Effects of different natural vegetation management measures on red soil erosion in hilly orchards

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Abstract: The effect of managing the natural vegetation with different mechanical and chemical methods to minimize runoff and soil erosion in the red soil hilly orchards was investigated. The traditional tillage without herbicide practiced by farmers resulted in 33.2 m^3/hm^2 runoff and 167.8 $t \cdot km^{-2}$ soil loss per year. The management of natural vegetation with sequential herbicide treatments such as paraquat, glyphosate, G-G-P (glyphosate-glyphosate-paraquat), P-P-G (paraquat-paraquat-glyphosate) and sod culture reduced the surface runoff by 47.7%, 20.8%, 31.4% and 41.3%, 45.5%, respectively. The five treatments also reduced the soil loss by 52.4%, 39.0%, 48.1%, 50.7%, and 55.2%, respectively, and the nutrient loss through runoff by 50.2%, 37.0%, 41.8%, 45.8%, and 60.3%, respectively. Average soil covers by natural vegetation 30 days after application with paraquat, glyphosate, G-G-P, P-P-G and tillage without herbicide were 67.2%, 30.3%, 36.8%, 51.2% and 55.1%, respectively, as compared with the sod culture method. It showed that paraquat applications allow to maintain a higher vegetation cover resulting in lower soil erosion, which is a promising measure for soil-water and soil fertility preservation.

Key words: natural vegetation management; herbicides; water and soil loss; hilly orchard; red soil

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1 Introduction

A land degradation survey showed that 83% of global land deterioration was caused by soil erosion. The total area of degenerated land worldwide has accounted for 15% of total land area, and 60% of that located in tropical and subtropical areas of red soil zone. From now on, most of efforts in global ecological preservation will be put on red soil area, because its natural resources and production potentials are more than two times than that in the temperate zones. The reclamation of red soil zone will not only transform it into production bases of food and commercial crops, but also be able to support 2.5 billion poor residents.

In China, red soil zones mainly distribute over 10 southern provinces and its total area is 1.13 million km^2 accounting for 11% of total land area in China. Those provinces have a large population of 260 million accounting for 23% of the national total population, and a wide arable land of 16 million km^2 accounting for 15% of total arable land area of China. Though it has only one sixth of arable land in China, its grain output, accounting for one third of the national output, could support one fourth of the whole population of China. Therefore a sustainable development of that region agriculture will play an important role for the whole country. Due to its subtropical and monsoon climate, the region has abundant fresh water, heat and other natural resources as well as huge production potentials. The potential climate-productivity ranged from 46 to 54 $t \cdot hm^{-2} \cdot a^{-1}$ in the region, were equivalent to 2.63 times of that in the Three Rivers Plain, 2.66 times of that in the Loess Plateau, 1.28 times of that in the Huang, Huai, Hai Rivers Plain. The region with 53 million km^2 of hilly land and excellent social geological conditions for swift economical development, has become one of the most important production bases of commercial forest and crops, rare and precious Chinese herbal medicines, as well as grains in China. However, as a result of the long-term irrational exploitation of land resources, the ecological environment of the whole region has been seriously damaged by severe land degradation. With its 80 million km^2 badly eroded farmland and the other 19

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million km^2 barren tillage, the region has become a severe eroded area, and only next to the famous Loess Plateau in Northeast China.

Zhejiang Province is one of the provinces with the most serious problem of large population and insufficient arable land although the nation since early 1980's, a large-scale program of exploiting red soil in mountainous area has been carried out in order to transform them into commercial woodland. Now soil erosion remains a very serious problem in the province, because too much attention had been paid to cultivation and too less to environment protection. According to the general survey of Zhejiang Provinces in 1998, the area with serious soil erosion has accounted for one fourth of the province total, and 78% of that was located in mountainous area. The hilly area with commercial forests is sloppy in topography and poor in soil water-nutrient conditions as well as frequent cultivating and weeding, then to result in a serious soil-nutrient loss by runoff. Previous studied[1,2] showed that a majority of annual eroded soil wears away at 3~4 times of rainfall during the rainy season. If the soil loss by heavy rains can be controlled, the situation of soil erosion can be improved significantly. For the above-mentioned purpose, some experiments of applying the herbicides to control and adjust the weeds in the woodland have been carried out so as to maintain a better balance between the fruit and weed as well as protect the soil. This report summarized the results of two years researches.

