Effects of Grazing Regimes on Grassland Runoff, Sediment Yield, and Nitrogen and Phosphorus Loss: Postprint

Authors: Fan Cai-Rui, Li Chang-You, Sun Biao, Shi Xiao-Hong, Yang Fang, Gao Hong-Bin

Date: 2018-03-08T00:00:00+00:00

Abstract

Investigating the processes of soil and water loss in grasslands under different grazing regimes holds significant theoretical importance for the ecological protection and management of grassland environments. This study selected three grazing regime grasslands (continuous grazing, rotational grazing, and rest grazing) in the Hulunbuir Grassland of Inner Mongolia as research sites. Artificial rainfall simulation experiments were conducted at intensities of 0.74 mm/min and 1.5 mm/min to measure runoff volume, sediment concentration, and total nitrogen and total phosphorus concentrations in runoff and sediment, and to explore the influence of vegetation interception on runoff. The results indicated that vegetation interception significantly reduced rainfall runoff, with the rest grazing grassland exhibiting the greatest reduction in runoff coefficient and the continuous grazing grassland the least. Sediment yield followed the order: continuous grazing > rotational grazing > rest grazing. Rainfall intensity significantly affected nitrogen and phosphorus concentrations in runoff, with total nitrogen concentration in continuous grazing grassland and total phosphorus concentration in rest grazing grassland being most influenced by rainfall intensity. The concentration variation curves of nitrogen and phosphorus loss processes were better fitted by a power function distribution. The rest grazing grassland showed the highest sediment nitrogen and phosphorus contents. The total nitrogen enrichment ratios of continuous grazing and rest grazing grasslands were essentially equivalent and both exceeded that of rotational grazing grassland. The total phosphorus enrichment ratio ranked as: continuous grazing > rest grazing > rotational grazing. The primary influencing factors for nitrogen, phosphorus, and sediment loss across the three grazing grasslands were runoff volume and sediment concentration. Therefore, appropriately converting continuous grazing grasslands to rest grazing and rotational grazing grasslands in the Hulunbuir Grassland would be conducive to reducing nutrient element

loss from soil and water and promoting the sustainable development of grassland ecosystems.

Full Text

Preamble

ACTA ECOLOGICA SINICA ChinaXiv Partner Journal Vol. 38, No. 4 Feb., 2018 DOI: 10.5846/stxb20161122378

Characteristics of Sediment Content and Phosphorus and Nitrogen Loss in Surface Runoff from Different Grazing Grasslands

FAN Cairui, LI Changyou*, SUN Biao, SHI Xiaohong, YANG Fang, GAO Hongbin

College of Water Conservancy and Civil Engineering, Inner Mongolia Agricultural University, Hohhot, Inner Mongolia 010018, China

*Corresponding author. E-mail: nndlichangyou@163.com

Abstract

Soil erosion is a primary cause of grassland soil fertility loss and ecosystem degradation. The process and degree of damage caused by soil and water loss differ under various grazing systems due to differences in vegetation coverage rates, and this information is crucial for guiding ecological and environmental protection practices and governance policies in grasslands. This study investigated the Hulunbuir grassland in Inner Mongolia, a region dominated by sandy soil that has experienced grassland degradation and area loss. We selected three grazing systems—free grazing, rotational grazing, and no grazing—based on different stocking rates, choosing one representative pasture for each system. Soil samples were collected, vegetation growth conditions were investigated, and soil total phosphorus and total nitrogen were assessed. Using a rainfall simulator, we simulated two rainfall intensities (0.74 mm/min and 1.50 mm/min), with each intensity applied twice in the same grazing pasture. During each simulated rainfall experiment, all runoff was collected to measure runoff volume. Runoff samples were collected every 3 minutes for a total of eight times after rainfall began. Each runoff sample was tested for runoff volume, sediment content, total phosphorus, and total nitrogen to assess the mechanism of phosphorus and nitrogen loss via rainfall runoff.

