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Water, Soil and Nutrient Loss in Limestone Soil under Simulated Rainfall

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The problem of water loss and soil erosion in limestone slopes of Taihang Mountain is very serious, with different vegetations playing different roles in water loss and soil erosion. The aim of this paper is to find out the roles of the two common shrubs, false indigo and ryegrass, in conserving water, soil and nutrients on limestone slopes through experiments with simulated rainfall. The results show that compared with the control group, the runoff yield times of false indigo and ryegrass are extended by 226 s and 264 s, respectively; the slope surface runoffs of false indigo and ryegrass decreased by 32% and 47%, and their sediment yields decreased by 64% and 71%, respectively. From bare slopes, slopes with false indigo and slopes with ryegrass, the loss of particulate nitrogen accounted for 62%, 46% and 53% of the total loss of nitrogen, respectively; the loss of particulate phosphorus accounted for 81%, 69% and 74% of the total loss of phosphorus, respectively; and the loss of particulate potassium accounted for 99%, 97% and 99% of the total loss of potassium, respectively.

1. Introduction

The total cultivated area in Hebei Province is 65,377 km^2, of which the middle- and low-yield fields account for more than 70% (Li and Shi, 2016). The limestone mountainous area of Taihang Mountain is mainly located in the west of Hebei Province, with an area of 6,670 km^2. It is subject to frequent natural disasters with an area of 62,957km^2 subject to water loss and soil erosion (Sun, 2006). With the aggravation of water loss and soil erosion in the mountainous areas, the deteriorating natural ecological environment is severely restricting the economic development of the area (Zhao et al., 2013; Zhao, 2016).
In recent years, many scholars have done a lot of researches on water loss and soil erosion, including the impact of various aspects such as water content in soil in early stage, slope inclination, rainfall intensity and slope vegetation coverage, etc. on water loss and soil erosion (Yang et al., 2014; Xiong et al., 2012; Zhang et al., 2016). In this paper, artificial rainfall simulation technique was used to study the characteristics of the loss of water, soil and nutrient in the limestone area of Taihang Mountain by selecting different slope vegetations so as to provide a scientific basis for the control and prevention of water loss and soil erosion in this area and provide reasonable suggestions for the construction of the forest fruits production base in mountainous area.

2. Materials and methods

2.1 Materials of experimental

In April 2013, we filled the soil in rain-fed steel tanks. After one year of natural compaction, we planted ryegrass and false indigo, which was planted in the previous year as seedlings, on April 20, 2014. The rainfall experiment started in August, with each rainfall lasting for 1 hour and the rainfall intensity being 80 mm/h. The rainfall experiment was repeated for 3 times.

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The experiment site is located in the rainfall hall of the National Engineering Research Center for Agriculture in Northern Mountainous Areas, Hebei Agricultural University. The experiment adopted QYJY-503 spray rainfall simulation equipment with the rainfall height of 11 m and the effective rainfall area of 144 m^2.
The soil used in the experiment was limestone soil collected from Baibao Township, Mancheng District, Baoding City with the pH value of 7.8, the porosity of 52% and the soil bulk density of 1.3 g / cm^3. The soil was divided into two layers, 0 ~ 20 cm and 20 ~ 50 cm, for collection and the steel tank was filled with the original order of the soil layers for one year of natural compaction. The 0 ~ 20 cm soil after natural compaction was measured and analyzed: the nitrogen content was 1.55 g / kg, the total phosphorus content was 0.57 g / kg, the total potassium content was 49.20 g / kg, and the water content was 7% ~ 9%.

