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

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Abstract: Due to severe soil erosion the fertility of the soils of the Chinese loess plateau decreases. Together with the sediment also nutrients are lost. Near Luoyang (Henan province, China) field plots were constructed to measure nutrient and soil losses under different tillage practices. In addition to the measurements under natural rainfall conditions, rainfall simulations were carried out on bare soil on the field and in the laboratory.

Rainfall simulations in the lab were used to correlate nutrient losses to sediment losses. The average enrichment ratios of phosphorus, organic carbon and $CaCO_3$ varied between 1 and 1.3. The influence of the unit sediment load on the enrichment values was limited. Similar values were found for the rainfall simulations on the field. In the beginning of the rainfall simulation a preferential transport of fine particles took place, but after 30 minutes the clay enrichment ratio decreased towards 1.

Nutrient analyses of the runoff from the field plots under natural rain indicated much higher enrichment ratios for organic carbon and available phosphorus. Possibly these values are due to application of P fertilizer, but additional field measurements have to confirm this.

1 Introduction

The soils of the Chinese loess plateau are very susceptible to soil erosion. Because nutrients are mainly adsorbed on soil particles, erosion leads to nutrient losses. Depending on the soil type, land use and erosion process, a preferential transport of clay-sized particles can occur. Although interrill erosion is assumed to be more selective than rill erosion (Miller & Baharuddin, 1987; Parsons *et al*., 1991), results showing the opposite are also published (Proffitt *et al*., 1991).

Nutrients are mainly adsorbed on clay-sized particles, which causes a higher nutrient content in the eroded soil compared to the original soil. Suspended sediment in runoff can contain 4 times more phosphorus and organic carbon, compared to the original soil (Sharpley, 1985; Weigand *et al*., 1998). Therefore it is important to know to what extent the eroded sediment is enriched in nutrients, in order to link soil losses to nutrient losses. Near Luoyang (Henan province, China) field plots were constructed to measure nutrient and soil losses under different tillage practices. In addition to the measurements under natural rainfall conditions, rainfall simulations were carried out on bare soil on the field and in the laboratory.

2 Methods and materials

In order to examine the correlation between erosion and nutrient load in runoff 3 different experiments were done: laboratory rainfall simulations on small soil pans and erosion experiments on field plots under simulated and natural rainfall. In the laboratory, rainfall intensities of 65 mm • h^{-1}, 85 mm • h^{-1} and 105 mm • h^{-1} were simulated using capillary tubes. Small soil pans (0.2m, 0.6 m and 0.9 m long) were filled with topsoil (0 cm—30 cm) from field plots situated near Luoyang (Table 1). During the experiments runoff and splash erosion were collected every 10 min. The sediment in the runoff and splash erosion samples was analysed for particle size, organic carbon (OC), $CaCO_3$ and available phosphorus (P_{av}). Particle size analysis was done following the sieve-pipette procedure described by De Leenheer (1966). OC was determined by the method of Walkley & Black (1934). $CaCO_3$ was analysed by titration with NaOH after addition of H_2SO_4. The P_{av} content was determined by extraction with $NaHCO_3$ (pH = 8.5). Afterwards the P content in the extract was determined colorimetrically (880 nm). A more detailed description of the experiments and analyses is given by De Roock (2001).

Table 1 Soil characteristics of the erosion plots near Luoyang (Henan province, China)

Depth (m)	0—2 μm (%)	2—50 μm (%)	50—2000 μm (%)	$CaCO_3$ (%)	OC (%)	P_{av} (%)	pH(KCl)
0—0.02	14.3	74.8	10.9	11.3	0.65	0.066	7.7
0.02—0.3	14.1	74.3	11.6	12.9	0.45	0.038	7.8
0.3—0.6	13.8	74.5	11.7	14.2	0.2	0.054	7.7
0.6—0.85	14.8	73.6	11.6	14.6	0.25	0.058	7.8
0.85—1.3	14.0	74.5	11.5	13.5	0.2	0.082	7.9

Field rainfall simulations were conducted on erosion plots near Luoyang (Henan province, China), situated in the Chinese loess plateau. The erosion plots are 15 m long, 3 m wide and have a slope of 10 %. Conventional tillage is applied. The soil characteristics of the field plots are given in Table 1. Rainfall intensities of 100, 135 and 200 mm • h^{-1} were simulated using a sprinkler system. Runoff was collected and the eroded sediment was analysed for particle size, OC, $CaCO_3$ and P_{av} following the procedure described above.

