


Article

Effects of Soil and Water Conservation Practices on Runoff, Sediment and Nutrient Losses

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Abstract: Rainfall is a major dynamic source of soil erosion and nutrient loss on slopes. Soil and water conservation practices and agricultural activities can change the soil surface morphology and thus affect erosion and nutrient losses. This study focused on the effects of several typical soil and water conservation practices and agricultural land, for the purpose of: (1) determining how these practices prevent erosion and nutrient loss and identifying the hydrodynamic mechanisms; and (2) determining the application conditions for different practices. Runoff, sediment, total nitrogen (TN) and total phosphorus (TP) in fish-scale pits, agricultural land, narrow terraces, shrub cover and bare land, under rainfall events in rainy seasons (from May to November) during the 2010–2015 period, were monitored. Slope hydrodynamic mechanisms and application conditions of these practices were also investigated. The results showed that compared with bare land, fish-scale pits performed the best in preventing runoff, sediment, TN and TP, followed by 30% shrub coverage, narrow terraces and agricultural land, successively. Total runoff, sediment, TN and TP losses in fish-scale pits site were 19.70%, 2.03%, 10.10% and 35.97% of those in bare land of the same area, respectively. Soil and water conservation practices could change the hydraulic characteristics of slopes, decrease Re (Reynolds) and Fr (Froude) numbers, thereby decreasing runoff, sediment, TN and TP losses. Fish-scale pits were suitable for the areas with small single rainfall and good water permeability. When rainfall was greater than 60 mm, narrow terraces had highest efficiency in reducing sediment loss; therefore, they were suitable for the areas with relatively high rainfall intensity and soils similar to the sandy loams of the study area. As to the practice of covering land with plants, the effect was sustainable due to the plants' long-term growth. Agricultural land was not recommended since the losses on it were relatively higher due to the impact of human activities. In reality, these practices may be applied in combination so as to effectively control water, soil and nutrient losses.

Keywords: soil and water conservation practices; soil erosion; nutrient loss; dynamic parameter

1. Introduction

Rainfall is a major cause of soil erosion and nutrient loss, which eventually results in non-point source pollution and ecological deterioration [1,2]. Nutrient loss is closely related to the occurrence of soil erosion. The general soil erosion equation RUSLE (Revised Universal Soil Loss Equation) of the United States has a classical description on the factors of erosion. It is considered that soil erosion is related to the factors of rainfall-runoff erosivity (most appropriately called the erosivity index, a statistic calculated from the annual summation of rainfall energy in every storm times its maximum

30-min intensity); soil erodibility (this factor quantifies the cohesive, or bonding character of a soil type and its resistance to dislodging and transport due to raindrop impact and overland flow); slope length and steepness (steeper slopes produce higher overland flow velocities; longer slopes accumulate runoff from larger areas and also result in higher flow velocities); cover-management (this factor is the ratio of soil loss from land cropped under specified conditions to corresponding loss under tilled, continuous fallow conditions); and support practices (included in this term are contouring, strip cropping and terracing). The existing soil and water conservation practices mainly change the slope steepness factor, slope length factor, cover-management factor and support practice factor. Implementation of soil and water conservation practices can change the hydrological conditions and dynamic characteristics of water flow on hillslopes [3,4], and reduce erosion and nutrient loss.

Narrow terraces, fish-scale pits, and plant cover are commonly used for soil and water conservation, and the research and application of these practices are relatively mature [5–7]. The process of water and soil nutrient loss is a process of energy conversion. Soil and water conservation practices change the topographical features of the slope, and have the functions of reducing raindrop kinetic energy, increasing slope roughness, storing and maintaining runoff and sediment. The most direct function is the reduction of erosion energy and the reduction in the amount of pollutant migration. Narrow terraces changed the slope steepness and the slope length, which has better energy elimination effect; fish-scale pits increased the roughness of the slope and could intercept and conserve runoff and sediment; plant cover could eliminate the energy of raindrops and conserve rainfall, and meanwhile could consolidate slope soil. Therefore, conditions for their application are also different. In recent years, the study and application of soil and water conservation practices for nutrient non-point source pollution control on steep slopes are on the increase, but they mainly focus on a single practice [8–10]. The studies on hydraulics and erosion are well developed. However, research on their relation to nutrient loss needs to continue [11,12]. Existing studies lack the characterization of the effects of different water and soil conservation practices using uniform hydrodynamic parameters.

Therefore, this study focuses on the effects of several typical soil and water conservation practices, for the purpose of: (1) determining how these practices prevent erosion and nutrient loss and identifying the hydrodynamic mechanisms or characteristic parameter regulation; and (2) determining the slope conditions for the application of different practices. These two problems are of great value for the effective application of slope-based soil and water conservation practices and for non-point source pollution control.

