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Fractal characteristics and stability of soil aggregates in karst rocky desertification areas

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Abstract Karst rocky desertification is one of the major ecological and environmental problems that threaten the sustainable development of southwestern China. This study focuses on a case study of the small watershed in Chenqi where karst rocky desertification is particularly severe. This paper considers samples of soils from six different land use patterns in Chenqi village. Various correlations are observed by using fractal theory, including an emerging model for studying soil aggregates. This study demonstrates how the fractal characteristics of soil structure and the stability of soil aggregates are crucial to better understanding karst rocky desertification. The fractal dimension of different land use patterns can be used to indicate the magnitude of soil destruction. Soil fractal dimension can be applied using different methods to characterize the changes in factors influencing the stability of soil structure. The results indicate a significant negative relationship between fractal dimension of soil aggregates and large aggregate content (of diameters 5–10 mm) and a significant positive relationship between fractal dimension and micro-aggregate content (<0.25 mm). The fractal dimension of soil aggregates is also significantly negatively correlated with both clay content and organic matter content. These results suggest that fractal dimension can be used as a reliable indicator of soil quality and presents advantages compared to using mean weight diameter.

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1 Introduction

Karst rocky desertification in southern China poses a serious problem for land development and the establishment of sustainable environmental solutions (Wang and Li 2007). Karst rocky desertification is a destructive type of land degradation characterized by severe soil erosion and widespread exposure of basement rocks. Relevant indicators of vast soil degradation include soil structure deterioration, texture and porosity spoilage, soil–water capacity decline and soil leanness which means the comprehensive representation of soil physical, chemical and biologic characteristics degradation (Wang et al. 2003; Long et al. 2006; Li et al. 2006). These conditions all lead to serious economic constraints on the development of the region (Wang et al. 2004a, b). Research on changes in soil structure stemming from karst rocky desertification typically has been limited to studies on basic physical and chemical properties. (Tang et al. 2001; Fu et al. 2007; He et al. 2008, 2009; Yang et al. 2011) Few studies, however, investigate the role of soil aggregates. As the basic unit of soil structure, soil aggregates can be crucial in improved understanding of karst rocky desertification (Wang and Wang 2005).

Since the 1980s, fractal theory, proposed by Mandelbrot, has become an effective tool to describe complex and irregular geometry. (Perfect and Kay 1995; Young and Crawford 1991; Crawford et al.1997; Young et al. 2001) Fractal theory has been applied successfully in geosciences research (Burrough 1981). Of particular importance, several studies have shown that soil is a system with fractal characteristics (Rieu and Sposito 1991; Turcotte 1986; Tyler and Wheatcraft 1992). Tyler and Wheatcraft (1992) and Yang and Luo (1993) proposed a model for determining the fractal dimension of soil by combining particle size distributions in soil samples with their corresponding weight distributions. This model later was used to study the fractal characteristics of soil structures observed in different types of land use, leading to establishing indicators of soil fertility (Wu and Hong 1999). Further use of fractal-based models has helped to characterize the texture, composition structure and uniformity of soil particles and aggregates (Liu et al. 2006; Huang and Zhan 2002). These models can yield additional insight into the mechanisms of karst rocky desertification. This study takes soil aggregates as key point to find out the mechanism of the process of karst rocky desertification and also showed the value of fractal theory.

This paper is based on the study of soil within six different land use patterns (shrub grassland, burned area, secondary young forest land, slope farmland, sparse shrub land, shrubs and trees mixed forest) in Chenqi village, Puding County, Guizhou Province which is the most typical area of the karst rocky desertification areas. Under the fractal model proposed by Yang and Luo (1993), three aspects require further attention: the first aspect relates to changes in fractal dimension and the fractal characteristics of soil aggregates during rocky desertification. The second aspect involves the relationship between the fractal dimension and the presence of particles of different sizes and organic composition. The third aspect deals with the stability of soil aggregates in six distinct land use patterns. Focusing on these three aspects can provide meaningful insights into qualitative and quantitative descriptions of rocky desertification.

2 Experimental investigation

The study area (Chenqi Village, Puding County, Guizhou Province) is located in the Houzhai underground river basin, a typical karst landform whose elevation ranges from

