Research Article

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Effects of vegetation cover of natural grassland on runoff and sediment yield in loess hilly region of China

Xining Zhao,[a,b,c,d] Xiaoli Chen,[a,c] Jun Huang,[a,c] Pute Wu[a,b,c*] and Matthew J Helmers[d]

Abstract

BACKGROUND: The effects of vegetation cover (VC) on runoff and sediment yield were investigated from rainfall simulation experiments in the Loess Plateau of China. Five VCs from 0% to 80% and three different rainfall intensities ($I_{2.0,\ 1.5,\ 0.75}$) were implemented.

RESULTS: The results indicated that runoff and sediment yields in slopes were significantly affected by I and VC, and when the VC amounted to 40% there occurred obvious benefits of runoff and sediment reductions and then amplitude decreased with the increase of VC. The runoff reduction benefits at $I_{1.5}$ and $I_{0.75}$ were much greater than that at $I_{2.0}$, while the sediment reduction benefits had no significant difference among different rainfall intensities. At $I_{2.0}$, the natural grassland slopes with high VC exhibited the characteristics of high runoff but low sediment production. There existed a power function relationship between cumulative runoff and sediment yield. The increase in cumulative sediment yield was less than the increase in cumulative runoff with increasing VC, and the sediment reduction benefit was greater than runoff reduction on natural grassland slopes.

CONCLUSION: The ratio of runoff reduction to sediment reduction can be used as a comprehensive index for assessing the benefits of runoff and sediment reduction in natural grassland.

Keywords: rainfall intensity; natural grassland; vegetation cover; runoff and sediment yield; loess hilly region of China

INTRODUCTION

Soil erosion is a serious problem in semi-arid catchments,[1,2] resulting in on-site productivity losses, ecological degradation, a poverty trap for local inhabitants and severe downstream environmental problems.[3−6] In addition to key soil and rainfall properties (especially rainfall intensity), vegetation cover and land management are particularly important for controlling runoff generation in semi-arid catchments by directly determining the hydraulic roughness of the surfaces where overland flow occurs.[7−10] The long-term, policy-driven 'Grain for Green' project was initiated in 1999 in China to promote vegetation restoration of barren or low-yielding farmland in this region. Since then, the vigorous development of grassland construction serves as an important link for the realization of comprehensive land utilization in loess hilly regions.[11]

Previous studies have indicated that vegetative cover is one of the most important factors controlling soil loss.[12,13] The potential of grassland for reducing runoff and sediment generation had been proved in loess hilly regions. Sediment in runoff from grassed slopes decreased rapidly as the vegetative cover area density increased from 0% to 60%.[14] In laboratory studies, increasing the vegetation cover for a given slope significantly reduced sediment concentration in runoff, sediment yield, runoff volume and flow velocity.[15] Gan *et al.* found that both ryegrass (*Lolium perenne* L.) and sainfoin (*Onobrychis viciaefolia* Scop.) could control soil erosion under simulated rainfall. Runoff decreased by 65% and 45% for ryegrass and sainfoin, respectively. Sediment yield was reduced by over 93% for both cover species.[14] Diminished vegetation cover may lead to the formation of soil crusts that increase the risk of soil and water loss.[16] Snyman and duPreez observed that rangeland degradation usually led to increased surface water runoff and soil compaction due to decreased vegetation cover.[17] Merzer reported that bare plots produced significantly more runoff than did a variety of vegetated plots.[18]

The artificial vegetation in the loess hilly regions has been greatly improved after implementation of the 'Grain for Green' project. However, many places experienced the occurrence of 'old

* Correspondence to: Pute Wu, Institute of Soil and Water conservation, Northwest A&F University, Yangling, Shaanxi 712100, China. E-mail: gizwpt@vip.sina.com

a Institute of Soil and Water conservation, Northwest A&F University, Yangling, Shaanxi 712100, China

b Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling 712100, Shaanxi, China

c Institute of Water Saving Agriculture in Arid Regions of China, Northwest A&F University, Shaanxi 712100, China

d Department of Agricultural and Biosystems Engineering, Iowa State University, IA 50011, USA

man trees', which witnessed no growth all year round. This is primarily caused by over-consumption of deep-layer soil water storage in their initial growth years, thus leading to severe soil 'dry layers' and resulting in vegetation degeneration or death due to water limitations. The depth of the active layers of loess soil water is mostly around 2 m and, once consumed, soil water in the layers below 2 m depth will be replenished for a long period.[19] Because of their highly developed root systems and high water consumption, artificial grasses and woody plants with high biomass can only consume deep-layer soil water though root systems if shallow-layer soil water cannot meet the demand of their growth. When soil water within the depths of root system distribution is over-consumed, soil dry layers will form, which will inevitably lead to the death of these plants. The extensive watershed-scale revegetation of the degraded, barren hillslopes in the Loess Plateau has produced a mosaic landscape with original natural vegetation, introduced grasses and plantation species that now account for 45.6% of the total semi-arid area.[20] Therefore, there is a great need to further investigate the process of runoff and sediment generation on natural grassland slopes. Natural grass vegetation distributes typically on hilly tops and steep slopes (>20°) and is subject to relatively fewer anthropogenic influences.

