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Effects of Counter Tillage and Slope Gradient on Nutrient Losses on Sloping Farmland

Shuning Lu [1,2], Chong Yao [1,2] and Faqi Wu [2,3,*]

1 Institute of Soil and Water Conservation, Northwest A&F University, Xianyang 712100, China
2 State Key Laboratory of Soil Erosion and Dryland Farming on Loess Plateau, Institute of Soil and Water Conservation, Northwest A&F University, Xianyang 712100, China
3 College of Natural Resources and Environment, Northwest A&F University, Xianyang 712100, China
* Correspondence: wufaqi@263.net

Abstract: Counter tillage is a typical cultivation practice on the Loess Plateau, which can influence the soil erosion process by intercepting runoff and increasing infiltration. However, few studies have investigated the mechanisms of nutrient losses associated with counter tillage. This study was conducted to reveal the effects of counter tillage and slope gradient on the soil nutrient loss mechanism on sloping farmland. In this study, the rainfall simulation was conducted with a rainfall intensity of 90 mm·h^{-1} and with five slope gradients (5.24%, 8.75%, 17.63%, 26.79%, 36.40%). The runoff plots involved the counter tillage (CT) and traditional plow (CK), in order to investigate the characteristics of soil erosion and available phosphorus (AP), ammonium nitrogen (NH_4^+-N) and nitrate nitrogen (NO_3^--N) losses. The soil erosion characteristics included the time until runoff generation, RR (runoff rate), and SR (sediment rate); the nutrient loss characteristics included nutrient loss concentrations, nutrient loss and nutrient loss rate in runoff or sediment. The results indicated that the RR and SR with a slope gradient of 5.24~26.79% on CT decreased by 11.77~94.92% and 20.69~99.27%, respectively, compared with that of CK. As the slope gradient increased (36.40%), a break in the ridge occurred and the reduction in the RR and SR was weakened; this was likely to be close to that of the CK. Nutrient losses differed significantly between different slope gradients and tillage practices. Nutrient losses increased with an increasing slope gradient. The nutrient losses of AP, NH_4^+-N, and NO_3^--N in runoff, with the slope gradient of 36.40%, increased 75.75%, 76.34%, 75.63%; meanwhile, in sediment, it increased 32.93, 30.70, 32.18 times, compared with the slope gradient of 5.24% on CT. The CT with the slope gradient of 5.24~26.79% had a good effect in controlling nutrient losses; however, for the slope gradient of 36.40%, the effects of CT in controlling nutrient losses decreased. The nutrient loss rate and RR or SR satisfied a linear positive correlation. The reduction benefits of nutrient losses on CT in runoff and sediment can reach 57.7% to 100% and 45.5% to 100%, respectively. In conclusion, CT is an effective tillage practice to control soil erosion and nutrient losses. This study can provide a reference for soil erosion and nutrient loss control on sloping farmland on the Loess Plateau.

Keywords: rainfall simulations; counter tillage; soil erosion; nutrient loss

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1. Introduction

The Loess Plateau has become one of the most serious areas of soil and water loss in China because of its complex geography and its intensive long-term cultivation. Sloping farmland is the main source of soil and water loss in the Loess Plateau, and it accounts for 60~80% of the total erosion in the watershed [1]. The nutrient loss associated with soil erosion is also one of the major environmental problems [2,3]. The migration of nutrients from sloping farmland thins the topsoil layer, which leads to soil quality degradation and a decrease in land productivity, as well as an increase in water pollution [4,5]. As reported by Liu et al. [6–8], suitable tillage practices can effectively control soil erosion and improve soil properties. In contrast, unreasonable tillage practices can increase soil erosion and lead to land degradation [9]. Tillage practices can change the runoff and sediment losses; they also affect the concentrations, contents, and presence patterns of nutrients in runoffs and sediments [10]. Therefore, exploring the effects of tillage practices on soil nutrient loss is essential for enhancing soil quality, preventing land degradation, improving food security, and promoting high-quality regional development.

Nutrient losses associated with soil erosion are mainly divided into two pathways: when rainfall intensity is small, runoff is slow and soil nutrients migrate vertically with the infiltrating runoff and sediment; when rainfall intensity is high, runoff is faster and soil nutrients migrate laterally with runoff and sediment [11]. Soluble nutrients in the soil can be dissolved in rainwater and lost as runoff, while those in particulate form are adsorbed on the soil surface or combined with sediment [12]. The differences in surface conditions make the two play different leading roles in the nutrient losses process. Some studies have shown that nitrogen and phosphorus in sediment on sloping farmland are the main form of nutrient loss in arid regions [13]; meanwhile, Baker concluded that nutrient losses in runoff account for more than 90 percent of nutrient losses [14].

Tillage practices mainly affect soil erosion processes by increasing filling and infiltration [15,16]. Xia [17] studied the effects of tillage practices on phosphorus and nitrogen losses, concluding that counter tillage was effective in reducing phosphorus losses in sediment, but that there was no significant impact on nitrogen losses; meanwhile, it has also been found that counter tillage increased the nitrogen loss concentrations and nitrogen losses [18].

In addition to tillage practices, slope gradient is also one of the important factors affecting soil erosion and nutrient losses. Slope gradient affects the runoff amount, shear force and erosion process by changing the force of gravity in the direction of the slope [19]; this ultimately affects the nutrient losses. Wang [20] concluded that nutrient losses increased in response to an increase in the slope gradient; however, Liu [21] pointed out that the nutrient concentrations in runoff and nutrient losses in sediment both decreased with an increasing slope; however, after decreasing to a certain value, they remained almost constant. The results of Sims [22] and Sharpley [23] showed that when the slope gradient increased, the contact time between the runoff and the soil surface decreased, the soluble nutrient losses decreased, but the eroded sediment increased; therefore, the nutrient losses in the sediment increased.

The Loess Plateau is located in an arid and semi-arid region in the northwest of China, with complex and variable surface structures, loose soil, poor water-holding capacity, few rivers on land, and agricultural water mostly depending on natural rainfall [24]. For sloping farmland, while rainfall recharges plants with the water they need, it also tends to cause soil erosion, nutrient losses and the export of pollutants [25]. In addition, because the main cultivated soil in the area is very poor in nitrogen and phosphorus, large amounts of fertilizers are usually used to improve soil fertility on the sloping farmland [26]. The excessive application of fertilizers can easily lead to nutrient losses and the eutrophication of water bodies [27,28]. Numerous studies [29] have shown that the loss of top soil and nutrients caused by soil erosion are the main cause of land quality degradation. The current research mainly focuses on the loss of the total nutrients. Few have studied the available nutrients that can provide essential nutrients for plant growth and can better represent soil fertility [30]. Counter tillage is a water harvesting and moisture storage tillage practice used on sloping farmland, which is perpendicular to the direction of runoff; it can increase infiltration and effectively intercept runoff, thus reducing soil separation and sediment transport [31,32]. Here, rainfall simulations were conducted to investigate the following points: (1) the effects of counter tillage and slope gradient on the soil erosion process on sloping farmland; (2) the effects of counter tillage and slope gradient on nutrient losses process; (3) the relationship between the nutrient loss process and the soil erosion process. We hypothesized that reasonable tillage practices can effectively control soil erosion and nutrient losses.

2. Materials and Methods

2.1. Study Area and Soil

The experimental site was in Yangling, Shannxi province, China. Yangling (34°14–34°20′ N, 107°59′–108°08′ E) is located in the Guanzhong Plain in Shannxi province. It is characterized by the warm temperate semi humid continental monsoon climate with an annual average temperature of 12.9 °C. In this area, the annual average precipitation is 550–650 mm, of which 60–70% is mainly concentrated in July to October. There are mainly short-term strong storms with a rainfall intensity of 1 to 3 $mm \cdot min^{-1}$.