The results show that stocking rates significantly affected surface runoff and sediment reduction. The no-grazing system exhibited the greatest reduction function, while free grazing showed the least. Regarding silt content in runoff, free grazing was the least effective system and no-grazing the most effective, suggesting that no-grazing grassland would best reduce soil erosion. Tolerance of rainfall intensity differed under different vegetation coverage. The runoff coefficient was reduced by 25.0%-45.7% for no-grazing grassland under the two rainfall intensities; rotational grazing grassland was reduced by 13.2%-20.2%; and free grazing grassland was reduced by 7.5%-12.4%. Runoff nitrate concentrations were significantly influenced by rainfall intensity under free grazing grassland (nitrogen loss significantly affected) and no-grazing grassland (phosphorus loss significantly affected). Moreover, the nitrogen and phosphorus loss curve followed a power function distribution. Soil and nutrient loss were mainly controlled by runoff volume and silt content in all three grazing systems. The no-grazing grassland showed the highest nitrogen and phosphorus loss in sediment. The rotational grazing system had the lowest enrichment rate. The greatest loss of nitrogen and phosphorus was observed in free grazing grassland. Nitrogen in sediment first increased and then decreased with increasing grazing intensity. The distribution of phosphorus loss in sediment was contrary to that for nitrogen in the three grazing types. Enrichment was observed in the loss of both nitrogen and phosphorus in runoff. The free grazing grassland had the most significant effects on the main influences. Accordingly, these results could provide vital baseline information for choosing grazing methods and grassland management practices and could facilitate the reduction of nitrate runoff losses and encourage the development of adaptable grazing methods.

Keywords: Different grazing systems; Simulated rainfall; Total nitrogen; Total phosphorus; Sediment

1. Study Area Overview

The experimental area was selected in the sandy grassland of the Hulunbuir grassland in Inner Mongolia, located in Baodong Sumu, Xin Barag Right Banner. The region has an arid to semi-arid climate with an annual average temperature of -0.6°C to 1.1°C, annual precipitation of 240.5–283.6 mm, annual evaporation of 1455.3–1754.3 mm, annual sunshine hours of 2694–3131 h, and a frost-free period of 110–160 days. The annual average wind speed is 3.38–3.92 m/s, and the elevation ranges from 700 to 1000 m. The main soil types are sandy soil and loamy sand, with dominant vegetation including *Leymus chinensis* (Leymus), *Stipa krylovii* (Stipa), and *Cleistogenes squarrosa* (Cleistogenes). Vegetation and soil characteristics are shown in Table 1.

Vegetation and soil properties in no grazing, rotational grazing, and free grazing grasslands

The Hulunbuir grassland, located in the core area of the Hulun Lake basin, has complex utilization patterns that can be summarized into three grazing systems. In summer 2015, we selected three representative grazing system pastures with typical stocking rates in Baodong Sumu, Xin Barag Right Banner, southern Hulunbuir grassland for rainfall simulation experiments. The locations were: free grazing (N 48°27 55 , E 117°16 20), rotational grazing (N 48°28 33 , E 117°13 09), and no grazing (N 48°28 33 , E 117°11 41). The theoretical stocking rate for free grazing pasture was 0.5 sheep units/ha, with actual rates reaching 0.9 sheep units/ha. Rotational grazing pastures mainly involved small-scale rotational grazing with a theoretical stocking rate of 0.5 sheep units/ha and actual rate of 0.5 sheep units/ha. No-grazing pastures were fenced for more than six months without grazing and mowed in autumn.

Rainfall simulation experiments were conducted in the three selected grazing pastures. A quadrat method was used for data measurement. Three flat grassland plots (5 m × 5 m) were selected in each grazing system, with vegetation growth and soil conditions investigated in 1 m × 1 m quadrats. Soil physicochemical properties were measured, including total phosphorus and total nitrogen in 0-10 cm soil, as well as vegetation indices such as root depth.