Many simulated rainfall experiments in China's Loess Plateau were conducted indoors or in outside artificial grass vegetation and the disturbed soil was chosen as the object of study. There is little knowledge concerning natural grassland. However, natural vegetation is widely distributed in the loess hilly region, but how vegetation cover and rainfall intensity influence runoff and sediment in natural grassland slopes is not clear. This study is part of a previous broader research effort. Its objective was to investigate the impact of vegetation cover of natural grassland on runoff and sediment yield on a loess hilly region of China under rainfall simulation. In China, economic development and environmental integrity are equally important in such under-developed regions. The investigation on runoff and sediment yield of grassland will provide scientific grounds and references for the implementation of 'Grain for Green' project in loess hilly regions of China.

MATERIALS AND METHODS

Study site description

This study was conducted in 2008 at the Mizhi experimental station of Northwest A&F University (37° 75′ N, 110°18′ E), located in Mengcha Village of northern Shaanxi, which is a typical semi-arid hilly region of the Loess Plateau. The climate is characterized by warm, humid summers and cold, dry winters. The mean annual values for frost-free period is 165 days, bright sunshine duration is 2716 h, air temperature is 8.9 °C and precipitation is 420 mm, with more than 70% received from June to September. The grand mean (taken over all years of record) for the annual algebraic sum of the accumulated differences between mean daily air temperature and 10 °C was 3470 °C. Local soil develops from wind-accumulated loess parent material, which is about 40–60 m in depth. The dominant soil in the region is Late Pleistocene loess or Malan loess, covered by a thick loess mantle with an average depth of more than 100 m. It is silty in texture and weakly resistant to erosion, with a dry bulk density averaging 1.35 g cm^{-3} over the 0–80 cm depth interval. The percentage by weight of particles in size ranges ≥0.02 mm, 0.02–0.002 mm and <0.002 mm were 86%, 7% and 6% respectively (Table 1).

The vegetation is forest–steppe zones which are transitions from warm temperate deciduous broad-leaved forests to dry grasslands. The original forest–steppe vegetation has been completely replaced. The natural secondary vegetation grows primarily on hilly tops and steep slopes, mainly covered by stipa grass species (*Stipa capillata* L.), along with wormwood (*Artemisia* L.) and wild chrysanthemum (*Chrysanthemum indicum* L.). Tree plantations established under the 'Green for Grain' revegetation were mainly Chinese date (*Zizyphus jujube* M.) and apricot (*Prunus armeniaca* L.). The region's main crops are foxtail millet (*Setaria italica* L.), maize (*Zea mays* L.), potato (*Solanum tuberosum* L.) and water melon (*Citrullus vulgaris* S.).[21]

Table 1. Some physical properties of soil of the experimental plots

Soil depth (cm)	Soil texture (%) Sand	Silt	Clay	Soil bulk density (g cm^{-3})
0–20	85.6	8.5	5.9	1.29
20–40	88.5	5.6	5.9	1.35
40–60	88.8	5.6	5.6	1.38
60–80	86.1	8.1	5.8	1.37
Mean	87.25	6.95	5.8	1.35

Experimental design and treatments

To estimate vegetation cover prior to rainfall simulation, vegetation images were obtained using a digital camera in a perpendicular direction to natural grassland slopes. Vegetation cover was estimated from the images through the classification function in ERDAS Imagine 8.4 (ERDAS Co., USA). Five different levels of vegetation cover (VC) were selected: 0%, 20%, 40%, 60% and 80%. There were 10 experimental plots with two plots for each VC. Plots used for natural grassland and bare slopes were 2.0 m × 1.5 m. In each plot, 2 mm thick steel plates projecting 30 cm above ground level were installed along the perimeter to form a runoff plot.

The portable rainfall simulator used in this study was described by Niu *et al.* and Huang *et al.* mainly consisted of (i) a watering device, and (ii) a rainfall generator (a water tank creating a special hydrostatic pressure and a needle plate with around 1300 needles producing raindrops). The watering device, a kind of Mariotte flask, can provide a constant water level in the water tank to guarantee high rainfall uniformity. The mean coefficient of uniformity was over 80% over several tests.[22,23] The rainfall simulation area was 2.0 m (length) × 1.5 m (width) and the raindrops fell from more than 2 m above this area. A variable-speed drive motor and camshaft were used to oscillate the drop-forming plate at a frequency required to produce a uniform distribution of raindrops across the plot. Adjustable supporting legs, 1.5 m in height, were used to maintain the drop-forming plate horizontal on various land slopes (Fig. 1).