2. Research Methods

2.1. Experimental Site

The study site is located at Longfengling Soil and Water Conservation Scientific Demonstration Site of Mentougou District, Beijing, China (N39°54', E115°35'). The study site has a semi-humid continental monsoon climate. Most of the precipitation occurs in June, July, August and September, with an annual precipitation of 626 mm. Soil samples were selected randomly in an "S" shape on the original slope for analysis. Five soil sampling points were selected, and one sample of approximately 500 g, which was taken at each point from a depth of 0 to 10 cm, was sealed in a plastic bag and then transported to the laboratory for chemical and physical analysis. Then, one cutting ring sample was collected at each point to determine the soil bulk density. Parts of the 500 g sample were sieved (2 mm) to remove roots and large stones. The particle-size distribution was determined by using the pipette method. The soil is classified as Kastanozem with a sandy loam texture ($54.51 \pm 0.08\%$ sand, $28.11 \pm 0.08\%$ silt, and $17.38 \pm 0.04\%$ clay) (Table 1) and is susceptible to erosion. The soil pH was determined using a pH probe in a 1:2.5 soil:water suspension. Soil organic matter (OM) was determined by $K_2Cr_2O_7$ oxidation at 180 °C. Soil total nitrogen (TN) was measured by the semi-micro Kjeldahl method, and soil total phosphorus (TP) was measured by the ultraviolet spectrophotometer method.

Table 1. Soil physical and chemical properties (mean of 5 samples).

| Particle Contents (%) | | | pH | Organic Matter (g/kg) | Total Nitrogen (g/kg) | Total Phosphorus (g/kg) | Soil Type | Soil Bulk Density (g/cm ³) |
|-----------------------|---------------|--------------|------|-----------------------|-----------------------|-------------------------|------------|----------------------------------------|
| <0.002 mm | 0.002–0.02 mm | 0.02–2 mm | | | | | | |
| 17.38 ± 0.04 | 28.11 ± 0.08 | 54.51 ± 0.08 | 6.74 | 5.81 | 0.22 | 0.84 | Sandy loam | 1.37 ± 0.02 |

2.2. Experimental Design

Following the collection of soil samples, six runoff sites were established in the experimental station. Runoff was collected in a series of runoff tanks, which had an inner diameter of 1.01 m, a height of 1 m and 9 diversion holes (Figure 1). After the first runoff tank had been filled up, the runoff water would overflow automatically to the next tank. The erosion and nutrient losses under every single rainfall event were monitored during the rainy seasons (from May to November). Runoff and sediment in the tanks were collected and measured after every rainfall event, and water samples were also collected for chemical analysis. In the course of the experiment, 77 rainfall events led to erosion and nutrient loss at one or more of the runoff plots.

**Figure 1.** Runoff tanks.

The basic information on the six runoff sites is:

Bare land is a slope with flat surfaces and without any plants. There are two runoff sites of bare land. One is 20 m long, 5 m wide and 15° slope, and the other is 10 m, 5 m and 15° slope (Figure 2a).

The fish-scale pits site is 20 m long, 5 m wide and 15° slope with a total of 20 pits in 10 rows and 2 columns. Each pit has a depth of 0.3 m and a width of 1 m. One-year-old Jingbai pear trees were planted at this site (Figure 2b).

