Study on Response Relation between Eco-Environment Change and Soil Erosion Process in Reclaimed Forestland of Loess Hilly Region in China

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Abstract: The soil erosion of Loess Plateau is the main cause of the worse eco-environment, and the control of erosion environment is the key to ensure the eco-environment construction successfully. Based on the 10 year's data observed in the Loess hilly region, the paper studied the response relation between eco-environment change and soil erosion process after forestlands reclaimed. The results showed that when the man-made changed the eco-environment to reclaim forestland, the intensity of man-made soil erosion was more 1,000 times than that of the natural erosion. Taken the soil erosion modulus unit erosivity of rainfall as the index, the soil erosion intensity increased apparently with the erosive time eroded. Then from the analysis of soil physical and forces properties, in 10^{th} year eroded after forestland reclaimed, the clay content and physical clay content decreased 2.74% and 3.01% respectively, which showed the soil particles had the tendency to skeleton soil, and the >0.25mm water stable aggregate content also decreased 58.7%, the soil unit weight increased and the soil shear strength decreased, all of which were easier to occur soil erosion. The correlation analysis showed that >0.25mm water stable aggregate content was the maximum effect factor to soil erosion, the partial correlated coefficient was 0.9728, and then were soil coarse grain and soil shear strength, the partial correlated coefficients were 0.8879 and 0.6020 respectively. The relation between the >0.25mm water stable aggregate content, the soil sheer strength and the soil erosion intensity were analyzed, which showed that the first and seventh year were the turn years of the soil erosion intensity after the forestlands reclaimed, revealed the change of eco-environment was the main cause to accelerate soil erosion. The degenerative soil eroded and eco-environment formed the peculiar erosion environment, which increased the soil erosion rapidly. So to return slope farmland into forest and grassland, to recover and reconstruct vegetation and improve the eco-environment were the key measurement to control soil erosion of Loess Plateau.

Keywords: loess hilly region, Reclaimed forestland, soil erosion, erosion environment, response relation

The serious soil erosion formed the weak eco-environment in Loess Plateau. In the modern soil erosion of Loess Plateau, the man-made accelerated erosion was the dominant erosion pattern[1,2]. There are many human activities to accelerate erosion, but the most influential activities are to destroy forest and grass, even to destroy vegetation. Reclamation by destroyed forestland and grassland artificially could increase soil erosion intensity rapidly in short-time and enlarge erosion space gradually, even to change erosion direction and worse eco-environment[3—5]. Based on the change about erosion intensity and the soil properties of the forestland and the reclaimed forestlands in different erosive time in Loess hilly region, the response relation between soil erosion process and eco-environment change was analyzed in this paper.

1 General situation about study region

The trial site was in the Ziwuling survey station of soil erosion and eco-environment in Fuxian county, Shaanxi province, China. Located in the 109º11'E and 36º05'N. The physiognomy types is the Loess hilly and gully region. The average altitude is 920m—1683m, the distribution density of ravine was 4.5 km/km^2. The annual mean temperate is 9℃.and annual mean rainfall is 576.7mm. The vegetation covering degree is more than 0.7.The soil type is the brown soil developed from the vegetation of forest and grass [6]. The survey station was set up in 1989, and many big runoff observation test plots on the natural slope were designated. Up to 1998, dada about 10's runoff and sediment have been collected. This paper would analyze the response relation between eco-environment and soil erosion process on dada about 3 plot and 7 plot. The 3 plot is the forestland and stood for the general situation of natural erosion, area of which is 1013.8m^2 and the slope is 14º—32º, the average length and width are 84.48m and 12m respectively. And the 7 plot is the reclaimed forestland and stood for the general situation of man-made accelerated erosion, area of which is 1,341.4m^2 and the slope is 14º—32º, the average length and width are 97.2m and 13.8m respectively. All plots were furrowed flat before rainy season coming, and the runoff and sediment were observed when produced runoff, the soil samples were collected in the end of October every year, and next year, the plots were furrowed flat again.

