https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022


Hydrology and Earth System Sciences
Discussions

# Investigating the effects of herbaceous root types on the soil detachment process at the species level

Jian-Fang Wang[a], Bing Wang[a, b], Yan-Fen Yang[a, b*], Guo-Bin Liu [a, b], Feng-Bao Zhang [a, b], Nu-Fang Fang [a, b]

a State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Northwest A&F University, Yangling, Shaanxi, 712100, PR China

b University of Chinese Academy of Sciences, Beijing, 100049, China

## HIGHLIGHTS

The effects of plant roots on soil detachment were detected at the species level.

The efficiency of a fibrous root system in reducing soil detachment is 25% higher than that of a tap root system.

Root length density can effectively reflect the effects of root type on soil detachment.

*Correspondingauthorat:StateKeyLaboratoryofSoilErosionandDrylandFarmingontheLoessPlateau, InstituteofSoilandWaterConservation,NorthwestA&FUniversity,Yangling, Shaanxi 712100, PR China.
E-mail addresses: w18691866409@163.com, yfyang@ms.iswc.ac.cn (Y.-F. Yang).
First author: (Jian-Fang Wang)

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022


Hydrology and Earth System Sciences
Open Access
EGU
Discussions

## Abstract

The changes in soil properties and root traits caused by plant growth might have great effects on the process of soil detachment by overland flow. On this basis, two typical herbaceous plants, *Bothriochloa ischcemum* (Linn.). Keng (BI; fibrous root system) and *Artemisia vestita* Wall. ex Bess (AG; tap root system), from the Loess Plateau were studied for one year under six planted densities of 5 plants $m^{-2}$, 10 plants $m^{-2}$, 15 plants $m^{-2}$, 20 plants $m^{-2}$, 25 plants $m^{-2}$, and 30 plants $m^{-2}$ to determine how the soil detachment rate responds to soil properties and plant root traits. In total, 24 steel tanks were planted, and two plots were used as bare soil controls. Their soil detachment rates were tested under a constant overland flow (1.5 l $s^{-1}$) on a 26.2% slope. The results showed that the soil detachment rate under the six planted densities ranged from 0.034 kg $m^2$ $s^{-1}$ to 0.112 kg $m^2$ s-1 for BI and was ranged from 0.053 $m^2$ $s^{-1}$ to 0.132 $m^2$ $s^{-1}$ for AG, which all greatly reduced soil detachment rate and were 68.17% to 92.33% and 69.20% to 87.27% less than that of the control. In general, BI was more effective in reducing the soil detachment rate than AG, achieving a mean soil detachment rate that was 23.75% lower. With increasing plant density, the soil detachment rate decreased as a power function ($R^2 = 0.23$, $p < 0.01$). The overland flow hydraulic characteristics, soil properties and root traits influenced by plant density were positively or negatively correlated with the soil detachment rate. Specifically, the soil detachment rate decreased with velocity, bulk density, root length density, and increased with shear stress and the Darcy–Weisbach friction factor as power or exponential functions ($R^2$ ranged from 0.16 to 0.54, $p < 0.01$). On this basis, the soil detachment rate ($D_r$) can be satisfactorily estimated by the overland flow velocity ($v$), soil bulk density (BD) and root length density (RLD) as a power function ($Dr = 5.636v^{0.118} \times BD^{-19.917} \times RLD^{-0.170}$;$R^2 = 0.58$; $NSE = 0.78$; $p < 0.01$).

**Key words:** soil detachment rate, root length density, overland flow, tap root system, fibrous root system, Loess Plateau

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022




## 1 Introduction

Soil erosion is a serious threat to land productivity and sustainability in both natural and human-managed ecosystems (Su et al., 2014; Fu et al., 2000; Li et al., 2015). Traditionally, soil erosion is affected by hydrology, soil, and vegetation (Foster, 1982), for which conservation tillage, vegetation and engineering measures are used to control soil loss (Rickson, 2014; García-Ruiz et al., 2015). The process of soil erosion as a result of rainfall or overland flow includes soil detachment (Wang and Zhang, 2017), sediment transport, and deposition (Ellison, 1947; Wu et al., 2018). Nearing et al. (1999) defined soil erosion as the dislodging of soil materials from their current place at a given time and area. soil detachment rate is a key parameter for both conceptually and physically based soil erosion models, as changes in soil detachment rate and sediment load determine whether the soil detaches or deposits (Nearing et al., 1989). For instance, in the conceptually based Areal Nonpoint Source Watershed Environment Response Simulation model (Beasley et al., 1980), and in the physically based models of Water Erosion Prediction Project model (Nearing et al., 1999) and European Soil Erosion Model (Morgan et al., 1998). In these soil erosion and sediment transport models, the hydrological part of the runoff process is simulated, which is the prerequisite or driving force for the occurrence of soil detachment.

The hydraulic characteristics of overland flow, which is affected by the hydrological elements of precipitation, vegetation water holding, soil infiltration, and evaporation, have a significant effect on soil detachment (Jonge L, et al., 2017). In general, the soil detachment rate increases with flow discharge, runoff depth, or flow velocity as a linear or power function (Zhang et al., 2002). In addition, the hydraulic parameters of shear stress, stream power, and unit stream power are normally used to simulate soil detachment processes. With increasing shear stress, stream power, and unit stream power, the soil detachment rate decreases (Nearing et al., 1991; Hairsine and Rose, 1992a, b; Zhang et al., 2002; Morgan et al., 2002). The effects of runoff hydraulics characteristics on soil erosion are generally detected under given conditions.

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022



In fact, runoff hydraulic parameters vary in the process of soil scouring by overland flow, and these variations might be more closely related to soil detachment during soil erosion. However, existing studies have not sufficiently determined these relationships. Soil property is an inherent characteristic of soil mass and determines the ability of soil to resist overland flow detaching. The soil texture or type of soil particle distribution, soil physical property of bulk density, cohesion, aggregate stability, soil hydrological properties of infiltration capacity, and soil organic matter all affect the soil detachment process (Su et al., 2014; Knapen et al., 2007; Ye et al., 2017). In addition, soil moisture is critical for estimating the infiltration rate and quantity of runoff generated during rainfall, which greatly affects the soil detachment process (Lee and Kim; 2021). Overall, with increasing clay content, bulk density, cohesion, water stable aggregates, aggregate median diameter, and organic matter content (Wang et al., 2018a; Vannoppen et al., 2017), and decreasing silt content and soil moisture, the soil detachment rate decreases (Knapen et al., 2007; Nachtergaele and Poesen, 2002).

Vegetation can effectively reduce soil erosion and is often used as a biological measure to control soil and water loss (Labriere et al., 2015; Liu et al., 2020; Burylo et al., 2014). The reduction in soil detachment as a result of vegetation is at least half attributed to the plant root system (Wang et al. 2014). The primary mechanism for plant roots to reduce soil detachment is the root system binding to the soil mass and thereby reinforcing the soil mass, which is called a root binding effect (De Baets et al., 2006; Knapen et al., 2007; Herbrich et al., 2018). In general, soil has high compression strength and low tensile strength, whereas plant roots exhibit the opposite properties (Simon and Collison., 2001). Thus, when a root interweaves into a soil mass during plant growth, the soil-root matrix has both high compression strength and tensile strength, intensifying the soil's resistance to flowing water (Xin et al., 2016). Roots also exudate secretions to stick to soil mass, which contributes to root bonding effects (Godo et al., 1980). The effects of plant roots on soil erosion are also varied due to the root types. For example, plants with fibrous root systems generally have many fine roots on the topsoil, giving them an erosion-reducing potential that is much more significant

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022




than that of tap root systems, which have large roots and fewer fine roots (Mamo and Bubenzer, 2001a, b). Wang and Zhang (2017) found that the soil detachment rate in grasslands with mainly tap root systems was as much as 14.7 times higher than that of grasslands with mainly fibrous root systems.