2.2 Design of experiment

This experiment adopted the rainfall steel tanks with the dimensions of 1.5 m x 0.5 m x 0.5 m. Percolation holes with the diameter of 3 mm and the spacing of 10 cm were provided at the bottom and the sides of each steel tank to ensure seepage and drainage of soil during rainfall (Chen et al., 2006). "V" runoff collection tanks were installed at the ends of the steel tanks to collect runoff. The rainfall intensity was set to 80 mm / h, and baffles were used to cover the soil tanks before each rainfall. After the rainfall intensity was stable, the baffles were opened for rainfall timing. Runoff was collected every 10 minutes after the start of the rainfall for a total of 6 times with the total time of 60 minutes. The volume of the runoff to be collected was measured, the water sample and the sediment were separated with filter paper, and the supernatant of the water sample was taken to measure the dissolved nitrogen, phosphorus and potassium. After the sediment was dried, it was weighed and the contents of nitrogen, phosphorus, and potassium nutrient were measured (Qin et al., 2016).
According to the requirements of the experiment, the following plot treatment method was adopted:
Laws of water loss and soil erosion on slopes covered by different vegetations: false indigo and ryegrass were used as slope vegetations. The planting density of false indigo was 20 plants / m^2, or 20 cm / plant, and the seeding quantity of ryegrass was 10 g / m^2. Ryegrass and false indigo were planted on April 20. To ensure consistent nutrient status on different slopes, NPK compound fertilizer was applied. Pure nutrients applied included N: 7. 0 kg / hm^2, P_2O_5: 6 kg / hm^2, and K_2O: 7. 0 kg / hm^2 (Che et al., 2016).
10 ° slopes were set uniformly as shown in Table 1. Steel tanks with the dimensions of 1.5 m x 0.5 m x 0.5 m were adopted. The limestone soil was filled in the steel tanks according to the sequence of soil collection in two layers, 0 ~ 20 cm and 20 ~ 50 cm, ensuring consistency of the steel tanks in nutrients, moisture, and content of organic matter at the early stage. And the experiment was repeated for three times (Mi et al., 2017; Chai et al., 2012). The experiments were conducted during the flourishing period of false indigo and ryegrass (with the coverage of more than 60%), and the runoff and sediment were saved and separated for follow-up experiments.

Table 1: Experiment plan

Treatment	Plot No.	Vegetation Height (cm)	Vegetation Type
1	1, 1*, 1**	-	CK (no vegetation)
2	2, 2*, 2**	70 ~ 90	False indigo
3	3, 3*, 3**	15 ~ 30	Ryegrass

Note: * and ** mean repeated treatment groups.

3. Results and analysis

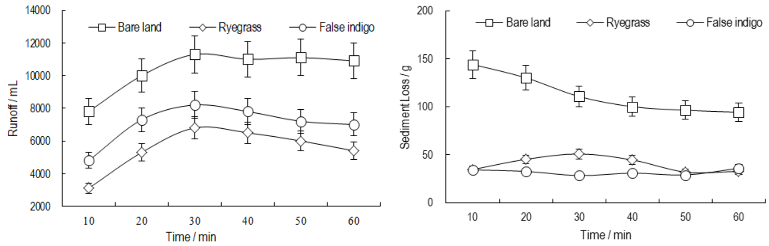
3.1 Soil erosion characteristics of slopes covered by ryegrass and false indigo

During the rainfall, when the surface runoff generating speed is greater than the infiltration speed, surface runoff will be generated (Li et al., 2016). The erosion of the water flow causes the soil particles on the slope to move with the runoff. The splashing of the raindrops and the erosion of the runoff are the driving forces for water loss and soil erosion (Zhao et al., 2013). Reasonable allocation of planting density can effectively alleviate the water loss and soil erosion in cultivated land and is also a key process in the production of agriculture and forestry (Lv, 2010).
By analyzing the sediment and runoff yield status of slopes with different vegetations (see Table 2), the runoff yield times for different vegetations were ordered as follows: ryegrass> false indigo> CK (control plot) at the fixed rainfall intensity of 80 mm / h. Compared with the control plot, the runoff yield times of false indigo and ryegrass were respectively extended by 226 s and 264 s. The characteristics of runoff and sediment yield on limestone slopes were displayed as follows: bare land> ryegrass slope> false indigo slope. Compared with the control group, the runoff yield times of false indigo and ryegrass were reduced by 32% and 47%, respectively.

Ryegrass roots were more developed than that of false indigo, thus having the soil retention ability superior to that of false indigo (Li et al., 2016).

