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The impact on soil erosion of water and soil conservation measures on sloping cropland in the black soil region, China

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Abstract. This study examines the effectiveness of several combinations of conservation measures at reducing soil erosion and runoff on test plots. By using engineering measures (rat holes and subsurface drainage pipes) as the core, and integrating those with subsoiling and short-ridge farming, different sets of conservation measures were applied to six plots of sloping cropland; one plot that utilized only conventional farming techniques served as the control plot. By measuring runoff and sediment yields from each plot under natural rainfall conditions, the impact on soil erosion of the different conservation measures was analyzed. All six water and soil conservation measures succeeded in retaining water and soil and in reducing soil erosion. The impact on the processes of runoff and sediment yield during individual rainfall events mainly manifested as increased lag time for discharge of runoff and sediment, reduction of the peak runoff intensity and erosion intensity, and decrease of runoff volume and sediment yield. Among all the conservation measures, those combining engineering and agricultural techniques were the most effective in reducing runoff and erosion, and simple application of short-ridge farming was able to retain rainfall and reduce runoff effectively. Moreover, it was possible to reduce runoff scouring and lessen soil erosion due to increased infiltration by the use of rat holes and subsurface drainage pipes. The Universal Soil Loss Equation was used to calculate the potential soil erosion amount in each test plot; calculated values were compared to values measured from the test plots, and found to be relatively accurate. These experimental results provide a theoretical foundation for preventing soil erosion of sloping cropland in the black soil region.

Key words. Black soil region, Sloping cropland, Water and soil conservation, Soil erosion, Universal soil loss equation.

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1. Introduction

The black soil region of Northeast China is the most important grain-producing region in China, as well as one of the top six regions suffering from water and soil loss. The root cause for this soil loss is that more than half of the cultivated lands are sloping farmlands, which are the most fragile part of the rural eco-tope [1]. Severe water and soil loss, especially on the sloping farmland, has reduced the black soil layer thickness that serves as the main support for grain yield by 50% [1], and erosion of this layer is ongoing. Soil organic matter and nutrient content decrease, and soil bulk density increases, with loss of the fertile black soil layer. As a result, the water- and nutrient-holding capacity of the soil is reduced and farmland productivity declines, thereby threatening regional grain security and sustainable agricultural development. Hence, theoretical research on soil erosion and water and soil conservation technologies, and implementation of effective water and soil conservation measures, have profound practical significance. To date, study of water and soil conservation technology has mainly focused on South China [2-8], and such studies in North China are relatively uncommon [9-10]. Moreover, study of water and soil conservation technologies has focused mostly on the conservation effects of single measures [11-17], and study of the integrated effects of several practices is less common [10,18-21]. The present study integrated two farming measures, subsoiling and short-ridge farming, with two engineering measures, rat holes and subsurface drainage pipes, on a series of test plots. Consequently, six water and soil conservation measures were established, and their integrated effects compared with conventional farming treatment, in order to analyze soil erosion under different sets of management practices and natural rainfall conditions, in order to identify optimal methods for retaining water and soil and improving water and soil resources in the black soil region.

2. Materials and methods

2.1. Experiment design

The experiment was carried out in 2015 and 2016, using a runoff plot with a gradient of 3° at a test site on Hongxing Farm, Agriculture Bureau of Heilongjiang Agricultural Reclamation Department, Beian Branch, located in the typical black soil belt in Northeast China. By installing rat holes and subsurface drainage pipes, integrating these techniques with subsoiling and short-ridge farming, we established six measures for water and soil conservation on sloping cropland, consisting of short-ridge farming (LQ), short-ridge farming + subsoiling (LS), rat hole + short-ridge farming (SQ), rat hole + subsurface drainage pipe + subsoiling (SAS), rat hole + subsurface drainage pipe + short-ridge farming (SAQ), and rat hole + subsurface drainage pipe + short-ridge farming + subsoiling (SAQS). The goal of the experiment was to analyze the water and soil conservation effect of each measure and to identify the best combination of techniques for water and soil conservation on sloping cropland in the black soil region. A plot without treatment (CK) was established as a control. Each plot had an area of 20 m × 5 m, and plots were separated by 1 m. All plots had the same exposure and slope position; all plots were planted with soybeans, and the water and fertilizer management was identical with that of the local fields.

