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VEGETATION RECONSTRUCTION IN UPLAND AND RAVINE REGIONS OF LOESS PLATEAU IN NORTHERN SHAANXI, CHINA

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Abstract

Arid regions of China such as upland and ravine regions of Loess Plateau in northern Shaanxi Province suffer severe degradation of vegetation, soil and water erosion, and desertification due to the fragility of the natural conditions. The efficient engineering managements in sloping fields and intercropping system of forest and grass have been proved to be important measures to reduce losses of soil and water and reconstruct vegetation in these regions. The slope separated terrace, large terraced field and large scale fish pit patterns in sloping fields were efficient in rainwater conservation and soil water content. The large terraced field + *Humulus scandens* + non timber product forest was the best conservation pattern in sloping fields with gradient from 15° to 20°, and a vegetation coverage of 47.2% was achieved at the same year and 75.9% after four years and soil erosion was 34.30% lower than control. As for sloping fields with gradient from 20° to 25°, slope separated terrace + *Humulus scandens* + arbor ecological forest was the optimum conservation pattern, which led to a vegetation coverage of 33.9% to 49.4% and 34. 30% decrease of soil erosion compared to control. All these measures reduced the effect of rain splash erosion on loose top soil, enhance soil water content, increase vegetation coverage, and promote the formation of the stable harmonious community of forest and grass in upland and ravine regions of Loess Plateau in northern Shaanxi of China.

Introduction

Upland and ravine regions of Loess Plateau have been suffering more and more serious degradation of vegetation, soil and water erosion, and desertification due to the fragility of the natural conditions. The loss of topsoil is about 21 billion tons per year, of which 16 billion tons flow into the Yellow Rive resulting in the riverbed increase and reservoir sedimentation, and serious threat to the ecological safety of the Yellow River Basin (Zhang *et al.*, 2007). For this reason, many studies have been carried out to find out optimal measures to solve this problem. For example, Wang *et al*., (1991) pointed out that the slope length and rainfall were the main factors of the sand loss in sloping field of Loess Plateau. However, the better vegetation cover could reduce the erosion process. Hu *et al*., (2004) proposed the configuration scheme and evaluation criteria of tree species in artificial arbor forests to feed the basis to evaluate erosion reduction of slope vegetation. To enhance the vegetation coverage in the slope field trees and grass plantation was an effective measure to reduce soil erosion and prevent ecological environment from deteriorating further (Cheng, 2001). Different tree species held different water consumption volume and pattern, which affected the status of soil moisture (Dobson *et al.*, 1997). Secondly, the optimized patterns of forest-grass intercropping system was put forward to reduce the degradation of vegetation, soil and water erosion, prevent slope soil erosion. Liu *et al.*, (2001) pointed out that on consideration of the site conditions and the characteristics of plant growth, the suitable models of trees and grass intercropping could establish a stable vegetation communities and reduce soil erosion. The planting grass could effectively prevent soil erosion, improve micro-topography (Daniels & Gilliam, 1996; Aase & Pikul, 1995); Gilley (2000) and Eghab *et al*., (2000) stated that Perennial herbs could significantly slow down the sloping land soil erosion.

To further explore the optimal environmental factors to improve soil moisture in the sloping fields, the main engineering managements of sloping fields in these regions need to study further to provide theoretical basis for vegetation restoration. Farmland with different engineering control measures and the optimized combination grass were also studied.

Materials and Methods

Natural conditions in experimental area: Experiments were conducted in Zhiyuan Hill area in Mizhi County of Shaanxi Province. It is a typical hilly and gully landform, arid area in north temperate and temperate forest steppe zones with slope area of 10 hm^2, slope anger of 20° to 25°, altitude of around 1000 m, average annual rainfall of about 400 mm and annual average temperature of 8.8℃, absolute highest temperature of 38℃, absolute lowest temperature of -35℃, without frost period of 160 days per year and aridity degree of 1.14 in Loess Plateau. The sum of rainfall in July, August and September occupied 70% of total annual rainfall. The soil is a typical loess soil with homogeneous and good aeration properties. Poor slope vegetation i.e., 20% coverage always induces the severe soil erosion.

