# Effects of Up-Slope Runoff and Sediment on Down-Slope Erosion Process

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**Abstract**: Soil erosion at hilly-gully region of the Loess Plateau has obviously erosion vertical zones from watershed boundary to gully edge, i.e., sheet zone dominated, rill zone dominated, and shallow gully zone dominated. To quantify effects of up-slope runoff and sediment on down-slope detachment, deposition and transport processes as well as mechanisms can provide importantly scientific bases for establishing erosion prediction model. Because of this, A dual-box system (one is test box and the other is feeder box) is used to quantify impacts of up-lope runoff and sediment on detachment, deposition and transport processes at down-slope sheet and rill erosion dominated zone. The results showed the additional sediment delivery ( $S$ ) at down-slope caused by up-slope runoff increases with an increase of rainfall intensity or runoff from up-slope, and with a decrease of sediment concentration in up-slope runoff. In addition, rill erosion and soil bulk density have great effects on the additional sediment delivery ( $S$ ).

**Keywords**: run-on water and sediment, erosion-deposition-transport, a dual-box system, the additional sediment delivery

## 1 Introduction

During slope water erosion processes, soil detachment, transport, and deposition occur simultaneously. But with the limits of research methods, the problem of studying slope erosion – deposition-transportation hasn't been solved well. Runoff infiltration, sediment concentration, as well as water and sediment transport has obviously vertical zones from watershed boundary to gully edge in the loess plateau. Furthermore, up-slope runoff and sediment have significant impacts on down–slope detachment, deposition and transportation processes. In the past, research work about this lay emphasis on the sediment delivery of different zones, which provide scientific basis for the apportiate layouts of soil and water measures, but there are few experiment to study mechanisms of different erosion zone and their relation. Chen (1992; 1993) divided the loessial hillslopes of the Loess Plateau of China into upslope, midslope and downslope sections, and studied the effect of runoff from upper slopes on erosion and sediment transport processes on downslope section. Chen pointed out that an increase in runoff sediment concentration from upper slopes resulted in a decrease of erosion downslope. Zheng and her coworkers (Zheng, 1997; Zheng *et al.*, 1998) established different sizes of runoff plots based on the vertical distribution of sheet, rill and shallow gully erosion zones on a loessial hillslope. Their results showed that increased runoff from upslope areas resulted in increased erosion on downslope. So, A dual-box system (one is the test box and the other is feeder box) is used to quantify effects of up-slope runoff and sediment under different rainfall intensity, run-on sediment concentration and soil surfaces of different soil bulk density. Results of this study will further the understanding of soil erosion processes and provide data for the development of a more accurate process-based erosion model.

## 2 Materials and methods

### 2.1 Soil sample collection

The soil used in this study was clay loess collected from Yangling Town, Shaanxi province, China. The soil was sampled from a very deep soil layer (6 m deep) of farmland; this layer would be C-Horizon. Particle size distribution and median diameter of the tested soil is seen in Table 1. A sufficient amount of soil was transported back to the laboratory for the experiments.

**Table 1 Particle size distribution and median diameter of the tested soil**

| Particle size(mm) | 0.25—0.05 | 0.05—0.01 | 0.01—0.005 | 0.005—0.001 | <0.001 |
|---|---|---|---|---|---|
| Percentage (%) | 8.33 | 48.83 | 7.39 | 11.18 | 24.27 |
| Median Diameter (mm) | | | 0.01217 | | |

### 2.2 Experimental setup

The simulated rainfall experiments were done in the simulation hall of Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resource, China. The study was conducted on a dual-box system consisting of a 5 m long test box and a 2 m long feeder box. Both boxes were 1 m wide and 0.5 m deep. These two boxes can be connected by a connecting device, which feed the runoff from the feeder box to the upper-end of the test box. The connecting devices consist of a separated board, an inverted triangle runoff-collecting flume, an outlet and a plastic tube.

The separate board that is an iron sheet of 2 m long, 30 cm deep inserted into the earth, the outlet Connected with plastic tube is located in the middle of a separated board and parallel to the soil downslope, inverted triangle runoff-collecting flume beneath the separated board connects the feeder box with test box. When these two boxes disconnected, the feeder runoff samples can be collected from plastic tube connecting the outlet located in the separated board, so the runoff from each box can be collected separately. When these two boxes connected, runoff from the feeder box drifted into the test box through collecting flume, which is similar to the effect of up-slope on down-slope processes. The connection and disconnection can be done quickly without stopping the rain.

