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Soil erosion and soil properties in reclaimed forestland of loess hilly region

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Based on data observed from 1989 to 1998 in the Ziwuling survey station, changes of soil erosion and soil physico-mechanical properties were studied after forestland reclamation. When the man-induced factors changed the eco-environment by reclaiming forestlands, the intensity of man-made soil erosion in reclaimed lands was 1,000 times more than that of natural erosion in forestlands. From the analysis of soil physical and mechanical properties, the clay content and physical clay content decreased 2.74% and 3.01% respectively, and the >0.25 mm water stable aggregate content decreased 58.7%, the soil unit weight increased and the soil shear strength decreased, all of which were easier to cause soil erosion. The results of the correlation analysis showed that the >0.25 mm water stable aggregate content was the greatest influencing factor on soil erosion, the partial correlated coefficient was 0.9728, and then were soil coarse grain and soil shear strength, the partial correlated coefficients being 0.8879 and 0.6020 respectively. The relationships between the >0.25 mm water stable aggregate content, the soil sheer strength and the soil erosion intensity were analyzed, which showed that the first and seventh years were the turning years of the soil erosion intensity after the forestland reclamation. The degenerative eroded soil and eco-environment formed the peculiar erosion environment, which aggravated the soil erosion rapidly.

Soil erosion and soil properties in reclaimed forestland of loess hilly region ZHA Xiaochun1, TANG Keli2 (1. College of Tourism and Environmental Science, Shaanxi Normal University, Xi´an 710062, China; 2. Institute of Soil and Water Conservation, CAS and Ministry of Water Resources, Yangling 712100, China) The serious soil erosion caused the fragile eco-environment in the Loess Plateau. In modern soil erosion of the Loess Plateau, the man-made accelerated erosion was the dominant erosion pattern (Tang et al., 1993a; 1993b). There are many kinds of human activities to accelerate erosion, of which the most influential activities are to destroy forest and grass, even to destroy vegetation. Reclamation at the expense of destruction of forestland and grassland artificially could increase soil erosion intensity rapidly in a short period of time and enlarge erosion space gradually, even change erosion direction and worsen eco-environment (Tang et al., 1987; Zha et al., 1992; Shi et al., 1996). Based on changes of erosion intensity and soil properties of the forestland and reclaimed forestlands in different number of erosive years in loess hilly region, the relationship between soil erosion process and soil properties was analyzed in this paper. 1 General situation of the study area The trial site was in the Ziwuling survey station of soil erosion and eco-environment in Fuxian county, Shaanxi province, China. Located at 109o11´E and 36o05´N, the physiognomic types are loess hilly and gully region, with average altitudes being 920-1,683 m, and the distribution density of ravines was 4.5 km/km2. The annual mean temperature is 9oC and annual mean rainfall is 576.7 mm. The vegetation covering degree is more than 0.7. The soil type is the brown soil developed from the vegetation of forest and grass (Tang et al., 1993c). The survey station was set up in 1989, and many big runoff observation test plots on the natural slope were designated. Up to 1998, data about 10 years´ runoff and sediment had been collected. This paper analyzes the responsive relation between eco-environment and soil erosion process. The plot 3 is the forestland and stands for the general situation of natural erosion. The area of the plot is 1,013.8 m2 and the slope is 14o-32o, the average length and width are 84.48 m and 12 m respectively. And the plot 7 is the reclaimed forestland and stands for the general situation of artificially accelerated erosion. The area of the plot is 1,341.4 m2, and the slope is 14o-32o, the average length and width are 97.2 m and 13.8 m respectively. All the plots were furrowed flat before rainy season, and the runoff and sediment were observed when run off produced. The soil samples were collected in the last days of October every year, and next year, the plots were furrowed flat again. 