Effect of tan-sheep rotational grazing on soil erosion in typical steppe on the Loess Plateau of China

Li-yuan Shi*, Fu-jiang Hou*, Shan-ning Lou†

State Key Laboratory of Herbage Improvement and Grassland Agro-ecosystems, Key Laboratory of Grassland Livestock Industry Innovation, Ministry of Agriculture and Rural Affairs, College of Pastoral Agriculture Science and Technology, Lanzhou University, Lanzhou, 730020, China

†Corresponding author. E-mail: lousn@lzu.edu.cn

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Abstract

The effect of stocking rate on soil erosion has been at the forefront of water and soil conservation studies in recent years. By observing soil erosion caused by rainfall in typical steppe on the Loess Plateau in China, this research aimed to further explore the effect of stocking rate on soil erosion. The results showed that all the concerned indicators of soil erosion (runoff, runoff coefficient, soil loss, soil organic carbon loss, and soil total nitrogen and total phosphorus loss) had a significant ($P < 0.001$) positive linear correlation with stocking rate alone, and precipitation alone, while the indicators of runoff and soil loss had a significant ($P < 0.01$) negative linear correlation with typical steppe biomass (aboveground biomass, litter mass, and belowground biomass). Both stocking rate and precipitation had large significant ($P < 0.01$) effects on soil erosion via changes in aboveground biomass, litter mass, and soil organic carbon.

Introduction

Soil erosion is widespread and a major environment threat to terrestrial ecosystems. The primary factors of causing soil erosion are precipitation, soil properties, topography and land cover change. Among these factors, soil and topography are generally stable and change little over time. Precipitation is an important factor to determine the severity of soil erosion. The Loess Plateau is the most serious soil erosion area in China. In the Loess Plateau, surface runoff increases with rainfall intensity. The frequency of precipitation will also influence soil moisture, which then influences vegetation development, and thus eventually decreases or increases erosion. Grazing further influences soil erosion by changing vegetation height and compaction of surface soil. Overgrazing is the most important human factor that has led to grassland degradation, and therefore is probably the main cause of soil erosion.

We quantitatively explored the effect of stocking rate on soil erosion by measuring soil erosion as a function of rainfall in the typical steppe on the Loess Plateau in northwestern China. This assessment was needed for scientific support for ongoing implementation and evaluation of ecological reconstruction and environmental management programs.

Methods and Study Site

This experiment was based on a long-term rotational stocking field trial on the Loess Plateau (37.12°N, 106.82°E) in northwestern China. Rotational grazing started in 2001, with 4 enclosures and 9 grazing paddocks (50×100 m) on typical grassland of the region. Local Tan-sheep were selected and divided into 3 groups of 4, 8 and 12 sheep in each group, corresponding to grazing rates of 2.67, 5.33 and 8.67 sheep ha^{-1}. Rotational stocking began in mid-June each year. Stocking was divided into three cycles (each cycle of 30 days, with new paddocks assigned every 10 days).

A subplot (0.5×0.5 m) was randomly selected in the area of flat and uniform vegetation around each runoff plot (Fig 1). Plant species were recorded and vegetation cover, density and biomass were measured. Four measurements were conducted during the rainy season from July to

September 2017 (sampling dates were July 22, August 4, August 20, and September 9). Rainfall, volume of surface runoff, and mass of alluvium in the sump of each runoff plot were measured. Soil organic carbon (SOC), soil total nitrogen (STN), and soil total phosphorus (STP) of alluvial sediment were measured in the laboratory after alluvial sediment was dried.

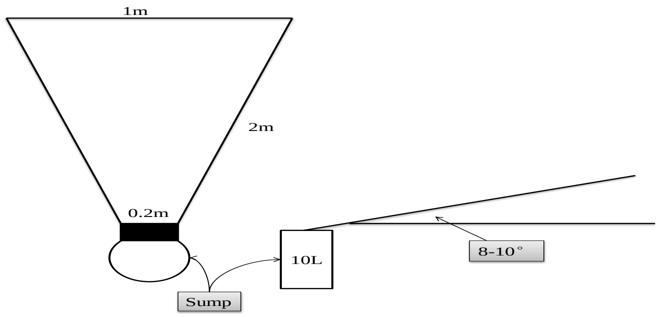

Figure 1. The top and side view of runoff plot.

Results and Discussion

Effects of stocking rate and precipitation on soil erosion

The effect of stocking rate alone and precipitation alone on all indicators of soil erosion were significant (P < 0.001). The combined effect of stocking rate and precipitation on runoff and soil total phosphorus loss was significant (P < 0.05), but this interaction on all other indicators was not significant (P > 0.05) (Table 1).

Table 1. Effects of stocking rate (SR) and precipitation (P) on all indicators of soil erosion, with statistical results of the general linear model (F-value, Pr > F).

