed about our study of the fractal features of the subalpine coniferous forests, soil particles, and microaggregates under different intensities of anthropogenic disturbances in the Miyaluo area of west Sichuan and investigated the effects of the disturbances on the forest soils attributed to different fractal dimensions. The study introduces a new way to investigate the recovery and reestablishment of subalpine coniferous forests.

Keywords Miyaluo area subalpine coniferous forest, fractal dimensions, soil particles, soil micro-aggregates, anthropogenic disturbances

1 Introduction

Fractal theory was first proposed by Mandelbrot in the mid-1970s. It is used to study natural figures and images with self-similarity but without characteristic length (Liang et al., 2003). Due to the interaction on the inner processes of physics, chemistry, biology, and so on, and disturbances of all kinds by geological processes and artificially imposed measures, soils appear to be complex natural parts in form, structure, and function. Results show that soils are systems with fractal characteristics (Turcotte, 1986, 1989; Taguas et al., 1999). Fractal theory is widely used in the study of soil structures, moisture features, and solute transfers (Scott and Stephen, 1989; Michel and Garrison, 1991a; Michel and Garrison, 1991b; Perfect et al., 1992; Scott and Stephen, 1992; Rasiah et al., 1993). The development of fractal theory offers an effective tool to investigate quantitatively complex systems such as soils.

Soil particles are the basic materials to form soil structures. The combination of different soil particle-size contents form different soil textures, which further affect the physical, chemical, and biological soil processes (Liao et al., 2002). The distribution of the soil particle-size is often used to analyze and predict the dynamic characteristics of soils, such as the quantity of maintained water, water permeability, and soil pores (Scott and Stephen, 1989; Scott and Stephen, 1992). Due to differences in dynamic and chemical characteristics among different soil particles of different size, the distribution of the soil particle-size dimensions is partly the decisive factor of the soil structure and its properties. Soil micro-aggregates consists of aggregated soil particles. Its quality and quantity can be used to evaluate the function of its structure, the intensity of its anti-dispersal and the ability to maintain water and fertility (Nanjing Institute of Soil Science, Chinese Academy of Sciences, 1983). The microaggregates of different sizes have different functions to maintain and provide fertilizer. The forming ratio of the “feature micro-aggregates”, which can better reflect the state of soil fertility and its actual regulating effect, is the index to evaluate soil fertility synthetically (Chen et al., 1994). So the quantitative description about the composition ratios among different soil particles and micro-aggregates of different sizes has been very important in soil studies.

Subalpine coniferous forests are a special kind of vegetation, distributed in mountainous areas at a certain elevation in regions of low latitude, consisting of cold-resistant alpine species such as spruce and fir (Liu, 2002). The subalpine coniferous forests of west Sichuan are mainly distributed along the Jingsha, Yalong, and Ming Rivers of the upper reaches of the Yangtze River. These subalpine forests are not only an important ecological barrier along the upper

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streams of the Yangtze River but also the center of many species with ecological functions to retain water, maintain the soil, adjust the climate, and protect biology diversity (Li, 1990; Liu et al., 2001). Since the 1950s, the primary forests in this area have been cut. At present, there are many coniferous plantations, and a few sub-forests have recovered after clear cutting (Wu et al., 2001a). Human activity is the external factor causing the forests, grasslands, farmlands, and the entire ecological and environmental system along the upper parts of the Ming River to degenerate (Rasiah et al., 1993). Anthropogenic disturbances, such as herding, gathering medicine, and collecting manure from the litter under the forests have a strong effect on the physical characteristics of the soil. Therefore, a study about the effect on the ecological system of the forests from anthropogenic disturbances in this area seems imperative (Pang et al., 2002b). Many scholars have carried out studies on the massive structure, the ecological function of litter, nutrient circulation features, and changes of soil characteristics at different recovering stages in this area (Pan and Liu, 1998; Hu et al., 2001; Lin and Liu, 2001; Lin et al., 2002; Pang et al., 2002a). Different fractal dimensions can reflect soil structures and features and we can learn something about soil characteristics by analyzing the different fractal dimensions about the distribution of the soil particles and micro-aggregates (Liang et al., 2003). This paper discusses our study of the fractal features of the subalpine coniferous forests soil particles and micro-aggregates under different intensities of anthropogenic disturbances in the Miyaluo area of west Sichuan and investigates the effects of the disturbance on the forest soils attributed to different fractal dimensions. The study introduces a new way to investigate the recovery and reestablishment of subalpine coniferous forests.