2.2. Layout of runoff plot

The plot was built using artificially simulated micro-topography. Natural conditions among all of the plots should essentially be the same, except for the water and soil conservation technologies. Subsoiling was carried out prior to sowing, and soil retaining walls were built upon the short-ridge farming before flood season (wall construction in 2015 was on July 5, and on July 9 in 2016) with a 1-m distance between the two walls. Both rat holes and subsurface drainage pipes were constructed with 60-mm-diameter plastic corrugated pipes. The subsurface drainage pipe was buried at a depth of 80 cm and parallel to the longitudinal axis of the plot, while rat holes were laid out in V-patterns, bisected by the longitudinal axis, 300 cm apart and at depths of 50 cm. Rat holes and subsurface drainage pipes intersected, so that water in the rat holes would flow into the subsurface drainage pipes. Ditches were laid out perpendicular to the subsurface drainage pipe, and 1 m below the plot, to capture drainage from rat holes, subsurface drainage pipes, and the earth's surface. Runoff automatic recording systems measure runoff and collect sediment at the end of each plot; runoff is discharged from the ditch after the volume is recorded. To prevent lateral seepage, the border of each plot is separated by iron plates set at 1 m below the ground surface. A typical plan view of a runoff plot containing rat holes and a subsurface drainage pipe is shown in Figure 1 [10].

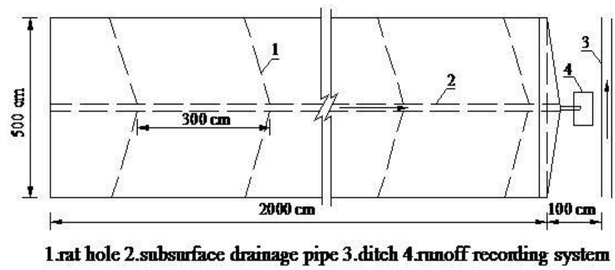

Fig. 1. Layout of typical runoff plot

2.3. Observation indexes and methods

(1) Rainfall and processing of rainfall

The date, duration, rainfall, and maximum rainfall intensity of each individual rain event was recorded by a tipping-bucket rain gauge installed at each runoff plot through the growing season. After the characteristics of all individual rainfall events were determined, they were used to define annual rainfall statistics.

(2) Volume and processing of runoff

A tipping flow meter was installed in the sump at the exit of each runoff plot, and the runoff hydrographs of individual rain events were recorded automatically; the annual runoff depth and runoff coefficients were calculated from these data.

(3) Yield and processing of sediment

Measurement of erosion processes and the sediment yield of individual rain events, as well as observation of runoff processes, should be carried out simultaneously. After runoff begins, a tipping-bucket runoff sample is collected every 5 min, and allowed to stand for 24 h. After removing the clear water, the remaining water is filtered through filter paper in order to trap any sediment; the filter paper must be allowed to dry for 6 h prior to weighing. The sediment yield of individual rain events can be determined from these data, allowing calculation of the annual soil erosion.

(4) Soil mechanical composition

The mechanical composition of the soil was measured by hydrometry: after air drying and crushing, soil samples were pressed through a 2-mm mesh sieve. In accordance with Stokes' Law, the suspension of a soil sample in a constant volume, after being dispersed, is allowed to stand for different periods; the mass content of each particle-size in suspension per liter is read out directly via the hydrometer, then percentage composition is calculated by the following empirical equations:

$$f_d = \frac{w - h_1}{w} \times 100\% \,. \tag{1}$$

$$f_s = \frac{h_1 - h_{120}}{w} \times 100\% \,. \tag{2}$$

$$f_c = \frac{h_{120}}{w} \times 100\% \,. \tag{3}$$

where w is the sample weight, (g); f_c is the fraction of clay-size particles (%); f_s is the fraction of silt-size particles (%); f_d is the fraction of sand-size particles (%); D_G is the geometric average soil particle diameter; h_1 is the hydrometer reading at 1 min; h_{120} is the hydrometer reading at 120 min.