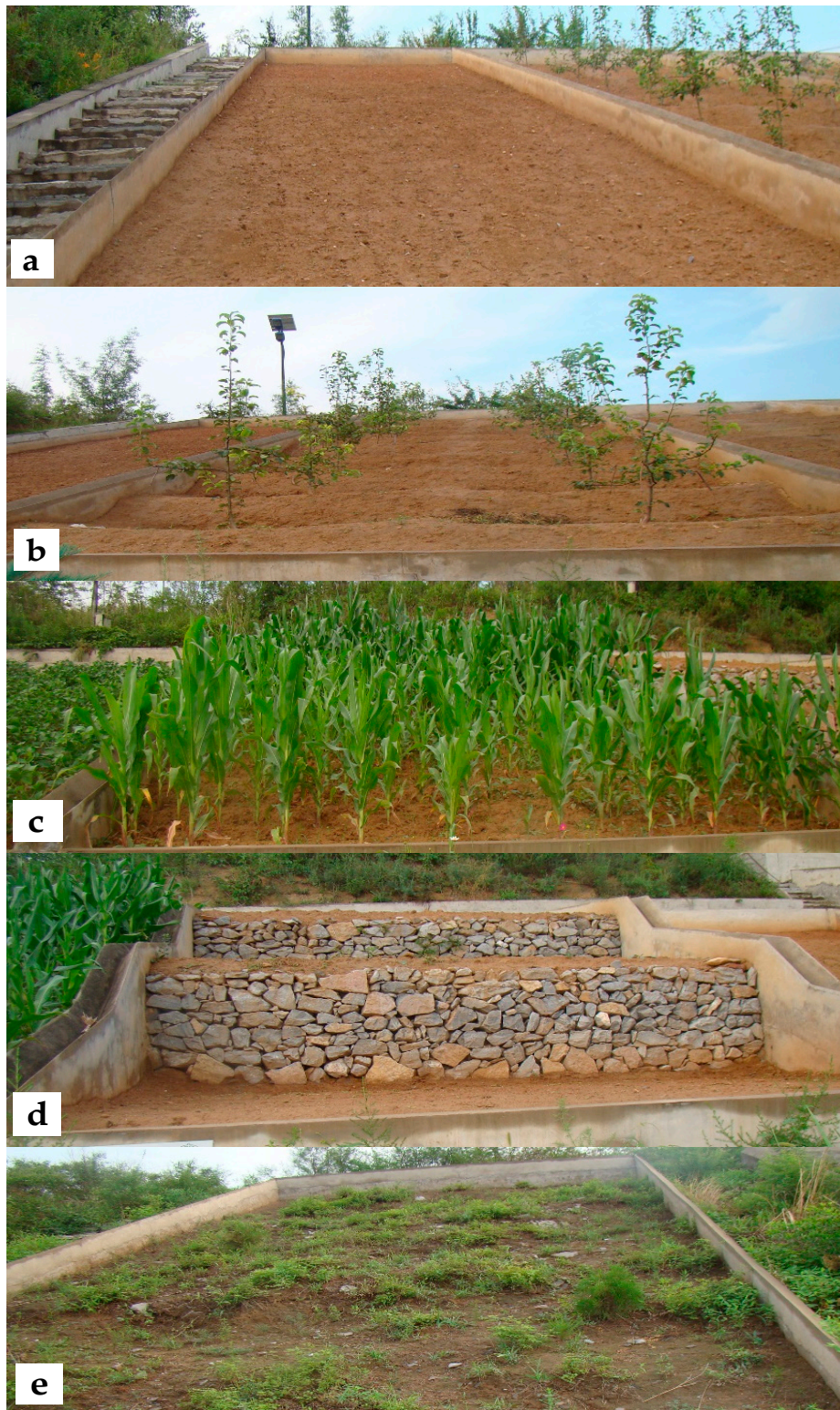


Figure 2. Runoff sites ((a) is bare land; (b) is fish-scale pits site; (c) is agricultural land; (d) is narrow terraces; (e) is shrub 30% site).

The agricultural land is a 10 m long, 5 m wide, 15° slope surface with corn planted in rows up-and-down slope. Corn is the crop most widely cultivated in the region. Row spacing is 0.5 m and plant spacing 0.25 m. 3 kg pure nitrogen and 0.8 kg phosphorus pentoxide were applied per year in this site (Figure 2c).

The narrow terraces site has 3 steps, and each step has a width of 3.3 m and a height of 1.33 m. Its length, width and slope are 10 m, 5 m and 15°, respectively. Nothing is planted in this site (Figure 2d).

The shrub 30% site is uniformly covered with naturally grown *Vitex negundo* and *Zinnia*. The coverage is the sum of the area of vertical projection of plants. This site has a length, width and slope of 10 m, 5 m and 15°, respectively (Figure 2e).

2.3. Measurements and Methods

Rainfalls were measured with a rain gauge cylinder. After each rainfall event, water level in each tank was measured with a ruler, tank contents were stirred, and two 500 mL samples were collected in plastic bottles. The plastic bottles were stored at 4 °C in a refrigerator for chemical analysis. Sediment in one of the 500 mL samples from each tank was allowed to settle, separated from the water, dried in an air-forced oven to a constant weight at 105 °C and weighed. The other 500 mL sample from each tank was taken to measure the concentration of TN (semi-micro Kjeldahl method) and TP (ultraviolet spectrophotometer method). Each treatment was conducted in triplicate. Water temperature was measured with a thermometer. The duration of runoff was observed with an infrared camera.

The average runoff velocity is expressed as $v = \frac{Q}{Bh}$, in which v is flow velocity (m/s), Q is runoff quantity (m³/s), B is width, and h is water depth, calculated by dividing the amount of rainwater in the tank by the area of the site [13].

Reynolds number is calculated by $Re = \frac{vR}{\mu}$, in which Re is Reynolds number, R is hydraulic radius, $R = Bh/(B + 2h)$, μ is kinematic viscosity coefficient (cm²/s) $0.01775/(1 + 0.0337t + 0.000221t^2)$, and t is water temperature (°), measured by a thermometer [14].

Froude number is calculated by $Fr = \frac{v}{\sqrt{gh}}$, in which Fr is Froude number and g is gravitational acceleration (9.8 m/s²).

2.4. Data Analysis

All of the figures and tables were made with Excel 2017 for runoff, sediment loss, TN loss, and TP loss, including regressions of their relationships. t -tests were analyzed with SPSS 17.0 (SPSS Inc., Chicago, IL, USA).

3. Results and Analysis

3.1. Total Runoff, Sediment and Nutrient Losses

A total of 316 rainfall events occurred at the experimental site during 2010–2015. The time interval between rainfall events was defined as being more than 6 h, otherwise it was the same rainfall event. Table 2 shows that the frequency of soil erosion in bare land is significantly higher than in the other runoff sites where soil and water conservation practices were implemented. Soil erosion occurs in 49–77 rainfall events accounting for only 16–24% of all rainfall events. This suggests that the frequency of soil erosion and nutrient loss can be reduced by soil and water conservation practices. The reduction was most evident in agricultural land, followed by shrub 30%. The prevention of soil erosion on agricultural land was attributed to the crops planted on the slope. As the crops grew, their coverage increased, especially in the later stage of growth when the crop covered almost the entire slope; the roots of these growing plants also assisted in stabilizing the surface. Therefore, the crops played a role in preventing erosion relative to the bare ground [15,16].