2 Study area and method

2.1 Natural survey

The study area is located in the Miyaluo forests, Li County, Sichuan Province (31°36′N, 102°57′E), belonging to the high-mountain valley zone from the Qinghai-Tibetan Platue to the Sichuan Basin (Zhang et al., 1981). It is situated in the range of the Qinghai-Tibetan Plateau Climate Zone, affected by a southeast monsoon. The weather data of Miyaluo Town, at an elevation of 2,700 m, for example, shows an annual rainfall of 1,165.7 mm, evaporation is 987.8 mm, average temperature of 6.5℃, and the accumulated temperature (≥0℃) ranges from 1,710 to 2,000 (Wu et al., 2001b). Pedogenin mother rock consists mainly of accumulated weathered material such as phyllite, slate, and dolomite. The soils, distributed at different elevations, are in order: brown soil (700–3,300 m), dark brown soil (3,300–3,600 m), brown sub-alpine coniferous forest soil (3,600–3,850 m), and sub-alpine meadow soil (over 3,850 m). The main forest patterns are *Rhododendron-Abies* forests, grass-*Abies* forests, moss-*Picea-Abies* forests, *Fargesia-Picea-Abies* forests, *Quercus-Picea-Abies* forests, and deciduous broad-leaved-*Picea-Abies* forests (Pang et al., 2002b).

2.2 Study method

The data in Table 1 were collected from reference (Pang et al., 2002). The formula is from reference (Pang et al., 2002b).

$$(R/R_{\max})^{3-D}=W(r<R)/W_{\mathrm{o}} \tag{1}$$

Table 1 Soil mechanical composition, micro-aggregate composition, bulk density and organic matter under the different intensities of human-induced disturbance

Disturbance intensity	Soil mechanical composition /%					Bulk density /(g·cm^{-3})	OM /(g·kg^{-1})
	1–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001		
None	27.84	26.53	13.80	21.22	10.61	0.73	168.40
	27.90	29.26	17.34	17.14	8.36	1.10	95.88
Slight	24.33	24.90	16.60	22.83	11.34	1.02	90.68
	32.58	28.60	13.08	20.63	5.11	1.32	39.19
Intermediate	33.95	23.74	11.35	20.02	10.94	1.11	86.02
	31.06	25.72	13.99	15.84	13.84	1.26	27.89
Intense	37.73	20.39	14.27	18.35	9.27	1.22	40.93
	43.29	20.22	11.12	18.20	7.08	1.22	12.19
	Soil micro-aggregate particle composition /%						
	>0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001		
None	69.80	21.28	3.55	2.48	2.84	0.73	168.40
	49.20	36.43	7.01	5.61	1.75	1.10	95.88
Slight	55.02	33.37	5.54	5.19	2.78	1.02	90.68
	55.67	30.69	7.16	3.07	3.41	1.32	39.19
Intermediate	43.38	30.89	8.58	13.73	3.43	1.11	86.02
	43.38	30.89	8.58	13.73	3.43	1.26	27.89
Intense	53.28	27.37	6.84	11.29	6.68	1.22	40.93
	52.73	30.27	8.50	7.82	2.68	1.22	12.19

The above data are collected from reference (Lin and Liu, 2001) and stand for A and B soil layers.

where R_{max} is the size of the biggest particle, W_o the total weight of particles at different levels, and D fractal dimensions.