2 Soil samples collection and analysis methods

Collection about soil samples: the soil samples of forestland were collected in the middle of 3 plot, and the samples of reclaimed forestland were collected in the middle of 7 plot. All the soil samples were collected in end of October every year, the collection depth was 0cm—20cm. Up to 1998, the 10's samples were collected to be analyzed.

Analysis about soil properties: the soil particles were measured with the methods of sucker[7], and the aggregate content was measured with the methods of sift to depart[7], the soil unit weight was measured with the methods of ring knife[7] and the soil shear strength was measured with the methods of shearing force instrument[8].

3 Analysis and results

3.1 Change about intensity of soil erosion in reclaimed forestland in different time eroded

The vegetation is a very important factor to affect soil erosion, and also is a very susceptive factor to accelerate and control soil erosion. Under of the influence of erosivity of rainfall, the erosion modulus was 2.20t/(km^2 • a) in forestland under the protection of the crown of the trees, and branches and defoliations and roots on soil surface (Table 1). When forestland was reclaimed, the erosion modulus increased rapidly, in the first year eroded, the erosion modulus was 2,031.15 t/(km^2 • a), which was more 1,000 times than that of the forestland, and in the second year eroded, the erosion modulus was up to 11,064.10 t/(km^2 • a). And with the increasing of the time eroded, the intensity of soil erosion developed sharply, but because of the difference of times and precipitations of erosive rainfall, the erosion modulus didn't increased with the erosive year eroded in the reclaimed forestland.

Analysis from the main erosivity of rainfall, Wischmeier[9] have taken the EI_{30} as the best index to analyze soil erosion early. Jiang Zhongshan *et al*[10] analyzed the natural rainfall of Loess region, then put forward the formula of erosivity of natural rainfall. According to this formula, the kinetic energy of the erosive rainfall were calculated in whole year, then the erosion modulus unit erosivity of rainfall ($\overline{S}$) were figured out in Table 1. Form Table 1, the forestland had the capability to control soil erosion, the $\overline{S}$ was only 0.002 (t •km^{-2} •a^{-1})/(J •m^{-2} •mm^{-1} •a^{-1}), when forestland was reclaimed, under the influence of human activities, in the first year eroded, the $\overline{S}$ was 1.91 (t • km^{-2} • a^{-1})/(J • m^{-2} • mm^{-1} • a^{-1}), and in the second year eroded, the $\overline{S}$ was 6.24 (t •km^{-2} •a^{-1})/(J •m^{-2} •mm^{-1} •a^{-1}). With the increasing of the erosive time eroded, the $\overline{S}$ increased apparently, Up to the 10th year eroded, the $\overline{S}$ was 26.53 (t • km^{-2} • a^{-1})/ (J • m^{-2} • mm^{-1} • a^{-1}). So when forestland was reclaimed, the intensity of soil erosion of the reclaimed forestland increased with erosive time eroded under the same erosivity of rainfall.

Table1 The erosion modulus in different time eroded

Time surveied	Time eroded	Erosive rainfall	Erosivity of rainfall ($\sum EI_{30}$)	Soil erosion modulus	Soil erosion modulus unit erosivity of rainfall ($\overline{S}$)	Times of erosiove rainfall
a	a	mm/a	J/(m^2 • mm • a)	t/(km^2 • a)	(t •km^{-2} •a^{-1})/(J •m^{-2} •mm^{-1} •a^{-1})	
1989	forestland	231.6	1,068.3	2.20	0.002	8
1989	1	210.9	1,062.8	2,031.15	1.91	7
1990	2	316.4	1,773.4	11,064.10	6.24	9
1991	3	245.1	1,451.9	9,609.34	6.62	12
1992	4	170.3	301.2	7,380.18	8.51	8
1993	5	149.1	947.0	8,255.00	8.72	6
1994	6	182.1	2,093.8	18,674.09	8.92	8
1995	7	213.4	1,642.0	16,667.36	10.15	11
1996	8	183.9	835.7	10,237.53	12.35	9
1997	9	40.8	119.9	2,274.61	18.98	5
1998	10	90.8	250.9	6,657.31	26.53	8