Table 2. Runoff, sediment and nutrient losses in different runoff sites during 2010–2015 (total loss is the monitored value; loss per unit area is obtained by dividing the monitored value by the plot area, and proportion to total loss from bare land is the proportion of the corresponding plot of the bare land with the corresponding size.).

| | | 20 m Plots | | 10 m Plots | | | |
|---------------------------|------------------------------------------------------|------------|-----------------|------------|-------------------|----------------|-----------|
| | | Bare Land | Fish-Scale Pits | Bare Land | Agricultural Land | Narrow Terrace | Shrub 30% |
| Number of erosions events | | 77 | 61 | 72 | 49 | 66 | 55 |
| Runoff | Total loss (m ³) | 66 | 13 | 29 | 17 | 15 | 9 |
| | Loss per unit area (m ³ /m ²) | 0.66 | 0.13 | 0.58 | 0.34 | 0.30 | 0.18 |
| | Proportion to total loss of bare land (%) | — | 19.70 | — | 58.62 | 51.72 | 31.03 |
| Sediment | Total loss (kg) | 7744 | 157 | 1971 | 432 | 117 | 147 |
| | Loss per unit area (kg/m ²) | 77.44 | 1.57 | 39.42 | 8.64 | 2.34 | 2.94 |
| | Proportion to total loss of bare land (%) | — | 2.03 | — | 21.92 | 5.94 | 7.46 |
| TN | Total loss (g) | 184 | 66 | 90 | 50 | 47 | 41 |
| | Loss per unit area (g/m ²) | 18.43 | 6.63 | 35.84 | 20.12 | 18.90 | 16.46 |
| | Proportion to total loss of bare land (%) | — | 35.97 | — | 56.14 | 52.73 | 45.93 |
| TP | Total loss (g) | 119 | 12 | 31 | 24 | 12 | 12 |
| | Loss per unit area (g/m ²) | 11.88 | 1.20 | 12.50 | 9.64 | 4.66 | 4.70 |
| | Proportion to total loss of bare land (%) | — | 10.10 | — | 77.12 | 37.28 | 37.60 |

Regarding the quantity of the runoff, sediment and nutrient losses, fish-scale pits performed the best. Total losses of runoff, sediment, TN and TP on the fish-scale pits site were 19.70%, 2.03%, 10.10% and 35.97% of those on bare land of the same area, respectively (Table 2). By changing the surface topography, fish-scale pits enabled the slope to collect water and sediment, thereby markedly reducing water, soil and nutrient losses [5].

As for other soil and water conservation practices, shrub 30% performed slightly better in reducing runoff than agricultural land and narrow terraces. Narrow terraces and shrub 30% functioned similarly in reducing sediment and TP losses, and both performed slightly better than agricultural land. Shrub 30% performed slightly better in reducing TN loss than agricultural land and narrow terraces. The main reason was that the plants could intercept rainfall and reduce kinetic energy of raindrops, especially in the later growth stage when their roots could also stabilize the soil. Since agricultural production activities disturbed the soil, erosion occurred easily and frequently. In addition, in the early stage of growth, crops could not yet cover the slopes and their roots were too fragile to fix soil. Therefore, the amount of nutrient loss on agricultural land over the study years was still relatively high. Soil erosion was reduced in narrow terraces mainly due to the change in the slope surface morphology. However, compared with other practices, their effect was not outstanding. For bare land, the nutrient loss in the 20 m runoff site was higher than that in 10 m runoff site, implying that the increase of slope length would lead to increase of erosion, which accorded with many other study results [17].

3.2. Runoff and Sediment

In order to investigate the mechanism and effect of soil and water conservation practices under single rainfall event conditions, 37 rainfall events, in which runoff occurred in all experimental sites, were studied. In the 37 rainfall events, rainfall was between 10 mm and 70 mm, and the number of

samples met the requirements of statistical analysis. All figures were based on the data of these 37 rainfall events.

According to Figure 3, both runoff and sediment increased with rainfall in all runoff sites. The increase was more obvious when the rainfall was less than 20 mm, while reducing and fluctuating when the rainfall exceeded 20 mm. As many other factors, including rainfall intensity, rainfall duration and soil moisture, also influence runoff and sediment, rainfall alone cannot be considered as an indicator. Figure 3 showed that runoff and sediment in the sites under soil and water conservation practices were significantly lower than in bare land, indicating that these practices are functioning well. According to *t*-test results, the impact of rainfall on runoff (*p* values for bare land 20 m, bare land 10 m, agricultural land 10 m, narrow terraces 10 m, fish-scale pits 20 m and shrub 30% 10 m are 0.004, 0.004, 0.035, 0.022, 0.021 and 0.020, respectively, all of which are less than 0.05) and sediment (*p* values for bare land 20 m, bare land 10 m, agricultural land 10 m, narrow terraces 10 m, fish-scale pits 20 m and shrub 30% 10 m are 0.004, 0.004, 0.041, 0.033, 0.039 and 0.025, respectively, all of which are less than 0.05) was significant.