The effects of root type differences on reducing soil detachment are reflected by the root traits of biomass and root morphology, including root mass density, root diameter, root length density, root surface area density, and root volume density. Previous studies have mostly used root mass density to quantify the effect of roots on soil detachment as it is easy to test. These studies show that the soil detachment rate decreases exponentially with increasing root mass density (Gyssels and Poesen, 2003). Root biomass is often highly correlated with morphological traits, enabling it to represent, to a large extent, certain morphological traits. These indexes have a good quantitative relationship with soil erosion. However, root biomass does not reflect soil erosion caused by root morphology well when the plant species vary and their root morphological traits of length, thickness, number, surface area, and volume are significantly different, especially at the species level. Therefore, root morphological traits should also be considered when simulating soil erosion, as they better indicate how plant roots affect the process of soil erosion. Previous studies have shown that the soil detachment rate decreases exponentially with root length density, root surface area density, and root volume density (De Baets et al. 2006; Zhou and Shang Guan. 2005; Ye et al. 2017). Plant roots also extrude soil masses and increase soil porosity during growth, and these effects are more apparent when the root diameter increases (Simon and Collison, 2001). Nevertheless, no significant relationship has been found between root diameter and the soil erosion rate (Vannoppen et al., 2015). According to the effective root density, which is a different expression of root diameter that refers to the number of roots with a diameter less than 1 mm in a certain soil cross-section, a negative correlation was found between root diameter and soil erosion rate (Li et al., 1991). In addition, plant root morphological traits are used in hydraulic root architecture models for plants that uptake water from the soil, indirectly influencing the soil erosion process

(Gayler et al., 2013). Whether the root system directly affects soil erosion or indirectly affects soil erosion. Their effects of root morphological traits on soil erosion are obvious.

Previous studies have examined the efficacy of plant root systems in reducing soil erosion and quantified the relationship between root traits and soil erosion rate based on root type and distribution (including the indirect effects on soil erosion via changing soil properties). However, most of these studies are still staying at vegetation community of different land use type. Thus, the effects of different species on reducing soil erosion remain unclear. To date, some hydraulic root architecture models have considered root water uptake and soil water distribution at the species level, which also affect the runoff process (Quijano et al., 2015). Studying the effects of plant root system on soil erosion at the species level is necessary to determine the mechanism of regional vegetation measures on controlling soil erosion. Although little work has been conducted to specifically study the effects of plant root systems on soil erosion at species level, soil samples are usually collected from natural grasslands and inevitably contain surrounding plant roots, which means the sample likely includes both plants with a tap root system and those with a fibrous root system. These studies seem to return to the community level of previous studies. Therefore, further studies about the effectiveness of plant root system in reducing soil erosion at species level was still needed, which would have great advantages for clarifying the effects of plant root system on controlling soil erosion and improving the accuracy of soil erosion model.

The Loess Plateau is an ecological security barrier of China, and is one of the most severely eroded regions in the world, with mean annual erosion rates ranging from 5000 Mg km$^{-2}$ yr$^{-1}$ to 10000 Mg km$^{-2}$ yr$^{-1}$ over the past twenty years.(Fu et al., 2000; Zheng, 2020). To control soil erosion, the “Grain for Green” plan was implemented in 1999 and vegetation began to succeed naturally. Meanwhile, grassland became the primary land use type (Li et al., 2015) and has variety of vegetation community. Among the species present, the zonal species is BI and the dominant species is AG. Therefore, it is necessary to determine the mechanism of a varied plant root system on soil erosion processes at the species level on the Loess Plateau, especially regarding the essential

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022



vegetation species. This research is also important for studying the response of hydrology processes to soil erosion induced by vegetation recovery. Therefore, the zonal species of BI with a fibrous root system and the dominant species of AG with a tap root system on the Loess Plateau were selected and planted under six densities to 1) illustrate varying soil properties and root traits and the corresponding variation in hydraulic characteristics of overland flow and soil detachment rates; 2) study the effects of hydraulic characteristics, soil properties, and root traits on soil detachment processes; and 3) estimate the soil detachment rate by developing a model based on hydraulic parameters, soil properties, and plant root traits.

## 2 Materials and methods

### 2.1 Experimental conditions and treatment design

The experiment was conducted in the Rainfall Hall of the State Key Laboratory of Soil Erosion and Dryland Agriculture on the Loess Plateau, Institute of Soil and Water Conservation, Ministry of Water Resources & Chinese Academy of Sciences at YangLing, Shaanxi Province. Clean water and other relevant facilities were provided for the scour process. To detect the effects of plant root systems on the soil detachment process, two typical herbaceous plants, BI and AG, were planted in steel tanks under six different planted densities of 5 plants $m^{-2}$, 10 plants $m^{-2}$, 15 plants $m^{-2}$, 20 plants $m^{-2}$, 25 plants $m^{-2}$, and 30 plants $m^{-2}$. These densities represent differences in root traits and their corresponding effects on soil properties. In addition, a bare soil was selected as the control, representing the response of the loessal soil to the soil detachment process without the influence of herbaceous plants.

### 2.2 Planting herbaceous plants

Herbaceous plants were planted in steel tanks under six different planting densities, for which each planting density was repeated twice. In total, twenty-four steel tanks were used for planting. Each steel tank was 2.0 m in length, 0.5 m in width and 0.5 m in depth. Before planting, the steel tanks were filled with loessal soil that was collected from the top soil (0 to 40 cm) of an abandoned farmland in Ansai County of the Shaanxi Province. The soil organic matter content was 3.23 g $kg^{-1}$, pH was 8.4, and the particle size distributions of the sand, silt, and clay contents were 31.16%, 59.31%, and 9.53%. Before filling with soil, the slope of the steel tanks was adjusted to zero, and plant roots and other debris were removed from the soil using a 2 mm sieve. For the process of soil filling, 5 cm of sand was laid at the bottom of the steel tanks to ensure that water could penetrate smoothly and evenly. To ensure uniformity in the soil bulk density in the steel tanks, the total soil weight was calculated by the fill volume and the designed bulk density (1.2 g $cm^{-3}$). Then, the prepared soil was divided 4 times to fill the steel tanks. The thickness of the filled soil in each tank was 10 cm. For each layer, the soil surface was raked lightly before packing the next layer to eliminate discontinuity.

For each steel tank, BI and AG were seeded by digging 3 mm apertures in the surface soil at six plant densities. After planting, the plants were watered every two days and the water amount of each tank was 16 mm. To prevent the surface from forming a physical crust, water was applied using a sprayer. Watering ceased when the plants appeared and were left to grow naturally. Weeds were hoed every 10 days during plant growth. Both types of plants experienced an entire growth period from the beginning of April to the end of September (totaling 153 days). During vegetation growth, the active accumulated temperature in the study area was 2184 °C, and the total rainfall amount was 517 mm. For the bare soil control, all the measures were kept the same except no vegetation was planted.

### 2.3 Soil detachment rate measurement process

Each planted steel tank was adjusted to a 26.2% slope and scoured by a constant overland flow (1.5 l $s^{-1}$) to obtain the soil detachment rate. To study the effect of different root systems on the soil detachment rate, the aboveground part of the plants

Hydrology and Earth System Sciences
Open Access
Discussions

under six plant densities was removed, leaving only the root system for the scouring test. A buffering tank with the length in 0.5 m, width in 0.2 m and height in 0.5 m was fixed on top of each steel tank to dissipate the flow energy, allowing water to overflow smoothly and uniformly into the steel tank. The overland flow rate and the slope gradient of the planted steel tank were adjusted to the designed value before scouring. A plastic film was laid on the steel tank to make sure the soil was not scoured by overland flow when calibrating the flow rate, and the difference in flow rate between the designed and practice values was controlled to be within 2%. During scouring, clean water enters the buffering tank and then enters the test soil tank. The velocity of the water flow was measured at a position of 1 m in the middle of the test steel tank using a fluorescent dye technique and was modified by a reduction factor according to certain flow regimes (Luk and Merz, 1992). The flow velocity and water temperature were measured every 5 s. When measuring the flow velocity, runoff and sediment samples were collected using a plastic bucket at sampling points below the catchment area. To reduce the potential effects of soil sampling on experimental results, testing was generally stopped at a certain scouring depth of 2 cm (Nearing et al., 1991; Zhang et al., 2002). Based on the pretest, the experiment lasted for 75 s. After scouring, the collected runoff and sediment were clarified, and the sediment was dried at 105 °Cfor 24 h and weighed to calculate the soil detachment rate (Dr; kg $m^{-2}$ $s^{-1}$).

$$Dr = \frac{M}{At}, \quad [1]$$

where M is dry weight of the sediment (kg), A is scour area ($m^2$), and t is time to receive sediment (s).

