Vegetation Destruction and Restoration Effects on Soil Erosion Process on the Loess Plateau

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Abstract: Vegetation destruction or natural vegetation restoration greatly affects soil erosion process and eco-environmental change. Studies on soil erosion on the Loess Plateau have been focused on soil erosion process and erosion control at severe soil erosion regions where vegetation was completely destroyed. However, there are few available data to quantify effects of vegetation destruction or natural vegetation restoration on soil erosion process. The Ziwuling area on the Loess Plateau, where original vegetation destruction by human activities about 130 years ago, the secondary vegetation restoration during the past about 130 years, and deforestation again, provides an experimental area to quantify effects of vegetation change on soil erosion and eco-environment. The objective of this paper was to use data from field investigation and runoff plot observation to quantify effects of vegetation change on soil erosion. The results showed that before the secondary vegetation restoration, i.e., about 130 years ago, soil erosion conditions in the Ziwuling region were similar to present loessial hilly-gully region of Yan'an-Ansai-Zhidan zone. After the secondary vegetation restoration, soil erosion was very slight, impacts of rainfall and topographical condition on soil erosion were not well obvious, and vegetation effect on soil erosion was predominated. Ephemeral gully erosion at hillslopes and gully erosion at gully slopes or valley ceased, and sediment deposition occurred in ephemeral gully and gully channels during process of the secondary vegetation restoration. Meanwhile, valley erosion and gravitative erosion was almost controlled by vegetation. The soil erosion was changed from man-made accelerated erosion to natural erosion under ecological balance. Once the secondary forest land was converted to cropland, soil erosion greatly increased, soil erosion rate from a newly deforested land reached 10,000 t/(km^2 • yr) to 24,000 t/(km^2 • yr), which was 787 to 1682 times greater, as compared to woodland. These results show that man-made accelerated erosion play in a cardinal role in the regions where vegetation was completely destroyed by human activities. These finding will help to improve the understanding relationship between vegetation change and soil erosion, and to provide powerful data to make strategies for rehabilitating better eco-environment in the northwestern region of China.

Keywords: deforestation, natural vegetation restoration, natural erosion, man-made accelerated soil erosion, the loess plateau

1 Introduction

Conversion of woodland to cropland or natural vegetation restoration greatly affects soil erosion process and eco-environmental change. Studies on soil erosion on the Loess Plateau have been focused on soil erosion process and erosion control at severe soil erosion region where vegetation was completely destroyed. Fruitful achievements have been achieved (e.g., Huang, 1953; Zhu, 1956, 1981 and 1982; Chen *et al*., 1988; Tang *et al*., 1991; Jing *et al*., 1993; Wang and Jiao. 1996; Cai *et al*., 1998; Xu, 1999; Laflen *et al*., 2000; Zheng and Gao, 2000). These research findings have increased the understanding on soil erosion issue and its associated environmental problems. However, there are few available data to quantitatively identify effects of vegetation destruction and natural vegetation restoration on soil erosion process. Moreover, although it was accepted that man-made accelerated soil erosion caused by deforestation could be to the primary cause of soil degradation and eco-environmental quality deterioration on the Loess Plateau, there are few data to support this recognition. The Ziwuling secondary forest area on the Loess Plateau, where the secondary vegetation have restored during the past about 130 years, provides an experimental area to quantify effects of vegetation change on soil erosion and eco-environment.

2 Methodology

2.1 Site description

The Ziwuling forest area, which occupied about 23,000 km^2, is the sole of naturally secondary vegetation region on the Loess plateau. It is situated in the hilly region between Dongzhi Plateau and Luochuan Plateau (Latitude 33°50′—36°50′ N and Longitude 107°30′ —109°40′ E). About 130 years ago, eco-environment of the Ziwuling region was similar to the surrounding region at present, i.e., original vegetation was completely destroyed, soil erosion was severe, and eco-environment was worsened. During the past about 130 years, the secondary vegetation was gradually restored, forming today's better eco-environmental landscape with green mountains and clear rivers. Therefore, The Ziwuling area provides an experimental area to quantify effects of vegetation change on soil erosion process and ecological environment.

