EFFECTS OF DIFFERENT NATIVE VEGETATION MANAGEMENT MEASURES ON RED SOIL EROSION IN HILLY ORCHARDS

Shui Jian-guo[A], Liao Gen-qing[B], Jeff Au[C] , Zhou Quan-kang[C] , Jean-louis Allard[D]

[A] Environmental Resources and Soil Fertilizer Institute of Zhejiang Academy of Agriculture Sciences Hangzhou 310021, P. R. China.
[B] Soil & Fertilizer Station of WuCheng District, Jinhua 321000. China.
[C] Syngenta (China) Investment Co. Ltd. Shanghai 200041. China.
[D] Syngenta Asia Pacific Pty Ltd. 250 North Bridge Road. 179101, Singapore

Abstract
The effect of managing the native vegetation with different mechanical and chemical methods to minimize runoff and soil erosion in the red soil hilly orchards was investigated. The traditional "clean tillage" without herbicide in controlling weeds practiced by farmers resulted in 33.2 $m^3 \cdot hm^{-2}$ 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%, and soil loss by 52.4%, 39.0%, 48.1%, 50.7%, and 55.2%, as well as the nutrient loss through runoff by 49.8%, 63.0%, 58.2%, 54.2%, and 39.7%, and enhanced citrus production by 8.4%, 9.2%, 8.8%, 8.0% and 4.0%, respectively, as compared with clean tillage without herbicide. Also, the above five treatments could enhance the annual soil nutrients (N+P+K+OM) by 9.3%, 5.3%, 6.2%, 7.4% and 7.1%, respectively, while the tillage without herbicide reduced by 4.4%, as compared with the original soil. The weed regeneration ratios after 30 days with application of 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. It showed that paraquat applications allowed maintenance of a higher vegetation cover resulting in lower soil erosion, which is a promising complement for soil-water and soil fertility preservation.

Additional Keywords: natural vegetation management; herbicides; Paraquat, Glyphosate, soil loss

Introduction
The total acreage of the world's red soil areas (tropical and subtropical zones) is about 64 million km^2, accounting for 45.2% of the world's total land area, with 2-5 billion people, or 48% of the global population. In the southern parts of China, including 15 provinces (regions), there are 2.18 million km^2 of red soils, occupying 1/5 of the country's total land area, with 480 million people, or 40% of the nation's population. In red soil areas there are 28 million hectares of cultivated land, which accounts for 30% of the country's total. One-third of the total cultivated land provides half of the state's total agricultural output value and feeds nearly half of the national population. With favourable social and natural conditions and a steady economic development, the red soil regions have become the important production bases of economic forests, fruit trees, cash crops and cereals in tropical and subtropical China (Zhou *et al*. 2002).

Since the red soil areas have excellent hydrothermal conditions, both the crop yield and the forest-grass biomass are likely to increase 1-4 times. The main constraints on the production potentials are the infertility, acid, and aridity of the soil. The strategy for controlling red soil resource utilization has involved concurrently developing agriculture and improving ecological environment, integrating the control with development, and making a virtuous ecology-economy cycle in spirals. With the growth in population and influenced by human activity, led to food shortages, which encouraged people to transform lakes into land for tillage, and extend reclamation activities toward hilly areas. Irrational development and utilization of red soils has brought about a series of problems with soil degradation. According to the general survey of Zhejiang Provinces in 1998 by using satellite photos, the area with serious soil erosion has accounted for one fourth of the province's total, and 78% of that was located in red earth of hill orchards. The hilly area with commercial forests is hilly in topography and poor in soil water-nutrient conditions as well as frequent cultivating and weeding, resulting in a serious soil-nutrient loss by runoff. Previous studies (Shui *et al*., 1989; Li *et al*., 2001; Huang *et al*., 1998 & 2002) showed that a majority of the annually eroded soil is lost during 3-4 rainfalls in 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 summarises the results of two years research.

Materials and Methods

Highlight of experimental zone

The experimental zone was established at "Jin-hua and Qu-zhou Basin" situated at mid-western part of Zhejiang Province and eastern part of China. It is located on latitude 28°15′N to 29°41′N, longitude 118°15′E to 120°47′E; and altitude of 50-70 m, with a total annual rainfall of 1676 mm. Total annual evaporation is 838.6mm(E601); annual average temperature is 17.7°C; total annual accumulated temperature (≥10°C) of 5534°C; frost free days number about 261. The zone has a typical subtropical and monsoon climate and plenty of undulating land surface. The soil in the region are classed as Q_2 red earth derived from the 4th Epoch red clay with a pH of 4.85, total N of 0.24 g kg^{-1}, total P_2O_5 of 0.17g kg^{-1},, total K_2O of 12.4g kg^{-1}, CEC 8.71 of cmol kg^{-1}; and red sandy soil derived from the 3rd Epoch red gritstone with a pH of 4.81, total N of 0.37 g kg^{-1}, total P_2O_5 of 0.21 g kg^{-1}, total K_2O of 9.13 g kg^{-1}, and CEC of 8.50 cmol kg^{-1}. The sloping land had been degraded badly and belongs to the degraded red soil with high acidity and low nutrients.