3.2 Degeneration about soil properties of reclaimed forestland in different time eroded

(1) Change about soil particles

From Table 2, under the influence of the human activities and erosivity of rainfall to different extent, the soil particles were different apparently. With the increasing of the erosive time eroded, compared the forestland with the reclaimed forestland, in the first year eroded, the coarse grain was 49.82%, and the second year eroded was 50.25%. Up to tenth year eroded, the coarse grain increased 3.18% from 49.30% of forestland to 52.48%. On the contrary, the soil clay content and physical clay content (<0.01mm) decreased progressively, in the first year eroded, the clay content and physical clay content of reclaimed forestland were17.88% and 38.98% respectively, the second year eroded were 17.48% and 38.34% respectively, up to tenth year eroded, the clay content and physical clay content decreased 2.74% and 3.01% from 17.88% and 19.98% of forestland to 15.14% and 36.67% respectively. Which showed the soil particle had the tendency to skeleton soil when thin grain was moved away first and the n coarse grain concentrated relatively.

Table 2 Soil characters about forestland and reclaimed forestland of different time eroded

Time eroded	0.005~0.001mm coarse grain	<0.001mm clay content	<0.01mm physical clay content	>0.25mm water stable aggregate content	Shear strength	unit weight	Soil porosity
a	%	%	%	%	kg/cm^2	g/cm^3	%
Forestland	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	1.01	59.63

(2) Change about >0.25mm water stable aggregate content

From Table 2, because the clay content and organic matter content of the forestland were highest than any other of reclaimed forestland, the >0.25mm water stable aggregate content in forestland was 60.19%. But when forestland was reclaimed, in the first year eroded, >0.25mm water stable aggregate content was 44.61%, which decreased 15.58% than that of the forestland, in the third year eroded, the >0.25mm water stable aggregate content was 38.63%, which decreased 5.98% than that of former. Up to the tenth year eroded, the >0.25mm water stable aggregate content was 28.60%, which decreased 31.59% than that of forestland. According to the anti-erosivity index about >0.25mm water stable aggregate content put forward by Guo Peicai[11], the forestland showed the better anti-erosivity, but with the increasing of the erosive time eroded, the anti-erosivity of reclaimed forestland worn off. So when forestland reclaimed, with the increasing of erosive time eroded, >0.25mm water stable aggregate content decreased progressively, which affected the soil structure and soil penetrability, when rained and produced runoff, the soil erosion could be produced easily.

(3) Change about soil unit weight and soil porosity

Form Table 2, the soil unit weight and porosity was 0.65g/cm^3 and 72.5% in forestland respectively, but when reclaimed, under the influence of human activities, with the increasing of erosive time eroded, the unit weight increased and porosity decreased. In the first year eroded, the soil unit weight and porosity was 0.87g/cm^3 and 65.24% respectively, which increased 33.87% of unit weight and decreased 7.26% of soil porosity than that of forestland. Up to the tenth year eroded, the soil unit weight and porosity was 1.04g/cm^3 and 59.63% respectively, which increased 60% of unit weight and decreased 12.87% of soil porosity than that of forestland. So the soil unit weight increased and soil porosity decreased, when rained and produced runoff, the water moisture couldn't be penetrated rapidly, the soil erosion could be produced easily.

(4) Change about soil shear strength

Jumics and Barer[12] defined shear strength that under the influence of shear tress, the soil and grain resisted the shear resistance from the continual shear of runoff, which reflected the capability of the soil to resist the outside force, and was an index of soil anti-erosivity. Normally, the intensity of soil erosion was related to the force propertied of soil surface, which was negative correlation with the soil shear strength[13]. From Table 2, in the forestland, the shear strength was 0.123kg/cm^2, which was account for the higher 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 year eroded, the shear strength was 0.102 kg/cm^2, which decreased 17.1% than that of forestland, the second year eroded was 0.10 kg/cm^2, which decreased 18.7% than that of forestland. Up to tenth year eroded, the shear strength was 0.074 kg/cm^2, which decreased 39.84% than that of forestland. So with the increasing of erosive time eroded, the shear strength decreased, which show that the forestland had the stronger anti-erosivity than that of reclaimed forestland.

