SIMULATION OF GRASSLAND EROSION IN CHINA

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Abstract. Systematically and deeply supplement grassland erosion research from erosion mechanisms and erosion models could meet the needs of grassland ecological quality assessment. This study conducted grassland erosion research using simulated rainfall experiments in China. The research results indicate that (1) the regulation effect of grass on stream power is mainly achieved by grass cover that can explain 82.86%-97.51%, and the regulation effect of grass on soil erodibility is mainly achieved by root volume that can explain 73.61%-97.94. (2). The contributions of the Rω (Reduction percentage of stream power) and RK (Reduction percentage of soil erodibility) to the decreasing erosion modulus (REM) are 61.02% and 33.55%, respectively, totaling to 94.57%. This finding indicates that herbaceous vegetation decreases the interrill erosion mainly by decreasing the stream power. 3). The NSE (Nash–Sutcliffe efficiency index) of the RHEM (A Rangeland Hydrology and Erosion Model) established by rain intensity, flow discharge and cover is 0.700, which is 0.142 larger than that of the revised RHEM established by rain intensity and flow discharge. More suitable composite grass indicators should be added to the parameters in the revised RHEM to improve the simulation effect of the model. The study will optimize global grassland use and management, and assist in the development of carbon reduction on Earth.
Keywords: soil erosion model, material and energy cycling, grassland management, carbon reduction, vegetation restoration

Introduction

Interrill erosion is the erosion caused by thin layer runoff, which is the main erosion type of grassland. Studying the impact of grassland erosion on the circulation, prediction, and evaluation of surface matter and energy is of significant importance. Due to environmental limitations and the strong survival ability of grass, grassland accounts for about half of the Earth' s land area (Williams et al., 1968) and is often used in urban greening and vegetation restoration (Ma et al., 2020; Liu et al., 2020). In recent years, so many researchers proved that vegetation can reduce the impact force of water by reducing runoff (Wainwright et al., 2002; Rey, 2003; Puigdefabregas, 2005; Kimiti et al., 2017; Wang et al., 2021b) and raindrop kinetic energy, and increase soil resistance to erosion by increasing soil aggregate stability and cohesion and by stabilizing the soil through the binding action of its roots (Gyssels et al., 2005; Usman et al., 2016; Hao et al., 2020). However, However, our knowledge of grassland erosion is limited due to the absence of systematic experimental studies, especially under steep slope conditions (Li and Pan, 2018).

Erosion research includes three parts: erosion characteristics, erosion mechanisms, and erosion models. Among them, erosion mechanisms and erosion models are the focus and difficulty of erosion research. A large amount of research has been conducted on the erosion mechanism from the external characteristics of grasslands. Scholars often use grass cover and root characteristics to explain the erosion mechanism, and apply

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them to erosion empirical models (Gyssels et al., 2005; Hao et al., 2020). However, in-depth research needs to be explained from the perspective of physical mechanisms, which not only helps to deeply explain the erosion mechanism, but also helps to connect with existing typical erosion models. At present, there is still relatively little research in this area. In addition, due to the fact that erosion research mainly focuses on bare land (Wei et al., 2007, 2008, 2009) and there are few major grassland erosion research projects, there are fewer models for grassland erosion. The most representative grassland model is RHEM, which is established using flow and rainfall intensity as parameters (Wei et al., 2007, 2008, 2009). Different from WEPP, USLE and other erosion models, RHEM is a model built using only grassland erosion data (Wang et al., 2021b). However, the simulation effect of RHEM in application is average (Panagos et al., 2015; Nouwakpo et al., 2016), and RHEM may still need to be improved and attempted in terms of parameters (Nouwakpo et al., 2016; Wang et al., 2021b). The coverage parameter is added to RHEM after modification. This study deeply analyzes the mechanism of grassland erosion from the perspective of changes in erosion dynamics and erosion resistance; On the other hand, using experimental data to establish a RHEM model and comparing the simulation effects of the modified RHEM model.