Simulated rainfall was applied for 120 min to bare hillslopes or with natural grassland cover at three rainfall intensities (0.75, 1.5 and 2.0 mm min^{-1}) in a 2 × 3 factorial experiment with three replications. According to the rainfall characteristics of the research areas, three rainfall intensities were chosen in the experiment. At the beginning of rainfall, rainfall intensity was calibrated and the coefficients of evenness degrees were calculated. If such coefficients were greater than 80%, the experiments were initiated. Simulated rainfall experiments were conducted in every plot from lower to higher degrees of rainfall intensity (I) with 9 days between each simulation. The soil water content was measured before

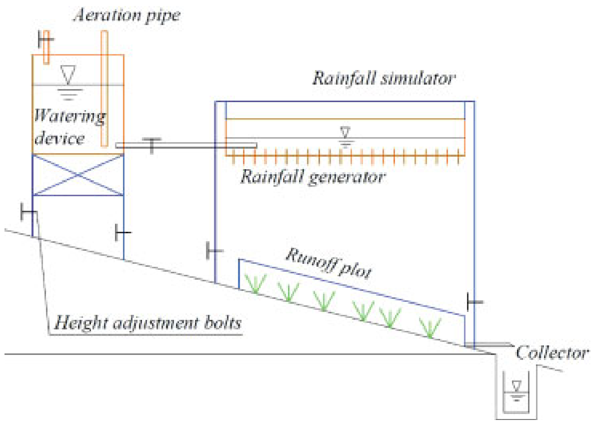

Figure 1. Schematic diagram showing rainfall simulator and runoff and soil erosion collection system.

rainfall and then each plot was watered with a watering can to maintain uniform soil moisture. The measured actual vegetation cover from 0% to 80% and rainfall intensity are shown in Table 2.

Measurements and data analyses

Surface runoff was appropriately routed to an outlet and the runoff amount and rate were measured using a tipping bucket rain gauge every 5 min. These data were used to determine the amount and rate of soil loss and overland flow. Soil moisture was measured gravimetrically on auger samples and bulk density on core samples taken in the vicinity of the experimental area before each experimental run in 10 cm intervals from 0 to 80 cm. In order to further investigate the regulatory effects of natural grassland slopes with different degrees of vegetation cover on runoff and sediment production, the ratio of runoff reduction to sediment reduction (E') was introduced. The 0% vegetation cover (i.e. bare land slopes) was used as a controlled group. The runoff and sediment reduction efficiency under various VC were determined using the following equations:

$$E_v = (V_0 - V_i)\,/V_0 \times 100\% \quad (1)$$

$$E_s = (S_0 - S_i)\,/S_0 \times 100\% \quad (2)$$

$$E' = (V_0 - V_i)\,/\,(S_0 - S_i) \quad (3)$$

where E_v (%) is the runoff reduction efficiency, E_s (%) is the sediment reduction efficiency, E' is the ratio of runoff–sediment reduction; V_i (mL) is the runoff volume for a plot with vegetation cover i (20%, 40%, 60% and 80%), V_0 (mL) is the runoff volume for the bare slope without vegetation cover, S_i (g) is the sediment yield for a plot with vegetation cover i (20%, 40%, 60% and 80%) and S_0 (g) is the sediment yield for the bare slope without vegetation cover.

Main and subtreatment effects were determined using the Proc GLM procedure in the SAS v9.1 package (SAS Institute, Cary, NC, USA). Vegetation cover from 0% to 80% and rainfall intensity treatment means were separated using the 5% (LSD0.05) and 1% (LSD0.01) least significant differences calculated using the error mean square values obtained from analyses of variance.

RESULTS AND DISCUSSION

Runoff

With the same rainfall intensity, runoff rate was negatively correlated with the percentage of vegetation cover (Fig. 2). As

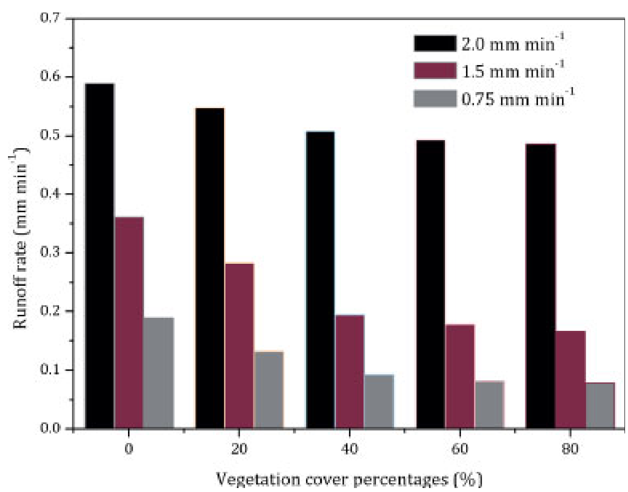

Figure 2. Average runoff rate in natural grassland slopes under different rainfall intensities and vegetation cover percentages.