The tested mean velocity was used to compute the shear stress (τ, Pa) and Darcy–Weisbach friction as follows:

$$\tau = \rho g h s, \quad [2]$$

$$h = \frac{Q}{VB}, \quad [3]$$

$$f = \frac{8ghs}{V^2}, \quad [4]$$

where ρ is the water density (kg $m^{-3}$), g is the gravitational acceleration (m $s^{-2}$), h is

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022



the overland flow depth (m), s is the tangent of the slope (m m$^{-1}$), Q is the flow discharge (m$^3$ s$^{-1}$), v is the mean flow velocity (m s$^{-1}$), and B is the steel tank width (0.5 m).

### 2.4 Soil properties and root parameter measurements

After scouring for five days, the soil properties were measured via "S" type sampling. Specifically, the bulk density was measured using a steel ring 5 cm in height and 5 cm in diameter. Soil cohesion was determined using an Eijkelkamp pocket vane tester. Soil aggregation was measured via a series of sieves with bore diameters of 0.25 mm, 0.5 mm, 1 mm, 2 mm, and 5 mm, and the soil organic matter content was measured using potassium dichromate. Each soil property measurement was repeated in triplicate for each steel tank, and the soil erodibility was calculated based on the soil organic matter content as:

$$K = \left\{0.2 + 0.3e^{\left[-0.0256S_1\left(1-\frac{S_2}{100}\right)\right]}\right\}\left[\frac{S_2}{n+S_2}\right]^{0.3}\left\{1-\frac{0.25C}{C+e^{(3.72-2.95C)}}\right\}\left\{1-\frac{0.7S_3}{S_3+e^{(-5.51+22.9S_3)}}\right\}, \qquad [5]$$

where $S_1$ is the sand content (%), $S_2$ is the silt content (%), n is the clay content (%), C is the soil organic matter content (g kg$^{-1}$), and $S_3=1-\frac{S_1}{100}$.

After measuring the soil properties, the plant roots in each steel tank were washed. The root length (RL, cm) was measured using a steel ruler (0.1 cm) and root diameter (RD, mm) was measured using electronic Vernier calipers (0.01 mm). Then, the roots were dried at 65 °C for 24 h and weighed to obtain the root mass (RM, kg). The root diameter mean value was weighted by root length. The root surface area (RSA, m$^2$) and volume (RV, m$^3$) were also calculated according to root length and diameter. Based on the steel tank volume, the soil detachment capacity (0.5 m$^3$), the root length density (RLD, km m$^{-3}$), root surface area density (RSAD, m$^2$ m$^{-3}$), root volume density (RVR, m$^3$ m$^{-3}$), and root mass density (RMD, kg m$^{-3}$) were calculated as:

$$RLD = \frac{RL}{V}, \qquad [6]$$

$$RSAD = \frac{RSA}{V}, \qquad [7]$$

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022



$$RVD = \frac{RV}{V}, \quad [8]$$

$$RMD = \frac{RM}{V}. \quad [9]$$

### 2.5 Statistical analysis

Pearson's correlation analyses ($p < 0.05$) and fitted curves were used to analyze and quantify relationships between the soil detachment rate and hydraulic parameters, soil properties, and root traits. In addition, a regression analysis was used to establish a model of soil properties, root traits, and the soil detachment rate. All analyses were conducted using SPSS 22.0 and Origin 2018 software.

## 3 Results

### 3.1 Variation in soil properties under two grasslands

The soil properties of bulk density, cohesion, water stable aggregate, soil organic matter, and soil erodibility (calculated based on the EPIC model) varied greatly between the six planting densities (Table 1). In particular, no significant difference was found between bulk density and plant density, maximum water stable aggregate values occurred when the plant density ranged from 10 plants m$^{-2}$ to 25 plants m$^{-2}$, and the soil organic matter content increased with increasing plant density. The cohesion and soil erodibility of the BI were high when the plant density ranged from 10 plants m$^{-2}$ to 25 plants m$^{-2}$. Meanwhile, the cohesion of AG increased with increasing plant density, and no significant relationship was observed between soil erodibility and plant density. In general, BI, which has a fibrous root system, had high bulk density, cohesion, water stable aggregate contents, and soil organic matter content, and low soil erodibility. Specifically, these soil properties of BI were, respectively, 1.01, 1.02, 1.11, and 1.73 times greater and 7.69% less than those of the AG. Herbaceous plant growth increased soil cohesion, water stable aggregate contents, and soil organic matter, while it decreased the soil bulk density and soil erodibility. The soil bulk density was 1.23 g $cm^{-3}$ for BI and 1.22 g $cm^{-3}$ for, which are 3.15% and 3.94%, respectively, less than that of the control. The soil cohesion values of BI and AG were near 4.60 kPa, and were 1.07 and 1.06, respectively, times greater than that of the control. The soil organic matter content was 10.69 g $kg^{-1}$ for BI and 6.19 g $kg^{-1}$ for AG, which are 3.44 and 1.99 times, respectively, greater than that of the control. Finally, soil erodibility was 0.36 for BI and 0.39 for AG, which are 10% and 2.5%, respectively, less than that of the control.

### 3.2 Differences in root traits between two herbaceous plants

The ratios of the maximum to minimum for the root traits of root diameter, root length density, root surface density, root volume density, and root mass density varied between 4.89 and 110.58, exhibiting significant differences in these root traits under six plant densities (Figure 1). With increasing plant density, changes in the root diameter of the two herbaceous plants were very small and the difference between the maximum and minimum was less than 0.1 mm. Other root traits, including root length density, root surface area density, root volume density, and root mass density, had high values when the plant density ranged from 15 plants $m^{-2}$ to 25 plants $m^{-2}$. These root traits also showed significant differences between BI and AG (Figure 1). Specifically, BI, which has a fibrous root system, had relatively high mean root length density (19.97 km $m^{-3}$), root surface area density (9.68 $m^2$ $m^{-3}$), and root mass density (1.55 kg $m^{-3}$) values, which were 3.83, 1.25, and 1.31, respectively, times greater than that of AG, which has a tap root system. Meanwhile, the mean root diameter and root volume density values of BI were low, and were 79.56% and 82.09% less than that of AG, respectively. Thus, remarkable relationships were observed among plant root traits. In particular, the root length density, root mass density, and root surface area density were positively correlated ($p < 0.01$; Table 2). Significant relationships among the root traits and soil properties were also detected (Table 2). For example, root mass density and root surface area density were positively correlated to soil cohesion ($p < 0.05$), and root

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022



length density was positively correlated with soil cohesion and soil bulk density ($p$ < 0.05).

### 3.3 Variation in hydraulic characteristics and soil detachment rate between two herbaceous plants

The hydraulic parameters of velocity, shear stress, and Darcy–Weisbach friction factor varied significantly according to plant density (Table 3). The velocity of BI was the smallest when the plant density was 15 plants m$^{-2}$, whereas the smallest velocity for AG occurred at a plant density of 5 plants m$^{-2}$. For both grasslands, minimum shear stress and Darcy–Weisbach friction factor values occurred when the plant density ranged from 15 plants m$^{-2}$ to 25 plants m$^{-2}$. In general, BI had a high velocity, and low shear stress and Darcy–Weisbach friction factor. The hydraulic parameters of BI ranged from 1.02 to 1.56 times greater, and from 1.51% to 40.31% and 5.81% to 78.15% less than that of those of AG, respectively.