Table 2: Runoff and sediment tields of slopes with different vegetations per plot (plot area: 0. 75 m^2)

Vegetation Type	Vegetation Height (cm)	Runoff Yield Time (s)	Total Runoff (L)	Total Sediment (g)	Runoff Depth (mm)	Sediment Modulus (g / m^2)
CK	-	103 c	62.2 a	676.18 a	13.80 a	901.57 a
False indigo	70~90	329 b	42.3 b	240.32 b	9.40 b	373.83 b
Ryegrass	15~30	367 a	32.9 c	191.46 c	7.31 c	255.27c



Part a *Part b*

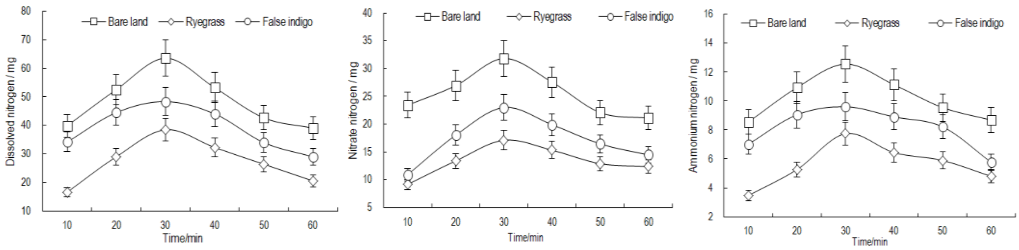
Figure 1: Runoff and Sediment Yields of Different Vegetations per Plot (plot area: 0. 75 m^2)

According to the analysis on the characteristics of runoff and sediment yields on the slopes of the plot (see Figure 1), it can be seen that the runoff and runoff yields on the three types slopes have similar trends, that is, rising between 0-30 min, reaching the peak at 30 min, and then declining slowly. The effect of raindrop splashing and runoff flushing on the soil particles on the slopes was gradually stabilized, thus causing the yields of runoff and sediment to gradually become stable (Tan et al., 2011). It can be seen from the figure below that the peak values of runoff yields of ryegrass land, false indigo land and bare land are 680 mL / min, 820 mL / min and 1130 mL / min, respectively.

3.2 Laws of nutrient loss in runoff

3.2.1 Laws of nitrogen loss in runoff

It can be seen from Figure 2 that the rates of dissolved nitrogen loss on the three slopes of different treatments show the following law during the whole process of rainfall: bare land> false indigo> ryegrass. Throughout the whole process of nitrogen loss, all three slopes showed the gradual increase in the loss of dissolved nitrogen in the early stage of the rainfall (reaching the peak at 30 min) and the gradually decrease in the loss with the progress of the rainfall. Compared with bare land, the dissolved nitrogen in ryegrass and in false indigo decreased by 39% and 24%, respectively. Through comparison and analysis, it was found that the laws of loss in nitrate nitrogen and ammonium nitrogen were similar to that of dissolved nitrogen, so nitrogen shows the same law of loss during the rainfall in all three forms. Ryegrass is superior to false indigo in terms of runoff interception, so, compared with false indigo, it has better retention effect on nitrogen in the runoff.



Part a Part b Part c

Figure 2: Nitrogen Loss in Runoff Per Plot (plot area: 0. 75m^2)

3.2.2 Laws of phosphorus loss in runoff

It can be seen from Figure 3 that the loss of dissolved phosphorus on the three types of slopes showed the following law: bare land > false indigo > ryegrass. Compared with the control group, the loss of dissolved phosphorus on slopes covered by false indigo and ryegrass were reduced by 35% and 54%, respectively. The loss of dissolved phosphorus in false indigo-covered slope and the control slope showed similar tendency during the rainfall, that is, the loss of dissolved phosphorus rose between 0 ~ 40 min (reaching the peak at about 40 min) and then decreased gradually. The loss of dissolved phosphorus on ryegrass-covered slope was dropping during 0 ~ 20 min, and then slowly rose till stability.

3.2.3 Laws of potassium loss in runoff

It can be seen from Figure 4 that the loss of dissolved potassium in the runoff showed the following law: bare land > false indigo > ryegrass. During the whole rainfall, the dissolved potassium losses on the three types of slopes showed an upward trend during the early state of rainfall. The dissolved potassium reached the peak at about 40 min while that of ryegrass-covered slope already reached the peak at 20 min. According to the loss of total dissolved potassium, ryegrass-covered slope showed the best nutrient retention capacity, and the loss of dissolved potassium on the false indigo-covered slope was slightly lower than that of the bare land slope. The highly-developed root and stem system of ryegrass can better reduce the flushing and carrying effect of the runoff on potassium (Tan et al.,2011).