Table 2. Measured and mean values of slope gradient and rainfall intensity (mm min^{-1}) in different vegetation cover under simulated rainfall

					RIR (mm min^{-1})			MRIR (mm min^{-1})		
CG	MSG (°)	VC (%)	MVC (%)	VCG (%)	$I_{0.75}$	$I_{1.50}$	$I_{2.00}$	$I_{0.75}$	$I_{1.50}$	$I_{2.00}$
1	21.20	0	0	0	0.74	1.45	2.15	0.73	1.44	2.19
	21.60	0			0.72	1.43	2.23			
2	21.10	19.60	19.05	20	0.68	1.44	2.14	0.70	1.42	2.17
	21.40	18.50			0.72	1.40	2.20			
3	20.80	41.70	41.15	40	0.70	1.45	2.17	0.71	1.46	2.15
	21.00	40.60			0.72	1.47	2.13			
4	21.40	61.30	62.30	60	0.72	1.52	2.09	0.71	1.49	2.12
	21.20	63.30			0.70	1.46	2.15			
5	22.10	83.20	82.40	80	0.72	1.53	2.18	0.73	1.51	2.13
	21.80	81.60			0.74	1.49	2.08			

CG, coverage grade; MSG, measured slope gradient; VC, vegetation cove; MVC, mean vegetation cove; VCG, vegetation cove grade; RIR, rainfall intensity rank; MRIR, mean rainfall intensity rank.

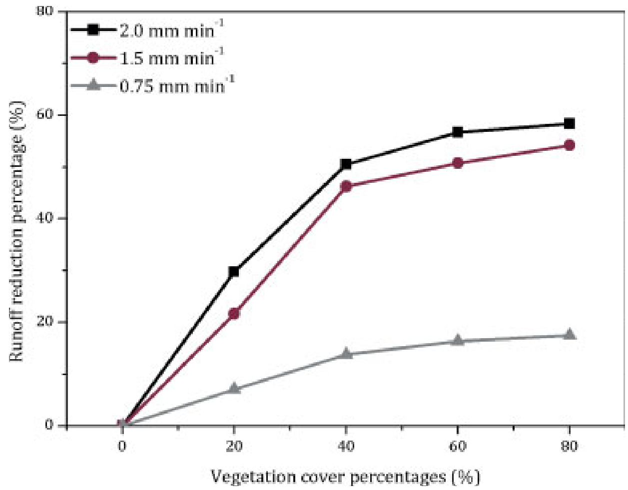

Figure 3. Runoff reduction benefits in natural grassland slopes under different rainfall intensities and vegetation cover percentages.

vegetation cover from 0% to 80%, increased runoff amount at $I_{2.00}$ decreased by 7.1%, 13.8%, 16.3% and 17.5%, respectively; runoff amount at $I_{1.50}$ decreased by 21.6%, 46.2%, 50.7% and 54.2%, respectively; and runoff amount at $I_{0.75}$ decreased by 29.7%, 50.5%, 56.7% and 58.4%, respectively. The reduction of runoff amount by increasing vegetation cover at 2.0 mm min^{-1} rainfall intensity was less evident compared to the two lower rainfall intensities (1.50 and 0.75 mm min^{-1}), indicating that high runoff was produced from natural grassland slopes at high rainfall intensity (2.0 mm min^{-1}) regardless of the level of vegetation cover. During high-intensity events, infiltration excess runoff is produced due to the lower infiltration rate compared to the rainfall intensity. As a result, much rainfall is lost in the form of runoff on hilly slopes and the benefit of vegetation in runoff reduction is less evident, as shown at lower rainfall intensities. Runoff reduction benefit greatly increased with the increase of vegetation cover and tended to be stable when vegetation cover was greater than 40% (Fig. 3). Runoff amount from various degrees of vegetation cover can be classified into three groups: 0%, 20% and 40–80%; there was a significant difference among these groups at the level of $P = 0.05$, indicating that there existed a critical value of vegetation cover. Runoff would be greatly increased if vegetation cover was below this critical value of 40%.

As expected, runoff rate exhibited a rapid increase at the initial stage of runoff generation and tended to become stable when it reached the runoff peak under various vegetation cover and rainfall intensities (Fig. 4). With the increase of vegetation cover, the delay of the first detected runoff response increased. This could be due to the interception of vegetation canopy and improved infiltration rate from higher vegetation cover. The impact of vegetation cover on runoff generation was less evident at $I_{2.00}$, as shown at lower intensities (1.50 and 0.75 mm min^{-1}). The relationship between slope runoff intensity and rainfall time at different degrees of vegetation cover can be well fitted by the following equation at $P = 0.05$: $V_d = e\ln(t) - f$ (where e and f are fitting parameters, t is rainfall time) and all correlation coefficients of the fitting equations were above 80%.

