Soil and water conservation and integrated management in watershed ecosystem of the Loess Plateau, China

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Abstract. The Loess Plateau is well known for severe soil erosion and ecosystem degradation. The key issues in this region are the food security (grain), ecological security and a sustainable economy. This paper reviews a range of studies on ecological restoration, and management and the benefit at watershed scale on the Loess Plateau. This includes several successful cases and failures in soil conservation. The paper presents practical soil conservation measures and related benefit analysis, and discusses some effective methods adopted in soil erosion control, research directions and future perspectives for the Loess Plateau.

Keywords: Soil erosion, ecosystem rehabilitation, management, Loess Plateau.

Introduction

The Loess Plateau is well known for its severe soil erosion and ecosystem degradation. In particular, deforestation, over cultivation and overgrazing and exponential population growth have caused massive amounts of soil to be lost (Jiang *et al*. 2013), which in turn has caused sedimentation of the Yellow River and its resultant "hanging river" (Cai 2001). This in turn has created wide spread flooding down stream, causing loss of life, livelihood and extensive population displacement. The degradation of the Loess Plateau is therefore an issue for the whole of China and hence the world.

The Loess Plateau region is situated in the upper-middle reach of the Yellow River and has an area of about 640,000 km^2. The plateau's soil is derived from wind blown deposits (loess) that has been transported from the arid inland areas, The plateau's soil are typically continuous Quaternary silty loess deposits of 50–300 m in thickness, except for the few rocky mountain areas in the plateau where the loess thickness is <50 m. The plateau consists of the High plain plateau (also called Yuan) and the Hilly and Gully plateau with an altitude of 1,000-2,000 m with a relative relief of 100-300 m.

These two types of plateaus are both deeply dissected by gullies and ravines, with the lengths mostly greater than 3-4 km/km^2, the maximum exceeds 10 km/km^2 (Zhou *et al.* 2013).

Population growth, vegetation degradation and plugging have been cited as the main cause of soil and water degradation on the Loess Plateau (Cai 2001). Currently the key issues facing agriculture and natural resource management on the Loess Plateau are grain food security, ecological security and a sustainable economy. The most effective method to resolve these three problems are ecosystem restoration, appropriate land management and sustainable utilization of resources.

The Chinese government has implemented a series of policies that encourage ecological restoration, soil and water conservation, and much research has been completed. This paper firstly, reviews several successful and failed cases in ecosystem rehabilitation and management, secondly present practical soil conservation technique and related benefit analysis, thirdly discusses a range of effective methods of soil erosion control, and lastly discusses research directions and future perspectives on the Loess Plateau.

Overview of the Loess Plateau

The Loess Plateau has an arid to semi-arid temperate climate and approximately 60% of the rain falls during the autumn months, coming in the form of high intensity storms, which often cause extreme soil erosion (Xin *et al.* 2011). The prevailing weather pattern is northerly monsoon during winter and a southerly monsoon in summer. Rainfall varies significantly between regions, with ~250 mm mean annual rainfall and a mean annual temperature of ~8°C in the north-west and ~650 mm mean annual rainfall and a mean annual temperature of ~14°C in the south-east and is classified as arid to semi-arid (Jiang *et al.* 2013).

Loess is one of the most erosion-prone soils known on the planet and is extremely sensitive to the forces of wind and water and easily blown or washed away. Severe soil erosion has made the eco-environment fragile in the Loess Plateau with about 1.64 billion tonnes of sediment transported into the Yellow River annually from 1919 to 1960 (Liu 1985; Mu 2012). This additional sediment has raised the riverbed and causes frequent devastating floods (World Bank 2001). The hilly and gully plateau areas such as Northern Shaanxi, the Western Shanxi, the Southern Ningxi and the Dingxi District of Gansu Province specifically suffer from severe soil erosion,

Population densities in the Loess Plateau on average exceed 100 people/km^2. However in some areas, the population density exceeds 300 people/km^2.