2.4. Universal soil loss equation and determination of its factors

The Universal Soil Loss Equation (USLE) was proposed by the American scientists, W. H. Wischmeier and D. Smith, in the following form:

$$A = RKLSCP \,. \tag{4}$$

where A is the normal soil erosion per unit area per year ($\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$); R is the rainfall erosivity ($\mathrm{J \cdot m^{-2}}$); K is the soil erodibility (amount of soil erosion per unit of rainfall erosivity in a standard test plot, $\mathrm{t \cdot hm^{-2} \cdot a^{-1}}$); L is the slope length (showing the ratio of soil erosion on an actual slope length to that in a standard test plot when other conditions are the same); S is the slope (showing the ratio of soil erosion on an actual slope to that in a standard test plot when other conditions are the same); C is a vegetation factor (showing the ratio of soil erosion in plot with actual biological measure to that in a standard test plot; P is a factor related to the water and soil conservation measures in use (showing the ratio of soil erosion in a plot with the specified measures of water and soil conservation to that in a standard test plot).

Using measured data of the volume of runoff and sediment yield of each conservation measure, the USLE was developed to estimate the amount of soil erosion amount for each measure. Since the test periods were short, the values of each factor for the two years were identical, except for the rainfall erosivity factor. Values of each factor were determined as described below.

(1) Rainfall erosivity factor (R)

The rainfall erosivity factor is a quantitative index used to describe the potential capacity for soil erosion caused by rainfall, as well as the only factor directly causing soil erosion in the USLE. In terms of the short-duration, high-intensity rainfall in the area of these plots, the rainfall erosivity factor in 2015 and 2016 was calculated by $E_{60}I_{30}$, as proposed by Xiankui Zhang [22].

(2) Soil erodibility factor (K)

The soil erodibility factor is an index reflecting the susceptibility of soil to erosion, related to characteristics of the soil if other factors remain unchanged. The soil erodibility factor in this study was calculated by the following empirical equations:

$$K = 0.0293 \cdot (0.65 - D_G + 0.24 D_G^2) \cdot e^A \,. \tag{5}$$

$$A = -0.0021 \frac{O_M}{f_c} - 0.00037 (\frac{O_M}{f_c})^2 - 4.02 f_c + 1.72 f_c^2 \,. \tag{6}$$

$$D_G = -3.5 f_c - 2.0 f_s - 0.5 f_d \,. \tag{7}$$

where O_M is the organic matter content,(%).

(3) Slope length (L) and slope (S) factors

The slope length and slope are dimensionless factors that reflect the impact of landforms on the amount of soil erosion. In general, they are combined into a compound landform factor *LS*. As the slope length and slope in each plot are identical in this study, the factor *LS* is given a value of 1.

(4) Vegetation factor (C) and conservation measure factor (P)

The vegetation factor refers to the ratio of the amount of soil erosion from land planted with specific crops to that from unvegetated and ploughed fallow land, when other influencing factors remain unchanged. The water and soil conservation measure factor refers to the ratio of the amount of soil erosion from farmland with specified water and soil conservation measures to that from farmland with downslope cultivation when other influencing factors remain unchanged. As water and soil conservation measures affect not only the soil erosion amount but also the growth of vegetation and therefore the value of the vegetation factor, C, these factors are combined in a compound factor (*CP)* in this study. This value was calculated for each conservation practice based on the measured amount of soil erosion (A) in 2015:

$$CP = \frac{A}{R \cdot K \cdot LS}\,. \tag{8}$$

2.5. Data processing methods

Basic data processing and statistical analysis were conducted with Excel, SAS V9, Mathematica 5.0, and SPSS 12, in order to describe quantitatively the impact of the water and soil conservation measures on the amount of soil erosion. The annual amount of soil erosion for each measure was modeled with the USLE, and model efficiency was analyzed using the absolute error, model efficiency coefficient, and correlation coefficients of model values and measured values. The model efficiency coefficient E_f and correlation coefficient R are defined as follows:

$$E_f = 1 - \frac{\sum (R_i - R_i')^2}{\sum (R_i - \bar{R})^2}\,. \tag{9}$$

$$R = \frac{\sum (R_i' - \bar{R}')(R_i - \bar{R})}{\sqrt{\sum (R_i' - \bar{R}')^2 \sum (R_i - \bar{R})^2}}\,. \tag{10}$$

where R_i is the measured amount of soil erosion on plot i (t·hm^{-2}); R_i' is the modeled amount of soil erosion on plot i (t·hm^{-2}); $\bar{R}$ is the average of the measured amounts of soil erosion (t·hm^{-2}); $\bar{R}'$ is the average of the modeled amounts of soil erosion (t·hm^{-2}).