1. Artificial Rainfall Simulator

To investigate the relationship between rainfall intensity and nitrogen/phosphorus loss in different grazing grasslands, this study used a self-made pipe-network rainfall simulator for different rainfall intensity simulations. The simulator had an effective rainfall height of 2.5 m, water supply pipeline pressure of 0-100 kPa, and effective rainfall area of 1.8 m × 1 m. The simulator mainly consisted of a power water supply system, water supply pipeline, return water system, 支架, and auxiliary system. Rainfall generators were vertically arranged pipes with uniformly distributed small holes. Rainfall intensity was changed by adjusting flow rate. Rigid baffles were used for protection around the runoff plots, and a V-shaped drainage channel was installed downslope to guide runoff into collection devices.

Rainfall intensity was determined by adjusting the inflow pipe flow rate and return pipe flow rate per unit time. Five rain gauges were arranged in the rainfall area. The rainfall intensity formula was:

$I = \Sigma H_i / (t \times n)$

where I is rainfall intensity (mm/h), H_i is water volume in measuring cylinder i (mm, $i = 1,2,\cdots 5$), t is measurement time (h), and n is number of measuring points.

Rainfall uniformity was measured using 10 same-sized beakers (500 mL) placed on the same plane in the rainfall area. The rainfall uniformity formula was:

$\text{Uniformity} = 1 - (\Sigma|H_i - H|) / (n \times H)$

where H_i is rainfall at measuring point i (mm), H is average rainfall at measuring points (mm), and n is number of measuring points. The simulator uniformity was 85%.

Raindrop diameter distribution was measured using the stain method, based on the principle that stain size on the same material is proportional to raindrop diameter. First, the relationship between raindrop diameter and stain diameter was calibrated. Then filter paper coated with magenta and talcum powder was used as the stain carrier for measuring terminal velocity. The calibration relationship was:

$$D = 0.42d^{0.846}$$

where D is actual raindrop diameter and d is stain diameter on filter paper.

2. Rainfall Simulation Experimental Design

According to rainfall data from Hailar, Xin Barag Left Banner, and Manzhouli meteorological stations from 1956-2015, the maximum daily rainfall was 72.2 mm in Xin Barag Right Banner. Based on the critical rainfall intensity that could produce stable runoff in the three grazing pastures during experiments, this study selected two rainfall intensities (0.74 mm/min and 1.50 mm/min) for low-slope rainfall simulation tests, with slope maintained at 4°-5°.

Rainfall simulation experiments were conducted in no-grazing, rotational grazing, and free grazing pastures. Each rainfall intensity was set for 40 minutes, with 1000 mL of rainwater collected as a blank control.

3. Vegetation Index Measurement

After rainfall began, a stopwatch was used to record the time to runoff initiation. Runoff samples were collected every three minutes for a total of eight samples. Sample volume was measured with a cylinder, then placed in 500 mL polyethylene bottles and taken to the laboratory for sediment content and water quality index determination.

During rainfall, dominant vegetation was measured in each grazing pasture. Ten plants of each dominant species were randomly selected and their height measured on-site with a tape measure. All vegetation in 1 m × 1 m quadrats was counted in the field.

Vegetation coverage was observed using the photographic method. A digital camera was used to take vertical images of quadrat areas under the three grazing systems, and computer image processing technology was used to extract vegetation information and calculate the percentage of coverage.

Vegetation interception was measured using the water balance method based on artificial rainfall experiments. Measurements were taken three times. Due to the short rainfall duration, measurements were conducted during midday with strong sunlight, and wind speed was light during the experiment, so evaporation during rainfall was negligible. The water balance equation was:

$$P_g = S + I + S_n + E$$

where E is evaporation during rainfall, P_g is total rainfall, I is canopy interception, S_n is soil moisture increase (weight difference before and after rainfall), and S is vegetation canopy interception.

4. Soil and Runoff Index Measurement

Soil moisture content was measured using the drying method: (weight before drying - weight after drying) / weight after drying. Soil porosity = (1 - bulk density / particle density) × 100%.