Experimental design

The soils in the experiments were red soil and sandy red soil, covering 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 5 years old in sandy red soil orchard and 9 years old in red soil orchard. Plot size was 5.5 x 6.5 m in width (parallel to contour line) and 17 x 23 m in length (vertical to contour line) covering an area of 110 to 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 1 m 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 September 2001 and was carried-out after each runoff event.

Experimental treatment and analysis

Six treatments including clean tillage (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 for glyphosate and once for paraquat, and P-P-G was twice for paraquat and once for glyphosate. The tillage without herbicide was on cultivating and weed killing, and no weed killing but cutting the weeds for mulch 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, the water and mud- sand samples were collected from the traps. The samples of water and soil were 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/T 1210-1275-1999).

Results and Discussion

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 clean tillage, 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 clean tillage is given as 100 %, the relative figures of sod culture, paraquat, glyphosate, G-G-P and P-P-G were reduced respectively by 45.5%, 47.7%, 20.8.2%, 31.4% and 41.3%(table1). 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 (Huang *et al*., 2002; Shui *et al.*, 2001; Zhang *et al*., 2001; Yuan *et al*., 2001).

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 the annual soil erosion rate to 30%–50%of traditional clean tillage. 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 km^{-2} as compared with clean tillage at 167.8 t km^{-2}. 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 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 clean tillage (167.8 t km^{-2}). Overall the two kinds of herbicides could produce equivalent effects as the sod culture.

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

Treatment	Red earth 1 (8º)		Red earth 2 (13º)		Sandy red soil3 (25º)		Runoff		Erosion	
	Runoff /m^3• hm^{-2}	Erosion /t•hm^{-2}	Runoff /m^3•. hm^{-2}	Erosion /t•hm^{-2}	Runoff /m^3•hm^{-2}	Erosion /t•hm^{-2}	/m^3•hm^{-2}	RR/%	/t•hm^{-2}	RR/%
Clean tillage	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 1st Sept.2001 to 31st Aug.2003; RR=Relative ratio; the same as follows.
Annual rainfall: 1634.4 mm for red earth and 1863.0 mm for sandy red soil.

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 (Sun *et al*., 2000). 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}			Total nutrients	
	1	2	3	1	2	3	1	2	3	kg·km-2	RR/%
Clean tillage	53.3	158.4	249.2	50.7	150.9	49.3	1485	4426	1980	2867.2	100
Sod Culture	16.5	49.5	122.0	14.6	43.5	30.7	472	1408	1131	1139.3	60.3
Paraquat	25.3	75.4	155.7	20.4	61.1	41.4	623	1861	1408	1427.2	50.2
Glyphosate	30.5	91.0	202.8	24.7	74.2	37.5	872	2604	1766	1804.6	37.0
G-G-P	28.4	85.0	185.3	23.1	69.1	38.4	780	2331	1640	1669.1	41.8
P-P-G	26.7	79.8	169.7	21.6	64.7	39.6	698	2048	1532	1554.1	45.8

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 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 in the first part of the experiment showed that the hilly region had 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 vesicular *Arbuscular mycorrhiza* fungi at different extents, and a great deal of research (Yin *et al*., 2002; Huang and Tang, 1994; Liu and Li, 2000; Li and Xie, 2002; Chen *et al*., 2002; Zhang *et al*., 2003) has confirmed that the fungal hyphae in citrus roots play an important role for phosphorous 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, as compared with sod culture. This indicated a quicker and more complete recovery of the weed flora following the applications of paraquat as compared with glyphosate (Table 3).

