Impact of Different Contour Hedgerows on Runoff, Nutrient and Soil on Sloping Farmland in Danjiangkou Reservoir Region of China

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Abstract Soil and water loss has been a major environmental problem in the Danjiangkou Reservoir Region. A study of 14° sloping farmland was performed on impact of different contour hedgerows on runoff, losses of soil and nutrients during 2008 and 2011, with five treatments and three replications. The winter wheat and summer maize were used as the test crops. Treatments consisted of four hedgerows: Amorpha (*Amorpha fruticosa* L.), Honeysuckle (*Lonicera japonica* Thunb.), Day-lily flower (*Hemerocallis citrina* Baroni.), and Sabaigrass (*Eulaliopsis binata*), and a control without hedgerow. Result showed that the runoff under the control treatment was much higher than that of hedgerows. Amorpha could reduce the runoff by 35.2% compared with the control. Soil losses in four hedgerows showed significant reduction in four years (*e.g.*, Amorpha: 78.3%; Honeysuckle: 77.1%). Nutrient losses in winter were much higher than that in summer, especially total nitrogen, total phosphorus and total potassium, even though there was an abundant precipitation in summer. Hedgerows greatly affected the soil and nutrient losses on slopping farmland compared with the control treatment, especially Amorpha treatment. The present study found that the Amorpha could be used as the hedgerow species for reducing soil and water loss in the Danjiangkou Reservoir Region.

Key words Contour hedgerow, Soil and water loss, Nutrient loss, Sloping farmland, Danjiangkou Reservoir Region

1 Introduction

Soil loss, defined as the detachment and dislocation of soil particles and soil parent material from the surface to another site[1-2], is a main reason for soil degradation[3]. The consequences of soil loss in terms of fertility degradation, sedimentation, and changes in hydrological regime in downstream areas, have been national and global concerns[4-6]. And degradation is particularly severe in regions with sloping and hilly terrains, agricultural activities have been expanded and intensified on fragile and sloppy areas through double and multiple cropping due to the pressure of population increasing and limited off-farm employment opportunities[7]. Apart from anthropogenic factors, many inherent natural factors such as active geology, steepness, fragility, and high intensity rainfall are also equally responsible for soil degradation[8].

In China, nearly one third of the land is affected by soil and water losses[9-10]. According to the national soil survey in 1981, soil erosion area of agricultural land was 4.54×10^7 ha in China, which is one of the most serious countries in the worldwide; and the soil erosion mainly occurs in the slope land[11]. In the Three Gorges Region, it has been reported that the annual soil loss from sloping farmland was approximately 157 million t, 46.2% of which comes from cultivated sloping farmland[12].

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Sloping croplands are the main sources of runoff and sediments, and the soil and water loss should be adequately controlled on these sloping croplands, many studies are concentrated on measures to reduce the runoff and soil losses.

Contour hedgerow, known as active hedge, is to plant trees or shrubs closely and horizontally along contour line on the slope land, to use to prevent soil and water losses from sloping croplands in several countries and regions[13-16], also could improve soil fertility and increase crop yields[17]. Surface flow from sloping farmland with contour hedgerows was potentially reduced by 26% - 60% and soil loss by more than 97% in the Jinsha Basin[2]. And the combination hedgerows and grass filter strips could reduce runoff by 33% and soil loss by 35%, compared with the control, on 2% - 5% slope; and increase the SOC stock by 0.38 - 1.00 mg/ha[18]. Obviously, hedgerows play an effective role on soil conservation on sloping farmlands.