2 Materials and methods

2.1 Highlight of experimental zone

The experimental zone was established at Jin-hua and Quzhou Basin situated at mid-western part of Zhejiang Province and other eastern part of China. Which located on Latitude from 28°15′N to 29°41′N, Longitude from 118°15′E to 120°47′E; and an altitude of 45~70 m; as well as with a total annual rainfall of 1676.7 mm; total annual evaporation of 838.6 mm (E601); annual average temperature of 17.7℃; total annual accumulated temperature (≥10℃) of 5534℃; Frost free days were about 261 d. The zone has a typical subtropical and monsoon climate and plenty of undulated land surface. The soil in the region are classificated as Q_2 red soil derived from the 4^{th} Epoch red clay with a pH of 4.85, total N of 0.24 $g \cdot kg^{-1}$, total P_2O_5 of 0.17 $g \cdot kg^{-1}$, total K_2O of 12.4 $g \cdot kg^{-1}$, CEC 8.71 of $cmol \cdot kg^{-1}$; and red sandy soil derived from the 3 rd Epoch red gritstone with a pH of 4.81, total N of 0.37 $g \cdot kg^{-1}$, total P_2O_5 of 0.21 $g \cdot kg^{-1}$, total K_2O of 9.13 $g \cdot kg^{-1}$, and CEC of 8.50 $cmol \cdot kg^{-1}$; The slope land had been degraded badly and belongs to the degraded red soil with high acidity and low nutrients.

2.2 Experimental design

The soils in the experiments were selected as red soil and sandy red soil, is covered a distance of 100 km in the east-to-west direction. Three locations with different slopes were selected as follows: two slopes of 8° and 13° with NS slope, and one slope of 25° with WE direction in contour sandy red soil. Each plot was planted with six Pomelo trees with a tree age of 9 years old in sandy red soil orchard and 5 years old in red soil orchard. Plot size was 5.5~6.5 m in width (parallel to contour line) and 17~23 m in length (vertical to contour line) coveringan area of 110~125 m^2 per plot. Refractory brick walls were build around. Also, at the bottom of each plot, a water-collecting tank with a size of 1m wide and 1 m long was built, which a switch and a gauging meter connected to a drainage line. The investigation, and water sampling and fresh mud-sand weighting began on the 1st Sept, 2001 and was carried-out after each runoff event.

2.3 Experimental treatment and analysis

Six treatments including tillage without herbicide, sod culture, paraquat, glyphosate, G-G-P (glyphosate-glyphosate-paraquat) and P-P-G (paraquat-paraquat-glyphosate) were established with a completely randomized block design and three replications. Herbicide applications, tillage and mulching were carried out at each end of April, June and August. 20% paraquat was applied at 3 $kg \cdot hm^{-2}$ and 10% glyphosate at 12 $kg \cdot hm^{-2}$. The G-G-P was twice times of glyphosate and the same as paraquat, and P-P-G was twice times of paraquat and the same as glyphosate. The tillage without herbicide was on cultivating and weed killing, and no weed killing was for sod culture treatment. The investigation included the effect on water and soil loss, the evolution of weed flora, the variation of soil fertility and the effects on the growth and output of fruits. After each runoff event, we water samples and mud-sand collected from the traps. The samples of water and soil was measured for the weight of the suspended load and tractional load contained, and nutrients contents in soil, according to "Forest Soil Analysis Method" published by the State Forest Bureau (LY/T1210-1275-1999).

