Soil Characteristics and Its Dynamic Variation in a Small Catchment on the Loess Plateau of China*

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Abstract: In this paper, taking Zhifanggou small catchment, which have been integrated controlled for more than 20 years in the typical hilly-gullied Loess Plateau, as research region, selecting 20 plots of different landuse types in the whole catchment in 1999, soil anti-scourability, stable infiltration rate, soil aggregate stability, saturated soil cohesion and soil organic matter content in these plots were measured. The experiment results showed that there had significant difference of these soil characteristics in different landuse types. Shrubland had the largest mean weight diameter (MWD) of soil aggregate stability and the strongest soil anti-scourability. The anti-scourability of shrub land and natural grassland was about 70—90 times of cropland. The content of O.M in cropland and planted grassland was about 1/2—1/3 of other landuse types. The value of stable soil infiltration rate and saturated soil cohesion was the highest in natural grassland. As a whole, the measuring values of these soil characteristics in woodland with acacia, shrubland with Caragana and natural grassland were much more higher than that in planted grassland and cropland. The variation of these characteristics in soil profile (0cm—50cm) was also significant. Generally speaking, the value of soil anti-scourability, stable infiltration rate, soil aggregate stability and soil organic matter content were all decreased clearly from upper to lower position in soil profile. The decreasing extent was reduced with the soil layer becoming deeper. According to the area of different landuse types in the catchment and its change in history, by spatial and temporal up scaling, the dynamics of these soil characteristics in the catchment after years' control measurement was analyzed. All these results provided valuable basic data for soil erosion modeling and laid foundation for qualitative assessing the soil quality and ecosystem health situation in the catchment with long term controlled measurement.

Keywords: soil characteristics, temporal and spatial variation, small catchment, loess plateau

1 Introduction

NOWHERE in the world, soil erosion is so serious as on Loess Plateau of China. In highly erodible loess soils of Plateau, the irrational land use, low vegetation coverage and cultivation in steep slope land have caused serious soil erosion and environment problems (Liu, 1999). Aware of these issues, the government of the P.R. of China promotes an integrated measurement to control soil erosion. After the three "five year project" in Zhi Fanggou catchment, significant economic, social and ecological benefits have been gained (Liu, 1999). As one of the main component of eco-system, soil characteristics and its' dynamics should be the main index for assessing the eco-system health situation. In order to know the soil characteristics and its' dynamics in controlled area after years' management, a model catchment was selected and several soil physical and chemical properties were measured. The results will provide valuable basic data for soil erosion modeling and lay foundation for qualitative assessing the soil quality and ecosystem health situation in the catchment with long term controlled measurement.

The Zhi Fanggou catchment (36°53′ N, 109°17′ E) is situated on the middle part of the loess

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plateau in northern Shaanxi province in China. The catchment has an area of 8.27km^2 and an altitude between 1,000m—1,350m. There are significant topographic variations with typical loess hills and gully landforms within the study area. Land use types including slope cropland, fallow land, grassland, shrub land, orchard land and woodland. The soils, developing on wind-accumulated loess parent material, are thick at an average of 50m—80m. The most common soil in the catchment is loess with texture of fine silt and silt soil. It is weekly resistant to erosion. The erosion rate is extreme serious at about 10,000—12,000 t • km^{-2} • yr^{-1} (Jiang *et al.*,1990).

2 Materials and methods

2.1 Measurement methods for soil characteristics

20 plots of different landuse types in Zhi Fanggou catchment was selected and soil samples of 5 layers (10cm per layer) from top to 50cm in the ground was taken in 1999 (see Table 1).