3.3 Correlation analysis between the soil properties and the intensity of soil erosion

Soil erosion resulted from the soil and rainfall together, whose development was related with the soil properties. When forestland was reclaimed, the intensity of soil erosion increased with the erosive time eroded but soil properties decreased. The correlation between soil the soil erosion modulus unit erosivity of rainfall ($\overline{S}$) and the coarse grain (0.05mm—0.01mm, X_1), clay content (<0.001mm, X_2), physical clay content (<0.01mm, X_3), >0.25mmm water stable aggregate content (X_4), soil shear strength(X_5), unit weight(X_6) and soil porosity(X_7) was analyzed in Table 3.

From 3, the correlation coefficient was 0.9526 between soil coarse grain and soil erosion intensity unit erosivity of rainfall, which was notable in α=0.01, and the clay content, physical clay content, >0.25mm water stable aggregate content and shear strength were also notable in α=0.01, the correlation coefficient were –0.8297, –0.8473, 0.8114 and –0.8416 respectively, but the unit weight and soil porosity was not notable in α=0.01. Besides the unit weight and soil porosity, the partial correlation between the soil erosion modulus unit erosivity of rainfall and the coarse grain, clay content, physical clay content,

>0.25mmm water stable aggregate content, soil shear strength was analyzed.

Table 3 Correlation coefficient of erosion modulus unit erosivity of rainfall and soil properties

	S	X_1	X_2	X_3	X_4	X_5	X_6	X_7
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

Table 4 Partial correlation coefficient of erosion modulus unit erosivity of rainfall and soil properties

	X_1	X_2	X_3	X_4	X_5
$\overline{S}$	0.8879	–0.2273	–0.1184	0.9726	0.6020

From Table 4, the partial correlation coefficients between erosion modulus unit erosivity of rainfall and >0.25mm water stable aggregate content was 0.9726, which showed that >0.25mm water stable aggregate content was the maximum effect factor to soil erosion, the improvement of water stable aggregate content could reduce soil erosion. Then was the coarse grain content, the partial correlation coefficients 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 force properties. So when forestland was reclaimed, with the increasing of erosive timed eroded, the decrease of >0.25mm water stable aggregate content and shear strength and the increase of coarse grain content were the main factors to produce soil erosion.

3.4 Effect about degeneration of soil properties on the intensity of soil erosion

(1) Annual change about erosion modulus unit erosiovity of rainfall ($\overline{S}$)

The annual change about erosion modulus unit erosiovity of rainfall ($\overline{S}$) form forestland to tenth year eroded of reclaimed forestland was analyzed. From Fig. 1, form forestland to the first year eroded when forestland reclaimed justly, the increment of $\overline{S}$ was 1.909 (t • km^{-2} • a^{-1})/(J • m^{-2} • mm^{-1} • a^{-1}), and the $\overline{S}$ of forestland was more 1,000 times than that of reclaimed forestland in first year. But form the first year to the second year eroded, the increment of $\overline{S}$ was 4.328 (t • km^{-2} • a^{-1})/(J • m^{-2} • mm^{-1} • a^{-1}), and the $\overline{S}$ of the second year eroded was only 3.3 times than that of the first year eroded in reclaimed forestland. Form the second year to the third year eroded, the increment of $\overline{S}$ was also only 0.38 (t •km^{-2} • a^{-1})/(J • m^{-2} • mm^{-1} • a^{-1}), which was lower far than that of the increment of form the first year to the second year eroded. So all of which showed that the first year was the turn year of soil erosion when forestland reclaimed justly.