	Runoff volume		Runoff coefficient		Soil loss		SOC		STN		STP	
	F	Pr > F	F	Pr > F	F	Pr > F	F	Pr > F	F	Pr > F	F	Pr > F
SR	57	<0.001	47	<0.001	35	<0.001	36	<0.001	15	<0.001	24	<0.001
P	649	<0.001	15	<0.001	214	<0.001	186	<0.001	165	<0.001	324	<0.001
SR×P	6	<0.001	<1	0.92	1	0.21	1	0.21	1	0.74	2	0.02

All indicators of soil erosion showed significant (P < 0.01) positive linear correlation with stocking rate (Table 2). For every unit increase in sheep stocking rate, runoff increased by 0.002 to 0.007 mm, runoff coefficient increased by 0.051 to 0.068%, soil loss increased by 9 to 21 kg ha^{-1}, soil organic carbon was lost by 0.05 to 0.12 kg ha^{-1}, soil total nitrogen was lost by 0.004 to 0.010 kg ha^{-1}, and soil total phosphorus was lost by 0.003 to 0.012 kg ha^{-1}. This may have been due to a decrease in above-ground biomass, belowground biomass and surface vegetation cover with an increase in stocking rate. Therefore, water infiltration capacity and substantial soil erosion resulted, as observed before (Gul and Whalen, 2013; Dai et al. 2015; Itano et al. 2017).

Table 2. Relationship between stocking rate and all indicators of soil erosion

	Precipitation (mm)	Stocking rate (sheep ha^{-1})		
		Regression equation	R^2	Pr > F
Runoff volume (mm)	3.3	R=0.0017SR+0.0247	0.547	<0.001
	5.1	R=0.0028SR +0.0458	0.492	<0.001
	10.9	R=0.0074SR+0.1008	0.766	<0.001
	12.8	R=0.0074SR+0.1252	0.751	<0.001
Runoff coefficient (%)	3.3	RC=0.0508SR+0.7477	0.547	<0.001
	5.1	RC=0.0548SR+0.8989	0.492	<0.001
	10.9	RC=0.0677SR+0.9244	0.766	<0.001
	12.8	RC=0.0578SR+0.9781	0.751	<0.001
Soil loss (kg ha^{-1})	3.3	S=8.54SR+78.25	0.681	<0.001
	5.1	S=13.39SR+152.12	0.680	<0.001
	10.9	S=12.28SR+299.96	0.538	<0.001
	12.8	S=20.85SR+291.85	0.553	<0.001
SOC (kg ha^{-1})	3.3	SOC=0.0453SR+0.3773	0.565	<0.001
	5.1	SOC=0.1053SR+0.6062	0.694	<0.001
	10.9	SOC=0.1150SR+1.7154	0.570	<0.001

	12.8	SOC=0.1236SR+1.6535	0.516	<0.001
STN (kg ha^{-1})	3.3	STN=0.0037SR+0.0500	0.399	<0.001
	5.1	STN=0.0069SR+0.1179	0.346	<0.01
	10.9	STN=0.0067SR+0.2040	0.312	<0.01
	12.8	STN=0.0097SR+0.1985	0.398	<0.001
STP (kg ha^{-1})	3.3	STP=0.0028SR+0.0328	0.590	<0.001
	5.1	STP=0.0049SR+0.0663	0.562	<0.001
	10.9	STP=0.0074SR+0.1822	0.440	<0.001
	12.8	STP=0.0122SR+0.1802	0.542	<0.001

All indicators of soil erosion showed significant (P < 0.05) positive linear correlation with precipitation (Table 3). When precipitation increased by 1 mm, runoff increased by 0.01 to 0.02 mm, runoff coefficient increased by 0.02 to 0.03%, soil loss increased by 24 to 31 kg ha^{-1}, soil organic carbon was lost by 0.15 to 0.21 kg ha^{-1}, soil total nitrogen was lost by 0.02 kg ha^{-1}, and soil total phosphorus was lost by 0.02 kg ha^{-1}.

Table 3. Relationship between and precipitation all indicators of soil erosion.

	Stocking rate (sheep ha^{-1})	Precipitation (mm)		
		Regression equation	R^2	Pr > F
Runoff volume (mm)	0	RF=0.0099PRE-0.0066	0.967	<0.001
	2.67	RF=0.0122PRE-0.0110	0.947	<0.001
	5.33	RF=0.0140PRE-0.0112	0.974	<0.001
	8.67	RF=0.0157PRE-0.0113	0.964	<0.001
Runoff coefficient (%)	0	RC=0.0165PRE+0.7455	0.257	<0.05
	2.67	RC=0.0230PRE+0.8552	0.229	<0.05
	5.33	RC=0.0267PRE+0.9994	0.336	<0.01
	8.67	RC=0.0271PRE+1.1594	0.317	<0.01
Soil loss (kg ha^{-1})	0	SL=23.79PRE+20.84	0.868	<0.001
	2.67	SL=24.57PRE+40.69	0.787	<0.001
	5.33	SL=29.06PRE+42.89	0.915	<0.001
	8.67	SL=30.71PRE+81.53	0.885	<0.001
SOC (kg ha^{-1})	0	SOC=0.1458PRE-0.0409	0.792	<0.001
	2.67	SOC=0.1716PRE-0.0220	0.811	<0.001
	5.33	SOC=0.1821PRE+0.0613	0.866	<0.001
	8.67	SOC=0.2051PRE+0.3350	0.870	<0.001
STN (kg ha^{-1})	0	STN=0.0159PRE+0.0145	0.843	<0.001
	2.67	STN=0.0167PRE+0.0246	0.736	<0.001
	5.33	STN=0.0167PRE+0.0492	0.741	<0.001
	8.67	STN=0.0199PRE+0.0391	0.874	<0.001
STP (kg ha^{-1})	0	STP=0.0168PRE-0.0156	0.898	<0.001
	2.67	STP=0.0183PRE-0.0159	0.851	<0.001
	5.33	STP=0.0222PRE-0.0283	0.951	<0.001
	8.67	STP=0.0236PRE-0.0123	0.954	<0.001