The soil used in this research was silt loam (USDA standard), which was developed on the Quaternary wind-accumulated Loess parent material. The soil organic matter content was 13.3%, the cation exchange capacity was 18.1 $cmol \cdot kg^{-1}$ and the pH was 8.2. The total nitrogen (TN) content, total phosphorus (TP) content, available phosphorus (AP) content, ammonium nitrogen ($NH_4{}^+$-N) content and nitrate nitrogen ($NO_3{}^-$-N) content of the test soil samples were 0.89, 1.22, 23.87, 10.37, and 14.33 $g \cdot kg^{-1}$, respectively. Gravel, silt and clay accounted for 30.0%, 43.7% and 26.3%, respectively.

2.2. Rainfall Simulations

The rainfall simulations were conducted on a 4.5 m × 1.4 m runoff plot where the soil was collected from the 0–20 cm depth of sloping farmland in Yangling. PVC frames were installed on the top and sides of each plot, and these frames were approximately 10 cm above the soil surface. A side sprinkle rainfall simulation system, produced by the Institute of Soil and Water Conservation, Chinese Academy of Sciences, was used. The rainfall uniformity, estimated by the Christiansen coefficient [33], was higher than 80%. The simulator consisted of a water tank (length × width × height, 2.0 m 2.0 m 1.5 m), a water pump (2.2 KW), water supply pipe (inner diameter 48 mm), two brackets (height 7 m) and two side sprinklers. Rainfall intensity can be achieved between 30–120 $mm \cdot h^{-1}$ by changing the hydrostatic pressure. Each bracket was equipped with a sprinkler head, which were 6 m away from each other. The rainfall height reached 7.5 m, so as to ensure that fall velocity of the raindrops was close to the terminal velocity.

Five slope gradients were chosen for this experiment: 5.24%, 8.75%, 17.63%, 26.79% and 36.40%. By analyzing the meteorological data in the study area, the rainfall intensity of this experiment was set to 90 $mm \cdot h^{-1}$, the rainfall time was set to 40 min, and the total rainfall of each experiment was 60 mm. At the same time, the counter tillage (CT) was selected as the pre-raining treatment, and the traditional plow (CK) was used as the control. On CT, the ridge height was approximately 6 cm, and the ridge spacing was about 14 cm. CK is plowed with a traditional agricultural instrument plow to break up and turn over soil about 20 cm. Before each rainfall, the plot was covered with a rain cloth, and the rainfall intensity was filtered several times to ensure that the rainfall intensity and uniformity met the test requirements. After it was stabilized, quickly lift the rain cover and recorded the time of runoff generation on the slope.

2.3. Soil Sample Collection and Analysis

During the rainfall simulation, runoff and sediment samples were collected into plastic buckets at intervals of 2 min until the rainfall ended. The samples were weighed and precipitated for 24 h. After the samples were completely precipitated, 500 mL of the runoff was taken and collected in a polyethylene plastic bottle at 4 °C. After pouring off the remaining runoff, the sediment was washed into an aluminum box and placed in an oven, which was set at 105 °C for 24 h. After drying, the sediment samples were weighed and stored in sealed bags for further testing and analysis.

Sample characteristics were analyzed using CleverChem380 automatic intermittent chemical analyzer, mainly to determine the concentrations of AP, $NH_4{}^+$-N and $NO_3{}^-$-N in runoff and sediment. In the process of instrument operation, the injection times were set as 3–4 times to avoid systematic errors. At the same time, 0 $mg \cdot L^{-1}$ (ultrapure water) and standard samples were placed randomly at intervals. Among them, available phosphorous

(AP) was determined by ammonium molybdate spectrophotometry method, ammonium nitrogen (NH_4^+-N) was determined by salicylic acid spectrophotometry method, and nitrate nitrogen (NO_3^--N) was determined by *N*-(1-NAPhthyl)-ethylenediamine spectrophotometric method.

2.4. Statistical Analysis

2.4.1. Runoff and Sediment Analysis

Based on the results of the weighing of runoff and sediment after rainfall, the runoff rate ($L \cdot m^{-2} \cdot min^{-1}$) and sediment rate ($kg \cdot m^{-2} \cdot h^{-1}$) during the rainfall were calculated using the following equations:

$$RR = \frac{V}{S.t} \tag{1}$$

$$SR = \frac{m}{S.t} \tag{2}$$

where RR and SR are runoff rate and sediment rate, respectively. V is the runoff volume, S is the plot area, t is the sampling interval time, m is the sediment quantity.

2.4.2. AP, NO_3^--N and NH_4^+-N Analysis

Based on the sample concentrations results ($mg \cdot g^{-1}$) from the automatic intermittent chemical analyzer, the nutrient losses (mg) in runoff and sediment and the nutrient losses rate ($mg \cdot m^{-2} \cdot h^{-1}$) were calculated. The nutrient losses were calculated by multiplying the nutrient concentrations and the runoff amount or sediment yield during that time period.

2.4.3. Analysis Methods

A one-way analysis of a variance (ANOVA) was applied to compare the significant differences between different slope gradient and tillage practice; Pearson's correlation analysis was used to test the relationship between each nutrient losses rate and RR or SR. The data analyses in this paper were completed using SPSS 20.0; all graphs were plotted using Origin 2021b.

3. Results

3.1. Runoff and Sediment Generation

Runoff is the driving force and carrier of sediment and nutrient transport. When soil erosion occurs on a slope, nutrient is lost along with the runoff and sediment, so analyzing the effects of CT and slope gradient on runoff and sediment can lay the foundation for revealing the soil nutrient losses mechanisms. As Figure 1 shown, the time to runoff generation differed between different slope gradients. The greater the slope gradient, the earlier the time to runoff generation; CT can delay the time to runoff generation. At a slope gradient of 5.24%, 8.75%, 17.63%, 26.79% and 36.40%, the time was delayed by 31.93, 26.65, 21.02, 17.40 and 11.58 min, respectively. The lower the slope gradient, the more pronounced the delaying effect. RR and SR generally increased with increasing slope gradient. RR and SR on CT with slope gradient of 5.24–26.79% were always lower than those of the CK. As the slope gradient increased (36.40%), a break of ridge occurred within 18–20 min, and there was a sudden change in RR and SR by that time. After the break, the RR and SR of CT gradually increased and reached the first peak at about 20 min, with RR and SR reaching 1.648 $L \cdot m^{-2} \cdot min^{-1}$ and 7.087 $kg \cdot m^{-2} \cdot h^{-1}$, respectively, which were greater than those of CK. Then the RR and SR of CT decreased sharply, and the second peak occurred at about 32 min, with the RR and SR of 1.163 $L \cdot m^{-2} \cdot min^{-1}$ and 3.770 $kg \cdot m^{-2} \cdot h^{-1}$, respectively, where the RR of CT was slightly greater than that of CK, while the SR was still lower that.