The field experiment was conducted at the Fuxian Ziwuling Soil Erosion and Eco-environmental Observatory, which was established in 1989 (Tang *et al*., 1993). This Observatory is located at the eastern slope of the Ziwuling secondary forest region. The annual temperature is 6 to 10ºC, precipitation ranged from 560 mm to 700 mm, in which 60% falls from June to September. The maximum precipitation in a month occupies 25% to 40% of the annual total, and the maximum daily rainfall is 87 mm. The canopy density of timber forest is more than 0.7, main tree species are Oak *(Quercus Liaotungensis koidz*), Poplar (*Populus davidiana Doze*) and *Birch (Betula platyphyua sukats*). The soil surface in the forestland is covered by a 2 cm to 5 cm deep litter layer. The soil had 6.7% sand, 72.1% silt and 21.2% clay. The soil had an obvious organic horizon, well aggregated with dense rooting system. However, leaching and alluvial horizons are not obvious.

2.2 Runoff plot establishment and data collection

A field survey was made to select a representative hill slope to establish runoff plots according to the typical topographical features. Total eight runoff plots were constructed, including one woodland plot, two deforested plots at a hill slope from watershed boundary to gully edges (plot area was 967 to 1,144 m^2), and one woodland plot, one deforested plot at an entire slope from watershed boundary to slope toe (plot area was 1,410 m^2 to 1,665 m^2), and one woodland plot, two deforested plots at gully slope from gully edges to slope toe (plot area was 244 m^2 to 406 m^2). The slope degree was from 5 to 32 degree at hill slopes, and from 37 to 42 degree at gully slope. Each plot was surrounded with concrete block borders for runoff plot isolation. A trough for runoff collection was installed in the down-slope of plot.

Storage containers of multi-slot divisor and collective container were used to collect runoff and sediment. After each runoff event, water level in each container was measured to calculate runoff volume, and four sediment samples were collected in 1-liter bottle from each storage container. The volumes of these sediment samples were measured. After sediment samples were set overnight, the excess water was poured from bottles. Then, the sediment samples were placed in oven at 105°C until the sediment was dried. Dry weight was then taken to calculate the sediment concentration and erosion rate.

3 Results and discussions

3.1 Soil erosion characteristics before the secondary vegetation restoration

According to field investigation and aero photo interpretation, soil erosion was very severe before the secondary vegetation restoration, i.e., about 130 years ago. Soil erosion scenario was similar to present soil erosion conditions at the surrounding regions of Yanan-Ansai-Zhidan zone. Soil erosion intensity was 8,000 t/(km^2 • yr) to 10,000 t/(km^2 • yr). The area of deforested lands took up above 50 % of total area of the hill slopes. Rill erosion, especially ephemeral gully erosion were well developed. Ephemeral gully density was 20 to 50 km/km^2, which is similar to the surrounding region, such as Ansai and Bayushan regions (Table 1). Meanwhile, the Ziwuling area is located in active regions of tectonic movement, gravitative erosion, such as landslide, land collapsing on gully slopes was active. For examples, landslide density was 5.3 landslides per square kilometer. This indicated that before the secondary vegetation was grown, ecological environment in the Ziwuling area was similar to the surrounding regions of Yanan-Aisai-Zhidan zone at present, i.e., soil erosion was severe, and ecological environment was worsened.