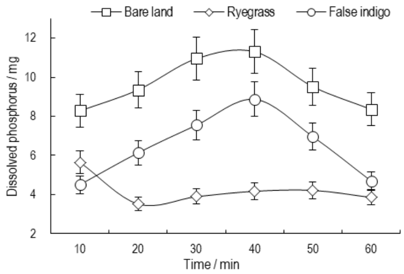


Figure 3: Phosphorus Loss in Runoff Per Plot (plot area: 0. 75m²)

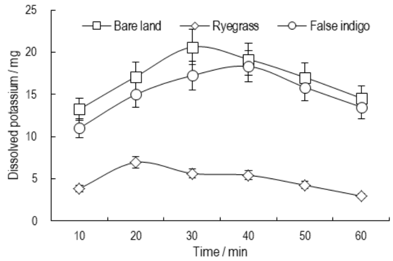
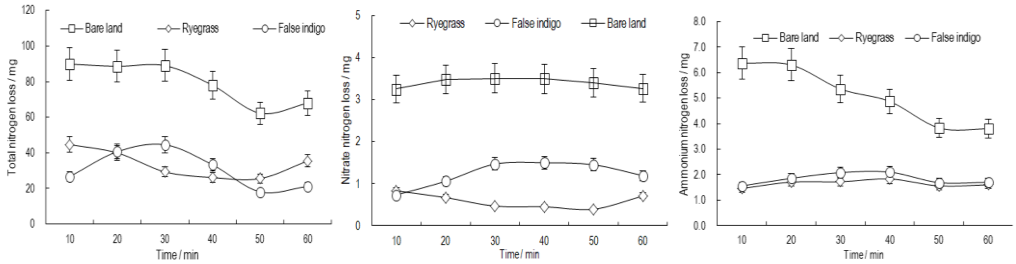


Figure 4: Potassium Loss in Runoff Per Plot (plot area: 0. 75m²)

3.3 Characteristics of nutrient loss in sediment

3.3.1 Laws of nitrogen loss in sediment

It can be seen from Figure 5 that during the whole rainfall, the total nitrogen losses in sediment on the three types of slopes showed great difference. The loss of total nitrogen in the sediment of the control slope showed a relatively steady trend in the first 30 minutes, and then the loss decreased gradually (reaching the bottom at 50min), and then rose slightly. As for the false indigo-covered slope, the total nitrogen loss showed a rising trend during the rainfall and reached its peak at 30 min; the total nitrogen content decreased while the progress of the rainfall and became stable after 50 min. On the ryegrass-covered slope, the total nitrogen loss was in a downward trend at the beginning of the rainfall and tended to be stable after 30 minutes.
The loss of ammonium nitrogen on the control slope was relatively stable during 0 ~ 20 minutes of rainfall, and then kept decreasing till stabilized at 50 min. The total nitrogen loss on the false indigo-covered slope was slightly higher than that of the ryegrass-covered slope, and neither slope showed significant changes in the total nitrogen during 0 to 40 min and then both slopes showed decease in the loss of total nitrogen after 40 min.



Part a Part b Part c

Figure 5: Nitrogen Loss in Sediment Per Plot (plot area: 0. 75m²)

In the early stage of rainfall, the loss of nitrate nitrogen on the false indigo-covered slope was slightly lower than that of the ryegrass-covered slope. However, with the progress of the rainfall, the loss of nitrate nitrogen

was increased and then stabilized after 30 min. The loss of nitrate nitrogen on the ryegrass-covered slope showed a downward trend in the early stage of the rainfall, and then became stabilized after 30 min.
The false indigo-covered slope showed similar laws of loss in total nitrogen, nitrate nitrogen and ammonium nitrogen during the rainfall, basically reached the peak at 30 min. The losses of total nitrogen, nitrate nitrogen and ammonium nitrogen on the ryegrass-covered slope were 201.22 mg, 3.54 mg and 12.90 mg, respectively.