In addition, the soil detachment rates varied significantly according to planting densities for both herbaceous plants (Figure 2). Regarding BI, the soil detachment rates ranged from 0.034 kg m$^2$ s$^{-1}$ to 0.112 kg m$^2$ s$^{-1}$ with a mean value of 0.061 kg m$^2$ s$^{-1}$, while the soil detachment rate of AG ranged from 0.053 kg m$^2$ s$^{-1}$ to 0.132 kg m$^2$ s$^{-1}$ with a mean value of 0.080 kg m$^2$ s$^{-1}$. Compared with the control, the soil detachment rates of these grasslands were 68.17% to 92.33% and 69.20% to 87.27% lower, respectively. In general, the effects of BI on reducing the soil detachment rate was much more effective than AG as its mean soil detachment rate was 23.75% lower. With increasing plant density, the soil detachment rate decreased as a power function (Figure 3, $p$ < 0.01). Regarding the hydraulic parameters of velocity, shear stress, and Darcy–Weisbach friction factor, the velocity was negatively correlated with the soil detachment rate, exhibiting a power function relationship. Conversely, the shear stress and Darcy–Weisbach friction factor were positively correlated with soil detachment rate. With increasing shear stress and Darcy–Weisbach friction factor, the soil detachment rate increased as a power function (Figure 4, $R^2$ ranged from 0.16 to 0.26, $p$ < 0.01).

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022



Regarding soil properties, bulk density was negatively correlated with the soil detachment rate. Specifically, with increasing bulk density, the soil detachment rate increased as a power function (Figure 5, $R^2 = 0.54$, $p < 0.01$). Finally, regarding root traits, root length density was negatively correlated with the soil detachment rate, exhibiting an exponential function relationship (Figure 6, $R^2 = 0.24$, $p < 0.01$). On this basis, the soil detachment rate ($D_r$) could be estimated by the velocity (v), soil bulk density (BD), and root length density (RLD) as a power function ($R^2 = 0.58$, $p < 0.01$; Eq. [10]).

$$Dr = 5.636v^{0.118} \times BD^{-19.917} \times RLD^{-0.170}, \qquad [10]$$

where the standardized coefficients of v, BD, and RLD are 0.049, -0.352, and -0.572, respectively. The performance of Eq. [10] seemed satisfactory as it had a determination coefficient ($R^2$) of 0.58 and a Nash–Sutcliffe efficiency coefficient (NSE) of 0.78 (Figure 7).

## 4 Discussion

### 4.1 Effects of hydraulic characteristics on soil detachment

Overland flow is the driving force of soil erosion and, in general, its hydraulic characteristics significantly affect soil detachment. Flow velocity is commonly used to reflect the speed of flowing water. A slow velocity refers to a low kinetic energy overland flow, which would increase the hydraulic radius, thereby increasing shear stress. Besides, the viscosity and friction increase when flow velocity slows, which increases the Darcy–Weisbach friction factor. Gong (2011) found that under slow flow velocity, large shear stress, and high Darcy–Weisbach friction factor conditions, soil erosion is reduced. Contrary to previous studies, this study found that the soil detachment rate decreased with flow velocity as a power function (Figure 4). This is mainly because the influence of velocity on soil detachment is relatively weak as compared with the influence of soil properties and plant root system. Thus, using the flow velocity to determine the soil detachment rate may not be appropriate. As given by Eq. [10], when hydraulic characteristics, soil properties, and root traits are used in combination to estimate the soil detachment rate, the results show that the soil detachment rate increases with flow velocity. Further, the standardized velocity coefficients given in Eq. [10] were almost an order of magnitude smaller than the bulk density and root length density. This confirms our theory that soil detachment is primarily affected by soil properties and plant root. Both the flow shear stress and Darcy–Weisbach friction factor are mainly affected by the surface resistance of sediment particles and underlying surface roughness. During the process of soil erosion, especially when erosion rill occurs and soil particles become eroded, soil surface undulation increases, thereby increasing the overland flow form shear stress and form resistance. This concept is consistent with our results, which showed that the soil detachment rate increased via power functions with shear stress and Darcy–Weisbach friction factor. In addition, the presence of vegetation increased form resistance, which further increased the Darcy–Weisbach friction factor and the soil detachment rate.

### 4.2 Effects of soil properties on soil detachment rate

Differences in soil properties reflect the ability of soil mass to resist soil erosion. In particular, bulk density represents the compatibility of soil mass. As bulk density increases, soil mass, in general, becomes more compact and soil cohesion improves, making the soil mass more resistant to detach as a result of flowing water (Chen et al., 2007). Clumping fine soil particles together into firm stable aggregates, which is known as soil aggregation, is a basic unit of soil structure and reflects the stability of soil. Water stable aggregates are often used as indicators of soil susceptibility to flowing water erosion. A high number of water stable aggregates would promote soil stability, increase soil resistance to flowing water erosion, and thus reduce the soil detachment rate (Wang et al., 2018b). During the formation of soil aggregates, the soil organic matter content improves. Soil organic matter is commonly used to represent soil nutrients (Geng et al. 2015). Previous studies indicate that soil organic matter increases adhesion between soil particles, making the soil mass harder to detach (Knape et al., 2007). Our results were consistent with previous research, showing that the soil detachment rate is negatively correlated with soil bulk density, cohesion, water stable aggregates, and soil organic matter, and the soil detachment rate decreased with increasing bulk density as a power function. However, the correlations between the soil detachment rate and cohesion, water stable aggregates, and organic matter were not significant. This is probably because the herbaceous plants were only planted for one year, and the formation of soil aggregates generally requires three to five years of vegetation (Semmel et al., 1990). Low soil cohesion, water stable aggregates, and organic matter content lead to weak effects on soil detachment. Meanwhile, soil erodibility refers to soil erosion resistance to flowing water and is calculated using the soil organic matter content and soil particle composition, based on the EPIC model. A high soil erodibility indicates that the soil mass is easily eroded by flowing water. In this study, soil erodibility was positively correlated with the soil detachment rate. Although the correlation between the soil detachment rate and soil erodibility was not significant because of the low organic matter content, overall, the plant roots of the herbaceous plants still reduced soil erodibility, thereby reducing soil detachment. Further, differences in soil properties were also observed between BI and AG. Compared with AG, BI had high bulk density, soil cohesion, water stable aggregate contents, and soil organic matter, and low soil erodibility, which led to a low soil detachment rate.

### 4.3 Effects of root system on soil detachment

Plant root systems can significantly reduce the soil detachment rate. IN this study, this effect varied between BI and AG because of differences in their root types. For example, BI, which has a fibrous root system, a large number of roots are distributed on the topsoil, making the root system more effective in preventing soil erosion. results were consistent with the previous research (De Baets et al. 2006; Wang et al. 2018b), revealing that the soil detachment rate of BI was 23.751% lower than that of AG, which has a tap root system. Previous studies have attributed this difference in the effect of plant root type on soil erosion to the root biomass (Herbrich et al., 2018). A plant root

