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Characteristics of Material Migration During Soil Erosion in Sloped Farmland in the Black Soil Region of Northeast China

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Abstract

Loss of soil and water from sloped farmland is a major cause of regional soil degradation and declining productivity. We conducted a preliminary study on the characteristics of sloped farmland in the black soil region of Northeast China using natural rainfall-runoff plot experiments in the field. In 0-20 cm soil depth, clay content (<0.002 mm), silt content (0.002-0.02 mm), specific surface area, <0.002 mm and 0.002 to 0.02 mm microaggregates content, available phosphorus, and total phosphorus tended to increase from the top to the bottom of the slope, while sand content (>0.05 mm), 0.02 to 0.05 mm and 0.05 to 0.25 mm microaggregates content, tended to decline. This suggests that soil material and nutrients were gradually transported from the top to the bottom of the slope because of erosion, soil tended toward desertification in texture, and fertility was degraded. The content of available phosphorus and total phosphorus was positively linearly related to clay content, specific surface area, and 0.002 to 0.02 mm microaggregates content. This indicates that soil nutrients migrated down with fine particles. Therefore, soil erosion leads to the migration and loss of soil nutrients, <0.002 mm fine particles and 0.002 to 0.02 mm microaggregates on the slope, which was the main cause of soil fertility degradation.

Keywords

sloped farmland, soil erosion, soil particle composition, microaggregates, phosphorus

Introduction

Environmental problems caused by soil erosion have received increasing attention. The black soil region of Northeast China is the third largest Mollisol region in the world. It has rich organic matter, a deep humus layer, and high nutrient content. It also has good physical, chemical, and biological characteristics. It plays an important role in food supplies (Ou, Rousseau, Wang, & Yan, 2017), producing 17.1% of the nation's grain yield (Z. Liu, Yang, Hubbard, & Lin, 2012). However, due to natural and human factors, severe soil erosion has led to thin soil layers, significantly reduced soil productivity, and significant changes in soil nutrient levels (D. D. Wang et al., 2010; X. Y. Zhang, Yue, Zhang, Kai, & Herbert, 2007). According to the 2010 China Soil and Water Loss and Ecological Safety Survey (Ministry of Water Resources, Chinese Academy of Sciences, Chinese Academy of Engineering, 2010), the thickness of black soil in the black soil region has dropped from 60–70 cm in the 1950s to the current 20–30 cm. In some areas, because of serious soil erosion problems, soil parent material has been exposed, and agricultural production capacity has been lost. These problems seriously threaten valuable black soil resources.

Sloped farmland is the main source of soil erosion. According to a report by the Songliao Water Resources Commission in 2002, the total cultivated area in the black soil region of Northeast China is $21.40 \times 10^4\,km^2$,

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and the area of sloped farmland is 12.80×10^4 km^2, more than 59% of the total cultivated land area. The area of soil erosion in the black soil region is 27.59×10^4 km^2, and the area of soil erosion in sloped farmland accounts for 46% of the total area of soil erosion (Xu, Xu, Chen, Xu, & Zhang, 2010); In the black soil region, water erosion is the main form of erosion and causes the biggest soil losses (Xu et al., 2010). Soil erosion is a gradual process, and there is spatial variability at different scales and topographies (Y. Y. Li, Shao, & Zhang, 2001; Zheng, 1998). Under rainfall erosion conditions, the slope material mainly migrates because of surface runoff. During cultivation, slope ridges change water and sand processes and also increase the spatial differentiation of soil erosion on the slope and the complexity of soil erosion. However, the sediment and nutrients that directly runoff from the slope are only one component of the slope material migration. Owing to the long slopes, small production flow or rainfall stopping, a large amount of material carried in the runoff will be deposited on different parts of the slope, and these sediments will become the source of material migration on the slope. The runoff sediment on the output slope may have been removed after multiple passes after deposition (Tian, 1997). These materials, which include soil particles, agglomerates, nutrients, and moisture, have important effects on the physical and chemical processes of soil (Lu & Li, 2002), and they play an important role in managing surface runoff and erosion (Díaz-Zorita, Perfect, & Grove, 2002; Madari, Machado, Eleno, Andrade, & Valencia, 2005; Zheng et al., 2004; H. Zhou, Lu, Yang, & Li, 2007), and they are the main reason for nutrient loss. Y. Y. Li, Shao, Zheng, and Zhang (2003) showed that the fine particles and nutrients in the surface layer of loess soil in a long-term erosion environment gradually migrated down the slope. G. L. Li, Yao, and Pang (2008) found that the clay content in soil and sediment gradually decreased and the sand content gradually increased with increasing slope, runoff, and sediment amount in a hilly loess region. However, only a few studies have been conducted on sloped farmland in the black soil region in recent years. An, Lu, Zheng, and Li (2011) and An, Zheng, Li, and Wang (2011) studied the effects of different factors on nutrient and aggregate migration on the slope surface of black soils. Gao (2014) studied the effects of different erosion modes on the migration of aggregates and microaggregates in sloped black soil. Zhang, Zheng, An, and Wang (2013) studied the law of nutrient migration in sloped farmland of black soil in a single way. However, there is little information on the migration characteristics, correlation, and spatial variability of sloped farmland materials in black soil region. Therefore, we investigated the effect of spatial variability and slope scale on particle composition and nutrient content in the 0 to 20 cm soil layer in the black soil region using field experiments. This work can further understand the process of soil erosion and degradation and explore the characteristics of material migration during the soil erosion process on the sloped farmland in black soil region.

