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Water, Soil and Nutrient Loss from Limestone Soil under Simulated Rainfall Conditions

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Adding limestone soil into soil body can effectively improve the performance of soil body and strengthen soil body. Thus, the study on the loss of water, soil and nutrient in limestone soil can provide data support and theoretical basis for the control of soil and water loss in mountainous areas and the control of non-point source pollution in small watershed. In this experiment, the effect of different rainfall intensity on the runoff time, runoff, sediment content and nutrient content of limestone soil is studied by taking soil in mountainous areas in Henan Province as a control through artificial simulated rainfall device. Under different rainfall intensity conditions, the runoff time of limestone soil is longer, the runoff is less, sediment and the loss nutrient content is less than that of soil in mountainous areas in Henan, indicating that limestone soil is expected to be used to prevent and control water and soil loss.

1. Introduction

Artificial simulated rainfall device system mainly includes water supply system, artificial rainfall simulator, runoff test soil plot and automatic sampler (Fang et al., 2012; Ao et al., 2016). As the key part of this experiment, artificial rainfall simulator is a small artificial rainfall simulator developed by the Institute of Soil and Water Conservation, CAS, which is capable of moving, changing rainfall intensity and pressure controlling (Yang et al., 2006; Cheema et al., 2012). The rainfall simulator consists of spray head, spray nozzle, pressure gauge, regulating cabinet, three lateral supporting steel frames, connected water guide pipe and submerged pump (Ghosh et al., 2018). The simulator can freely rotate 360° to change the direction of the rain cover, and can change the height of rainfall at will by adjusting the length of the steel tube and the position of the three lateral supports at the bottom (Ren, 2003). The variation range of rainfall intensity is 15 mm/h-150 mm/h, and the rainfall uniformity is over 80%. The adjustment of the rainfall intensity is accomplished by changing the pressure valve in the water distribution pipe and orifice size of the outlet orifice plate in the nozzle head. The soil tank is a movable variable slope steel soil tank with a dimension of 0.5 m wide × 2 m long and a depth of 0.4 m. The slope is controlled by adjustable screws. The soil tank is 0.02-0.03 m thick, and has a porous structure to facilitate drainage. 0.5-meter-thick plastic baffles are added to both sides and top of the soil tank to prevent rainfall and sediment from splashing out. V-type weir is installed at the lower end of the soil tank and connected into graduated plastic barrel by a plastic pipe to collect and measure the runoff volume. The rainfall water mainly comes from the city pipeline tap water. When the runoff samples during each rainfall are collected, the rainwater in several rainwater collecting tanks arranged on the rainfall slope is collected and taken back to the laboratory for the determination of each nutrient element (Jun et al., 2010; Tai et al., 2016). In this study, the result of the final determination of nutrient elements in runoff samples has eliminated the corresponding nutrient content values in rainwater.

2. Using artificial simulated rainfall devices to study the loss of water, soil and nutrients in limestone soil during rainfall

In order to analyze the dynamic change process of water content, soil and nutrient in limestone soil under different rainfall intensity, the artificial rainfall simulator is adopted and the soil (ADMS) in the mountainous

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areas in Henan Province is taken as the control group from the point of view of runoff time, runoff, sediment content and nutrient content.

2.1 Experimental soil

The reference soil is taken from the mountainous areas in Henan Province, and the limestone soil is self-prepared by the experimental base with the ratio of 3 (soil): 1 (sand): 1 (limestone). The soil sample is conducted air drying and sieved through 4.75 mm holes to remove large-grained rocks and organic debris.

Table 1: Basic physical and chemical properties of two soils before rainfall

Soil type	pH	Conductivity (μS·cm-1)	Total N (g·kg-1)	Total P (g·kg-1)	Total K (g·kg-1)	Water content (%)	Unit weight (g·cm-3)
ADMS	7.08	113.52	4.35	0.83	5.21	10-13	1.2±0.2
LSS	6.83	135.21	5.92	0.51	6.57	10-13	1.2±0.2

Note: ADMS represents soil in mountainous areas in Henan Province; LSS represents limestone soil.