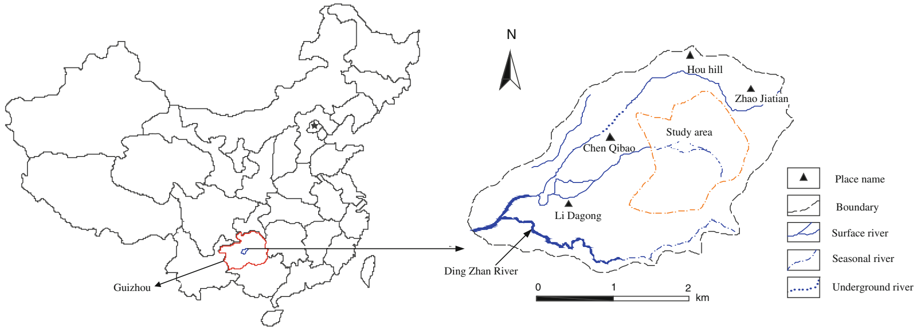


Fig. 1 Location of study area

1,309 to 1,524 m (Fig. 1). The hillside is very steep as the underlying bedrock is Triassic system Guanling limestone and marl. In June 2007, the Institute of Geochemistry of the Chinese Academy of Sciences selected six typical land use patterns to study (shrub grassland, burned area, secondary young forest land, slope farmland, sparse shrub land, shrubs and trees mixed forest). According to the characteristics of different land use patterns and vegetation conditions, they established six large total slope runoff fields along the mountain with different areas but basically the same slope (Fig. 2). Table 1 shows the physical characteristics of those runoff fields. Representative soil samples were collected in 6 × 3 groups (soil layers: 0–20 cm) from the 6 runoff fields of the study area. The slope farmland field was modeled upon forest reclamation for farming, while the other five field categories represented different types of post-soil destruction woodland. The soil parent materials are Triassic gray-black thick limestone (T_2g^{2-2}) and gray-white thin marl (T_2g^{2-1}), while the soil itself is loess whose color ranges from brownish red to brownish yellow.

2.1 Sample preparation

The collection and maintenance of soil samples for physical and mechanical analysis were performed in accordance with established geotechnical methods. The specimen preparation of aggregates was limited in the plough area of 10 cm × 10 cm, making sure that the samples were not compressed to maintain their structures intact. The external layers that made contact with equipment were stripped. Soil samples weighting about 3–4 kg were then isolated, slightly dried and gently split along natural structure surfaces into clods measuring about 1 cm in diameter. All gravel and coarse roots present were discarded.

2.2 Test method

The soil samples were separated into three groups, respectively, by quartering method for parallel tests, and the final results took average. Two types of analyses (dry air and Yoder wet sieve) were performed on the samples. The aggregates' structure analysis in dry air took account of the content of different particle sizes in the following ranges: >5, 2–5, 1–2, 0.5–1, 0.25–0.5 mm and <0.25 mm. Water stability structure analysis using the Yoder wet sieve method to determine the quality percentage content of aggregates used the same size ranges. Determination of soil organic matter used the heavy collateral potassium capacity method.

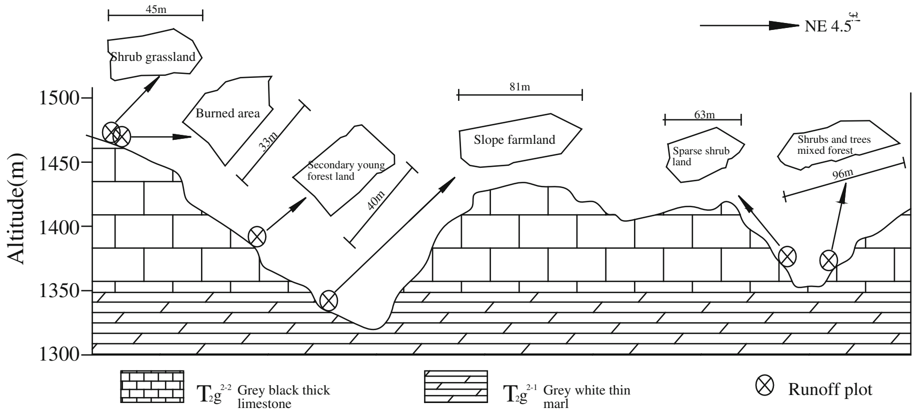


Fig. 2 Location of six runoff fields

2.3 Fractal dimension calculation method

Yang and Luo (1993) put forward a model which is accurate and simple to describe the fractal characteristics of soil by using the weight distribution of particles instead of the size distribution of particles.

$$\frac{W\left(\delta > \overline{d_i}\right)}{W_0} = 1 - \left(\frac{\overline{d_i}}{\bar{d}_{\mathrm{Max}}}\right)^{3-\mathrm{D}} \tag{1}$$

or

$$\left(\frac{\overline{d_i}}{\bar{d}_{\mathrm{Max}}}\right)^{3-\mathrm{D}} = \frac{W\left(\delta \le \overline{d_i}\right)}{W_0} \tag{2}$$

where D is the fractal dimension, δ is threshold, $\overline{d_i}$ is the average of two adjacent sieving size fraction d_i and d_{i+1}; $\bar{d}_{\mathrm{Max}}$ is the average diameter of the biggest soil particles, $W\left(\delta > \overline{d_i}\right)$is the accumulated weight of soil particles with larger particles than d_i and W_0 is the whole weight of all soil particles. Conducting Eq. (2) in logarithmic relationship, the slope of the curve can be derived as the value of (3-D). Therefore, the determination of D can yield by the regression method. The calculation of the fractal dimension and the analysis of data applied the Origin software for processing.