The change to the eco-environment has been identified as the main cause of increased soil erosion (Zha and Tang 2003). This change has been caused by a number of factors primarily the unique geographical location and low rainfall. Firstly, the topography, specifically the slope from south to north, provides a gradient to encourage severe soil erosion. Secondly, the low rainfall reduces the water available for plant growth which in turn leads to poor vegetative growth of forests and grasslands and large areas of low-efficiency and low-yielding vegetation. As human activities increase and the population becomes more affluent, the natural vegetation is coming under pressure and areas are being cleared for farming and grazing. This increased utilization in turn is increasing the rate of soil erosion. Widespread ecological degradation in the form of severe soil erosion and water shortages has constrained sustainable socioeconomic development of this area in recent decades. So, it is imperative to encourage and implement ecological restoration and management in a sustainable way to effectively manage the physical, social and economic environments of the Loess Plateau.

Agricultural activity on the Loess Plateau has a history of more than 6000 years and continues to be the main industry. However, agriculture is also one of the main drivers of soil erosion on the Loess Plateau.

The implementation of a range of ecological engineering projects has resulted in a contraction in the area farmed for grain production on the Loess Plateau. For example the Grain for Green Program (GFGP), launched in 1999 has involved up to 0.12 billion farmers, and has assisted in retiring and re-vegetating up to 9.27 million ha of steeply sloping croplands (Li 2009). However, it is important to ensure the ability to produce food remains, after soil and water conservation management measures are implemented

Government policies to address ecosystem degradation

In the 1980's the Chinese government recognized the range of problems arising from ecosystem degradation and implemented a range of policies to address ecosystem degradation with the specific aim to control soil erosion and combat land degradation. These policies, which have fostered an environmental-friendly society, have drawn widespread attention to the practices of soil erosion control and ecological restoration. The programs included a range of significant ecological engineering projects including:

- the Grain for Green Program,
- the Natural Forest Resources Conservation Program,
- Three North (north, northwest and northeast China) Shelter Belt Construction Program,
- the China Watershed Management Project, and,
- the Natural Restoration Program.

For example, when completed, the Grain for Green policy aims to convert over 13 million ha of cropland to forest or grass land, 6 million of the targeted area is cultivated land with a slope of greater than 25^o (World Wildlife Fund 2003). These projects have in full or part reconstructed, typical vegetation communities (natural grassland and woodland), by either natural succession or replanting of cropland at regional and watershed scales.

Research on soil and water conservation measures

In the last few decades, much research has been completed on the integrated ecosystem management and restoration of the Loess Plateau. A regional network of long term field stations has been established under the support by the Chinese Ecosystem Research Network (CERN) from the Chinese Academy of Science. Integrated observation systems at the plot, small watershed and regional scale were developed and from these, strategies for conservational eco-agriculture on the plateau for grain food security, ecological security and economical sustainable were developed to address the fundamental question; can re-vegetation and integrated soil and water conservation management strategies be coordinated to promote grain food security, ecological security and sustainable economy on the Loess Plateau?

Vegetation and rainfall are the two driving factors causing soil erosion and nutrient loss in the Loess Plateau. Re-vegetation has become the focus of soil and water conservation and ecosystem rehabilitation in this area. Long term research found that the main driver for ecosystem succession on the Loess Plateau is the pattern of land use, while re-vegetation is the key measure for ecosystem rehabilitation. The ecosystem rehabilitation models at different scales have been established which provide real case scenarios for research and extension for local farmers.

Ecological restoration projects

Ten years of monitoring in a paired catchment study measured 2.2 t/km^2·a of sediment from a natural forest as compared to 2031 t/km^2·a for a cleared forest, that is, 1000 times more sediment than from natural erosion (Zha and Tang 2003). Measurement of the soil in the cleared catchment showed clay content, water-stable aggregates, and soil shear strength all decreased significantly, while the bulk density (ρ) increased. Changes to landuse (farmland converted to forestland or grassland) significantly prevented soil erosion and improved soil physical and chemical properties, soil water contents and aboveground vegetation characteristics in this area (Lü *et al*. 2012). Cropland transforming to grassland or shrubland also significantly increased soil organic carbon at patch scale. At the small watershed scale, soil organic carbon stocks increased by 19% in 0-20 cm soil depth because of farmland-converted forestland or grassland from 1998 to 2006, an average soil organic carbon sequestration rate of 19.92 t C/y/km^2 (Wang *et al*. 2011). This clearly shows that over-utilization and over-exploitation of natural vegetation under no-policy management is the main driving force for vegetation and environmental degradation, soil erosion occurring on the Loess Plateau (Lü *et al*. 2012).