Experiment design-I: A sloping field was selected with gradient from 15° to 20° in the test area with 5 hm^2area. The following engineering managements of sloping fields were carried out in winter of 2007: I-large terraced field (straight ridge terrace); II-slope-separated terrace; III-large fish-scale pit (Fig. 1). In each treatment, the same intercropping pattern of forest and grass was conducted. Large terraced field was the wide terraces with 2-3m width and different length; Slope-separated terrace was inter-pattern of 2-3 m interval of natural slope and a reversed slope terrace from bottom to top with 1-1.5 m width and different length; large fish-scale pit was a digged pit with 1m diameter, layout of "品" form at each 2-3m interval. Trees and grass were planted in each treatment area in spring of 2008. The main plant species was *Robinia pseudoacacia* (locust) with uniform size and planting density of 2m×2m, witch were intercropped *Medicago sativa* (alfalfa) *Agropyron cristatum* (wheatgrass), *Rumex acetosa* (Rumex). The experimental plot area was 200 m^2 with 3 replicates at random arrangement. The natural *Robinia pseudoacacia* planted in slope land was treated as the control.

Experiment design-II: The slope farmland was divided into the three types i.e. 15°-20° sloping field, 20°-25° sloping field, and beyond 25° according to the natural slope. The engineering managements of sloping fields were same as Experiment design-II**.** The main forest and grass species were *Armeniaca vulgaris* (apricot), *Juglans regia* (walnut), *Robinia pseudoacacia* (locust), *Hippophae rhamnoides sinensis* (sea-buckthorn) and *Humlus scandens* 、 *Medicago sativa* (alfalfa), *Agropyron cristatum* (wheatgrass). The three treatments groups were as following: group-I -15°-20° large terraced field: (1) Locust + *Humulus;* (2) Apricot + *Medicago*; (3) forest + *Agropyron*; group-II -20°-25° slope-separated terrace: (1) *Robinia* + *Humulus;* (2) *Robinia* + *Medicago* ; (3) *Robinia* + *Agropyron*; group-I-beyond 25° large fish-scale pit: (1) *Hippophae* + *Humulus;* (2) *Hippophae* + *Medicago*; (3) *Hippophae* + *Agropyron.* The natural forest in waste slope land was treated as control treatment.

Fig. 1. Three engineering managements of sloping fields in this study.

Measurements and calculations: The 100 m^2 vegetation plot was selected for each treatment using random sampling method to study the soil moisture loss due to the destruction of vegetation after the above engineering managements. Measurement of water loss at terraced ridge was done by each 20 cm to analyze vegetation growth and water use efficiency. The water content in different soil layers of each treatment was measured using Time Domain Reflectometry (TDR) in each November when rainy season ended and plants stopped growth. Vegetation coverage was measured using straightedge measurement for square sampling plot. Ten trees were randomly sampled for each treatment to measure vertical projection area of tree using straightedge measurement.

Statistical analysis: Each value presents the mean ± S.E. of three years (2008-2010).The data for all parameters were analyzed statistically using the SAS software package (SAS Institute Inc., Cary, NC, USA, 1996). The analysis of variance (ANOVA) was followed by the least significance test (LSD) to determine the significance of the means at the 0.05 level.

Results and discussion

Effects of management models in slopping fields on of rainwater storage ability and dynamic changes of soil moisture in 0-60 cm soil layer: Rainfall is the only resource of soil reservoir in sloping fields in Loess Plateau. The soil moisture is determined by rainwater infiltrations, soil evaporation and plant transpiration, which is dependent on the growth status of plants during their growing period (Li & Zhang, 2003). This may also directly affect increase of vegetation coverage (Zhang, 2007). In experiment design-I, we found that the absorbance ability of rainwater in soil of each treatment was quite different due to different management models in sloping fields. In order to measure the capacity of rainfall storage, soil moisture content of each soil layer was respectively measured by using TDR at random sampling method on the 5th day after rainfall of 50-60 mm one time in summer (Table 1). Treatments-I, II and III both had better capacity to absorb rainfall in soil in different soil layers (%) in experiment design-I. As compared with control, soil moisture contents in treatments-I, II and III were respectively increased by 20.0%, 19.4% and 7.2% only in 0-50 cm soil layer. The intercropping models of Locust + Rumex and Locust + Wheatgrass had better rainwater storage ability as compared with Locust + Alfalfa in treatments-I, II and III.

