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Soil erosion and management on the Loess Plateau

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Abstract: The Loess Plateau is well known to the world for its intense soil erosion. The root cause for river sedimentation of Yellow River (Huanghe) and its resultant "hanging river" in certain section is soil and water loss on the Loess Plateau. The Loess Plateau has a long cultivation history, hence population growth, vegetation degeneration and plugging constitute the chief reason for serious soil and water loss on Loess Plateau. This paper analyses several successful cases and failures in soil conservation, presents practical soil conservation technique and related benefit analysis, and discusses some effective methods adopted in China in soil erosion control, research directions and future perspectives on Loess Plateau.

Soil erosion and management on the Loess Plateau CAI Qiang-guo (Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China) 1 Introduction The Loess Plateau situated in northern China covers the drainage basins in the middle reaches of the Yellow River. It starts from the western piedmont of Taihang Mountains in the east, reaches the eastern slope of the Wushao and Riyue mountains, connects the northern part of the Qinling Mountains in the south and borders the Great Wall in the north, covering an area of about 380,000 km2 (Figure 1). The region is overlain extensively by Quaternary loess in great thickness, hence the name Loess Plateau. The continuous loess covering on mountains, hills, basins and alluvial plains of differing height ranges from 100-300 m in thickness. The Loess Plateau is one of the source places of the Chinese nation with an agricultural development history of 4,000-5,000 years, therefore, human activities exert great influence on the soil formation and evolution[1]. In most part of the region, the altitude of the Loess Plateau is 1,000-2,000 m and relative relief is 100-300 m. The relief declines gently from northwest to southeast, consequently, the direction of flow of the Huanghe and its major tributaries generally eastward. Loess geomorphology is the dominant feature on the Loess Plateau along with middle and low rocky mountains. The rugged undulating ground surface dissected by gullies and ravines, broken and barren, composes the chief characteristics of the loessic landforms. Geomorphologically, modern erosion process is intense. The density of gullies and ravines on the Loess Plateau is mostly over 3-4 km/km2, the maximum exceeds 10 km/km2. The type of loess geomorphology is mainly divided into loessic Yuan (flat ridge), loessic Liang (ridge), loessic Mao (gentle slope) and various types of gullies and valleys. Apparent changes in regional distribution of loess geomorphologic patterns are featured clearly from the south-north trending profiles made in northern Shaanxi or eastern Gansu: the northern part is hilly area of loessic Mao, changing gradually southward into Liang dominated hills, up to the surroundings of Yan´an, the hilly area of loessic Liang and Mao increases, loessic Liang dominated hills occur again further southward, and then comes the loessic Yuan. Regional changes in loess geomorphology west of Liupan Mountains differ from that of the east, where loessic Yuan occurs to the northern part, hills with loessic Mao are mostly found in the central part, and hills with lengthy loessic Liang mostly in southern part. Figure 1 Location and scope of the Loess Plateau Steep slope featured landforms constitute the essential characteristics of the Loess Plateau. With the exception of west Henan, southeast Shanxi, northwest Shanxi and Fenhe-Weihe valley, the area of slopeland with a grade of over 15 degrees in the remaining part makes up more than 40 % of the total land area, and slopeland with a grade of over 25 degrees in west Shanxi, north Shaanxi, and southeast Gansu accounts for more than 30 %. Loess is a kind of texturally even, structurally loosen, calcium content rich, and highly porous Quaternary wind-borne accumulates. Grain-size composition is largely silty-sand, characterized by precipitous horizontal zonation. Sandy loess belt, silty loess belt and clayey loess belt are identified orderly from north to south on the Loess Plateau. Annual precipitation on the Loess Plate au is less than 700 mm which is spatially uneven distributed. Precipitation decreases gradually from south to north and from east to west (Figure 2). Rainstorms and heavy rainstorms are relatively concentrated on north Shaanxi, west Shanxi and Inner Mongolia on the Loess Plateau and rainfall is highly concentrated on summer, the