3 Experimental results and analysis

Soil aggregates are the material basis of soil fertility. Soil aggregates with large diameters (greater than 10 mm) are not conducive to water conservation and crop emergence, while aggregates with diameters that are too small (less than 0.25 mm, known as micro-aggregates) can clog pores and damage soil permeability (Wu and Hong 1999). This experiment investigated aggregate diameters between these two extremes (0.25 and 10 mm) and also considered micro-aggregates (less than 0.25 mm). For different land use patterns, the lands suffer from different human activities such as farming, deforestation and burning, and the types and conditions of vegetation are also diverse. As a result, different types of land use

Table 1 Land use characteristics of runoff fields

Runoff plot	Land use pattern	Human activity	Location of hillside	Area (m^2)	Slope gradient (°)	Vegetation type	Coverage of tree layer (%)	Coverage of shrub layer (%)	Coverage of surface layer (%)	Exposing rate of bedrock	Soil parent material
1	Shrub grassland	Resumed after the fire	Middle-upper part	1,255.1	37	Shrub, ferns	0	50	80	35	Thick limestone
2	Burned area	Fire	Middle-upper part	684.3	32	Shrub, ferns	0	0	0	35	Thick limestone
3	Secondary young forest land	Closing forest	Upper part	1,146.4	35	Evergreen broad-leaved forest	85	50	70	30	Thick limestone
4	Slope farmland	Maize vegetable rotation	Lower-middle part	2,440.4	30	Maize, ferns	5	0	0	30	Thin marl layer
5	Sparse shrub land	Overgrazing	Lower-middle part	2,890	31	Shrub	0	45	20	50	Thick limestone
6	Shrubs and trees mixed forest	Light grazing	Lower-middle part	2,439.6	36	Evergreen and deciduous broadleaved forest	90	20	90	50	Thick limestone

lead to different physical, chemical and biologic characteristics of soil. And the size distribution of soil particles also shows diverse characteristics according to land use patterns. Different types of human land use not only change the surface of natural landscape, but also have a profound impact on the soil itself. This use can dramatically change the quality and quantity of aggregates in the short term (Long et al. 2005). Studies have shown that smaller fractal dimensions of soil aggregates can lead to smaller soil bulk density, looser soil and a stronger ability for soil and water conservation, while larger fractal dimensions of soil aggregates can cause less stable soil structure and poor soil anti-erosion ability (Fredlund and Hahardjo 1993). The fractal dimensions found in different land use patterns can be used to indicate the magnitude of soil destruction.

3.1 Fractal characteristics of soil aggregates under different land use patterns (dry sieve method)

Table 2 reveals the particle size distribution of soil aggregates with six different land use patterns after dry sieve analysis. The soil aggregates' fractal dimension was calculated by using the formula $\left(\frac{\overline{d_i}}{d_{\mathrm{Max}}}\right)^{3-D} = \frac{W\left(\delta \le \overline{d_i}\right)}{W_0}$ combined with regression analysis.

The relevant parameters of calculation are shown in Table 3. The fractal dimension of soil aggregates in study area is between 2.519 and 2.678, with an average of 2.605. Greater fractal dimension leads to both lower aggregate (>0.25 mm) and lower large aggregate (>5 mm) contents, indicating that the soil structure is less stable. The six different land use patterns, sorted from higher to lower fractal dimension, are sparse shrub land, slope farmland, burned area, shrubs and trees mixed forest, secondary young forest lands and shrub grassland, with the same order maintained according to lower to higher MWD (mean weight diameter). The relationship between fractal dimension and MWD is shown in Fig. 2. Fractal dimension and MWD have a significant negative correlation (correlation coefficient of −0.991). Results indicate that the conclusions for the evaluation of the same soil aggregate conditions are equal according to fractal dimension and MWD (Fig. 3).

Analysis of the damage extent of six different land use patterns is based on the general consensus that soil with smaller fractal dimension has better quality. The aggregates' fractal dimension results show that the damage extent (from highest to lowest) of the five states of woodland after deforestation is sparse shrub land, burned area, shrubs and trees mixed forest, secondary young forest land and shrub grassland. It seems that with the

Table 2 Particle size distribution of soil aggregates (dry sieve analysis)

Land use pattern	Number of text sample	Sample number	Mass percentage of different size soil aggregates (mm)					
			10–5	5–2	2–1	1–0.5	0.5–0.25	<0.25
Shrub grassland	S01	3	34.36	24.99	11.91	7.01	7.63	14.1
Burned area	S02	3	23.87	16.86	16.98	12.08	8.49	21.72
Secondary young forest land	S03	3	30.58	16.56	13.57	11.4	11.44	16.45
Slope farmland	S04	3	18.48	19.74	11.74	15.07	9.41	25.56
Sparse shrub land	S05	3	12.8	16.71	17.52	11.41	13.95	27.61
Shrubs and trees mixed forest	S06	3	28.67	16.28	13.83	12.11	10.54	18.57