Soil total nitrogen and sediment total nitrogen were measured using the Kjeldahl method (GB7173-87) with a Kjeldahl nitrogen analyzer. Soil total phosphorus and sediment total phosphorus were measured using the nitric acid-sulfuric acid digestion method (GB9837-1988) with a microwave digester and UV-Vis spectrophotometer. Each batch of samples was duplicated.

Total phosphorus in runoff was measured using the ammonium molybdate spectrophotometric method (GB11893-1989) with a HITACHI U-2001 visible spectrophotometer. Total nitrogen in runoff was measured using the alkaline potassium persulfate digestion UV spectrophotometric method (GB11894-1989) with a HITACHI U-2001 UV-Vis spectrophotometer.

Sediment content was determined using the filtration-drying method: the filter paper used for filtering runoff samples was weighed before and after drying, and the mass difference was calculated.

2. Results and Analysis

2.1 Effects of Grazing Systems on Runoff and Sediment Yield

During rainfall runoff, the effects of different grazing systems on nutrient element loss are mainly reflected in the interception role of grass stems and the dispersion effect on runoff, as well as the fixing effect of vegetation roots on soil. Runoff and sediment are the main carriers of nutrient element loss. Vegetation roots affect soil porosity and bulk density, which control runoff infiltration rate and thus affect runoff volume. Grassland vegetation reduces runoff and sediment erosion to achieve soil nutrient conservation. The impact of vegetation on slope water, soil, and nutrient loss differs under different coverage levels.

Figure 2 shows the runoff coefficient and sediment transport rate changes under different grazing pastures. The runoff coefficient change characteristics were similar across the three grazing systems. The rainfall runoff coefficient increased with rainfall time initially, then reached a stable state. Runoff reached stable state at 21 minutes under 0.74 mm/h rainfall intensity and at 15 minutes under 1.50 mm/h rainfall intensity. Free grazing pasture had the maximum runoff volume, while no-grazing pasture had the minimum. Single-factor ANOVA showed significant differences in runoff coefficients between different grazing types ($p < 0.05$), indicating that different grazing types have different interception effects on rainfall runoff. Free grazing pasture had the weakest runoff interception.

Due to vegetation interception in different grazing pastures, interception amounts were 0.957 mm, 0.613 mm, and 0.431 mm respectively during a single 0.5 mm/min rainfall process. The longer the rainfall duration and the greater the rainfall intensity, the weaker the interception effect. Vegetation interception had a significant effect on runoff volume in all three grazing pastures. Raindrops first reached vegetation leaf surfaces and were adsorbed and intercepted, providing a buffering effect on rainfall and significantly slowing runoff. Under both rainfall intensities, no-grazing pasture reduced runoff coefficient the most (25.0%-45.7%), rotational grazing reduced it moderately (13.2%-20.2%), and free grazing reduced it the least (7.5%-12.4%).

Total runoff coefficient in three grazing grasslands

The erosion reduction effect of different grazing systems is mainly reflected in increased vegetation coverage, reduced water flow velocity, and decreased runoff volume, thereby reducing erosive force. Sediment yield peaked in the early runoff stage, then gradually decreased with increasing runoff. Soil erosion developed rapidly, and sediment yield increased sharply. As surface soil was gradually stripped and eroded by rainfall, sediment transport rate showed a fluctuating decline during the runoff process and finally reached a stable state. This was mainly due to strong rainfall scouring in the early runoff stage. Single-factor ANOVA showed that increased rainfall intensity had a significant effect on sediment transport rate ($p < 0.05$), indicating a significant difference between the two intensities. Sediment transport rate reflects the degree of soil erosion by rainfall.