3. Results and analysis

3.1. Impact on annual soil erosion amount exerted by different technical modes

Rainfall is the principle source of overland runoff, as well as the major factor causing soil erosion. Rainfall during the soybean growth period in 2015 and 2016 was 562.7 mm and 603.0 mm, respectively, higher than the normal annual value for the area. Abundant rainfall was available to provide necessary moisture for the soybean crop, and to present the risks of soil erosion and nutrient loss.

The different conservation measures resulted in significant differences in soil erosion during the study period (Table 1). From the average value of erosion during the two years, the order of effectiveness of these practices, from least to most effective, is:

CK > LQ > LS > SQ > SAS > SAQ > SAQS.

The control plot (CK) showed the greatest net soil erosion, 11.235 t·hm^{-2}·a^{-1}. In contrast to the control case, all the technical measures showed some ability to reduce erosion, among which SAQS was the most effective, followed by SAQ, with annual average soil erosion amounts of 1.65% and 8.63%, respectively. Integration of subsoiling and short-ridge farming with rat holes and subsurface drainage pipes reduced soil erosion effectively by retaining runoff, encouraging infiltration, and reducing runoff scouring.

Table 1. Net annual soil erosion with each management practice ($t \cdot hm^{-2}$)

Test plot	CK	LQ	LS	SQ	SAQ	SAS	SAQS
2015	5.17	2.45	1.96	0.97	0.48	0.66	0.09
2016	6.07	2.78	2.07	1.01	0.49	0.81	0.10
Mean	5.62	2.615	2.015	0.99	0.485	0.735	0.095

The temporal distribution of soil erosion in 2015 and 2016 for each management practice is shown in Figure 2. Soil erosion occurred mainly from June to August, reflecting the distribution of rainfall. The monthly distribution of soil erosion in 2015 and 2016 for each management practice was almost the same, and could be divided into two stages: the first lasting from May to June, when there was no soil retaining wall from short-ridge farming, and therefore no retention of runoff and conservation of water and soil by the wall. The effectiveness of the different management measures during these two months, from least effective to most effective, was:

CK > LQ > LS > SQ > SAQ > SAS > SAQS.

The second stage lasted from July to September. Although there was greater rainfall during these three months than during the previous two months, and intense rainfall occurred more frequently, the amount of erosion for LQ decreased significantly compared to CK because of the soil retaining wall built for short-ridge farming, which was then available to retain runoff and lessen water and soil loss. By integrating short-ridge farming with rat holes, subsurface drainage pipes, and subsoiling, the retained runoff was allowed to soak rapidly into the soil, and the amount of erosion decreased further, with SAQ and SAQS showing almost no soil erosion during the two years. The effectiveness of the different management measures during these months, from least effective to most effective, was:

CK > LQ > LS > SAS > SQ > SAQ = SAQS.

This order reflects the amount of runoff from each test plot.

Coefficient of variation (CV) is a statistic that describes the variability relative to the mean value, and can be used to characterize the amount of variability of soil erosion for each management practice during the growing season. That is, the larger the CV is, the more significant the impact of a given practice on conserving water and soil. In order to eliminate effects due to different monthly amounts of rainfall, the amount of erosion per unit rainfall per month was calculated for each test plot. The value of the CV for the amount of erosion with each management practice during the growing season was also calculated, and is given in Table 2. In general, CV<10% denotes weak variability, $10\% \leq \text{CV} \leq 100\%$ denotes moderate variability, and CV>100% denotes strong variability [23, 24]. Test plots SQ, SAQ, and SAQS showed strong variability in the amount of erosion, while plots CK, LQ, LS, and SAS showed moderate variability. These results indicate that integration of the two engineering measures, rat holes and subsurface drainage pipes, with the two farming measures, short-ridge farming and subsoiling, could effectively slow rainfall runoff and reduce loss of water and soil.

