Sediment Load in Runoff from Small Plots: Laboratory and Field Rainfall Simulation Tests on Chinese Loess Soils

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Abstract: The soils of the Chinese loess plateau are affected by severe soil erosion. Near Luoyang (Henan province, China) field plots were constructed to measure soil erosion rates under different tillage practices. In addition to the erosion measurements under natural rainfall conditions, rainfall simulations were carried out on the field and in the laboratory.

Rainfall simulations in the lab were used to find a sediment transport equation for short slopes. A strong correlation was found between the stream power of the runoff water and the unit sediment load. This relationship was similar to the one found for Belgian soils. Comparison with other sediment transport equations in literature showed differences due to rainfall impact. Without rainfall impact lower sediment load values were found.

Rainfall experiments on the field were used to verify the results of the laboratory experiments. Preliminary results showed also a good correlation between stream power and unit sediment load. Additional field rainfall experiments are carried out to confirm these results and to extend the sediment transport equation for higher stream power values. Runoff measurements are also continuing for field plots under natural rainfall to validate the results from the laboratory and field experiments.

1 Introduction

The soils of the Chinese loess plateau are very susceptible to erosion by overland flow. About 60% of the loess plateau area is affected by an average annual soil loss of 2500 ton • km^{-2} (Shi *et al.*, 2000). Besides the on-site impact on soil fertility, the high erosion rates also have off-site consequences. The average silt content in the Yellow River is 37.3 g • l^{-1}, but can rise towards 160 g • l^{-1} during extreme rainfall events (Tang *et al.*, 1993). Sediment deposition in the river increases the inundation risk in he lower parts of the landscape. Therefore, different erosion control measures are promoted but little research has been done on the impact of tillage practices.

Near Luoyang (Henan province, China) field plots are constructed to measure soil erosion rates under different tillage practices. The total rainfall amount in the region around Luoyang varies between 560 and 864 mm • y^{-1}, but short, intense rainfall events result in high soil losses. Because runoff and erosion occur mainly during these rainfall events it is important to assess erosion and runoff on a rainfall event basis. Therefore the Sediment Transport Model (Biesemans, 2000) will be used to estimate soil losses at a field scale level. In order to adapt this model to Chinese loess soils, rainfall experiments are done in the laboratory and on field plots. Based on these experiments a sediment transport equation can be constructed that relates slope and runoff discharge to sediment transport. To validate these results and to examine the impact of different tillage practices on erosion, additional field plots are constructed and monitored during natural rainfall events.

2 Methods and materials

Two types of experiments were conducted: laboratory rainfall simulations on small soil pans and field rainfall simulations on a conventionally tilled erosion plot. The laboratory rainfall simulations were done on air-dried soil aggregates (< 8 mm), equally distributed in a soil pan, 0.3 m wide and 0.2, 0.6 or 0.9 m long. In the experiments topsoil originating from erosion plots near Luoyang was used (Table 1). During the rainfall simulations, runoff and splash erosion were collected every 10 minutes. Sediment concentration in the runoff water was determined by evaporation. Rainfall was simulated using capillary tubes at intensities of 65, 85 and 105 mm/h. The small dimensions of the soil pans prevented rill initiation. Therefore only interrill erosion was simulated in the laboratory.

Table 1 Characteristics of the loess soil at the erosion plots near Luoyang (Henan province)

Depth (m)	0—2 μm (%)	2—50 μm (%)	50—2000 μm (%)	$CaCO_3$ (%)	OC (%)	pH(KCl)
0—0.02	14.3	74.8	10.9	11.3	0.65	7.7
0.02—0.3	14.1	74.3	11.6	12.9	0.45	7.8
0.3—0.6	13.8	74.5	11.7	14.2	0.2	7.7
0.6—0.85	14.8	73.6	11.6	14.6	0.25	7.8
0.85—1.3	14.0	74.5	11.5	13.5	0.2	7.9

The field rainfall simulations were carried out on erosion plots near Luoyang (Henan province), situated in the Chinese loess plateau. The soil characteristics are given in Table 1. The field plots are 15 m long, 2 m wide and have a slope of 10 %. Conventional tillage was applied on the field plots. Rainfall intensities of 135 and 165 mm • h^{-1} were simulated using a sprinkler system and runoff discharge was measured. After 2.5, 5, 7.5, 10, 15, 20, 25 and 30 minutes a sample was taken to determine the sediment concentration in the runoff water. Prior to the rainfall simulations a rainfall distribution test was conducted to determine the variability in rainfall intensities. In this way representative point locations could be indicated to measure rainfall intensity.