The order of soil erosion magnitude was free grazing > rotational grazing > no grazing. The cumulative sediment yield in no-grazing pasture was 1.47-1.72 times that of free grazing pasture, indicating that no-grazing pasture is better for reducing soil erosion and sediment interception than free grazing pasture. Both runoff coefficient and sediment transport rate reached maximum values in free grazing pasture, demonstrating that vegetation coverage has a very important influence on slope runoff and sediment transport mechanisms.

[Figure 2: see original paper] Characteristics of runoff and sediment under different grazing grasslands

2.2 Effects of Grazing Systems on Nitrogen and Phosphorus Loss Processes

Different grazing pastures have different soil nutrient element contents. Grazing systems significantly affect vegetation type and coverage, which in turn affect nutrient concentration changes in slope runoff. The main factors affecting runoff nutrient concentration during rainfall are rainfall amount, vegetation type, and coverage.

Figure 3 shows the concentration changes of total nitrogen and total phosphorus in runoff over time under different rainfall intensities. The concentration change trends of total nitrogen and total phosphorus in runoff from different grazing systems were basically similar, with maximum values reached in the early rainfall-runoff stage, then decaying to a stable value with fluctuations.

Total nitrogen concentration varied widely (0.83-1.74 mg/L) with a relatively gentle decline, while total phosphorus concentration varied less (0.25-0.56 mg/L) and stabilized earlier than total nitrogen, mainly due to phosphorus' s strong adsorption capacity and less dissolution in runoff.

Rainfall intensity significantly affected nitrogen and phosphorus concentrations in runoff. Free grazing pasture total nitrogen concentration and no-grazing pasture total phosphorus concentration were most affected by rainfall intensity. Total nitrogen concentration increased by 0.096 mg/L in free grazing pasture (the most affected) and only 0.053 mg/L in rotational grazing pasture (the least affected). For total phosphorus concentration, no-grazing pasture was most affected by rainfall intensity, with concentration increasing by 0.056 mg/L under 1.5 mm/min compared to 0.74 mm/min rainfall intensity, while rotational grazing was least affected with only 0.029 mg/L increase.

Current scholars have summarized many models for nutrient concentration changes during runoff, which can be divided into power function models and exponential function models. This study used both to describe total nitrogen and total phosphorus concentration changes in runoff from different grazing pastures. Power functions better simulated the concentration changes than exponential functions, with determination coefficients greater than 0.85 under different rainfall intensities. Power functions also fit total phosphorus better than total nitrogen.

[Figure 3: see original paper] Change of nitrogen and phosphorus concentration in runoff

Fitting process of nitrogen and phosphorus concentration in different grazing grasslands

2.3 Effects of Grazing Systems on Sediment Nutrient Concentration Changes

The process of sediment nutrient changes with runoff duration in different grazing pastures showed that total nitrogen content gradually decreased with rainfall duration and fluctuated within a certain range. Under high rainfall intensity in the same grazing pasture, total nitrogen content in sediment increased significantly. No-grazing pasture had significantly higher nitrogen content in sediment than rotational and free grazing pastures ($p < 0.05$).

Total phosphorus showed a different pattern from total nitrogen. The decreasing trend of total phosphorus over time was more gradual, without the sudden drop seen in total nitrogen, mainly due to phosphorus's strong adsorption capacity. No-grazing pasture had the highest total phosphorus content in sediment, while rotational grazing had the lowest. Single-factor ANOVA showed significant differences between no-grazing and free grazing pastures ($p < 0.05$), but no significant difference between rotational and free grazing pastures ($p > 0.05$).

[Figure 4: see original paper] Dynamics of nutrient concentration in sediment from different grazing grasslands

Cumulative sediment and nutrient enrichment ratio under different grazing grasslands

Analysis of total nitrogen and total phosphorus loss in sediment from the three grazing pastures under different rainfall intensities showed that total nitrogen loss in sediment first increased then decreased with grazing intensity. Under 0.74 mm/min rainfall, free grazing pasture increased by 40.94%, rotational grazing by 41.14%, and no-grazing by 50.83%. Total phosphorus loss showed the opposite pattern, increasing by 29.23% and 29.34% respectively. The proportion of fine particles in sediment was positively correlated with nutrient loss.