At the same time, from fourth year to fifth year eroded and from fifth year to sixth year eroded, the increments of $\overline{S}$ were only 0.208 (t • km^{-2} • a^{-1})/(J • m^{-2} • mm^{-1} • a^{-1}) and 0.202 (t • km^{-2} • a^{-1})/(J • m^{-2} • mm^{-1} • a^{-1}), but from sixth year eroded to seventh year eroded, the increments of $\overline{S}$ were 1.232

(t • km^{-2} • a^{-1})/ (J • m^{-2} • mm^{-1} • a^{-1}), which showed the intensity of soil erosion began to increase. Then from seventh year eroded to eighth year eroded, the increments of $\overline{S}$ were 2.099 (t • km^{-2} • a^{-1})/ (J • m^{-2} • mm^{-1} • a^{-1}) and from ninth year eroded to tenth year eroded, the increments of $\overline{S}$ were 7.555 (t • km^{-2} • a^{-1})/ (J • m^{-2} • mm^{-1} • a^{-1}). So from fifth year to sixth year eroded, the increment of $\overline{S}$ increased a few, but from seventh to tenth year eroded, the increment of $\overline{S}$ increased sharply, which showed then seventh year eroded was also a turn year of soil erosion.

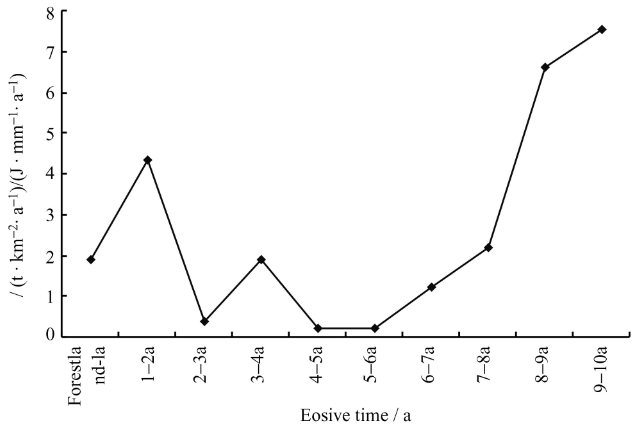

Fig. 1 Annual increment change about soil modulus unit erosivity of rainfall

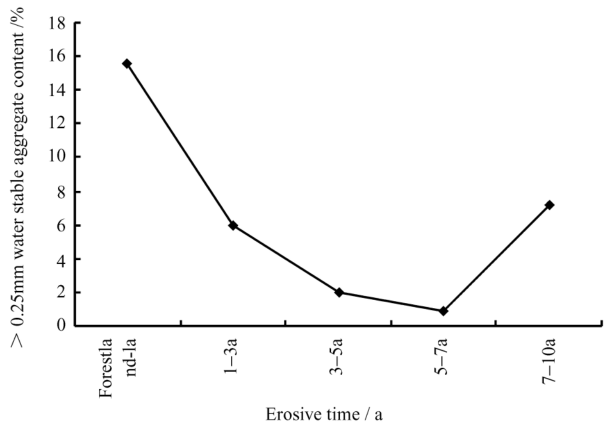

Fig. 2 Annual change about >0.25mm water stable aggregate content

(2) Analysis between >0.25mm water stable aggregate and intensity of soil erosion

From Fig. 2, the turn years of annual change about >0.25mm water stable aggregate content were also the first year and the seventh year when forestland reclaimed. >0.25mm water stable aggregate content of forestland was 60.19%, but when forestland was reclaimed, in the first year eroded, >0.25mm water stable aggregate content was 44.61%, which was 15.98% decreased, and in third year eroded, >0.25mm water stable aggregate content of forestland was 38.63%, and was 5.98% decreased from first year to third year eroded, which showed 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 justly.

And from third year to fifth year and from fifth to seventh year eroded, >0.25mm water stable aggregate content were 1.97% and 0.90% decreased respectively, but from seventh year to tenth year eroded, >0.25mm water stable aggregate content were 1.97% decreased, and 2.39% decreased every year, which was far more than that of former. So in the seventh year eroded, the soil erosion intensity also increased sharply, and was a turn year, which was caused by the human activities to change the erosion environment.