Table 1 Ephemeral gully distribution density in different regions

Regions	Distributed density, %					
	< 20	20—30	30—40	40—50	≥50	20—40
Ansai	19	41	30	6.6	3.4	71.0
Baiyushan	9	31.8	40.9	13.6	4.7	72.7
Ziwuling	4.2	23.9	45.1	21.2	3.6	69.0

3.2 Soil erosion features after the secondary vegetation restoration

More than 130 years ago, population in the Ziwuling region moved out to other places due to nationality dispute, the secondary vegetation has gradually evolved, forming to today’s landscape with green mountains and clear rivers. According to field investigation, the secondary vegetation firstly grew at depression locations where soil moisture condition was better than other topographic locations. On the hill slopes, vegetation grew earlier in ephemeral gully channels than at hill slopes. Similarly, vegetation grew earlier in gully bottom or valley bottom than on gully slopes or valley slopes. After the secondary vegetation was growing at the depression locations, soil erosion at these locations was reduced by vegetation. Meanwhile, eroded sediment from hill slopes and gully slopes or valley slopes was captured at the depression locations by growing vegetation, which caused eroded sediment was deposited in ephemeral gully channels on hill slopes and gully bottoms on gully slopes. Figure 1 showed that the depth of sediment deposition at ephemeral gully channels on hill slopes reached 60cm to 70cm during the secondary vegetation restoration, and the depth of sediment deposition in gully bottom or valley bottom was more than 100 cm. In addition, sediment deposition in ephemeral gully or gully bottom caused that slope surface tended to be leveled, which resulted in reduction of sheet erosion and rill erosion, and sediment transport rate from hill slopes to ephemeral gully channels or from gully slopes to gully bottoms.

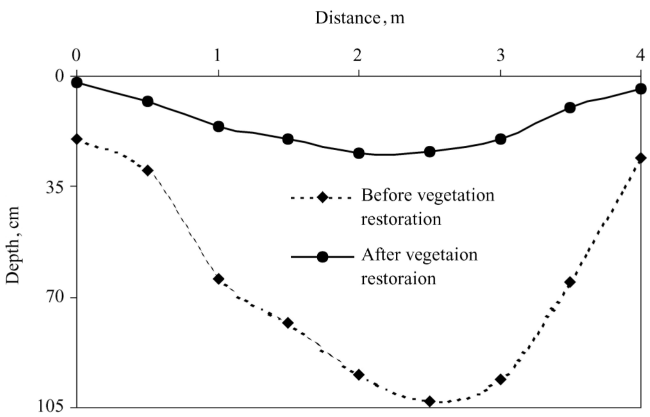

Fig. 1 The crossed sections of an ephemeral gully channel before and after the secondary vegetation restoration (the space between two crossed sections represented sediment deposition)

Moreover, vegetation growth stabilized gully slopes and valley slopes, which caused a decrease of gravitative erosion. Field investigation demonstrated that vegetation grown on old landslides was similar to that the surrounding places, and new landslide occurred rarely. These results showed that during the secondary vegetation restoration of the Ziwuling region, soil erosion changed from accelerated erosion under human activities to natural erosion process under natural ecological balance. Therefore, in the most of places on the Loess Plateau, where original vegetation was completely destroyed by human activities, implementing natural vegetation restoration could be the best strategy for reducing soil loss, and improving eco-environmental condition.

The data from field runoff plots (Table 2 and Table 3) showed that under current vegetation cover, soil loss from woodland was very slight (Figure 2), and effects of rainfall and slope degree, and slope length on soil erosion were not obvious. This indicated that in the Ziwuling region, vegetation effect on soil erosion occupies a predominant position.

Table 2 Annual soil loss rates from woodland and cropland

Plot locations	Land use	Slope length, m	Slope, degree (°)	Soil loss t/(km^2 • yr)
Hill slope	Woodland	80	5—32	13.0
	Cropland	99	5—32	10,448
	Cropland	86	5—32	10,371
Gully slope	Woodland	38	37—42	14.4
	Cropland	49	37—42	24,222
	Cropland	41	37—41	20,192
Hill + gully slope	Woodland	122	5—42	10.0
	Cropland	124	5—42	15,969

Table 3 Soil loss rates from woodland and cropland on gully slope under different rainfall events