Methods

Site Description

The test area was located in the Xingmu Soil and Water Conservation Science and Technology Demonstration Park in Dongliao County, Jilin Province (E 125° 22′ N, 42° 58′). This area is located in the southeast of Jilin Province and belongs to the low hilly area of the black soil region in Northeast China (Figure 1). It is considered a cold temperate zone, with a semihumid and continental monsoon climate. The annual average temperature is 5.2°C, and the annual average precipitation is 658 mm. Rainfall is unevenly distributed, with 80% of the total rainfall occurring from June to August each year (Fan, Cai, Chen, & Cui, 2005). More than 90% of the cultivated land in the test area has a slope of more than 5°, and the soil on the sloped farmland is dominated by brown soil and meadow soil. The major economic crop is maize.

Experimental Design

There are many runoff observation plots in the test area, and the slope surface is the original soil, which has not been disturbed by artificial excavation. The cell sizes are 20×5 m. In this experiment, plots with slopes of 5°, 8°, and 10° were selected, and each slope was arranged with a control (bare slopes, no fertilizer), horizontal ridge rotation (corn, soybean), and horizontal ridge grass strip (*Medicago sativa*) for a total of nine plots (Figure 1). NPK fertilizers (total nutrient $\geq$45%, ratio N 24%, P_2O_5 10%, K_2O 11%) were applied to the experimental plots (except the controls) before the annual cultivation. The amount of chemical fertilizer used per unit of cultivated land is about 900 kg/hm^2.

Observation and Sampling

Soil samples were collected in mid-April (before fertilization) in 2013, 2014, and 2015. Sampling points were established every 2 m along the 20 m plots for a total of 11 sampling points per plot. The sampling depth was 0 to 20 cm and three samples were taken at each sampling point and mixed. We collected 500 g of soil using the quarter method, which was naturally dried and analyzed (Table 1). Runoff and sediment were observed by runoff sediment automatic monitors from May to September (rainy season). The meteorological data (Figure 1) were measured by

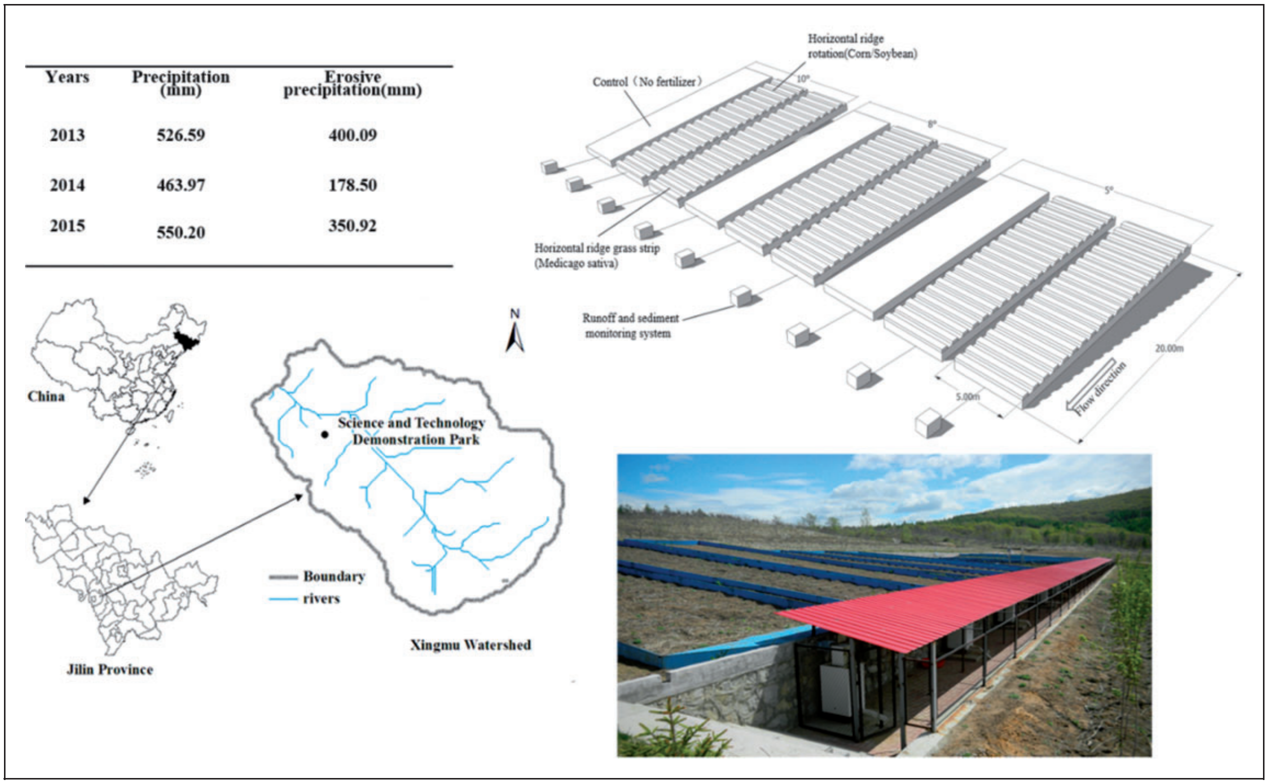

Figure 1. Location of the study area and layout of the test plots.

Table 1. Physical and Chemical Properties of Soil in Each Test Plot.