In addition to these experiments runoff was collected and analysed from 4 field plots, during a natural rainfall event. On these field plots different tillage practices are applied: conventional tillage (CT), subsoiling (SS), reduced tillage (RT) and no tillage (NT).

3 Results and discussion

The loss of nutrients in relation to erosion and the nutrient content of the soil is often expressed by means of enrichment ratios. The enrichment ratio (ER) is the ratio of the nutrient content in the eroded sediment to the nutrient content in the original soil. If the ER of a nutrient is higher than 1, the eroded sediment is enriched in that nutrient. Research has shown that nutrient enrichment is related to soil properties, land use and erosion processes (Sharpley, 1985; Proffitt *et al.*, 1991).

In the rainfall simulation experiments only one soil type is used. During the simulations no rill formation is observed, because of the small dimensions of the soil pans. Therefore it is assumed that mainly the intensity of the interrill erosion process will influence the ER. However, no influence of erosion intensity, expressed as unit sediment load, on the ER of OC could be observed (Fig. 1). For the different texture classes and nutrients, similar low ER values are found (Table 2). The ER values for splash erosion are also low but the values in Table 2 indicate that coarse particles (> 50 μm) are more susceptible to splash erosion than finer particles (< 20 μm). Similar results were also reported by other researchers (Meyer *et al*., 1975; Proffitt et al., 1991; Sutherland *et al*., 1995).

On the erosion plots near Luoyang 5 rainfall simulations were conducted to examine the nutrient losses at the field scale. The results of these experiments are in agreement with the results of the laboratory rainfall simulations, in this way that also on the field plots low ER values are found. The change of ER in function of time during the rainfall simulations (Table 3) indicates that in the beginning of the experiment the eroded sediment has a higher content of small particles (< 20 μm), but it decreases as the rainfall simulation continues. The opposite can be seen for coarse particles. This phenomenon can be explained by the increase of runoff velocity above a certain threshold value, causing an increase in transport of coarse particles (Beuselinck *et al*., 1999). The ER values of OC, $CaCO_3$ and P_{av} are also rather low, indicating the low selectivity of the erosion process.

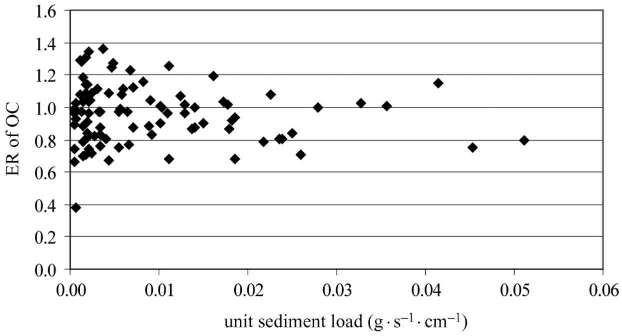

Fig. 1 Enrichment ratio (ER) of organic carbon (OC) as a function of unit sediment load

Table 2 **Average enrichment ratio values (± std. dev.) of particle size classes and nutrients (OC = organic carbon, P_{av} = available phosphorus) in sediment in runoff and splash erosion from laboratory rainfall simulations**

	Average ER in runoff sediment	Average ER in splash erosion sediment
0—2 µm	1.05 ± 0.19	0.89 ± 0.10
2—20 µm	1.06 ± 0.17	0.95 ± 0.07
20—50 µm	0.97 ± 0.10	1.02 ± 0.06
50—100 µm	1.13 ± 0.30	1.20 ± 0.19
100—200 µm	1.09 ± 0.41	1.39 ± 0.30
200—500 µm	0.52 ± 0.22	1.46 ± 0.61
500—2000 µm	0.15 ± 0.10	0.70 ± 0.22
OC	0.98 ± 0.18	0.92 ± 0.17
$CaCO_3$	1.14 ± 0.09	1.16 ± 0.07
P_{av}	1.26 ± 0.20	1.08 ± 0.37

