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Effects of tillage practices on nutrient loss and soybean growth in red-soil slope farmland

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Abstract

Field experiments were conducted to examine the effect of tillage practices on sediment and nutrient loss and soybean growth under natural rainfall conditions. Three tillage practices were applied: downslope ridge (check), downslope ridge + contour living hedgerow, and cross ridge. Cross ridge tillage reduced surface runoff by 69% and sediment yield by 86%, compared to the check treatment. The downslope ridge with a contour living hedgerow reduced surface runoff by 24% and sediment yield by 53%. Additionally, compared to the check plot, nutrient losses carried by runoff were reduced by over 68% and that carried in the sediment was reduced more than 85% in the cross ridge plot. Nutrient losses in runoff were reduced by 20% to 30% in the downslope ridge and contour living hedgerow plot and those carried in the sediment were reduced by 44% to 57%. Cross ridge tillage soybean yields exceeded those of the downslope ridge and downslope ridge + contour living hedgerow treatments by 16% – 18%. Cross ridge tillage could contribute to the prevention sediment and nutrient loss and could improve crop yield, and thus it is recommended to be applied to mild slopes in the red soil region.

Key Words: Red soil, Slope farmland, Tillage practices, Nutrient loss, Crop growth

1 Introduction

Sloping farmland is an important resource, and also a major source of soil and water loss in China. In recent years, with the increased use of sloping farmland and chemical fertilizer, soil and water loss and non-point source pollution on sloping farmland caused by agricultural activities are gradually coming into focus (Quan & Yan, 2002; Zhu et al., 2005). In-depth systematic studies of the effect of tillage practices on soil erosion, nutrient loss, and crop growth under natural rainfall conditions could not only provide technical support for soil and nutrient loss control and agricultural non-point source pollution control and prevention, but also offer a theoretical basis to the forecast of land productivity and crop yields, which is of great significance.

There have been a large number of studies on soil erosion and non-point source pollution on sloping farmland in terms of characteristics of runoff and sediment yield, law and influencing factors of nutrient loss, and control and prevention measures of soil erosion and water loss (Guo et al., 2010; Lin et al., 2010; Zhao et al., 2004; Lin et al., 2007; Li et al., 2003; Wang et al., 2010; Huang et al., 2007; Wang et al., 2010; Luo et al., 2007), but

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studies on the impacts of different tillage practices on nutrient loss and crop growth on sloping farmland of red soil is still relatively rare. Crops are mainly soybeans, peanuts and other cash crops on the red-soil sloping farmland in Jiangxi Province, China. For this study, standard runoff plots were built on red-soil sloping farmland in Jiangxi Province where soybeans were planted, and agricultural management was carried out fully in accordance with the practices of local farmers. Surface runoff, sediment loss, nutrient loss and crop growth were measured on plots with different tillage practices to provide a scientific basis to guide the development and use of red soil sloping lands and to provide information useful for the control and prevention of agricultural non-point source pollution in the red-soil region in southern China.

2 Research methodology

2.1 *Site description*

The study site was in Jiangxi Ecological Science and Technology Park of Soil and Water Conservation. The science and technology park is located in the Yangou Watershed of the Poyang Lake Basin, in De'an County of northern Jiangxi Province, China (115°42′38″– 115°43′06″E, and 29°16′37″– 29°17′40″N). The site is in the subtropical monsoon climate zone. The mean annual rainfall is 1,350 mm. The mean annual temperature is about 17℃. The annual sunshine duration is 1,650 to 2,100 hours. The average annual frost-free period is 249 days. The landform is low hills, with an altitude of 30 to 100 m, slope of 5° to 25°. The soil parent materials are primarily Quaternary red clay, and the zonal vegetation is subtropical evergreen broadleaf forest. This park is situated in the center of red soil in China, the topography and soil conditions of which are representative of Jiangxi Province and the red-soil region of southern China.