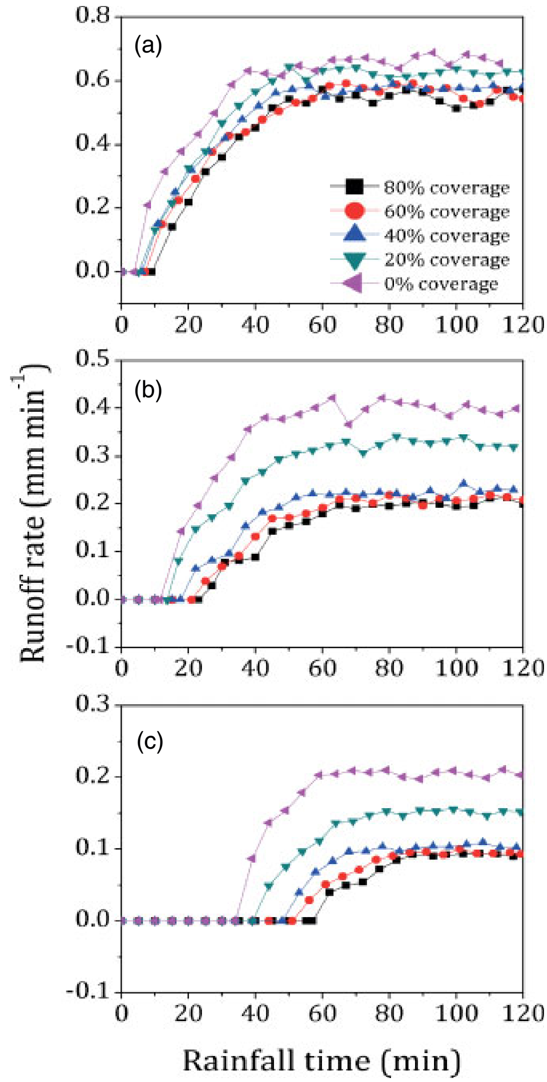

Figure 4. Dynamic changes of runoff rate in natural grassland slope with different vegetation cover percentages at three rainfall intensities: (A) 2.0 mm min^{-1} rainfall intensity; (B) 1.5 mm min^{-1} rainfall intensity; (C) 0.75 mm min^{-1} rainfall intensity.

Sediment

Similar to runoff, sediment yield was negatively correlated with vegetation cover under the same rainfall intensity (Fig. 5). When vegetation cover from 0% to 80% increased, sediment yield at $I_{2.00}$ decreased by 39.0%, 74.0%, 86.8% and 89.4%, respectively; at $I_{1.50}$ it decreased by 44.1%, 73.2%, 82.8 and 86.2%, respectively; at $I_{0.75}$ it decreased by 52.8%, 79.1%, 87.4% and 88.6%, respectively. Although the amplitudes for the decrease of average runoff intensity were smaller at $I_{0.75}$ and $I_{1.50}$ than at $I_{2.00}$, the amplitudes for the decrease of average sediment yield intensity remained generally constant for all rainfall intensities. At high rainfall intensity (2.00 mm min^{-1}), natural grassland slopes at different levels of vegetation cover exhibited characteristics of high runoff but low sediment production during heavy rainfall events.

Sediment reduction benefits were evident at different levels of vegetation cover and rainfall intensity, and such benefits increased with the increase of vegetation cover (Fig. 6). However, when the vegetation cover amounted to over 40%, the amplitudes for sediment reduction benefits became smaller and gradually approached stable. Sediment reduction benefits at $I_{2.00}$ were more significant than runoff reduction benefits, which showed characteristics of high runoff and low sediment production under

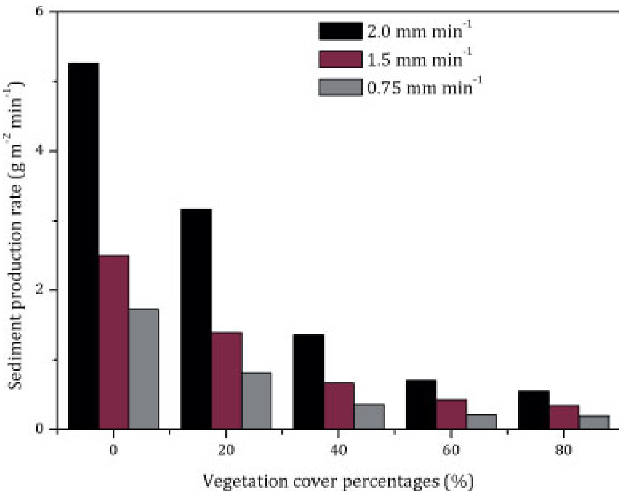

Figure 5. Sediment yield intensity in natural grassland slopes under different rainfall intensities and vegetation cover percentages.