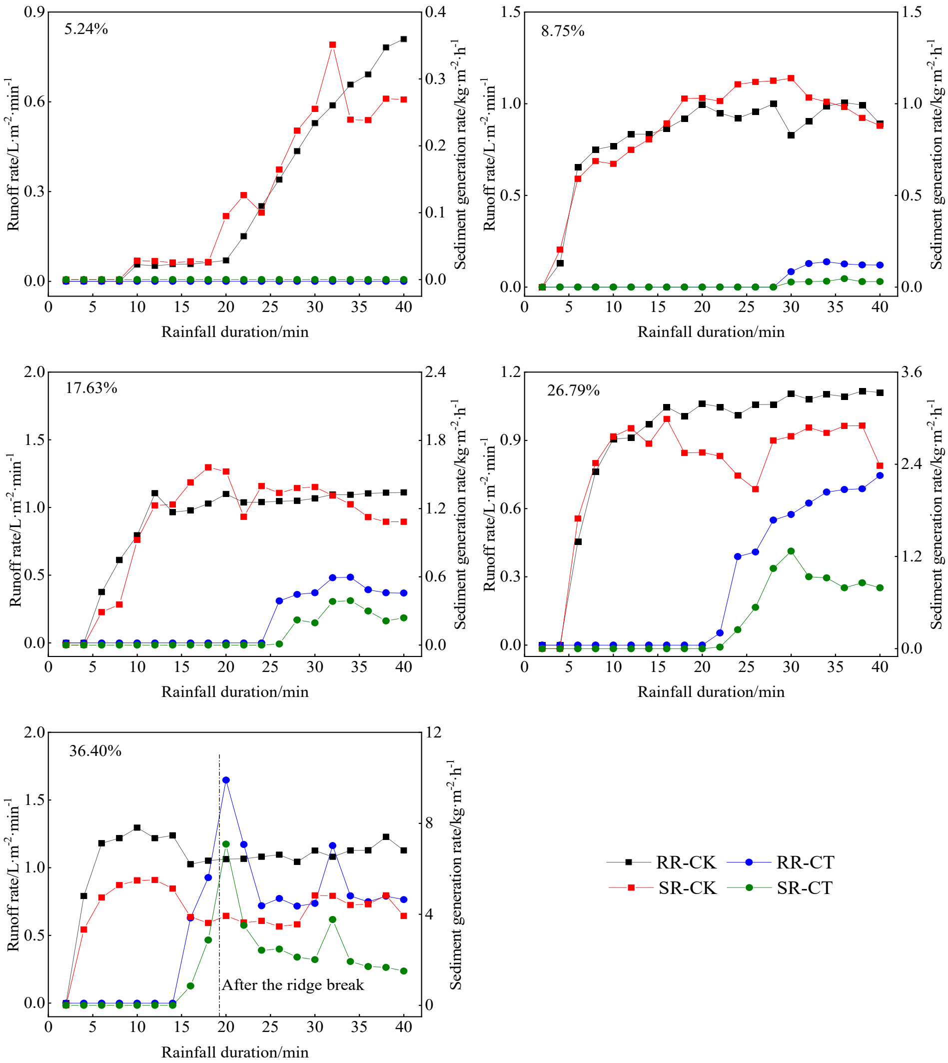

Figure 1. The runoff and sediment rate under different tillage practices and slop gradients. RR-CK: runoff rate of traditional plow; RR-CT: runoff rate of counter tillage; SR-CK: sediment generation rate of traditional plow; SR-CT: sediment generation rate of counter tillage.

3.2. Nutrient Losses in the Runoff

A comparative analysis of the nutrient losses processes in runoff was carried out and the results were shown in Figure 2. At the beginning of the rainfall, the nutrient losses fluctuated with the rainfall duration, as the rainfall progressed, the variation gradually stabilized. The nutrient losses in runoff increased in response to an increase in the slope gradient. At a slope gradient of 36.40%, the AP, NH_4^+-N and NO_3^--N losses can reach 5.02, 6.18, 8.92 mg, respectively, on CK, and 5.09, 7.77, 11.28 mg, respectively, on CT. The nutrient losses of AP, NH_4^+-N, NO_3^--N in runoff with the slope gradient of 36.40% increased 75.75%, 76.34%, 75.63%, compared with the slope gradient of 5.24% on CT. With the slope gradient of 5.24–26.79%, those losses from the CT were lower than that of CK; when the slope gradient was greater (36.40%), there was a break on CT, before the break, the nutrient losses from CT were less than that of the CK; after the break, the nutrient losses increased sharply, at around 20 to 25 min, the AP, NH_4^+-N and NO_3^--N losses reached their peaks throughout the rainfall calendar, which were 1.52, 7.77 and 1.53 times higher than that of CK, respectively. The relationship between nutrient losses in runoff was: NO_3^--N > NH_4^+-N > AP.

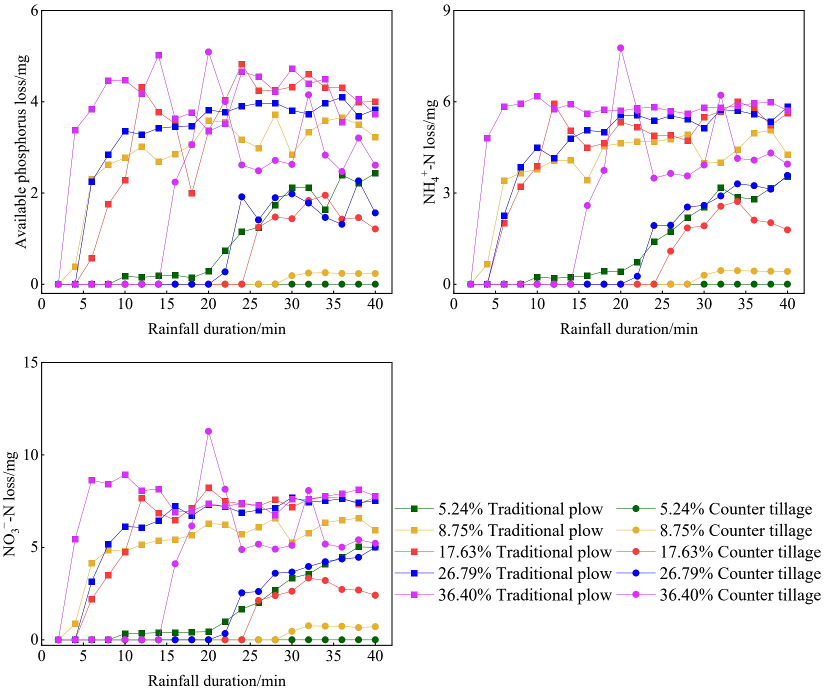

Figure 2. Nutrient losses in the runoff.

Nutrient loss concentrations did not vary consistently on CT and CK (Table 1). On CK, the mean loss concentrations of AP, NH_4^+-N and NO_3^--N increased with an increasing slope, and the maximum of three nutrient concentrations were reached at a slope gradient of 36.40%, with 0.2463, 0.3464, 0.4539 mg·L^{-1}, respectively. The mean concentrations of NO_3^--N at slope gradients of 5.24% and 8.75% were 0.4259 and 0.4270 mg·L^{-1}, respectively, which were significantly different from other slope gradients, according to Duncan′s new multiple range tests ($p < 0.05$). On CT, peaks of the mean concentrations of AP, NH_4^+-N and NO_3^--N appeared on 17.63%, with 0.2560, 0.3376 and 0.4579 mg·L^{-1}, respectively. It was also noted that the mean concentrations of AP and NH_4^+-N were only significantly different at lower slope gradients, while the mean concentrations of NO_3^--N were significantly different at all five slope gradients. The mean concentrations of the three nutrient were as follows: NO_3^--N > NH_4^+-N > AP. Overall, apart from the smaller nutrient loss concentrations at a slope gradient of 5.24% and 8.75% on CT, the mean loss concentrations of AP, NH_4^+-N and NO_3^--N did not differ significantly under CT and CK (Table 1); however, there were significant differences in the nutrient losses (Table 2).

Table 1. The mean concentrations of the nutrient loss in runoff.