2.2 *Experiment design*

Nine standard runoff plots with a slope of 10°, were installed on the same slope where soil thickness, physical and chemical characteristics and slope grades are relatively uniform. Each plot was 100 m^2 in size (20 m×5 m). To prevent surface runoff from flowing into and out of the plots, each plot was surrounded by a 12 cm thick boundary ridging made of concrete bricks, 20 cm above the surface and 30 cm underground. There were rectangular collecting channels and circular collecting tanks below each plot to collect runoff and sediment. Three collecting tanks were designed for each plot, namely A, B and C, according to the local maximum 24-hour storm and runoff volume once in 50 years that may occur. They were made of stainless steel, 1 m in diameter and 1.2 m in height, and the water inlets were 1 m high. Tank A and B had 5 circular flow-dividing holes around the tank walls by "five-group" method, and four groups of contents in tank A were discharged and one group flowed into tank B; like A, four groups of contents in tank B were discharged and one group flowed into tank C. The flow-dividing holes were all 0.8 m high. Each tank was calibrated. Gauges were stuck on the tank walls to observe the water level. In order to facilitate runoff discharge, a circular hole with a diameter of 10 cm and a rubber valve were set on the bottom of each tank.

According to the common local management mode of soybean planting on slope farmland, three treatments, each with 3 replications, were randomly located on the slope. Soybeans were planted on June 18, 2011 and harvested on October 3, 2011 on each plot except control plot (nudation plot). Experimental treatments and design are elaborated in Table 1.

Table 1 Treatments and design of the experiment

Treatment number	Tillage	Descriptions
I	downslope ridge (control)	Ridge width was 70 cm, and height was 30 cm. Soybeans were planted with 20 cm of spacing in the rows and 35 cm of spacing between the rows on the ridge. Downslope ridge tillage was the tillage practice.

Continued

Treatment number	Tillage	Descriptions
Ⅱ	downslope ridge+contour living hedgerow	Ridge width was 70 cm, and height was 30 cm. Soybeans were planted with 20 cm of spacing in the rows and 35 cm of spacing between the rows on the ridge. Tillage practice was downslope ridge tillage. Contour living hedgerows of day lilies were located every 5 meters on the slope, and there were 2 rows in each hedgerow, with 20 cm of spacing between the rows and 20 cm of spacing in the rows. The day lilies were planted by seedling transplant.
Ⅲ	cross ridge	Ridge width was 70 cm, and height was 30 cm. Soybeans were planted by 20 cm of spacing in the rows and 35 cm of spacing between the rows on the ridge. Contour cross ridge tillage was the tillage practice.

2.3 *Observation objects and measurement methods*

Runoff and sediment yield and nutrient loss were measured after individual rainfalls that caused runoff. Crop growth and production were measured at harvest.

(1) Amounts of runoff and soil erosion. Amounts of runoff were recorded by the gauges on the collecting tanks, and amounts of soil erosion were calculated based on water samples where the oven drying method was used to determine sediment concentration.

(2) Nutrient contents in runoff and sediment. After rainfall, when the collecting tanks had been standing for some time, an appropriate amount of runoff liquid was taken from each tank into a plastic bottle and concentrated sulfuric acid stabilizer was added to the liquid for analytical determination, mainly for analyzing N, P and other nutrient contents in runoff. Then an appropriate amount of runoff liquid was taken from each tank during stirring of the tank stored in a plastic bottle for analyzing the sediment content in runoff. At last, the water in the collecting tanks was discharged, and the sediment in the bottom of each tank was put into a plastic bag for analytical determination, mainly for analyzing C, N, P nutrient contents in the sediment. Conventional chemical analysis methods were adopted to determine the nutrient contents in runoff and sediment.

(3) Crop growth and yield indicators. The biomass of soybean when harvested was calculated by dry weight by weighing. Soybean growth indicators were determined through direct measurement

3 Results and discussion

3.1 *Treatment effect on runoff and sediment yield*

Runoff and sediment yield on sloping farmland for the 3 plot types are shown in Table 2. Runoff and sediment yields were the greatest in the downslope ridge tillage where runoff was 6.9% of rainfall, and soil erosion was 1,214 t km^{-2}, demonstrating that irrational use and treatment of sloping farmland was one primary cause of soil erosion and water loss. Compared with the plot treated by downslope ridge tillage, runoff and sediment yields in the plot treated by downslope ridge tillage + contour living hedgerow were reduced by 24.3% and 52.8% respectively, while those in the plot treated by cross ridge tillage were reduced by 68.9% and 85.7% respectively.