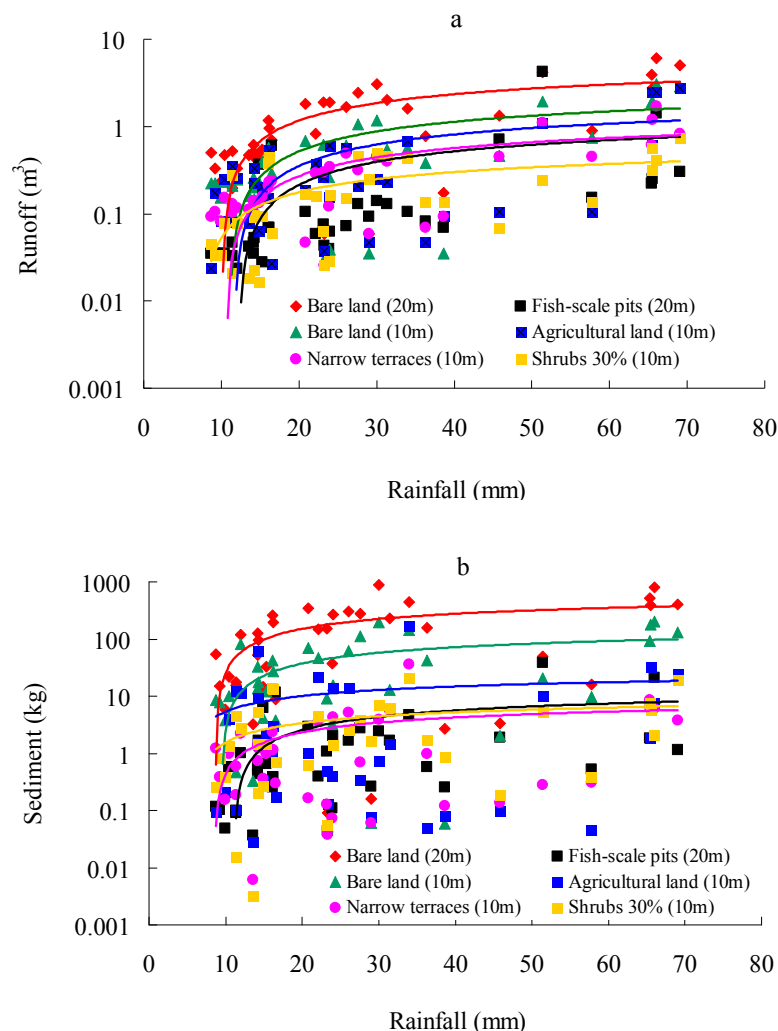


Figure 3. Relationship between runoff, sediment and rainfall under different soil and water conservation practices; (a) relationship between runoff and rainfall; (b) relationship between sediment and rainfall.

For runoff loss, the sequence is bare land 20 m > bare land 10 m > agricultural land 10 m > narrow terraces 10 m > fish-scale pits 20 m > shrub 30% 10 m. Fish-scale pits and shrub 30% could both intercept water flow, so they showed an outstanding performance in runoff reduction. For sediment

loss, the sequence is bare land 20 m > bare land 10 m > agricultural land 10 m > fish-scale pits 20 m > shrub 30% 10 m > narrow terraces 10 m. All of the fish-scale pits, shrub 30% and narrow terraces clearly prevented sediment loss and the differences between them were relatively small. Sediment loss is a very complicated process, in which many influential factors are involved. Every soil and water conservation practice has its own advantages and disadvantages in reducing rainfall power and intercepting rainfall. For example, terraces change the surface topography of the slope so that the rainfall is almost vertical to the slope (under calm conditions), thereby effectively reducing the energy of the rainfall. Fish-scale pits can not only eliminate rainfall energy, but also intercept water and sediment. Plant cover can reduce the energy of the rainfall and intercept part of the water stream and so on. Therefore, sediment loss under different practices is closely related to the characteristics of each single rainfall event, which explains why there were intersections of trend lines.

3.3. Hydraulic Parameter

Hydraulic characteristics of runoff are important indicators of soil erosion mechanisms [2]. The experimental results show that soil and water conservation practices exert significant influences on the Reynolds number and the Froude number of slope flow (Figure 4). Upon significance analysis by *t*-test, the impact of average rainfall intensity on *Re* (*p* values for bare land 20 m, bare land 10 m, agricultural land 10 m, narrow terraces 10 m, fish-scale pits 20 m and Shrub 30% 10 m are 0.003, 0.003, 0.011, 0.008, 0.010 and 0.009, respectively, all of which are less than 0.05) and *Fr* (*p* values for bare land 20 m, bare land 10 m, agricultural land 10 m, narrow terraces 10 m, fish-scale pits 20 m and Shrub 30% 10 m are 0.003, 0.003, 0.008, 0.009, 0.011 and 0.009, respectively, all of which are less than 0.05) was significant.

For all the runoff sites, both *Re* and *Fr* show an increasing trend with increasing average rainfall intensity. *Re* numbers are all under 500 and the slope flows are all laminar flow; *Fr* numbers are all under 1.0 and slope flows are all subcritical flow. The conservation practices significantly reduced *Re* and *Fr*, and the sequences of trend lines were: bare land 20 m > bare land 10 m > agriculture land 10 m > narrow terraces 10 m > shrub 30% 10 m > fish-scale pits 20 m. *Re* is the ratio of the inertia force to viscous force of slope flow fluids. The decrease of *Re* number indicates that the viscous force of fluids is predominant, the disturbance of the slope flow is weakened by the viscous force, and the flow is stable, which consequently leads to weak disturbance of surface soil particles and slight soil erosion. *Fr* is the ratio of inertia force to gravity. The decrease of *Fr* indicates that gravity is predominant and the flow velocity is relatively stable, which means less disturbance on the surface and decreased soil erosion. Therefore, soil and water conservation practices can change the hydraulic characteristics of slopes, thereby reducing soil erosion and nutrient loss.