2.2 Experiment design

The soil sample is evenly distributed on the soil tank, and then the soil sample is scraped to a uniform thickness of 0.4 m with a scraper. In this experiment, 2 rainfall intensities are set: 65 mm/h and 85 mm/h. The slope is 20° and two simulated rainfalls are carried out respectively. The soil bulk density before experiment is controlled to (1.2±0.2) g/cm3, and the water content is controlled to 10%-13%. During the experiment, the soil in the soil tank is thoroughly turned over and compacted. Then rainfall began until the surface produces runoff. The experiment will be carried out when the surface soil water content and bulk weight meet the requirements. The slope during the experiment is adjusted by the hydraulic device provided by the steel tank. Runoff time is calculated after the start of rainfall. The runoff bucket will be changed every 8 minutes from the start of the runoff, and rainfall is collected for 7 consecutive times until the end of the rainfall. The calibration procedure of rainfall intensity is as follows. The runoff tank is covered with plastic cloth, and then several rain gauges are arranged on the slope surface. And the rainfall intensity is calculated according to formula (1) by adjusting the nozzle orifice plate and water pressure. Many attempts will be made until the rainfall intensity meets the requirements, then the plastic cloth is removed and the experiment starts.
The formula for calculating rainfall intensity is as follows:

$$P = 10 \times \frac{V/S_1}{t} \tag{1}$$

Where, P is rainfall intensity, mm/min; V is the average rainfall of each bucket measured with the measuring cylinder, mL; S_1 is the area of the bucket mouth of the rainfall bucket, cm^2; t is measurement time, min.

2.3 Measurement of sample

After the rainfall, the total volume of runoff is measured, and the water sample and sediment in the runoff are separated with filter paper to determine the total nitrogen, total phosphorus and water-soluble potassium in the water sample. After drying, the sediment is weighed and its total nitrogen, total phosphorus and total potassium are measured. The total nitrogen in the water sample adopts alkaline potassium persulfate ultraviolet spectroscopy, the total phosphorus adopts ammonium molybdate spectrophotometric method and the soluble potassium uses flame photometry. The total nitrogen in the sediment is determined by semi-micro kjeldahl, the total phosphorus is determined by NaOH fusion-Mo-Sb anti-colorimetric method, the available phosphorus is determined by mol·L-1NaHCO3 method, the total potassium is determined by NaOH fusion-flame photometry, and the available potassium is determined by NH4OAc-flame photometry (Attanandana et. al., 1999; Rehim et al., 2013). Excel2003 and SPSS18.0 software are used for processing data and variance analysis.

3. Data processing and analysis

3.1 Comparison of runoff time

In the process of simulated rainfall, the stronger the rainfall is, the shorter the runoff time is. The runoff time of soil in mountainous areas in Henan under different rainfall intensities is shorter than that of limestone soil ($p < 0.05$), and the results are shown in Table 1. The results show that limestone soil has strong water permeability, and a large amount of water can penetrate into the limestone soil after rainfall starts, thus delaying the runoff time.

Table 1: Runoff-yielding time (s)

	Rainfall intensity	
	65mm/h	85mm/h
ADMS	173	115
LSS	587	541

Note: ADMS represents soil in Dabie Mountain Area; LSS represents limestone soil.

3.2 Comparison of runoff and sediment content

In the process of simulating rainfall, runoff of them shows the trend of rising first and then fluctuating gently and runoff increases with the increase of rainfall intensity. However, the runoff of the soil in the mountainous areas in Henan Province is significantly higher than that of limestone soil, and the increase rate of runoff at the initial stage of rainfall is significantly higher than that of limestone soil, as shown in Figure 1. Raindrop wash produces soil erosion and carries a large amount of sediment, leading to the loss of some soil nutrients with sediment. It can be seen from Figure 2 that the sediment loss of two kinds of soil under simulated rainfall conditions is greatly different. The sediment loss of limestone soil is small and fluctuates little in the whole rainfall process while the sediment loss of soil in the mountainous areas in Henan Province is large and appears the law of rising first and then decreasing and tending to be gentle. However, there is no significant difference in sediment content under different rainfall intensity conditions.