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022



system with high biomass indicates that the root system has a strong ability to reinforce the soil, thereby reducing soil erosion (Wang et al., 2021). In this study, soil detachment did not appear to be sensitive to root biomass and no significant relationship was found between the soil detachment rate and root mass density. This indicates that root mass density only reflects root biomass and might not explain the difference in root morphological characteristics very well. Thus, the aforementioned difference in soil detachment rate caused by the different root types in BI and AG are actually the result of differences in root morphological traits, including root diameter, root length density, root surface area density, and root volume density (Zhou and Shangguan. 2005). Regarding root diameter, both significantly positive and negative relationships between root diameter and soil detachment rate have been detected in previous studies, indicating the plant root diameter is an important variable for the soil erosion process (De Baets et al., 2007; Ye et al., 2017). However, some studies found no significant correlation between root diameter and the soil detachment rate, indicating that their relationship cannot be directly established. Rather, a relationship can only be observed when the root diameter is expressed as the number of plant roots (diameter less than 1 mm) within a soil cross-section, which was proposed as the effective root density by Li et al. (2015). In our study, no relationship was observed between the soil detachment rate and root diameter. This is probably because the difference between the maximum and minimum root diameters was less than 0.1 mm, and this change is too small to reflect the soil detachment rate well. A long root length signifies that more plant roots are interspersed in the soil mass, increasing resistance to overland flow scouring and enhancing the resistance of the soil mass. Thus, the soil detachment rate decreases with root length density as a power function (Figure 5). A large root surface area refers to a large contact area between the plant roots and soil, and root volume represents more plant roots grown in the soil, which all indicate that soil stability is strengthened, making it difficult to detach the soil mass via flowing water. Although some previous studies have shown that the soil erosion rate decreases with root surface area density or root volume density, no significant relationships were found between the soil detachment rate and root surface area density or root volume density in this study. Regarding root surface area density, because of the poor correlation between root diameter and soil detachment rate, the root surface area density is generally calculated by both root length and root diameter, as reported by previous studies (Manoli et al., 2014). For root volume density, a high value does not indicate that the effects of the plant root system on reducing soil erosion are enhanced. Wang et al. (2021) found that, when there is little difference in root volume, an herbaceous plant with a fibrous root system generally has a long root length, which results in a strong ability to bind and bond with the soil mass, making its effects on reducing soil detachment more effective than that of an herbaceous plant with a fibrous root system. In other words, root volume density may not be a good root parameter for reflecting the relationship between plant root type and soil detachment.

## 5 Conclusions

In this study, we found that the soil detachment rate significantly decreased as a power function ($R^2 = 0.23$, $p < 0.01$), with increasing plant density for two herbaceous plants, becoming 85.80% and 81.19% lower than that of the control for the BI and AG grasslands, respectively. The soil detachment rate also exhibited different behaviors according to two plant root type. In general, BI, which has a fibrous root system, effectively reduced the soil detachment rate, achieving a mean soil detachment rate that was 23.75% less than that of AG, which has a tap root system. The hydraulic characteristics of flow velocity, shear stress, and Darcy–Weisbach friction factor were found to be correlated to the soil detachment rate ($p < 0.01$), which decreased with increasing velocity and increased with shear stress and the Darcy–Weisbach friction factor as power functions (mean $R^2$ ranged from 0.16 to 0.26, $p < 0.01$). The effects of soil properties on the soil detachment rate were also varied greatly as a result of differences in plant density and plant species. Specifically, the soil detachment rate decreased with increasing bulk density as a power function ($R^2 = 0.54$, $p < 0.01$). The different soil detachment rates caused by root types can be explained well using root traits, including root length density, root surface area density, root volume density, and the root biomass trait of root mass density, which all affected the soil detachment rate. In particular, an exponential function was observed between root length density and the soil detachment rate ($R^2 = 0.24$, $p < 0.01$). In general, the soil detachment rate could be estimated effectively using the overland flow velocity, soil bulk density, and root surface length density ( $Dr = 5.636v^{0.118} \times BD^{-19.917} \times RLD^{-0.170}$ ). The performance of the model developed in this study was satisfactory ($R^2$=0.58; NSE=0.78).

## CRediT authorship contribution statement

**Jian-Fang Wang**: Conceptualization, Methodology, Field work, Writing. **Bing Wang**: Methodology, Field work, Reviewing and Editing. **Yan-Fen Yang**: Conceptualization, Methodology, Reviewing and Editing, Supervision. **Guo-Bin Liu**: Reviewing and Editing. **Feng-Bao Zhang**: Reviewing and Editing. **Nu-Fang Fang**: Reviewing and Editing.

All authors have read and agreed to the published version of the manuscript.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgments

This work was supported by National Natural Science Foundation of China (42130717), and the Chinese Academy of Sciences (CAS) "Youth Scholar of West

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022


Hydrology and Earth System Sciences
Discussions

China" program (XAB2019A04). We should also thank to the Ansai Research Station of Soil and Water Conservation, Chinese Academy of Sciences, Ministry of Water Resource, and the State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Northwest A&F University for technical help.

## References

Beasley DB, Huggins LF, Monke EJ. ANSWERS: a model for watershed planning. T ASABE 23(4):938–0944, 1 dio:10.13031/2013.34692, 1980.

Burylo, M., Dutoit, T., Rey, F., Species traits as practical tools for ecological restoration of marly eroded lands. Restor. Ecol. 22, 633–640, https://doi.org/10.1002/esp.3248, 2014.

Chen, L., W. Wei, B. Fu, and Y. Lü. Soil and water conservation on the Loess Plateau in China: Review and perspective. Prog. Phys. Geogr. 31:389–403, https://doi.org/10.1177/0309133307081290, 2007.

De Baets, S., Poesen, J., Gyssels, G., Knapen, A., Effects of grass roots on the erodibility of top soils during concentrated flow. Geomorphology 76, 54–67. https://doi.org/10.1016/j.geomorph.2005.10.002, 2006.

De Baets, S., Poesen, J., Knapen, A & Galindo, P. Impact of root architecture on the erosion–reducing potential of roots during concentrated flow. Earth Surface Processes and Landforms. 32 (9), 1323–1345. https://doi.org/10.1002/esp.1470, 2007.

Ellison, W.D., Soil erosion studies: Part I. Agric. Eng. 28, 145–146, 1947.

Foster, G. Modeling the erosion process. In: C.T. Haan and D.L. Brakensiek, editors, Hydrologic modeling of small watersheds. Am. Soc. Agric. Engineers,St. Joseph, MI. p. 295–380. 1982.

Fu, B., L. Chen, K. Ma, H. Zhou, and J. Wang. The relationships between land use and soil conditions in the hilly area of the Loess Plateau in northern Shaanxi, China. Catena 39:69–78, https://doi.org/10.1016/S0341-8162(99)00084-3, 2000.

García-Ruiz, J.M., Beguería, S., Nadal-Romero, E., González-Hidalgo, J.C., Lana-Renault, N., Sanjuán, Y., A meta-analysis of soil erosion rates across the world. Geomorphology 239, 160–173, https://doi.org/10.1007/s11104-010-0382-6, 2015

Gayler, S., Ingwersen, J., Priesack, E., Wohling, T., Wulfmeyer, V., and Streck, T.: Assessing the relevance of subsurface processes for the simulation of evapotranspiration and soil moisture dynamics with CLM3.5: comparison with field data and crop model simulations, Environ. Earth Sci., 69, 415–427, https://doi.org/10.1007/s12665-013-2309-z, 2013.

Geng, R., Zhang, G.H., Li, Z.W., Wang, H., Spatial variation in soil resistance to flowing water erosion along a regional transect in the Loess Plateau. Earth Surf. Process. Landf. 40, 2049–2058, https://doi.org/10.1002/esp.3779, 2015..

Gong J G, Jia Y W, Zhou Z H, et al. An experimental study on dynamic processes of ephemeral gully erosion in loess landscapes. Geomorphology, 125, 203-213, https://doi.org/10.1016/j.geomorph.2010.09.016, 2011.

Godo G H, Reisenauer H M. Plant Effects on Soil Manganese Availability. Soil Science Society of America Journal, 44, 993-995, https://doi.org/10.2136/sssaj1980.03615995004400050024x, 1980.

Gyssels, G., Poesen, J., The importance of plant root characteristics in controlling concentrated flow erosion rates. Earth Surf. Process. Landf. 28, 371–384, https://doi.org/10.1191/0309133305pp443ra, 2003.

Hairsine, P.B., Rose, C.W., Modeling water erosion due to overland flow using physical principles. 1. Sheet flow. Water Resour. Res. 28, 237–243, https://doi/10.1029/91WR02380, 1992a.

Hairsine, P.B., Rose, C.W., Modeling water erosion due to overland flow using physical principles. 2. Rill flow. Water Resour. Res. 28, 245–250, https://doi/10.1029/91WR02381, 1992b.

Herbrich, Marcus, Gerke, et al. Root development of winter wheat in erosion-affected soils depending on the position in a hummocky ground moraine soil landscape. Journal of plant nutrition and soil science, 181, 147-157, https://doi.org/info:doi/10.1002/jpln.201600536, 2018.

