

# ECO-ENVIRONMENT CHANGE AND SOIL EROSION PROCESS IN THE RECLAIMED FORESTLAND OF THE LOESS PLATEAU

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**ABSTRACT:** Serious soil erosion has made the eco-environment fragile in the Loess Plateau. Based on the 10-year data observed from 1989 to 1998 in the Ziwuling Survey Station in loess hilly region, the eco-environment change and soil erosion process in reclaimed forestland were studied in this paper. The results showed that the intensity of man-made soil erosion caused by forestland reclamation was 1000 times more than that of the natural erosion. From the analysis of soil physical and mechanical properties, in the 10th year after forestland was reclaimed, the clay content and physical clay content decreased 2.74 percentage point and 3.01 percentage point respectively, the >0.25mm waterstable aggregate content decreased 31.59 percentage point, the soil bulk density increased and soil shear strength decreased, all of which were easier to cause soil erosion. The correlation analysis showed that >0.25mm waterstable aggregate content was the key factor affecting soil erosion, and the secondary factors were soil coarse grain and soil shear strength. The relation between the >0.25mm waterstable aggregate content, the soil shear strength and the soil erosion intensity were analyzed, which showed that the first year and the seventh erosion year were the turn years of the soil erosion intensity after the forestland was reclaimed, revealed that the change of eco-environment was the main cause to accelerate soil erosion, and the worse environment caused soil erosion to be serious rapidly.

**KEY WORDS** loess hilly region; reclaimed forestland; soil erosion; eco-environment change

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## 1 INTRODUCTION

Serious soil erosion has made the eco-environment fragile in the Loess Plateau. In the modern soil erosion of the Loess Plateau, the man-made erosion was the dominant erosion pattern (TANG *et al.*, 1993a, 1993b). Many human activities accelerate soil erosion, but the most influential activities are to destroy forest and grass, even to destroy all vegetation. Reclamation by destroying forestland and grassland artificially could rapidly increase soil erosion intensity in short time and enlarge erosion space gradually, even change erosion direction and worsen erosion environment (TANG *et al.*, 1987; ZHA *et al.*, 1992; SHI and TANG, 1996). Based on the change of erosion intensity and the soil properties of the forestland and the reclaimed forest-

land in different erosion times in loess hilly region, the eco-environmental change and soil erosion process was analyzed in this paper.

## 2 STUDY AREA

The Ziwuling Survey Station of Soil Erosion and Eco-environment in Fuxian County, Shaanxi Province, China, was selected as study area. It is located in 109° 11'E and 36°05'N. The landform type is loess hilly and gully region. In the area, the average altitude is 920–1683m above sea level; the distribution density of gully, 4.5km/km<sup>2</sup>; annual mean temperature, 9°C; annual mean precipitation, 576.7mm; vegetation coverage, more than 0.7. The soil type is the brown soil developed in forestland and grassland (TANG *et al.*, 1993c).

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The survey station was set up in 1989, and many big runoff observation plots on natural slope were designated. Up to 1998, data about 10-year runoff and sediment have been collected. This paper analyzed the eco-environment and soil erosion process on the basis of the data from plot 3 and plot 7. The plot 3 is the forestland and stands for the general situation of natural soil erosion, with an area of 1013.8m<sup>2</sup> and a slope of 14°–32°, its average length and width are 84.48m and 12m respectively. And the plot 7 is the reclaimed forestland and stands for the general situation of man-made soil erosion, with an area of 41.4m<sup>2</sup> and a slope of 14°–32°, its average length and width are 97.2m and 13.8m respectively. Both plots were furrowed flat before rainy season, and the runoff and sediments were observed when producing runoff. The soil samples were collected in the end of October each year, and the plots were furrowed flat again in the next year.

### 3 MATERIALS AND METHODS

The soil samples of forestland were collected in the middle of plot 3, and the samples of reclaimed forestland were collected in the middle of plot 7. All the soil samples were collected in the end of October each year, the profile depth was 0–20cm. Up to 1998,

10-year samples were collected and analyzed.