Type	Slope Gradient	The Mean Loss Concentrations of AP/(mg·L^{-1})	The Mean Loss Concentrations of NH_4^+-N/(mg·L^{-1})	The Mean Loss Concentrations of NO_3^--N/(mg·L^{-1})
CK	5.24%	0.2314 cd	0.3215 c	0.4259 c
	8.75%	0.2324 cd	0.3223 c	0.4270 c
	17.63%	0.2355 cd	0.3323 cd	0.4526 d
	26.79%	0.2437 cd	0.3362 cd	0.4531 d
	36.40%	0.2463 cd	0.3464 d	0.4539 d
CT	5.24%	0.0000 a	0.0000 a	0.0000 a
	8.75%	0.1304 b	0.2297 b	0.3755 b
	17.63%	0.2560 d	0.3376 cd	0.4579 d
	26.79%	0.2182 c	0.3156 c	0.4295 c
	36.40%	0.2332 cd	0.3293 cd	0.4516 d

CK means traditional plow, CT means counter tillage. Different lowercase letters in the same column (traditional plow or counter tillage) indicate significant differences between groups ($p < 0.05$), while the same letters indicate non-significant differences between groups ($p > 0.05$).

Table 2. The mean losses of nutrient in runoff.

Type	Slope Gradient	The Mean Losses of AP /(mg)	The Mean Losses of NH_4^+-N/(mg)	The Mean Losses of NO_3^--N/(mg)
CK	5.24%	1.1820 b	1.6190 b	2.1983 b
	8.75%	2.9920 c	4.1067 d	5.4481 d
	17.63%	3.5815 de	4.8909 e	6.7571 ef
	26.79%	3.5900 de	5.0219 e	6.7585 ef
	36.40%	4.1048 e	5.7624 f	7.5943 f
CT	5.24%	0.0000 a	0.0000 a	0.0000 a
	8.75%	0.2320 b	0.4114 a	0.6751 a
	17.63%	1.5045 b	2.0080 bc	2.6888 bc
	26.79%	1.5867 b	2.5401 c	3.4771 c
	36.40%	3.0848 cd	4.3929 de	6.0489 de

CK means traditional plow, CT means counter tillage. Different lowercase letters in the same column (traditional plow or counter tillage) indicate significant differences between groups ($p < 0.05$), while the same letters indicate non-significant differences between groups ($p > 0.05$).

3.3. Nutrient Losses in the Sediment

The nutrient losses in the sediment generally fluctuated with the rainfall duration (Figure 3). The nutrient losses in the sediment all increased with an increasing slope gradient. On a slope gradient of 36.40%, the losses of AP, NH_4^+-N and NO_3^--N on CK were in the ranges of 36.658–67.734, 28.933–31.961, 19.409–44.150 mg, respectively; meanwhile, the losses of AP, NH_4^+-N and NO_3^--N on CT were in the ranges of 10.447–73.443, 5.323–55.530, 6.876–53.390 mg, respectively. The nutrient losses of AP, NH_4^+-N, and NO_3^--N in sediment increased 32.93, 30.70, 32.18 times, compared with the slope gradient of 5.24% on CT. The nutrient losses with the slope gradient of 5.24–26.79% on CT were always lower than that of CK; as the slope gradient increased (36.40%), the SR increased sharply and exceeded that of the CK due to the break in the ridge; meanwhile, the difference in nutrient loss concentrations between the two practices was small, resulting in the nutrient losses on CT being greater than that of the CK. The losses of AP, NH_4^+-N and NO_3^--N in sediment on CT peaked at around 22 min, and were 1.52, 1.91 and 1.61 times that of the CK, respectively. Overall, the relationship between the losses of nutrients in the sediment was: AP > NO_3^--N > NH_4^+-N. The losses of AP were dominated by sediment, and its losses were 1.53–12.58 times that of the runoff; when the slope gradient was small, the losses of NH_4^+-N and NO_3^--N were dominated by runoff, and as the slope increased, the losses pathway changed to be dominated by the sediment.

The mean loss concentrations of AP and NO_3^--N showed fluctuating trends with an increasing slope gradient; the mean loss concentrations of NH_4^+-N increased with an increasing slope gradient (Table 3). The maximum of the mean loss concentrations of AP, NH_4^+-N and NO_3^--N on CK were reached at slopes of 17.63%, 36.79% and 17.63%, with 0.0494, 0.0283 and 0.0340 $mg \cdot g^{-1}$, respectively; the maximum of the mean loss concentrations of AP, NH_4^+-N and NO_3^--N on CT were all reached at slopes of 36.40%, with 0.0456, 0.0278 and 0.0323 $mg \cdot g^{-1}$, respectively. The mean loss concentrations of AP were significantly greater than the other two, while the mean NH_4^+-N concentrations were the smallest. With the exception of an unproductive runoff, the mean loss concentrations of AP, NH_4^+-N and NO_3^--N differed significantly between different slope gradients and the two practices (Table 4).

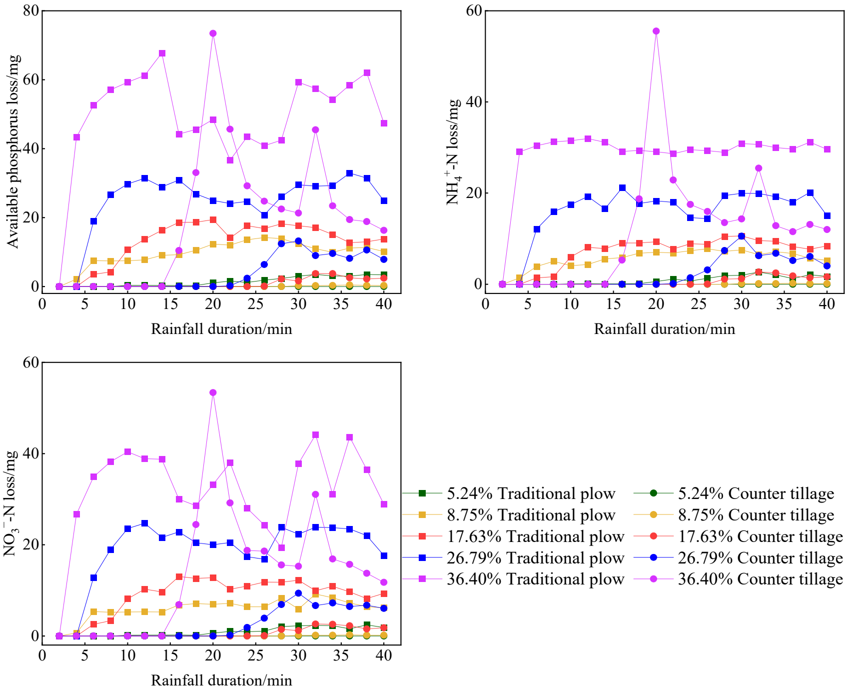

Figure 3. Nutrient losses in the sediment.

Table 3. The mean concentrations of the nutrient loss in sediment.

Type	Slope Gradient	The Mean Loss Concentrations of AP/(mg·g^{-1})	The Mean Loss Concentrations of NH_4^+-N/(mg·g^{-1})	The Mean Loss Concentrations of NO_3^--N/(mg·g^{-1})
CK	5.24%	0.0467 e	0.0256 c	0.0307 d
	8.75%	0.0452 e	0.0264 c	0.0278 c
	17.63%	0.0494 f	0.0265 c	0.0340 e
	26.79%	0.0421 cd	0.0272 c	0.0322 de
	36.40%	0.0476 ef	0.0283 c	0.0311 d
CT	5.24%	0.0000 a	0.0000 a	0.0000 a
	8.75%	0.0399 bc	0.0210 b	0.0215 b
	17.63%	0.0384 b	0.0250 c	0.0277 c
	26.79%	0.0425 d	0.0267 c	0.0300 cd
	36.40%	0.0456 e	0.0278 c	0.0323 de

CK means traditional plow, CT means counter tillage. Different lowercase letters in the same column (traditional plow or counter tillage) indicate significant differences between groups ($p < 0.05$), while the same letters indicate non-significant differences between groups ($p > 0.05$).