2 Soil samples collection and analysis methods Collection of soil samples: 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 at the end of October every year, the sampling depth was 0-20 cm. Up to 1998, the 10 years´ samples has been collected and analyzed. Analysis about soil properties: the soil particles were measured with the methods of sucker, the aggregate content was measured with the methods of sift to depart, the soil unit weight was measured with the methods of ring knife, and the soil shear strength was measured with the methods of shearing force instrument (Xu et al., 2000). 3 Analysis and results 3.1 Analysis of soil erosion intensity of reclaimed forestland in different number of erosion years Vegetation is a very important factor to affect soil erosion, and also a very susceptive factor to accelerate and control soil erosion. Under the influence of erosivity of rainfall, the erosion modulus was 2.20 t/(km2.a) in forestland for the protection of the crown of the trees, branches, defoliations and roots on soil surface (Table 1). When forestland was reclaimed, the erosion modulus increased rapidly, in the first erosion year, the erosion modulus was 2,031.15 t/(km2.a), which was more than 1,000 times that of the forestland, and in the second erosion year, the erosion modulus was up to 11,064.10 t/(km2.a). With the increase of the number of erosion years, the soil erosion intensity developed sharply. Because of the difference in the number of erosion years and precipitations of erosive rainfall, the erosion modulus did not increase with the number of erosion years in the reclaimed forestland. For analyzing the main erosivity of rainfall, Wischmeier (1959) took the EI30 as the best index to analyze soil erosion, the earliest of all. Jiang Zhongshan et al. (1983) 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 was calculated for the whole year, then the erosion modulus unit erosivity of rainfall (S) was figured out (Table 1). Table 1 indicates that the forestland had the capability to control soil erosion, the S was only 0.002 (t · km-2)/(J · m-2 · mm-1), when forestland was reclaimed, under the influence of human activities, in the first erosion year, the S was 1.91 (t · km-2)/(J · m-2 · mm-1), and in the second year, the S was 6.24 (t · km-2)/(J · m-2 · mm-1). With the increase of the number of the erosion years, the S increased apparently. Up to the tenth erosion, the S was 26.53 (t · km-2)/(J · m-2 · mm-1). So when forestland was reclaimed, the soil erosion intensity of the reclaimed forestland increased with the erosion years under the same erosivity of rainfall. 3.2 Analysis of soil properties of reclaimed forestland in different number of erosion years Soil erosion was resulted under common actions of soil and rainfall, whose generation and development was related to the soil properties. When forestland was reclaimed, the soil erosion intensity increased with the number of erosion years erosive time but soil properties degraded. In the first erosion year, the coarse grain was 49.82%, and the second year was 50.25% (Table 2). Up to the tenth year, the coarse grain of forestland increased from 49.30% to 52.48%, an increase of 3.18. On the contrary, the soil clay content and physical clay content (<0.01 mm) decreased progressively. In the first year, the clay content and physical clay content of reclaimed forestland were 17.88% and 38.98% respectively, the second year were 17.48% and 38.34% respectively, up to the tenth year, the clay content and physical clay content decreased from 17.88% and 19.98% of the forestland to 15.14% and 36.67% respectively, a decrease of 2.74% and 3.01% each. This showed that soil particles tended to become skeleton soil when fine grain was moved away first and then coarse grain concentrated relatively. The >0.25 mm water stable aggregate content in forestland was 60.19%. But when forestland was reclaimed, in the first erosion year, >0.25 mm water stable aggregate content was 44.61%, a decrease of 15.58% over the forestland, in the third year, the >0.25 mm water stable aggregate content was 38.63%, which decreased 5.98% than that of the former. Up to the tenth year, the >0.25 mm water stable aggregate content was 28.60%, a decrease of 31.59% over the forestland. So when forestland was reclaimed, with the increase of the number of erosion years, >0.25 mm water stable aggregate content decreased progressively, which affected the soil structure and soil penetrability, when rainfall and runoff was produced, soil erosion could be produced easily. The soil unit weight and porosity was 0.65 g/cm3 and 72.5% in forestland respectively(Table 2). But when reclamation took place, under the influence