In "Grain for Green" Project, targeted arable lands where slope exceeded 46% and were convert to forest or grassland, while local farmers received grain and cash subsidy from the government for the loss of food due to offset the decrease in cropland (Chen *et al*. 2007). As a result between 1986 and 1997 the area of grassland with high coverage changed from 423 km^2 to 35035 km^2 on the Loess Plateau (Meng *et al.* 2009).

Natural restoration

Natural restoration is considered as an effective restoration approach for degraded grasslands in the world. Since the "Natural Forest Protection Project" was launched and grazing was prohibited in certain areas, rehabilitation by natural succession has become an important method of re-vegetation in the plateau. Long-term natural grassland regeneration studies (15-25 years) suggest that natural regeneration could significantly improve both above and below ground biomass, and species diversity in the steppe of the Loess Plateau (Cheng *et al.* 2011; Zhao *et al.* 2011). By reducing grazing pressure by goats for short periods in the Zhifanggou watershed of the loess hilly and gully region, the number of species (7% to 73%), coverage (20% to 88%) and above ground biomass (7% to 73%) increased sharply, while soil erosion rate decreased from 14000 to 1210.2 t/(km^2·a) (Wang *et al.* 2003). Additionally following revegetation, temporal and spatial distribution of soil organic carbon (SOC) increased (Wang *et al.* 2012c), this additional SOC sequestration should contribute significantly to decreasing the carbon concentration in atmosphere. SOC content increased by 27.5% (3.41 g/kg to 4.35 g/kg) after the change from cultivated crops to natural grass during the 8 years from 1998 to 2006, vegetation cover change significantly increased soil organic carbon sequestration in this area (Wang *et al.* 2011).

Soil infiltration rate and saturated hydraulic conductivity both increased significantly after natural grassland regeneration mainly due to the increase in root biomass and the subsequent improvement of soil effective porosity (Bo *et al.* 2007). Excluding stock for 15 years at a long-term natural regeneration management site improved the soil physical properties, decreased soil bulk density, increased soil water content, and soil–water holding capacity, and the soil water retention as compared to sites that stock were excluded for only 5 years. The exclusion of stock and allowing natural regeneration also protected the soil from water erosion (Wu *et al.* 2013), and grassland that was natural regenerated (specifically *Stipa bungeana* communities) increased soil infiltration rates. This increase in infiltration is attributed to the plant roots length density, improvement in soil structure and porosity by root growth. Additionally the soil under the regenerated grasslands increased soil organic matter content and water stable aggregates (Wang and Liu 2009).

Microbial biomass, physical and chemical soil properties improved significantly after 20 to 25 years since natural succession. Wei *et al.* (2012) found after 50 years of restoration on abandoned farmland in the Huanglong mountain Forest Area, soil structure measured by macro-aggregates significantly increased (P<0.01) and SOC increased in both the soil matrix and the macroaggregates. This suggests that it is possible to recovery soil fertility and soil microbial biomass by natural vegetation recovery under erosive slope cropland in the loess hilly area (Xue *et al.* 2009).

It was found that to optimize the benefits of a 15 years of grazing exclusion on soil properties the management of the exclusion must be well planned to allow for the changes in soil respiration rates and the increases to soil organic carbon (Wu *et al*. unpublished data). The nutrient content of the soil increased significantly after 30 years of restoration, while clearing of vegetation in the semi-arid Loess Plateau could be reversed by allowing secondary succession of vegetation on a large spatial scale (Wang *et al.* 2012b). It was found in Wuqi County, that plants indigenous to the local area was the most successful, and these plants gradually evolved into a stable vegetation community (Ren *et al.* 2003).

All these results suggested that long-term natural regeneration is an effective restoration approach to protect species diversity, restore vegetation productivity and improve soil water capability and soil quality on the Loess Plateau, although this effect may take some time.

Anthropogenic restoration

In irrigated areas of the Yellow River Valley which is one of the main maize growing region in China, raised-bed planting has improved maize productivity and adoption of this technology could ensure a major source of China's maize supply (Zhang *et al.* 2012). A range of farming techniques and practices have been studied and implemented for arable soil erosion control of the Loess Plateau. Contour tillage, plastic film mulching, straw mulching, direct seeding to date have been the most effective soil protection strategies to control water erosion. After implementing these soil conservation strategies, soil loss was reduced by $1.4×10^8$ t/y for the whole Loess Plateau.

