Fractal characteristics of soil particle size in loess hilly areas with different years of conversion

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Abstract. The purpose of this study was to investigate the change of soil particle composition and its effect on the fractal dimension of grassland under different years of conversion. The changes of soil particle composition and soil fractal dimension were analyzed by taking the 8-year grassland and 31-year grassland in the Yuanzegou watershed of the loess hilly region as the research objects, and taking the sloping farmland as the control. The results showed that the clay content of soil was increased by 69.6%, 47.6% and 8.80%, 8.7%, respectively, in the 31-year grassland and the 8-year grassland in the 0-20cm, 20-40cm. The decrease of sand content was 38.7%, 18.2% and 15.6%, and 13.5%, respectively, which were significantly different from that of the 31-years grassland (P<0.05). The contents of particles in the 40~60cm soil layer did not change significantly. fractal dimension range from 2.6 to 2.7, the expression for the conversion of 31 years grassland>grassland>changing slope farmland 8 years, the fractal dimension of soil particles increased along with the increasing length of the grass farmland, in 0~20, 20~40cm soil layer, the conversion of 31 years grassland soil particles fractal dimension D and slope have significant difference (P<0.05). The fractal dimension of soil particle volume was positively correlated with soil clay (P<0.01), and positively correlated with soil particle size on farmland and grassland after 31 years of conversion (R²=0.6970, 0.6701), but not on grassland after 8 years of conversion. There was a negative correlation between soil sand content and fractal dimension of soil particles in the three plots, but there was only a significant difference in slope farmland.

Key words: Grassland; Cropland; Fractal dimension of soil; Conversion of fixed number of year; loess hilly areas.

1. Introduction
As a porous medium composed of various substances such as water, air and different particles, soil is a complex geometry with irregular shape and self-similarity characteristics [1]. Fractal theory can be used
to describe the irregular and self-similar characteristics of object structure. Based on the self-similar characteristics of soil particles, fractal theory has been introduced into soil science to better reflect the changes of soil properties and structure. Since Yang Peiling [2] and Wang Guoliang [3] and other scholars put forward and continuously optimized the calculation model of soil particle fractal dimension, Chinese scholars have made a lot of achievements in the study of soil particle fractal dimension in the aspects of land use change [4], vegetation ecological restoration [5] and soil environmental remediation [6-7]. It can be seen that the fractal characteristics of soil particles can not only represent the physical and chemical properties of soil, but also play a certain role in the restoration of regional ecological environment.

In the loess hilly region, valleys are horizontal and horizontal, with loose structure and serious soil and water loss and erosion [8]. In order to reduce soil erosion on the Loess Plateau, since 1999, the Chinese government has implemented a large area of conversion of farmland to forest (grass), and a large area of easily eroded sloping farmland has been transformed into grassland and forest land [9]. The change of land vegetation not only affects the ecological environment, but also changes the soil structure. According to The theory of PFS [10], vegetation needs to consume nutrients to meet its own development in the early stage of restoration, which is the nutrient consumption stage, while the later stage is the nutrient storage stage. Therefore, different vegetation restoration years have different effects on soil structure and physical and chemical properties. The fractal dimension of soil particles can be used to measure the change of vegetation restoration and soil quality, but it is rare to quantify the influence of vegetation restoration time on soil structure by the fractal dimension theory of soil particles. Based on grain for typical small watershed in qingjian county, yulin city of shaanxi province as the research object, in farmland, for comparison, the classic fractal dimension model, study different fixed number of year of the grain for the grass grass (grain for 8 years, the grass, grain for 31 years) of soil particle size distribution and the change of the fractal dimension characteristic, explores under different fixed number of year of the grain for the grass the fractal dimension of soil particles and the correlation of soil particles. It is expected to provide some scientific basis for the land resource management, vegetation restoration and sustainable development of conversion of farmland to forest (grass) in small watershed of loess hilly region.

