НОВЫЕ МЕТОДЫ И РЕЗУЛЬТАТЫ ИССЛЕДОВАНИЙ ЛАНДШАФТОВ В ЕВРОПЕ, ЦЕНТРАЛЬНОЙ АЗИИ И СИБИРИ

Монография в 5 томах

Том II Изучение и мониторинг процессов в почвах и водных объектах

В содружестве с Академией почвенного плодородия Митчерлиха (МИТАК), Паулиненауэ, Германия

Москва 2018
NOVEL METHODS AND RESULTS
OF LANDSCAPE RESEARCH IN EUROPE,
CENTRAL ASIA AND SIBERIA

Monograph in 5 Volumes

Vol. II  Understanding and Monitoring Processes in
Soils and Water Bodies

With friendly support of the Mitscherlich Academy
for Soil Fertility (MITAK), Paulinenaue, Germany

Moscow 2018

Коллектив авторов и редакторов под руководством В.Г. Сычёва (Москва), А. Сапарова (Алматы), Ф. Ойленштайна (Мюнхеберг).

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This monograph shall inform you about up to date methodologies and recent results in landscape research. It is intended as a guide for researchers, teachers, students, decision makers, stakeholders interested in the topic of landscape science and related disciplines. It provides information basis for decision makers at various levels, from local up to international decision bodies, representing the top level of landscape science in a very short form.

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ISBN 978-5-9238-0246-7
ISBN 978-5-9238-0248-1 (Том 2)
DOI 10.25680/3139.2018.68.11.002

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Chapter II/52: MEASUREMENT METHODS FOR TILLAGE EROSION EFFECTS ON WATER EROSION IN A STEEP SLOPE LANDSCAPE

Глава II/52: Методы измерения эффектов перемещения почвы при обработке на водную эрозию в ландшафтах крутих склонов

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ABSTRACT. Few specific experimental methods have so far been developed with respect to the effects of tillage erosion on runoff and sediment concentrations on the whole slope. Simulated tillage and artificial rainfall events were applied to runoff plots (2 m × 8 m) with a slope of 15°. The short slope (8-m long) was divided into two sections of upper and lower slopes, each of which was subject to different mechanisms of interactions. At upper slopes, soil loss by tillage exposed subsurface soil or even parent material, which was less erodible to water erosion than surface soil with higher organic matter content, more stable structure and higher infiltration rates. Thus, we measured hydrodynamic parameters and runoff rates. At lower slopes, tillage erosion would transport soil to areas of concentrated overland water flow, i.e. rills and convergent landforms. Thus, we measured runoff and sediment concentrations under different soil infilling amounts which represent tillage erosion rates. The developed methods would be valid for such landform conditions as steep and short slopes.

Резюме. До настоящего времени было разработано небольшое количество специальных экспериментальных методов, относящихся к эффектам перемещения почвы при обработке на водную эрозию. Цель разработанного метода — интегральное изучение эффектов перемещения почвы при обработке на водный сток и накопление продуктов эрозии в пределах всего склона. На участках площадью (2 м × 8 м) с уклоном 15° были применены модельная обработка почвы и искусственные дожди. Короткий склон (8 м) был разделен на две части, верхнюю и нижнюю, каждая из которых характеризовалась различными механизмами взаимодействий. В верхней части склона удаление почвы при обработке приводило к обнажению подповерхностных слоев почвы или даже почвообразующей породы, которые менее подвержены водной эрозии, чем поверхностный слой с более высоким содержанием органического вещества, более стабильной структурой и повышенной водопроницаемостью. Поэтому мы измеряли гидродинамические параметры и модуль стока. В нижней части склона обработка перемещает почву на участки повышенного поверхностного стока (промоины и депрессии). Поэтому мы измеряли водный сток и накопление продуктов эрозии при заполнении промоин различным количеством почвы, моделирующим перемещение при обработке. Разработанные методы могут быть применимыми для таких условий рельефа, как крутые и короткие склоны

KEYWORDS: artificial rainfall, tillage intensity, runoff rate, sediment concentration

Ключевые слова: искусственные осадки, интенсивность обработки почвы, скорость стока, концентрация осадков

INTRODUCTION

Studies have demonstrated that water and tillage erosion simultaneously contribute to total soil erosion within the agricultural landscape [1]. However, the erosion intensity of each type may vary with changes in erosion processes, with an interaction between tillage erosion and water erosion. A few soil erosion workers speculated that tillage erosion would act as a delivery mechanism for water erosion, transporting soil to areas of concentrated overland water flow, i.e. rills and convergent landforms [1, 2]. Although it is a fact that tillage erosion increases the severity and extent of water erosion, few specific experimental methods have so far been developed with respect to the effects of tillage erosion on water erosion. This method developed aimed to integrally examine the effects of tillage erosion on runoff and sediment con-
centrations on the whole slope, with observations on runoff at upper slopes and soil delivery at lower slopes.