Table 3. Effects of herbicide on weed regeneration rate

Treatment	Red earth 1 (8º)		Red earth 2 (13º)		Sandy red soil3 (25º)		Mean	
	Weeds/m^2	RR/%	Weeds/m^2	RR/%	Weeds/m^2	RR/%	Weeds/m^2	RR/%
Clean tillage	386	56.3	271	59.4	155	49.5	270	55.1
Sod Culture	685	100	456	100	314	100	485	100
Paraquat	471	68.8	298	65.3	212	67.5	327	67.2
Glyphosate	166	24.2	127	27.8	122	39.0	138	30.3
G-G-P	249	36.4	163	35.6	121	38.5	178	36.8
P-P-G	346	50.5	227	49.8	168	53.4	247	51.2

Contribution of herbicide to soil fertility

Soil fertility is the basis to resolve the natural vegetation and the main factor of soil degradation. To resolve the natural vegetation is the most basic condition to increase biodiversity and establish the fine agro-ecological models. The observations for two-yr experiment, the clean tillage could reduce the soil OM, N, P, K by 12.9%, 7.5%, 5.3% and 5.5%, respectively, while the herbicide treatments of paraquat, glyphosate, G-G-P and P-P-G could enhance the soil OM, N, P, K by 25.2%, 11.1%, 63.1% and 4.0% as compared with the original soil. The average annual increase rates of total nutrients of OM+N+P+K would be increased(reduced) by -4.4% for clean tillage, 7.1% for sod culture, 9.3% for paraquat, 5.3% for glyphosate, 6.2% for G-G-P, 7.4% for P-P-G (Table 4), which indicated the obvious biological enrichment effect of red soil (Huang and Tang, 1994; Yin *et al*., 2003; Wang *et al*., 1999).

Table 4. Effects of herbicide on soil fertility*

Treatment	OM/ kg·km^{-2}		N / kg·km^{-2}		P_2O_5 / kg·km^{-2}		K_2O / kg·km^{-2}		Total nutrients/ kg·km^{-2}		
	2001	2003	2001	2003	2001	2003	2001	2003	2001	2003	±%**
Clean tillage	9.20	8.01	0.36	0.33	0.19	0.18	10.8	10.21	20.55	18.7	-8.8
Sod Culture	9.20	11.92	0.36	0.41	0.19	0.26	10.8	10.91	20.55	23.5	+14.3
Paraquat	9.20	12.49	0.36	0.40	0.19	0.27	10.8	11.23	20.55	24.4	+18.6
Glyphosate	9.20	10.83	0.36	0.39	0.19	0.34	10.8	11.18	20.55	22.7	+10.7
G-G-P	9.20	11.16	0.36	0.39	0.19	0.35	10.8	11.21	20.55	23.1	+12.4
P-P-G	9.20	11.59	0.36	0.42	0.19	0.28	10.8	11.31	20.55	23.6	+14.8

*Sampling date: Sept.2001 and Sept.2003. **the increase rates or decrease rates as compared between 2001 and 2003.

Contribution of herbicide to citrus yield

Soil fertility is the basis of plant growth. The yield measurement on Nov 2003 showed the relative yields of sod culture, paraquat, glyphosate, G-G-P and P-P-G were estimated at 104%, 108.4%,109.2%,108.8% and 108%, respectively, as compared with clean tillage 100%, which all herbicide's treatment showed the higher significantly differences at 0.05% level for Duncan test expect for sod culture (Table 5).

Table 5. Effects of herbicide on citrus yields (one plant yield)

Treatment	Red earth 1(8º)		Red earth 2(13º)		Sandy red soil3(25º)		Mean yield	
	Yield/ kg	RR/%	Yield/ kg	RR/%	Yield/ kg	RR/%	Yield/ kg	RR/%
Clean tillage	30.1b*	100	28.8b	100	16.5b	100	25.1b	100.0
Sod Culture	31.2ab	103	30.0ab	104	17.1ab	104	26.1ab	104.0
Paraquat	32.3a	107	31.3a	108	18.0a	108	27.2a	108.4
Glyphosate	32.4a	108	31.5a	109	18.3a	110	27.4a	109.2
G-G-P	32.5a	108	31.4a	109	18.1a	109	27.3a	108.8
P-P-G	32.3a	107	31.3a	108	17.8a	108	27.1a	108.0

* The different letters in same column are significant according to Duncan′s test at P>0.05.

Conclusions

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.

In hilly red soil orchards, the treatments of paraquat, glyphosate, sod culture, G-G-P and P-P-G reduced soil nutrient losses by 49.8%, 63.0%, 39.7%, 58.2% and 54.2%, respectively as compared with tillage without herbicide, which may result in improved soil fertility and better yield in the long term. Thus, the average annual increase rates of total nutrients of OM+N+P+K could be increased (or reduced) by -4.4% for clean tillage, 7.1% for sod culture, 9.3% for paraquat, 5.3% for glyphosate, 6.2% for G-G-P, 7.4% for P-P-G; and the relative yields of sod culture, paraquat, glyphosate, , G-G-P and P-P-G were estimated at 104.0%, 108.4%,109.2%,108.8% and 108.0%, respectively, as compared with clean tillage 100%, All herbicide's treatment present significant differences at 0.05% level for Duncan test.