3 Results and analysis

3.1 Influence of herbicide on surface runoff

In the present study, statistics of the 3 experiments showed that the average annual runoff was 33.2 m^3/hm^2 for tillage without herbicide, 18.1 m^3/hm^2 for sod culture, 17.4 m^3/hm^2 for paraquat, 26.3 m^3/hm^2 for glyphosate, 22.8 m^3/hm^2 for G-G-P, 19.5 m^3/hm^2 for P-P-G. If the runoff rate of the tillage without herbicide is given as 100%, the relative figures of sod culture, paraquat, glyphosate, G-G-P and P-P-G were respectively 54.5%, 52.3%, 79.2%, 68.6% and 58.7% (table 1). Also physical characters of soil could influence the runoff rate. In the experiments, the runoff rate in sandy red soil was lower than that of the other two tests in red soil. It may be caused by the higher sand content in sandy red soil and its contour cropping pattern. This result was closely related with the previous studies[3~6].

Table 1 Effects of herbicide on soil loss in red soil hilly orchards

Treatment	Red soil 1(8°)		Red soil 2(13°)		Sandy red soil 3(25°)		Runoff		Erosion	
	Runoff /$m^3 \cdot hm^{-2}$	Erosion /$t \cdot hm^{-2}$	Runoff /$m^3 \cdot hm^{-2}$	Erosion /$t \cdot hm^{-2}$	Runoff /$m^3 \cdot hm^{-2}$	Erosion /$t \cdot hm^{-2}$	/$m^3 \cdot hm^{-2}$	Relative change/%	/$t \cdot hm^{-2}$	Relative change/%
Tillage without herbicide	23.9	76.4	53.4	230.6	22.5	196.5	33.2	100	167.8	100
Sod culture	15.5	26.0	29.9	76.1	9.0	123.7	18.1	54.5	75.2	44.8
Paraquat	14.2	29.8	28.1	92.2	10.1	117.9	17.4	52.3	80.0	47.6
Glyphosate	19.1	41.6	40.5	123.4	19.5	142.5	26.3	79.2	102.5	61.0
G-G-P	17.0	33.0	35.2	98.8	16.2	129.6	22.8	68.6	87.1	51.9
P-P-G	15.0	31.2	30.4	95.2	13.1	121.8	19.5	58.7	82.7	49.3

* Note: Test time: from the 1st Sept, 2001 to the 31st Aug, 2003; the same as follows
Annual rainfall: 1634.4 mm for red soil and 1863.0 mm for sandy red soil.

3.2 Effects of herbicides on soil erosion

The hilly orchards have abundant sunshine and heat, well ventilation and fluent drainage. As well as less pollution of pesticide or chemical fertilizer compared with the plain area. In this regard, it can easily be developed as production bases of green foods and organic foods. However, due to its rolling landform, the region will be easily suffered from soil erosion when the surface vegetation layer destroyed. Table 1 showed that in the red soil orchards with 8° and 13° along-slopes the treatments of paraquat, glyphosate, sod culture, G-G-P and P-P-G reduced theannual soil erosion rate to 30%~50% of traditional tillage without herbicide. In the 25°contour orchards of sandy red soil, the above-mentioned three treatments could reduce the erosion rate by about 1/3. Generally, as paraquat applied, The average soil erosion rate was estimated at 80.0 $t \cdot km^{-2}$ with paraquat as compared with 167.8 $t \cdot km^{-2}$ with tillage without herbicide. The figures with treatment of glyphosate, sod culture, G-G-P and P-P-G were 102.5, 75.2, 87.1 and 82.7 $t \cdot km^{-2}$, respectively. The erosion rate could be reduced by 52.4%, 39.0%, 55.2%, 48.1% and 50.7%, respectively, in comparison with traditional tillage without herbicide (167.8 $t \cdot km^{-2}$). Overall the two kinds of herbicides could produce equivalent effects as the sod culture.