Slope (°)	Measures	Bulk density (g/cm³)	Water content (%)	Organic matter (g/kg)	Available phosphorus (mg/kg)	Total phosphorus (g/kg)	Loss of sediment (kg/km²)		
							Year of 2013	Year of 2014	Year of 2015
10	Control	1.31	12.92	12.65	7.49	0.32	6,281	2,138	4,928
10	Rotation	1.24	19.18	16.43	18.97	0.39	680	261	468
10	Grass strip	1.25	19.33	16.26	18.67	0.38	906	361.5	515
8	Control	1.32	13.54	14.44	7.67	0.31	4,454	1,342	3,954
8	Rotation	1.27	19.89	18.38	19.14	0.38	614	181	464
8	Grass strip	1.27	18.47	17.72	18.26	0.38	805	293	313
5	Control	1.29	14.24	15.21	7.97	0.31	3,187	1,179	2,807
5	Rotation	1.22	20.21	18.89	18.69	0.39	471	54	120
5	Grass strip	1.24	19.26	18.55	18.67	0.38	544	69	140

meteorological monitoring instruments. Each time the runoff sediment was monitored, 100 g of sediment was collected. At the end of the rainy season, the sediment in each plot was mixed to determine its nutrient content.

Soil Properties Analysis

The soil mechanical compositions were measured using a GSL-101BL laser particle distribution measuring instrument. We used the U.S. Department of Agriculture (1951) classification standard (Huang, 2000). The soil microaggregate contents were determined using the pipette method of G. Q. Liu (1996). The content of available phosphorus (AP) in soil was determined using the $NaHCO_3$ extraction-molybdenum antimony colorimetric method. The total phosphorus (TP) in the soil was determined using the $HClO_4$-H_2SO_4 digestion-molybdenum antimony colorimetric method.

The soil-specific surface area (SSA, cm^2/g) was calculated according to the empirical formula from Foster, Young, and Neibling (1985):

$$SSA = 0.05\ (Sa\%) + 4.0\ (Si\%) + 20\ (Cl\%) \quad (1)$$

where Sa, Si, and Cl are the percentages of sand (>0.05 mm), powder (0.05–0.002 mm), and clay (<0.002 mm), respectively, in the soil.

The soil structure coefficient was calculated using the following formula:

$$\text{Soil structure coefficient } (\%) = 100 - a/b \times 100 \quad (2)$$

where a is the percentage of <0.002 mm fraction from the soil microagglomeration results and b is the percentage of <0.002 mm fraction from the soil particle results (G. Q. Liu, 1996).

Data Analysis

Data were subjected to statistical analysis using SPSS 18.0 (IBM Corporation). All the illustrations and graphs of the monitored data were prepared using Origin Pro 9.0 (Origin lab, Inc., USA) and Excel 2010.

Results

Changes in Particle Composition and SSA of Sloped Farmland

After 3 years of observations (2013 to 2015), the clay content (<0.002 mm) in each test plot showed an upward trend from top to bottom along the slope (Figure 4). The silt content (0.05–0.002 mm) fluctuated and the trend was not obvious, but the intensity of the change was large. The fine silt content (0.002–0.02 mm) was greater in the bottom of the slope compared with the top. The sand content (>0.05 mm) showed a downward trend from top to bottom along the slope. The SSA tended to increase from top to bottom along the slope (Figure 2).

Soil Microaggregates Content and Structural Coefficient of Sloped Farmland

The 0.05 to 0.002 mm microaggregates content comprised the majority of the total microaggregates in the 0 to 20 cm surface soil layer (57.60%–61.66%; Figure 3). From the perspective of spatial variation, the 0.02 to 0.05 mm microaggregates content and sand (0.05–0.25 mm) showed big decreases with increasing slope length. At the same time, the 0.002 mm and 0.02 to 0.002 mm microaggregates contents increased with increasing slope length.

We found that the soil structure coefficient increases with increasing clay content. There was a strong positive linear relationship between soil structure coefficient and soil clay content (Figure 4).

Changes in Phosphorus Content in Sloped Farmland

The AP content in the surface soil of each test plot significantly reduced year by year (Figure 5). From the perspective of spatial variation, the AP content in the soil showed a greater upward trend in the lower part of the slope. The AP content of sediment in each slope control plot was higher or close to the AP content of the soil from the respective plots. The AP content in the sediment of the crop rotation and the grass strip plots was consistently lower than the AP content in the respective soils.

There was no statistically significant difference in soil TP content among the slopes of the test plots from 2013 to 2015 (Figure 6). There was spatial variation in TP content along the slope of each test plot, with fluctuations and generally higher values lower in the slopes. The TP contents of the runoff and sediments were lower than those in the soils.

Discussion

The Compositions of Soil Particles are Consistent With Changes in SSA

In the different slopes, the average clay content at the bottom of the slope was 24.42%, 21.14%, and 18.69% higher than those at the top of the slope for the 10°, 8°, and 5° plots, respectively. The silt content (0.002–0.05 mm) of each slope test plot did not change greatly. The fine silt content (0.002–0.02 mm) increased along the slope, and the bottom of the slope increased by 23.67%, 18.92%, and 17.77% compared with the top of the slope, respectively. The soil particles that moved down the slope in each test plot were mainly fine particles, especially clay particles (<0.002 mm). The soil sand content of each slope test plot decreased along the slope. There was 14.09%, 15.72%, and 13.10% less sand content at the bottom of the 10°, 8°, and 5° plots, respectively, showing that the soil in the test plot had obvious sandification from the top to the bottom of the slope. Consistent with research conducted by Yan and Yang (2005), the soil lost from the slope was mainly physical clay, and the proportion of sand increased accordingly. From the top of the slope to the bottom of the slope, the proportion of sand decreased, and the proportion of silt increased.