Materials and methods

A total of 108 rainfall events (see *Table 1*). The cumulative EM (Erosion modulus) is the sum of the erosion rate measured during each sampling event, multiplied by time per unit area in the runoff time. The instruments and measurement procedures used to obtain the experimental data were the same as in previous studies (Wang et al., 2021a, b). The REM under a specific slope and rainfall intensity is calculated as EM of a bare soil minus the EM of soil with the given cover, divided by the EM of the bare soil. The RK under a specific slope and rainfall intensity is calculated from the erodibility of bare soil minus the erodibility of the soil with the given cover, divided by the erodibility of bare soil. The Rω under a specific slope and rainfall intensity is calculated as the stream power on bare soil at the given slope, minus the stream power of the given cover and slope, divided by the stream power on bare soil at the given slope. All statistical analyses were carried out using Excel or SPSS 18.0.

Table 1. *Experiment design*

S (°)	I (mm/min)	C (%)	Replicates	unit
15	0.7, 1.0, 1.5, 2.0, 2.5	0, 30, 40, 50, 60, 70	2	60
7, 10, 15, 20, 25	1.5	0, 30, 40, 50, 60, 70	2	60
Remark	12 units were repeated			
Total				108

S is slope, °; I is rainfall intensity, mm/min; C is cover, %

The shear stress (Nearing et al., 1991), stream power (Prosser and Rustomji, 2000) and unit stream power (Wang et al., 2016) are calculated as Related research. The contribution of independent variables to the dependent variable is calculated as follows:

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$$O_i = \frac{\mathrm{R}^2}{\sum_{i=1}^{n} \beta_i^2} \times 100\% \qquad \text{(Eq.1)}$$

where O_i is the contribution of the ith factor; R^2 is the multiple correlation coefficient, $\beta_i^2 = b_i \frac{\sigma_i}{\sigma_y}$, b_i is the regression coefficient of the ith factor, σ_i is the mean square deviation of the ith factor and σ_y is the mean square deviation of the dependent variable. The following statistical parameters were used to evaluate the performance of the simulated results:

$$NSE = \frac{\sum (O_i - P_i)^2}{\sum (O_i - \bar{O})^2} \qquad \text{(Eq.2)}$$

where NSE is the Nash–Sutcliffe efficiency index (Nash and Sutcliffe, 1970), O_i is the measured value, P_i is the predicted value, $\bar{O}$ is the average measured value, $\bar{P}$ is the average predicted value, and N is the number of samples.

Results

Effect of herbaceous vegetation on Rω

The relationship between the EM and shear stress or stream power under different cover densities can be defined by power equations (*Table 2*). The R^2 of the equations are large (generally greater than 0.95), and the value of the R^2 for a given shear stress equation is less than that calculated for a stream-power equation under the same conditions. Hence, stream power is the best for describing interrill erosion among the three hydraulic parameters considered.

Grass affects stream power is mainly through grass cover and stem basal cover. The calculation under different rainfall intensities showed contribution rates of 82.86%-97.51%, and1.48%-14.82% (*Table 3*). Similarly, the calculation under different slopes showed contribution rates of 86.36%-97.51%, and 1.48%-20.44% (*Table 4*). Further analysis showed the regulation effect of grass on stream power is mainly achieved by grass cover.

Table 2. *Effect of herbaceous vegetation on the relationship of EM and the hydraulic parameters*

C (%)	Empirical equation	R^2	Empirical equation	R^2	Empirical equation	R^2
0	$EM = 9.454\tau^{1.458}$	0.921	$EM = 50.10\omega^{1.099}$	0.956	EM = 0.948ln(U) + 4.545	0.486
30	$EM = 5.457\tau^{1.274}$	0.899	$EM = 52.81\omega^{1.127}$	0.967	EM = 0.958ln(U) + 4.532	0.535
40	$EM = 4.674\tau^{1.270}$	0.903	$EM = 58.45\omega^{1.167}$	0.967	EM = 0.924ln(U) + 4.368	0.559
50	$EM = 4.067\tau^{1.254}$	0.915	$EM = 59.29\omega^{1.186}$	0.960	EM = 0.897ln(U) + 4.226	0.608
60	$EM = 3.624\tau^{1.283}$	0.906	$EM = 71.26\omega^{1.256}$	0.958	EM = 0.838ln(U) + 3.967	0.612
70	$EM = 3.394\tau^{1.318}$	0.931	$EM = 84.72\omega^{1.332}$	0.934	EM = 0.757n(U) + 3.598	0.624