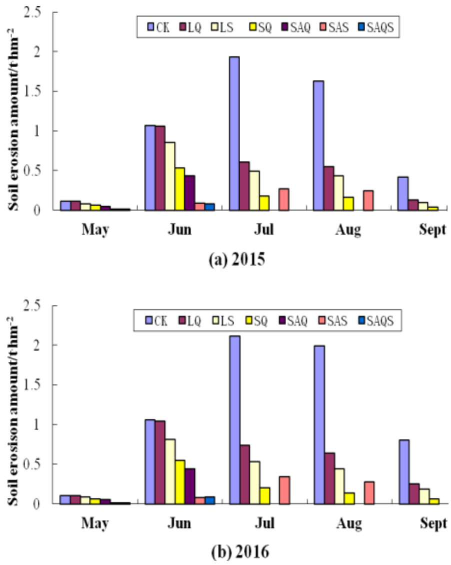

Fig. 2. Temporal distribution of erosion on each plot

Table 2. CV of soil erosion for each management practice (%)

Test plot	CK	LQ	LS	SQ	SAQ	SAS	SAQS
2015	43.27	92.30	95.89	118.57	180.29	43.78	173.94
2016	51.38	92.42	96.10	126.28	177.53	57.20	176.40
Mean	47.33	92.36	96.00	122.43	178.91	50.49	175.17

3.2. Impact of different management practices on soil erosion during individual storms

Storm events on June 29, 2015 and July 21, 2016 were selected for analysis of the effectiveness of each management practice in controlling soil erosion during single storms.

The rainfall on June 29, 2015 lasted 95 min and amounted to 57.9 mm; the maximum rain intensity was 68 mm·h^{-1}, and the average rain intensity was 36.6 mm·h^{-1}. This storm occurred before construction of the short-ridge farming measures, therefore all test plots using this measure were without the soil retaining wall. Variation of runoff and erosion with time for each test plot is shown in Figure 3.

Figure 3(a) shows generally similar patterns of runoff with time for each test plot: with continuation of rainfall and increasing rainfall intensity, each plot began to produce runoff, and the runoff intensity increased rapidly; however, when rainfall intensity began to decrease, the runoff intensity continued to increase, since the water content of soil at this time was high. With a second peak of rainfall intensity, runoff intensity rapidly reached its peak; as rainfall intensity subsequently declined until the rain stopped, runoff intensity decreased rapidly. Runoff shows an obvious hysteresis