Danjiangkou Reservoir, the largest artificial reservoir in Asia, is the core water region for the South-to-North Water Diversion Project, due to abundant rainfall and erosive topographic conditions, tremendous soil and water loss occurs during summer storms. According to the remote sensing survey of Yangtze River basin Conservation Monitoring Center in 2004, billion tons of soil was eroded in the reservoir region, with 65% coming from slope lands. As a result, soil erosion becomes a serious challenge for agricultural sustainable development and environment protection in reservoir region. Effects of hedgerows on improvement of soil physical properties[19-22], soil and water conservation[4,20,23], soil fertility improvement[15,24-25] and control of non-point source pollution [11,26-27] had been widely studied in the world, and particularly some studies have focused on its influence on micro-topographic features[28] and the shape change of slope[29-30].

Although contour hedgerows have been proven to be an effective means for addressing soil erosion and ameliorating soil fertility in many countries, direct transplantation of foreign experiences to the Danjiangkou Reservoir Region may not generate desired results because it is necessary to attune appropriate hedgerow spices to fit local geographical and socio-economic conditions. The objectives of this study were to determine the effectiveness of hedges of Amorpha, Honeysuckle, Day-lily flower, and Sabaigrass on the soil and water losses and nutrients losses in runoff, to select the fitting hedgerow species for sloping farmland in Danjiangkou Reservoir Region, and try to analyze the reasons for nutrients loss worse in winter.

2 Materials and methods

2.1 General description of the experiment site The experiment site was constructed at Xiaofuling Village (32°45′31″ N, 111°09′27″ E), Danjiangkou County, Hubei Province, is a small village locatThe experiment site was constructed at Xiaofuling Village (32°45′31″ N, 111°09′27″ E), Danjiangkou County, Hubei Province, is a small village located at about 4 km northwest of the Danjiangkou Reservoir Region. This site is characterized by a subtropical monsoon climate with the mean annual temperature of 15.8 ℃. The mean annual rainfall is 804 mm, of which over 49% mainly occurs in the period of July to September. Mountain yellow-brown soil dominates this area, usually 20 – 30 cm in depth with relatively light texture and poor soil fertility. The physical and chemical properties of the experimental field: pH: 6.3; soil organic matter (SOM): 13.31 g/kg; total phosphorus (TP): 0.12 g/kg; total potassium (TK): 9.29 g/kg; available nitrogen (AN): 48.49 g/kg; available phosphorus (AP): 10.51 g/kg; available potassium (AK): 136.61 g/kg.

2.2 Experimental plot design and land treatment Runoff plots (3 m × 11 m) were established on an-on sloping farmland of 14° Xiaofuling Village in June 2007. Conflux trenches were installed into the topsoil to collect the overland flow. And runoff tanks (1 m × 1 m × 1 m) were installed under the conflux trenches to collect the runoff and eroded soil after rainstorms (Fig. 1).

Four contour hedgerow treatments were studied: Amorpha: *Amorpha fruticosa* L. (T_2), Honeysuckle: *Lonicera japonica* Thunb. (T_3), Day-lily flower: *Hemerocallis citrina Baroni*. (T_4), and Sabaigrass: *Eulaliopsis binata* (T_5). Each treatment had three runoff plots. In these plots, two strips of hedgerow were spaced 4.5 m apart in the contour and crops grew between them (Fig. 1). The width of the hedgerow belt was 1 m and the hedge crops were planted in two rows with 0.3 m spacing (Fig. 1). The rest of three runoff plots with no species in the hedge (conventionally equivalent to continuous cropping) acted as control in this experiment (CK). And all treatment plots were randomized.