amount of precipitation in July, August and September occupies 50 % - 70 % of the annual total. Figure 2 Annual precipitation in the middle reaches of the Yellow River 2 Soil erosion problem on the Loess Plateau Figure 3 is an erosional silt delivery intensity distribution map of the Loess Plateau region compiled by using hydrological data. One can see from the map that erosional silt delivery intensity is generally high in areas along a line north of Qingyang, Yan´an and Daning sandwiched between Liupan Mountains and Luliang Mountains. The volume of erosional silt produced exceeds 5,000 t/km2 · a, of which the maximum is found in middle and lower reaches of Huangpuchuan, Kuyehe and Jialuhe drainage basins, being over 20,000 t/km2 · a. It is generally low in areas south of the line, largely below 5,000 t/km2 · a, and in forest area of Ziwuling, it is less than 500 t/km2 · a. The erosional amount can reach around 5,000 t/km2 · a in the upper reaches of Weihe and the Zulihe drainage basin west of Liupan Mountains, and it is smaller than the value in the remaining area. The area with erosional amount greater than 5,000 t/km2 · a covers about 145,000 km2 in the region, being 37.1 % of the Plateau´s area; that greater than 10,000 t/km2 · a covers about 50,000 km2, or 12.8 % of the Plateau´s area. The silt produced accounts for about half of the annual average silt discharge of the Huanghe River, the distribution areas are concentrated in the upper reaches of Malian River, drainage area above Jinfoping of Beiluo River, area from Yanhe River to Huangpuchuan, and Qiushuihe drainage basin west of Shanxi. The areas subject to most intense erosional silt delivery are almostly located in the loessic hilly-gully area. Land resources on the Loess Plateau are seriously disturbed due to intense modern soil erosion, the resulting gradual impoverished land and serious deteriorated eco-environment exerted great impact on local industrial and agricultural production. According to estimation, per ton soil loss contains 0.8-1.5 kg of ammonia, 1.5 kg total phosphorus and 20 kg total potassium. Calculation based on annual loss of 1.6 billion tons of soil, a total amount of about 38 million tons of ammonia, phosphorus and potassium is lost. At present, content of soil organic matter in loess region is less than 1 %, even below 0.5 %, soil granulate structure is very poor, natural productivity is very low, per unit area crop yield is not only low but is also instable. Although the total livestock number has increased, the quality dropped; output value of by-products in most part of the region only accounts for a very limited portion of the rural area. Recently though rural economy has made great progress, it still falls into the category of poverty-stricken region in comparison with many other regions throughout the country. Figure 3 Distribution of erosional silt delivery intensity on the Loess Plateau region Yellow River is a famous silt-laden river in the world. According to measurement data of 1919-1990 obtained by hydrological station of Shanxian County, the annual average suspended load transported from Yellow River to the lower reaches through this station is about 1.6 billion tons. According to statistics of 11 world rivers (Table 1) which have a total sediment discharge of 6 billion tons annually, the suspended load migrating into sea from Yellow River makes up 28 % of these rivers´ total, yet the Yellow River drainage area only occupies 5.4 % of their grand total. The annual runoff volume of Yellow River is only about one ninth of the Yangtze River, yet the suspended load of Yellow River is nearly four times as much as that of Changjiang. The extremely intense erosion on the Loess Plateau usually results in high silt-laden flow in gully causes and river channels during rainstorm period. According to hydrologic and sedimentation observations that the silt content in slope runoff resulting from rainstorms in loess hilly-gully area largely exceeds 200 kg/m3, the maximum can reach 889 kg/m3, silt content of flood water gullies and ravines is normally over 300 kg/m3, the maximum is 1,240 kg/m3. Silt content is even higher in some tributaries of Yellow River, the maximum is largely more than 1,000 kg/m in Huangpuchuan and Wuding rivers. Estimation based on hydrological data indicates that of the 1.6 billion tons of suspended load released from Sanmen Gorge annually, about one fourth deposit in the downstream channels of the Yellow River. Consequently, the channel bed of the river confined by dykes on both banks has being lifted up at a rate of 8-10cm annually, causing the lower reaches of the Yellow River a “ hanging river ” on the ground. At present, the downnstream channel has already become 3-8 m higher over the adjacent ground, the maximum reached 12 m, but the flood release capacity has dropped gradually. Since the 1950s, the project to heighten the dykes of Yellow River implemented in three periods has achieved a great deal in guaranteeing the safety of people´s life and property as well as economic construction, the threat of disasterous dyke breaching still exists and is aggravating day by day. If the intense erosion on the Loess Plateau failed to be controlled, it would be very difficult to realize the goal of exploiting hydropower and eleminating the scourge of floods of Yellow River. 