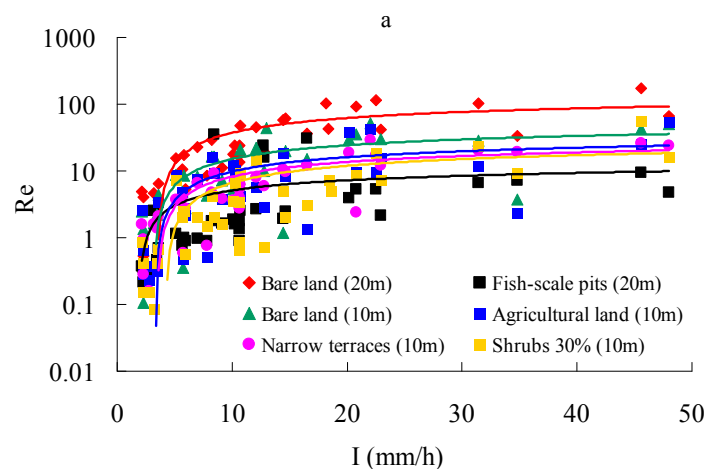


Figure 4. Cont.

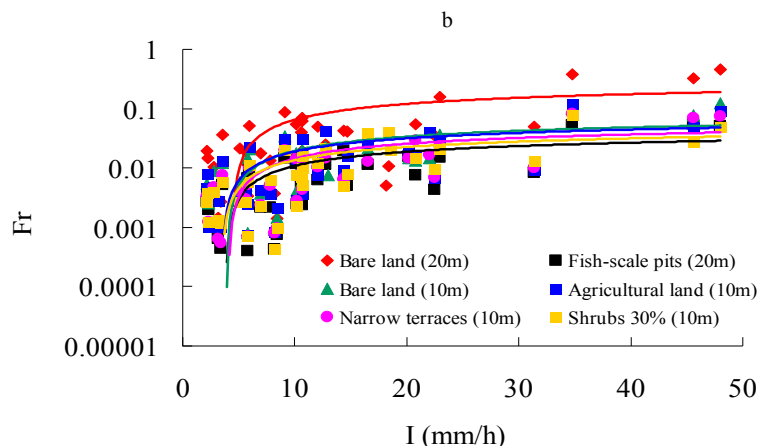


Figure 4. Relationship between I (average rainfall intensity) and Re and Fr ; (a) relationship between Re and rainfall intensity; (b) relationship between Fr and rainfall intensity.

3.4. Total Nitrogen (TN) and Total Phosphorus (TP)

Runoff and sediment are the carriers of nutrients. Soil and water conservation practices exert influences on nutrient loss by retaining runoff and reducing erosion. TN and TP losses under different soil and water conservation practices are shown in Figure 5. According to t -test result, the impact of rainfall on TN (p values for bare land 20 m, bare land 10 m, agricultural land 10 m, narrow terraces 10 m, fish-scale pits 20 m and shrub 30% 10 m are 0.015, 0.011, 0.042, 0.037, 0.039 and 0.034, respectively, all of which are less than 0.05) and TP (p values for bare land 20 m, bare land 10 m, agricultural land 10 m, narrow terraces 10 m, fish-scale pits 20 m and Shrub 30% 10 m are 0.014, 0.013, 0.047, 0.038, 0.042 and 0.039, respectively, all of which are less than 0.05) was significant.

Such practices have an obvious effect on the reduction of nutrient loss, which resembles runoff and sediment losses. TN and TP have two forms, soluble and insoluble. Soluble N and P exist in runoff and originate from the dissolution of surface soil nutrients during rainfall and soil erosion; insoluble N and P are mainly incorporated in sediment particles. N element is present in both dissolved state and particulate state, and runoff and sediment are its important carriers. P element mainly exists in the particulate state, and sediment is its main carrier. According to Figure 5, the change of TP was less regular than TN with the change of rainfall, mainly because soil and water conservation practices greatly reduced the amount of sediment erosion, and other factors such as rainfall intensities were not completely considered in this study. Different rainfall forms and soil and water conservation practices produce different erosion patterns, which inevitably result in differences in the content of different nutrient components.

For TN loss, the sequence is bare land 20 m > bare land 10 m > agricultural land 10 m > narrow terraces 10 m > shrub 30% 10 m > fish-scale pits 20 m. For TP loss, the sequence is bare land 20 m > bare land 10 m > agricultural land 10 m > shrub 30% 10 m > narrow terraces 10 m > fish-scale pits 20 m. Fish-scale pits had the best effect on preventing nutrient loss, mainly because they could intercept runoff segment by segment. Therefore, the practice of fish-scale pits is an important means for pollutant source control [5]. A slight difference was found between shrub 30% and narrow terraces, mainly owing to their different functioning principles and different rainfall conditions. With narrow terraces, flow velocity on slopes was slowed down and infiltration was increased mainly because the angle of inclination of the slope was changed, and raindrops were substantially perpendicular to the slope, thereby reducing their erosive power. For the shrub 30% practice, in addition to the reduction in raindrop erosion power, the leafy canopy of the shrubs also intercepted rainfall.