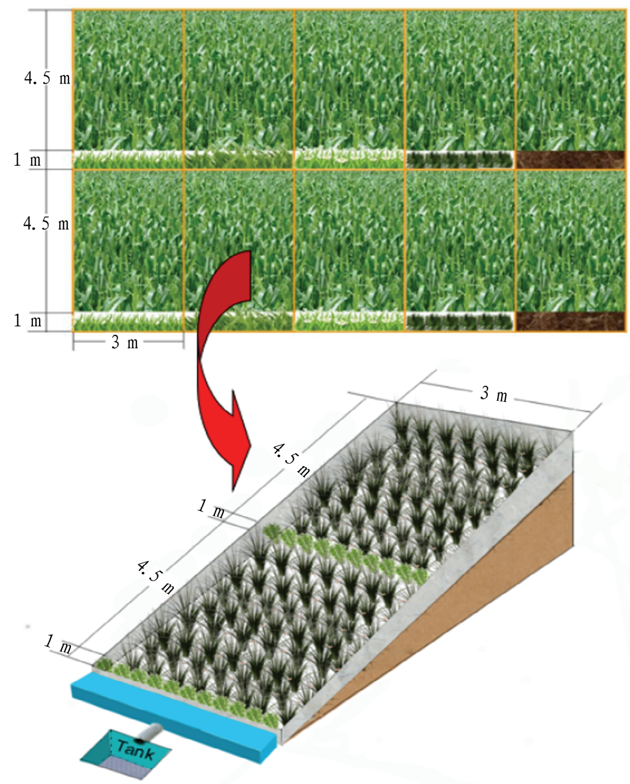

Fig. 1 Treatment layout of the field experiment

The hedges were transplanted in June 2007. In June of each year, all hedges were clipped to the height of 0.5 m by hand shears. All grass clippings and cut stems were removed from the plots. In August, the hedges were trimmed again after they had grown to heights averaging from 0.9 m to 1.4 m. Winter wheat (*Triticum aestivum*) was grown between middle October and early May, and summer maize (*Zea mays*) was grown between late May and early October, which were identical to local patterns of crop production. Table 1 shows the description of crops tested and nutrients applied used for different crops.

Table 1 Description of test crop and nutrient application

Test crop	Sowing date	Sowing rate//kg/ha	Fertilizer amount//kg/ha		
			Urea	Calcium super phosphate	Potassium chloride
Winter wheat	Mid October	150	187.5	375	112.5
Summer maize	Late May	45	262.5	375	75.0

2.3 Runoff and sediment measurements Runoff and sediments from each plot began to collect from October 2008, after each individual rainstorm whenever runoff was observed in runoff tanks. Then the amounts of the runoff and sediments were recorded. To determinate the amount of eroded soil, the runoff was first carefully mixed with the sediment that had settled in the bottom of tank to produce relatively homogeneous slurry. One slurry sample with a value of 500 mL was collected at each runoff tank. The composite sample was divided into two parts. One part was used to measure the sediment content by filter paper. The amount of sediment was equal to the runoff volume multiplied by the sediment concentration measured. The second part was filtered through a wetted Millipore filter paper (0.45 μm). The filtrate was preserved with 4 M H_2SO_4 at 4 ℃ and later used for chemical analysis[31].

2.4 Statistical analysis The analysis of variance (ANOVA) was performed by SPSS 13.0 (SPSS Inc., Chicago, US). Two-way ANOVA and Fisher's protected LSD test were used to compare the mean difference ($P<0.05$) of runoff, soil loss and nutrient loss by runoff in each crop growing season among the treatments and years. Standard deviation of the means was calculated using Microsoft Excel 2010 software.

3 Results

3.1 Effects of hedgerows on soil and water loss Runoff was significantly influenced by precipitation and hedgerow treatments. In Danjiangkou Reservoir Region, there was an abundant precipitation in summer during the study period, so the runoff in growth season of maize was higher than that of wheat (Table 2). In growth season of wheat, runoff was decreased year by year. However, in maize growth season, the runoff in all treatment plots in 2011 was higher than that in 2010 due to an extremely high rainfall event occurring (Fig.2). There was a significantly difference in the runoff among each treatment. Runoff in the control plot was significantly ($P<0.05$) higher than that in hedgerow plots. In 2008, at the beginning of the trial, treatments with hedgerow reduced runoff by 20.3% – 42.6% compared with the control. Over 4-year passed, T_2 and T_3 always played an effective role in reducing runoff.