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.

Discussion

Five kinds of weeds were observed that were less sensitive to glyphosate after treatment in the orchard. They were *Erigeron canadensis* and *Conyza bonariensis* from *Chrysanthemum* family, *Polygonum lapathifolium* from *Polygonaceae* family, and *Acalypha australis* from *Euphorbiaceae* family. It was 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, this phenomenon was not seen in the paraquat treatment. It suggests that great attention should be paid to applying different measures alternately in production. Finally, further study is recommended to monitor the development of herbicide resistance, and the alternative use of glyphosate and paraquat is most likely a more sustainable option in vegetation management in hilly orchards.

Acknowledgements

This study was supported by Syngenta (China) Investment Co. Ltd., Swiss.

References

Chen Jie, Chen Xin, and Fang Zhiguo (2002). Spatial distribution Characteristics of weed species diversity In a watershed ecosystem in southern China' s hilly area. *Acta Ecologica Sinica*, 22(3):440-443 (in Chinese).

Huang Qianru, et al. (1998). Study on the erosion of different ecological types of red soil in hilly land. *Acta Agriculturae* Jiangxi, ,10(3):7-12 (in Chinese).

Huang Qianyou, Peng Tingbai and Wang Keling (2002). Study on resources protection of water and soil and development technology in harmony in the hillside field. *Chinese Journal of Eco-agriculture*,10(3):98-101(in Chinese).

Huang Qin and Tang Zhenyao (1994). Advances in research on citrus vesicular-arbuscular mycorrhiza: A literature review. *Acta Horticulturae Scinica*, 21910:47-53 (in Chinese).

Huang Qin, and Tang Zhenyao (1994). Advances in research on citrus vesicular-arbuscular mycorrhiza:A literature review[J]. Acta H orticulturae Sinica, 21(1):47-53 (in Chinese).

Li Zhizhen, and Xie Yiqing (2002). Advances and application prospect of VA Mycorrhiza. *Acta Agriculturae Universitatis Jiangxiensis,* 24(4): 448-453 (in Chinese) .

Li Zhongpei, Zhang Taolin,Yang Yansheng (2001). Process and comprehensively harnessing techniques of soil and water loss in hilly red soil regions. *Bulletin of Soil Water Conservation* 21(2):12-17.

Liu Runjin, and Li Xiaolin (2000). Arbuscular Mycorrhizae and Application[M]. Beijing:*Science Press*, 1-45(in Chinese).

Shui Jianguo, et al. (1989). Effects of different uses of red soil slopes on soil and water loss. *Journal of Soil and Water Conservation* 3(1): 84-90 (in Chinese).

Shui Jianguo, et al. (2001). Water and soil loss in different ecological models on sloping land of red soil. *Journal of Soil and Water Conservation* 15(2):33-36(in Chinese) .

Sun Bao, Zhao Q iguo, L u Guonian (2000). Spatio-temporal variability of red soil fertility in low hill region. *Acta Pedologica Sinica*, 39(2):190-198 (in Chinese).

Wang Xingxiang, Zhang Taolin, and Zhang Bin (1999). Nutrient cycling and balance of sloping upland ecosystems on red soil. *Acta Ecologica Sinica,* 19(3):335-341(in Chinese).

Yin Dixin, Tang Huabing, and Zhu Qing (2003). Nutrient balance and soil fertility change in different conservation measures on sloping field. *Journal of Soil and Water Conservation,* 16(1):72-75(in Chinese).

Yin Dixin,Tang Huabing,Zhu Qing (2002). Nutrient balance and soil fertility change in different conservation measures on sloping field. *Journal of Soil and Water Conservation*, 16(1):72-75 (in Chinese).

Yuan Donghai, et al. (2001). Properties of soil and water loss from slope field in red soil in different farming systems. *Journal of Soil and Water Conservation* 15(4):66-69(in Chinese).

Zhang Yong, Zeng Ming, and Xiang Bingquan (2003). Ecological significance of arbuscular mycorrhiza biotechnology in modern agricultural system. *Chinese Journal of Applied Ecology,* 14(4):613-617(in Chinese).

Zhang Xianming, et al. (2001). Benefits of soil and water conservation measurement on orchard slope land of red soil. *Journal of Soil and Water Conservation*, 15(2):102-104(in Chinese) .

Zhao Qiguo, Wang Mingshu, and Sun Bao (2002). The red soil material cycling and its regulation. Beijing: Science Press (in chinese).