Soil anti-scourability, stable infiltration rate, soil aggregate stability and soil organic matter content of these samples were measured. Saturated cohesion of surface soil was also measured. All these characteristics was measured as follows:

Table 1 Basic information of the experiment plot

Landuse type	Vegetation type	Plot number	Topography	Sampling date
Cropland	Foxtail millet	1	Steep slope	4.30—5.28;
	Potato	3	Steep slope, terrace, gentle slope	8.23—8.31;
	Pearl millet	3	Gentle slope1, steep slope2	10.9—10.22
	Soybean	2	Gentle slope, steep slope	
	Maize	1	Terrace	
Woodland	Poplar, Acacia	3	Slope	6.29—8.7
Shrub land	Caragana korshinskii	3	Slope	6.26—8.14
Planted grassland	Melilot	1	Slope	7.16
Natural grassland	Bothriochloa ischaemum, Sophora viciifolia, Artemisia giraldii, Stipa bungeana	3	Slope	7.13—8.7

(1) Soil anti-scourability

Soil anti-scourability was measured using washing original state soil method (Liu, 1997). Special equipment named Anti- scouring mini-flume was used with runoff of 1.4L/min (the amount is based on the premise that all the rainfall at 2mm/min (the maximum density in the Loess Plateau) in a standard plot of 5×20 m^2 was lost as runoff.) to scouring the soil sample in the groove. The soil sample was saturated before washing and the slope of the groove was regulated according to the selected plots. 20 samples with 4 repeats in each of 5 layers were taken in the experiment. Soil anti-scourability was calculated as follows:

$$s_0 = \frac{Q \cdot T}{M}$$

Where S_0 is soil anti-scourability (l • min • g^{-1}), Q is total runoff for scouring (ml), T is scouring time and M is the dry soil weight lost in the groove.

(2) Soil steady infiltration rate

Soil steady infiltration rate was tested by infiltration cylinder (the height is 12cm and the diameter is 10cm) method. Soil samples were saturated for 12 hours before measurement and constant water head of

2cm was kept during measurement. The outflow in every 3-minute was measured until the infiltration was stable. 15 soil samples with 3 repeats in each of 5 layers were taken. Soil steady infiltration rate was calculated as follows:

$$V = \frac{Q_i}{S} \bullet \frac{10}{ti}$$

$$K_t = V \bullet \frac{L}{(H + L)}$$

$$K_{10} = \frac{K_{ti}}{(0.7 + 0.03t)}$$

Where V is soil steady infiltration rate (mm • min^{-1}), Q_i is the outflow from the cylinder during ti (ml), S is the botom area of the cylinder(cm^2), L is the height of soil sample(cm), H is the height of the water head(cm) and K_t is the infiltration coefficient in T ℃.

(3) Aggregate stability

A set of sieves (5mm、2.5mm、1mm、0.5mm and 0.25mm) were prepared. The saturated soil sample (soil sample is wetted by capillary water to get rid of air in soil) was put in the equipped sieves. Then put the sieves in water and shake it up to down for 1 minute (Zhu, 1989). Weigh the aggregate left in each size of sieve and calculate the percentage of each particle class. Mean weight diameter (*MWD*) (Bissonnals, Y.L.E.1996) was also calculated as follows:

$$MWD = \sum_{I-1}^{n} X_i \bullet W_i$$

MWD—Mean weight diameter(mm)

X_i—Average diameter of each particle class(mm)

W_i—Percentage of aggregate relating to X_i(%)

(4) Soil surface cohesion

A kind of pocket shear tester is used in the measurement as follows (Brunori, *et al.*, 1989):

① Wet the soil thoroughly with the sprinkler to saturate it. Make sure the pocket vane tester shows 0.

② Push the pocket vane tester into the ground, until the vanes are no longer visible.

③ Turn carefully to the right, until the soil fails. If the value is above 8 use the smaller vane. If the value is below 2 use the larger vane.

Calculate the average cohesion value by 0.02 for the large vane, 0.10 for the middle vane and 0.25 for the small vane (unit：kg • cm^{-2}). 10 repeats of cohesion in each plot were conducted in the experiment.

Organic matter content was measured using $K_2Cr_2O_7$ oxidation method.

The variance analysis of each characteristic was done according to different landuse types.