The SSA is a basic intrinsic property of soil. It can comprehensively reflect the particle size, gradation composition, mechanical properties, and various chemical

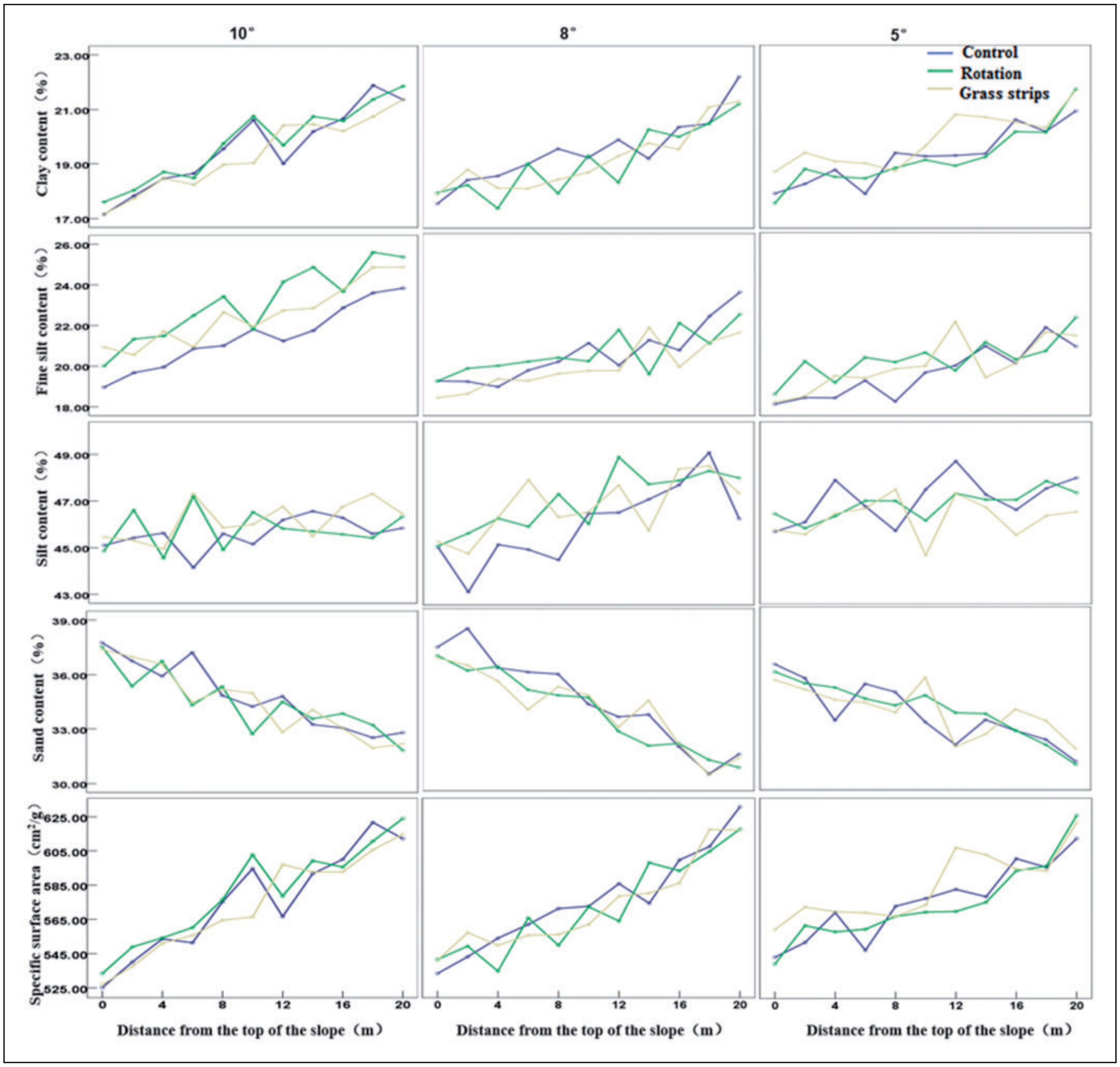

Figure 2. Variation of soil particle composition and specific surface area with slope surface.

properties of soil (Y. Y. Li et al., 2001). Therefore, the temporal and spatial changes of SSA can reflect the characteristics of soil degradation in slope more comprehensively. The formula for calculating the SSA value of soil indicates that it is most strongly influenced by the clay content. The SSAs of each test plot increased moving down the slope, and this trend was consistent with the trend in clay content. The average clay content at the bottom of the 10°, 8°, and 5° slopes were 16.75%, 15.45%, and 13.28% greater, respectively, than those at the top. This suggests that the water holding capacity of the soil and fertilizer retention performance was gradually reduced moving down the slope. Therefore, the loss of fine particles in the soil of sloped farmland in the black soil region affected by soil erosion is likely the main cause of soil texture sandification and fertility degradation on sloped land.

Soil Microaggregates and Soil Structure Coefficients Are Closely Related to Soil Particles

In soil, particles are typically cemented together to form composite soil particles or agglomerates. Under rainfall erosion conditions, the impact of raindrops, the soaking of rainwater, and the erosion of runoff can lead to the dispersion of agglomerates and the loss of runoff, leading to soil particle migration on slopes (Slattery & Burt, 1997). In cultivated land, the structure of soil is mainly reflected in the changes in microaggregates content (Y. Y. Li et al., 2003). The distributions of soil