Additional to the erosion plots for rainfall simulations, field plots were constructed to monitor runoff and soil loss during natural rainfall events. In order to examine the effect of tillage on soil erosion, different tillage practices were applied on the fields: conventional tillage (CT), reduced tillage (RT), subsoiling (SS) and no tillage (NT).

3 Results and discussion

3.1 Laboratory rainfall simulations

Several sediment transport equations have been proposed to predict erosion rates. The application of these equations is sometimes limited due to the use of parameters that are difficult to measure or estimate. Nearing *et al.* (1997) examined data from different erosion experiments, and found that the best predictor for unit sediment load q_s (g • s^{-1} • cm^{-1}) was stream power of runoff, ω (g • s^{-3}), as calculated by

$$\omega = \rho_w \, g \, S \, q$$

where ρ_w = density of water (g • cm^{-3})
g = gravitational constant (cm • s^{-2})
S = slope gradient (m • m^{-1})
q = unit discharge of runoff (cm^2 • s^{-1})

Nearing *et al.* (1997) found that nearly all data followed a logistic function curve. The advantage of using the stream power concept is that no data are needed concerning runoff velocity. Because it is difficult to measure the runoff velocity accurately in interrill areas, the stream power concept was also applied in this study.

The results of the laboratory rainfall simulations on the loess soil show a strong correlation between stream power and unit sediment load, but the relationship differs from the one found by Nearing *et al.* (1997) (Fig. 1). This can be explained by the influence of raindrop impact on sediment transport. In the erosion experiments done by Nearing *et al.*, (1997) overland flow was simulated in a flume without rainfall. The impact of raindrops causes detachment of soil particles and increases sediment transport capacity (Guy *et al.*, 1987). Similar results were obtained for rainfall simulations done on different silt loam and silt soils in Belgium (Biesemans, 2000). The results are in good agreement with those found for the Chinese loess soil (Fig. 1). Another indication of the importance of rainfall impact on sediment transport is shown in Fig. 2, giving the relationship between kinetic energy of the rain and the measured splash erosion. The increase of splash erosion with increasing kinetic energy indicates that sediment transport on the loess soil is strongly influenced by rainfall kinetic energy. This has to be taken into account in assessing the sediment transport capacity, because of the high rainfall intensities that occur during rainstorms in the region around Luoyang.

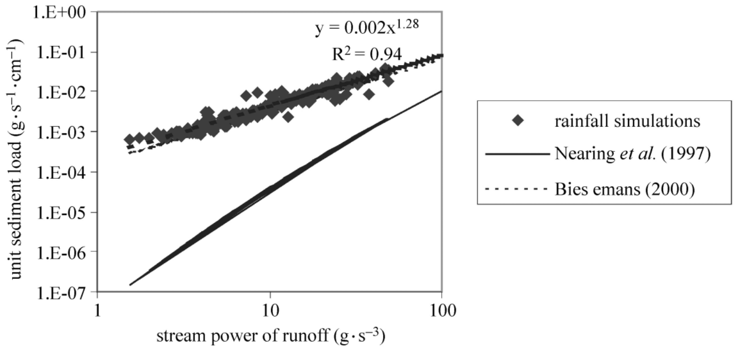

Fig.1 Relationship between stream power of runoff water and unit sediment load based on the laboratory rainfall simulations, compared with the results obtained by Biesemans (2000) and Nearing et al. (1997)