The significance level of the equation is 0.01

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Table 3. *Relationships of reduction percentage of stream power with grass cover and Phytyl cover under different rainfall intensities*

I (mm/min)	Empirical equation	R^2	F test	Contributions rate (%)	
				GC	PC
0.7	Rω=0.343Ln(GC)-0.042Ln(PC)+0.499	0.998	$F=853>F(2,2)_{0.01}=99$	97.16	2.73
1.0	Rω=0.457Ln(GC)-0.075Ln(PC)+0.614	0.935	$F=14>F(2,2)_{0.1}=9$	89.12	4.46
1.5	Rω=0.209Ln(GC)-0.019Ln(PC)+0.326	0.989	$F=98>F(2,2)_{0.05}=19$	97.51	1.48
2.0	Rω=0.278Ln(GC)-0.0426Ln(PC)+0.312	0.999	$F=1947>F(2,2)_{0.01}=99$	95.79	4.16
2.5	Rω=0.272Ln(GC)-0.143Ln(PC)+0.459	0.977	$F=70>F(2,2)_{0.05}=19$	82.86	14.82

Rω is reduction percentage of stream power, %; GC is grass cover, %. PC is Phytyl cover, %

Table 4. *Relationships of reduction percentage of stream power with grass cover and Phytyl cover under different slopes*

S (°)	Empirical equation	R^2	F test	Contributions rate (%)	
				GC	PC
7	Rω=0.236Ln(GC)-0.031Ln(PC)+0.340	0.999	$F=719>F(2,2)_{0.01}=99$	96.70	3.16
10	Rω=0.263Ln(GC)-0.062Ln(PC)+0.283	0.999	$F=2526>F(2,2)_{0.01}=99$	90.66	9.30
15	Rω=0.209Ln(GC)-0.019Ln(PC)+0.326	0.989	$F=98>F(2,2)_{0.05}=19$	97.51	1.48
20	Rω=0.434Ln(GC)-0.12Ln(PC)+0.389	0.986	$F=68>F(2,2)_{0.05}=19$	86.36	12.20
25	Rω=0.133Ln(GC)+0.05Ln(PC)+0.470	0.986	$F=70>F(2,2)_{0.05}=19$	78.17	20.44

Rω is reduction percentage of stream power, %; GC is grass cover, %. PC is Phytyl cover, %

Effect of herbaceous vegetation on RK

In a fundamental sense, soil erodibility should be defined as the amount of soil loss per unit of exogenic force or erosivity, such as rainfall, surface flow and seepage. Stream power is the best hydraulic parameter to describe interrill erosion, among the three hydraulic parameters calculated. As discussed above, soil erodibility is calculated though the erosion rate as a function of stream power.

Table 5 shows the following: RK was positively related to root length (RL), root surface area (SA), and root volume (RV) with good correlation. The correlation coefficient was in the range of 0.916-0.950. *Table 6* shows the following: reduction of soil erodibility was positively related to organic matter (OM), < 0.002 particle composition (PG), soil bulk density (SD), and soil porosity (SP) with good correlation. The correlation coefficient was in the range of 0. 939-0.961. Moreover, R^2 of the correlation between RK and SD is 0.944, which is slightly larger than R^2 of SP with 0.939. Therefore, Grass affects soil erodibility is mainly through root volume and soil bulk density. The relationship between the RK and RV, and SD can be described with binary logarithmic equations. The calculation under different slopes showed contribution rates of 73.61%-97.94, and 0.04%-0.22% (*Table 7*). Further analysis showed the regulation effect of grass on soil erodibility is mainly achieved by root volume, and the control effect by soil bulk density is minimal.