3.3.2 Laws of phosphorus loss in sediment

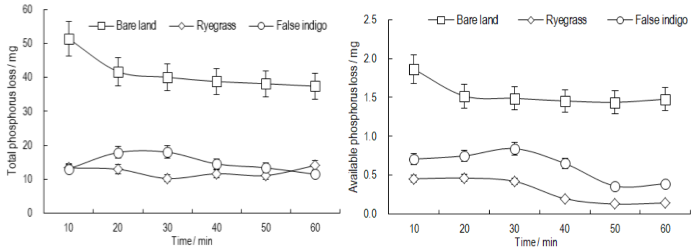


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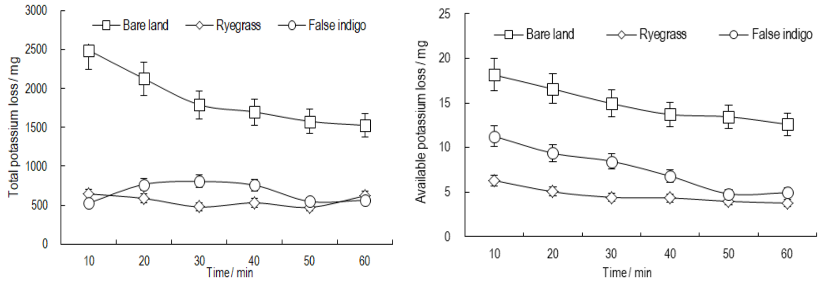
Figure 6: Phosphorus Loss in Sediment Per Plot (plot area: 0. 75m^2)

It can be seen according to the laws of phosphorus loss in soil (see Figure 6) that the loss of phosphorus on the control slope was much higher than that on the other two slopes, and the laws of phosphorus loss on the control slope were consistent, namely, decreasing with the progress of the rainfall and becoming stable after 20 min. Compared with the control slope, the total phosphorus loss on the ryegrass-covered slope was reduced by 70%, and that on the false indigo-covered slope was reduced by 64%. Compared with the control slope, the available phosphorus loss on the ryegrass-covered slope was reduced by 80%, and that on the false indigo-covered slope was reduced by 60%.

3.3.3 Laws of potassium loss in sediment

It can be seen from Figure 7 that the loss of potassium showed the following law: bare land > false indigo slope > ryegrass slope. Due to the high potassium content in limestone soil, the potassium enrichment in the sediment was very high. Compared with the control slope, the total potassium loss on the false indigo-covered slope was reduced by 65%, and that on the ryegrass-covered slope was reduced by 70%. During the rainfall, there were certain differences between the laws of loss in total potassium on the ryegrass-covered slope and the false indigo-covered slope. At the beginning of the rainfall, the loss on the false indigo-covered slope showed a slow rising trend while that on the ryegrass-covered slope showed a declining trend. Compared with the control slope, the available potassium loss on the three types of slopes showed a consistent law. Compared with the control slope, the available potassium loss was reduced by 48% on the false indigo-covered slope and reduced by 69% on the ryegrass-covered slope.



Part a Part b

Figure 7: Potassium Loss in Sediment Per Plot (plot area: 0. 75m^2)

4. Conclusions

According to relevant data, the sediment and runoff yields on the ryegrass-covered slope, false indigo-covered slope and bare land showed a similar trend: rising during 0-30 min, reaching the peak at 30 min, and then declining slowly. The effect of raindrop splashing and runoff flushing on the soil particles on the slopes was gradually stabilized, thus causing the yields of runoff and sediment to gradually become stable (Xiong et al., 2012; Jia, 2010). The peak values of runoff yields of ryegrass land, false indigo land and bare land are 680 mL

/ min, 820 mL / min and 1130 mL / min, respectively. Ryegrass performed better than false indigo in terms of sediment retention and can better embody the water and soil conservation effect of herbage; Sediment and runoff yields on different slopes showed the following law: base land > false indigo land > ryegrass land, and compared with the control group, the runoff yields on the false indigo-covered slope and ryegrass-covered slope were reduced by 32% and 47%, and the sediment yields on the two types of slopes were reduced by 64% and 71%, respectively. The runoff yield laws were the same: the runoff yield rate increased with the progress of the rainfall, and reached the peak at about 30min, and then declined gradually till stability; The nutrient loss law is: according to analysis on the granular nutrients, the loss of particulate nitrogen on the bare slope, the false indigo-covered slope and the ryegrass-covered slope accounted for 62%, 46% and 53% of the total loss of nitrogen, respectively; the loss of particulate phosphorus accounted for 81%, 69% and 74% of the total loss of phosphorus, respectively; and the loss of particulate potassium accounted for 99%, 97% and 99% of the total loss of potassium, respectively. False indigo and ryegrass can properly reduce the loss of particulate nitrogen and phosphorus but have little effect on reducing the loss of particulate potassium.

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