The soil particles were measured with sucker, water-stable aggregate content was measured with sift, the soil bulk density was measured with cutting ring, and the soil shear strength was measured with shearing force instrument (XU *et al.*, 2000).

## 4 RESULTS AND DISCUSSIONS

### 4.1 Analysis of Soil Erosion Intensity in Reclaimed Forestland in Different Times

Vegetation is a very important factor to affect soil erosion, and also is a very susceptible factor to accelerate and control soil erosion. Under the influence of erosivity of rainfall, the erosion modulus was only 2.20 t/(km<sup>2</sup>·a) in forestland owing to the protection of plants on soil surface (Table 1). When forestland was reclaimed, the erosion modulus was rapidly increased. In the first erosion year, the erosion modulus was 2031.15t/(km<sup>2</sup>·a), which was 1000 times more than that of the forestland, and in the second erosion year, the erosion modulus was up to 11 064.10t/(km<sup>2</sup>·a). But because of the difference of times and erosive rainfall, the erosion modulus didn't increased with the erosive time in the reclaimed forestland.

Table 1 The erosion modulus in forestland and reclaimed forestland in different times in Ziwuling, Shaanxi Province

Year	Time after reclamation (a)	Erosive rainfall (mm/a)	Erosivity of rainfall ( $\sum EI_{30}$ ) (J/m <sup>2</sup> ·mm·a)	Soil erosion modulus (t/km <sup>2</sup> ·a)	Soil erosion modulus per unit erosivity of rainfall ( $\bar{S}$ ) (t/km <sup>2</sup> )/(J/m <sup>2</sup> ·mm)	Times of erosive rainfall
1989	0*	231.6	1068.3	2.20	0.002	8
1989	1	210.9	1062.8	2031.15	1.910	7
1990	2	316.4	1773.4	11064.10	6.240	9
1991	3	245.1	1451.9	9609.34	6.620	12
1992	4	170.3	867.2	7380.18	8.510	8
1993	5	149.1	947.0	8255.00	8.720	6
1994	6	182.1	2093.8	18674.09	8.920	8
1995	7	213.4	1642.0	16667.36	10.150	11
1996	8	183.9	835.7	10237.53	12.350	9
1997	9	40.8	119.9	2274.61	18.980	5
1998	10	90.8	250.9	6657.31	26.530	8

\* 0 indicates forestland

For analyzing the main erosion of rainfall, WISCHMEIER (1959) took  $EI_{30}$  as the best index to analyze soil erosion early. JIANG Zhong-shan (1983) analyzed the natural rainfall of the loess region, and proposed the formula of erosivity of natural rainfall. According to this formula, the kinetic energy of the rainfall erosion was calculated in whole year, and the erosion modulus per unit erosivity of rainfall ( $\bar{S}$ ) was figured out (Table 1). From Table 1,  $\bar{S}$  was only

0.002(t/km<sup>2</sup>)/(J/m<sup>2</sup>·mm) in forestland, which indicated that forestland had the capability to control soil erosion. When forestland was reclaimed, under the influence of human activities, in the first erosion year,  $\bar{S}$  was 1.91(t/km<sup>2</sup>)/(J/m<sup>2</sup>·mm), and in the second erosion year, was 6.24(t/km<sup>2</sup>)/(J/m<sup>2</sup>·mm). With the increasing of the erosive time,  $\bar{S}$  increased apparently. Up to the 10th erosion year,  $\bar{S}$  was 26.53(t/km<sup>2</sup>)/(J/m<sup>2</sup>·mm). So when forestland was reclaimed, the eco-environment

was changed artificially, the soil erosion intensity of the reclaimed forestland increased with erosive time under the same erosion of rainfall.

4.2 Analysis of Soil Properties of Reclaimed Forestland in Different Times

Soil erosion resulted from both soil and rainfall, its development was related with soil properties. When forestland was reclaimed, soil properties became worse with the erosive time, which made the soil erosion intensity increase.