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Tables 5. *Pearson correlation analysis between RK and root characteristics*

	RL	**RA**	**RV**	**RD**	**RW**	**RK**
RL	1	0.998**	0.991**	0.497	0.973**	0.916*
RA	0.998**	1	0.998**	0.545	0.962**	0.933*
RV	0.991**	0.998**	1	0.599	0.943*	0.950*
RD	0.497	0.545	0.599	1	0.301	0.790
RW	0.973**	0.962**	0.943*	0.301	1	0.800
RK	0.916*	0.933*	0.950*	0.790	0.800	1

**Significant correlation at 0.01 level. *Significant correlation at 0.05 level. RL: Root length, RA: The average root surface area, RV: The average root volume, RD: The average root diameter, RW: Root dry weight, RK: Reduction of soil erodibility

Tables 6. *Pearson correlation analysis between RK and soil characteristics*

	OM	**PG**	**SD**	**SP**	**RK**
OM	1	-0.968**	0.996**	-0.996**	-0.960**
PC	-0.968**	1	-0.948*	0.948*	0.961**
SD	0.996**	-0.948*	1	-1.000**	-0.944*
SP	-0.996**	0.948*	-1.000**	1	0.939*
RK	-0.960**	0.960**	-0.944*	0.939*	1

**Significant correlation at 0.01 level. *Significant correlation at 0.05 level. OM: Organic matter, PG: < 0.002 particle composition, SD: Soil bulk density, SP: Soil porosity, RK: Reduction percentage of soil erodibility

Table 7. *Relationships of reduction percentage of soil erodibility with root volume and soil bulk density under different slopes*

Slope (°)	**Empirical equation**	**R^2**	**F test**	**Contributions rate (%)**	
				RV	**SD**
7	RPK=0.131Ln(RV)+0.035Ln(SD)-0.288	0.980	$F=348>F(2,2)_{0.05}=19$	97.94	0.06
10	RPK=0.061Ln(RV)-0.323Ln(SD)+0.161	0.958	$F=22.>F(2,2)_{0.05}=19$	95.58	0.22
15	RPK=0.098Ln(RV)-0.210Ln(SD)-0.02	0.908	$F=226>F(2,2)_{0.01}=99$	90.74	0.04
20	RPK=0.123Ln(RV)+0.044Ln(SD)-0.388	0.969	$F=30>F(2,2)_{0.05}=19$	96.75	0.10
25	RPK=0.0168Ln(RV)-0.079Ln(SD)+0.025	0.738	$F=3>F(2,2)_{0.3}=2$	73.61	0.14

RPK is reduction percentage of soil erodibility, %; RV is root volume, cm^3; SD is soil bulk density, g/cm^3

Contributions of R ω and RK to REM

The results described in the present study indicate that the relationship between REM and stream power or soil erodibility could explain the mechanism, by which the herbaceous vegetation cover affects interrill erosion, as indicated in the following equation:

$$REM = 0.95R\omega + 0.79RK + 0.11 \quad \text{(Eq.3)}$$
$$(R^2 = 0.95,\ Sig < 0.01;\ F(2,42) = 365.53 > F(2,42)_{0.01} = 5.15)$$

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where REM is the reduction of erosion modulus (%), Rω is the reduction of stream power (%) and RK is the reduction of soil erodibility (%). *Equation 5* indicates that the relationship between the REM and the Rω or RK could be linear. In addition, *Equation 5* shows a positive correlation between the REM and the Rω or RK, thus supporting the hypothesis that herbaceous vegetation could effectively decrease interrill erosion by decreasing the stream power. The contributions of the decreasing stream power and soil erodibility to the decreasing interrill erosion are 61.02% and 33.55%, respectively, totaling to 94.57%. This finding indicates that herbaceous vegetation decreases the interrill erosion mainly by decreasing the stream power.

Simulation of grassland sheet erosion

In previous studies, flow discharge and rainfall intensity were often used to simulate sheet erosion, but the RHEM has always been a difficult point in the simulation (Wei et al., 2009; Wang et al., 2021b). In this study, the power function of flow discharge and rain intensity was used to simulate sheet erosion (*Fig. 1*), and 10% of the data were used for testing. In addition, the cover is added to *Equation 4* to optimize the RHEM. The established model and simulation effect are shown in *Equation 5* and *Figure 2*.