Nutrient enrichment occurs during rainfall soil erosion, where sediment nutrient content is higher than in the source soil. This is because fine particulate organic matter with large specific surface area is easily carried into runoff sediment. The enrichment ratio equals the ratio of nutrient content in sediment to that in source soil. Total nitrogen enrichment ratios were basically equal in free grazing and no-grazing pastures, both higher than in rotational grazing. Total phosphorus enrichment ratio was highest in free grazing, followed by no-grazing, and lowest in rotational grazing. Enrichment ratios of nitrogen and phosphorus in all three grazing systems increased with rainfall intensity.

3. Discussion

Grassland vegetation has important ecological functions in regulating surface runoff and conserving soil and water. As the largest natural grassland in China, the Hulunbuir grassland' s ecological environment has attracted continuous attention. Grazing methods not only determine grassland vegetation growth conditions but also change underlying surface soil physicochemical properties, which affect soil water cycling and consequently vegetation growth and soil erosion during rainfall.

This study investigated the effects of different grazing systems on nitrogen, phosphorus, and sediment loss characteristics in the Hulunbuir grassland. The rainfall-runoff-sediment process is mainly the process of rainfall doing work on surface soil. The three grazing pastures showed significant differences in runoff and sediment yield under different rainfall intensities. Free grazing pasture had sparse and short vegetation (35%-48% coverage), so rainfall kinetic energy directly impacted the soil surface, disturbing soil particles and clogging pores with disturbed particles, resulting in more sediment entering runoff. With increasing rainfall intensity, this effect became more significant.

In no-grazing pasture, vegetation coverage reached 83%-92%. Raindrop kinetic energy was first intercepted by vegetation, reducing energy before reaching the soil surface, decreasing soil disturbance and maintaining infiltration rates. However, as rainfall intensity increased, the buffering effect of vegetation gradually weakened. Research by Gan Yixian et al. showed that runoff intensity increases with rainfall intensity, which is consistent with our results.

During rainfall erosion, the mechanical composition of original soil changed significantly as runoff interacted with soil particles. Runoff carried fine silt and clay particles into flow, resulting in higher percentages of fine particles in sediment than in original soil. This enrichment of fine particles, with their large specific surface area, led to more nitrogen and phosphorus adsorption. The enrichment ratio patterns differed from some previous studies due to differences in background soil nutrient contents. In our natural grassland sites, no-grazing and rotational grazing pastures had about twice the phosphorus content of free grazing pasture, and no-grazing had about twice the nitrogen content of rotational and free grazing pastures. Despite free grazing having the highest sediment yield, its enrichment ratios were similar to no-grazing due to these background differences.

Enrichment ratios of nitrogen and phosphorus in sediment from all three grazing systems decreased gradually with increasing cumulative sediment amount, consistent with results from Guo Xinsong et al. This indicates that in areas with frequent rainfall-runoff events, soil nutrient content will gradually decrease, leading to soil impoverishment and ecological degradation.

Many factors affect nitrogen, phosphorus, and sediment loss, with underlying surface conditions playing a crucial role. The three grazing pastures had significantly different surface conditions: free grazing had low soil nitrogen and phosphorus, small porosity, and sparse vegetation; rotational grazing had similar phosphorus content to free grazing but the smallest porosity; no-grazing had the highest nitrogen and phosphorus content and porosity with the most vigorous vegetation growth. These differences led to varying sediment loss under the same rainfall intensity.

Sediment content in runoff had different effects on nitrogen and phosphorus loss among grazing pastures. The effect was greatest in no-grazing pasture and smallest in free grazing pasture, mainly because no-grazing pasture had less soil disturbance and thus less sediment content, contributing less to nitrogen and phosphorus loss. This is consistent with research by Zhang Liping et al. in bamboo forest slopes. Sediment content had a greater effect on phosphorus loss than nitrogen loss, mainly because fine clay and silt particles with large specific surface area adsorbed more phosphorus due to its strong adsorption capacity, resulting in higher phosphorus concentrations in runoff.