PRINCIPLE AND PROCEDURE

It is assumed that interactions may exist between tillage erosion and water erosion, and tillage erosion exacerbate water erosion by altering hydrodynamic parameters, soil erodibility, and delivering soil to rills in a hillslope landscape where both water and tillage erosion are important processes of soil redistribution. A short slope was divided into two sections of upper slope and lower slope, each of which was subject to different mechanisms of interactions. At upper slopes, soil loss by tillage exposes subsurface soil or even parent material, which is less erodible to water erosion than surface soil with higher organic matter content, more stable structure and higher infiltration rates. Thus, we measure hydrodynamic parameters and runoff rates. At lower slopes, tillage erosion would transport soil to areas of concentrated overland water flow, i.e. rills and convergent landforms [1, 2, 3]. Thus, we measure runoff and sediment concentrations under different soil infilling amounts.

The treatments of different tillage periods and soil fluxes (the soil transport rate per unit width in the tillage direction along a hillslope profile, i.e., kg m$^{-1}$) were designed in upper and lower slope positions, respectively, within runoff plots (2 m wide and 8 m long), with an average gradient of 15°. Runoff flowed into a rectangular cement trough at the bottom of the plot and was then directed to the outlet point and collected.

Tillage-duration treatment: we designed four types of soil profiles with different depths (bedrock exposure, 10, 20, and 45 cm deep) at the upper slope positions (0–3 m) of the runoff plots to represent different tillage intensities (Fig. 1A). A plastic sheet was used to cover the surface of runoff plots at the upper slope positions to represent the bedrock exposure by long-term tillage. Additionally, we dug out the soil of 10 cm and 20 cm in depth, respectively, from the upper slope positions of runoff plots. Then, a plastic sheet was placed on the surface of exposed soils, and the soil was backfilled to the plot and packed to its original bulk density. These treatments were considered as soil depths of 10 cm and 20 cm at the upper slope positions, while the original runoff plot (i.e., 45 cm deep at the upper slope positions) was considered the control (CK).

The soil loss rate at the upper slope positions of the runoff plots was calculated according to the following equation:

$$ S_t = 10 \cdot V / \rho_b / A \quad (1) $$

where $S_t$ is the soil loss rate (kg ha$^{-1}$), $V$ is the volume of simulated rills (m$^3$), $\rho_b$ is the bulk density of soil (kg m$^{-3}$), $A$ is the area of the runoff plot (m$^2$).

The tillage erosion rate was calculated according to the empirical model by Zhang et al. [4] in the experimental area. The formula can be expressed as follows:

$$ R = 10 \cdot D \cdot \rho_b \cdot (k_1 + k_2 S) / L \quad (2) $$

where $R$ is the tillage erosion rate (Mg ha$^{-1}$ tillage pass$^{-1}$), $D$ is the depth of tillage layer (m), $k_1$ and $k_2$ are the soil transport coefficients (kg m$^{-1}$ tillage pass$^{-1}$), $S$ is the slope gradient (m m$^{-1}$), and $L$ is the slope length (m). The coefficients $k_1$ and $k_2$ were 0.1066 and 0.4902 kg m$^{-1}$ tillage pass$^{-1}$, respectively [4].

Tillage times can be expressed as:

$$ T = S_t / R \quad (3) $$

where $T$ is tillage times. If a tillage operation was performed once per year, then 51.97, 31.09, and 10.36 tillage operations approximate 52-, 31-, and 10-year tillage, respectively.