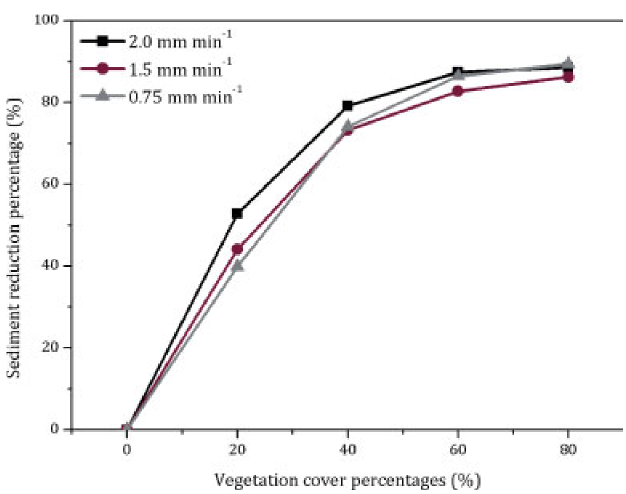

Figure 6. Sediment reduction benefits in natural grassland slopes under different rainfall intensities and vegetation cover percentages.

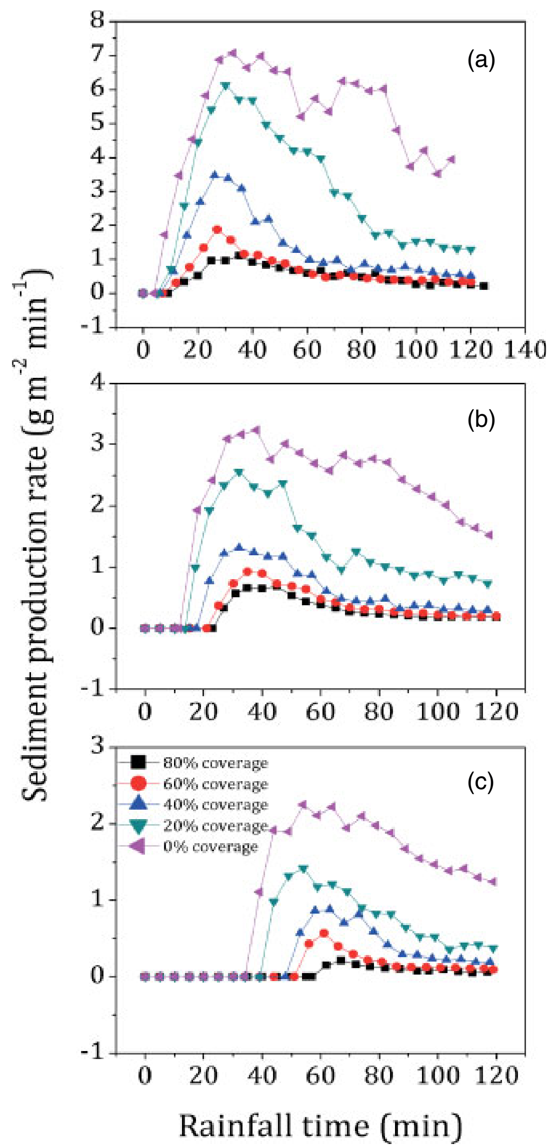

Figure 7. Dynamic changes of sediment yield intensity in natural grassland slope with different vegetation cover percentages at three rainfall intensities: (A) 2.0 mm min^{-1} rainfall intensity; (B) 1.5 mm min^{-1} rainfall intensity; (C) 0.75 mm min^{-1} rainfall intensity.

heavy precipitation. Similar to runoff, the effects of vegetation cover on sediment yield can also be classified into three groups: 0%, 20% and 40–80%. There was no significant difference within these groups, while significant differences were noted among these groups at $P = 0.05$. Results suggest that even a small amount of vegetation cover (20%) could effectively reduce soil loss from slopes. When vegetation cover reached 40%, sediment reduction effects approached stability and further increase in vegetation cover did not lead to significantly greater sediment reduction. This is consistent with the findings of Yu *et al.*,[24] who also concluded that 40% vegetation cover is effective in soil and water conservation. Other research suggested that the regulatory effects of vegetation on runoff and sediment production tended to become stable when vegetation cover amounted to 60–80%.[15] As a result, 60% vegetation cover was claimed as the effective value for preventing water and soil loss. Based on a research study of the middle reaches of the Yellow River, it was found that further increase in vegetation cover did not have obvious impacts on soil and water conservation in the study area.[25] The discrepancy of the reported critical values of vegetation cover from different studies might be due to the differences in scale, region and subjects selected in their research. However, all these research results demonstrated that there occurred a critical value of vegetation cover during the process of vegetation restoration in loess hilly regions.[19]