$$\text{RHEM: } SE = 1.26 \times 10^{-8} I^{2.52} q^{-0.74}$$
$$(R^2 = 0.718,\ Sig < 0.01;\ F(2,72) = 91.59 > F(2,72)_{0.01} = 4.91);\ NSE = 0.558 \qquad \text{(Eq.4)}$$

$$\text{Modified RHEM: } SE = 1.66 \times 10^{-13} I^{3.54} q^{-1.55} C^{-0.89}$$
$$(R^2 = 0.855,\ Sig < 0.01;\ F(3,71) = 139.72 > F(3,71)_{0.01} = 4.07);\ NSE = 0.700 \qquad \text{(Eq.5)}$$

In the formula: SE-sheet erosion rate, $kg.m^{-2}.s^{-1}$; q- flow discharge, $m^2.s^{-1}$; I-rain intensity, $mm.min^{-1}$; C-coverage, %. It can be seen from the above formula that the efficiency coefficient NSE of the Modified RHEM established by rain intensity, flow discharge and cover is 0.142 larger than the efficiency coefficient NSE of the RHEM established by rain intensity and flow discharge, and the efficiency coefficient NSE of the Modified RHEM established by rain intensity and flow discharge is less than 0.6. It can be seen that the Modified RHEM established by rainfall intensity, flow discharge and cover is more suitable, and it is not advisable to establish the grassland sheet erosion model only with rain intensity and flow discharge.

Discussion

Sheet erosion mechanism of grassland slope under steep slope conditions

The results of this experiment show that the contribution of grass to Rω mainly comes from grass cover and planting cover which is same to the previous research (Li and Pan, 2018). The blade of grass has a positive effect on the flow rate of the water flow (Perkins et al., 2018; Hao et al., 2020), but the grass base cannot display the double effect of the grass cover. Therefore, the contribution of grass cover to the impact of Rω is significantly greater than that of planting.

Further analysis of the correlation between vegetation characteristics and RK shows that the contribution of grass to RK mainly comes from grass root volume and soil bulk density, which is different from previous research (Chau and Chu, 2017). Because the effect of root consolidation soil can achieve the best effect in a short time (Shaurav et

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al., 2018), and the roots need to improve soil properties for a long time and change little, so the contribution of grass root volume to RK is much greater than the contribution of soil bulk density to RK.