The measurement of soil moisture content of each treatment in experiment design-II are shown in Table 2. All engineering measures had a significant impact on soil moisture content in sloping fields. After each raining, the soil moisture content in each treatment group in 0-50 cm soil layer increased above control groups. Soil moisture contents in groups-I, II and III were greater averagely by 14.0%, 10.4% and 9.7% than control group respectively. These results suggested that the engineering measures are beneficial for collecting runoff and mandatory infiltration. The ability to collect rainfall was in order of group I> group II> group III> control group. Wang (1995) pointed out that the soil depth of around 50 cm held high plant root activity, such the engineering measures had an important role in plant growth in slope fields. Additionally, different grass configuration models caused differences in soil moisture contents in slope fields. In the treatment groups-I and II, soil moisture contents of intercropping of *Humulus* and each tree species in 0 to 100 cm soil layer were greater than other combinations treatments. In the slope field of 25°, intercropping of *Humulus* and each tree species could effectively reduce evaporation and promote plant growth. Thirdly, in each treatment, alfalfa and tree species combinations led to decrease in soil moisture content significantly, whose moisture content was less than control group. Such, the intercropping models between alfalfa and each tree species consumed a large amount of water, which were not suitable to planting in these area. In group Ⅲ, the combination of wheatgrass and each tree species had better responses than the combination of *Humulus* and each tree species. In the soil depth of 50 to 100 cm, soil water content changed little and higher than control group by over 9.0%. These results showed that wheatgrass is a shallow root plant, and absorbs less soil water below 50 cm soil depth. The covering of stems and leaves on the ground can reduce evaporation and improve soil moisture status.

Table 1. Effects of management models in slopping fields on absorbance ability of rainwater in soil in different soil layers (%) in experiment design-I.

Treatment		0~50 cm layer	50~100 cm layer	100~150 cm layer
	Locust + Rumex	7.2 a	6.2 a	6.0 a
I-Large terraced field	Locust + Alfalfa	7.1 a	5.9 a	5.9 a
	Locust + Wheatgrass	7.2 a	6.1 a	6.0 a
	Locust + Rumex	7.3 a	6.3 a	6.0 a
II-Slope-separated terrace	Locust + Alfalfa	7.1 a	6.0 a	5.9 a
	Locust + Wheatgrass	7.2 a	6.2 a	6.1 a
	Locust + Rumex	6.5 b	6.1 a	6.0 a
III-Large fish-scale pits	Locust + Alfalfa	6.3 bc	5.7 a	5.7 a
	Locust + Wheatgrass	6.5 b	6.0 a	5.9 a
Waste sloping field (control)	Locust	6.0 c	5.7 a	5.5 a

Different letters in the same column, indicate significant differences for each parameter determined among treatments. Mean values with the same letter within variables are not significantly different at the 0.05 level. The same as following tables

Table 2. Effects of management models in sloping fields on absorbance ability of rainwater in experiment design-II.

Treatment		0~50cm layer	50~100cm layer	100~150 cm layer
	Locust + *Humulus*	7.63 a	6.45 b	5.67 b
I-Large terraced field	Apricot +Alfalfa	7.36 ab	5.73 d	4.85 e
	Apricot + wheatgrass	7.57 a	6.89 a	5.91 a
	Control (Apricot in waste slope land)	6.53 cd	6.69 ab	5.83 ab
II-Slope-separated terrace	Locust + *Humulus*	6.91 c	6.05 c	5.73 b
	Locust + Alfalfa	6.12 d	5.26 e	4.93 e
	Locust + Wheatgrass	7.04 b	6.57 b	5.89 a
	Control (Locust in waste slope land)	5.88 e	5.62 d	5.42 c
III-Large fish-scale pits	Sea-buckthorn + *Humulus*	5.79 e	6.08 c	5.67 b
	Sea-buckthorn + Alfalfa	5.27 f	5.82 cd	4.91 e
	Sea-buckthorn + Wheatgrass	5.97 de	6.11 c	5.79 ab
	Control (Sea-buckthorn in waste slope land)	5.25 f	5.41 e	5.25 d

To study the dynamic changes of soil moisture, the tested points were randomly selected in each treatment to measure soil moisture in 0-60 cm soil layer by using TDR in November (Fig. 2). The soil water contents of all treatments were declined after planting, which indicated that the rapid recovery of vegetation in slope fields led to the gradual increase of soil water usage. The natural rainfall could not replenish sufficiently to water loss in soil, such the soil water deficit frequently occurred. In addition, lower water usage was due to the shortage of vegetation in slope field. The similar decrease trend of soil moisture content could be found from soil surface to bottom after long term of planting (Fig. 2; Table 1).