It was found that the direct planting is most effective erosion control measure and the most widely implemented. This mainly included the constructions of woodlands, shrublands, grasslands singularly or combination on the Loess Plateau. The soil moisture content under the plantings increased with stand age due to improvements in soil water-holding capacity and water-retention properties in areas of higher rainfall, while in dry areas, the variation in after-planting soil moisture content with stand age was negligible (Jin *et al.* 2011). This suggests that direct planting measures need to consider the climate specifically the rainfall when selecting areas to implement these practices.

Replanted forests and shrubs increased the soil water deficit more than replanted grassland in the loess hilly region (Wang *et al.* 2002). The longer the grasslands were rested from farming, the better they conserved soil and water. Soil quality and soil capability and water conservation in replanted grasslands was notably superior than replanted forest and shrub land (Pan *et al.* 2006). This suggests replanting farm land with grass is more effective approach than replanting with shrub and forest of controlling water and soil losses in the Loess Plateau regions.

In the loess hilly area, forbs can provide an environment to allow successful vegetative succession and establishment of shrub communities. This is particularly the case if the soil supporting the initial forb community is high in soil nutrient (Zhang *et al.* 2009). Plant species established under arid climatic conditions have a significant effect on the biological properties of the soil in the rhizosphere. All re-vegetated soil showed higher microbial activity compared with control soil, with soil under natural grassland species Zhang *et al.* (2011). Jiang *et al.* (2013) suggested that the ecological restoration of forbs should be considered a priority for vegetation restoration under a global warming scenario. This is contrary to previous policies where trees and shrubs have been prioritized. This conclusion was reached after analysis of the natural vegetation types since the Last Glacial Maximum on the Loess Plateau which suggested that revegetation should choose or prefer native forb species such as *Corylus*, *Juglans* and *Selaginella sinensis* or other forbs that can adapt to the local climate.

Integrated management in watershed ecosystem

On the Loess Plateau population poverty and ecological degradation are interlinked in a vicious cycle. It's crucial for the ecological rehabilitation in Loess Hilly Region to rebuild the ecological-economic harmony. Ecological restoration is an essential pathway to the ecological and economic coupling and harmonization in the loess hilly region, as ecological restoration can improve resource use and conversion efficiency, while decreasing the environment loading ratio, the appropriation of biological productive area for economic activities (Dang *et al.* 2008).

The effect of water and soil loss on the eco-environment was explored using a meso-scale model (DPSIR), and found that the sensitive indices were;

- the Grain for Green program,
- pressure on farm land,
- the sediment transport modulus, and
- erosive precipitation.

These indices are hysteretic to the changes in the eco-environment, as contrast to the factors that drove the landuse change (Wang *et al.* 2012a).

The population carrying capacity and the production of agricultural products per unit area all increased in the Zhifanggou watershed (loess hilly and gully region) after the implementation of the Grain to Green Policy (Zhou *et al.* 2009). There was improvement in the energy indexes and efficiency of agricultural eco-economic system after the policy was implemented as compared to prior to implementation (Zhou *et al.* 2009). Importantly the population carrying capacity in the Zhifanggou watershed ranged from 113-900 people/km^2 (watershed area 8.27 km^2) before implementation of the "Grain for Green policy as compared to 148-1185 people/km^2 after (Zhou *et al.* 2009). The comprehensive management of small watersheds has been the feature of soil conservation in last decades. This method has control-led soil erosion in gully and inter-gully areas, trapping sediments, increasing agricultural production and improve-ing eco-environment. However there can be a long period of time between adoption and the response of the eco-environment.

Case studies of Zhifanggou Catchment and Wuqi County in the loess hilly and gully region have showed that ecological restoration in these catchments increased the diversity of industries as measured by the Shannon indices, and improved the industrial structure in this catchment (Dang *et al.* 2009). Ecological rehabilitation increased local farmers' living standards remarkably. These studies indicated that the relationship between economic development and ecological rehabilitation and environmental protection can be harmonious in the loess hilly and gully region. Using the Zhifanggou Watershed as an example, it was found by using a hierarchical approach that the ecosystem health index of watershed improved from 0.178 in 1985 to 0.707 in 1999 after 20 years of soil conservation practice (Liu *et al.* 2003).