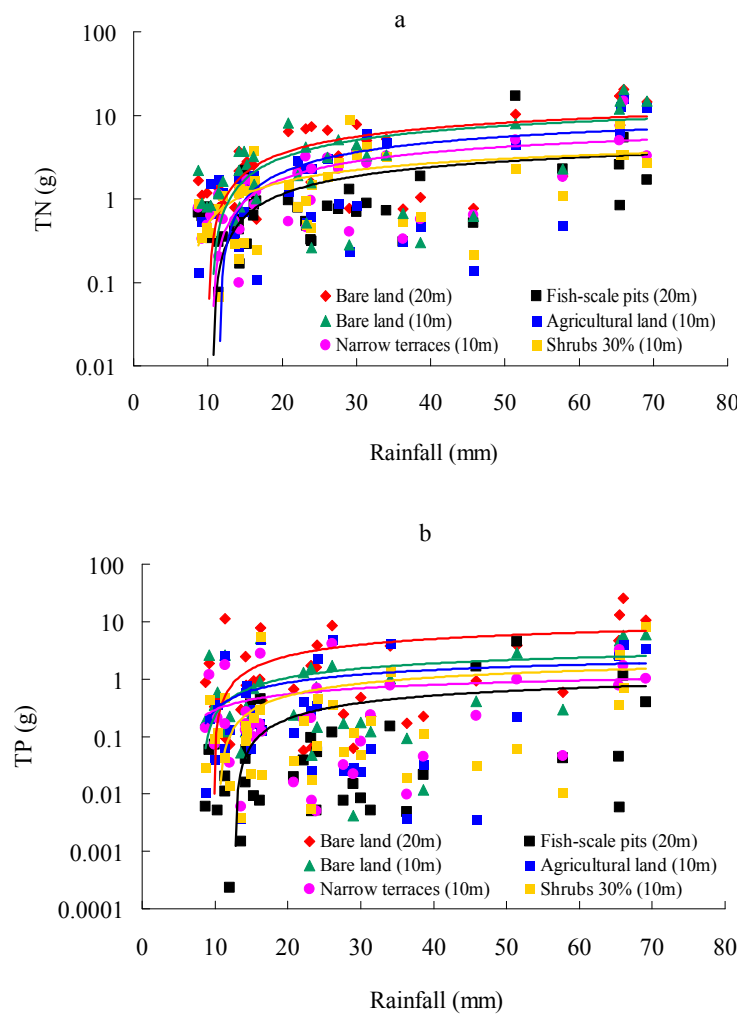


Figure 5. Relationship between total nitrogen and phosphorus losses and rainfall under different soil and water conservation practices; (a) relationship between total nitrogen (TN) loss and rainfall; (b) relationship between total phosphorous (TP) loss and rainfall.

4. Discussion

Soil and water conservation practices exert great influence on runoff, sediment and nutrient losses on slopes, but the mechanisms of their influence vary (which may affect one or more factors in the RUSLE equation). Runoff, sediment, TN and TP loss on steep slopes involve complicated processes, and the conservation practices change the surface morphology, making the processes even more complicated and making it more difficult to predict the nutrient losses. Among the 37 rainfall events during which runoff occurred in all of the plots, 25 had a rainfall of less than 30 mm, 8 had between 30–60 mm, and 4 recorded more than 60 mm. This study estimated runoff, sediment and nutrient losses per unit of rainfall in the plots under different water conservation practices and on agricultural land in different ranges of rainfall, as shown in Table 3.

Table 3. Sediment, runoff, TN loss and TP loss under different rainfall ranges in respective plots.

| | Fish-Scale Pits, 20 m | | | Agricultural Land, 10 m | | | Narrow Terraces, 10 m | | | Shrubs 30%, 10 m | | |
|-----------------------------|-----------------------|-------|------|-------------------------|-------|------|-----------------------|-------|------|------------------|-------|------|
| | <30 | 30–60 | >60 | <30 | 30–60 | >60 | <30 | 30–60 | >60 | <30 | 30–60 | >60 |
| Rainfall (mm) | <30 | 30–60 | >60 | <30 | 30–60 | >60 | <30 | 30–60 | >60 | <30 | 30–60 | >60 |
| Sediment (kg/mm) | 0.08 | 0.16 | 0.16 | 0.38 | 0.56 | 0.25 | 0.09 | 0.13 | 0.09 | 0.12 | 0.13 | 0.14 |
| Runoff (m ³ /mm) | 0.01 | 0.02 | 0.04 | 0.02 | 0.01 | 0.03 | 0.02 | 0.01 | 0.02 | 0.01 | 0.02 | 0.02 |
| TP (g/mm) | 0.01 | 0.02 | 0.03 | 0.03 | 0.04 | 0.05 | 0.02 | 0.01 | 0.03 | 0.01 | 0.01 | 0.02 |
| TN (g/mm) | 0.04 | 0.08 | 0.04 | 0.07 | 0.09 | 0.18 | 0.07 | 0.06 | 0.12 | 0.08 | 0.05 | 0.06 |

The fish-scale pits change the topography of part of a slope and can intercept runoff and convert part of runoff into infiltration, and thus adjust the velocity and amount of runoff, thereby reducing erosive power. As water flows into the pits, not only is the flow velocity decreased by increasing infiltration, but the output of sediment is reduced by sediment being trapped within the pits. This reduces the loss of high-quality soil from the surface layer. Table 3 shows the effect on the reduction of runoff, sediment and nutrient losses. According to Table 3, the effectiveness of fish-scale pits in preventing runoff, sediment and nutrient losses decreases with increasing rainfall. In particular, when the rainfall is between 1–30 mm, fish-scale pits functions well when compared to other practices.

Under intensive rainfall conditions, runoff and sediment yield on slopes exceed the interception capacity of pits, and excess runoff and sediment will overflow. Owing to the limited capacity of the pits, they are often destroyed in high rainfall areas because they are fully filled with sediment and runoff [5]. However, fish-scale pits are suitable for areas where individual rainfall events are low to moderate or where the soil has high infiltration capacity. In earth-rock mountainous areas, stones are often used to build fish-scale pits, which can decrease their risk of being destroyed, but such pits have reduced water-holding capacity because they are usually permeable.