2.2 Temporal and spatial upscale of the soil characteristics

In order to better understand how soil quality had changed after 20 years of environmental rehabilitation in the catchment, we upscaled the experiment results of plot scale to catchment scale and calculated the soil characteristics values of past year using the data of experiment year based on the representative of the selected plots and following precondition:

- The analysis to the soil characteristics in plot scale demonstrated that the measured soil characteristics have significant difference in different landuse types. Compared to the change of landuse types, the influence of temporal variation on the soil characteristics can be neglected.
- Water area, bare rock, the area of villages and roads were not included into the total area of the catchment based on the neglectable area of water area, bare rock, villages and roads and the assumption that the area didn't change greatly during history.
- The anti-scourability of terrace was not considered in calculating the total anti-scourability of the catchment for the reason of no soil loses in terrace normally.

The soil characteristic of the catchment were calculated using the following equation:

$$V = \sum P_i \times V_i$$

Where V is the value of the soil characteristic on catchment scale. P_i is the area percentage of the landuse type, i , to the area of the catchment. V_i is the value of the soil characteristic in the landuse type, i, on plot scale.

The soil characteristics of the catchment in history were calculated by the area percentage of the landuse type in the historical year.

3 Result and discussion

3.1 Soil characteristics and its variation in soil profile

3.1.1 Soil anti-scourability

The measuring result showed that there was significant difference of soil anti-scourability among landuse types in Zhi Fanggou catchment. The sequence of anti-scourability was shrub land> natural grassland> woodland> planted grassland> cropland (see Table 2). The anti-scourability of shrub land and natural grassland was about 70—90 times of cropland. The anti-scourability in planted grassland, which was slope cropland two years ago, was about 10 times of cropland. It seems that soil anti-scourability in slope cropland can be improved quickly after changing landuse type.

Soil anti-scourability in profile of all kinds of landuse types decreased sharply from upper layer to lower except cropland, which had the highest value in the layer of 10cm—20cm. This maybe also influenced by the amount of root in profile. Besides, the anti-scourability in the layer of 40cm—50cm in woodland, shrub land and natural grassland had higher value than the upper layer (see Fig.1).

Table 2 Soil indicators characteristics in different land use type*

Characteristics	Cropland	Woodland	Shrub land	Natural grassland	Planted grassland
Anti-scourability ($l \cdot min \cdot g^{-1}$)	0.042	2.538	4.237	3.470	0.585
Stable infiltration rate ($mm \cdot min^{-1}$)	0.65	1.11	0.85	1.93	0.78
M.W.D of water stable aggregate (mm)	1.74	2.81	2.91	2.54	2.06
Cohesion ($kg \cdot cm^{-2}$)	0.082	0.111	0.082	0.111	0.119
Content of O.M. (%)	0.46	0.95	0.89	0.43	1.33

*Note: The data in the table is the average of 5 layers from top to 50cm in the ground (only saturated soil cohesion in surface layer was measured).

3.1.2 Soil infiltration

Infiltration is the process that water enters into soil, which is an important tache in transform of precipitation, surface water, soil moisture and ground water. Reduced infiltration leads to less water stored in the soil for later use by crops and often reduces crop yields. Runoff associated with low infiltrations is also the driving force for soil erosion, a problem for sloping lands (Connolly *et al.*, 1998). Soil infiltration capacity can be expressed using steady infiltration coefficient, K_{10}.

The measurement result showed that there was great difference of K_{10} among landuse types. The sequence was woodland> natural grassland> shrub land> planted grassland, cropland (see Table 2). K_{10} in soil profile decreased rapidly from upper layer to lower (see Fig.2).

3.1.3 Soil aggregate stability

In general, soil aggregate stability is positively correlated with organic content, which commonly declines under arable cropping. A decrease in organic content with a consequent reduction in aggregate stability in cultivated soils generally leads to soil degradation problems such as crusting, runoff and erosion (Bissonnais *et al.*, 1997;Guerra, 1994; Sullivan, 1990). The mean weight diameter of soil aggregate stability (*MWD*) reflects the size of stable soil aggregate. Generally speaking, good soil structure has higher *MWD*, which makes the soil porous and the infiltration ability can be increased obviously.