Table 3 **Change in time of the average enrichment ratio values (± std. dev.) of the textural classes and nutrients (OC = organic carbon, P_{av} = available phosphorus) during the field rainfall simulations**

	Time intervals during the rainfall simulation (min)					
	0—10	10—20	20—30	30—40	40—50	50—60
0—2 µm	1.66±0.52	1.21±0.30	1.07±0.12	1.07±0.33	0.96±0.11	1.14±0.39
2—20 µm	1.75±0.23	1.40±0.27	1.28±0.21	1.25±0.35	1.01±0.04	0.98±0.16
20—50 µm	0.61±0.27	0.88±0.16	0.95±0.08	0.94±0.22	1.06±0.05	0.94±0.16
50—100 µm	0.22±0.14	0.49±0.38	0.64±0.29	0.78±0.36	0.98±0.15	0.80±0.29
100—200 µm	0.21±0.14	0.39±0.26	0.52±0.19	0.58±0.26	0.71±0.04	0.73±0.28
200—500 µm	0.11±0.09	0.20±0.15	0.25±0.07	0.31±0.17	0.41±0.07	0.46±0.22
500—2000 µm	0.08±0.05	0.11±0.10	0.12±0.05	0.19±0.13	0.22±0.04	0.32±0.20
OC	1.37±0.14	0.96±0.17	0.90±0.09	0.95±0.21	0.85±0.06	0.83±0.13
$CaCO_3$	1.39±0.22	1.39±0.20	1.36±0.27	1.45±0.35	1.31±0.17	1.27±0.14
P_{av}	1.21±0.18	1.07±0.18	2.0±1.8	0.99±0.14	0.87±0.20	2.0±2.2

In order to verify the results of the erosion experiments and to examine the effect of tillage on soil and nutrient losses, runoff from field plots under natural rainfall was analysed. Because only one rainfall event was monitored, the results are limited and therefore only give an indication of nutrient and soil losses under the different tillage practices. Measurements are still continuing to provide more validation data. The results of the field measurements show the ER values of OC and P_{av} are much higher (Table 4). This can be explained by the application of P fertilizer on the field plots. The crop residues on the fields also act as a source of P_{av} and OC, causing higher ER values of P_{av} and OC. Therefore, a more intensive soil sampling (both in space and time) should be carried out in order to have more detailed data about the nutrient content of these field plots.

Table 4 Enrichment ratio values of particle size classes and nutrients (OC = organic carbon, P_{av} = available phosphorus) in runoff sediment from field plots (CT = conventional tillage; SS = subsoiling; RT = reduced tillage; NT = no tillage) after a rainfall event of 48.4 mm (19—24 September 2000)

Plot	0—2 µm	2—20 µm	20—50 µm	50—2000 µm	OC	$CaCO_3$	P_{av}
CT	1.57	2.37	0.35	0.04	3.28	1.72	7.36
SS	1.64	2.05	0.47	0.12	2.25	1.77	9.85
RT	1.85	2.28	0.30	0.03	2.00	1.39	5.17
NT	1.69	2.38	0.30	0.03	1.93	1.11	5.27

4 Conclusions

Laboratory rainfall simulations are used to correlate nutrient losses to sediment losses. The results of the laboratory experiments indicate that selective transport of soil particles and nutrients is limited. The low sediment load values of the interrill erosion process do not cause a preferential transport of small particles. On the other hand the particle size analysis of the splash erosion indicates that coarse particles (> 50 µm) are more susceptible to splash erosion.

The results of the field rainfall simulations show that in the beginning of the experiments the eroded sediment is enriched in nutrients and small particles (< 20 µm). Afterwards the ER values decrease towards 1, indicating that the combination of rill and interrill erosion processes does not cause a preferential transport of nutrients and soil particles.

During the laboratory and field experiments no net deposition is observed. Therefore the results of these experiments indicate that preferential sediment and nutrient transport caused by rill and interrill erosion, is limited. If net deposition occurs, the ER values can be much higher due to the selectivity of the deposition process.

Nutrient analyses of the runoff from the field plots under natural rain indicate higher enrichment ratios, compared to the rainfall simulations. Possibly these values are due to fertilizer application, but additional field measurements have to confirm this.

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