From Table 2, in the first erosion year after reclamation, the coarse grain was 49.82% in total, and in the third erosion year, it was 50.59% in total. Up to the tenth year, the coarse grain increased 3.18 percentage point, i.e. from 49.30% in forestland to 52.48% in reclaimed forestland. On the contrary, the soil clay content and physical clay content (<0.01mm) decreased progressively, in the first erosion year, the clay content and physical clay content of reclaimed forestland were 17.46% and 38.98% respectively, and in the third erosion year they were 16.44% and 38.39% respectively. Up to the tenth erosion year, they decreased 2.74 percentage point and 3.01 percentage point, i.e. from 17.88% and 39.98% in forestland to 15.14% and 36.97% in reclaimed forestland, respectively. It showed the soil particle had the tendency to skeleton soil when fine grain was first moved away and then coarse grain concentrated relatively.

The content of >0.25mm waterstable aggregate con-

tent in forestland was 60.19%. But when forestland was reclaimed, in the first erosion year, >0.25mm waterstable aggregate content was 44.61%, which decreased 15.58 percentage point than that of the forestland, in the third erosion year, the >0.25mm waterstable aggregate content was 38.63%, which decreased 5.98% compared with that in the first year. Up to the tenth year, the >0.25mm waterstable aggregate content was 28.60%, which decreased 31.59 percentage point than that of forestland. So when forestland was reclaimed, with the increasing of erosive time, >0.25mm waterstable aggregate content was obviously decreased, which affected the soil structure and soil penetrability. When it rained with runoff, the soil erosion could be produced easily.

From Table 2, the soil bulk density and porosity was 0.65g/cm<sup>3</sup> and 72.5% in forestland respectively, but when the forest was reclaimed, under the influence of human activities, with the increasing of erosive time, the soil bulk density increased and porosity decreased. In the first erosion year, the soil bulk density and porosity was 0.87g/cm<sup>3</sup> and 65.24% respectively, an increase of 33.87% of soil bulk density and a decrease of 7.26 percentage point of soil porosity over forestland. Up to the tenth erosion year, the soil bulk density and porosity were 1.04g/cm<sup>3</sup> and 59.63% respectively, an increase of 60% of soil bulk density and a decrease of 12.87 percentage point of soil porosity over forestland. So when it rained and produced runoff, soil water couldn't be penetrated rapidly, and soil erosion could be produced easily.

Table 2 Soil characters in forestland and reclaimed forestland in different times  
in Ziwuling, Shaanxi Province

Time after erosion (a)	0.01–0.05mm coarse grain(%)	<0.001mm clay content(%)	<0.01mm physical clay content (%)	>0.25mm water stable aggregate content(%)	Shear strength (kg/cm <sup>2</sup> )	Bulk density (g/cm <sup>3</sup> )	Soil porosity (%)
0	49.30	17.88	39.98	60.19	0.123	0.65	72.50
1	49.82	17.46	38.98	44.61	0.102	0.87	65.24
3	50.59	16.44	38.39	38.63	0.100	0.90	64.25
5	51.08	15.79	38.52	36.66	0.097	0.93	63.26
7	51.31	15.37	37.22	35.76	0.079	0.95	62.60
10	52.48	15.14	36.97	28.60	0.074	1.04	59.63

Normally, the intensity of soil erosion was related to the mechanical properties of soil surface, which had negative correlation with the soil shear strength (PAN and BERGSMA, 1995). From Table 2, in the forestland, the shear strength was 0.123kg/cm<sup>2</sup>, which accounted for the higher content of organic matter, the denser root system etc. But when the forestland was reclaimed, with the decreasing of organic matter content and soil cementation etc., the shear strength decreased,

in the first erosion year, the shear strength was 0.102kg/cm<sup>2</sup>, which decreased 17.1% than that of forestland, in the third erosion year, it was 0.100kg/cm<sup>2</sup>, which decreased 18.7% than that of forestland. Up to the tenth erosion year, the shear strength was 0.074kg/cm<sup>2</sup>, which decreased 39.84% than that of forestland. So with the increasing of erosive time, the shear strength decreased, which showed that the forestland had the stronger anti-erosion than that of re-

claimed forestland.