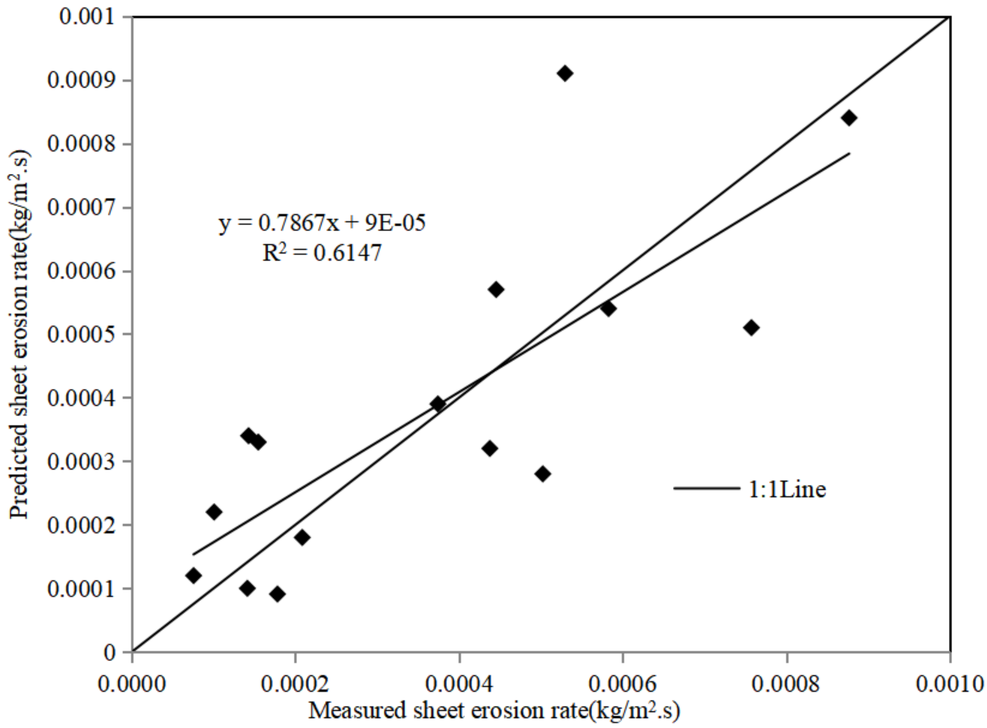

Figure 1. *Measured versus modeled SE (SE = 1.26 ×10^{-8}I$^{2.52}$q$^{-0.74}$)*

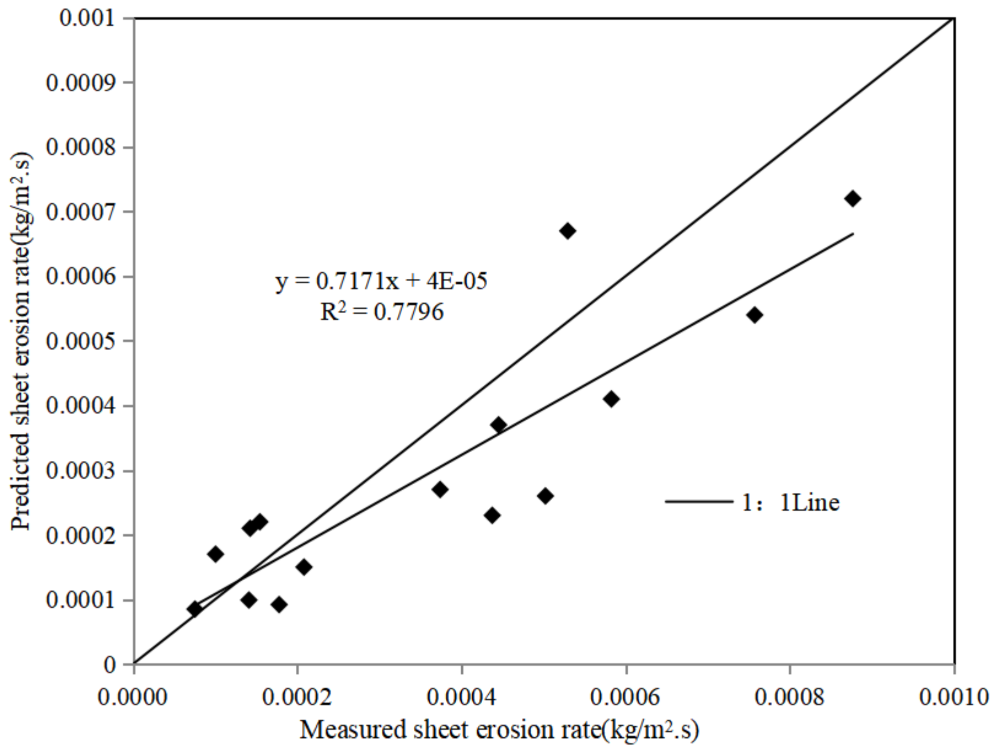

Figure 2. *Measured versus modeled SE (SE = 1.66 ×10^{-13}I$^{3.54}$q$^{-1.55}$C$^{-0.89}$)*

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Reflection on grassland erosion models from the perspective of grassland erosion mechanism

The overall impact of vegetation on water flow power, and the presence of vegetation will have an impact. And underground grass roots affect soil erodibility by improving soil properties (Geng et al.,2017), and require long-term improvement to produce results. So the effect of grass cover reducing erosion rate by reducing water flow power is greater than that of grass cover reducing erosion rate by reducing erodibility. From the perspective of erosion mechanism, it can be seen that the parameters in the erosion model should represent the total energy of erosion and the energy consumption of grass on erosion, while the parameters in RHEM only represent the total energy of erosion, and the parameter coverage in modified RHEM to consider the erosion consumption rate and erosion kinetic energy. However, although the modified RHEM simulation effect has increased, it still needs improvement, and the optimization and characterization of grass characteristics should be a breakthrough point (Guo et al., 2019, 2020).