2. Materials and methods

2.1. Study area
In this study, yuanzegou watershed, located in Qingjian County, Yulin City, Shaanxi Province (37°15'N, 118°18'E), is selected in the hilly gully region in the north of the Loess Plateau. It has deep slopes and gullies, deep gullies and severe water and wind erosion. The region has a temperate continental monsoon climate, with an average annual precipitation of 505mm. The rainfall is mainly from July to September, with an average annual temperature of 8.6°C. The lowest monthly temperature is -6.5°C (January), and the highest monthly temperature is 22.8°C (July). Since the implementation of the measures, a large area of sloping farmland in the basin has been converted into grassland and artificial economic woodland, mainly including 8-year grassland, 31-year-old grassland and jujube forest.

2.2. Study subjects and soil sample collection
In August 2017, the 8-year grassland and the 31-year grassland were selected as the research objects in the basin, and the sloping farmland was taken as the control. The sample land information was shown in Table 1. According to the size of the sample plot, a soil drill with a diameter of 40mm was used to randomly select the soil sample. A layer with a depth of 20cm was taken, and a total of 3 layers were taken, namely 0-20cm, 20-40cm, and 40-60cm. The detailed geographic information of the sample plot was recorded with portable handheld GPS (MG838, UniStrong). Three sample points were randomly selected near each point and evenly mixed in each layer. Plant roots and gravel were picked out and put into self-sealing bags and brought back to the laboratory for use. A total of 18 samples were taken,
including 7 samples for sloping farmland, 6 samples for 8-year grassland and 5 samples for 31-year grassland.

Table 1. Environmental factors of the sample land

| Land uses            | samples | Altitude (m)       | Slope  | Aspect  | vegetation                     |
|----------------------|---------|--------------------|--------|---------|--------------------------------|
| Cropland             | 7       | 954.30 ~ 1015.00   | 3.19   | 11.63   | Setaria italica, Vigna radiate |
| 8-year-old grassland | 6       | 930.80 ~ 1019.20   | 21.65  | 15.75   | Artemisia capillaris           |
| 31-year-old grassland| 5       | 1031.3 ~ 1094.80   | 2.88   | 290.7   | Stipa bungeana                |

2.3. Determination of the fractal dimensions of the soil samples

The collected soil samples were brought back to the laboratory for natural dry, and then passed through a 2-mm sieve to determine the soil particle size distribution. Said take 5 g soil samples in a disposable plastic cup, add 10 ml of hydrogen peroxide solution, then add 10 ml of hydrochloric acid, let stand for 3 to 5 days, observation of soil sample bubbling situation every day, until the full response to the carbonate in soil samples completely eliminate, bubble, no longer add distilled water, let stand for 24 h, repeatedly until test pH pH at 6.5 ~ 7.0, and then adding sodium hexametaphosphate after ultrasonic treatment for 30 s, [11] with melvin laser granulometer (Mastersizer2000, pennsylvania-based firm Instruments Ltd) determination of soil particle size distribution. In this study, soil particle sizes were divided into 8 grades according to the American system of soil classification standards, which were 0~0.001, 0.001~0.002, 0.002~0.005, 0.005~0.01, 0.01~0.02, 0.02~0.05, 0.05~0.1 and 0.1~2mm, respectively. Soil texture classification according to the American Agricultural System, soil particle sizes are divided into clay particles (<0.002mm), powder particles (particle size 0.002~ 0.05mm) and sand particles (0.05~2mm).

2.4. Calculation of the fractal dimensions of soil particles

In this paper, according to the fractal theory model of soil particle volume derived by Wang Guoliang [4], the fractal dimension D of soil is calculated, and the formula is:

$$V(r < R) = \frac{V_T}{\lambda V} = \left(\frac{R}{\lambda V}\right)^{3-D}$$

In the formula, V(r< R) represents the sum of the particle size volume of all soil particles less than R, V_T represents the total volume of soil particles, R represents the characteristic scale of a certain particle size, and the calculation is expressed by the upper and lower limit arithmetic mean of this area, lambda V represents the maximum particle size value in the grading of soil particle size, and D represents the volume fractal dimension of soil particles.

Calculate the fractal dimension of the soil, take the logarithm of both sides of the formula, carry out linear fitting to the point, the slope of the fitted line is 3-D, thus can be calculated volume fractal dimension D, dimensionless.