### 4.3 Correlation Analysis Between Soil Properties and Intensity of Soil Erosion

The correlation between the soil erosion modulus per unit erosivity of rainfall ( $\bar{S}$ ) and the coarse grain (0.01–0.05mm,  $X_1$ ), clay content (<0.001mm,  $X_2$ ), physical clay content (<0.01mm,  $X_3$ ), >0.25mm waterstable aggregate content ( $X_4$ ), soil shear strength ( $X_5$ ), soil bulk density ( $X_6$ ) and soil porosity ( $X_7$ ) were analyzed in Table 3.

Table 3 Correlation coefficient of erosion modulus per unit erosivity of rainfall and soil properties in Ziwuling, Shaanxi Province

	$\bar{S}$	$x_1$	$x_2$	$x_3$	$x_4$	$x_5$	$x_6$	$x_7$
$\bar{S}$	1							
$x_1$	0.9526	1						
$x_2$	-0.8297	-0.9574	1					
$x_3$	-0.8473	-0.9343	-0.9343	1				
$x_4$	0.8114	-0.9233	0.9152	0.9195	1			
$x_5$	-0.8416	0.9278	0.9185	0.9897	0.9294	1		
$x_6$	-0.8029	0.9054	-0.8844	-0.9157	-0.9937	0.9385	1	
$x_7$	-0.8029	0.9054	-0.8844	-0.9157	-0.9937	0.9385	1	1
$r_{0.05}=0.811$		$r_{0.01}=0.917$						

which showed that >0.25mm waterstable aggregate content was the maximum effect factor to soil erosion, the improvement of waterstable aggregate content could reduce soil erosion. Then was the coarse grain content, the partial correlation coefficient was 0.8879, which showed the clay could be moved away firstly in the process of soil erosion and the cementation matter reduced, the soil had the tendency to change into skeleton soil. And then was soil shear strength, the partial correlation coefficient was 0.6020, which showed soil erosion was related with the soil mechanical properties. So when forestland was reclaimed, with the increasing of erosive time, the decrease of >0.25mm waterstable aggregate content and shear strength and the increase of coarse grain content were the main factors to produce soil erosion.

### 4.4 Effect of Soil Properties Change on Intensity of Soil Erosion

#### 4.4.1 Annual change of erosion modulus per unit erosivity of rainfall ( $\bar{S}$ )

The annual change of erosion modulus per unit erosivity of rainfall ( $\bar{S}$ ) from forestland to the tenth year of reclaimed forestland was analyzed. From forestland to the first erosion year when forestland reclaimed, the increment of  $\bar{S}$  was 1.909(t/km<sup>2</sup>)/(J/m<sup>2</sup>·mm),  $\bar{S}$  of

From Table 3, the correlation coefficient was 0.9526 between soil coarse grain and soil erosion modulus per unit erosivity of rainfall, which was significant in  $\alpha = 0.01$ . The correlation of  $\bar{S}$  with clay content, physical clay content, >0.25mm waterstable aggregate content and shear strength were also significant in  $\alpha = 0.01$ , the correlation coefficients were -0.8297, -0.8473, 0.8114 and -0.8416 respectively, but the correlation coefficient of  $\bar{S}$  with the soil bulk density and soil porosity was not significant in  $\alpha = 0.01$ .

The partial correlation coefficient between  $\bar{S}$  and >0.25mm waterstable aggregate content was 0.9726,

forestland was 1000 times more than that of reclaimed forestland in the first erosion year (Fig. 1). But from the first erosion year to the second erosion year, the increment of  $\bar{S}$  was 4.328(t/km<sup>2</sup>)/(J/m<sup>2</sup>·mm), and  $\bar{S}$  of the second year was 3.3 times more than that of the first year in reclaimed forestland. From the second erosion year to the third erosion year, the increment of  $\bar{S}$  was only 0.38 (t/km<sup>2</sup>)/(J/m<sup>2</sup>·mm), which was much lower than that of the increment from the first erosion year to the second erosion year. So the results showed that the first year was the turn year of soil erosion when forestland reclaimed properly.