3 Cause analysis of soil erosion and land degradation Modern global soil erosion issue is inseparable from human activities, the development of soil erosion has become a world principal environmental problem, some scholars hold that artificial acceleration of erosion has become the cancer of land[2]. In a country like China which has a long history of cultivation, the p roblem has become even more protruding. Soil and water loss is serious on modern Loess Plateau where erosion landforms featuring by barren land, ravines and gullies can be found everywhere. Particularly the surging silt-laden Yellow River under conditions of rainstorm induced floods usually presents irresistible natural force. Human destruction on vegetation can happen in a short while or extremely short while, however, aggravation of human induced soil erosion would be several hundred times serious than natural erosion. The cause of black burin happened in United States in 1934 was the destruction of forest and vegetation and reclamation, resulting in a shocked outcome of losing fertile topsoil in a short while. The discussion on cause for intense soil erosion and land degradation is of crucial importance to the identification of control and management measures of the Loess Plateau. 3.1. Impact of human activities on intense soil erosion process and eco-environmental evolution in historical period A vast amount of historical data proved that there used to have extensive flatland, few ravines and gullies, lush forests and grass as well as clear river water on Loess Plateau in history[3]. Zhu Kezhen, a well-known Chinese climatologist indicated[4] that climate in Yellow River drainage basin 5,000 years ago fitted the North Asia subtropics of present day Changjiang drainage basin with a temperature of around 2 oC higher than present. The black loamy soil and loutu profile in the loess deposits developed around 7,000 years ago indicated that the climate then related to soil formation process was warmer and more humid than today´s when erosion was slight due to luxuriant forest and grass vegetation. Since 3,000 years BP, the climate tended to be desiccated, entering into a transitional period of relative intense loess deposition and erosion. What is more important is human activities were entering into a more and more prosperous period, natural vegetation was seriously disturbed due to farming practices and overgrazing and soil erosion tended to be drastically developed. In light with UNEP and FAO investigation data, two thirds of land on Earth was once covered by forests, being as large as 7.6 billion hm2, but today only 2.64 billion hm2 were left over; 80 % of Asia´s farmland were originated from forests. Population growth was the root cause for farmland expansion, and farmland expansion was at the expense of damaging natural vegetation, so the natural erosion was evolved into human accelerated erosion, aggravating eco-environmental deterioration. China has a long farming history and the Yellow River drainage basin as the source place of Chinese national culture witnessed earlier development history of farming and animal husbandry. Since the 6th century to the 15th century, population on the Loess Plateau had been around 25 % of the country´s total. Afterwards, population continued to increase and reached over 40 million in 1840. 