Conclusion

The change in grassland erosion is mainly controlled by the overall reduction of water flow power by vegetation, contributing 61.02%. The root fractal dimension contributed the most to the water reducing effect of grass. The parameters of the erosion model should represent rainfall, vegetation, and soil characteristics. The simulation effect of a revised RHEM established by adding Parameters of grassland coverage is better than the RHEM. This study deeply elucidates the mechanism of grassland erosion and establishes a revised RHEM. The study will provide important guidance for the evaluation and prediction of the virtuous cycle of grassland material and energy, optimize global grassland use and management, and assist in the development of carbon reduction on Earth.

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Conflict of interests. The author(s) declare no competing interests.

Data availability statement. The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

REFERENCES

[1] Bochet, E., Poesen, J., Rubio, J. L. (2006): Runoff and soil loss under individual plants of a semi-arid mediterranean shrubland: influence of plant morphology and rainfall intensity. – Earth Surface Processes Landforms the Journal of the British Geomorphological Research Group 31(5): 536-549.

[2] Chau, N. L., Chu, L. M. (2017): Fern cover and the importance of plant traits in reducing erosion on steep soil slopes. – Catena. https://doi.org/10.1016/j.catena.2016.12.016.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_58755884

[3] Wang, D. D., Wang, Z. L., Zhang, Q. W., Zhang, Q. L., Tian, N. L., Liu, J. E. (2018): Sheet erosion rates and erosion control on steep rangelands in loess regions: sheet erosion rates and erosion control on steep rangelands. – Earth Surface Processes and Landforms 43. https://doi.org/10.1002/esp.4460. Vegetation influences on infiltration in Hawaiian soils

[4] Wang, D. D., Yuan, Z. J., Jing, D. W., Zhao, C. Y. (2021a): Response of Grassland Slope Erosion to Vegetation Characteristics. – IOP Conference Series: Earth and Environmental Science 668(1): 012013.

[5] Wang, D. D., Yuan, Z. J., Cai, Y. T., Jing, D. W., Liu, F., Tang, Y., Song, N. N., Li, Y. Y., Zhao, C. Y., Fu, X. Y. (2021b): Characterisation of soil erosion and overland flow on vegetation-growing slopes in fragile ecological regions: a review. – Journal of Environmental Management 285: 112165-112165.

[6] Geng, R., Zhang, G. H., Ma, Q. H., Wang, H. (2017): Effects of landscape positions on soil resistance to rill erosion in a small catchment on the Loess Plateau. – Biosystems Engineering 160: 95-108.

[7] Guo, M. M., Wang, W. L., Shi, Q. H., Chen, T. D., Kang, H. L., Li, J. M. (2019): An experimental study on the effects of grass root density on gully headcut erosion in the gully region of China's Loess Plateau. – Land Degradation & Development 30(17): 2107-2125.

[8] Guo, M. M., Wang, W. L., Wang, T. C., Wang, W. X., Kang, H. L. (2020): Impacts of different vegetation restoration options on gully head soil resistance and soil erosion in loess tablelands. – Earth Surface Processes and Landforms 45(4): 1038-1050.

[9] Gyssels, G., Poesen, J., Bochet, E., Li, Y. (2005): Impact of plant roots on the resistance of soils to erosion by water: a review. – Progress in Physical Geography 29(2): 189-217.

[10] Hao, H. X., Wei, Y. J., Cao, D. N., Guo, Z. L., Shi, Z. H. (2020): Vegetation restoration and fine roots promote soil infiltrability in heavy-textured soils. – Soil & Tillage Research 198: 104542-104542.

[11] Kimiti, D. W., Riginos, C., Belnap, J. (2017): Low-cost grass restoration using erosion barriers in a degraded African rangeland. – Restoration Ecology 25(3): 376-384.

[12] Li, C., Pan, C. (2018): The relative importance of different grass components in controlling runoff and erosion on a hillslope under simulated rainfall. – Journal of Hydrology 558: 90-103.

[13] Liu, Y., Song, H. M., An, Z. S., Sun, C. F., Trouet, V., Cai, Q. F., Liu, R. S., Leavitt, S. W., Song, Y., Li, Q., Fang, C. X., Zhou, W. J., Yang, Y. K., Jin, Z., Wang, Y. Q., Sun, J. Y., Mu, X. M., Lei, Y., Wang, L., Li, M. R., Cui, L. L., Zeng, X. L. (2020): Recent anthropogenic curtailing of Yellow River runoff and sediment load is unprecedented over the past 500 y. – Proceedings of the National Academy of Sciences 117(31): 201922349.