3 Results and analysis

3.1 Fractal dimensions of soil particles and micro-aggregates

According to the distribution data of the sub-alpine coniferous forests soil particles and micro-aggregates under different intensities of anthropogenic disturbances in the Miyaluo area, their relationship can be worked out by separately applying lg(d/d_{max}) as the horizontal scale and lg($W(r<d)/W_r$) as the vertical scale to draw a coordinate system (Figs. 1 and 2). All the relative indices are more than 0.8, indicating that the distribution of soil particles and micro-aggregates represent fractal characteristics. The fractal dimensions of the subalpine coniferous forests soil particles and micro-aggregates are different under different intensities of anthropogenic disturbances in west Sichuan (Figs. 1 and 2). They range from 2.679,0 to 2.708,6, from 2.607,2 to 2.722,6, from 2.461,4 to 2.611,9 and from 2.418,3 to 2.540,8.

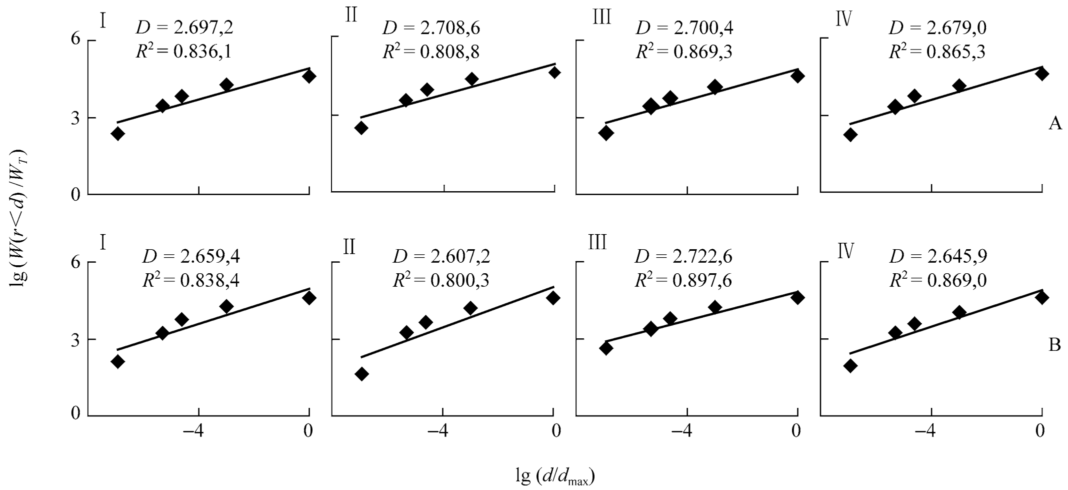

Fig. 1 Relationship between lg(d/d_{max}) and lg($W(r<d)/W_T$) of soil particle-size distribution in subalpine coniferous forests under different human-induced disturbances. Ⅰ: None, Ⅱ: Slight, Ⅲ: Intermediate, Ⅳ: Intense, A and B stand for A and B soil horizons