Land use	Precipitation (mm)	I_{30} (mm/min)	PI_{30} (mm^2/min)	Soil loss (t/km^2)
Woodland	22.3	0.48	10.7	3.6
	40.8	0.52	21.2	4.2
	15.1	0.38	5.7	2.5
	38.3	0.73	28.0	1.2
Cropland	38.3	0.73	28.0	4,080
	40.8	0.52	21.2	3,602
	13.2	0.21	2.8	147
	64.2	0.23	14.8	105

3.3 Accelerated erosion process after conversion of the secondary forestland to cropland

Once the secondary forestland of the Ziwuling region was converted to cropland, soil erosion greatly increased. Soil loss rates from a newly deforested land were 10,371 t/(km^2 • yr) to 24,222 t/(km^2 • yr), which was 787 and 1682 times greater than from woodland (Table 2). This result indicated in the most of regions of the Loess Plateau, where original vegetation was destroyed by human activities, man-made accelerated erosion occupies the predominant position.

After conversion of woodland to cropland, rill erosion and ephemeral gully erosion was dominated at hill slopes (Figure 3). Rill erosion was 3,400 t/(km^2 •yr) ton 6,700 t/(km^2 •yr), occupying above 30% of the total soil loss, ephemeral gully erosion was 7,200 t/(km^2 • yr) to 12,600 t/(km^2 • yr), taking up above

52% of the total soil loss. On the gully slopes, gully erosion, such as gully head-cuts, gully channel deep cutting, and gully sidewall collapsing was dominated. Meanwhile, after woodland was converted to cropland, rainfall and topography significantly affected accelerated erosion (Table 3).

Fig. 2 Natural erosion under current vegetation cover

Fig. 3 Accelerated soil erosion (rill and ephemeral gully erosion) on a hill slope after the secondary vegetation destruction

4 Conclusions

From field investigating soil erosion process before and after the secondary vegetation restoration of the Loess Plateau, China, and monitoring accelerated erosion process in a newly deforested lands in the Ziwuling region of the Loess Plateau, this paper quantitatively evaluated the effects of vegetation restoration and deforestation on soil erosion process, the following conclusions were derived:

Before the secondary vegetation restoration, i.e., about 130 years ago, soil erosion in the Ziwuling region was similar to the surrounding region of Yanan-Ansai-Zhidan zone. Soil loss rate reached 8,000 t/(km^2 • yr) to 10,000 t/(km^2 • yr). Rill erosion and ephemeral gully erosion was dominated at hill slopes, and gravitative erosion and valley erosion were dominated on gully slopes or valley slopes.

During the past about 130 years of the secondary forest restoration, vegetation firstly grew in the depression locations of ephemeral gully channels and gully bottoms or valley bottoms where soil moisture condition was better that other topographic locations, then vegetation grew later on hill slopes, gully slopes or valley slopes. As natural vegetation was evolved, ephemeral gully erosion at hillslopes and gully erosion at gully slopes or valley ceased, and sediment deposition occurred in ephemeral gully and gully channels. Soil erosion was changed from man-made accelerated erosion to natural erosion. Soil erosion rate under current vegetation cover was very slight, impacts of rainfall and topographical condition on soil erosion were not well obvious, and vegetation effect on soil erosion was predominated. Meanwhile gravitative erosion and valley erosion were also controlled by vegetation.

Once the secondary forest of the Ziwuling region was destroyed, man-made accelerated erosion greatly increased. Soil loss rates from a newly deforested land were 10,371 t/(km^2 • yr) to 24,222 t/(km^2 • yr), which was 787 and 1,682 times greater than from woodland. Rill erosion and ephemeral gully erosion was dominated at hill slopes and gully erosion was dominated on the gully slopes. Meanwhile, rainfall and topography obviously affected on soil erosion.

These results indicated that in the most of places on the Loess Plateau, where original vegetation was completely destroyed by human activities, implementing natural vegetation restoration could be the best strategy for eco-environmental rehabilitation.

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