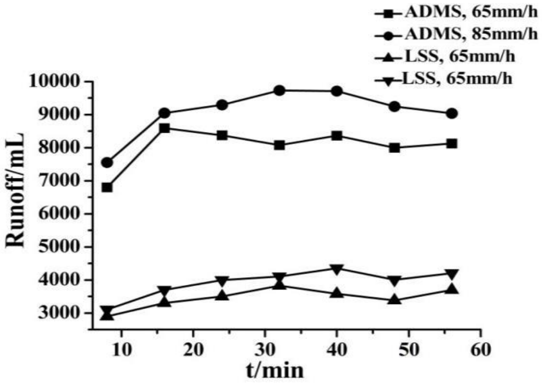

Figure 1: The runoff at different time

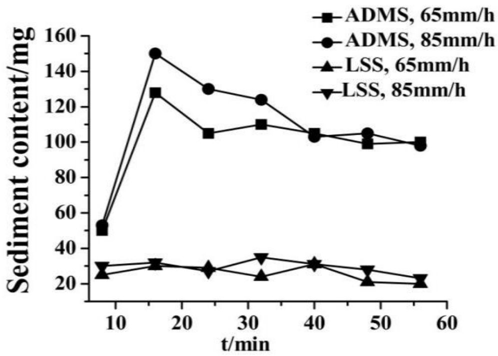

Figure 2: The sediment content at different time

3.3 Comparison of nutrient content in runoff water sample

The loss of total nitrogen, total phosphorus and water-soluble potassium carried by runoff of limestone soil and soil in mountainous areas in Henan Province is compared under simulated rainfall conditions. As shown in Figure 3, the total nitrogen content in soil runoff water sample in Henan Mountain Area increases first and then decreases with runoff loss; the total nitrogen loss of limestone soil is relatively small and it also tends to increase first and then decrease. The total nitrogen content is negatively correlated with rainfall intensity. The possible reason is that when the rainfall intensity is small, the runoff speed is slow so that more nitrogen-containing compounds can be dissolved. When the rainfall intensity is great, the surface soil is washed away rapidly and the nitrogen-containing compounds are dissolved less.

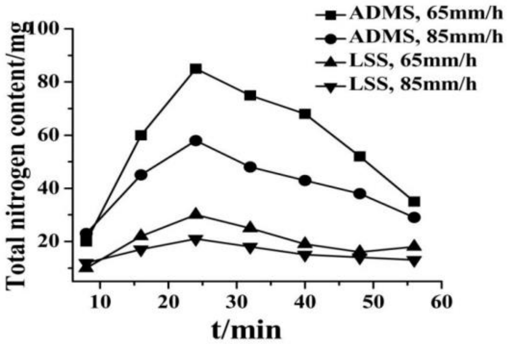

Figure 3: The total nitrogen content in runoff's water at different time

As shown in Figure 4, the total phosphorus content in the runoff water samples of the two types of soils is low, indicating that the fixing effect of the two types of soils on phosphorus is strong so that the vertical migration of phosphorus on the soil surface is very weak.

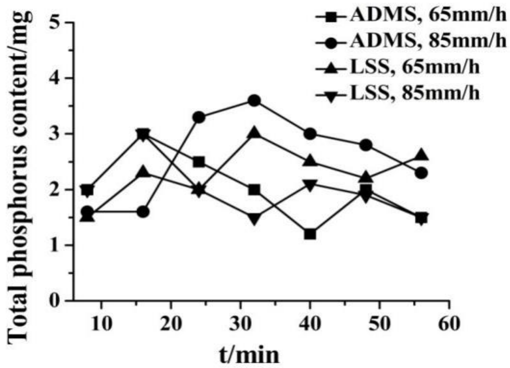

Figure 4: The total phosphorus content in runoff's water at different time

Figure 5 shows the change law of dissolved potassium loss in runoff water sample during simulated rainfall. The variation trend of dissolved potassium loss is approximately the same as the variation trend of runoff, which increases first and then decreases and tends to be stable. The loss of dissolved potassium in limestone soil is lower than that is soil in mountainous areas in Henan. The dissolved potassium content in water sample with low rainfall intensity is at a higher level as a whole. This may be that when the runoff on the slope is small, more potassium-containing compounds can be carried away by the runoff after being dissolved.