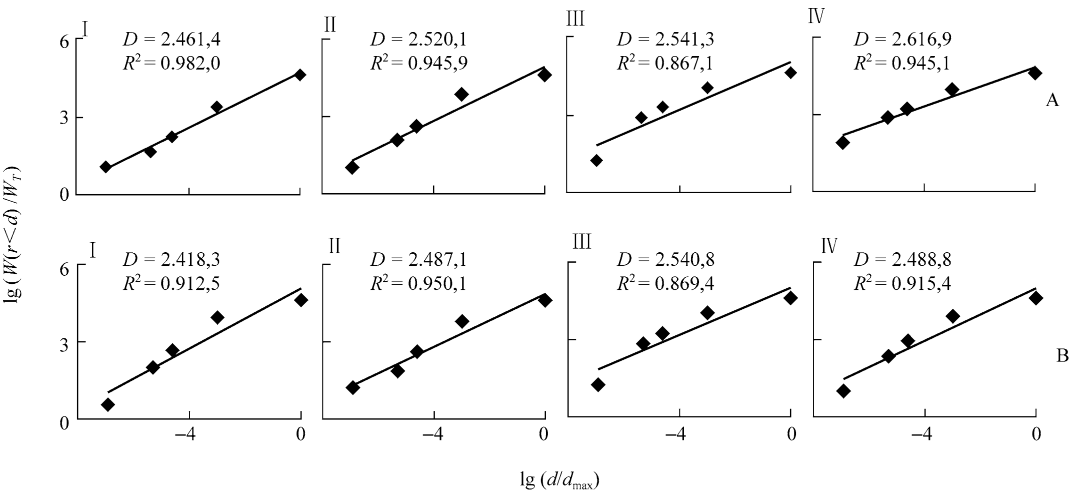

Fig. 2 Relationship between lg(d/d_{max}) and lg($W(r<d)/W_T$) of soil micro-aggregate particle size distribution in subalpine coniferous forests under different human-induced disturbances. Ⅰ: none, Ⅱ: slight, Ⅲ: intermediate, Ⅳ: intense, A and B stand for A and B soil horizons

3.2 The relationship between fractal dimension and the soil particle size

The fractal dimension of soil particles and micro-aggregates is relative to the accumulated content of soil particles and micro-aggregates of different sizes. The relative analysis shows that there is a significant positive relationship between the fractal dimension of the subalpine coniferous forest soil particle distribution and the content of particles of size (<0.001 mm) under different intensities of anthropogenic disturbances in the Miyaluo area (P<0.01). However, there is no statistically significant relationship between the fractal dimensions of the subalpine coniferous forest soil micro-aggregates distribution and the content of different sized particles under different intensities of anthropogenic disturbances in the area (P>0.05) (Table 2).

3.3 The relationship between fractal dimension, the content of soil organic matter, and bulk density

The soil particle formation is the important basic matter to make up the soil structure, which can infect the state of soil structure and the transformation of soil organic matter to some degree. The state of soil aggregates is an important factor affecting soil fertility, soil ventilation, and rot-resistance. So the relationship between the fractal dimensions of the subalpine coniferous forest soil particles and micro-aggregates and organic matter and bulk density of different layers is analyzed under different intensities of anthropogenic disturbances in the Miyaluo area.

The result indicates that there is a significant negative relationship between the fractal dimension of the subalpine coniferous forest soil micro-aggregates and the content of soil organic matter under different intensities of anthropogenic disturbances in the area (P<0.05) (Table 3).

4 Discussions

The fractal dimensions of soil particle-size distributions cannot only describe the soil particle size distributions, but can also indicate the level of its quality. The greater the fractal dimension of soil particle, the more inseparable is the soil structure. When fractal dimensions >2.88, the clay and ventilation of soil quality are weaker. As well, the smaller the fractal dimension, the looser is the soil quality and the better is its ventilation (Liao et al., 2002). The fractal dimensions of the subalpine coniferous forest soil particles between different layers range from 2.68 to 2.71 and from 2.61 to 2.72 (all fractal dimensions <2.88) under different intensities of anthropogenic disturbances in west Sichuan (Fig. 1). The Pedogenin mother rock is an important factor affecting the formation of soil particles. The original rocks in the research area are phyllite and slate, the soil weathering is characteristic of mechanical breaks. The soil quality is rough, there are thicker particles, and there is less clay (Liu and Hong, 2001). This indicates that there are loose alpine coniferous forest soil structures with better ventilation under different intensities of anthropogenic disturbances in the Miyaluo Area. With disturbances on the increase, the fractal dimensions of soil layers A and B first rises, than falls. A slight and middle anthropogenic disturbance may cause the soil structure to be more inseparable,