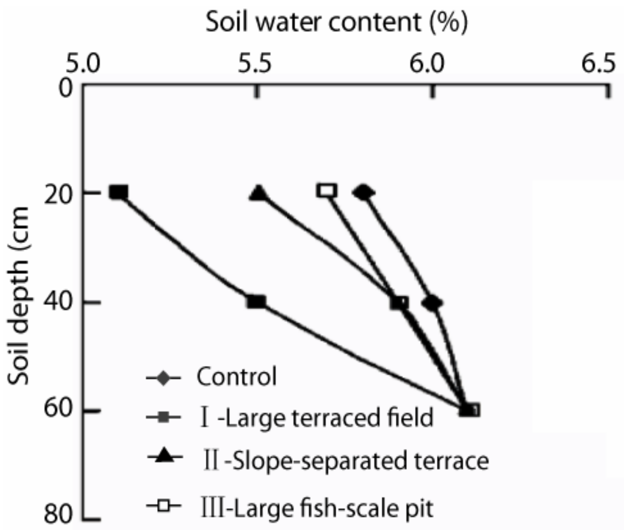

Fig. 2. Dynamic changes of soil moisture in surface soil of each treatment after engineering treatments in sloping fields.

This suggested that the growth status of artificial vegetation on the Loess Plateau might be determined by absorption of rainwater. Such the *soil dry layer* would emerge a few years later, which restricts the growth of vegetation. The above viewpoint was consistent with the findings of many researchers in recent years (Zhang *et al*., 2003; Wang & Shao, 2004). We also observed the different responses of different configuration modes of forest and grass on soil moisture content, and soil moisture content of alfalfa and locust combination in each treatment decreased most quickly. Moreover, regardless of treatment group and tree species, greater soil moisture content was found in Rumex planted treatment because of its poor growth and death in these drought sloping fields. Annual rainfall of these area was in the range of 350 mm to 420 mm where soil erosion was serious. It was obvious that alfalfa and locust combination absorbed the largest amount of soil moisture, led to soil water deficit and induced the appearance of the *soil dry layer*. Therefore, strong-roots grass and tree species should not be avoided to plant in these sloping fields, and reducing the planting density may mitigate the formation of the *soil dry layer* (Zhao & Li, 2002; Guo *et al*., 2002).

Effects of management models in sloping fields on grass growth and vegetation cover: Soil water content affected the growth of tree and grass and vegetation coverage in sloping fields. Comparative analysis of each treatment about the growth conditions of forest, grass and vegetation coverage is shown in Table 3. The vegetation status of all three treatment groups was better than control. As compared with control, the vegetation coverage in all treatments was increased by 12.7%-19.7%, which showed that the engineering management was beneficial to store rainfall and improve vegetation coverage. The order of grass growth and vegetation cover was slope-separated terrace > large terraced field > fish-scale pits > control. When the grass production, vertical projection area and vegetation coverage for combination of locust and wheatgrass reached 20800 kg/hm^2, 2.86 m^2, and 53.6% respectively in level terrace field, which were greater by 38.4%, 50.5% and 20. 8% than control, by 5.5%, 29.4% and4.1% than large terraced field, and by 22 .6%, 24.3% and 5.4% than large fish-scale pit, respectively.

Table 3. Effects of management models in slopping fields on the growth condition of grass and vegetation coverage.

Treatment		Herbage yield (kg/hm^2)	Vertical projection area of plant canopy (m^2)	Vegetation coverage (%)
I- Large terraced field	Locust + Rumex	23648 a	1.19 f	39.4 b
	Locust + Alfalfa	15745 d	1.32 b	41.1 a
	Locust + Wheatgrass	15283 d	1.19 f	38.0 bc
II- Slope-separated terrace	Locust + Rumex	19626 b	1.26 c	41.9 a
	Locust + Alfalfa	18905 c	1.44 a	41.8 a
	Locust + Wheatgrass	12033 f	1.36 b	36.8 c
III- Large fish-scale pits	Locust + Rumex	11883 g	1.18 f	32.9 d
	Locust + Alfalfa	13495 e	1.28 c	39.7 b
	Locust + Wheatgrass	11883 g	1.22 c	31.2 d
Waste sloping field (control)	Locust	10861 h	1.07 g	29.6 e

Effects of management models in sloping fields on growth of forage grass, young tree and vegetation coverage: The better vegetation growth is a premise to form a good coverage and reduce soil erosion in slope fields. The growth of forage grass, young tree and vegetation coverage under different management models are shown in Table 4.