This demonstrated that the contour living hedgerow and cross ridge tillage had significant water detention and soil conservation effects. This was because contour living hedgerow and cross ridge tillage could effectively slow down the surface runoff, which would increase seepage decreasing runoff. The lowered runoff volumes, along with water storage between ridges perpendicular to the slope, would reduce runoff detachment and promote the sediment deposition on the slope and reduce sediment yield.

The experimental observations showed that: the runoff and sediment reduction effects of cross ridge tillage were more obvious than downslope ridge tillage + contour living hedgerow. One reason was that cross ridge tillage could play a role in soil and water conservation earlier in the year through the interception effects of ridges while the water detention and soil conservation effects of day lily hedgerows will gradually appear with the growth of plants. The runoff reduction effects of downslope ridge tillage with the hedgerow were not as good as its sediment reduction effects, which might be because the hedgerow mainly played a role in intercepting runoff, reducing runoff velocity, and trapping sediment in the early growth stage, and therefore it posed more significant impacts on sediment yield than runoff yield.

A detailed analysis of the runoff and sediment yields for each rainfall in each plot during the experimental period revealed that the storm rainfall on August 22, 2011 (precipitation amount of 35.3 mm, rainfall duration of 315 min) caused serious soil erosion and water loss in all plots. The downslope ridge plot, downslope ridge + contour living hedgerow plot and cross ridge plot had surface runoff volumes of 0.60 m^3, 0.45 m^3, 0.20 m^3, and sediment erosion amounts of 77.2 kg, 41.9 kg, 16.8 kg, respectively. The runoff volume caused by this intense rainfall was about 60% of the total runoff volume in the experimental period across all treatments. Sediment yield from this single storm ranged from 63% of the total erosion occurring on the downslope ridge plot to 96.9% of the erosion occurring on the cross ridge plot. It was thus clear that it were only a small number of heavy rainfalls that made larger contributions to soil erosion and water loss on sloping farmland. It is important when developing sloping farmland to select crops whose harvest and planting times are not in a period with heavy rainfalls, thus avoiding serious soil and water loss.

Table 2 Runoff and sediment yield for each treatment

Tillage	Runoff			Sediment yield		
	Surface runoff (m^3)	Runoff reduction (%)	Runoff coef. (%)	Sediment yield (kg)	Sediment reduction (%)	Soil erosion modulus (t km^{-2})
Downslope ridge	1.02a*	—	6.9a	121.4a	—	1,214a
Downslope ridge +contour living hedgerow	0.77a	24.3	5.2a	57.3a	52.8	573a
Cross ridge	0.32b	68.9	2.1b	17.4b	85.7	173b

* Treatments with different letters were significantly different ($P=0.05$).

3.2 *Treatment effect on nutrient loss*

Nutrients carried by runoff and sediment are major component of soil nutrient loss. The loss of nutrients carried by runoff under different treatments is shown in Table 3. According to Table 3, nutrients carried by runoff in downslope ridge tillage + contour living hedgerow plot and cross ridge tillage plot were both smaller than that in the downslope ridge tillage plot, and the interception efficiencies (defined as the reduction in loss for downslope ridge tillage + contour living hedgerow or cross ridge tillage and downslope ridge tillage) for total phosphorus, total nitrogen and ammonia-nitrogen in plots with the two former tillage treatments were 28.3% – 73.6%, 20.9% – 71.4%, 30.3% – 68.6% respectively. While both contour living hedgerow and cross ridge tillage significantly reduced nutrient loss, the cross ridge tillage was the more effective treatment because it had the most effect on runoff. With the growth of day lilies, the interception of nutrients carried by runoff of contour living hedgerow will increase.