of human activities, with the increase of the number of erosion years, the unit weight increased and porosity decreased. In the first erosion year, the soil unit weight and porosity was 0.87 g/cm3 and 65.24% respectively, an increase of 33.87% of the unit weight and a decrease of 7.26% of soil porosity over the forestland. Up to the tenth year, the soil unit weight and porosity was 1.04 g/cm3 and 59.63% respectively, an increase of 60% of unit weight and a decrease of 12.87% of soil porosity over the forestland. Because of soil unit weight increase and soil porosity decrease, when rainfall and runoff was produced, the water moisture could not be penetrated rapidly, hence soil erosion could be produced easily. Normally, the intensity of soil erosion was related to the mechanical properties of soil surface, which was negatively correlated with soil shear strength (Pan et al., 1995). In the forestland, the shear strength was 0.123 kg/cm2, attribu ting to the higher organic matter content, the denser root system, etc. (Table 2). But when the forestland was reclaimed, with the decrease of organic matter content and soil colloid etc., the shear strength decreased. In the first erosion erosion year, the shear strength was 0.102 kg/cm2, a decrease of 17.1% over the forestland, the second year was 0.10 kg/cm2, a decrease of 18.7% over the forestland. Up to the tenth year, the shear strength was 0.074 kg/cm2, a decrease of 39.84% over the forestland. So with the increase of the number of erosion years, the shear strength decreased, which showed that the forestland had the stronger anti-erosivity than reclaimed forestland. 3.3 Correlation analysis between the soil properties and the intensity of soil erosion The correlation between soil erosion modulus unit erosivity of rainfall and the coarse grain (0.05-0.01 mm), clay content (<0.001 mm), physical clay content (<0.01 mm), >0.25 mm water stable aggregate content, soil shear strength, unit weight and soil porosity was analyzed. The result showed that the correlation coefficient between soil coarse grain and soil erosion intensity unit erosivity of rainfall was 0.9526, which was notable in $\alpha = 0.01$, and the clay content, physical clay content, >0.25 mm water stable aggregate content and shear strength were also notable in $\alpha = 0.01$, the correlation coefficients were -0.8297, -0.8473, 0.8114 and -0.8416 respectively, but the unit weight and soil porosity were not notable in $\alpha = 0.01$. 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, >0.25 mm water stable aggregate content, soil shear strength was analyzed. The partial correlation coefficients between erosion modulus unit erosivity of rainfall and >0.25 mm water stable aggregate content was 0.9726, which showed that >0.25 mm water stable aggregate content was the main influencing factor to soil erosion, the improvement of water stable aggregate content could reduce soil erosion. Then was the coarse grain content (0.05-0.001 mm), the partial correlation coefficient was 0.8879, which showed that the clay could be moved away firstly in the process of soil erosion and the colloid matter reduced, the soil tended to become skeleton soil. Further then then was soil shear strength, the partial correlation coefficient was 0.602, which showed that soil erosion was related with soil mechanical properties. So when forestland was reclaimed, with the increase of the number of erosion years, the decrease of >0.25 mm water stable aggregate content and shear strength and the increase of coarse grain content were the main factors aggravating soil erosion. 3.4 Effect of soil properties on the intensity of soil erosion 3.4.1 Analysis of annual change of erosion modulus unit erosiovity of rainfall The annual change of erosion modulus unit erosiovity of rainfall (S) from forestland to the tenth year of reclaimed forestland was analyzed. From forestland to the first erosion year when forestland was reclaimed properly, the increment of S was 1.909 (t·km-2)/(J·m-2·mm-1), and the S of forestland was 1,000 times more than that of reclaimed forestland in the first year (Figure 1). But from the first year to the second year, the increment of S was 4.328 (t·km-2)/(J·m-2·mm-1), and the S of the second year was only 3.3 times more than that of the first year in reclaimed forestland. From the second to the third year, the increment of S was also only 0.38 (t·km-2)/(J·m-2·mm-1), which was far lower than that of the increment from the first to the second year. So all of which showed that the first year was the turning year of