Table 3 Characteristic parameters of soil aggregates (dry sieve analysis)

Land use pattern	Number of text sample	>5 mm Dry aggregates (%)	>0.25 mm Dry aggregates (%)	Mean weight aggregates (mm)	Fractal dimension	Correlation coefficient
Shrub grassland	S01	34.36	85.9	3.73	2.519	0.9962
Burned area	S02	23.87	78.28	2.78	2.616	0.9966
Secondary young forest land	S03	30.58	83.55	3.23	2.567	0.9978
Slope farmland	S04	18.48	74.44	2.43	2.657	0.9928
Sparse shrub land	S05	12.8	72.39	1.98	2.678	0.9923
Shrubs and trees mixed forest	S06	28.67	81.9	3.08	2.591	0.9982

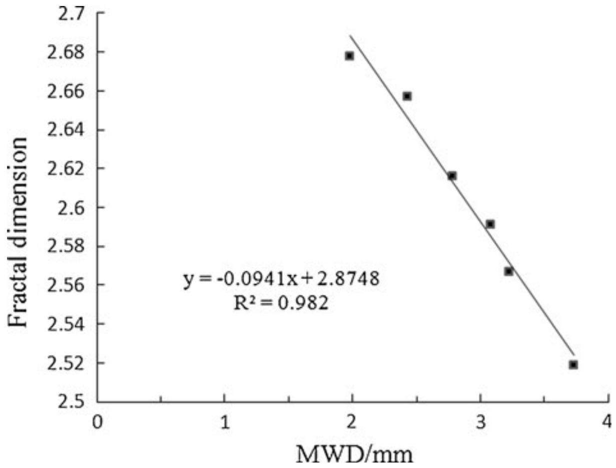


Fig. 3 Relationship between fractal dimension and MWD

intervention of human activities, the changing patterns of land use—such as deforestation—and large-scale burning have increased the environmental impact. This impact has resulted in sparse vegetation, loss of fine soil particles, enrichment of coarse particles and bare rock exposure, leading to desertification. Greater intensity of land destruction and use causes more serious destruction of soil aggregates. Except for sparse shrub land, slope farmland, where woodland is reclaimed for farming, damages soil aggregates the most. Woodland reclamation changes the physical properties of soil, especially the distribution of soil organic carbon and microorganisms living in the environment. This situation creates conditions that facilitate decomposition and transformation of soil organic matter, changing the quality and size of aggregates. Increase in farming intensity can promote the recycling of soil organic matter and reduce both the soil aggregate effect and the proportion of large aggregates, thus increasing the proportion of micro-aggregates. This outcome results in decreasing the stability of soil aggregates. Therefore, taking measures

Table 4 Fractal dimension and proportion of aggregates in different land use patterns

Land use pattern	Mass percentage of different size soil aggregates (mm)						Fractal dimension
	10–5	5–2	2–1	1–0.5	0.5–0.25	<0.25	
Shrub grassland	34.36	24.99	11.91	7.01	7.63	14.1	2.519
Burned area	23.87	16.86	16.98	12.08	8.49	21.72	2.616
Secondary young forest land	30.58	16.56	13.57	11.4	11.44	16.45	2.567
Slope farmland	18.48	19.74	11.74	15.07	9.41	25.56	2.657
Sparse shrub land	12.8	16.71	17.52	11.41	13.95	27.61	2.678
Shrubs and trees mixed forest	28.67	16.28	13.83	12.11	10.54	18.57	2.591

Table 5 Regression and correlation analysis about fractal dimension of soil aggregates and the content of aggregates with different grain sizes

Size of soil aggregates (mm)	Regression equation	Correlation coefficient (r)	Significant level (P)
10–5	$D = 2.781 - 0.007x$	−0.9783**	<0.01
5–2	$D = 2.766 - 0.009x$	−0.5372	Not significant
2–1	$D = 2.431 + 0.012x$	0.5122	Not significant
1–0.5	$D = 2.411 + 0.017x$	0.7456	Not significant
0.5–0.25	$D = 2.453 + 0.015x$	0.5746	Not significant
<0.25	$D = 2.377 + 0.011x$	0.9896***	<0.001

*, **, *** is significant at the 0.05, 0.01 and 0.001 level, respectively

for converting cropland to forest is crucial for creating a more effective cycle to alleviate the karst desertification hazards and to maintain the ecological system.

Table 4 shows the fractal dimension of soil aggregates and the content of aggregates with different grain sizes. The changing proportion of large aggregates (10–5 mm) and micro-aggregates (<0.25 m) is related to fractal dimension. Using regression analysis, results shown in Table 5 indicate that the soil aggregates' fractal dimension only has significant relationship with the content of large aggregates (10–5 mm) and micro-aggregates (<0.25 m). Fractal dimension of soil aggregates is significantly negatively correlated with 10–5 mm aggregates content, with correlation coefficient of −0.9783. Fractal dimension of social aggregates is significantly positively correlated between fractal dimension of soil aggregate and content of micro-aggregates (<0.25 m), as the correlation coefficient is 0.9896, but no significant relationship exists with the other aggregate sizes.