Sediment production on natural grassland slopes exhibited a two-stage pattern 'from dramatic rise to gradual drop' (Fig. 7). The drop rate of sediment intensity was higher for higher vegetation cover. At the initial stage of runoff generation, sediment yields increased rapidly, primarily consisting of loose soil particles which can easily be transported, eroded and carried by slope runoff. Increase of vegetation cover can decrease loose soil particles and/or intercept the suspended sediment in runoff. The benefit of vegetation cover in runoff reduction could also limit the flushing effect of runoff water. At the middle and late stages of runoff generation, interrill erosion occurred, creating relatively large amounts of sediment and resulting in relatively large fluctuations in slope sediment yield intensity. In addition, different degrees of undulation occurred in the processes of sediment yield at slopes with relatively low vegetation cover, because of the existing spatial differences among microtopographies and the regulation and redistribution effects of slope-formed rills on runoffs after rainfall events. With the increase of vegetation cover, the interception, storage and infiltration accruement effects of grassland slopes on rainfall began to become salient, and the underground parts of root systems became consolidated with soil and promoted the amelioration of soil structures, resulting in increasingly reduced amounts of surface soil particles carried by rushing runoffs and the rapidly decreased intensities of sediment yield. Therefore, the initial stage of runoff yield contributed most to sediment yield, and the sediment reduction effects were mainly embodied in the middle and later stages of runoff generation.

Relationship between runoff and sediment

The relationship between cumulative sediment yield and cumulative runoff at different rainfall intensities and vegetation cover can be fitted by a power function equation as $S = aV^b$, where S refers to cumulative sediment yield, V represents cumulative runoff, and a and b are fitting parameters) (Fig. 8). The correlation coefficients of the fitted equation were greater than 90% and significant at $P = 0.05$. The cumulative sediment yield increased with gradual accruements of cumulative runoff. However, as vegetation cover increased, the increase of cumulative sediment yield was slower than the increase of cumulative runoff amount, indicating that the sediment reduction benefit of natural grassland was greater than its runoff reduction benefit. Many previous studies indicated that slope runoff and sediment yield vary according to plot scale.[26] The scale in this experiment was 2.0 m × 1.5 m; the existing runoff and sediment processes and models such as USLE and WEEP were used for the relatively large-scale slope. Most models, using a small-scale slope, contained mainly two types: (i) empirical statistical models, such as our results; and (ii) a mathematical physical model based on Saint-Venant equations. There must be difference between various scales in studying slope runoff and sediment generation, and it needs further in-depth study.

The regulatory effects of natural grasslands on runoff and sediment can be realized through both the above-ground and underground parts of grasslands. The above-ground parts mainly function as intercepting rainfall, lowering net rainfall in surfaces and reducing the kinetic energy of raindrops. The underground parts mainly function to consolidate soil by root systems and improve soil structutre.[21] Higher values of E' signify that, compared with bare land, natural grassland requires a higher amount of runoff reduction to achieve a unit sediment reduction (Fig. 9). Results showed that values of E' were much higher at $I_{0.75-1.50}$ than at $I_{2.00}$, indicating that per unit runoff reduction needed for the reduction of per unit sediment on slopes was smaller at high rainfall intensities, thus further demonstrating natural grasslands' characteristics of high runoff and low sediment production under heavy rainfall events. The values of E' were less sensitive to vegetation cover, especially when VC > 40%.

In semi-arid loess hilly regions, rainfall from June to September accounts for 60–80% of the annual rainfall and are mostly frequent heavy rains of high intensity and short duration. Water and soil loss along the slope in these regions is mainly caused by slope runoff washings during heavy rains.[27] From this study, runoff reduction benefits at $I_{2.00}$ were not obvious at different levels of vegetation cover when compared with those at $I_{0.75-1.50}$. In contrast, sediment reduction benefits were markedly increased with the increase of vegetation cover, exhibiting the characteristics