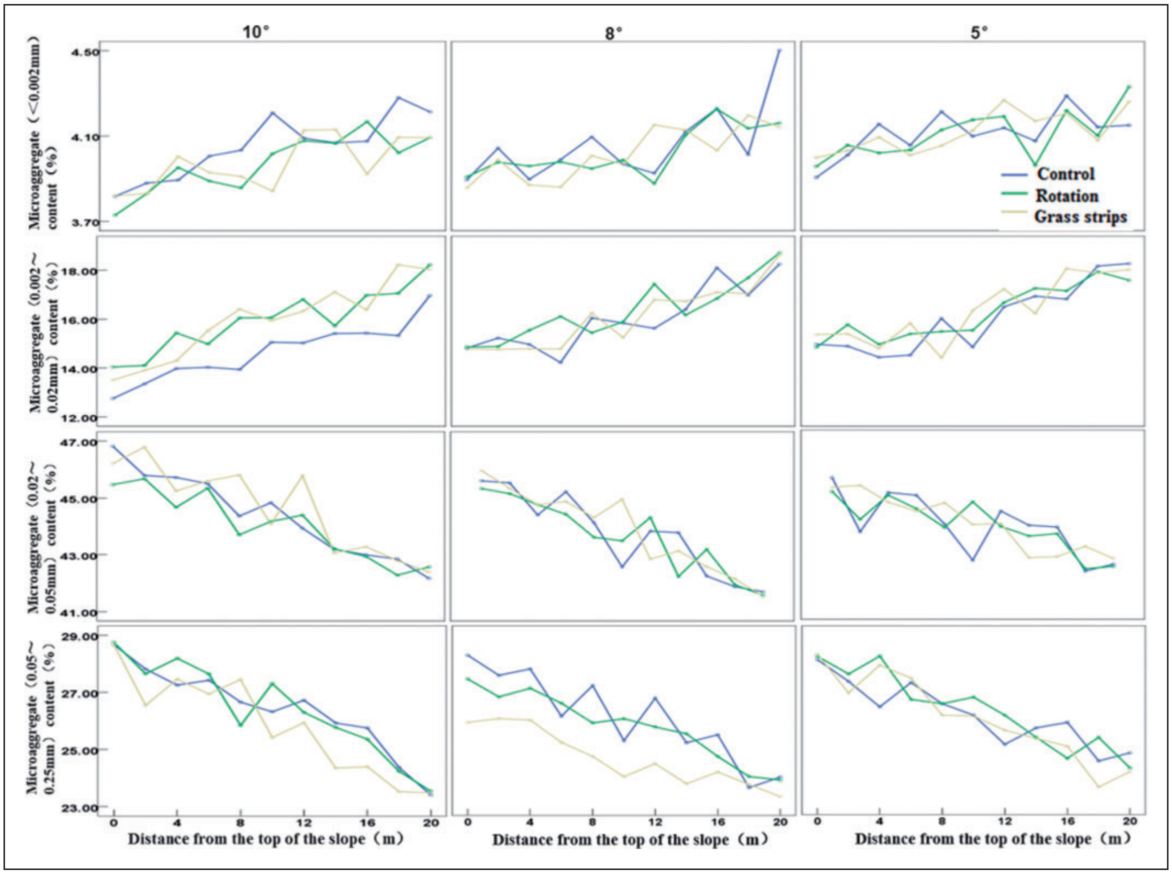

Figure 3. Soil microaggregates content as a function of slope.

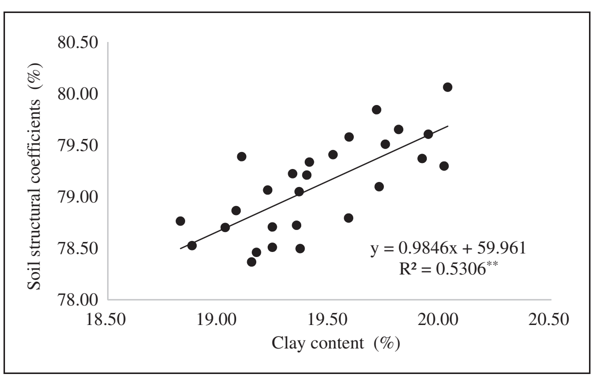

Figure 4. Linear relationships between soil structural coefficients and clay content. ** indicates $p < .01$.

microaggregates on the slope surface had similar trends as the particle analysis, that is, there were more large-particle-size microaggregates in the upper part of the slope, while there were more small-particle-size microaggregates in the lower part of the slope. There were significant linear relationships between the microaggregates content of both the fine silt and coarse fractions and the slope length (Table 2). There were significant positive linear relationships between 0.02 to 0.002 mm microaggregates content and slope length, and there was a significant negative linear relationship between the 0.02 to 0.05 mm microaggregates content and slope length.

The soil structure coefficient is an indicator for the ability of soil to form microaggregates and for the stability of soil microaggregates (G. Q. Liu, 1996). Previous studies have shown that soil with less organic matter content has a high correlation with clay content and soil aggregate content (Z. X. Zhu, 1983). This suggests that the clay content is important for the formation of soil microaggregates structures. The loss of clay in the sloped soil not only leads to the desertification of the soil texture, but also reduces the aggregate content of the soil, which causes the structural deterioration of the soil and ultimately leads to a decrease in the soil's ability to retain water and nutrients. Our results suggest that the soil structure gradually increases with increasing clay from the top of the slope. On the other hand, the soil structure deteriorated with the increase in soil erosion intensity and the reduced soil clay content.