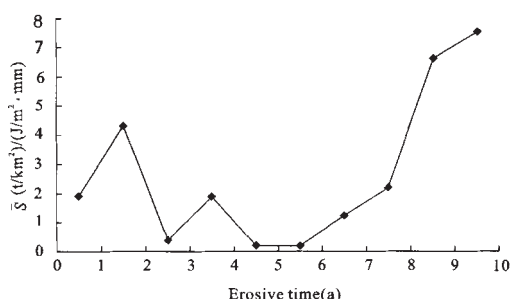


Fig. 1 Annual increment change about soil modulus per unit erosivity of rainfall in Ziwuling, Shaanxi Province

At the same time, from the fourth erosion year to the fifth erosion year and from the fifth erosion year to the sixth erosion year, the increments of  $\bar{S}$  were only 0.208

( $\text{t}/\text{km}^2$ )/( $\text{J}/\text{m}^2 \cdot \text{mm}$ ) and  $0.202 (\text{t}/\text{km}^2)/(\text{J}/\text{m}^2 \cdot \text{mm})$ , but from the sixth erosion year to the seventh erosion year, the increment of  $\bar{S}$  was  $1.23 (\text{t}/\text{km}^2)/(\text{J}/\text{m}^2 \cdot \text{mm})$ , which showed the intensity of soil erosion began to increase. Then from the seventh erosion year to the eighth year, the increment of  $\bar{S}$  was  $2.099 (\text{t}/\text{km}^2)/(\text{J}/\text{m}^2 \cdot \text{mm})$  and from the ninth erosion year to the tenth erosion year, the increment of  $\bar{S}$  was  $7.555 (\text{t}/\text{km}^2)/(\text{J}/\text{m}^2 \cdot \text{mm})$ . So from the fifth erosion year to the sixth erosion year, the increment of  $\bar{S}$  increased a few, but from the seventh to the tenth erosion year, the increment of  $\bar{S}$  increased sharply, which showed that the seventh erosion year was also a turn year of soil erosion.

#### 4.4.2 Correlation analysis between $>0.25\text{mm}$ water-stable aggregate and soil erosion intensity

The turn years of annual change of  $>0.25\text{mm}$  water-stable aggregate content were also the first erosion year and the seventh erosion year after forestland was reclaimed (Fig. 2). The  $>0.25\text{mm}$  waterstable aggregate content of forestland was  $60.19\%$ , but when forestland was reclaimed, in the first erosion year,  $>0.25\text{mm}$  waterstable aggregate content was  $44.61\%$ , which decreased  $15.58$  percentage point, and in the third erosion year,  $>0.25\text{mm}$  waterstable aggregate content of forestland was  $38.63\%$ , which decreased by  $5.98$  percentage point from the first erosion year to the third erosion year. The results showed that the natural erosion environment was changed and the natural erosion changed into man-made accelerated erosion. So the soil erosion intensity increased sharply in the first year when forestland was justly reclaimed.

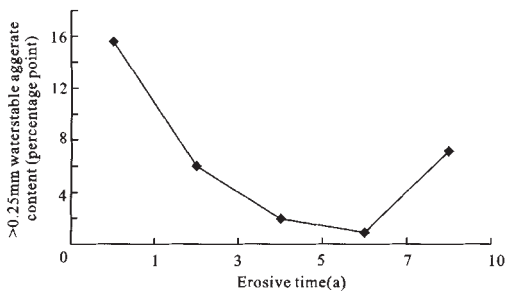


Fig. 2 Decrease change of  $>0.25\text{mm}$  waterstable aggregate content in Ziwluling, Shaanxi Province

And from the third erosion year to the fifth erosion year and from the fifth to the seventh erosion year,  $>0.25\text{mm}$  waterstable aggregate content decreased by  $1.97$  percentage point and  $0.90$  percentage point respectively, but from the seventh erosion year to the tenth erosion year,  $>0.25\text{mm}$  waterstable aggregate content decreased by  $7.17$  percentage point, with an annual decrease of  $2.39$  percentage point. So in the

seventh erosion year, the soil erosion intensity also increased sharply, and it was a turn year, which was caused by the human activities to change the erosion environment.