Results suggest that large aggregates can improve the stability of soil aggregates, increasing soil fertility while micro-aggregate volume is too small which is easy to clog pores and are not conducive to the aggregates' stability, affecting the permeability of the soil and reducing soil fertility (Qi et al. 2011). The fractal dimension of aggregates can be an indicator of the content of 10–5 mm of large aggregates and <0.25 m micro-aggregates. As fractal dimensions cannot only express the particle size distribution with simple calculation, but also reflect the content of large aggregates and micro-aggregates, fractal dimension promises to be a superior metric to mean weight diameter.

3.2 Relationship between soil aggregate fractal dimensions and content of soil particles

Organic matter, clay and free oxides are important cement for the formation of aggregates. It is generally believed that the soil organic matter is dominant when the soil has a high content of soil organic matter and a low content of clay and iron oxide. However, when soil organic matter has low organic matter and high clay content, aluminum and iron oxide soil, the formation of soil aggregates depends mainly on clay content (Su and Zhao 2009).

Figures 4, 5, 6 and 7 show the relationship between fractal dimension of soil aggregates with different land use patterns and the content of sand, silt, clay and organic matter. The regression and correlation analysis results are shown in Table 6. The analysis results illustrate that the fractal dimension of soil aggregates has significant negative correlation

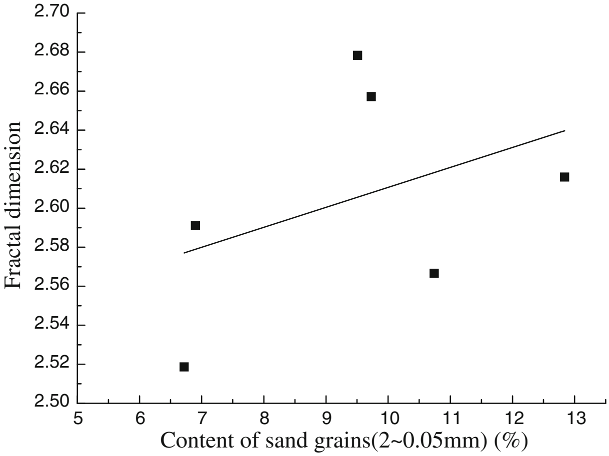


Fig. 4 Relationship between fractal dimension of soil aggregates and the content of sand grains

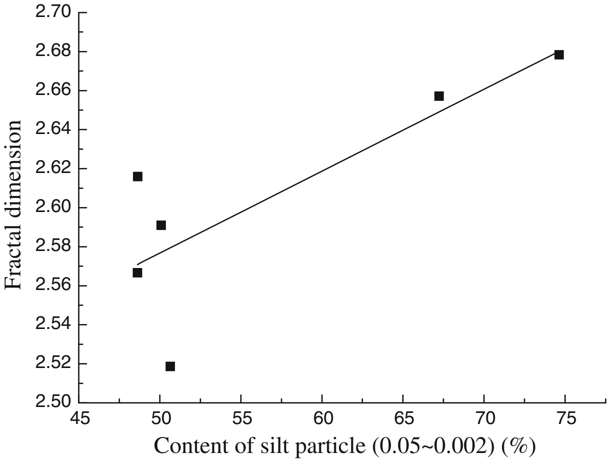


Fig. 5 Relationship between fractal dimension of soil aggregates and the content of silt particles

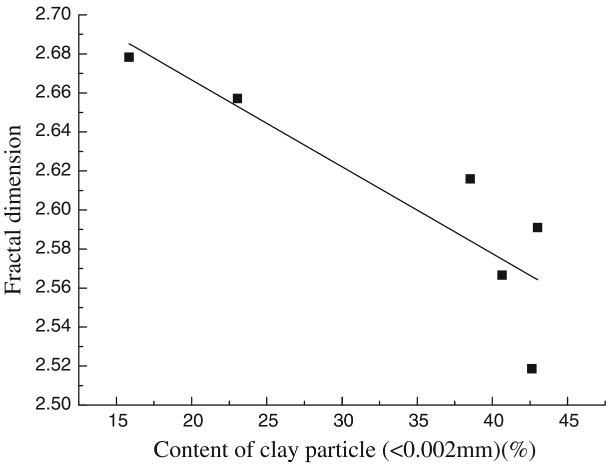


Fig. 6 Relationship between fractal dimension of soil aggregates and the content of clay particles

Fig. 7 Relationship between fractal dimension of soil aggregates and the content of organic matter