Table 2 Correlation between fractal dimensions of soil particle-size, soil micro-aggregate particle size distribution and content of different soil particle-sizes in subalpine coniferous forests under different human- induced disturbances

Fractal dimension	Particle size (1–0.05 mm)	Particle size (0.05–0.01 mm)	Particle size (0.01–0.005 mm)	Particle size (0.005–0.001 mm)	Particle size (<0.001 mm)
D_{PA}	–0.840	0.767	0.202	0.909	0.996**
D_{PB}	–0.247	–0.127	0.230	–0.947	0.992**
D_{MA}	–0.549	0.124	0.657	0.795	0.936
D_{MB}	–0.367	–0.833	0.768	0.679	0.888

D_{PA} and D_{PB} stand for fractal dimensions of soil particle-size distribution at A and B horizons respectively. D_{MA} and D_{MB} are the fractal dimensions of soil micro-aggregate particle size distribution at A and B horizons. Significance levels: * P<0.05, ** P<0.01.

Table 3 Correlation between fractal dimensions of soil particle-size, soil micro-aggregate particle size distribution, bulk density and organic matter of soil in subalpine coniferous forests under different human- induced disturbances

Fractal dimension	Bulk density	Organic matter
D_{PA}	–0.426	0.460
D_{PB}	–0.200	–0.064
D_{MA}	0.848	–0.963*
D_{MB}	0.748	–0.817

D_{PA} and D_{PB} stand for fractal dimensions of soil particle-size distribution at A and B horizons. D_{MA} and D_{MB} are the fractal dimensions of soil micro-aggregate particle size distribution at A and B horizons. Significance levels: * P<0.05, ** P<0.01.

so its fractal dimension increases. However, strong anthropogenic disturbances cause surface runoff to increase due to the direct impact of rainfall on the ground through the forest gaps, so that many small-sized soil particles flow away with the surface runoff. It is the loss of thin soils and the rough soil texture that can result in the fractal dimensions of soil to fall (Pang et al., 2002b).

The soil micro-aggregate consists of aggregated soil particles. Its quantity and composition is an important index showing the effect of soil ventilation, rot-resistance, and fertility. In general, with the intensity of the disturbance increasing, the content of giant-aggregates in soil decreases, while the content of small-micro-aggregates increases (Table 1), soil becomes inseparable and the fractal dimension increases (Fig. 2) This research result is similar to the fractal characteristics of soils of original *Castanopsis kanakamii* stands (Liu and Hong, 2001). There is a significant positive relationship between the fractal dimension of both A and B layers and the content of soil particles (<0.001 mm) (Table 2). The result indicates that the fractal dimensions of soil particles and micro-aggregates can reflect their composition or texture. But the significant relationship between the fractal dimensions and soil particles of different size is not different (Liao et al., 2002). The significant negative relationship between the fractal dimensions of soil micro-aggregates and the content of soil organic matter (Table 3) is similar to the result of Rasiah et al. (1993). Soil organic matter and soils with a strong aggregating ability may be reduced with increased disturbances. Thus, the fractal dimension of soil micro-aggregates increases (Fig. 2).

The distribution of soil particles and micro-aggregates of different sizes is an important index for physical characteristics of soils. Its irregularity, complication, and unchangeable standard characteristics make the fractal self-similarity distribution become a suitable and natural model. The result indicates that fractal dimension can efficiently reflect the changes of formation of subalpine coniferous forest soil particles and micro-aggregates and the change of the content of soil organic matter under different intensities of anthropogenic disturbances in the Miyaluo area. The methodology to model the quantitative relationship between the fractal dimensions of subalpine coniferous forest soil particles and soil fertility characteristics is very important for the application of fractal theory in investigating the characteristics of soil structure and its fertility and disclosing the regularity of soil fertility. It may introduce a new method and measure for investigation of the subalpine coniferous forest eco-system.

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