Table 2 Total runoff of each hedgerow treatment in different crop season (m^3/ha)

Treatment	Wheat growth season			Maize growth season		
	2008	2009	2010	2008	2009	2010
CK	12.3 ±0.9 a	8.9 ±2.6 a	3.7 ±2.1 a	27.7 ±1.3 a	11.7 ±2.4 a	14.6 ±1.1 a
T_2	7.0 ±1.0 d	6.2 ±0.8 b	2.0 ±0.6 b	17.9 ±0.6 b	8.6 ±1.0 b	7.7 ±1.6 b
T_3	8.9 ±1.0 c	5.7 ±0.9 b	2.3 ±2.4 b	17.4 ±2.2 b	9.2 ±0.6 c	9.8 ±0.5 bc
T_4	9.1 ±0.9 c	7.4 ±2.3c	2.9 ±1.9 c	20.5 ±1.8 c	9.8 ±2.6 c	10.7 ±2.7 c
T_5	10.0 ±1.0 c	6.3 ±0.2 c	2.6 ±3.2 c	23.7 ±2.1 c	9.5 ±1.5 c	10.8 ±1.2 a

Note: Values are means ± standard deviation, $n=3$. For each column, means followed by different letters indicate significant difference based on Fisher's protected *LSD* test ($P=0.05$).

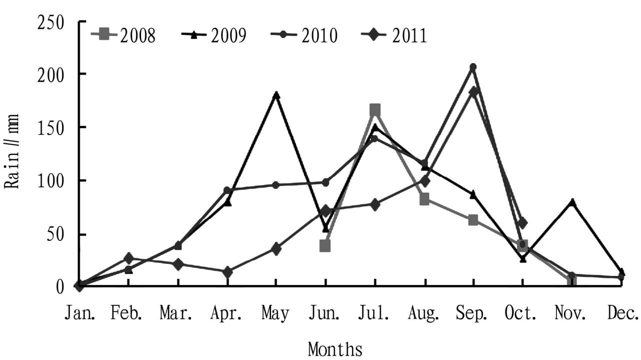

Fig. 2 Monthly rainfall pattern in Danjiangkou location during study period

Hedgerows were more significantly ($P<0.05$) effective at intercepting sediment erosion compared with the control (Table 3). Soil sediment erosion in the control plot was 2 to 6 times of that in hedgerow plots in the maize growing season. Soil losses in T_4 and T_5 plots were 2.5 to 3 times of that in T_2 and T_3 plots in the maize growing season in 2010 and 2011. Average cumulative soil loss over 6 cropping season, T_2 was much more effective on intercept soil losses, up to 78.4%, the second was T_3 to 77.2%, compared with the control.

3.2 Effects of hedgerows on the nutrient loss Hedgerows on slope lands act as a physical barrier and filter strips to hold up water and soil during the maize seasons, all hedgerow treatments significantly reduced the losses of SN, TN, TP, PO_4^{3-} and NH_4-N compared with control treatment (Table 4). And the interception of different hedgerow treatments on the nutrient losses was different. The SN loss of T_2 was around half of T_4 and T_5, which was significantly lower than that of T_4 and T_5 ($P<0.05$) (Table 4). The SP loss of T_2 was significantly lower than the T_3 and T_5 ($P<0.05$). And the PO_4^{3-} and NH_4-N loss of T_2 was significantly lower than other hedgerow treatments. The difference of nutrient losses between T_4 and T_5 was not significant. There was a significant difference in the NO_3-N and TK loss among the treatments and years. The NO_3-N loss in the first experiment year was 50% – 90% higher than the second and third experiment year. But there was no significant difference in the NO_3-N loss between the second and the third experiment year. The highest of NO_3-N loss was observed in CK, and the lowest was observed in T_2. The TK loss in the third experiment year was slightly higher than that in the first year. The highest of TK loss was observed in CK, and the lowest was observed in T_3.