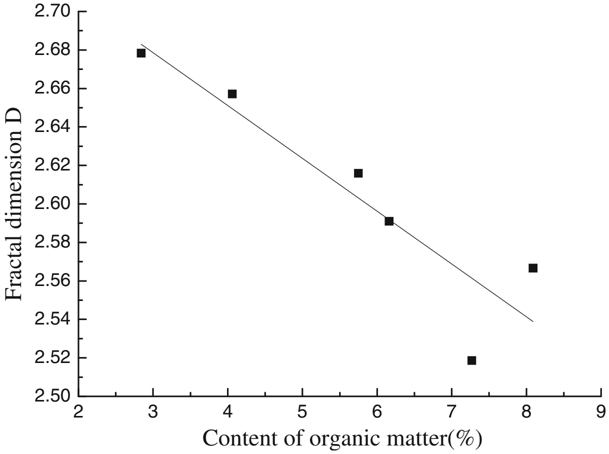


Table 6 Regression and correlation analysis about fractal dimension of soil aggregates and the content of sand, silt, clay and organic matter

Different size particles	Regression equation	Correlation coefficient (*r*)	Significant level (*P*)
Sand grain (2–0.05 mm)	$D = 2.509 + 0.010x$	0.4061	Not significant
Silt particle (0.05–0.002 mm)	$D = 2.368 + 0.004x$	0.8058	Not significant
Clay particle (<0.002 mm)	$D = 2.755 - 0.004x$	−0.8741*	<0.05
Organic matter	$D = 2.760 - 0.027x$	−0.9183*	<0.05

*, **, *** is significant at the 0.05, 0.01 and 0.001 level, respectively

with clay content and organic matter content, as the correlation coefficients are −0.8741 and −0.9138, respectively, but no significant correlation exists between the fractal dimension of soil aggregates and contents of sand and silt.

The content of the clay and organic matter plays an important role in the formation of aggregates owing to providing a cohesive force which attributes to the increase in soil aggregates. Clay with large high-specific surface area supplies strong absorption for adjacent particles to form molasses. Organic matter can contribute to the stability of the aggregate structure, performance of water storage, permeability, aeration and anti-erosion ability. So, the quantity of clay and organic matter has close relationship with the amount of soil aggregates. Excessive land use causes damage of clay and decomposition of organic matter. In a word, rational land use pattern possesses important role in the maintenance of soil organic matter and clay content together with improving the quality of soil.

3.3 Analysis of the water stability of soil aggregate with different land use patterns

Soil fractal dimension can be applied to characterize the changes to factors influencing the stability of soil structure. The water stability of soil aggregates directly impacts the behavior of the surface water and soil. Soil aggregates are sensitive to rainfall infiltration and soil erosion. The content of water stable aggregate is one of the indicators for gauging soil resistance to erosion since water. They have a significant role in maintaining the stability of the soil structure.

The distribution of water stable aggregates by wet sieving is shown in Table 7. The corresponding characteristic parameters of soil aggregate structure are shown in Table 8. The land use patterns, sorted from highest to lowest by fractal dimension as determined through the wet sieve method, are {sparse shrub land, slope farmland, burned area, shrub grassland, shrubs and trees mixed forest, secondary young forest lands}, while by dry sieve method the order is {sparse shrub land, slope farmland, burned area, shrubs and trees mixed forest, secondary young forest lands, shrub grassland}. For different land uses patterns, soil aggregates show diverse sensitivity to water. And after wet sieve method, the quality and quantity of soil aggregates change differently. So, there is a little difference between the two sorted lists, and the water stability of soil aggregates of secondary young forest lands seems superior to the other land use patterns. By contrast, after the wet sieving process, the relative content of water stable aggregates is reduced:the content of >5 mm water stable aggregates (ranging from 12.80 to 34.36 % in the dry sieve case) decreases to 0–20.65 % (average 7.93 %), while >0.25 mm water stable aggregates (ranging from 72.39 to and 85.90 % in the dry sieve case) decreases to 26.76–66.38 % (average 49.57 %). Table 8 also shows that the burned area has the highest percentage of aggregate disruption reaching 100.00 %, with sparse shrubbery next highest, and the lowest

Table 7 Particle size distribution of soil aggregates (wet sieve analysis)

Land use pattern	Number of text sample	Sample number	Mass percentage of different size soil aggregates (mm)					
			10–5	5–2	2–1	1–0.5	0.5–0.25	<0.25
Shrub grassland	S01	3	15.69	9.76	7.17	10.76	16.65	39.97
Burned area	S02	3	0	2.95	10.65	13.39	21.32	51.69
Secondary young forest land	S03	3	20.65	12.87	12.38	9.83	10.65	33.62
Slope farmland	S04	3	2.81	2.71	6.98	10.49	12.67	64.34
Sparse shrub land	S05	3	1.46	4.23	3.98	7.87	9.22	73.24
Shrubs and trees mixed forest	S06	3	6.98	9.57	11.18	13.87	18.65	39.75

Table 8 Characteristic parameters of soil aggregates (wet sieve analysis)