Rill infilling treatment: To simulate the impact of tillage erosion on rills, three artificial rills (0.20 m wide $\times$ 0.15 m deep $\times$ 4.00 m long) with a contour distance of 40 cm were established using a hoe at the lower slope positions (5–8 m) of the runoff plot (Fig. 1B). The infilling soil derived from the runoff plot was crushed and passed through a 10-mm mesh sieve to filter out coarse materials, and then weighed to determine the mass of infilling soil. In this experiment, 3 treatments for soil infilling of rills were set up. The soil flux was used to determine the intensity of infilling soil in rills as follows:

$$ Q_s = F / N \quad (4) $$

where $Q_s$ is the soil flux (kg m$^{-1}$), $F$ is the weight of infilling soil in rills (kg), and $N$ is the distribution length of infilling soil in rills (m). The calculated results are presented in Table 1.

Rainfall simulation: Simulated rainfall was applied to the runoff plots for the duration of 30 min at 90 mm h$^{-1}$ (for different tillage intensities) and 70 min at 50 mm h$^{-1}$ (for different soil fluxes) to determine runoff and soil detachment rates (Fig. 1). The chosen rainfall intensity of 90 mm h$^{-1}$ is typical of intense storms in the sub-humid climate regions of China that are dominated by monsoon climate conditions. A pre-experiment showed that the rainfall intensity of 50 mm h$^{-1}$ could just generate rainfall erosivity in our
The artificial rainfall equipment was developed by the Institute of Soil and Water Conservation, CAS. The rainfall equipment includes four sprayers with an upright distance of 6.5 m from the middle axes of the runoff plot and a rainfall height of 8 m. The rainfall intensities were set up by adjusting water pressure and nozzle sizes. The rainfall intensities were calibrated by ten rain gauges (with a radius of 7.5 cm and height of 25 cm) that were distributed over both sides of the runoff plot. The homogeneous coefficient reached 90%, which was characterized by Christiansen’s uniformity coefficient (CU). To ensure consistent rainfall intensities among all rainfall events with the same rainfall, a pre-experiment was carried out for each rainfall event.

Table 1 Differences in the soil flux after filling soil in the rill of the lower slope positions

<table>
<thead>
<tr>
<th>Erosion intensity</th>
<th>Infilling type</th>
<th>Infilling soil weight (kg)</th>
<th>Soil flux (kg m⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-tillage</td>
<td>No-infilling rill</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Moderate erosion</td>
<td>Half-infilling rill</td>
<td>39.43</td>
<td>9.86</td>
</tr>
<tr>
<td>Intensive erosion</td>
<td>Full-infilling rill</td>
<td>98.86</td>
<td>24.72</td>
</tr>
</tbody>
</table>

The same tillage operations were performed in runoff plots for each rainfall event to retain the similar soil physical properties to those before the first simulated rainfall event. It took several days (3–5 days) to allow drying the soil so that soil water contents before each rainfall event could range from 15% to 18%. Soil water contents were measured using time domain reflectometry (TDR, Trase system, Soil Moisture Equipment Corp., USA). The runoff and sediment samples were collected at the end of the plot outlet with a 6000-ml plastic bucket every 2 min. to determine runoff amounts and sediment concentrations after water initially flowed out from the plot. The collected samples were deposited, separated from water suspension, dried in a forced-air oven at 105 °C for 24 h and weighed. The sediment concentration was determined as the mass ratio of the dry sediment to the sampled water suspension. Surface flow velocities at the upper, middle, and lower slope positions were measured by means of KMnO₄ solution during the simulated rainfall event, after the flow discharge stabilized. The upper, middle, and lower slope positions were marked from 0 m to 3 m, from 3 m to 6 m, and from 6 m to 8 m within the runoff plots, respectively. A time tracer travelling across a marked distance (0.5 m) was determined according to the colour-front propagation using a stop-match [5, 6, 7]. For each slope position, 5 to 8 repeated values were observed. A millimetre-scale ruler was used to determine the width of the water-crossing section [8].

Figure 1 – Plot designs for the rainfall simulation experiments: (A) different thickness of soil layers at the upper slope positions and (B) infilling soil in rills at the lower slope positions.
Calculation: Soil detachment rates were calculated by the following formula [9]:

\[ D_r = S_c \cdot R_a / A \cdot t \] (5)

where \( D_r \) is the soil detachment rate (g m\(^{-2}\) min\(^{-1}\)), \( S_c \) is the sediment concentration of each sample during the measured time (g m\(^{-3}\)), \( R_a \) is the total runoff amount in each sample during the measuring time (m\(^3\)), and \( t \) is the sampling inter-time (min).