Over the 3-year's study, hedgerow treatments significantly reduced all nutrient losses except TN in the wheat growing season (Table 5). And the effects of different hedgerow treatment on the nutrient losses were significant different ($P<0.05$). Compared with T_3, T_4 and T_5, T_2 was more efficient in reducing the TP and PO_4^{3-} loss (Table 5).

In total nutrient losses, except NH_4-N, the others in the wheat growing season were higher than that in maize growing season (Table 6). In the maize season, there was significant difference ($P<0.05$) in all nutrient losses between control and hedgerows, except phosphorus; while in the wheat season, there was significant difference ($P<0.05$) just in orthophosphate, nitrate nitrogen and ammonium nitrogen loss between control and hedgerows. We found that the volume of runoff was not the only factor influenced runoff nutrient loss, but the nutrient concentration in runoff was an important factor.

Table 3 Sediment erosion of hedge plants in different crop season (kg/ha)

Treatment	Wheat growth season			Maize growth season		
	2008	2009	2010	2008	2009	2010
CK	31.4 ±2.1 a	19.3 ±2.0 a	10.3 ±1.9 a	134.6 ±2.0 a	223.6 ±2.1 a	116.1 ±1.6 a
T_2	25.5 ±2.9 b	7.3 ±1.0 b	1.5 ±0.2 b	30.5 ±1.0 b	40.6 ±2.6 b	16.8 ±0.5 b
T_3	27.5 ±0.9 b	9.3 ±2.0 b	2.3 ±1.0 b	36.1 ±0.8 b	40.4 ±1.5 b	16.1 ±1.2 b
T_4	19.5 ±1.0 c	10.4 ±0.9 b	3.3 ±1.9 b	46.5 ±2.0 c	106.6 ±1.9 c	30.1 ±0.5 c
T_5	26.5 ±2.1 b	17.3 ±2.2 a	3.1b ±0.7c	68.2 ±1.1 a	111.6 ±1.1 c	39.8 ±0.4 c

Note: The same as in Table 2.

Table 4 Loss of soil nutrients (10^2 kg/ha/yr) under different treatments in maize season (mean of observations in 2009 –2011)

Treatment	SN	TN	SP	TP	PO_4^{3-}	NH_4-N	NO_3-N	TK
CK	15.12 ±0.09 a	13.38 ±0.09 a	4.02 ±0.03 a	2.42 ±0.04 a	1.70 ±0.02 a	5.60 ±0.02 a	9.22 ±0.03	58.36 ±0.62
T_2	5.53 ±0.09 b	6.72 ±0.10 b	1.33 ±0.04 b	0.83 ±0.03 b	0.46 ±0.02 b	2.09 ±0.02 b	3.78 ±0.03	14.20 ±0.63
T_3	9.09 ±0.08 c	8.50 ±0.09 b	1.58 ±0.04 c	1.70 ±0.03 b	0.82 ±0.01 c	2.60 ±0.03 b	6.01 ±0.02	30.26 ±0.62
T_4	9.37 ±0.10 bc	8.49 ±0.10 c	2.12 ±0.04 a	1.13 ±0.04 c	0.43 ±0.02 d	3.12 ±0.02 c	4.83 ±0.03	18.88 ±0.62
T_5	10.42 ±0.10 c	9.62 ±0.10 c	2.01 ±0.03 c	1.33 ±0.04 c	1.42 ±0.02 d	3.20 ±0.02 c	6.52 ±0.04	22.67 ±0.63

Note: Means within a column for the treatment with different letHYPERLINK "C:\Users\PC\Downloads\are" 5% level. CHYPERLINK "C:\Users\PC\Downloads\without"3: Honeysuckle; T_4: Day-lily flower; T_5: Sabaigrass; NO_3-N: nitrate nitrogen, NH_4-N: ammonium nitrogen, SN: solute-nitrogen, SP: solute-phosphorus, PO_4^{3-}: orthophosphate. The same in Table 5 –6.