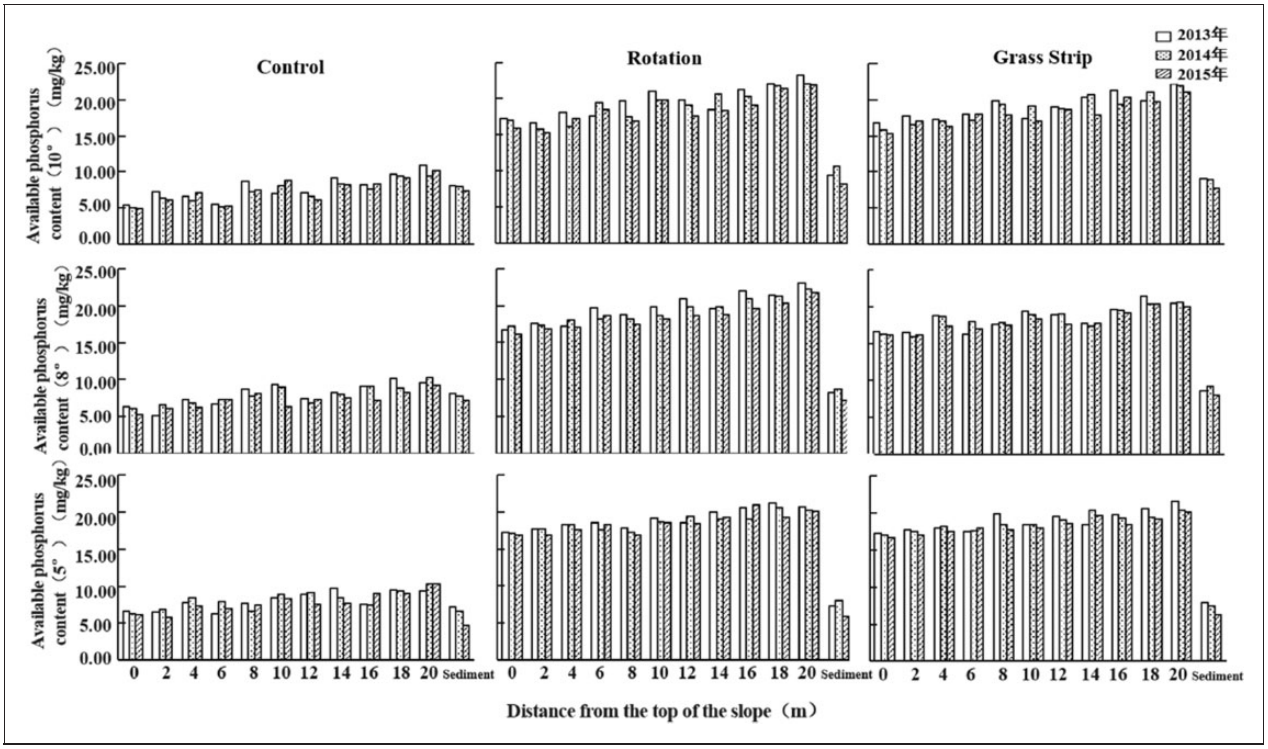

Figure 5. Changes in available phosphorus content in each test plot.

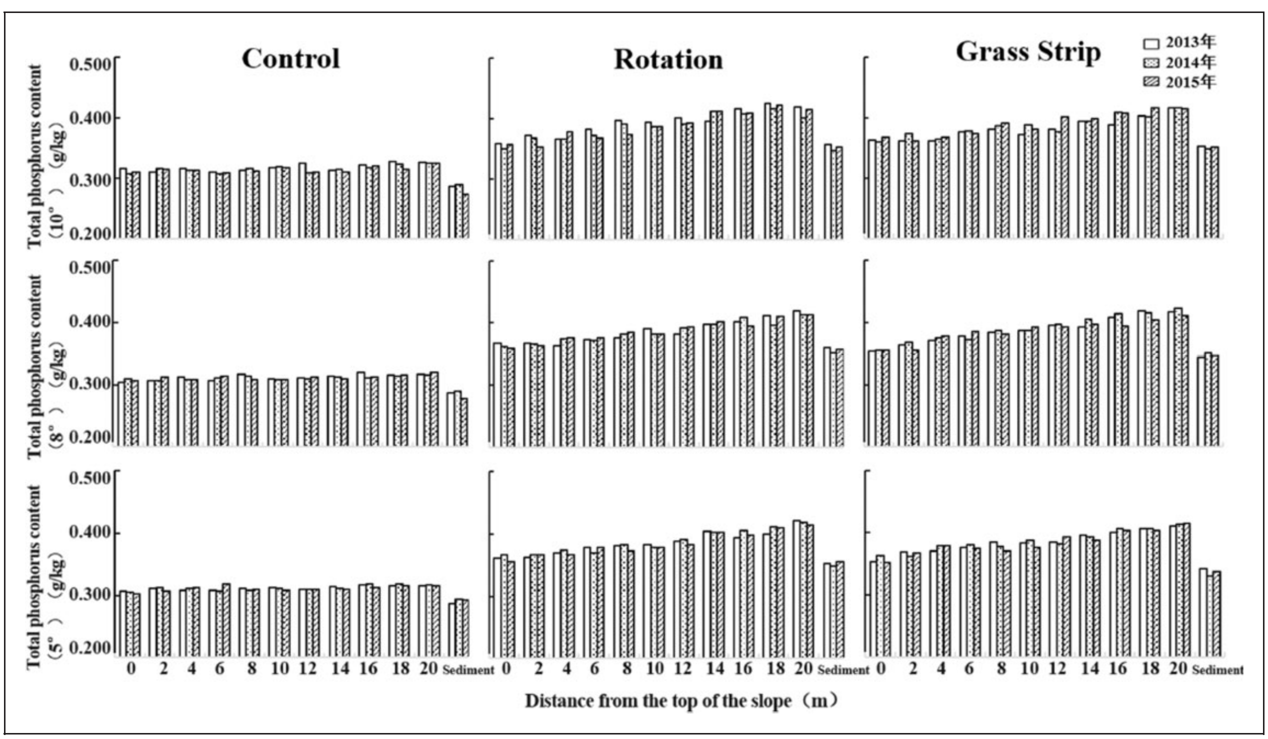

Figure 6. Changes in total phosphorus content in the soil of each test plot.

Table 2. Equations of Fine and Coarse Silt Fraction With Slope Length in Test Plots.