Table 4. The mean losses of the nutrient in sediment.

Type	Slope Gradient	The Mean Losses of AP/(mg)	The Mean Losses of NH_4^+-N/(mg)	The Mean Losses of NO_3^--N/(mg)
CK	5.24%	1.8086 a	1.1262 a	1.2081 a
	8.75%	10.1525 bc	5.9015 b	6.2822 bc
	17.63%	14.5036 c	7.9067 b	9.8517 c
	26.79%	27.2810 d	17.6238 c	20.9227 d
	36.40%	51.6579 e	30.0610 d	33.7575 e
CT	5.24%	0.0000 a	0.0000 a	0.0000 a
	8.75%	0.3237 a	0.1704 a	0.1749 a
	17.63%	2.3170 a	1.5668 a	1.6824 a
	26.79%	7.9802 b	5.1084 b	5.5353 b
	36.40%	29.5164 d	18.3709 c	20.8656 d

CK means traditional plow, CT means counter tillage. Different lowercase letters in the same column (traditional plow or counter tillage) indicate significant differences between groups ($p < 0.05$), while the same letters indicate non-significant differences between groups ($p > 0.05$).

3.4. Nutrient Reduction Benefits

The impact of CT on reducing nutrient losses in runoff and sediment at five slope gradients are shown in Figure 4. The smaller the slope gradient is, the more significant the effects are. However, CT was effective in controlling nutrient losses on any slope gradient. The effects of CT in reducing nutrient losses in sediment range from 57.7% to 100%; meanwhile, the effects in runoff range from 45.5% to 100%. The effects of CT in reducing nutrient losses in sediment were greater than those in runoff.

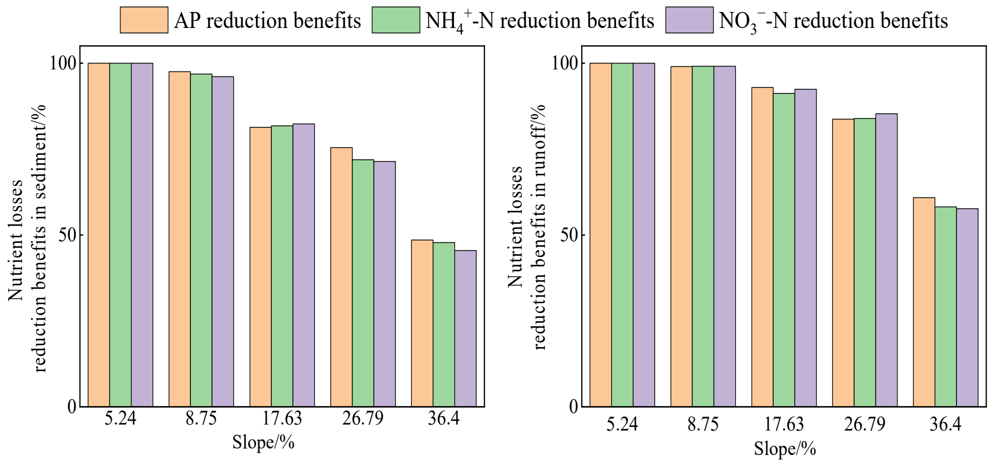

Figure 4. Nutrient reduction benefits.

3.5. Relationship between Nutrient Losses Rate and RR or SR

A regression analysis was carried out on the relationship between the nutrient losses rate and RR or SR (Table 5). The analysis indicated that there was a significant positive correlation between the nutrient losses rate and RR or SR, with R^2 ranging from 0.918 to 0.991. The regression coefficients for AP, NH_4^+-N and NO_3^--N in runoff were 0.918, 0.974 and 0.991, respectively, indicating that the magnitude of the relationship between the three nutrient loss concentrations in runoff was as follows: NO_3^--N > NH_4^+-N > AP. Meanwhile, the regression coefficients of the three nutrients in the sediment were 0.984, 0.973 and 0.976, respectively, indicating that the relationship between the magnitude of the three nutrient loss concentrations in sediment was: AP > NO_3^--N > NH_4^+-N.

Table 5. Relationship between nutrient loss and runoff and sediment generation.

Type	Nutrient in Runoff		Nutrient in Sediment	
	Regression Equation	**R^2**	**Regression Equation**	**R^2**
AP	y = 14.547 − 0.293	0.918	y = 46.098x − 0.560	0.984
NH_4^+-N	y = 20.207x − 0.293	0.974	y = 27.390x + 0.135	0.973
NO_3^--N	y = 27.686 − 0.729	0.991	y = 31.267x + 0.242	0.976

4. Discussion

Rainfall is the main driver of soil erosion and nutrient losses [34]. The increase in slope gradient resulted in a decrease in the vertical component of raindrops landing on the slope, and an increase in the component along the slope, which reduced the infiltration rate and sped up the movement of runoff along the slope [35,36]; this resulted in an earlier runoff generation. The increase in the slope gradient can promote the formation of rill erosion on the surface, with an increase in both rill flow and flow velocity, ultimately leading to an increase in the runoff rate [37,38]. An increase in the RR reduced the residence time of rainfall on the slope, resulting in less rainfall infiltration and an increase in the runoff volume. The runoff rate and runoff amount increased the erosive capacity of the soil, and the dispersing, scouring and transporting capacity of the runoff on soil particles [39].

Furthermore, an increase in the number of rills led to an increase in sediment [40], so the SR increased in response to an increase in the slope gradient (Figure 1).

The CT increases the infiltration capacity [41]. The depth and volume of the gullies are larger and rainfall does not start to generate runoff until the gullies are full [42]. Meanwhile, the CK has a flatter surface and little surface relief, making it almost impossible to accumulate rainwater and intercept runoff, which is more likely to reach the outlet and form runoff. The CT increases the soil surface roughness and shortens the slope length [43,44], which effectively slows down the runoff and promotes sediment deposition on the slope [45]. However, when the slope gradient is greater and the rainwater fills the gully, runoff overflows along the upper side of the ridge and washes the shoulder, resulting in laminar erosion and a reduction in the height of the ridge on the slope; the erosion reduction benefits of CT are subsequently reduced [46,47]. As the erosion process progresses, the ridge is washed away and the rainwater collected in the gully pours out, increasing the RR on the slope; once the ridge is washed away, the surface will be subject to severe rill erosion [48], which, in turn, will have a significant impact on runoff and sediment loss processes [49].

On CK, nutrient concentrations in runoff increased with an increasing slope gradient, which is consistent with the findings of Kinnell [50] and Zhang [51]. Changing the slope gradient would change the splash force on the soil surface and the scouring effect of runoff on the slope, which ultimately affects the runoff characteristics and the nutrient contents in runoff and sediment [52,53]. The losses of NH_4^+-N and NO_3^--N in runoff are significantly greater than the losses of AP, due to the fact that phosphorus is easily fixed by the soil, while nitrogen is easily lost by runoff [54,55]. The losses of NO_3^--N are always greater than the losses of NH_4^+-N in runoff, indicating that NO_3^--N is the main way that nitrogen is lost via surface runoff [56,57] In addition, the sediment-bound state phosphorus is the main way that phosphorus is lost [58], so the phosphorus loss concentrations in sediment are significantly greater than in runoff. The losses of NO_3^--N in sediment are greater than the losses of NH_4^+-N; this is due to the fact that NH_4^+-N is easily absorbed, immobilizes on the soil surface and is hard to move.