Ecological restoration in the Zhifanggou watershed increased the Shannon indices (from 1.110 to 1.126), showing the improvement of industrial structure, this was accomplished by a transition to integrated productivity and increased the local farmers' living standard over the period of 1998-2005 (Dang *et al.* 2009). It has been shown that re-vegetation reduced soil erosion and nutrient discharge, improved the ability of the watershed to cycle nutrients and improved the nutrient balance which in turn increased the overall health of the watershed (Zhao *et al.* 2004). Taking Chaigou and Hejiagou watersheds of Wuqi County in Shaanxi Province as example, it was found that after 10 years of re-vegetation biodiversity and community features had improved in the ratification restoration areas, but the biomass, soil water conservation were better in the naturally restored areas (Zheng *et al.* 2010).

Industries that develop after re-vegetation were those that were suited to the local catchment characteristics, and there were policies in place that had appropriate structural regulations for land uses and rural industries (Dang and Liu 2009). Specifically the rural industry was characterized by crop farming evolving towards diversification. It was found that ecological rehabilitation increased the level of socioeconomic development in the case study of Yangou catchment on the loess hilly and gully region. The economic characteristics, namely, the rural production values and the net income per peasant (in 1990 prices), of the Yangou catchment increased from 803×10^4 Yuan and 1 230 Yuan (RMB) in 2000 to $1\,069 \times 10^4$ Yuan and 1 855 Yuan in 2005, respectively. This increase was after the implementation of soil and water conservation research and demonstrations under the Grain for Green Program (Dang and Liu 2009). After ~20 years' of continuous rehabilitation management of a range of watersheds in the hilly Loess Plateau, soil erosion was controlled and the watershed eco-economic system improved (Dai *et al.* 2006). The changes in social and economic factors showed that the eco-environmental restoration is not just the ecological restoration, but a process involved that involves social and economic development as well

Soil and water conservation and ecological restoration at different scales have played an important role both in local economic development and environmental improvement and provide an insight into sustainable economic development on the Loess plateau in to the future.

Problems and challenges

Both the Natural Forest Conservation Program and the "Grain for Green" Program on the Plateau have been highly successful, however, the duration of subsidies has been too short for forests to recover fully or for trees to grow large enough to yield sufficient harvest and income to offset losses from the converted land (Liu *et al*. 2008). These programs do however provide good opportunities for restoring and conserving ecosystem services, and while there have been many challenges and unexpected outcomes as discussed in this paper, many studies show that if subsidies end, some of converted forest and grassland will be revert to cropland, and forests will be logged again (Hu *et al*. 2006; Shen *et al*. 2006). Fortunately, the government has realized the issue and decided to extend the period of subsidies to 2016 (The State Council 2007) There is insufficient monitoring, evaluation and reporting of the restored vegetation and additionally there are many key theory and practical problems need to be resolved (Zhang and Liu 2007). In the future, short, medium, long term goals for vegetation restoration need to be clear, the aims of the programs be expanded, and the rate of natural restoration should be increased.

The fundamental measures for rehabilitation of natural vegetation communities on the Loess Plateau are fencing and fertilizer (when the conditions are suitable). These simple steps combined with natural re-vegetation allows for the following:

- use of the local species of trees and grasses and the non native species for rehabilitation,
- measures that protect the soil during preparation and subsequent management are adopted, by encouraging local species to establish,
- a river basin is used as the fundamental unit of management, this optimizes the spatial layout and area composition of landscape position and allows gradual rebuilding of the introduced vegetation which in turn allows for self-rejuvenate and continuous utilization of the community.

It is important to note that government departments should protect these existing outcomes by continuation of existing policies as well as expand the proportion of naturally rehabilitated areas by encouraging large scale contract farmers and additional investment for re-vegetation. Further there should be encouragement to increase research and re-vegetation in the Loess plains and the same time promote the innovation capability of re-vegetation of the loess plains.

Prospective issues

The successful performance of re-vegetation and soil and water conservation measures has been largely due to the innovative ecosystem management systems and mechanisms. Ecological rehabilitation is widely used in reversing environmental degradation and contributes to the improvement of ecosystem services and adaptability to climate change. Although some prevention measures had been performed continuously over the last 50 years, the efficiency of these measures has been limited and the improvement to the eco-environment is slow. Further research on the eco-system rehabilitation should focus on natural re-vegetation of the eco-system, the effect of re-vegetation on the environment and as well the stability of this news ecosystem in the context of the new ecological-economic balance in different eco-system scales, the ecological service in watershed eco-systems, and watershed management with the global change.

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