2.5. Statistical analysis

Univariate analysis of variance (anova) was used to compare the effects of conversion years on soil particle size and fractal dimension, and LSD method was used for difference comparison. Data processing and drawing were performed using Excel2010, and data analysis was performed using Spss20.

3. Results

3.1. Characteristics of soil particle distribution in grassland with different years of conversion

As shown in Table 2, the volume changes of soil clay particles (0~0.002mm) in the study area ranged from 12.5% to 21.2%, powder particles (0.002~0.05mm) from 67.4% to 71.6%, and sand particles (0.05~2mm) from 11.4% to 18.6%. On the whole, the volume fraction of soil clay particles in the study
area was the largest, followed by clay particles and sand particles. In the 0-20cm soil layer, compared with the farmland, the soil clay content in the 31-year grassland increased significantly (P<0.05) by 69.6%, while the soil clay content in the 8-year grassland increased by 8.80%, but the difference was not significant. The sand content in the 31 year-grassland decreased significantly (P<0.05) by 38.7%, while the sand content in the 8-year-grassland decreased by 15.6%, with no significant difference. There was little change in grain content. In the 20-40cm soil layer, the change trend of soil particle content in the 31-year grassland and the 8-year grassland was the same as that in the 0-10cm soil layer, and the increase of clay content was 47.6% and 8.7%, respectively. Moreover, there was significant difference between the clay content in the 31-year-old grassland and that in farmland (P<0.05). The decrease of sand content was 18.2% and 13.5% respectively, and there was no significant difference compared with farmland.

3.2. Fractal characteristics of soil particles in grassland of different years of conversion

The fractal dimension in reclaimed grassland and sloping farmland is shown in Table 2. The fractal dimension D of soil particles is between 2.6 and 2.7. In the 0~60cm soil layers, the fractal dimension D was all shown as 31 year-grassland>8 year-grassland> farmland, which increased with the increase of the number of years of grassland. In the 0~20cm, 20~40cm soil layer, there was significant difference between the fractal dimension D in 31-year grassland and farmland (P<0.05).

Table 2. Soil texture and fractal dimension of grassland with different years of conversion

| Soil depth (cm) | Land uses             | Clay(%) | Silt(%) | Sand(%) | Fractal dimensions |
|----------------|-----------------------|---------|---------|---------|-------------------|
| 0~20          | farmland              | 12.5±1.9b | 68.8±6.0a | 18.6±7.8a | 2.639b           |
|                | 8-year-old grassland  | 13.6±1.6b | 69.9±2.3a | 15.7±2.3ab | 2.654b           |
|                | 31-year-old grassland | 21.2±3.1a | 67.4±2.1a | 11.4±1.1b | 2.728a           |
| 20~40          | farmland              | 12.6±1.7b | 70.4±4.2a | 17.0±5.7a | 2.640b           |
|                | 8-year-old grassland  | 13.7±1.0b | 71.6±0.9a | 14.7±0.5a | 2.654b           |
|                | 31-year-old grassland | 18.6±6.8a | 67.4±5.5a | 13.9±2.9a | 2.704a           |
| 40~60          | farmland              | 13.5±0.5a | 71.0±1.8a | 15.5±1.7a | 2.653a           |
|                | 8-year-old grassland  | 15.3±5.0a | 69.3±3.6a | 15.4±3.7a | 2.672a           |
|                | 31-year-old grassland | 15.4±5.0a | 69.3±3.6a | 15.4±3.7a | 2.672a           |

3.3. Relationship between fractal dimension of soil particles and soil particle size distribution

Figure 1. Correlation between fractal dimension of soil particle volume and soil particle distribution in farmland and grassland with different years of conversion.
The correlation between fractal dimension of soil particles and soil particle size distribution is shown in Figure 1. The fractal dimension of soil particles increased with the increase of soil clay content in farmland, 31-year-old grassland and 8-year grassland. The R² of the regression equation was 0.9976, 0.9845 and 0.9898, respectively, indicating that the fractal dimension of soil particle volume was significantly positively correlated with soil clay (P<0.01). There was a significant positive correlation between soil silt content and soil particle fractal dimension (R²=0.5986, 0.6308) in farmland and 31-year-grassland, but there was no significant correlation between soil silt content and soil particle fractal dimension in 7-year grassland. There was a negative correlation between soil sand content and fractal dimension of soil particles, but there was a significant difference only in farmland, and the other relationships were weak.