Table 5 Loss of soil nutrients (10^2 kg/ha/yr) under different treatments in wheat season (mean of observations in 2009 –2011)

Treatment	SN	TN	SP	TP	PO_4^{3-}	NH_4-N	NO_3-N	TK
CK	19.71 ±0.11 a	16.17 ±0.10 a	6.04 ±0.03	5.78 ±0.03 a	3.43 ±0.02 a	2.47 ±0.02 a	3.75 ±0.03 a	93.43 ±0.63
T_2	11.21 ±0.11 b	8.70 ±0.10 a	1.19 ±0.04	2.16 ±0.03 b	0.72 ±0.02 b	1.14 ±0.02 b	1.48 ±0.02 b	40.01 ±0.47
T_3	16.53 ±0.11 b	13.08 ±0.10 a	3.62 ±0.04	4.80 ±0.04 bc	1.54 ±0.02 b	1.59 ±0.01 b	2.60 ±0.03 b	47.47 ±0.45
T_4	17.19 ±0.10 b	13.91 ±0.09 a	4.04 ±0.03	4.43 ±0.04 bc	2.08 ±0.0 1b	1.74 ±0.02 a	3.04 ±0.03 a	42.14 ±0.40
T_5	18.08 ±0.09 a	17.02 ±0.08 a	3.64 ±0.04	4.57 ±0.04 a	1.9 ±0.02 a	1.76 ±0.02 a	3.03 ±0.02 a	51.40 ±0.37

Table 6 Loss of total soil nutrients (10^2 kg/ha/yr) under different treatments in the maize and wheat season in 2009 –2011

	Treatment	SN	TN	SP	TP	PO_4^{3-}	NH_4-N	NO_3-N	TK
Maize	CK	45.3 ±0.04 a	40.1 ±0.03 a	12.0 ±0.01 a	7.1 ±0.01 a	5.2 ±0.01 a	16.9 ±0.02 a	27.6 ±0.02 a	175.4 ±0.13 a
	T_2	16.6 ±0.03 b	20.0 ±0.04 b	3.9 ±0.02 b	2.5 ±0.01 a	1.6 ±0.02 a	6.2 ±0.03 b	11.3 ±0.02 b	42.1 ±0.12 b
	T_3	27.4 ±0.04 b	25.4 ±0.03 b	7.1 ±0.01 b	5.1 ±0.01 a	4.1 ±0.02 a	7.7 ±0.03 b	17.9 ±0.02 b	91.7 ±0.13 b
	T_4	28.1 ±0.02 c	25.4 ±0.4 b	6.3 ±0.01 b	3.2 ±0.02 a	1.3 ±0.01 a	9.4 ±0.03 b	14.3 ±0.02 b	56.7 ±0.12 b
	T_5	31.1 ±0.30 c	28.9 ±0.03 b	4.7 ±0.01 b	4.0 ±0.02 a	1.3 ±0.02 a	9.5 ±0.03 b	19.6 ±0.03 b	68.2 ±0.12 b
Wheat	CK	59.2 ±0.07 a	48.7 ±0.06 a	18.1 ±0.03 a	17.3 ±0.03 a	10.2 ±0.01 a	7.6 ±0.01 a	11.4 ±0.01 a	280.3 ±0.58 a
	T_2	33.7 ±0.06 a	26.1 ±0.05 a	3.5 ±0.04 a	6.1 ±0.02 a	2.0 ±0.01 b	3.3 ±0.02 b	4.5 ±0.01 b	120.2 ±0.58 a
	T_3	49.6 ±0.07 a	39.3 ±0.06 a	10.7 ±0.03 a	14.3 ±0.03 a	4.4 ±0.02 b	4.7 ±0.02 b	7.9 ±0.01 b	142.4 ±0.57 a
	T_4	51.5 ±0.06 a	41.8 ±0.06 a	12.1 ±0.04 a	13.3 ±0.02 a	6.3 ±0.02 b	5.2 ±0.02 b	8.9 ±0.01 b	126.3 ±0.58 a
	T_5	54.2 ±0.07 a	50.9 ±0.05 a	10.7 ±0.04 a	13.7 ±0.02 a	5.6 ±0.01 b	5.3 ±0.01 b	9.1 ±0.02 b	154.2 ±0.57 a