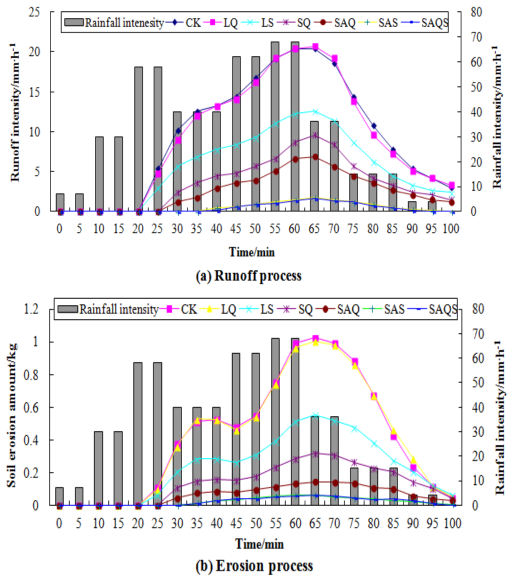

Fig. 3. Runoff and erosion on each test plot due to rainfall of June 29, 2015

with rainfall, as all plots began to yield runoff after 20 min of rain, and the peak of runoff intensity occurred 10 min after peak rainfall intensity. After precipitation stopped, runoff continued on all plots except SAS and SAQS. Test plots CK and LQ showed the highest values of runoff intensity, 20.4 mm·h^{-1} and 20.7 mm·h^{-1}, respectively; the peak runoff intensity of LS, 12.6 mm·h^{-1}, was significantly less than that from CK and LQ; peak runoff rates from SQ and SAQ were 9.6 mm·h^{-1} and 6.9 mm·h^{-1}, respectively, and the runoff intensity curves for SAS and SAQS were almost flat, with peak rates of only 1.8 mm·h^{-1}. The volume of runoff from each plot is shown in Table 3.Rainfall intensity influences erosion processes through splash effects on the soil surface and changes in the shear forces applied by runoff [7]; the variation of erosion with time is therefore slightly more complicated than that seen for runoff, and two distinct peaks appear, as shown in Figure 3 (b). Because the soil moisture content was extremely low before the storm since it had been dry for several days, and the vegetation cover was low this early in the growing season, the volume of interception storage was also very low. Hence, the influence of a strong splash effect began at the very start of precipitation, making the soil loose. Then, the runoff intensity increased, contributing to the first soil-erosion peak. With the continuation of rainfall and a slight decline in rainfall intensity, the surface soil hardened, and erosion stability increased; when rainfall exceeded the soil's capacity for infiltration, runoff occurred, and the water on the soil surface weakened the impact force of the raindrops. This reduced work by the kinetic energy of rainfall on the surface soil [8], and the amount of soil erosion decreased. With a subsequent increase in runoff intensity, sediment transport from the plot increased gradually, leading to the second soil-erosion peak. There were significant differences in the amount of soil erosion from plots using different management practices, with the largest amounts of soil erosion occurring on CK and LQ, and the smallest on SAS and SAQS, which yielded 5.76% and 5.69%, respectively, of the erosion from CK. The amount of soil erosion under different management measures, from least effective to most effective, was:

CK > LQ > LS > SQ > SAQ > SAS > SAQS.

Table 3. Volume of runoff and soil erosion amount from each test plot due to the rainfall of June 29, 2015

Test plot	CK	LQ	LS	SQ	SAQ	SAS	SAQS
Depth of runoff (mm)	16.4	16	9.8	6.125	4.3	0.91	0.801
Proportion relative to CK (%)	100	97.56	59.76	37.35	26.22	5.55	4.88
Soil erosion amount (kg)	8.684	8.672	4.900	2.858	1.375	0.500	0.494
Proportion relative to CK (%)	100	99.86	56.43	32.91	15.83	5.76	5.69

The geographic position, natural conditions and soil characteristics of all the plots were essentially identical; therefore, the differences in runoff and sediment features among the plots were related to farming measures and engineering measures adopted on each plot. On the date of this storm, the soil retaining walls had not been built for the short-ridge farming, therefore the conditions on both plots CK and LQ were essentially the same, and there is little difference between the runoff and sediment data from these two plots. Since there was no effect of these retaining walls on any of the plots, only subsoiling and rat holes in LS and SQ acted to reduce runoff and limit loss of water and soil. By loosening soil layers, subsoiling increased the effective porosity of the soil, improving its capacity for infiltration and water storage. Rat holes also increased the gas and water permeability of the soil effectively, in part by forming cracks that extend to the soil surface from the rat tunnels, which increased infiltration and reduced runoff effectively. By reducing stagnant water in the plow layer, the subsurface drainage pipe increased the rate at which surface water could drain away. Because of the effect of the subsurface drainage pipe, the volume of runoff and soil erosion from plot SAQ was less than that of SQ. By integrating rat holes and subsurface drainage pipes with subsoiling, it is possible to retain water and soil effectively; the volumes of runoff and sediment from SAS and SAQS were less than those from SAQ, again indicating that subsoiling can increase infiltration and reduce the loss of water and soil effectively.

The rainfall on June 21, 2016 lasted 115 min, with a total depth of precipitation of 52.25 mm, a maximum rain intensity of 70 $\mathrm{mm{\cdot}h^{-1}}$, and an average rain intensity of 27.26 $\mathrm{mm{\cdot}h^{-1}}$. The rainfall intensity graph shows a single peak, with low initial rainfall intensity, increasing to maximum value after 50 min, and decreasing gradually to the end of the storm. This rainfall occurred after soil retaining walls had been built on all plots applying short-ridge farming methods. Variation of runoff and erosion from each test plot with time is shown in Figure 4.