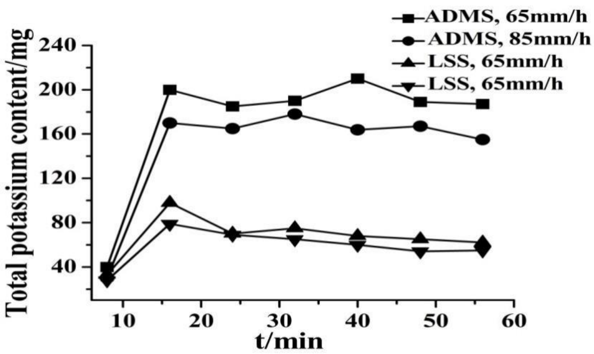

Figure 5: The total potassium content in runoff's water at different time

3.4 Comparison of nutrient content in sediment

The loss of total nitrogen, total phosphorus and water-soluble potassium in sediment in limestone soil and soil in mountainous areas in Henan Province is compared. As can be seen from Figure 6, the total nitrogen content of soil in Henan Mountain Area increases first and then decreases and tends to be gentle while the total nitrogen content of limestone soil is less and has a gentle fluctuation trend. The rainfall intensity has no effect on the total nitrogen content of sediment.

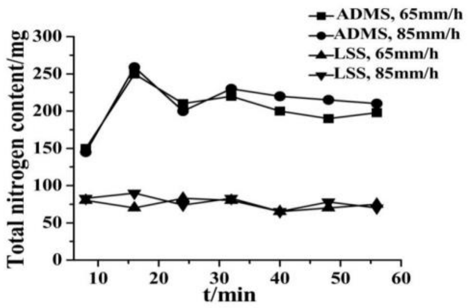

Figure 6: The total nitrogen content in runoff's sediment at different time

Phosphorus is adsorbed in the soil, so the larger the sediment content is, the more phosphorus it carries. As shown in Figure 7, the sediment loss in soil in the mountainous areas in Henan Province is higher than that in limestone soil, so the total phosphorus loss is higher than that in limestone soil. There is a trend of increasing first and decreasing later and tending to be stable, and the rainfall intensity has no effect on it. Compared with the runoff total phosphorus loss, the loss sediment carries more phosphorus.

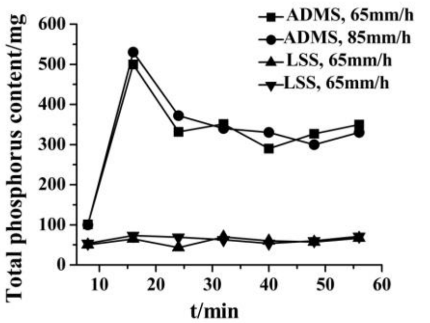

Figure 7: The total phosphorus content in runoff's sediment at different time

Figure 8 shows that there is less dissolved potassium in loss sediment of limestone soil and soil in the mountainous areas in Henan Province possibly because most of the dissolved potassium is dissolved in the rainwater. In addition, limestone soil losses less sediment so it also carries relatively few nutrients. However, the loss of water-soluble potassium in the first rainfall is the lowest in both kinds of soil.

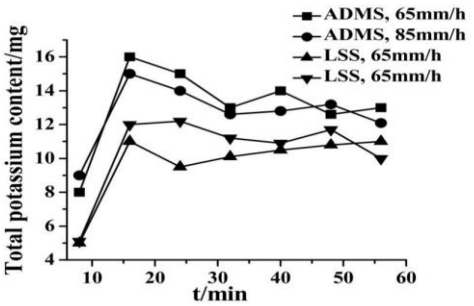

Figure 8: The total potassium content in runoff's sediment at different time

4. Conclusion

In this paper, the effect of different rainfall intensity on the runoff time, runoff, sediment content and nutrient content of limestone soil is studied by taking soil in mountainous areas in Henan Province as a control through artificial simulated rainfall device. The result shown that under different rainfall intensity conditions, the runoff time of limestone soil is longer, the runoff is less, sediment and the loss nutrient content is less than that of soil in mountainous areas in Henan.

Acknowledgments

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