Agricultural land is a form of agricultural production on slopes. In this study, corn was planted (corn is the crop most widely cultivated in the region); this cover had a poor effect in controlling runoff, sediment and nutrient losses (Table 3). This practice had a decreasing effect with increasing rainfall. In some cases, runoff, sediment and nutrient losses on agricultural land were even higher than those on bare land. The plot was planted in late June, the surface of agricultural land was still incompletely covered in the rainy season (July and early August); therefore, the soil surface of agricultural land was more easily eroded when a rainfall event occurred [18,19]. In addition, the disturbance of soil by agricultural production and fertilizer application also had an impact. Therefore, even though some slopes are suitable for cultivating, cultivation on them is not recommended since it may aggravate soil, water and nutrient losses and lead to serious environmental problems.

Narrow, level terraces are the only practice in this study that completely changes the slope topography and thus requires the largest project workload. Theoretically, if it is supposed that rain falls down vertically, the kinetic energy of rainfall is depleted to the maximum extent [20,21], so narrow terraces are able to eliminate the rainfall erosivity completely, but splash erosion will still occur [22,23]. Therefore, narrow terraces are most suitable for the areas with high rainfall intensity and soils similar to the sandy loams of the study area. Table 3 shows that when rainfall is greater than 30 mm, narrow terraces have the most significant effect on sediment reduction compared with other conservation practices, and the effect changes insignificantly as rainfall increases, which is mainly due to their excellent ability to reduce rainfall erosivity. However, terraces cannot store runoff when rainfall is greater than the infiltration rate, so their effect on runoff reduction is poorer than fish-scale pits. Nutrient availability declines during prolonged rainfalls. This is related to many factors including the proportion of different nutrient elements in soil, and the residence time of soil moisture. The correlation between TN, TP and runoff and sediment is low, implying that there are complicated changes and various influencing factors. In this study, no crops were planted on narrow terraces and the slope was built completely flat. In reality, slopes can be tilted inward so as to better conserve water and soil. In real agricultural production, narrow terraces are often planted with crops or trees. Due to the plant cover and the stabilising of soil by plant roots, the factors of slope steepness, cover management and support practice are changed, and the soil and water conservation will be enhanced [21].

The impact of plant cover on soil, water and nutrient losses is mainly attributed to the interception and dispersion of rain water by stems, stalks and leaves of plants, and to the resistance of roots to soil erosion [6,24–26]. It can be seen from Table 3 that in this study, plant cover was one of the effective practices to prevent water, soil and nutrient losses, and the effect was relatively stable, and changed only slightly as rainfall increased. When cultivating plants, consideration should be given to ensuring that water resources can maintain the long-term natural growth of plants; otherwise, plants on slopes may die, thus failing to achieve a sustainable effect.

5. Conclusions

Fish-scale pits, narrow terraces, shrubs and agricultural land can all effectively reduce the frequency and amount of soil erosion and nutrient loss on slopes. For a single rainfall event, fish-scale pits, narrow terraces, and shrubs all function in reducing runoff, sediment, TN and TP losses to different extents, while agricultural land performs the worst. For runoff loss, bare land 20 m had the best performance, followed by bare land 10 m, agricultural land 10 m, narrow terraces 10 m, fish-scale pits 20 m, and shrub 30% 10 m in sequence. For sediment loss, the best performance was seen in bare land 20 m, followed in sequence by bare land 10 m, agricultural land 10 m, fish-scale pits 20 m, shrub 30% 10 m, and narrow terraces 10 m. For TN loss, bare land 20 m did the best, and then bare land 10 m, agricultural land 10 m, narrow terraces 10 m, and shrub 30% 10 m in sequence, and fish-scale pits 20 m performed the most poorly. For TP loss, bare land 20 m had the best performance, followed in sequence by bare land 10 m, agricultural land 10 m, shrub 30% 10 m, narrow terraces 10 m, and fish-scale pits 20 m. Regarding the quantity of the runoff, sediment and nutrient losses, fish-scale pits performed the best. Total losses of runoff, sediments, TN and TP on the fish-scale pits site were 19.70%, 2.03%, 10.10% and 35.97% of those on bare land of the same area, respectively.

With an increase in the average rainfall intensity, the slope hydraulic parameters of Re and Fr also increase, and flows are all laminar and subcritical. Soil and water conservation practices can change the hydraulic characteristics, reduce Re and Fr numbers, and decrease the occurrence of surface disturbance and soil erosion, thereby reducing runoff, sediment and nutrient losses. The sequence of trend lines from top to bottom is: bare land 20 m, bare land 10 m, agriculture land 10 m, narrow terraces 10 m, shrub 30% 10 m, fish-scale pits 20 m.

Soil and water conservation practices vary in their ability to prevent runoff, sediment and nutrient losses, so they need to be applied selectively when rainfall is less than 30 mm. Fish-scale pits are suitable for areas where individual rainfall are low and soil has excellent water permeability. Agricultural land practices disturb surface soil layer and may cause runoff, sediment and nutrient losses to increase, and thus corn cropping is not recommended as a preventative measure. Narrow terraces can reduce rainfall erosivity to the greatest extent and are suitable for areas with high rainfall intensity and soils similar to the sandy loams of the study area. Where plant cultivation is concerned, available water resources should be sufficient to ensure the long-term natural growth of plants so as to sustainably reduce water, soil and nutrient losses.

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