The sequence of *MWD* in different landuse types was that shrub land> woodland> natural grassland>planted grassland> cropland (see Table 2). As a whole, *MWD* in soil profile decreased from upper layer to lower layer (see Fig.1). The MWD in 10cm—20cm was higher than that of 0cm—10cm in cropland, planted grassland and shrub land, which maybe attributed to the influence of farming activities on the topsoil.

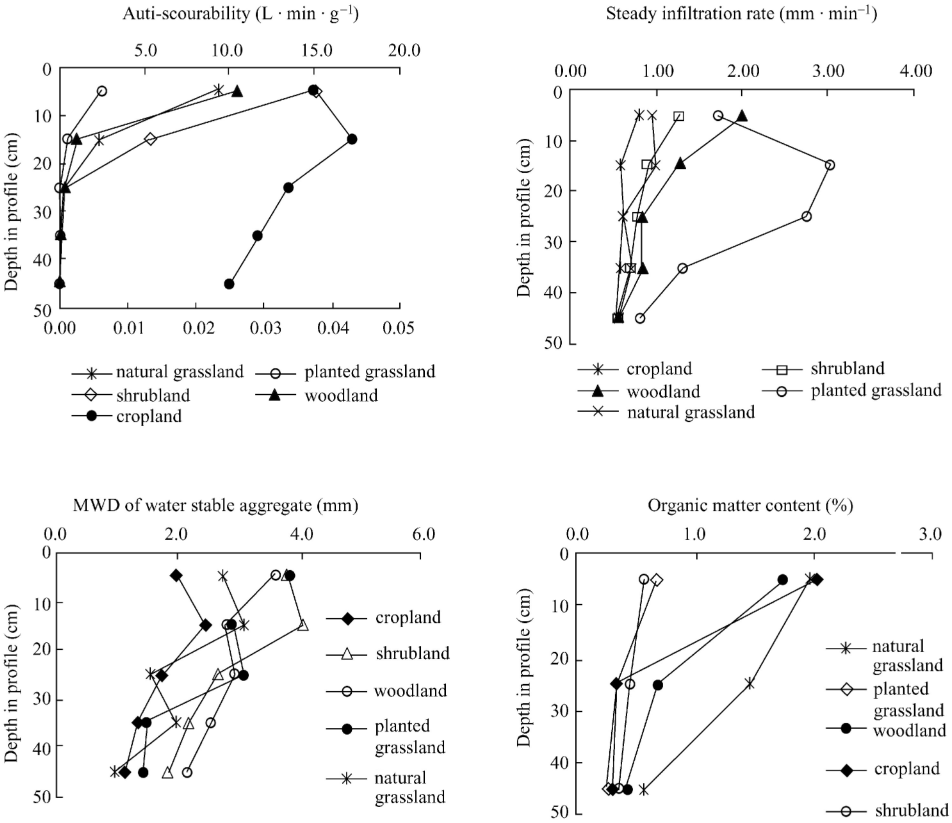

Fig. 1 Soil characteristics of landuse types in profile

3.1.4 Soil saturated cohesion

Soil cohesion is one of the measurement indexes of soil resistance, which shows soils' ability to resist the destruction of outside force. Generally speaking, soil erosion shows a negative relation with soil cohesion. Soil cohesion is related with soil type, O.M, soil water content and so on (Brunori, *et al.*, 1989).

The measuring result showed that the sequence of soil cohesion in different landuse types was that woodland, grassland> shrub land, cropland, however, there has no significant difference in landuse types (see Table 2).

Soil moisture content, bulk density, plasticity index and O.M. have great effect on soil cohesion. Besides, plant root in soil also affect soil cohesion. That is why the saturated cohesion in topsoil of cropland and shrub land is lower.

3.1.5 Soil organic matter content

Soil organic matter content is a relatively stable, integrating soil characteristic that reflects long-term land use and is an important indicator of soil quality (Pulleman, *et al.*, 2000). It's also the basis of soil fertility and the formation of stable aggregate. Table 2 demonstrated that there was significant difference of soil organic content among landuse types in Zhi Fanggou catchment. The content of O.M in cropland was close to that of planted grassland, which was about 1/2—1/3 of other landuse types. The sequence was that natural grassland> woodland> shrub land> cropland and planted grassland (see Table 2). The content of O.M in soil profile decreased from top to lower layer clearly (see Fig.1).