These results are basically consistent with Zhao Wei et al.’ s rainfall simulation experiments on different grassland utilization methods in the Hulun Lake basin. Zhao et al. found that sediment content was highly correlated with nutrient loss, and nitrogen loss was also affected by soil nitrogen content. However, they did not test enrichment phenomena during loss processes. She Diao et al.’ s results in the Loess Plateau differed, possibly due to lower phosphorus content in loess soils preventing enrichment.

Research on nitrogen and phosphorus release from water sediments shows that when water nitrogen and phosphorus concentrations decrease, sediment nutrients will gradually release into water, causing secondary pollution. Therefore, reducing free grazing area that causes soil degradation and nutrient loss, and strengthening ecological restoration, are important for sustainable grassland management.

Hulun Lake is the largest freshwater lake in Inner Mongolia, located in the Hulunbuir grassland. Its main inflow rivers are the Kherlen River and Uldz River. The Kherlen River originates in Mongolia' s Kent Mountains, with 206 km in China and 1058 km abroad. The Uldz River originates from Lake Buir (a China-Mongolia border lake) and is 223 km long. Both rivers are affected by grazing activities on their banks. Under our experimental rainfall intensities, runoff total nitrogen concentration (0.99-1.4 mg/L) was much lower than the Kherlen River' s mean total nitrogen concentration (2.5 mg/L), indicating that grazing activities have little impact on the Kherlen River' s nitrogen concentration, which is mainly affected by upstream inflow. However, runoff total phosphorus concentration (0.27-0.49 mg/L) was significantly higher than both rivers' concentrations (0.21-0.23 mg/L), indicating that phosphorus from grazing pastures is a major pollution source for Hulun Lake' s inflow rivers, while nitrogen pollution comes from other sources.

4. Conclusions

Different grazing systems significantly mitigated rainfall runoff and sediment yield. As grassland coverage increased among the three grazing systems, runoff and sediment yield intensity decreased. The order of mitigation effects was: no grazing > rotational grazing > free grazing.

Rainfall intensity significantly affected nitrogen and phosphorus concentrations in runoff. Free grazing pasture total nitrogen concentration and no-grazing pasture total phosphorus concentration were most affected by rainfall intensity. The total nitrogen and total phosphorus concentration change curves in all three grazing systems better fit power functions. No-grazing pasture had the highest sediment nitrogen and phosphorus content. Total nitrogen loss in sediment from the three grazing systems first increased then decreased with grazing intensity, while total phosphorus showed the opposite pattern. Both nitrogen and phosphorus showed enrichment during loss processes. Free grazing and no-grazing pastures had basically equal total nitrogen enrichment ratios, both greater than rotational grazing. Total phosphorus enrichment ratio was highest in free grazing, followed by no-grazing, and lowest in rotational grazing.

The primary influencing factor for nitrogen and phosphorus loss in all three grazing systems was runoff volume, while the primary factor for sediment loss was sediment content. Free grazing pasture nitrogen, phosphorus, and sediment loss were most significantly affected by runoff volume and sediment content. No-grazing and rotational grazing pastures provided significant protection against nitrogen, phosphorus, and sediment loss. Therefore, gradually changing grazing methods in sustainable grassland management will help reduce soil erosion and improve regional ecological conditions. However, control of nitrogen and phosphorus in watershed water bodies requires alternative approaches.

References

[1] Review and prospect of soil erosion science research in China, 2008, 30(1): 12-16.

[2] Ahuja L R. Modeling soluble chemical transfer to runoff with rainfall impact as a diffusion process. *Soil Science Society of America Journal*, 1990, 54(2): 312-321.

[3] Ahuja L R. Characterization and modeling of chemical transfer to runoff // Stewart B A. *Advances in Soil Science*. New York: Springer, 1986: 149-188.