1949-1986 experienced a drastic population growth period, an increase of 1.2 folds (Table 2). Pollution growth bounds to cause expansion of cultivated land, aggravating destruction of forest and grass vegetation. Desertification expansion, reduction of forest belt, soil erosion and vicious circulation of eco-environment resulting from devastation of reclamation without restraint stimulated the increase in drought and flood occurrence frequency. China witnessed 110 flood events and 95 drought events from the 7th to the 20th century, of which several droughts occurred 2.7 times averagely every centennial in the first seven centuries and 10.8 times every centennial in the late seven centuries. Once natural eco-equilibrium was sabotaged by human activities, impacts of natural factors of precipitation and topography on soil erosion would be relatively precipitous. Human accelerated erosion has not only increased sediment delivery to the Yellow River but caused drastic decline of soil quality. Experiment and observation indicated that after 20 years reclamation of the forestland, the content of organic matter in topsoil has approached to C Horizon and dropped from 27.15 g/kg to 5.45 g/kg, an annual average decline of 3.8%. After reclamation of forestland, relative humidity of atmosphere dropped by 0.68 % - 1.5 % averagely in 5 years, soil temperature rose by 9.4 oC, 8 oC, 5.3 C and 3.5 oC respectively from ground surface to 5 cm, 10 cm and 20 cm horizons[5]. The sabotage of human activities to nature eco-balance constitutes the principal reason for erosion aggravation and occupies a leading position in modern erosion process. It is just because of resting on the principle of preserving soil and water with vegetation cover that many countries have adopted soil and water conservation measures on slopeland such as nontillage, less tillage and mulching with crop residuals. Intensification of forest and grass vegetation rehabilitation and constant improvement should be taken as a fundamental measure to conserve soil and water and harnessing Yellow River. 3.2 Current status of vegetation and vegetation to human aggravation of erosion development Most part of the Loess Plateau is confined to the warm temperate semi-humid, semi-arid climatic zone, part to mesothermal semi-arid climatic zone, and the northwestern part of the Plateau to mesothermal arid climatic zone. The corresponding natural vegetation zone consists of forest belt, forest steppe belt, steppe belt and desert steppe belt (Figure 4). There are relative more vegetation types on the Loess Plateau, including over 500 species of herbs, more than 250 species of woody plants, and over 300 species of resources plants, but the available resources of various plants are limited. In fact, natural vegetation of forest and grass on the Loess Plateau has been seriously devastated and the existing ones are only in sporadic distribution on some of the mountains, even in summer when plants are in luxuriant state, the vast land still appear yellow. The forest coverage in the region is only 7.1 %, 6 percent age less than the country´s average level. The existing forests are mainly distributed in the southeastern part of the Plateau, on rocks or earthen rocky mountains. In the vast expanse of loess hilly areas and loessic Yuan, only sporadic trees are distributed in the vinicity of villages and towns and sparse grass and shrubs are on non-cultivated land. Ziwuling was the only place with forest vegetation better preserved on loess overlain area of the Loess Plateau, however, forest vegetation was also seriously damaged in the past several decades, and forest boundary line has been retreating at an annual average rate of 0.5 km. Since the region´s forest vegetation was so deficient that aggravated development of soil erosion is inevitable. Grassland area accounts for 30.5 % of the total land area, of which 60 % has already degraded or decertified. Most of the ridge and gentle slopes, even valley slopes in the loess hilly area have been reclaimed. Consequently, gully erosion and gravity erosion was induced and accelerated due to serious slope erosion. In the case vegetation in most part of the region on the Loess Plateau was devastated, nature balance got disordered, obviously, human accelerated erosion play the leading role erosion rate far exceeded natural erosion. Figure 4 Natural zones on the Loess Plateau It is known to all that the mechanism of vegetation restraining erosion is first of all, the interception of plant foliage, then the function of wash durability and surface runoff reduction of withered twig and dead leaf layers, and lastly fixation of plant root system and amelioration of soil physio-chemical properties to increase anti-erodibility and wash durability of soils. Meanwhile, plants are unfavorable for soil erosion development by improving environmental quality and providing wild-animal habitats. Vegetation interceptability is influenced by factors like vegetation type, canopy density, precipitation volume and precipitation intensity. The significance of anti-erosion of vegetation interceptability lies in to reduce actual rain intercepted on the ground so as to reduce soil erosion. For instance, in gully drainage basin of Huanglongshan temple, the average rainfall during floody season is 322-390 mm, the annual intercepting