	Fine silt (0.02–0.002 mm)	Coarse silt (0.02–0.05 mm)
Equations	$Y = 0.178x + 14.176$ $R^2 = .574^{**}$	$Y = -0.174x + 45.772$ $R^2 = .574^{**}$

$^{**}p < .01$.

Temporal and Spatial Variation Characteristics of Nutrient Content in Sloped Farmland

The degradation of sloped farmland caused by soil erosion leads to the loss of a large amount of fertile topsoil, the deterioration of soil quality, and decreases in productivity. At the same time, soil erosion caused by sloped erosion leads to the loss of a large amount of sediment and water-soluble nutrients, which can affect the environment. Phosphorus is an essential nutrient for plants and is increasingly being used as fertilizer to increase yields. However, because of the behavior of phosphorus in the soil, after fertilizer is applied to the soil, only a small amount of plant is absorbed and used, and the remainder accumulates in the soil and rarely migrates to the deep layers (Saepk, 1997). The rate of phosphorus migration is also very slow under water saturation; nitrate behaves differently, migrating easily with water seepage or surface runoff. Relatively speaking, phosphorus is mainly lost in the form of surface runoff generated by slope precipitation. B. Z. Liu et al. (1995) found that the loss of phosphorus in eroded soil lagged behind nitrogen, mainly because the proportion of nitrogen loss in water-soluble state is larger than that of phosphorus. Therefore, when investigating the relationship between soil degradation and nutrient loss in sloped farmland in the black soil region, phosphorus should be the main focus.

The AP content of the control plot (which was not fertilized) decreased year by year. In the control plots with slopes of 10°, 8°, and 5°, the average AP contents in 2015 were 4.37%, 10.45%, and 3.04% lower, respectively, than they were in 2013. Although the rotation plots and the grass strip plots were fertilized before the annual cultivation, the AP content still decreased year by year. The average AP content of the crop rotation plots and grass strip plots with slopes of 10° in 2015 decreased by 6.09% and 5.10%, respectively, compared with 2013. In 2015, the average AP contents of the crop rotation plots and grass strip plots in the 8° slope were 6.12% and 2.99% lower, respectively, than those in 2013. The average AP contents of the crop rotation plots and grass strip plots with 5° slopes in 2015 were 3.24% and 3.87% lower, respectively, than those in 2013. This shows that available nutrients are being lost because of soil erosion. At the same time, soil nutrients were enriched at the bottom of the slope. In the test plots with 10° slopes, the average AP contents in the bottom of slope of the bare land, crop rotation, and grass strip treatments in 2015 increased by 98.59%, 34.18%, and 36.34%, respectively, compared with the top of the slope. The average AP contents at the bottom of slope of the test plots with 8° slopes increased by 64.43%, 34.35%, and 24.12%, respectively, compared with the top of the slope. The average AP contents at the bottom of the plots with 5° slopes increased by 57.25%, 19.44%, and 21.89%, respectively, compared with the top of the slope. This indicates that soil nutrients migrated down the slope under erosive conditions. In addition, the AP in the runoff and sediment of the 10° and 8° control plots was higher than the average AP content of the soil. The AP content in the runoff and sediment of the 5° slope control plot was 1.836 mg/kg less than the average AP content of the soil. The average AP content of the runoff and sediment for each slope of the rotation and grass strip plots was lower than that in the soil. This shows that the AP content is greatly affected by fertilization.

The effect of soil erosion on total nutrients is relatively slow and that the loss of nutrients is not as obvious as the loss of available nutrients. At the same time, the TP contents of each test plot tended to be larger at the bottom compared with the top of the slope. From 2013 to 2015, the average TP contents at the bottom of the 10° slope plot of the control, rotation, and grass strip plots were 4.67%, 15.94%, and 14.47% higher, respectively, than those of the top of the slope. The average TP contents at the bottom of the 8° slope plots were 3.58%, 14.52%, and 17.75% higher, respectively, than those at the top of the slope. The average TP contents at the bottom of each treatment slope of the 5° sloped plot were 3.76%, 15.68%, and 15.90% higher, respectively, than those at the top of the slope. This is consistent with the trends in soil clay content and SSA (Figure 2). In addition, the TP of the runoff and sediment indicate that the TP content is not significantly enriched in the lost sediment.

Communities that were rotated and contained grass strips had better soil with better abilities to intercept sediment, suggesting that rotation and grass strips can reduce the migration of substances caused by slope erosion. To reduce runoff and sediment yield on slopes, reduce nutrient loss, and protect the environment, considerable research has been done on slope management measures at home and abroad (An, Zheng, et al., 2011; Andraski, Mueller, & Daniel, 1985; Blevins, Frye, Baldwin, & Robertson, 1990; McDowell & Sharpley, 2002; Y. D. Zhu, Cai, Zhang, & Hu, 2003).

Table 3. Correlations Between Soil-Specific Surface Area and Both AP and TP.

	10°	8°	5°
Control			
AP	0.816**	0.710**	0.646**
TP	0.571**	0.604**	0.548**
Rotation			
AP	0.787**	0.679**	0.638**
TP	0.768**	0.830**	0.787**
Grass strip			
AP	0.816**	0.741**	0.654**
TP	0.818**	0.813**	0.759**

Note. AP = available phosphorus; TP = total phosphorus.
**$p < .01$.

Table 4. Regressions Equations of AP and TP With Soil Clay Content and 0.02 to 0.002 mm Microaggregates Content.