The interaction of nutrient loss with rainfall is a complex dynamic process, which is influenced by multiple factors, such as soil, rainfall, nutrient physical and chemical properties; slope gradients and CT have less of an effect on nutrient loss concentrations (Tables 1 and 3) and nutrient losses are mainly determined by runoff and sediment [59]. In this study, the maximum loss of AP, NH_4^+-N and NO_3^--can reach 1.68, 1.08, and 1.25 $kg \cdot ha^{-1}$ at a rainfall intensity of 90 $mm \cdot h^{-1}$ and total rainfall of 60 mm. The nutrient losses rate and RR or SR show a significant positive correlation [60]. There is a large variation in nutrient losses under different slope gradients and tillage measures (Tables 2 and 4), which is consistent with Lin's findings [61]. Nutrient losses in runoff and sediment show a fluctuating trend with rainfall duration; on the one hand, this is due to a change in nutrient loss concentrations, and, on the other hand, due to the large variability in the runoff amount and the sediment yield [62,63]. On CK, the runoff amount is small at the beginning of the runoff generation. As the rainfall progresses, soil water content increases but water infiltration decreases; the runoff amount becomes larger at this time. Then, the rills increase, rill erosion intensifies, and the soil in the gullies provides loose, non-cohesive sediment to transport and deposit [64]; this results in variations in runoff amount and sediment yield. Before the ridge is broken, runoff scours the ridge and erosion sediment mainly consists of soil debris material, produced by raindrops splashing and stripping the ridge; as the erosion process proceeds, the height of the ridge on the slope decreases, the runoff or sediment reduction benefits decrease, and the amount of runoff and sediment on the slope increases. After the ridge is broken, rills appear on the slope, and the width, depth and density of the rills increase [65]; at this time, the rainwater collected in the ridge and ridge itself will become the main material source of slope erosion.

The reduction in nutrient losses on CT decreases with an increasing slope, due to the fact that an increase in slope gradient leads to a decrease in the reduction effect of runoff or sediment on CT. Ridges on a greater slope gradient have to divert more force to balance their own gravity than on lower slopes, causing them to easily destabilize and collapse [66]. Moreover, when the ridge is washed out, the erosion process occurs at the end of the rills and rill flow carries a large amount of sediment away [67]. However, the reduction benefits of nutrient losses on CT are positive at all slope gradients, so CT is still an effective tillage practice for controlling soil erosion and nutrient losses, regardless of whether the ridge is destroyed.

5. Conclusions

This study explored the effects of counter tillage and slope gradient on soil erosion and nutrient loss processes through rainfall simulations. The results showed the following: (1) The greater the slope gradient, the earlier the time to runoff generation. At a slope gradient of 5.24%, 8.75%, 17.63%, 26.79% and 36.40%, the time to runoff generation was delayed by 31.93, 26.65, 21.02, 17.40 and 11.58 min, respectively, on CT. The lower the slope gradient, the more pronounced the delaying effect. The runoff rate and sediment rate increased with an increasing slope gradient. Counter tillage can significantly reduce the runoff rate and sediment rate with the slope gradient of 5.24–26.79%; when the slope gradient was greater, the ridge break would occur on CT, then the runoff rate and sediment rate would increase and would be close to or greater than CK. (2) Counter tillage and slope gradient had small effects on nutrient loss concentrations in runoff and sediment, but had significant effects on nutrient losses. When the slope gradient was small, counter tillage significantly reduced the nutrient losses in runoff and sediment; as the slope increased, the reduction effects of nutrient losses on counter tillage decreased due to the break in the ridge. The maximum losses of AP, NH_4^+-N and NO_3^--N in runoff can reach 1.52, 7.77 and 1.53 times that of a traditional plow, and the maximum losses of the three nutrients in sediments can reach 1.52, 1.91 and 1.61 times that of a traditional plow. Nutrient losses in runoff were dominated by NO_3^--N, while the nutrient losses in sediment were dominated by AP. (3) There was a linear positive correlation between the runoff nutrient loss rate and runoff rate or sediment rate. (4) The reduction benefits of nutrient losses in sediment on counter tillage were greater than those in runoff. The reduction benefits of nutrient losses on counter tillage were excellent on any slope gradient.

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References

1. Tang, K.L. *Varieties of Erosion and Runoff Sediment in Yellow River Basin*; Chinese Sciences and Technique Press: Beijing, China, 1993; pp. 12–13. (In Chinese)
2. Bronick, C.J.; Lal, R. Soil structure and management: A review. *Geoderma* **2004**, *124*, 3–22. [CrossRef]
3. Xu, G.C.; Cheng, Y.T.; Li, P.; Li, Z.B. Effects of natural rainfall on soil and nutrient erosion on sloping cropland in a small watershed of the Dan River, China. *Quat. Int.* **2015**, *380–381*, 327–333. [CrossRef]
4. Guo, S.S.; Zhu, Z.R.; Leting, L. Effects of climate change and human activities on soil erosion in the xihe river basin, China. *Water* **2018**, *10*, 1085. [CrossRef]
5. Jane, Q. China faces up to groundwater crisis. *Nature* **2010**, *466*, 308.