[14] Ma, Z. G., Fu, C. B., Zhou, T. J., Yan, Z.W., Li, M. X., Zheng, Z. Y., Chen, L., Lv, M. X. (2020): Status and ponder of climate and hydrology changes in the Yellow River Basin. – Bulletin of the Chinese Academy of Sciences 1: 52-60.

[15] Nash, J., Sutcliffe, J. V. (1970): River flow forecasting through conceptual models part I–A 412 discussion of principles. – J. Hydrol. 10(3): 282-290.

[16] Nearing, M. A., Bradford, J. M., Parker, S. C. (1991): Soil detachment by shallow flow at low slopes. – Soil Science Society of America Journal 55(2): 351-357.

[17] Nouwakpo, S. K., Weltz, M., Hernandez, M., Champa, T., Fisher, J. (2016): Performance of the Rangeland Hydrology and Erosion model for runoff and erosion assessment on a semiarid reclaimed construction site. – Journal of Soil & Water Conservation71(3): 220-236.

[18] Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., Alewell, C. (2015): The new assessment of soil loss by water erosion in Europe. – Environmental Science & Policy 54: 438-447.

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DOI: http://dx.doi.org/10.15666/aeer/2206_58755884

[19] Perkins, S. K., Stock, D. J., Nimmo, R. J. (2018): Vegetation influences on infiltration in Hawaiian soils. – Ecohydrology 11(5): 1.
[20] Prosser, I. P., Rustomji, P. (2000): Sediment transport capacity relations for overland flow. – Prog. Phys. Geogr. 24: 179-193.
[21] Puigdefabregas, J. (2005): The role of vegetation patterns in structuring runoff and sediment fluxes in drylands. Earth Surf. – Processes Landforms 30(2): 133-147.
[22] Rey, F. (2003): Influence of vegetation distribution on sediment yield in forested marly gullies. – Catena 50(2): 549-562.
[23] Shaurav, A., Banjara, A., Wang, J., William B. P., Patterson，S. (2018): Novel approach in sampling and tensile strength evaluation of roots to enhance soil for preventing erosion. – Open Journal of Soil Science 8(12): 330-349.
[24] Usman, S., Noma, S. S., Kudiri, A. M. (2016): Dynamic surface soil components of land and vegetation types in Kebbi State Nigeria. – Eurasian Journal of Soil Science 5(2): 113-120.
[25] Wainwright, J., Parsons, A. J., Schlesinger, W. H. (2002): Hydrology vegetation interactions in areas of discontinuous flow on a semi-arid Bajada, southern New Mexico. – J. Arid Environ. 51(3): 319-338.
[26] Wang, D. D., Wang, Z. L., Shen, N., Chen, H. (2016): Modeling soil detachment capacity by rill flow using hydraulic parameters. – Journal of Hydrology 535: 473-479.
[27] Wei, H. Y., Nearing, M. A., Stone, J. J. (2007): A comprehensive sensitivity analysis framework for model evaluation and improvement using a case study of the rangeland hydrology and erosion model. – Trans. ASABE 50(3): 945-953.
[28] Wei, H. Y., Nearing, M. A., Stone, J. J., Breshears, D. D. (2008): A dual Monte Carlo approach to estimate model uncertainty and its application to the Rangeland Hydrology and Erosion Model. – Trans. ASABE 51(2): 515-520.
[29] Wei, H. Y., Nearing, M. A., Stone, J. J., Guertin, D. P., Spaeth, K. E., Pierson, F. B., Nichols, M. H., Moffett, C. A. (2009): A new splash and interrill erosion equation for rangelands. – SSSA J. 73(4): 1386-1392.
[30] Williams, R. E., Allred, B. E., Denio, R. M., Paulsen, H. A. (1968): Conservation, development, and use of the world's rangeland. – J. Range Manage. 21: 355-360.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_58755884