From Fig. 3, the curve could be divided in the seventh erosion year (the waterstable aggregate content was  $35.76\%$ ), from forestland to the seventh erosion year after reclamation, the effect curve of  $>0.25\text{mm}$  waterstable aggregate content on soil erosion intensity increased gently, but from the seventh erosion year to the tenth erosion year, the effect of curve of  $>0.25\text{mm}$  waterstable aggregate content on soil erosion intensity increased sharply, which showed the seventh erosion year was a turn year when soil erosion environment was changed by human activities.

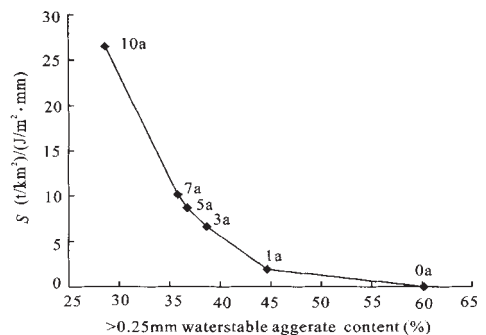


Fig. 3 Change curve of soil modulus per unit erosivity of rainfall with  $>0.25\text{mm}$  waterstable aggregate content in Ziwluling, Shaanxi Province

#### 4.4.3 Correlation analysis between soil shear strength and soil erosion intensity

The intensity of soil erosion was negatively related with the mechanical properties of soil surface. From Fig. 4, the curve between the shear strength and the erosion modulus per unit erosivity of rainfall showed that when soil shear strength decreased, the intensity of soil erosion increased. And Fig. 4 also showed clearly that the first and the seventh years were the turn years of the intensity of soil erosion when forestland was reclaimed.

## 5 CONCLUSIONS

Vegetation was one of the factors to affect soil erosion, and also was an importance factor to control soil erosion. Under the influence of human activities, the intensity of man-made accelerated erosion was  $1000$  times more than that of natural erosion when forestland was reclaimed, and the intensity of soil erosion was increased with the erosive time. In the 10th year after forestland was reclaimed, the clay content and physical

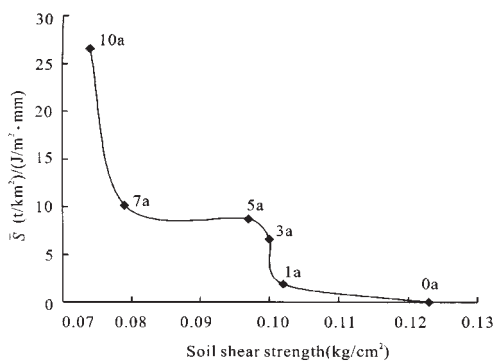


Fig. 4 Change curve of soil erosion modulus per unit erosivity of rainfall with soil shear strength in Ziwouling, Shaanxi Province

clay content decreased 2.74 percentage point and 3.01 percentage point respectively, the >0.25mm water-stable aggregate content also decreased 31.59 percentage point, and the soil bulk density increased and the soil shear strength decreased, all of which were easier to result in soil erosion. The correlation analysis showed that >0.25mm waterstable aggregate content was the maximum effective factor to soil erosion, the partial correlation coefficient was 0.9728, and then were soil coarse grain and soil shear strength, the partial correlation coefficients were 0.8879 and 0.6020 respectively. The relation between the >0.25mm water-stable aggregate content, the soil shear strength and the soil erosion intensity were analyzed, which showed that the first and the seventh erosion years were the turn years of the soil erosion intensity after the forestland was reclaimed, and revealed that the change of eco-environment was the main cause to accelerate soil erosion. The peculiar erosion environment made the soil erosion increase rapidly. So to return slope farmland into forest and grassland, to recover and reconstruct vegetation were the key points to improve the soil erosion environment and ensure the virtuous development of eco-environment in the Loess Plateau.

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