Figure 4(a) shows that, at the very beginning of the storm, no plots yielded runoff, due in part to the weak rainfall intensity. After 30 min, runoff began from

CK, and after 65 min of rain, measurable runoff was produced successively from LQ, LS, and SAS. Ten minutes later, runoff began from SQ, and no measurable runoff came from SAQ and SAQS at any time during the storm. The time-series of runoff measured from the five plots showed a single peak, consistent with the variation in rainfall intensity. However, the time of peak runoff intensity varied among the plots, and the peak values of runoff intensity showed significant differences.

The graph of erosion with time for each plot was almost identical to the graph of runoff with time for the same plot, as shown in Figure 4(b). The erosion rate for CK varied with rainfall intensity, including the small plateau at 45–50 min. Since the soil retaining walls had been constructed by the date of this storm, they were able to retain rainwater and runoff, and the erosion process of LQ, which shows only a single smooth curve with no plateau, is very different from that of CK. The volumes of runoff from LS, SAS, and SQ were less than that from LQ, so their curves for the erosion process have smaller amplitudes than that for LQ. No runoff was produced from SAQ and SAQS, and there was therefore no measurable soil erosion. The volume of runoff and sediment amount from each plot is shown in Table 4.

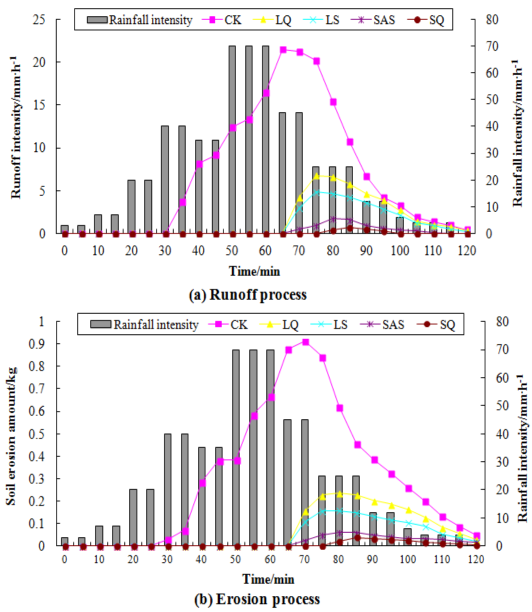

Fig. 4. Runoff and erosion from each test plot caused by the rainfall of June 21, 2016

Table 4. Volume of runoff and soil erosion from each test plot caused by the rainfall of June 21, 2016

Test plot	CK	LQ	LS	SQ	SAQ	SAS	SAQS
Depth of runoff (mm)	14.29	3.19	2.34	0.16	0	0.59	0
Proportion relative to CK (%)	100	22.32	16.38	1.12	0	4.13	0
Soil erosion amount (kg)	7.569	1.696	1.117	0.181	0	0.413	0
Proportion relative to CK (%)	100	22.41	14.76	2.39	0	5.46	0

Over the course of the storm, the impact of the different management practices on retaining rainfall and runoff and restraining loss of water and soil became more apparent, i.e., the delayed onset of runoff, reduction of peak runoff intensity and volume, and decreased runoff and sediment yield. Although the duration and the maximum intensity of rainfall were higher than in the storm of June 29, 2015, the vegetation cover was in vigorous growth during the 2016 storm, which had obvious impacts on interception storage and raindrop impact energy. Hence, conversely, the soil erosion from CK was lower than that on June 29, 2015.

In comparing the two events, it is clear that all management practices were able to retain water and soil to some extent. Especially after the soil retaining walls were built, the treatment including short-ridge farming was able to retain rainfall and runoff and limit soil erosion. However, to manage greater rainfall intensity, short-ridge farming should be integrated with measures that can increase infiltration, especially engineering measures such as rat holes and subsurface drainage pipes.

3.3. Simulation of the amount of soil erosion with different management practices

The potential soil erosion was calculated by employing the USLE under different assumed management practices. The rainfall erosivity factor, R, for the test plots was calculated by $E_{60}I_{30}$, as described in Section 2.4.1, and the soil erodibility factor K and vegetation and water and soil conservation measure factor CP for each plot was calculated with equations (5) through (8). The results are shown in Table 5 and Table 6, respectively.