Jonge L, Moldrup P, Jacobsen O H. Soil-Water Content Dependency of Water Repellency in Soils. Soil Science, 172, 577-588, https://doi.org/10.1097/SS.0b013e318065c090, 2017.

Knapen, A., Poesen, J., Govers, G., Gyssels, G., Nachtergaele, J., Resistance of soils to concentrated flow erosion: a review. Earth. Rev. 80, 75–109, https://doi.org/10.1016 /j.earscirev.2007.08.001, 2007.

Labriere, N., Locatelli, B., Laumonier, Y., Freycon, V., Bernoux, M., Soil erosion in the humid tropics: a systematic quantitative review. Agric. Ecosyst. Environ. 203, 127–139, https://doi.org/10.1016/j.agee.2015.01.027, 2015.

Lee Eunhyung and Kim Sanghyun. Characterization of soil moisture response patterns and hillslope hydrological processes through a self-organizing map. Hydrol. Earth Syst. Sci., 25, 5733–5748, https://doi.org/10.5194/hess-25-5733-2021, 2021.

Li, Y., Zhu, X.M., Tian, J.Y. Effectiveness of plant roots to increase the anti-scourability of soil on the loess plateau. Chin. Sci. Bull. 36 (24), 2077–2082.1991.

Li, Z. W., G. H. Zhang, R. Geng, and H. Wang. Rill erodibility as influenced by soil and land use in a small watershed of the Loess Plateau, China. Biosystems Eng. 129:248–257, https://doi.org/10.1016/j, 2015.

Liu, J. X., Liu, G. B., Dennis. C., Wang, B., Wang, Z. Y., Xiao, J., Effects of soil-incorporated plant litter morphological characteristics on the soil detachment process in grassland on the Loess Plateau of China. Science of the Total Environment. 705, 13465, https://doi.org/10.1016/j.scitotenv,2020.134651, 2020.

Luk, S., Merz, W. Use of the salt tracing technique to determine the velocity of overland flow. Soil Technol. 5, 289-301. 1992.

Mamo, M., Bubenzer, G., Detachment rate, soil erodibility, and soil strength as influenced by living plant root part I: laboratory study. Trans. ASAE 44, 1167–1174, https://doi.org/10.13031/2013.6445, 2001a.

Mamo, M., Bubenzer, G., Detachment rate, soil erodibility, and soil strength as influenced by living plant root part II: field study. Trans. ASAE 44, 1175–1181, https://doi.org/10.13031/201 3.6446, 2001b.

Manoli, Bonetti, Domec, et al. Tree root systems competing for soil moisture in a 3D soil-plant model. ADV WATER RESOUR, 6, 32-42, https://doi.org/10.1016/j.advwatres.2014.01.006, 2014.

Morgan, R.P.C., J.N. Quinton, R.E. Smith, G. Govers, J.W.A. Poesen, K. Auerswald, et al. The European Soil Erosion Model (EUROSEM): A dynamic approach for predicting sediment transport from fields and small catchments. Earth Surf. Processes Landforms 23:527–544. doi:10.1002/(SICI)1096-9837(199806)23:6<527::AID-ESP868>3.0.CO;2-5, 1998.

Morgan, R.P.C., Quinton, J.N., Smith, R.E., Govers, G., Poesen, J.W.A., Auerswald, Chisci, Nachtergaele, J., Poesen, J., Spatial and temporal variations in resistance of loess–derived soils to ephemeral gully erosion. Eur. J. Soil Sci. 53 (3), 449–463, https://doi.org/10.1079/9780851990507.019, 2002.

Nearing, M.A., G.R. Foster, L.J. Lane, and S.C. Finkner. 1989. A process-based soil-erosion model for USDA-Water Erosion Prediction Project Technology.Trans. ASAE 32:1587–1593. doi:10.13031/2013.31195, 1989.

Nearing, M. A., Bradford, J. M., Parker, S. C., Soil detachment by shallow flow at low slopes. Soil Sci. Soc. Am. J. 55 (2), 339–344, https://doi.org/10.2136/sssaj 1991. 0361599500550 0020006x, 1991.

Nearing, M. A., Simanton, J. R., Norton, L. D., Bulygin, S. J., Stone, J., USDA, A., Soil erosion by surface water flow on a stony, semiarid hillslope. Earth Surf. Proc. Land. 24 (8), 677–686, https://doi.org/10.1002/(SICI)1096-9837(199908)24:83.0.CO;2-1, 1999.

Quijano, J. C. and Kumar, P.: Numerical simulations of hydraulic redistribution across climates: The role of the root hydraulic conductivities, Water Resour. Res., 51, 8529–8550, https://doi.org/10.1002/2014wr016509, 2015.

Rickson, R.J., Can control of soil erosion mitigate water pollution by sediments? Sci. Total Environ. 468, 1187–1197, https://doi.org/10.1016/j.scitotenv.2014.12.086, 2014.

Semmel H, Horn R, Hell U, Dexter A.R, Schulze E.D, The dynamics of soil aggregate formation and the effect on soil physical properties, Soil Technology, 3, 113-129, http://doi.org/10.1016/S0933-3630(05)80002-9, 1990.

Simon, A., Collison, A., Scientific basis for streambank stabilization using riparian vegetation. Proceedings of the 7th Federal Interagency Sedimentation Conference, March 25–29, Reno, Nevada, V47–V54, https://doi.org/10.1002/esp.287, 2001.

Su, Z.L., Zhang, G.H., Yi, T., Liu, F., Soil detachment capacity by overland flow for soils of the Beijing region. Soil Res. 179, 446–453, https://doi.org/10.1097/SS.0000000000000089, 2014.

Vannoppen, W., De Baets, S., Keeble, J., Dong, Y., Poesen, J., How do root and soil characteristics affect the erosion-reducing potential of plant species. Ecol. Eng. 109, 186–195, https://doi.org/10.1016/j.earscirev.2017.08.011, 2017.

Wang, B., G.H. Zhang, X.C. Zhang, Z.W. Li, Z.L. Su, T. Yi, et al. Effects of near soil surface characteristics on soil detachment by overland flow in a natural succession grassland. Soil Sci. Soc. Am. J. 78:589–597. doi:10.2136/sssaj2013.09.0392, 2014.

Wang, B., Zhang, G.H. Quantifying the binding and bonding effects of plant roots on soil detachment by overland flow in 10 typical grasslands on the Loess Plateau. Soil Sci. Soc. Am. J. 81, 1567–1576, https://doi.org/10.2136/sssaj2017.07.0249, 2017.

Wang, B., Zhang, G.H., Yang, Y.F., Li, P.P., Liu, J.X., The effects of varied soil properties induced by natural grassland succession on the process of soil detachment. Catena 166, 192–199, https://doi.org/10.1016/j.agee.2018.07.016, 2018a.

Wang, B., Zhang, G.H., Yang, Y.F., Li, P.P., Liu, J.X., Response of soil detachment capacity to plant root and soil properties in typical grasslands on the Loess Plateau. Agri. Ecosyst. Environ. 266, 68–75, https://doi.org/10.1016/j.agee.2018.07.016, 2018b.

Wang, B., Li, P. P., Huang, C.H., Liu, G. B & Yang, Y. F. Effects of root morphological traits on soil detachment for ten herbaceous species in the Loess Plateau. Science of the Total Environment, 754 (14),142304. https://doi.org/10.1016/j.scitotenv.2020.142304, 2021.

Wu, B., Wang, Z., Zhang, Q., Shen, N., Distinguishing transport-limited and detachment limited processes of inter-rill erosion on steep slopes in the Chinese loessial region. Soil Tillage Res. 177, 88–96, https://doi.org/10.1016/j.still.2018.104661, 2018.

Xin, Z., Qin, Y., Yu, X., Spatial variability in soil organic carbon and its influencing factors in a hilly watershed of the Loess Plateau, China. Catena 137, 660–669, https://doi.org/10.1016/j.catena.2016.01.028, 2016.