Then from Fig. 3, the curve could be divided in the seventh year eroded, from forestland to the seventh year eroded, the effect curve of >0.25mm water stable aggregate content on soil erosion intensity increased gently, but from seventh to the tenth year eroded, the effect curve of >0.25mm water stable aggregate content on soil erosion intensity increased sharply, which showed the seventh year was a turn year when soil erosion environment was changed by human activities.

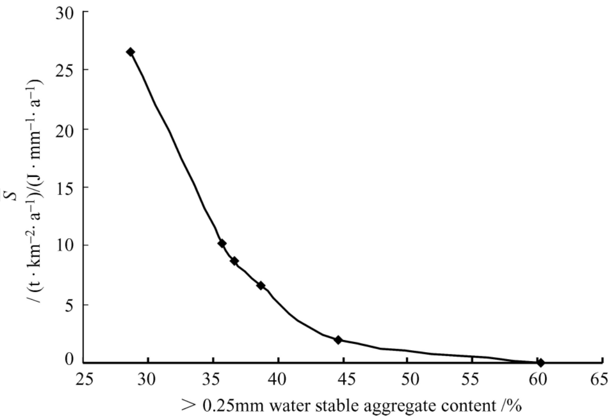

Fig. 3 Change curve about soil modulus unit erosivity of rainfall and >0.25mm water stable aggregate content

(3) Analysis about soil shear strength and intensity of soil erosion

The intensity of soil erosion was related with the force properties of soil surface, and the correlation was negative. Form Fig. 4, the curve between the shear strength and the erosion modulus unit erosivity of rainfall showed that when soil shear strength decreased, the intensity of soil erosion increased. And in the Fig. 4 was also showed clearly that the first and seventh year eroded were the turn years of the intensity of soil erosion when forestland reclaimed.

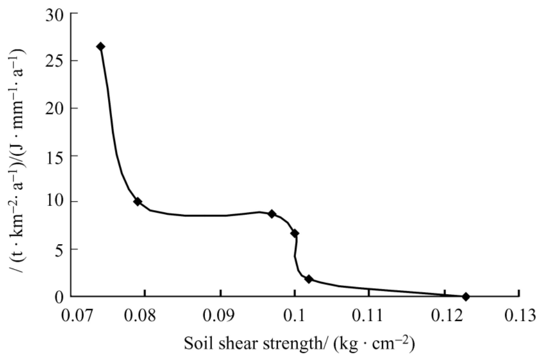

Fig. 4 Change curve about soil modulus unit erosivity of rainfall and soil shear strength

4 Conclusion

The vegetation was one of factors to affect soil erosion, and also was an importance factor to accelerate and control soil erosion. When forestland was reclaimed, under the influence of human activities, the intensity of man-made accelerated erosion was far more1000 times than that of natural erosion, and the intensity of soil erosion increased with the erosive time eroded. Then from the analysis of soil physical and forces properties, in 10th year eroded after forestland reclaimed, the clay content and physical clay content decreased 2.74% and 3.01% respectively, which showed the soil particle had the tendency to skeleton soil. And the >0.25mm water stable aggregate content also decreased 58.7%, and the soil unit weight increased and the soil shear strength decreased, all which were easier to occur soil erosion. The correlated analysis showed that >0.25mm water stable aggregate content was the maximum effect factor to soil erosion, the partial correlated coefficient was 0.9728, and then were soil coarse grain and soil shear strength, the partial correlated coefficients were 0.8879 and 0.6020 respectively. The relation between the >0.25mm water stable aggregate content, the soil sheer strength and the soil erosion intensity were analyzed, which showed that the first and seventh year were the turn year of the soil erosion intensity after the forestlands reclaimed, revealed the change of eco-environment was the main cause to accelerate soil erosion. The degenerative soil eroded and eco-environment formed the peculiar erosion environment, increased the soil erosion 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 Loess Plateau.

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