3.3 Effects of herbicides on soil nutrient losses

The red soil region has an abundant natural water and heat resources, rapid organism-growing cycle, and high production potentials. However, due to its rolling landform, huge and focused rainfall, as well as irrational land use, water and soil loss happened frequently resulting in the soil nutrients loss. As a result, the lack of water and nutrient has become the key interfering factor for the sustainable development of the whole area agriculture[7]. The conservation of water and soil could break the barrier of water and nutrient loss. In the experiments, the soil nitrogen losses in the treatment of sod culture, paraquat, glyphosate, G-G-P and P-P-G treatments reduced by 59.2%, 44.3%, 29.6%, 35.2% and 40.0%, respectively. As for soil P_2O_5, the correspondent figures were 64.6%, 51.0%, 45.6%, 48.0% and 49.8%, respectively, while for K_2O were 60.2%, 50.5%, 27.2%, 42.0% and 46.0%, respectively, as compared with tillage without herbicide. In average, the N, P, K nutrients put together were 60.3%, 50.2%, 37.0%, 41.8% and 45.8%, respectively. The effectiveness of paraquat was significantly better than that of glyphosate (table 2).

Table 2 Effects of herbicide on preventing nutrient losses in hilly red soil orchards

Treatment	N/kg·km^{-2}				P_2O_5/kg·km^{-2}				K_2O/kg·km^{-2}			
	1	2	3	mean	1	2	3	mean	1	2	3	mean
Tillage without herbicide	53.3	158.4	249.2	153.6	50.7	150.9	49.3	83.6	1485	4426	1980	2630
Sod culture	16.5	49.5	122.0	62.7	14.6	43.5	30.7	29.6	472	1408	1131	1047
Paraquat	25.3	75.4	155.7	85.5	20.4	61.1	41.4	41.0	623	1861	1408	1301
Glyphosate	30.5	91.0	202.8	108.1	24.7	74.2	37.5	45.5	872	2604	1766	1651
G-G-P	28.4	85.0	185.3	99.6	23.1	69.1	38.4	43.5	780	2331	1640	1526
P-P-G	26.7	79.8	169.7	92.1	21.6	64.7	39.6	42.0	698	2048	1532	1420

3.4 Effects of herbicide on weed flora

The natural weeds have its advantages in species diversity, good resistance to environmental stress, fast growth, high yield, multiple purposes and longer life cycle. Exploiting of natural weeds may be an indispensable measure to prevent soil erosion, recover soil fertility, and improve the ecological conditions in the region. While sod culture in the orchard would be a practicable method based on combining exploitation with soil-water preservation and the application chemical of herbicide could be an even more efficient measure, for time and labor saving, highly efficient, inexpensive and long-term residue effects, as well as not to be suffered from the bad weather such as continuous rainfall, and not any damage to soil structure. Therefore the modern agriculture could not be apart from them. If the advantages of both the weed and herbicide can be jointly utilized, the land degradation will be much relieved. In the rainy seasons, let the weed grow to maintain soil, and to kill them in the drought season for better growth of fruits and forests. The observations at first part of the experiment showed that the hilly region had a numerous species of wild weeds including 96 species from 27 families as the region was located at a transitional zone between plains and mountains. The root systems of 39 weed species from 17 families could be infected with the VA fungus at different extents, and a great deal of research[8~12] has confirmed that the fungal hyphae in citrus roots play an important role for phosphor uptake. For this reason, a variety of weeds should be maintained in the orchards as long as the production is not affected. The measurement of weed regeneration rate showed that, after 30 days from applying the herbicides, the weed regeneration ratios of the weed with application of paraquat, tillage without herbicide, glyphosate, G-G-P and P-P-G were 67.2%, 55.1% and 30.3%, 36.8% and 51.2%, respectively. This indicated a quicker and more complete recovery of the weed flora following the applications of paraquat as compared with glyphosate (Fig. 1).