Table 5. Distribution of rainfall erosivity factor R ($\mathrm{J{\cdot}m^{-2}}$)

Year	May	Jun	Jul	Aug	Sept	Total
2015	4.91	7.80	28.69	17.03	9.92	68.35
2016	5.21	8.27	30.42	18.06	10.52	72.48

Table 6. Soil erodibility factor K and the vegetation and water and soil conservation measure factor CP for each test plot

Test plot	CK	LQ	LS	SQ	SAQ	SAS	SAQS
K	0.3042	0.3152	0.2950	0.2958	0.3037	0.2965	0.3124
CP	0.2487	0.1137	0.0972	0.0480	0.0231	0.0326	0.0042

Simulation of the amount of soil erosion in each test plot was carried out by applying the USLE with the 2016 values of R, and the calculated results were compared with measured data; results are shown in Table 7. The absolute errors for all test plots were less than 10%, except for SAS, which had an error of 13.58%. Moreover, the degree of correlation between the simulated and measured values was extremely high, with a correlation coefficient of 0.999, and the efficient coefficient of the model calculated with equation (9) was as large as 0.985, indicating almost ideal simulation results, and reliable test results.

Table 7. Simulation results of soil erosion amount in 2016

Test plot	CK	LQ	LS	SQ	SAQ	SAS	SAQS
Measured value ($t{\cdot}hm^{-2}{\cdot}a^{-1}$)	6.07	2.78	2.07	1.01	0.49	0.81	0.10
Simulation value ($t{\cdot}hm^{-2}{\cdot}a^{-1}$)	5.48	2.60	2.08	1.03	0.51	0.70	0.095
Absolute error (%)	9.72	6.47	0.48	1.98	4.08	13.58	5.00

4. Conclusions

Soil erosion is one of the world's most widespread ecological problems, causing serious damage and presenting a major problem in many countries. Consequently, conducting theoretical research on soil erosion and water and soil conservation, and exploring effective methods for water and soil conservation have profound practical significance. Most studies of water and soil conservation technologies consider the effect of water and soil conservation by single measures, and Chinese soil conservation research has focused mainly on the loess plateau and in South China, while studies in the black soil region of Northeast China are relatively uncommon, despite the increasingly serious soil erosion and deterioration of soil productivity in this region. In this project, we integrated engineering practices (rat holes and subsurface drainage pipes) with cultivation practices (subsoiling and short-ridge farming) to develop six water and soil conservation measures for sloping cropland in the black soil region. Test results showed that all the conservation measures were able to retain water and soil and reduce erosion to some extent, with application of even simple retaining walls as part of short-ridge farming (LQ) significantly reducing soil loss compared to plots with no management measures. Conservation measures that integrated short-ridge farming with subsoiling, rat holes, and subsurface drainage pipes had the greatest impact on reducing runoff and erosion.

In all the integrated conservation practices, short-ridge farming played an important role. After soil retaining walls were constructed as part of the short-ridge farming, all test plots containing this measure were better able to retain runoff and reduce erosion. This is because short-ridge farming, which is able to retain runoff from rainfall, extends the time for rainwater infiltration, increases the amount of infiltration, and reduces the contradiction between heavy rainfall and light infiltration; it also reduces runoff scouring of soil and the amounts of both nutrient loss and soil erosion. The effectiveness of this practice could be increased by integrating short-ridge farming with subsoiling, rat holes, and subsurface drainage pipes, especially the latter two measures. By loosening soil at depth, breaking the plow pan and reducing soil hardness, subsoiling is able to increase effective porosity, allowing for better circulation of gas and moisture up and down, improving the infiltration rate of the soil and increasing soil water content. Although rat holes and subsurface drainage pipes are among the oldest farmland drainage technologies, they are still effective at increasing soil infiltration, by transforming part of the overland runoff into subsurface water during the rainy season and reducing loss of water and nutrients. Any rainwater infiltrated into soil during the dry season increases the soil water content and plays a role in resisting drought and saving water. These features and effects are exactly those needed in technologies for water and soil conservation. With continuous development and perfection of these measures and their supporting technologies, we look to apply them widely for prevention of soil erosion and effective reduction of water and soil losses.

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