4. Discussion
In this study, the clay content of grassland in the soil layer of 0~40cm was significantly higher than that of farmland for 31 years after conversion, and that of grassland for 8 years after conversion was significantly higher than that of farmland, but the difference was not significant. The sand content of the grassland in 31 years of converted farmland was significantly lower than that of farmland, and the sand content in 8 years of converted farmland was lower than that of farmland, but the difference was not significant. The 40-60cm soil layer showed little change. This indicates that returning cultivated land to grassland can increase the clay content of surface soil and reduce the sand content. Moreover, the longer the years of returning cultivated land to grassland, the greater the clay content increases and the more the sand content decreases. There are three main reasons for the analysis. First, compared with sloping farmland, grassland reduces soil turnover, and the vegetation covering the ground increases soil roughness, reduces wind erosion and rainfall erosion, so that soil fine particles can be retained. Second, the plant residues in grassland are mainly concentrated in the surface soil, which increases the content of soil organic matter, provides energy for the growth of microorganisms, and accelerates the mineralization of soil organic carbon while accelerating the particle mineralization. Thirdly, based on the theory of PFS [10], vegetation will consume a large amount of soil nutrients in the early stage of restoration, and soil organic matter will decrease, and nutrients will accumulate in the later stage. Therefore, the clay content of the grassland in the 31-year-old reverted farmland is significantly greater than that in the sloping farmland, while the difference between the grassland in the 8-year reverted farmland and the sloping farmland is not significant.

The fractal dimension of soil is a parameter that reflects the geometric shape of soil structure. The higher the fractal dimension of soil particles is, the finer the soil texture is and the more compact the soil structure is. The smaller the fractal dimension is, the looser the soil is. This study found that 3 piece of sample to the fractal characters of soil particles in 0~20, 20~40, 40~60 cm soil layer soil particles are characterized by the size of the fractal dimension D grain for 31 years grassland>grassland>changing slope farmland 8 years, the change trend of fractal dimension and the change of the clay soil, soil clay content is higher, the bigger the fractal dimension of soil particles. On the one hand, water erosion and wind erosion are serious in small watershed, and the loss of fine particulate matter in sloping farmland soil leads to the aggravation of surface soil coarsenization and the small fractal dimension. Therefore, the fractal dimension of soil particle volume can be used to reflect the particle loss of soil with different particle sizes. On the other hand, due to the increase of fine matter content and the decrease of coarse matter content in grassland soil, the fractal dimension of soil particles was increased, which was beneficial to soil and water conservation and vegetation restoration in small watershed.

In order to clarify the relationship between soil particle distribution and soil fractal dimension, the correlation analysis of soil particle distribution and soil fractal dimension was carried out. The fractal dimension of soil particle size in all three plots was positively correlated with soil clay. However, there was a significant positive correlation with soil powder grains only on sloping farmland and 31-year-old grass, and a significant negative correlation with sand grains except on agricultural land. Under different site conditions and different years of returning tillage, the correlation of fractal dimensions between silt,
sand and soil particles was significantly different, which may be related to vegetation type, vegetation restoration years, soil nutrient structure, topography and topography.

5. Conclusions
The conversion of tilled land into grassland in the small watershed of Yuanzegou in loess hilly region will increase the surface soil clay content (0–40cm) and reduce the sand content, and the difference is significant with the increase of the number of years of tilled land in different soil layers, the fractal dimension showed 31-year grassland > 8-year grassland > farmland, and there were significant differences between the two in the 31-year grassland at the 0-40 cm soil layer. The fractal dimension of soil particles was positively correlated with clay and powder particles, but negatively correlated with sand particles.

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