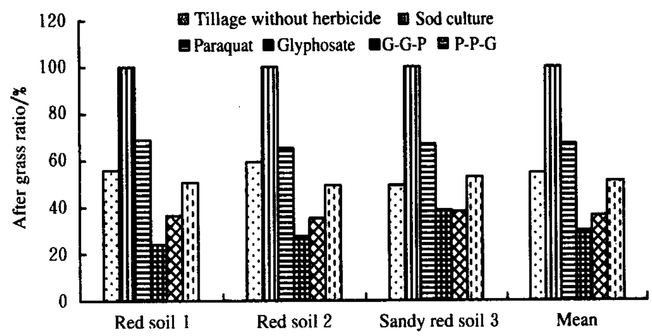

Fig. 1 Effects of herbicide on aftergrass of weed

4 Conclusions and discussion

4.1 Conclusions

1) The application of herbicides in the hilly red soil orchards could efficiently control the water and soil loss. The applications of paraquat, glyphosate, sod culture, G-G-P and P-P-G could reduce the surface runoff rate by 47.7%, 20.8%, 45.5%, 31.4% and 41.3% from that of the traditional tillage without herbicide, respectively. In addition to that, the figures for soil erosion rates were 52.4%, 39.0%, 55.2%, 48.1% and 50.7%, respectively. As for the prevention of soil and water losses, paraquat may be the same useful as sod culture and better than glyphosate.

2) In hilly red soil orchards, the treatments of paraquat, glyphosate, sod culture, G-G-P and P-P-G reduced soil nutrient losses by 50.2%, 37.0%, 60.3%, 41.8% and 45.8% respectively as compared with tillage without herbicide, which may result in improved soil fertility and better yield in the long term.

3) The weed regeneration rate, paraquat, glyphosate, tillage without herbicide, G-G-P and P-P-G are able to get the weed recovered to 67.2%, 30.3%, 55.1%, 36.8% and 51.2% compared with sod culture. Weed recovered faster and more completely in the plots treated with paraquat as compared with glyphosate. This may explain the lower runoff and soil loss in those plots.

4.2 Discussion

Five kinds of Glyphosate-resistant weeds were tested in the orchard. They are Erigeron canadensis and Conyza bonariensis from chrysanthemum family and polygonum lapathifolium and polygonum lapathifolium from polygonaceae family, and Acalypha australis from euphorbiaceae family. It noted that Erigeron canadensis and polygonum lapathifolium were mainly grown in red soil orchard, while conyza bonariensis and acalypha australis were mainly grown in red sandy soil orchard. However, no resistance weed against paraquat has ever been discovered up to now. Using G-G-P and P-P-G could get better weed-killing effects. It suggests that great attention should be paid to applying different measures alternately in production. Finally, the actual mechanism of this resistance should be further studied.

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不同自然植被管理措施对红壤丘陵果园水土流失的影响

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摘 要: 丘陵是"山—丘—谷"的过渡地带, 生态系统脆弱, 一旦植被遭破坏, 极易水土流失。在红壤丘陵园地应用除草剂调控水土流失试验结果表明: 与传统的清耕法相比, 克无踪、草甘膦、草草克、克克草和生草法可使地表径流量分别减少 47.7%, 20.8%, 31.4%, 41.3%和 45.5%; 可使土壤侵蚀量分别减少 52.4%, 39.0%, 48.1%, 50.7%和 55.2%; 可使土壤养分分别减少 50.2%, 37.0%, 41.8%, 45.8%和 60.3%。除草剂对杂草再生率影响, 与生草法比较, 克无踪可达 67.2%, 草甘膦达 30.3%, 草草克 36.8%, 克克草 51.2%和清耕法 55.1%; 克无踪调控杂草效果分别是草甘膦的 2.2 倍, 清耕法的 1.2 倍。克无踪调控杂草效果显著, 有望成为红壤丘陵园地培肥与水保相得益彰的有效措施。

关键词: 植被管理; 除草剂; 水土流失; 丘陵果园; 红壤