Table 3 Total nutrient losses carried by runoff under different treatments

Tillage	Total phosphorus		Total nitrogen		Ammonia-nitrogen	
	Loss (kg km^{-2})	Interception efficiency (%)	Loss (kg km^{-2})	Interception efficiency (%)	Loss (kg km^{-2})	Interception efficiency (%)
Downslope ridge tillage	0.14	—	23.5	—	7.45	—
Downslope ridge tillage+contour living hedgerow	0.10	28.3	18.6	20.9	5.19	30.3
Cross ridge tillage	0.04	73.6	6.7	71.4	2.34	68.6

The loss of nutrients carried by sediment under these treatments is shown in Table 4. The loss of nutrients carried by sediment was less in downslope ridge tillage + contour living hedgerow plot and cross ridge tillage plot than in the downslope ridge tillage plot. As with nutrients in runoff, the losses of nutrients in sediment were much reduced by the contour living hedgerow and the cross ridge tillage. Among the two tillage practices, cross ridge tillage had a higher interception efficiency for total phosphorus, total nitrogen and organic matter(>85%); while the downslope ridge tillage + contour living hedgerow had a lower interception efficiency for nutrients carried by sediment, 44.4% – 56.7%, which reflected the greater sediment reduction effect of cross ridge tillage. With the growth of day lilies, the interception efficiency for nutrients carried by sediment of contour living hedgerow will increase.

Table 4 Total nutrient losses carried by sediment under different treatments

Tillage	Total phosphorus		Total nitrogen		Organic matter	
	Loss (kg km^{-2})	Interception efficiency (%)	Loss (kg km^{-2})	Interception efficiency (%)	Loss (kg km^{-2})	Interception efficiency (%)
Downslope ridge tillage	390.1	—	701.9	—	7,646	—
Downslope ridge tillage+ contour living hedgerow	217.1	44.4	304.2	56.7	3,471	54.6
Cross ridge tillage	53.9	86.2	90.6	87.1	1,074	86.0

In terms of the forms of nitrogen loss under the different treatments, the loss of nitrogen carried by sediment accounted for more than 94% of the total nitrogen loss, while the loss of nitrogen carried by runoff accounted for less than 6%, indicating that nitrogen loss caused by soil erosion and water loss in sloping farmland was mainly in the form of nitrogen carried by sediment. In terms of the forms of phosphorus loss, the loss of phosphorus carried by sediment under the different treatments all accounted for more than 99.9% of the total phosphorus loss, while the loss of phosphorus carried by runoff occupied was less than 0.1%, phosphorus loss caused by soil erosion and water loss on sloping land was mainly in the form of phosphorus carried by sediment (see Table 5). Therefore, the control and prevention of nitrogen and phosphorus loss using soil and water conservation measures should focus on sediment reduction.

Table 5 Nitrogen and phosphorus loss forms under different treatments

Tillage	Proportion of different forms of nitrogen in total nitrogen (%)		Total nitrogen (kg km^{-2})	Proportion of different forms of phosphorus in total phosphorus(%)		Total phosphorus (kg km^{-2})
	Nitrogen carried by runoff	Nitrogen carried by sediment		Phosphorus carried by runoff	Phosphorus carried by sediment	
Downslope ridge tillage	3.2	96.8	725.3	0.03	100.0	390.2
Downslope ridge tillage+ contour living hedgerow	5.8	94.3	322.8	0.05	100.0	217.2
Cross ridge tillage	3.2	96.8	97.4	0.07	99.9	53.9

3.3 *Treatment effect on soybean growth*

As shown in Table 6, the biomass of soybean roots, stems, leaves and fruits in the cross ridge tillage plot were greater than those in the downslope ridge tillage plot and downslope ridge tillage + contour living hedgerow plot. Total biomass of cross ridge tillage was 16.2% and 18.8% higher than that of the other two types of plots. Cross ridge tillage increased soybean production, mainly because the interception effect of ridges in cross ridge tillage plot not only reduced runoff velocity, but also directly intercepted and stored large amounts of runoff and sediment, increasing soil moisture and decreasing nutrient loss on ridges, resulting in the highest soybean biomass. In downslope ridge tillage + contour living hedgerow treatment, as hedgerows took up some area of farmland, soybean planting area was reduced. Meanwhile, in the early growth stage, hedgerows mainly played a role in intercepting runoff, and had a small impact on runoff volume and soil moisture on ridges. Thus, the biomasses of soybean roots, stems, leaves, fruits and the total biomass in downslope ridge tillage plot and downslope ridge tillage + contour living hedgerow plot were similar.