Land use pattern	Number of text sample	>5 mm water stable aggregates (%)	>0.25 mm water stable aggregates (%)	Mean weight aggregates (mm)	Fractal dimension	Correlation coefficient	Percentage of aggregate disruption	
							PAD5	PAD0.25
Shrub grassland	S01	15.69	60.03	1.82	2.787	0.9863	54.34	30.12
Burned area	S02	0	48.31	0.51	2.841	0.9162	100	38.29
Secondary young forest land	S03	26.65	66.38	2.34	2.735	0.9991	32.47	20.55
Slope farmland	S04	2.81	35.66	0.62	2.892	0.9522	84.79	52.09
Sparse shrub land	S05	1.46	26.76	0.5	2.923	0.9657	88.59	63.04
Shrubs and trees mixed forest	S06	6.98	60.25	1.25	2.777	0.9683	75.65	26.01

The percentage of aggregate disruption $PAD_5 = (>5$ mm air-dried aggregates- >5 mm water stable aggregates)/air-dried aggregates 5 mm × 100 %; the percentage of aggregate disruption $PAD_{0.25} = (>0.25$ mm air-dried aggregates- >0.25 mm water stable aggregates)/0.25 mm air-dried aggregates × 100 %

Fig. 8 MWD (mean weight diameter) of the soil aggregates with six land use patterns

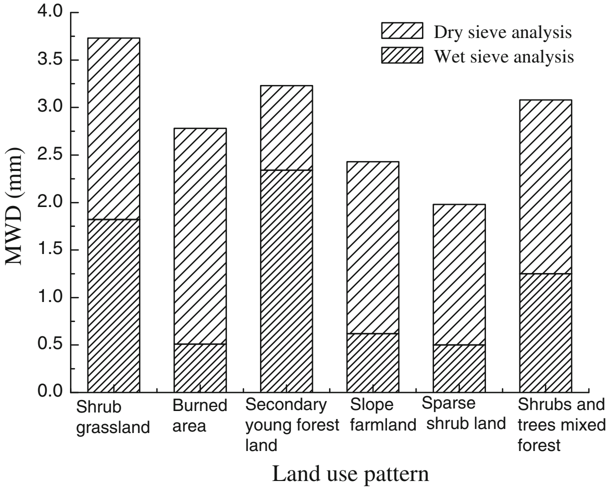
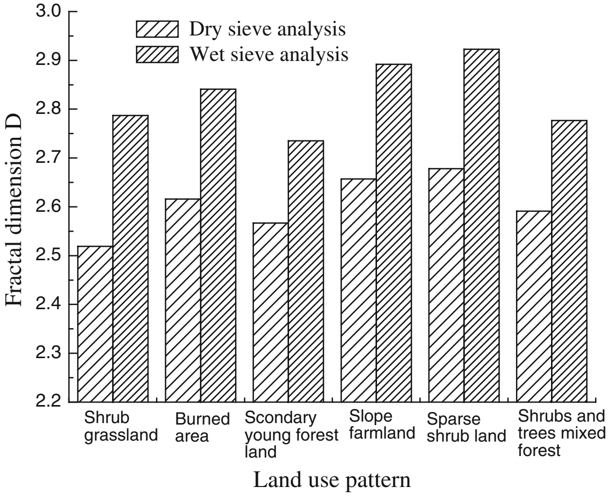


Fig. 9 Fractal dimension of the soil aggregates with six land use patterns



percentage found in secondary young forest lands. Examining >0.25 mm aggregates, the percentage of aggregate disruption ranges from 20.55 to 63.04 %, the highest found in sparse shrub land, followed by slope farmland, and the minimum found in secondary young forest lands.

The result illustrates that after water sieving, large aggregates of burned lands basically decompose into micro-aggregates. This phenomenon makes it clear that woodland burning has a very serious negative impact on the water stability of soil aggregates by decreasing the stability of large aggregates. Thus, preventing rocky desertification requires restriction on the burning of woodlands, maintenance of soil aggregate water stability and improving resistance to soil erosion on precipitation.

Figure 8 shows the MWD (mean weight diameter) of the soil aggregates is significantly reduced after wet sieving, as the burned area possesses the largest reduction, followed by sparse shrub land, with secondary young forest lands at the minimum. Figure 9 shows that by wet sieving, the fractal dimension of soil aggregate has a significant increase with shrub grassland having the largest increase, followed by sparse shrub land, and secondary young forest having the minimum rise. From this result, we can create a meaningful recommendation: land use patterns such as burning, farming and overgrazing which have a very negative impact on the stability of soil aggregates should be avoided, and forest conservation (as seen in secondary young forest lands) can play a very effective role in the protection of soil as plants' roots can improve moisture conditions of soil, increase soil organic matter content, form a good soil/vegetation system, and increase the aggregates' stability and corrosion resistance. Simply, forest conservation is the preferred measure to ease rocky desertification.