Ye, Z. L., Guo, Z.X. Li, C.F. Cai., The effect of baaiagrass roots on soil erosion resistance of Aquults in subtropical China. Geomorphology,285, 82–93, https://doi.org/10.1016/j.geomorph.2017.02.003, 2017.

Zhang, G. H., Liu, B. Y., Nearing, M. A., Huang, C. H., Zhang, K. L., Soil detachment by shallow flow. Trans. ASAE 45 (2), 351–357, https://doi.org/10.13031/2013.8527, 2002.

Zheng, H., Xiao, Y. C., Yan, H. L., et al. Quantifying the rill–detachment process along a saturated soil slope. Soil and Tillage Research.204, 1–9, https://doi.org/10.1016/j.still.2020. 104726, 2020.

Zhou, Z. C., and Z. P. Shang Guan. Soil anti–scouribility enhanced by plant roots. J. Integ Plant Biol. 47:676–682, https://doi.org/10.1111/j.1744-7909.2005.00067.x, 2005.

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022


Hydrology and Earth System Sciences
Discussions

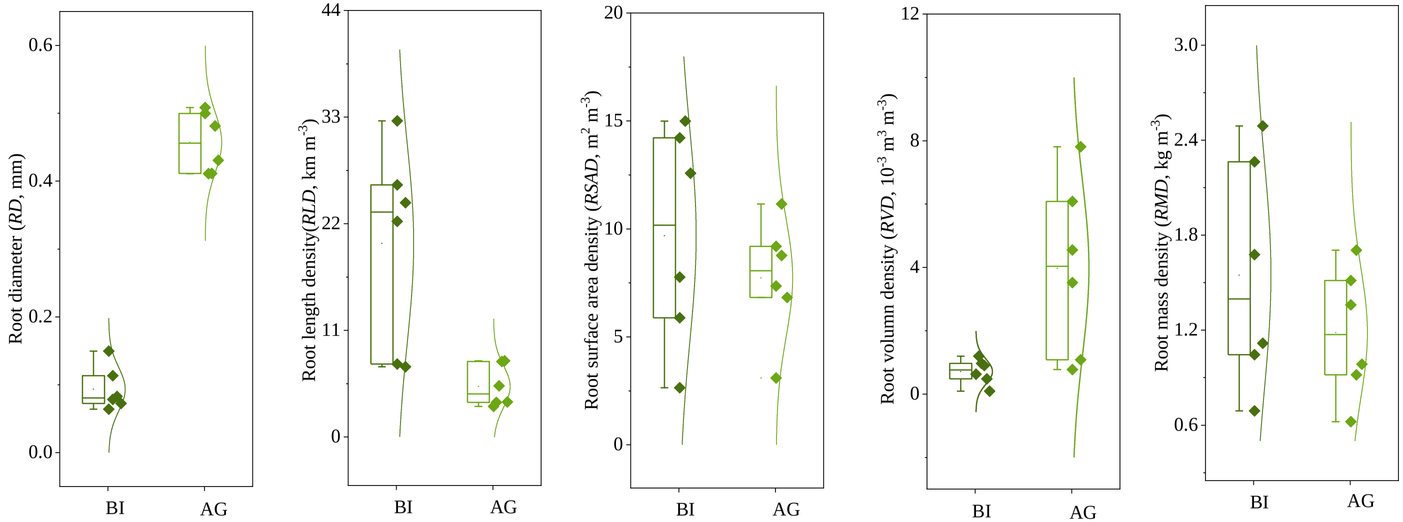


Figure 1 Root traits of *RD*, *RLD, RSAD, RVR* and *RMD* between *Bothriochloa ischcemum* (Linn.). Keng and *Artemisia vestita Wall*. ex Bess herbaceous plants

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022


Hydrology and Earth System Sciences
Open Access
Discussions

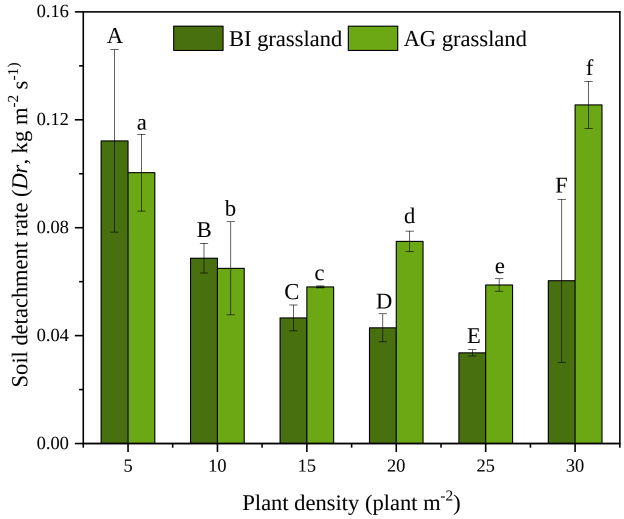


Figure 2 Soil detachment rate (*Dr*) in different plant densities.

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022




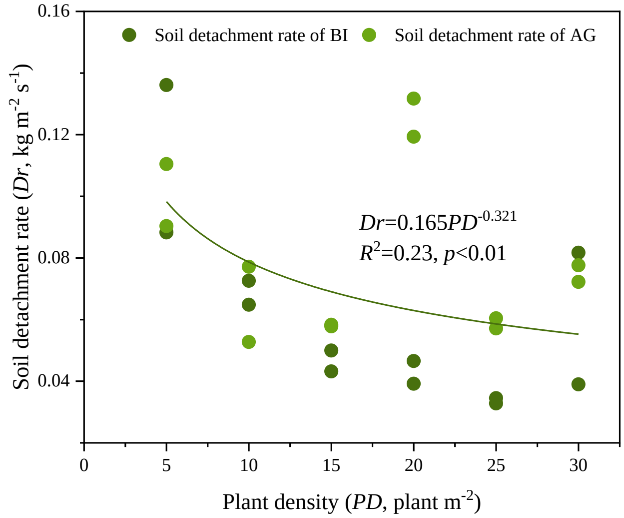


Figure 3 Soil detachment rate ($Dr$) as a power function of plant density ($PD$)

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022



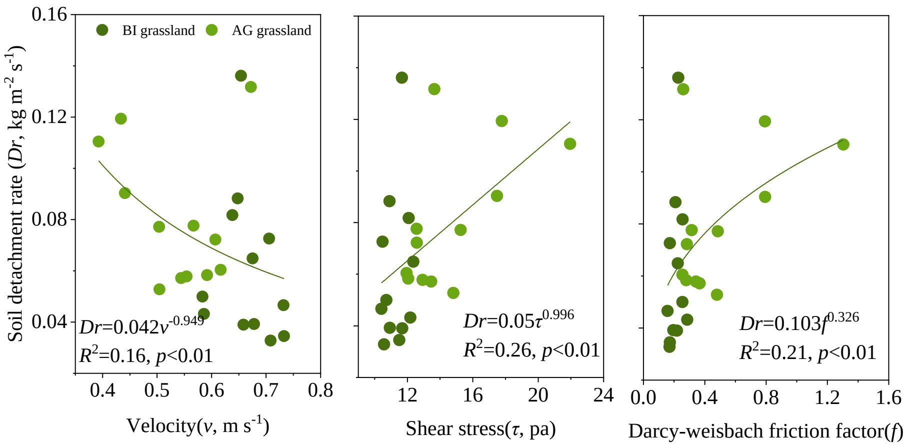


Figure 4 Soil detachment rate (*Dr*) as a power function of velocity (*v*), shear stress ($\tau$) and darcy-weisbach friction factor(*f*)