Relationship between soil erosion and steppe biomass

Correlation analysis was conducted between runoff, soil loss, and steppe biomass (AGB, LM and BGB) at different levels of precipitation (Table 4). The runoff and soil loss showed significant (P < 0.01) negative linear correlation with steppe biomass.

Structural equation model of stocking rate and precipitation on soil erosion

Stocking rate had a significant (P < 0.001) direct effect on aboveground biomass, litter mass, soil organic carbon loss, and runoff; and the action values were -0.782, -0.519, 0.363, and 0.201, respectively. However, the effect of stocking rate on soil loss was not significant (P > 0.05). In comparison, the precipitation had a significant (P < 0.05) effect on aboveground biomass, litter loss, soil organic carbon loss, runoff, and soil loss; and the action values were -0.239, 0.389, 0.852, 0.921, and 0.213, respectively (Fig. 2).

Implications

Combined with this paper, it is available that under small rainfall scale, the difference of soil erosion for different paddocks with different stocking rate is significant. Moreover, the amount of soil erosion increases with increase in stocking rate. However, under large rainfall scale, the difference of soil erosion for different paddocks with different stocking rate is no longer significant. In addition, the precipitation at this time has a dominant impact on soil erosion; after that, with increase in precipitation, soil loss is no longer increase, yet, runoff continue to increase.

Table 4. Relationship between runoff, soil loss and steppe biomass at different precipitation. Aboveground biomass (AGB), Litter mass (LM), Belowground biomass (BGB)

	Precip	Runoff volume (mm)			Soil loss (kg ha^{-1})		
	(mm)	Regression equation	R^2	Pr > F	Regression equation	R^2	Pr > F
AGB (g 0.25 m^{-2})	3.3	RF=0.0011AGB+0.0627	0.471	<0.001	SL=-6.25AGB+284.96	0.679	<0.001
	5.1	RF=0.0019AGB+0.1066	0.640	<0.001	SL=-7.20AGB+396.55	0.547	<0.001
	10.9	RF=0.0052AGB+0.2687	0.554	<0.001	SL=-9.84AGB+610.50	0.518	<0.001
	12.8	RF=0.0042AGB+0.2549	0.555	<0.001	SL=-12.73AGB+678.43	0.485	<0.001
LM (g 0.25 m^{-2})	3.3	RF=-0.0020LM+0.0467	0.572	<0.001	SL=-8.81LM+180.60	0.522	<0.001
	5.1	RF=-0.0026LM+0.1041	0.590	<0.001	SL=-10.16LM+393.99	0.546	<0.001
	10.9	RF=-0.0071LM+0.2254	0.657	<0.001	SL=-11.25LM+500.93	0.434	0.001
	12.8	RF=-0.0043LM+0.2343	0.638	<0.001	SL=-12.31LM+601.88	0.491	<0.001
BGB (g 0.25 m^{-2})	3.3	RF=-0.0099BGB+0.046	0.536	<0.001	SL=-41.66BGB+174.46	0.446	0.001
	5.1	RF=0.0172BGB+0.0852	0.492	<0.001	SL=-66.01BGB+315.62	0.427	0.001
	10.9	RF=0.0454BGB+0.2234	0.498	<0.001	SL=-93.40BGB+539.19	0.549	<0.001
	12.8	RF=0.0385BGB+0.2309	0.431	0.001	SL=-141.54BGB+651.73	0.551	<0.001

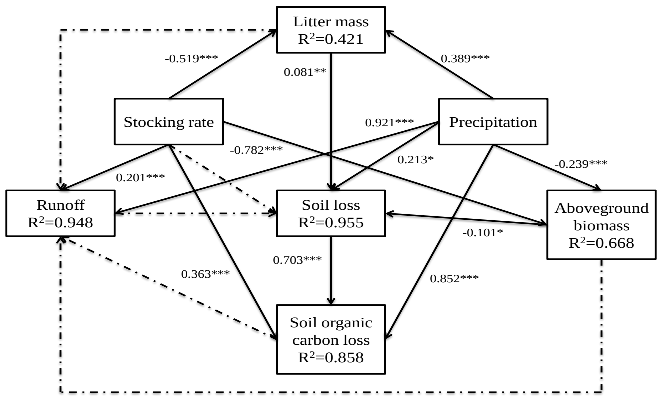

Figure 2. Effect of stocking rate and precipitation on runoff and soil loss.

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