6. Liu, Y.; Tao, Y.; Wan, K.Y.; Zhang, G.S.; Liu, D.B.; Xiong, G.Y.; Chen, F. Runoff and nutrient losses in citrus orchards on sloping land subjected to different surface mulching practices in the Danjiangkou Reservoir area of China. *Agric. Water Manag.* **2012**, *110*, 34–40. [CrossRef]
7. Li, Z.W.; Liu, C.; Dong, Y.T. Response of soil organic carbon and nitrogen stocks to soil erosion and land use types in the Loess hilly-gully region of China. *Soil Tillage Res.* **2017**, *166*, 1–9. [CrossRef]
8. Kladivko, E.J.; Donald, R.J.; Mannering, J.V. Conservation tillage effects on soil properties and yield of corn and soya beans in Indiana. *Soil Tillage Res.* **1986**, *8*, 277–287. [CrossRef]
9. Yang, S.Q.; Han, R.Y.; Xing, L.; Liu, H.Y.; Wu, H.J.; Yang, Z.L. Effect of slope farmland soil and water and soil nitrogen and phosphorus loss based on different crop and straw applications and ridge patterns in the basin of the main stream of the Songhua River. *Acta Ecol. Sin.* **2018**, *38*, 42–47. [CrossRef]
10. Zhao, L.S.; Hou, R.; Wu, F.Q.; Keesstra, S. Effect of soil surface roughness on infiltration water, ponding and runoff on tilled soils under rainfall simulation experiments. *Soil Tillage Res.* **2018**, *179*, 47–53. [CrossRef]
11. Huo, J.Y.; Liu, C.J.; Yu, X.X.; Chen, L.H.; Zheng, W.G.; Yang, Y.H.; Yin, C.W. Direct and indirect effects of rainfall and vegetation coverage on runoff, soil loss, and nutrient loss in a semi-humid climate. *Hydrol. Process.* **2020**, *35*, 1085–1099. [CrossRef]
12. Sharpley, A.N. The Enrichment of Soil Phosphorus in Runoff Sediments. *J. Environ. Qual.* **1980**, *9*, 521–526. [CrossRef]
13. Qian, X.Y.; Shen, G.X.; Huang, L.H. Characteristics of nitrogen and phosphorus losses with rainfall-runoff from sandy dry field in Chongming Dongtan. *J. Soil Water Conserv.* **2010**, *24*, 11–14.
14. Baker, J.L.; Laflen, J.M.; Johnson, H.P. Effects of tillage systems on runoff losses of pesticides: A rainfall simulation study. *Am. Soc. Agric. Biol. Eng.* **1978**, *21*, 0886–0892. [CrossRef]
15. Zhang, J.H.; Jia, L.T.; Zhang, Z.L. Tillage erosion effect on soil hydrological properties in a hilly landscape. *J. Hydrol. Eng.* **2017**, *22*, 04017034. [CrossRef]
16. Zhao, L.S.; Fang, Q.; Hou, R. Effect of rainfall intensity and duration on soil erosion on slopes with different microrelief patterns. *Geoderma* **2021**, *396*, 115085. [CrossRef]
17. Xia, L.Z.; Liu, G.H.; Ma, L.; Yang, L.Z. The effects of contour hedges and reduced tillage with ridge furrow cultivation on nitrogen and phosphorus losses from sloping arable land. *J. Soils Sediments* **2014**, *14*, 462–470. [CrossRef]
18. Cherobim, V.F.; Huang, C.H.; Favaretto, N. Tillage system and time post-liquid dairy manure: Effects on runoff, sediment and nutrients losses. *Agric. Water Manag.* **2017**, *184*, 96–103. [CrossRef]
19. Sun, L.Y.; Fang, H.Y.; Qi, D.L. A Review on Rill Erosion Process and Its Influencing Factors. *Chin. Geogr. Sci.* **2013**, *23*, 389–402. [CrossRef]
20. Wang, H.; Wang, Q.J.; Shao, M.A. Laboratory experiments of soil nutrient transfer in the loess slope with surface runoff during simulated rainfall. *Trans. Chin. Soc. Agric. Eng.* **2006**, *6*, 39–44.
21. Liu, B.Z.; Li, G.L.; Wu, F.Q.; Zhao, X.G. The regular patterns of the loss of soil nutrients on Southern Loess Plateau. *J. Soil Water Conserv.* **1995**, *9*, 76–86.
22. Sims, J.T.; Simard, R.R.; Joern, B.C. Phosphorus Loss in Agricultural Drainage: Historical Perspective and Current Research. *J. Environ. Qual.* **1998**, *27*, 277–293. [CrossRef]
23. Sharpley, A.N.; Kleinman-Peter, J.A.; Heathwaite, A.L.; Gburek, W.J.; Weld, J.L.; Folmar, G.J. Integrating Contributing Areas and Indexing Phosphorus Loss from Agricultural Watersheds. *J. Environ. Qual.* **2008**, *37*, 1488–1496. [CrossRef] [PubMed]
24. Cui, Y.S.; Pan, C.Z.; Liu, C.L.; Luo, M.J.; Guo, Y.H. Spatiotemporal variation and tendency analysis on rainfall erosivity in the Loess Plateau of China. *Hydrol. Res.* **2020**, *51*, 1048–1062. [CrossRef]
25. Bouraima, A.K.; He, B.H.; Tian, T.Q. Runoff, nitrogen (N) and phosphorus (P) losses from purple slope cropland soil under rating fertilization in Three Gorges Region. *Environ. Sci. Pollut. Res.* **2015**, *23*, 4541–4550. [CrossRef] [PubMed]
26. Yan, X.Y.; Gong, W. The role of chemical and organic fertilizers on yield, yield variability and carbon sequestration—Results of a 19-year experiment. *Plant Soil* **2010**, *331*, 471–480. [CrossRef]
27. Cai, Z.J.; Wang, B.; Xu, M.G.; Zhang, H.M.; Zhang, L.; Gao, S.D. Nitrification and acidification from urea application in red soil (Ferralic Cambisol) after different long-term fertilization treatments. *J. Soils Sediments* **2014**, *14*, 1526–1536. [CrossRef]
28. Haygarth, P.M.; Condron, L.M.; Heathwaite, A.L. The phosphorus transfer continuum: Linking source to impact with an interdisciplinary and multi-scaled approach. *Sci. Total Environ.* **2005**, *344*, 5–14. [CrossRef]
29. Protielje, R.; Van der Molen, D.T. Relationships between eutrophication variables: From nutrient loading to transparency. *Hydrobiologia* **1999**, *408*, 375–387. [CrossRef]
30. Wang, G.Q.; Wu, B.B.; Zhang, L.; Jiang, H.; Xu, Z.X. Role of soil erodibility in affecting available nitrogen and phosphorus losses under simulated rainfall. *J. Hydrol.* **2014**, *514*, 180–191. [CrossRef]
31. Arnhold, S.; Ruidisch, M.; Bartsch, S.; Shope, C.L. Simulation of runoff patterns and soil erosion on mountainous farmland with and without plastic-covered ridge-furrow cultivation in South Korea. *Trans. ASABE* **2013**, *56*, 667–679. [CrossRef]
32. Liu, S.; Qin, T.L.; Lv, X.Z.; Shi, X.; Dong, B.; Wang, J.; Liu, C. Experimental study of runoff and sediment yield affected by ridge direction and width of sloping farmland. *Front. Earth Sci.* **2021**, *9*, 694773. [CrossRef]
33. Christiansen, J.E. The uniformity of application of water by sprinkler system. *Agric. Eng.* **1941**, *22*, 89.
34. Wang, S.B.; Song, Y.L.; Wang, K.Q.; Zhao, Y.Y.; Zhang, J.H.; Yan, T.Y.; Chen, Y. Effects of reverse-slope terrace on nitrogen and phosphorus loss in sloping farmland of red loam under different rainfall patterns. *Trans. Chin. Soc. Agric. Eng.* **2018**, *34*, 160–169.