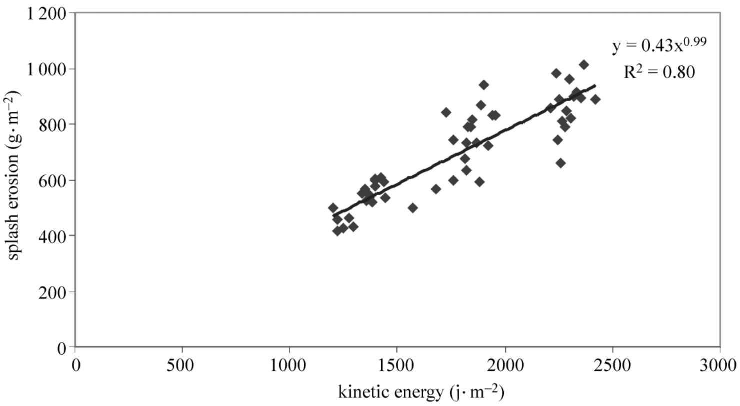

Fig.2 Relationship between rainfall kinetic energy and splash erosion

Rainfall intensity, slope gradient and unit discharge are incorporated into the equation that Zhang *et al.* (1998) proposed to predict interrill erosion rates. The results of the laboratory rainfall simulations indicate that slope length also has an important effect on sediment load, resulting in the following equation for interrill erosion:

$$q_s = 0.3777\ I\ q^{0.5}\ S^{2/3}\ \lambda \qquad (R^2 = 0.89)$$

where q_s = unit sediment load ($g \cdot cm^{-1} \cdot min^{-1}$)

I = rainfall intensity ($mm \cdot h^{-1}$)

q = unit discharge of runoff ($cm^2 \cdot min^{-1}$)

S = slope gradient (%)

λ = slope length (cm)

The interrill soil erodibility is given by the coefficient 0.3777. This value is similar to the erodibility coefficient of 0.40 that was found by Zhang *et al.*, (1998) for a silt loam soil.

3.2 Field rainfall simulations

The results of the field experiments indicate a different relationship between stream power of runoff and unit sediment load (Fig. 3). The overland flow during the field experiments caused rill formation, resulting in lower sediment load values because the rainfall impact on sediment transport in rills is much lower than for interrill erosion. Therefore the relationship found by Nearing *et al.* (1997) is in better agreement with the results of the field experiments, although it also overestimates these values.

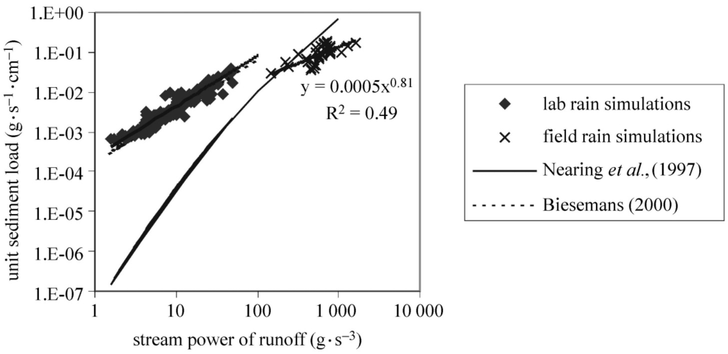

Fig. 3 Relationship between stream power of runoff water and unit sediment load based on field rainfall simulations, compared with the results of the laboratory rainfall simulations and the results obtained by Nearing *et al.,* (1997) and Biesemans (2000)

3.3 Runoff and soil loss caused by a natural rainfall event

In order to validate the erosion experiments and to examine the effect of tillage on soil loss, runoff from field plots under natural rainfall is analysed. Because only one rainfall event was monitored, the data are limited and therefore only give an indication of soil losses under the different tillage practices. Measurements are still continuing to provide more validation data. The results of the field measurements show that the alternative tillage practices produce more runoff and soil loss than the conventional tillage (Table 2). This may be caused by the compaction and sealing of the soil surface, although additional data are needed to confirm these results.

Table 2 Total runoff and soil loss from field plots with different tillage practices after a natural rainfall event of 48.4 mm (19—24 September 2000)

Field plot	Runoff (l)	Soil loss (g)
Conventional tillage	152	350
Subsoiling	323	1,158
Reduced tillage	169	391
No tillage	166	536

4 Conclusions

The results of laboratory rainfall simulations indicate the importance of rainfall impact on the sediment transport in interrill areas. Sediment load values are much higher compared to flume studies without rainfall simulation. A high correlation was found between stream power of runoff and unit sediment load. However, the sediment transport equation based on the laboratory results overestimates the field rainfall simulation results. This indicates that sediment transport to rills is larger than the transport capacity in rills.

Preliminary results of runoff measurements from field plots during a natural rainfall event indicate that conventional tillage causes less runoff and soil loss compared to alternative tillage practices. However, additional data are needed to confirm this and to validate the rainfall simulation results.

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