To further determine the relationships between the mean weight diameter, fractal dimension and PAD (percentage of aggregate disruption), we used regression and correlation analysis. The relationships are shown in Figs. 10 and 11, while regression and correlation analysis results are shown in Table 9. The analysis shows that the mean weight diameter of the soil aggregate has a significant negative correlation with the percentage of aggregate disruption of >5 mm aggregates (PAD5), as the correlation coefficient is −0.9768, while no significant correlation exists between the mean weight diameter and the percentage of aggregate disruption of >0.25 mm aggregates (PAD0.25) as the correlation coefficient is −0.8114. However, a totally opposite relationship exists between the fractal dimensions and the percentage of aggregate disruption:the fractal dimension has a significant linear relationship with the percentage of aggregate disruption of >0.25 mm aggregates (with a correlation coefficient of 0.9886). It is clear that the content of the large aggregates (>5 mm) influence the mean weight diameter while the content of the aggregates (>0.25 mm) plays an important role on the fractal dimension, so the fractal dimension is more suitable than the mean weight to express the change of the content of different size of aggregates.

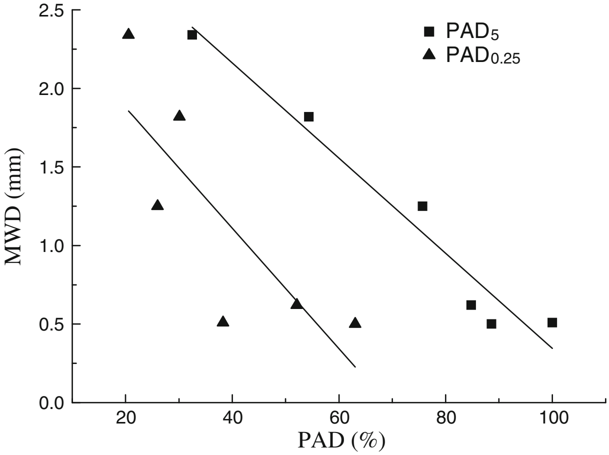


Fig. 10 Relationship between MWD and PAD

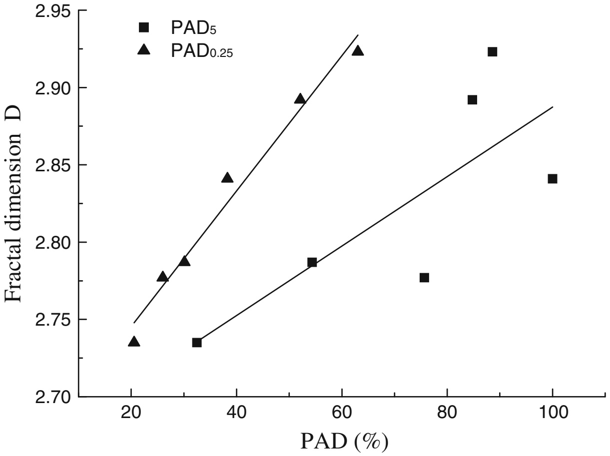


Fig. 11 Relationship between Fractal dimension and PAD

Table 9 Regression and correlation analysis about MWD, fractal dimension and PAD

Dependent variable	Independent variable	Regression equation	Correlation coefficient (r)	Significant level (P)
MWD	PAD5	$y = -0.0303x + 3.3720$**	−0.9768**	<0.01
	PAD0.25	$y = -0.0384x + 2.6445$	−0.8114	Not significant
D	PAD5	$y = 0.0022x + 2.6627$	0.7738	Not significant
	PAD0.25	$y = 0.0044x + 2.6579$	0.9886***	<0.001

*, **, *** is significant at the 0.05, 0.01, and 0.001 level, respectively

4 Conclusions

1. Through the dry sieve method, sparse shrub land has the largest fractal dimension and shrub grassland has the smallest. But by the wet sieve method, there is a little difference as secondary young forest lands occupy the smallest fractal dimension which indicates that its water stable aggregates have better stability than the other land uses.
2. The land use pattern with larger fractal dimension suffers from more serious soil erosion. Greater intensity of land destruction and use causes more serious destruction of soil aggregates. Woodland reclamation, burning, farming and overgrazing should be avoided. Taking measures for converting cropland to forest and protecting forest are crucial for creating a more effective cycle to alleviate the karst desertification hazards and to maintain the ecological system.
3. The fractal dimension of soil aggregates is significantly negatively correlated with the content of large aggregates (10–5 mm) and significantly positively correlated with the content of micro-aggregates (<0.25 mm).
4. The fractal dimension of soil aggregates has a significant negative correlation with clay content and organic matter content.
5. The quality of aggregates and the MWD (mean weight diameter) of the soil aggregate are significantly reduced after wet sieving, while the fractal dimension is increased. The mean weight diameter of the soil aggregate has a significant negative correlation

with the percentage of aggregate disruption of >5 mm aggregates (PAD5) as the fractal dimensions has a significant linear relationship with the percentage of aggregate disruption of >0.25 mm aggregates (PAD0.25).

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