35. Fox, D.M.; Bryan, R.B.; Price, A.G. The influence of slope angle on final infiltration rate for interrill conditions. *Geoderma* **1997**, *80*, 181–194. [CrossRef]
36. Jordan, G.; Rompaey, A.V.; Szilassi, P. Historical land use changes and their impact on sediment fluxes in the Balaton basin (Hungary). *Agric. Ecosyst. Environ.* **2005**, *108*, 119–133. [CrossRef]
37. Zhao, H.L.; Guo, Y.R.; Zhou, R.L.; Zhao, X.Y. Effects of vegetation cover on physical and chemical properties of bio-crust and under-layer soil in Horqin Sand Land. *Ying Yong Sheng Tai Xue Bao* **2009**, *20*, 1657–1663.
38. Kimaro, D.N.; Poesen, J.; Msanya, B.M. Magnitude of soil erosion on the northern slope of the Uluguru Mountains, Tanzania: Interrill and rill erosion. *Catena* **2008**, *75*, 38–44. [CrossRef]
39. Zhang, G.H.; Liu, Y.M.; Han, Y.F.; Zhang, X.C. Sediment transport and soil detachment on steep slopes: I. Transport Capacity Estimation. *Soil Sci. Soc. Am. J.* **2009**, *73*, 1291–1297. [CrossRef]
40. Lei, T.W.; Nearing, M.A.; Haghighi, K.; Bralts, V.F. Rill erosion and morphological evolution: A simulation model. *Water Resour. Res.* **1998**, *34*, 3157–3168. [CrossRef]
41. He, X.L.; Zheng, Z.C.; Li, T.X. Effects of Tillage Practices on Soil Erosion and Phosphorus Loss in Sloping Cropland of Purple Soil. *Sci. Agric. Sin.* **2013**, *2*, 2492–2500.
42. Saskia, K.; Joao, P.N.; Patricia, S.; Tony, P.; Ronald, P.; Masselink, R.; Artemi, C. The way forward: Can connectivity be useful to design better measuring and modelling schemes for water and sediment dynamics. *Sci. Total Environ.* **2018**, *644*, 1557–1572.
43. Stevens, C.J.; Quinton, J.N.; Bailey, A.P.; Deasy, C.; Silgram, M.; Jackson, D.R. The effects of minimal tillage, contour cultivation and in-field vegetative barriers on soil erosion and phosphorus loss. *Soil Tillage Res.* **2009**, *106*, 145–151. [CrossRef]
44. Guo, S.F.; Zhai, L.M.; Liu, J.; Liu, H.B.; Chen, A.Q.; Wang, H.Y.; Wu, S.X.; Lei, Q.L. Cross-ridge tillage decreases nitrogen and phosphorus losses from sloping farmlands in southern hilly regions of China. *Soil Tillage Res.* **2019**, *191*, 48–56. [CrossRef]
45. Locke, M.A.; Krutz, L.J.; Steinriede, R.W. Conservation management improves runoff water quality: Implications for environmental sustainability in a glyphosate-resistant cotton production system. *Soil Water Manag. Conserv.* **2015**, *79*, 660–671. [CrossRef]
46. Rudi, H.; Ingmar, M.; Chen, L.D.; Coen, R.; Jannes, S. Soil erosion simulations of land use scenarios for a small Loess Plateau catchment. *Catena* **2003**, *54*, 289–302.
47. Hou, L.; Xie, X.L.; Yao, C.; Wu, F.Q. Erosion process and characteristics of different specifications of fish-scale pit slope. *Trans. Chin. Soc. Agric. Eng.* **2020**, *36*, 62–68.
48. Lin, Y.; Qin, F.; Zheng, Z.C.; Zhang, L.; Liu, L.X.; Xu, W.; Wu, C.L.; Li, T.X. Characteristics of variations in soil surface microtopography and soil erosion on the cross ridge slope under different rainfall conditions. *Sci. Soil Water Conserv.* **2015**, *13*, 32–38.
49. Rowntree, K.M. Sediment yields from a laboratory catchment and their relationship to rilling and surface armouring. *Earth Surf. Process. Landf.* **1982**, *7*, 153–170. [CrossRef]
50. Kinnell, P.I.A. The Effect of Slope Length on Sediment Concentrations Associated with Side-Slope Erosion. *Soil Sci. Soc. Am. J.* **2000**, *64*, 1004–1008. [CrossRef]
51. Zhang, R.R.; Li, M.; Yuan, X.; Pan, Z.C. Influence of rainfall intensity and slope on suspended solids and phosphorus losses in runoff. *Environ. Sci. Pollut. Res.* **2019**, *26*, 33963–33975. [CrossRef]
52. Wallace, C.B.; Burton, M.G.; Hefner, S.G.; Dewitt, T.A. Effect of preceding rainfall on sediment, nutrients, and bacteria in runoff from biosolids and mineral fertilizer applied to a hayfield in a mountainous region. *Agric. Water Manag.* **2013**, *130*, 113–118. [CrossRef]
53. Qin, W.; Zuo, C.Q.; Yan, Q.H.; Wang, Z.X.; Du, P.F.; Yan, N. Regularity of individual rainfall soil erosion in bare slope land of red soil. *Trans. Chin. Soc. Agric. Eng.* **2015**, *31*, 124–132.
54. Sutton, M.A.; Howard, C.M.; Erisman, J.W. *The European Nitrogen Assessment: Sources, Effects and Policy Perspectives*; Cambridge University Press: Cambridge, UK, 2011; Volume 5.
55. Liu, R.M.; Wang, J.W.; Shi, J.H.; Chen, Y.X.; Sun, C.C.; Zhang, P.P.; Shen, Z.Y. Runoff characteristics and nutrient loss mechanism from plain farmland under simulated rainfall conditions. *Sci. Total Environ.* **2014**, *468–469*, 1069–1077. [CrossRef] [PubMed]
56. Xing, W.M.; Yang, P.L.; Ren, S.M.; Ao, C.; Li, X.; Gao, W.H. Slope length effects on processes of total nitrogen loss under simulated rainfall. *Catena* **2016**, *139*, 73–81. [CrossRef]
57. He, S.Q.; Ma, R.; Wang, N.N.; Wang, S.; Li, T.X.; Zheng, Z.C. Comparison of nitrogen losses by runoff from two different cultivating patterns in sloping farmland with yellow soil during maize growth in Southwest China. *J. Integr. Agric.* **2022**, *21*, 222–234. [CrossRef]
58. Wang, J.; Guo, X.S.; Wang, Y.Q. Effect of straw mulch on nitrogen and phosphorus loss from farmlands in Chaohu Lake Region under natural rainfall condition. *Chin. J. Eco-Agric.* **2010**, *18*, 492–495. [CrossRef]
59. Teixeira, P.C.; Misra, R.K. Measurement and prediction of nitrogen loss by simulated erosion events on cultivated forest soils of contrasting structure. *Soil Tillage Res.* **2005**, *83*, 204–217. [CrossRef]
60. Ao, C.; Yang, P.L.; Zeng, W.Z.; Chen, W.L.; Xu, Y.; Xu, H.L.; Zha, Y.Y.; Wu, J.W.; Huang, J.S. Impact of raindrop diameter and polyacrylamide application on runoff, soil and nitrogen loss via raindrop splashing. *Geoderma* **2019**, *353*, 372–381. [CrossRef]
61. Lin, C.W.; Tu, S.H.; Huang, J.J.; Chen, Y.B. The effect of plant hedgerows on the spatial distribution of soil erosion and soil fertility on sloping farmland in the purple-soil area of China. *Soil Tillage Res.* **2009**, *105*, 307–312. [CrossRef]
62. Xia, L.Z.; Liu, G.H.; Wu, Y.H.; Ma, L.; Li, Y.D. Protection methods to reduce nitrogen and phosphorus losses from sloping citrus land in the Three Gorges Area of China. *Pedosphere* **2015**, *25*, 478–488. [CrossRef]

63. Dai, T.Y.; Wang, L.Q.; Li, T.N.; Qiu, P.P.; Wang, J. Study on the characteristics of soil erosion in the black soil area of Northeast China under natural rainfall conditions: The case of Sunjiagou Small Watershed. *Sustainability* **2022**, *14*, 8284. [CrossRef]
64. Wang, Y.; Fan, J.B.; Cao, L.X.; Zheng, X.B.; Ren, P.; Zhao, S.L. The influence of tillage practices on soil detachment in the red soil region of China. *Catena* **2018**, *165*, 272–278. [CrossRef]
65. Ding, W.F.; Huang, C.H. Effects of soil surface roughness on interrill erosion processes and sediment particle size distribution. *Geomorphplogy* **2017**, *29*, 801–810. [CrossRef]
66. Liu, M.X.; Wang, J.A.; Yan, P.; Liu, L.Y.; Ge, Y.Q.; Li, X.Y.; Hu, X.; Song, Y.; Wang, L. Wind tunnel simulation of ridge-tillage effects on soil erosion from cropland. *Soil Tillage Res.* **2006**, *90*, 242–249. [CrossRef]
67. Luo, J.; Zheng, Z.C.; Li, T.X.; He, S.Q. Spatial heterogeneity of microtopography and its influence on the flow convergence of slopes under different rainfall patterns. *J. Hydrol.* **2017**, *545*, 88–99. [CrossRef]