4 Discussions

The results from this study were used to reveal the impact of different contour hedgerows on control of nutrient, soil and water loss on slope land in Danjiangkou Reservoir Region. Results showed that hedgerows could notably reduce soil erosion and runoff soon after their establishment. The ridges built by hedgerows could reduce the slope steepness, and form natural terraces on sloping lands. Hedgerow treatments could effectively reduce soil nutrient losses. Results and findings of this paper will contribute towards a technical reference for the promotion and adoption of hedgerows in the Danjiangkou Reservoir Region.

4.1 Soil losses Study showed that surface runoff happened in the place with low water permeability or high soil moisture firstly. Surface runoff area depended on the comprehensive results of the rainfall characteristics, the surface characteristic and some other aspects [32 –33]. Studies on the relationship between rainfall and runoff had been reported by many researchers[2,34 –35]. These relationships had been consistently described as having a linear correlation. In Danjiangkou Reservoir Region, an abundant precipitation in summer, so the runoff in growth season of maize was higher than that of wheat.

This study showed that hedgerows played an effective role on soil conservation as reported in other studies [2,15,36-37]. Especially Amorpha and Honeysuckle played an efficacious role on soil conservation. This could be explained that hedgerows acted as a buffer strips to slow down the speed of runoff and as a filter to make water permeated, so they could reduce surface flow. More sediments in the treatments with hedgerows was infiltrated in soil[38-39] due to the hedgerows acted as permeable barriers for slowing down runoff [35]. The control of runoff and soil losses was not only affected by the presence of hedges but also by an improved crop performance to protect the soil from rainfall splash and erosion [40].

4.2 Nutrient losses Except T_5, the hedgerow treatments significantly reduced the nutrient losses compared with control treatment during both maize and wheat growing season (Table 4-5). The smallest nutrient losses were generally observed in T_2. This probably because Amorpha has an extensive root system, it can prevent water and soil losses, thus reducing the nutrient losses.

The NO_3-N loss during the maize growing season was higher in the first experiment year than that in the second and third year. The counter hedgerow had not built up the effective interception system, and the NO_3-N was easily lost with the runoff.

The TN and TP losses in the wheat growing season were higher than that in the maize growing season. This might because that vegetative cover is less in winter, at the beginning of rainfall, surface soil is dry, loose, and susceptible to splashing and erosion. This results in relatively large sediment losses at the initiation of runoff and the ability of plant stems and leaves intercept raindrops is lower, canopy had a low buffering power; finally, absorption of plant roots is also feeble, microorganism lives were rarely. The raindrops touch down the bare soil, along large power erosion and splashing, leading to a large number of runoff and soil loss, and nutrient losses. Therefore, in winter, it is recommended to adapt to local evergreen hedgerows were planted, increase the area of vegetative cover to protect soil losses, reduce the nutrient loss on sloping farmland and alleviate the agricultural non-point source pollution in downstream. In summer, the runoff water reaching a hedgerows buffer strip flows over a rougher and more porous surface, causing it to slow down and infiltrate into the soil, furthermore, hedgerows and crops cover area are much more than that of in winter, so the nutrient losses are less than that of in winter.

5 Conclusions

Contour hedgerows could enhance the efficiency of soil conservation, thereby reducing runoff and intercepting sediment, realizing a lower nutrient loss by runoff on sloping farmland. (i) Among the four hedgerow treatments, *Amorpha fruticosa* L. and *Lonicera japonica* Thunb. are the most effective on water and soil conservation. (ii) Nitrogen and phosphorus losses in winter are larger than that of in summer. Potassium loss is much larger than other nutrients over 3-year study.

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