Table 6 Soybean biomass under different tillage practices

Tillage	Root mass (g)	Stem mass (g)	Leaf mass (g)	Fruit mass (g)	Total biomass(g)
Downslope ridge tillage	3,108	6,839	7,011	10,755	27,713
Downslope ridge tillage+ contour living hedgerow	3,449	6,122	6,727	10,572	26,870
Cross ridge tillage	3,707	8,194	8,714	12,473	33,087

According to Table 7, the effective pod number per plant, 100-seed dry weight, average plant height, and average basal stem of soybeans in the cross ridge tillage plot were all higher than those in downslope ridge tillage plot and downslope ridge tillage + contour living hedgerow plot, demonstrating that cross ridge tillage could, to an extent, promote soybean growth. This was because cross ridge tillage could effectively increase soil seepage and soil moisture of ridges through ridges intercepting runoff, therefore the soybeans grew better in cross ridge tillage plot. There were almost no significant differences between the effective pod numbers per plant, 100-seed dry weight, average plant heights, and average basal stem of soybeans in the downslope ridge tillage plot and the downslope ridge tillage + contour living hedgerow plot, likely because the hedgerow could only intercept runoff and slow runoff velocity, and exerted no significant influence on increasing soil moisture of ridges and on promoting soybean growth.

Table 7 Soybean growth index under different tillage practices

Tillage	Pods per plant	100-seed dry weight (g)	Plant height (cm)	Basal stem (mm)
Downslope ridge tillage	17.0	18.1	47.8	6.2
Downslope ridge tillage+ contour living hedgerow	17.6	18.5	49.1	6.2
Cross ridge tillage	18.0	19.6	51.5	6.7

4 Conclusion and suggestion

1) In terms of runoff and sediment yields, the analysis of experimental observations indicated that compared to downslope ridge tillage plot, runoff and sediment yields in the plot treated by cross ridge tillage were reduced by 68.9% and 85.7% respectively, while those in the plot treated by downslope ridge tillage + contour living hedgerow were reduced by 24.3% and 52.8% respectively. Therefore, on gentle slopes, microtopography reconstruction by adopting cross ridge tillage treatment and contour living hedgerow treatment can, to an extent, reduce runoff and sediment yields.

2) In respect of nutrient output, the analysis showed that compared with downslope ridge tillage, the interception efficiencies for nutrient carried by runoff and sediment were above 68% and 85% respectively in cross ridge tillage plot, while those were 20.9% – 30.3% and 44.4% – 56.7% respectively in downslope ridge tillage + contour living hedgerow plot. Hence, on gentle slopes, microtopography reconstruction by adopting cross ridge tillage treatment and contour living hedgerow treatment can reduce nutrient loss.

3) For soybean growth, cross ridge tillage increased soybean growth and production; there was no significant difference in soybean growth and production between downslope ridge tillage and downslope ridge tillage + contour living hedgerow.

As only a small number of heavy rainfalls made greater contributions to soil and water loss and nutrient loss, the crops whose harvest and planting times are not in a period of heavy rainfalls should be selected to avoid causing serious soil erosion and water loss when developing sloping farmland. Overall, the cross ridge tillage had greater effects on reducing soil erosion and water loss and nutrient loss, and promoting soybean growth on slope farmland of red soil than the contour living hedgerow. However, because this experimental cycle was relatively short, the impacts of living hedgerow on soil, water and nutrient loss and crop production in developing slope land of red soil needs further observation and in-depth study.

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