In group-I and II, the intercropping of *Humulus* and each tree species had better growth responses. For example, *Humulus* and apricot intercropping model, height of apricot plants was greater than control. The vegetation coverage in the above model more increased by 51.9% than control group by 30.5%. The *Humulus* and walnut intercropping model, height of walnut plants was greater than control by 33.6%. During the experiment period, it was found that *Humulus* monoclonal branches grew up to 22-87cm, and main stems to 2.1-3.6 m. The yield of *Humulus* could reach 12000-27000 kg/hm^2, which was 2 to 5 times higher than those of alfalfa and wheatgrass. It is concluded that *Humulus* was not the first ideal grass in slope fields, but a high-quality feed for sheep and cattle or other livestock. However, the ability of natural intercropping of alfalfa and each tree species declined, whose soil moisture content had dropped to less than 5%. Wheatgrass and other tree species combinations caused growth slowly. Therefore, it did not form an effective cover on the ground and not suitable for below 25° slope fields. In group Ⅲ, combination of *Humulus* and alfalfa had a poor growth due to low soil moisture content in steep slope field, while the combination of wheatgrass grew well, whose yield reached 13720 kg/hm^2. The vegetation coverage reached 36.3%, increased by 11% comparing with control. Therefore, this model might be not suitable for steep slopes fields.

Table 4. Effects of management models on growth of forage grass, young tree and vegetation coverage.

Treatment		Amount of pasture growth (kg/hm^2)	Height of apricot (cm)	Vegetation coverage (%)
I-Large terraced field	Locust + *Humulus*	23525 b	131.3 a	66.5
	Apricot + Alfalfa	26720 a	122.0 b	44.8
	Apricot + wheatgrass	18532 c	110.5 c	39.3
	Control (Apricot in waste slope land)	-	97.3 d	15.2
	Valnut + *Humulus*	23955 b	124.8 a	62.7
	Valnut + Alfalfa	27705 a	116.9 b	46.7
	Valnut + wheatgrass	18235 c	114.3 b	38.4
	Control (Valnut in waste slope land)	-	92.9 c	16.0
II-Slope-separated terrace	Locust + *Humulus*	18748 b	235.4 a	42.3
	Locust + Alfalfa	20630 a	231.0 a	36.3
	Locust + Wheatgrass	12282 c	235.5 a	27.9
	Control (Locust in waste slope land)	-	217.8 b	13.3
III-Large fish-scale pits	Sea-buckthorn + *Humulus*	13132 b	73.1 ab	23.4
	Sea-buckthorn + Alfalfa	13995 a	69.2 b	26.7
	Sea-buckthorn + Wheatgrass	13382 ab	78.4 a	33.0
	Control (Sea-buckthorn in waste slope land)	-	77.4a	21.8

Effects of management models in sloping fields on water conservation benefits: A good vegetation coverage is the guarantee for reducing soil erosion. The combination of engineering measures and grass and forest intercropping could greatly improve the vegetation coverage (Table 5). The average annual runoff, sediment for apricot/walnut +*Humulus* treatment in group Ⅰand Ⅱ reduced by 62.4%,34.3% and 57.0%, 67.04% respectively than control. The large fish-scale pits in more than 25° slope field, the configuration of wheatgrass and shrub was the best combination, the average annual runoff and sediment reduced by 43.4% and 65.4% respectively compared with control group (Table 5).

Table 5. Effects of different treatments on runoff volume and sediment amount.