amount of trees (Pinus tabulaeformis Carr., Populus davidiana Dode) and shrubs (Lespedeza bicolor Turcz, etc.) is 46-99 mm, the intercepting rate is 12.5-26.7 %[6]. In other words, precipitation here reduced by 12.5-26.7% compared with treeless drainage basins, hence naturally mitigating runoff wash; meanwhile, vegetation interception can also prevent raindrop splashing on and raindrop disturbance to thin flow layer of water on the slopes and such kind of disturbance is the major driving force on slope runoff erosion[7]. Result of our rainfall simulation experiment[8] indicated that rate of splash erosion of 50 % coverage has already been reduced by over 70 % in contrast to coverless ground. The experiment actually implies that in terms of merely rainfall induced splash erosion, when vegetation coverage reaches around 50 % on gentle slopes, soil splash erosion has already been greatly reduced. The functions of wash durability and surface runoff reduction of withered twig and dead leaf layers vary with each vegetation type. According to measurement of secondary forest area in Ziwuling of borderland between Shaanxi and Gansu provinces by Cheng Jimin (1987)[9], the maximum amount of water absorbed by withered twig and dead leaf layer is related with factors of dry weight, thickness, bulk density and storage. Water content of Populus davidiana Dode is 124.5 %, equivalent to a 10 mm precipitation. In other words, no runoff can be resulted during a 10-20 mm precipitation event in forest area of Populous daviviana Dode on Ziwuling Range. Experimental research indicated that withered twig and dead leaf layer plays a great role to rainfall runoff infiltration. In forest area of Ziwuling the infiltration rate of surface layer (0-15 cm) in the initial 30 minutes can reach 17.4 mm/min, being 2.6 times of the farmland, stable infiltration rate, 12.5 mm/min, 4.3 times that of farmland[10]. Result of field artificial rainfall experiment (rainfall intensity 1.28 mm/min, rainfall duration 38.6 min) indicated that under high intensity rainfall conditions, all the 38.6 mm precipitation fallen on the forestland infiltrated, and only 8.6 mm infiltrated on the farmland. Therefore, it is very important to soil and water conservation by preserving withered twigs and dead leaves under forests. Li Yong et al. (1993)[11] studied and obtained vegetation control soil erosion module on the Loess Plateau, i.e., a combination of herbs, shrubs and woody plants. Root systems of herbal plants can prevent surface washing whereas shrubs and woody plants can raise anti-erodibility of deep stratum (>50 cm) soil mass, the function is particularly obvious on steep slope with greater grade (normally greater than 30 degrees). Herbal plant generally functions insignificantly in preventing creeping of surface layer soil mass and sometimes promotes water infiltration into soils because of root system, resulting in increase weight of soil mass, reducing soil resistance to shearing and accelerating steep slope topsoil creeping. To prevent shallow layer sliding, it is essential to rely on extensional force of root systems of woody plants and deep-rooted shrubs. In order to synthetically explain the anti-erodable effect of plants, we conducted runoff experiment on small plots. The runoff plots were located on the ridges of Wangjiagou in Lishi of west Shanxi Province, the surface materials were Lishi loess of middle Pleistocene, ground gradient was 22 degrees and five plots were located. Polymerized grasses with coverage of 0 %, 20 %, 40 %, 60 % and 80 % respectively were planted. Observations of natural precipitation of these plots were conducted along with several groups of rainfall simulation experiments[12]. Results of both items were basically similar, when vegetation coverage wa

s 20 % - 40 %, soil and water reduction rate was 54 % - 79 %, when vegetation coverage was 60 % - 80 %, soil and water reduction rate was 77 % - 95 %, indicating a very apparent effect of polymerized grass vegetation on soil erosion. Another group of data on natural precipitation observation indicated that after steep slope farmland (18-30 degrees) was abandoned for grass planting, the quantity of soil eroded was reduced by 77.6 % annually. In addition, we also set up five experimental troughs and cultivated Awnless Brome in them, the actual coverage were 0 %, 34 %, 60 %, 75 %, and 100 % respectively and two types of rainfall simulation experiments were carried out with rainfall intensity being 0.81 mm/min and 1.3 mm/min separately. Results showed that when rainfall intensity was 0.81 mm/min and rainfall duration was 30 minutes, rainfall runoff on slopes with coverage of 60 % and 