Correlation analysis demonstrated that there were significant positive correlation between steady infiltration rate and organic matter content:

$$y=0.3583e^{1.0153x} \quad R=0.7973^{**}(n=24)$$

Where, y is K_{10}, x is organic matter content.

This showed that with the increasing of O.M, soil structure was improved and became porous, thus the infiltration capacity can be increased.

3.2 Temporal variation of soil characteristics

The temporal variation of several soil characteristics from 1938 to 1999 was showed in Fig.2. There were several phases of these characteristics in the catchment in history. During 30s only small area of slope land in the catchment was used as cropland and most of the slope land was used as woodland, shrub land and grassland, which made the eco-system to be at fine development. So the value of the soil characteristics in 1938y was the highest. In 1958y the activity of open up wasteland led to the degradation and maladjustment of the eco-system. The values of the soil characteristics at this time descent to the lowest point. The value of the soil characteristics from 1958 to 70s had no change or ascent slowly. After the implement of the integrated control measurement in the catchment from 1980, the value of the soil characteristics ascent quickly from the end of 70s to 90s and became steady in 90s and then ascent in 1997.

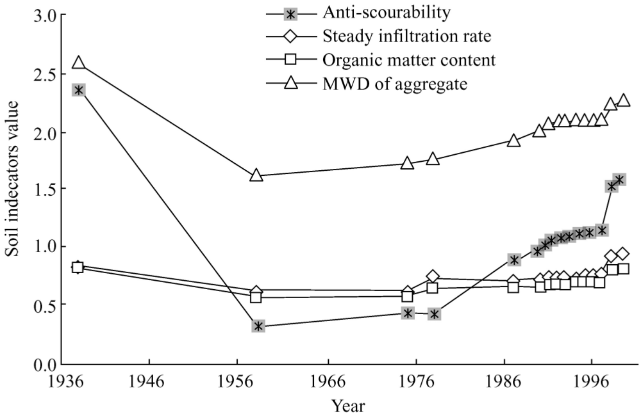

Fig. 2 Temporal variation of soil characteristics in Zhi Fanggou wtershed

4 Discussion

As a whole, all these soil indicators mentioned above have obvious differences in 0cm—20cm of the soil profile according to different landuse types. This demonstrates that soil characteristics in the upper layer (0cm—20cm) in the profile are important and should pay more attention in indicators measurement.

Healthy soil is the basis of a healthy ecosystem. After years' integrated control measurement (the measures included changing landuse types, building level terrace, vegetable rehabilitation, developing cash crops and trees.) in Zhi Fanggou catchment, soil quality in the catchment was improved significantly. However, the driving force for these changes is landuse change rather than the improvement of the intrinsical attribution of the soil quality. That means adjusting landuse types is the key to improve soil quality in rehabilitation of degraded ecosystem.

5 Conclusion

(1) There had significant difference of the soil characteristics measured in different landuse types. Shrubland had the largest mean weight diameter (*MWD*) of soil aggregate stability and the strongest soil

anti-scourability. The anti-scourability of shrub land and natural grassland was about 70—90 times of cropland. The content of O.M in cropland and planted grassland was about 1/2—1/3 of other landuse types. The value of stable soil infiltration rate and saturated soil cohesion was the highest in natural grassland.

(2) The measuring values of these soil characteristics in woodland with acacia, shrubland with Caragana and natural grassland were much more higher than that in planted grassland and cropland. The variation of these characteristics in soil profile（0cm—50cm）was also significant. Generally speaking, the value of soil anti-scourability, stable infiltration rate, soil aggregate stability and soil organic matter content were all decreased clearly from upper to lower position in soil profile. The decreasing extent was reduced with the soil layer becoming deeper.

(3) After the implement of the integrated control measurement in the catchment, the value of the soil characteristics ascent quickly from the end of 70s to 90s and became steady in 90s and then ascent in 1997. These changes showed the positive effect of integrated control measurement and landuse types on soil quality.

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