Treatment		Volume of runoff (m^3/hm^2)	Total volume of silt (kg/hm^2)
I-Large terraced field	Apricot/Walnut + *Humulus*	16.05 c	5074 d
	Apricot/Walnut + Alfalfa	17.70 c	5990 c
	Apricot/Walnut + Wheatgrass	19.75 b	6496 b
	Control *(*Apricot in waste slope land)	26.06 a	6779 a
II-Slope-separated terrace	Locust + Humulus	21.95 c	5489 c
	Locust + Alfalfa	30.95 b	6636 b
	Locust + Wheatgrass	30.90 b	6597 b
	Control (Locust in waste slope land)	34.46 a	9168 a
III-Large fish-scale pits	Sea-buckthorn + *Humulus*	37.67 b	5996 c
	Sea-buckthorn + Alfalfa	39.18 b	7082 b
	Sea-buckthorn + Wheatgrass	29.62 c	5552 d
	Control (Sea-buckthorn in waste slope land)	49.81 a	9337 a

For below 25° slope fields, large platform fields management + *Humulu*s was the best combination for water conservation. After the annual rainy season in every year, the growth of *Humulus* could quickly cover the surface in a short time and effectively reduced the splash erosion. Meanwhile, intertwined branches trail across the ground could make the surface difficult to form a large runoff, and effectively prevent soil erosion, which the soil erosion ratio could reduce by 34.3%. While the effects of water conservation of alfalfa and wheatgrass were not obvious due to ineffective formation of coverage in a short time, and more intense erosion, however, the soil erosion ratio of this model reduced by15.5% compared with control. Compared with control, the strong erosion occurred in the natural slope with three erosion ditch with 5.7 m length, 3 m to 8 cm width, and 2 cm to 5cm depth. For more than 25° slope field, large fish-scale pits + wheatgrass combination can effectively conserve water. However, *Humulus* and alfalfa did not grow better, which led to ineffective coverage formation, and more serious erosion of surface soil. Whereas, wheatgrass planting models could improve the coverage relatively and water conservation, whose soil erosion decreased by 68.17% as compare with control. Finally, after intensive rainfall, we found that there was no obvious splash erosion effect and infiltration trace under wheatgrass model, while alfalfa and *Humulus* models exhibited such obvious effects in outer edges of large fish-scale pits. Meanwhile, 2-3 cm wide and 3-5 cm long small erosion gully appeared in natural slope fields.

Conclusion

The best engineering management in sloping fields in the hilly and gully regions of Loess Plateau could attribute to slope-separated terrace model. It did not show better rainfall conservation and infiltration, but reduced loss of soil moisture at sides of the ridge. The moisture contents in 0~50cm soil in the above model were greater by 13.1% than control, by 2.1% than large terraced field, and by 2.6% than large fish-scale pits. Thus, the grass and tree species might be collocated reasonably to promote better growth and vegetation coverage. For example, the forage yield, crown projection area, vegetation coverage of locust and wheatgrass combination could reach 20800 kg/hm^2, 2.8 m^2 and 53.6% respectively, which were higher than control by 38 .4%, 50. 5% and 20. 8%. Such, it's suggested that locust and wheatgrass combination could be promoted for application in these area. For large terraced field, soil evaporation of the ridge side was strong. Therefore, the width of terracing field area should not be less than 3 m. Additionally, strong root system and high-density planting would accelerate the development speed of *soil dry layer* of Loess Plateau. Such, the recovery of vegetation might be determined the matching reasonable engineering measures, and tree and grass species configuration. According to the experiment design-I: slope-separated terrace and reasonable configuration of vegetation could slow down the formation of the *dry soil layer*, improve the ability of natural regeneration of vegetation. To sum up, slope-separated terrace was the best mode of Loess Plateau slope engineering management.

The engineering management and grass/forest combinations could effectively improve the coverage of vegetation in Loess Plateau. For 15°-20° slope field, large platform + *Humulus* + economic forest management mode could improve the slope vegetation coverage, which can be up to 75.9%, 36.4% and 54.5% higher than control respectively. Such, it could effectively reduce the loose topsoil erosion, scour, retain runoff, increase infiltration, improve soil holding capacity, and promote the survival and growth of seedlings. Soil erosion could be reduced compared with control by 34.3%, which achieved better the ecological and economic benefits. For the 20°-25°slope, the bench terrace + tree ecological forest (*Robinia pseudoacacia, Pinus tabuliformis, Platycladus orientalis*) + *Humulus scandens* management models were best. These models could make the vegetation coverage up to 33.9% to 49.4%, effectively improve the collecting runoff, soil moisture in 0~100cm soil layer, which soil erosion modulus dropped 57% than control. For more than 25° slope, large fish-scale pits + bush + *Agropyron cristatum* management was best, whose vegetation coverage attained 28.7% to 36.3%, which were higher than control by 12.2% and 10.5% respectively. Soil erosion modulus was drop out 68.17% than control.

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