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022


Hydrology and Earth System Sciences
Discussions

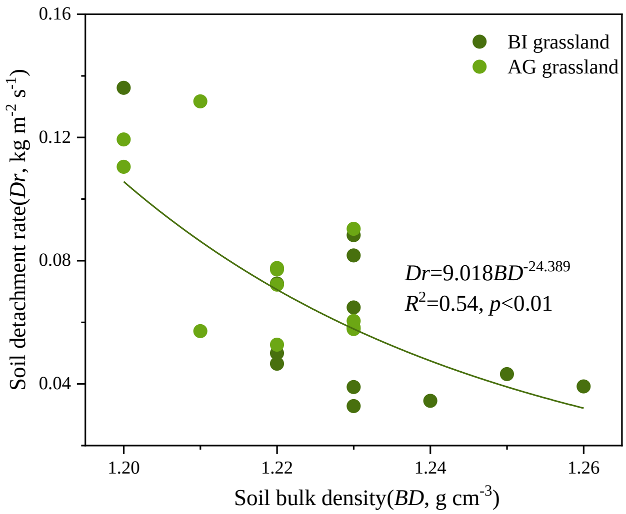


Figure 5 Soil detachment rate (*Dr*) as power function of soil bulk density (*BD*)

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022



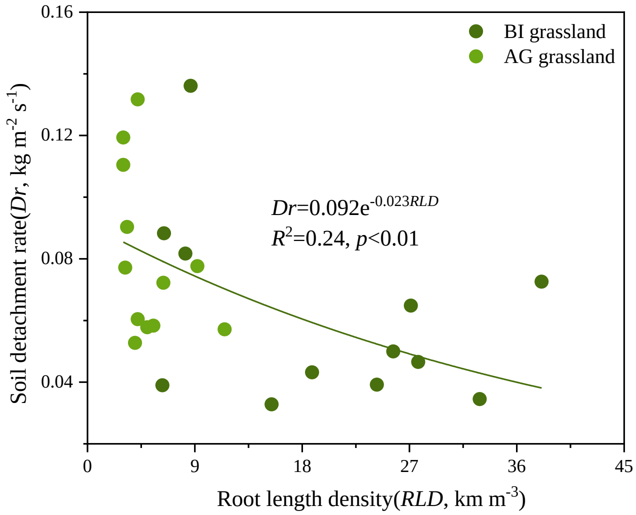


Figure 6 Soil detachment rate (*Dr*) as exponential function of root length density (*RLD*).

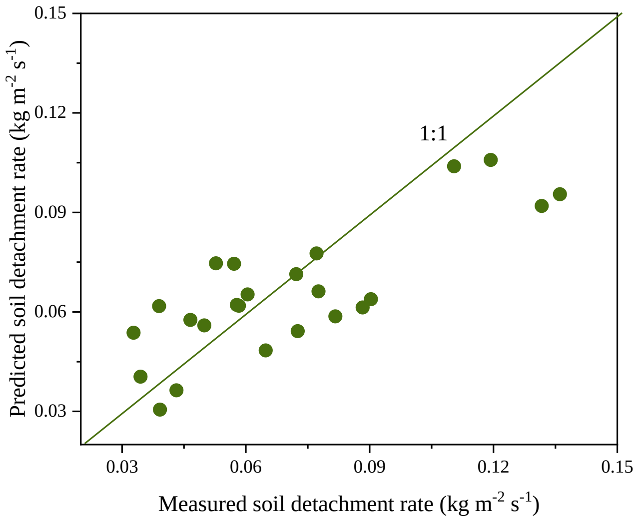


Figure 7 Compared with measured soil detachment rate and soil detachment rate

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022



Table 1 Variation of soil properties by plant growth between *Bothriochloa ischcemum* (Linn.). Keng (BI) grasslands and *Artemisia vestita* Wall. ex Bess (AG) grasslands

| Plant density plant $m^{-2}$ | Bulk density (g cm-3) | | Cohesion (KPa) | | Water stable aggregate （%） | | Soil organic matter (g $kg^{-1}$) | | Soil erodibility | |
|---|---|---|---|---|---|---|---|---|---|---|
| | BI | AG | BI | AG | BI | AG | BI | AG | BI | AG |
| 5 | 1.22 | 1.22 | 4.18 | 4.36 | 1.6 | 0.63 | 6.6 | 4 | 0.39 | 0.4 |
| 10 | 1.23 | 1.22 | 4.83 | 4.49 | 1.91 | 1.19 | 7.22 | 5.09 | 0.39 | 0.39 |
| 15 | 1.24 | 1.23 | 4.95 | 4.58 | 2.05 | 0.97 | 7.69 | 5.97 | 0.38 | 0.39 |
| 20 | 1.24 | 1.22 | 4.68 | 4.68 | 2.23 | 0.9 | 12.75 | 8.11 | 0.34 | 0.38 |
| 25 | 1.24 | 1.22 | 4.72 | 4.54 | 2.06 | 0.48 | 13.15 | 6.35 | 0.34 | 0.39 |
| 30 | 1.23 | 1.21 | 4.1 | 4.68 | 1.95 | 0.09 | 16.75 | 7.64 | 0.31 | 0.38 |
| Bare control | 1.27 | | 4.3 | | 2.88 | | 3.31 | | 0.4 | |

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022


Hydrology and Earth System Sciences Discussions

Table 2 Correlation coefficient among of soil properties, root traits and soil detachment rate

| | v | τ | f | Coh | BD | SWAC | SOC | K | RD | RMD | RLD | RSAD | RVD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RD | -0.717** | 0.656** | 0.697** | 0.014 | -0.312 | -0.114 | -0.626 | 0.192 | 1 | | | | |
| RMD | 0.377 | -0.564** | -0.472* | 0.617** | 0.379 | 0.261 | 0.000 | -0.296 | -0.148 | 1 | | | |
| RLD | 0.700** | -0.718** | -0.721** | 0.440* | 0.423* | 0.274 | 0.467 | -0.263 | -0.685** | 0.654** | 1 | | |
| RSAD | 0.390 | -0.478 | -0.446* | 0.624* | 0.351 | 0.005 | -0.034 | -0.295 | -0.037 | 0.872** | 0.562** | 1 | |
| RVD | -0.246 | 0.116 | 0.179 | 0.318 | -0.157 | 0.012 | -0.550 | -0.050 | 0.673** | 0.412* | -0.189 | 0.510* | 1 |
| Dr | -0.441* | 0.535** | 0.503* | -0.244 | -0.700** | -0.213 | -0.443 | 0.190 | 0.280 | -0.361 | -0.560** | -0.351 | 0.104 |

Note: * $p<0.05$, ** $p<0.01$, n=24

Where v, τand f are velocity, shear stress and Darcy-weisbach friction factor of overland flow. Coh, BD, SWAC, SOC and K are soil properties of cohesion, bulk density, water stable aggregate, organic matter and soil erodibility. RD, RMD, RLD, RSAD and RVD are root traits of root diameter, root mass density, root length density, root surface area density and root volume density.

https://doi.org/10.5194/hess-2022-30
Preprint. Discussion started: 25 January 2022

Hydrology and Earth System Sciences
Discussions

Table 3 Variation of velocity, shear stress, Darcy-weisbach friction factor between *Bothriochloa ischcemum* (Linn.). Keng (BI) grasslands and *Artemisia vestita* Wall. ex. Bess (AG) grasslands

| Plant density plant $m^{-2}$ | Velocity $m\ s^{-1}$ | | shear stress Pa | | Darcy-weisbach friction factor | |
|---|---|---|---|---|---|---|
| | BI | AG | BI | AG | BI | AG |
| 5 | 0.651±0.004 | 0.417±0.034 | 11.289±0.541 | 19.724±3.159 | 0.219±0.013 | 1.049±0.361 |
| 10 | 0.690±0.021 | 0.504±0.000 | 11.424±1.329 | 15.038±0.310 | 0.198±0.036 | 0.482±0.004 |
| 15 | 0.585±0.002 | 0.573±0.027 | 11.451±1.038 | 12.476±0.623 | 0.270±0.022 | 0.311±0.045 |
| 20 | 0.705±0.038 | 0.587±0.028 | 10.676±0.368 | 12.576±0.008 | 0.177±0.027 | 0.299±0.022 |
| 25 | 0.721±0.017 | 0.581±0.051 | 11.045±0.661 | 12.705±1.068 | 0.172±0.001 | 0.311±0.079 |
| 30 | 0.684±0.014 | 0.553±0.169 | 11.892±0.278 | 15.716±2.914 | 0.237±0.027 | 0.527±0.377 |