	Control	Rotation	Grass strip
Soil clay content			
AP	$Y = 0.607x - 4.100$ $R^2 = .401$**	$Y = 0.846x + 2.544$ $R^2 = .470$**	$Y = 0.972x - 0.135$ $R^2 = .619$**
TP	$Y = 0.002x + 0.280$ $R^2 = 0.250$**	$Y = 0.010x + 0.191$ $R^2 = .533$**	$Y = 0.010x + 0.200$ $R^2 = .610$**
Microaggregates (0.02–0.002 mm) contents			
AP	$Y = 0.585x - 1.398$ $R^2 = .422$**	$Y = 0.461x + 10.033$ $R^2 = .395$**	$Y = 0.849x + 2.840$ $R^2 = .411$**
TP	$Y = 0.001x + 0.296$ $R^2 = .108$**	$Y = 0.010x + 0.192$ $R^2 = 0.599$**	$Y = 0.010x + 0.190$ $R^2 = .510$**

Note. AP = available phosphorus; TP = total phosphorus.
**$p < .01$.

Relationships Between Phosphorus Content and Soil SSA, and Clay Particle and Microaggregates Content

There was a significant positive correlation between AP and TP and SSA (Table 3). This shows that changes in soil SSA not only reflect changes in soil physical properties but also reflect changes in soil nutrients. SSA can reflect the influence of different factors on soil fertility, and it is a comprehensive index that can be used to evaluate the changes of soil properties.

Changes in the fine particle composition of soil had the greatest influence on SSA (Table 3). We previously described how SSA was greatly affected by clay content. Therefore, we conclude that the migration and loss of soil fine particles due to surface erosion is the most direct cause of the changes in soil nutrient content in sloped farmland in the black soil region.

TP and AP contents both had significant positive correlation linear correlations with clay content and fine powder (0.02–0.002 mm) microaggregates (Table 4). This result suggests that the phosphorus content of the soils in the experimental plots and the migration of soil microaggregates along the slope were mainly caused by the migration of fine-grained microaggregates or single particles. These fine particles have large SSAs and have strong adsorption effects on nutrient elements (Huang, Ding, Dong, Cai, & Zhang, 1998). Therefore, the soil clay, silt, and soil nutrients in the lower part of the slope were obviously enriched. This observation is consistent with many previous studies. Huang et al. (1998) found that in purple soil, the TP in the lost sediment was mainly enriched in microaggregates of 0.02 to 0.002 mm and <0.002 mm single particles. The lost AP was mainly concentrated in 0.02 to 0.002 mm and <0.002 mm microaggregates and <0.002 mm single particles. Guo, Liu, Shi, Hou, and Li (2003) studied the distribution of soil nutrients on different slopes in a small watershed on the Loess Plateau and found that soil nutrient performance was characterized by enrichment at the slope foot and losses at the top of the slope. X. C. Zhang et al. (2013) found that the soil nutrient content of the slope erosion area was significantly lower than that of the sedimentary area in a study of the impact of sloping farmland on soil nutrients in the black soil region of Northeast China.

Factors Affecting Soil Material Migration on Sloped Farmland

The test plots in this study were divided into three slopes: 10°, 8°, and 5°. From the sediment yields in the control plots of each slope (Table 1), the greater the slope, the more the amount of sediment was lost, and the more severe was the erosion. Degree of slope and slope length affect soil erosion on slopes (C. B. Zhang, 2008). When the slope changes, the flow velocity and shear of the slope will change, which will affect the erosion process and the migration of soil nutrients due to runoff (Chen & Hao, 2017). Small changes in slope do not greatly affect the runoff process but can have a significant effect on soil loss processes on the slope surface (Kong, Wang, & Fan, 2007). H. Wang (2006) studied the migration characteristics of surface nutrients with surface runoff on loess slope when the slope changed from 5° to 25° and concluded that there is a critical slope of about 15°. When the slope is less than 15°, nutrient flow increases with slope. At the same time, the sediment yield of the test plots with measures was smaller than that of the control plots (Table 1). It indicated that the horizontal ridge rotation and the horizontal ridge grass strip have a good effect on soil erosion control. In addition, rainfall is the main source of soil loss. Rainfall erosivity is an indicator of the dynamics of rainfall on soil stripping and handling erosion (J. Zhou, 2009) and is important in evaluating the effects of rainfall on soil particle change and nutrient loss. In our study, erosive rainfall was 400.09, 178.50, and 350.92 mm in 2013, 2014, and 2015, respectively. The loss of sediment in each plot (Table 1) 2013 > 2015 > 2014, the difference in sediment yield between each plot was large. Since this study was mainly aimed at the influence of soil erosion process on the migration of slope material. According to the observed data (Figure 1), the erosive rainfall in the study area from 2013 to 2015 was 400.09, 178.50 and 350.92mm, respectively and the sediment yield in each test plot (Table 1) was 2013 > 2015 > 2014. It indicated that the loss of sediment in each plot increased with the increasing of erosive rainfall.

Implications for Conservation

The black soil region in northeast China is an important grain production base in China, with valuable land resources. It is important to gain an in-depth understanding of the mechanisms leading to soil degradation of sloped farmland in the black soil region and discuss the factors that lead to material migration characteristics, correlation, mutual relationship, and spatial variability on sloped farmland in the black soil region. These insights will provide a scientific basis for protecting black soil resources and inform future studies investigating methods to prevent soil erosion. The results of this study show that the migration and loss of materials on sloped farmland in the black soil region were mainly composed of fine particles, especially soil clay (<0.002 mm) and microaggregates (0.002–0.02 mm). The main reason for the degradation of soil fertility on sloped land was the loss of soil clay and 0.002 to 0.02 mm microaggregates content. Therefore, it is important to control the rate of soil degradation and accelerate the restoration and reconstruction of degraded ecosystems in order to maintain the country's food security, stability, and sustainable ecological development.

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