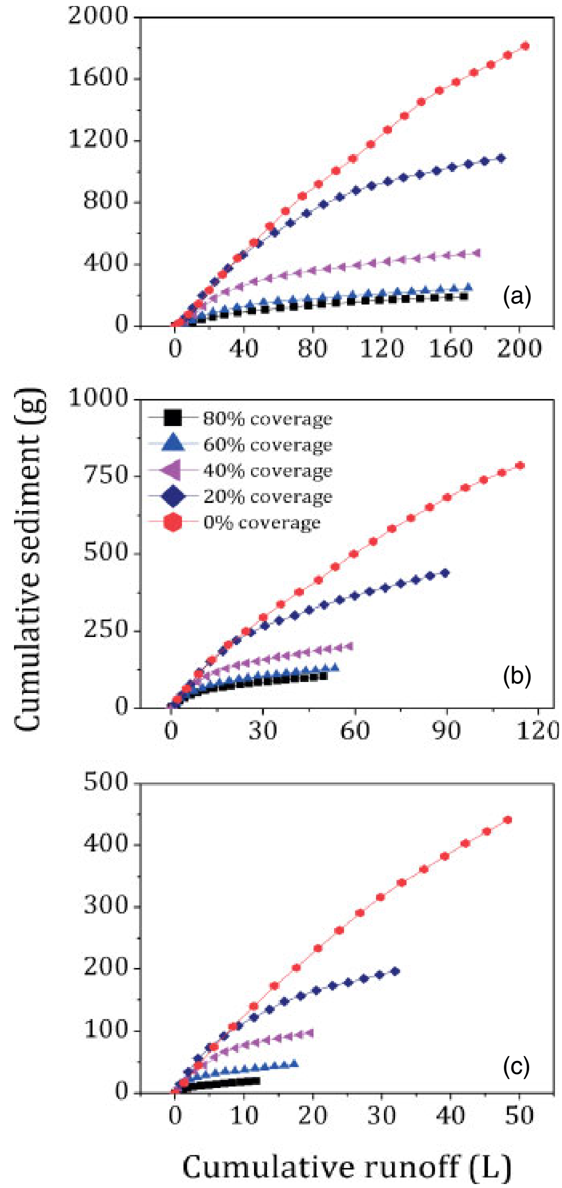

Figure 8. Relationship between cumulative runoff and sediment yield in natural grassland slope under different vegetation cover percentages at three rainfall intensities: (A) 2.0 mm min^{-1} rainfall intensity; (B) 1.5 mm min^{-1} rainfall intensity; (C) 0.75 mm min^{-1} rainfall intensity.

of high runoff amount but low sediment yield under heavy rainfall. The coexistence of drought-caused water shortage and severe soil/water loss has been a main cause of ecological and environmental vunerability in the semi-arid loess hilly region in China, and also a bottleneck factor for social and economic development in this region. With the characteristics of high runoff but low sediment production during heavy rainfall events, the widespread natural secondary grassland on steep slopes could provide effective approaches for runoff collection on slopes. In addition, it has the potential for simulatenously controlling soil erosion and alleviating drought-caused water shortage. However, the widely distributed natural grassland vegetation can adapt to natural environments in local areas and form the most stabilized vegetation communities, thus having a significant function in regulating slope rainfall runoff and controlling water and soil loss. Therefore, while artificial forest and grass vegetation are important

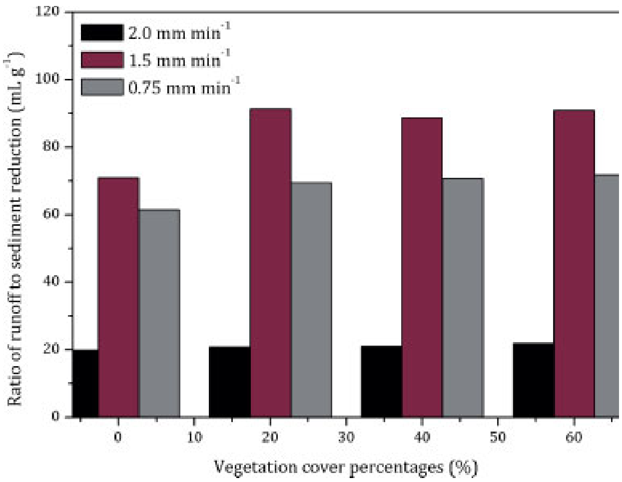

Figure 9. Ratio of sediment and runoff reduction in natural grassland slopes under different rainfall intensities and vegetation cover percentages.

for re-establishing ecological systems in loess hilly regions, the functions and benefits that natural grassland vegetation can provide by enhancing water resource unitlization and soil erosion control should receive more attention and need further research.

CONCLUSION

Vegetation cover and rainfall intensity exert significant effects on slope runoffs. With the same vegetation cover, runoff rate on slopes increases as rainfall intensity increases, while runoff reduction benefits decrease. The runoff reduction benefit of natural grassland is greater at lower rainfall intensity (1.5 and 0.75 mm min^{-1}) than at high rainfall intensity (2.0 mm min^{-1}). At a rainfall intensity of 2.0 mm min^{-1}, natural grasslands at various vegetation cover exhibit the characteristics of high runoff production during high rainfall events. The benefit of increasing vegetation cover in runoff and sediment reduction was more evident when vegetation cover was between 30% and 40%. Further increase of vegetation cover (>40%) only slightly increased runoff reduction benefit. Runoff rate had a logarithmic function relationship over time of runoff genetation under different levels of vegetation cover. The ratio of runoff reduction to sediment reduction could be applied as an evaluation index for assessing runoff and sediment reduction in natural grasslands. In this study, it is suggested that 40% represents the critical value for regulating runoff and sediment in natural grassland.

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