For both soil boxes, the depth of soil was approximately 50 cm. These two boxes were placed under two simulators with side-nozzle (Chen *et al*., 1984). The height of raindrops falling was 16 m， the designed rainfall intensities were 50mm/h、70mm/h and 90mm/h. Under the condition of keeping the similar runoff of the feeder box, The sediment concentration in runoff was varied by progressively covering portions of the surface with plastic film that prevented direct raindrop impact to create different runoff with different sediment concentration during each run. Experimental treatments are seen in Table 2.

**Table 2 List of experimental treatments**

| Treatments | Rainfall intensity (mm/h) | Soil surface condition | Bulk density ($g/cm^3$) | Cover on feeder box(%） | Replications | Research contents |
|---|---|---|---|---|---|---|
| 1 | 50 | Loose soil | 1.08—1.12 | 0; 50; 75; 100 | 2 | Effects of run-on water and sediment on down-slope erosion processes |
| 2 | 90 | Loose soil | 1.08—1.12 | 0; 50; 75; 100 | 2 | |
| 3 | 130 | Loose soil | 1.08—1.12 | 0; 50; 75; 100 | 2 | |
| 4 | 50 | Compact soil | 1.25—1.31 | 0; 50; 75; 100 | 2 | |
| 5 | 90 | Compact soil | 1.25—1.31 | 0; 50; 75; 100 | 2 | |
| 6 | 130 | Compact soil | 1.25—1.31 | 0; 50; 75; 100 | 2 | |

### 2.3 Experiment procedure

Preparation of soil boxes included adding fresh soil collected from the field, breaking up clods into 3 cm to 4 cm sizes, and smoothing out the visual irregularities on the surface by hand and with a rake. Both boxes were prepared the same way. Both boxes of the test box and feeder box were set to the selected rainfall intensity (Table 2). The run started with 0% cover on the feeder box, thus the highest level of sediment production. Runoff samples from both boxes were collected in album box every minute. After collecting 8 runoff samples from each box separately, the two boxes were connected to let the runoff from the feeder box discharge to the upper-end of the test box. After 2-3 minutes of equilibration time, four runoff samples were collected from the test box that was receiving runoff input from the feeder box. After collecting runoff samples from the test box with the feeder input, the connecting equipment was removed and two additional runoff samples were collected from each box separately. These two final runoff samples were used to account for the temporal change of sediment delivery as the soil surface eroded. After all runoff samples were collected with 0% cover for the feeder box, 25% the feeder box surface was covered by pieces of plastic film. The sequence of collecting runoff samples was repeated: four samples from both boxes separately, four samples from test box with feeder input, and again two samples from each box separately. The same sampling procedure was repeated for 50%, 75% and 100% covers of the feeder box. During each run, the volume for every sample was measured. The entire run lasted about 65 minutes or so.

After each run the samples were set overnight, The boxes were decanted of excess water and placed in ovens at 105℃ for at least 12 hours or until the samples were dried. Dry weight was then taken to calculate the sediment delivery and concentration. Each run was replicated at least twice.

### 2.4 Sediment data analysis

For each run, runoff and sediment rates were averaged from 6 samples, 4 before connection and 2 after disconnection, for both test and feeder boxes separately, and from 4 samples when two boxes are connected. Let $S_f$ and $S_t$ be the sediment delivery from the feeder and test boxes separately and $S_{ft}$ the sediment delivery from the test box with the feeder sediment input. Depending on the magnitude of $S_{ft}$, relative to $S_f$ and $S_t$, there are some possible process scenarios on the test box (Huang *et al.*, 1998):

Scenario 1: $S_{ft} < S_f$, additional deposition, or deposition > erosion;
Scenario 2: $S_{ft} = S_f$, simultaneous erosion and deposition, deposition = erosion;
Scenario 3: $S_f < S_{ft} < S_f + S_t$, simultaneous erosion and deposition, erosion> deposition;
Scenario 4: $S_{ft} = S_f + S_t$, equilibrium, no effects from feeder water and sediment;
Scenario 5: $S_{ft} > S_f + S_t$, additional erosion in the test box from the feeder water.

## 3 Results and discussions

### 3.1 Quantitative analysis of effects of up-slope runoff and sediment

During rainfall, up-slope runoff and sediment is a medium of water energy between different landforms, and it has impacts not only on runoff infiltration rate but also on sediment transportation. An important indicator to quantify effects of up-slope runoff and sediment on down-slope erosion process is the additional sediment delivery ($S$) caused by up-slope runoff, The value $S$ is presented in the following equation: $S = S_{ft} - S_f - S_t$.