Soil erodibility has long been considered the soil physiochemical property that apparently depends on the soil intrinsic properties and prevailing extrinsic field conditions at the time of measurements. Soil erodibility factor \( K \) is related to soil detachment rates and average shear stress; thus, it can be expressed as [10]:

\[ D_r = K \cdot (\tau - \tau_c) \] (6)

where \( K \) is the soil erodibility factor (g N\(^{-1}\) min\(^{-1}\)), \( \tau \) is the effective shear stress (Pa), \( \tau_c \) is the critical shear stress (Pa). \( K \) and \( \tau_c \) can be obtained through regression analysis between \( D_r \) and \( \tau \) (i.e., \( K \) becomes equal to the slope of the line, and the x-intercept is \( \tau_c \)).

Effective shear stress is thus more conveniently calculated according to the following formula (Liu et al., 2010):

\[ \tau = \rho \cdot g \cdot h \cdot \sin \theta / 1000 \] (7)

where \( \rho \) is the density of water (assumed to have a constant value of 1000 kg m\(^{-3}\) at 25 °C), \( g \) is the gravitational acceleration (9.8 N kg\(^{-1}\)), \( h \) is the mean runoff depth (mm), and \( \theta \) is the slope gradient. \( h \) was calculated with the equation developed by Pan and Shangguan [6]:

\[ h = R_t / (1000 \cdot U \cdot W \cdot t_d) \] (8)

where \( R_t \) is the runoff amount during \( t \) time (m\(^3\)), \( U \) is the mean flow velocity (m min\(^{-1}\)), \( W \) is the width of water-crossing section (m), and \( t_d \) is the rainfall duration (min). Values of surface flow velocity are used to estimate \( U \) as follows:

\[ U = \alpha \cdot V_s \] (9)

where \( \alpha \) is a coefficient, \( V_s \) is surface flow velocity (m min\(^{-1}\)). For laminar flow over a smooth bed, Horton et al. [11] theoretically showed that the ratio of \( V_s \) to \( U \) was 0.67.

CONCLUSIONS
The experimental method for the effects of tillage erosion on water erosion was developed for measuring runoff and sediment concentrations on the whole slope under intensive tillage. Upper slopes and lower slopes were subject to different mechanisms of tillage effects on water erosion. At upper slope positions, hydrodynamic parameters and runoff rates were measured under different tillage erosion intensities, while at lower slope positions runoff and sediment concentrations were detected under different soil infilling amounts into rills. The developed methods would be valid for such landform conditions as steep and short slopes. This method needs to be improved in the future studies to have general applicability to other landform conditions.

ACKNOWLEDGMENTS
The authors wish to acknowledge the financial support for this study provided by the National Natural Science Foundation of China (41571267) and the National Basic Research Program of China (2015CB452704).

REFERENCES


Chapter II/53: QUANTIFYING THE EFFECTS OF TILLAGE ON WATER EROSION

Глава II/53: КОЛИЧЕСТВЕННОЕ ОПРЕДЕЛЕНИЕ ЭФФЕКТОВ ОБРАБОТКИ ПОЧВЫ НА ВОДНУЮ ЭРОЗИЮ

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ABSTRACT. How tillage erosion influences water erosion remains unresolved, when those two processes of soil erosion simultaneously exist in a hillslope landscape. Simulated tillage and artificial rainfall events were applied to runoff plots (2 m × 8 m) with a slope of 15° to quantify the effects of tillage on water erosion. Mean runoff rates were 2.26, 1.19, and 0.65 L min⁻¹ and that mean soil detachment rates were 1.53, 1.01, and 0.61 g m⁻² min⁻¹ during the 70-min simulated rainfall events for 52-, 31-, and 10-year tillage, respectively. Compared with the soil flux of 0 kg m⁻¹, cumulative detachment amounts for the soil fluxes of 9.86 and 24.72 kg m⁻¹ increased by 40.02% and 100.94%, respectively, during the 30-min rainfall event. As tillage intensity increased, critical shear stress trended to decrease for all soil fluxes. It is suggested that tillage erosion increases soil erodibility and delivers the soil for water erosion in sloping fields, thereby accelerating water erosion.