[4] Mechanism and model of interaction between slope soil nutrients and rainfall-runoff. *World Sci-Tech R & D*, 2001, 23(2): 7-12.

[5] Characteristic analysis of effective mixing depth model for slope soil solute migration with runoff. *World Sci-Tech R & D*, 2010, 41(6): 671-676.

[6] Effects of vegetation types on runoff, sediment yield, and nitrogen and phosphorus loss on loess slopes. *Transactions of the CSAE*, 2016, 32(14): 195-201.

[7] Study on erosion particle characteristics of sand-covered slopes under simulated rainfall. *Soils*, 2016, 53(1): 39-47.

[8] Sediment loss characteristics and nutrient enrichment effects of three soil types under simulated rainfall. *Journal of Soil and Water Conservation*, 2014, 28(3): 23-28.

[9] Research progress on soil and water loss effects of slope cover patterns in arid and semi-arid regions. *Acta Ecologica Sinica*, 2013, 33(1): 12-22.

[10] Analysis of nitrogen and phosphorus loss characteristics in different particle size sediments under artificial rainfall conditions. *Journal of Soil and Water Conservation*, 2016, 30(3): 39-43.

[11] Effects of human activities on vegetation coverage and landscape pattern in typical red soil erosion areas of subtropical China. *Acta Ecologica Sinica*, 2016, 36(21): 6353-6362.

[12] Effects of artificial grass planting on soil erosion in comprehensive rocky desertification control in Guizhou. *Journal of Soil and Water Conservation*, 2013, 27(4): 67-72, 77.

[13] Sensitivity evaluation and spatial differentiation characteristics of soil and water loss in southwest karst region. *Acta Ecologica Sinica*, 2011, 31(21): 6960-6968.

[14] Characteristics of water, soil, nitrogen, and phosphorus loss in three utilization methods of grassland in Hulun Lake basin. *Transactions of the CSAE*, 2011, 27(9): 220-225.

[15] Butler D M, Ranaivoson A N, Franklin D H, Poore M H, Green J T. Ground cover impacts on nitrogen export from manured riparian pasture. *Journal of Environmental Quality*, 2007, 36(1): 155-162.

[16] Comprehensive investigation report of Inner Mongolia Dalai Lake National Nature Reserve. Inner Mongolia University Press, 2013: 3-337.

[17] Canopy interception of grassland vegetation in Hulun Lake basin under different grazing systems. *Acta Ecologica Sinica*, 2015, 35(14): 4716-4724.

[18] Research progress on mechanisms and control measures of soil nutrient loss with surface runoff. *Transactions of the CSAM*, 2016, 47(6): 67-82.

[19] Simulation experiment on runoff and sediment yield processes of different grazing grasslands. *Journal of Soil and Water Conservation*, 2016, 30(1): 47-53.

[20] Review of nutrient enrichment ratio research in soil erosion process. *Science of Soil and Water Conservation*, 2007, 5(1): 124-130.

[21] Soil erosion characteristics of karst slope farmland based on simulated rainfall experiments. *Chinese Journal of Applied Ecology*, 2012, 23(4): 881-888.

[22] Simulation of sediment and nitrogen-phosphorus load characteristics in bamboo forest slopes. *Journal of Soil and Water Conservation*, 2009, 7(1): 124-130.

[23] Nutrient enrichment law of erosion sediment in slope farmland. *Journal of Northwest Forestry University*, 2016, 27(9): 2754-2760.

[24] Lai D Y F, Lam K C. Phosphorus sorption by sediments in a subtropical constructed wetland receiving stormwater runoff. *Ecological Engineering*, 2009, 35(5): 735-743.

[25] Pollutant flux of Kherlen River, the main inflow river of Hulun Lake, during wet season (2010-2014). *Research of Environmental Sciences*, 2016, 28(2): 281-286.

Note: Figure translations are in progress. See original paper for figures.