Data shown in Table 3, for loose soil surface, the additional sediment delivery ($S$) caused by up-slope runoff accounts for the total sediment delivery $S_{ft}$ at down-slope 72.4% to 92.7%. For compact soil surface, the additional sediment delivery ($S$) caused by up-slope runoff accounts for the total sediment delivery $S_t$ at down-slope 45.5% to 83.7%. Furthermore, the value of $S$ increases with an increase of rainfall intensity. When the runoff in feeder box discharging into the test box for loose surface treatment, the sediment delivery $S_{ft}$ at down-slope is 4.6 to 17.9 times the sediment delivery $S_t$. without feeder input. For compact surface treatment, the sediment delivery $S_{ft}$ at down-slope is 2.8—7.3 times the sediment delivery $S_t$ without feeder input. Because of runoff discharging into down-slope, so runoff in test box has strong erosion and transportation capacity, the additional sediment delivery ($S$) caused by up-slope accounts for $S_{ft}$ is as high as 90%.

From this analysis, up-slope runoff and sediment played a key role on down-slope erosion processes. Therefore, up-slope runoff is intercepted to infiltration on site is a key measure to control soil erosion at hillslope.

### 3.2 Down-slope erosion process

Runoff data shown in Table 3 indicated a reasonable mass balance between total runoff from both boxes disconnected ($Q_f$ +$Q_t$) and the total runoff from the test box with feeder input ($Q_{ft}$) for loose and compact surface treatments. Under selected conditions, the results also showed that the sediment delivery ($S_{ft}$) in the test box when the two boxes connected always exceeds that of the sum of the sediment delivery ($S_f$+$S_t$) when the two box disconnected for loose surface treatments. The results showed the sediment from feeder box discharging into down-slope is totally transported by down-slope runoff. Moreover, up-slope causes additional detachment at the down-slope, and sediment regime at down-slope is detachment and transported dominated. But for compact surface treatments, under rainfall intensity of 50mm/h, $S_f < S_{ft} < S_f + S_t$, this showed erosion, deposition and transport processes occur simultaneously at down-slope, and up-slope runoff causes additional sediment $S$. Under rainfall intensity of 90mm/h and 130mm/h, $S_{ft} > S_f + S_t$, this showed down-slpe erosion process is transported dominated. Up-slope runoff and sediment concentrations, rainfall intensity and soil bulk density restrict effects of up-runoff and sediment on down-slope erosion process.

**Table 3 Comparison of sediment delivery with feeder input and without feeder input**

| Rainfall intensity ( mm/h) | Feeder box | Test box | | | | | Remarks column |
|---|---|---|---|---|---|---|---|
| | $S_f$ ( g/min) | $S_t$ ( g/min) | $S_{ft}$ ( g/min) | $S_{ft}$ / $S_t$ | $S$ ( g/min) | $S$ / $S_{ft}$ (%) | |
| 50 | 11.3 | 43.4 | 198.3 | 4.6 | 143.6 | 72.4 | Loose soil |
| 90 | 33.4 | 108.6 | 1,946.6 | 17.9 | 1,804.6 | 92.7 | |
| 130 | 89.5 | 245.5 | 3,147.1 | 12.8 | 2,812.1 | 89.4 | |
| 50 | 11.3 | 22.3 | 61.8 | 2.8 | 28.1 | 45.5 | Compact soil |
| 90 | 33.4 | 197.5 | 620.7 | 3.1 | 389.8 | 62.8 | |
| 130 | 89.5 | 468.2 | 3,423.6 | 7.3 | 2,866.0 | 83.7 | |

### 3.3 Impacts of soil bulk density and rainfall intensity on slope-erosion processes

The effects of up-slope runoff and sediment on down-slope erosion processes is analyzed in the above. Relative research results also showed soil bulk density had significant impacts on soil moisture preservation and soil anti-erodibility (Zheng *et al.*, 1987). Data showed the additional sediment delivery caused by up-slope runoff is closely related with soil bulk density, the reason is mainly soil bulk density affected slope-erosion processes. Under rainfall intensity of 50mm/h, the loose surface is easily eroded than compact soil surface, so there was rill erosion in slope. For compact surface treatment, the surface has long strong capacity of resisting the raindrop impacts and runoff scouring, there was no rill erosion on slope, the surface after the run showed crescent –shaped scouring pits. Under rainfall intensity of 90mm/h for loose surface, the occurrence of rill erosion is formed earlier than that of compact surface treatment, and rill erosion develop actively, so, the additional sediment delivery caused by up-slope is larger than that of compact surface treatment. For the strong rainfall intensity, once rill is formed, rill erosion developed faster, when the feeder box is covered with 100%, the additional sediment delivery is larger than that of loose surface treatments. In the past, relative results showed that soil erosion is decreased with the increase of soil bulk density. Apart from two particular conditions (one is rainfall intensity of 50 mm/h and the feeder box is covered with 0%. The other is rainfall intensity of 130 mm/h and the feeder box is covered with 100%), our experiment also showed the additional sediment delivery for loose soil surface treatment is larger than that of compact surface treatment. By comparison of erosion for both loose and compact soil surface, the results explained that up-slope runoff must be controlled efficiently in loose loess plateau, which is important to adopt comprehensive harness of biological and engineer measures.