soil erosion when forestland was reclaimed properly. At the same time, from the fourth to the fifth erosion year and from the fifth to the sixth erosion year, the increments of S were only 0.208 (t·km-2)/(J·m-2·mm-1) and 0.202 (t·km-2)/(J·m-2·mm-1), but from the sixth to the seventh year, the increment of S was 1.232 (t·km-2)/(J·m-2·mm-1), which showed that the intensity of soil erosion began to increase. Then from the seventh to the eighth year, the increment of S was 2.099 (t·km-2)/(J·m-2·mm-1) and from the ninth to the tenth year, the increment of S was 7.555 (t·km-2)/(J·m-2·mm-1). So from the fifth to the sixth year, the increment of S increased a little, but from the seventh to the tenth year, the increment of S increased sharply, which showed that the seventh year was also a turning year of soil erosion. 3.4.2 Analysis between > 0.25 mm water stable aggregate and intensity of soil erosion The turning years of annual change of >0.25 mm water stable aggregate content were also the first year and the seventh year when forestland was reclaimed (Figure 2). The >0.25 mm water stable aggregate content of forestland was 60.19%, but when forestland was reclaimed, in the first erosion year, > 0.25 mm water stable aggregate content was 44.61%, which was a decrease of 15.98%, and in the third year, > 0.25 mm water stable aggregate content of forestland was 38.63%, and was a 5.98% decrease from the first year to the third year, which 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 reclaimed properly. And from the third to the fifth year and from the fifth to the seventh year, >0.25 mm water stable aggregate contents decreased by 1.97% and 0.90% respectively, but from the seventh to the tenth year, >0.25 mm water stable aggregate content was a 1.97% decrease, and a 2.39% decrease every year, which was far more than that of the former. So in the seventh year, the soil erosion intensity also increased sharply, and it was a turning year, which was caused by the human activities to change the erosion environment. Then, the curve could be divided in the seventh erosion year, from forestland to the seventh year, the ef fect curve of >0.25 mm water stable aggregate content on soil erosion intensity increased gently, but from the seventh to the tenth year, the effect curve of >0.25 mm water stable aggregate content on soil erosion intensity increased sharply, which showed the seventh year was a turning year when soil erosion environment was changed by human activities (Figure 3). 3.4.3 Analysis of soil shear strength and intensity of soil erosion The intensity of soil erosion was related with the mechanical properties of soil surface, and the correlation was negative. 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 (Figure 4). And the first and the seventh years were the turning years of the intensity of soil erosion when forestland was reclaimed. 4 Conclusion Vegetation was an important 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 1,000 times more than that of natural erosion, and the intensity of soil erosion increased with the increase of the number of erosion years. Then from the analysis of soil physical and mechanical properties, in the tenth erosion year after forestland was reclaimed, the clay content and physical clay content decreased 2.74% and 3.01% respectively, which showed that the soil particles tended to become skeleton soil. And the >0.25 mm water stable aggregate content decreased 58.7%, and the soil unit weight increased and the soil shear strength decreased, all of which were easier to induce soil erosion. The correlated analysis showed that >0.25 mm water stable aggregate content was the greatest influencing factor on soil erosion, the partially correlated coefficient was 0.9728, and then soil coarse grain and soil shear strength, the partially correlated coefficients were 0.8879 and 0.6020 respectively. The relation between the >0.25 mm water stable aggregate content, the soil sheer strength and the soil erosion intensity were analyzed, which showed that the first and the seventh years were the turning years of the soil erosion intensity after the forestlands were reclaimed, revealing the change of eco-environment was the main cause attributing to the aggravated soil erosion. The degenerative eroded soil and eco-environment formed the peculiar erosion environment, inducing rapid soil erosion. So to return slope farmland to forestland and grassland, and 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.

关键词： loess; reclaimed forestland; soil erosion; soil properties; Shaanxi