100 % reduced by 68 % and 89 % respectively than on bare land; erosion induced sediment yield reduced by 95 % and 98 % respectively. Even for a heavy rainstorm with an intensity of being 1.3 mm/min, runoff reduction being 52 % and 89 % respectively, the erosion induced sediment yield would be 89 % and 98 % respectively. When grass coverage reached 75 %, the resultant runoff would be reduced by over 75 % and silt yield by 95 % in contrast to bare land. In the case of stable infiltration, 80 % of the rainfall would be infiltrated into soil with a stable infiltration being 4 times of bare land, silt content in slope runoff reduced by an order of magnitude compared with bare land, a powerful demonstration of the role of grass vegetation [13]. In order to estimate effect of soil and water conservation of artificial pastures, five years runoff and silt observational data for 12 types of pastures (average vegetated degree being 73) grown on steep slopes (28 degrees) were calculated on an average basis. In terms of the annual runoff depth (mm) and erosion module (t/km2) of the 12 types of pastures compared with bare land, water and silt reduction efficiency of artificial pasture was 47.5% and 74.7% respectively. In Wangjiagou drainage basin of west Shanxi, comparison of the observational data of the grass reservation facilities installed in the natural runoff experimental plots on Hongtu gully slopes for eight years (1959-1966) with observational data of Hongtu gully slopes where random grazing was allowed (Table 3), one can find that runoff and erosion amount was reduced by 93.7% and 97.4% respectively after several years´ grass reservation. Numerous research[14,15] indicated that there used to have fine vegetation on the Loess Plateau in human history, though Yellow River was silty in ancient times, the erosion intensity was no doubt much lower than the present, the increasingly serious erosion was resulted from man´s devastation of vegetation. Table 3 Water and silt reduction efficiency of grass reservation by prohibited cultivation on Hongtu gully slopes 3.3 Impact of ploughing on accelerated soil erosion When people discuss the cause for such a serious soil erosion Loess Plateau, they normally consider the extremely weak ability of loess in resisting water erosion as an important reason. Of course the anti-erodibility of loessial soils is lower than other loamy soils, yet result of runoff washing experiments carried out on Malan loess slopes indicated that virgin loess on gentle slopes (15 degrees) without being disturbed by ploughing still have better ability to resist runoff washing. The experimental method we adopted was to release water to wash small troughs digging on natural waste slopes where farming was given up for many years. The ground surface was covered with sparse weeds and soil was late Plestocene loess. The cross section of the experimental trough digging on ground surface was inverse triangle, 20 cm deep, opening was 30-38 cm wide and included angle on the bottom was about 60 degrees. Water used for the experiment was clear water from pond, the entrance flow discharge was 1800, 1200, 500 and 250 ml (sec)-1, the experimental trough was 10, 20, 30 and 40 m. Experimental results indicated that the maximum entrance flow (1,800 ml (sec)-1) and the maximum silt content of the longest trough (40 m) was less than 0.6 kg · m-3, an indication of slight erosion of the internal walls of the trough. However, this by no means to say that it was caused by inadequate erosional energy of the trough water flow. The actual measurement indicated that the maximum flow velocity initially as water was releasing might exceed 1.2 m (sec)-1, even water flow reached balanced state after energy dissipated by erosion, the flow velocity could also reach 1.0 m (sec)-1. In the laboratory and field rainfall simulation experiments for farmland rill erosion study, the maximum surface water flow velocity measured by the same method was no more than 0.1 m (sec), the maximum flow velocity in the rills seldom exceeded 0.3 m (sec)-1. This can be inferred that the energy the water flow in the rills possessed was by far the greastest in comparison with the energy on slopes of the sloping farmland and energy of water flow in the rills under similar conditions. However, silt content in rill water measured in our laboratory and field experiments was normally 100-200 kg.m-3, the highest can exceed 500 kg.m-3[16], several hundred times higher than the maximum silt content at cross section of the rill flow, different soil structure was mainly accountable for such a great difference.

关键词： soil erosion; control technique; management; Loess Plateau