Rainfall intensity also important impacts on down-slope erosion process. Under loose surface and compact surface, when rainfall intensity increased from 50 mm/h to 90 mm/h or 130 mm/h, both the sediment delivery $S_{ft}$ with feeder feeder input and the sediment $S_t$ without feeder input increase with rainfall intensity. Fig. 1 and Fig. 2 showed effects of up-slope runoff and sediment on slope erosion process under different rainfall intensity. When the up-slope runoff discharging into the test box, the sediment delivery increased promptly (peaks). When the two boxes disconnected, the sediment delivery decreased (valley), when rainfall intensity increased from 50 mm/h to 90 mm/h and 130 mm/h, for loosed soil surface treatments, the sediment delivery increased from 107.2g/min—449.5g/min to 957 g/min — 31,261g/min and 2,509.2 g/min—4,587.8g/min separately. For compact surface soil surface treatments, the sediment delivery increased from 17.6 g/min—146.7g/min to 478 g/min—1,051 g/min and 1,940.5 g/min—5,940g/min separately.

Above analysis is showed that loess plateau of loose soil in the rain-storm erosion process easily develop serious rill erosion, and bring the tremendous hazard to agriculture Therefore, up-slope runoff must be controlled efficiently in loose plateau, it is important to adopt comprehensive harness of biological and engineer measures.

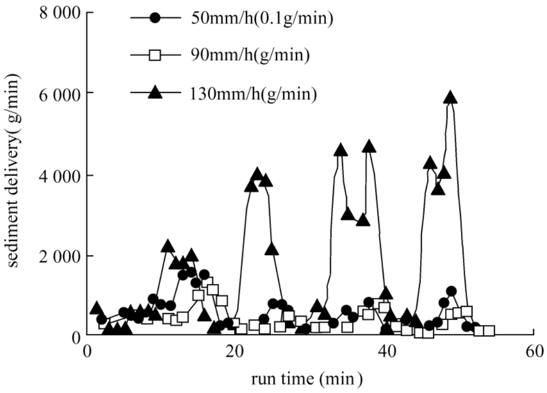

**Fig. 1** Erosion process of sediment delivery (loose soil)

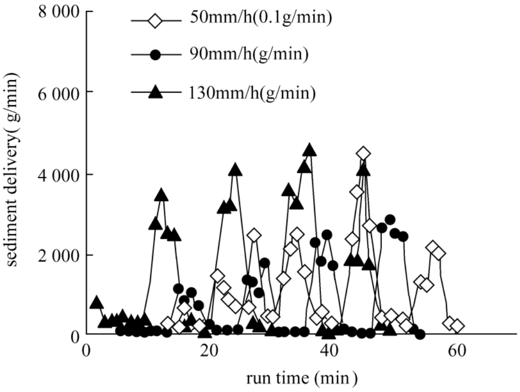

**Fig. 2** Erosion process of sediment delivery (compact soil)

## 4 Conclusions

A dual box system is used to quantify effects of up-slope runoff and sediment on down-slope erosion processes under different rainfall intensity, sediment concentration and bulk density.

Up-slope runoff and sediment have significant impacts on down-slope detachment, deposition and transportation. For loose surface treatment, up-slope runoff caused additional detachment at down-slope, and sediment regime at down-slope is detachment and transport dominated. For compact surface, sediment regime is detachment, deposition and transport dominated.

The additional sediment delivery ( $S$ ) caused by up-slope runoff is an indicator to quantify effects of up-slope runoff and sediment on down-slope sediment production. For the loose and compact surface treatments, the additional sediment delivery ( $S$ ) caused by up-slope runoff accounts for the total sediment delivery $S_{ft}$ at down-slope 72.4% to 92.7% and 45.5% to 83.7%, separately. Therefore, up-slope runoff is intercepted to infiltrate on-site is a key measure to control soil erosion at hillslopes.

The additional sediment delivery ( $S$ ) at down-slope caused by up-slope runoff increases with an increase of rainfall intensity or runoff from up-slope, and with a decrease of sediment concentration in upslope runoff. In addition, rill erosion development and soil bulk density have great effects on the additional sediment delivery ( $S$ ).

Depending on the facts of the additional sediment delivery increases with runoff and sediment concentration, It is vital of adopting comprehensive measures to harness loess plateau.

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