Soil-Water Losses in Hilly Red-earth Region of China and Its Control Strategies

Shui Jianguo and ***Liu Chacha***

Zhejiang Academy of Agricultural Sciences, Hangzhou Zhejiang Province, 310021,P.R.China
E-mail: jsbs@public.ly.jl.cn

Abstract: The observations from 14-yr long-term investigation on the soil-water losses in the sloping red-earth (slope 8°—15°) showed that: soil-water losses were closely correlated with land slope and vegetative coverage. Runoff rate in sloping red-earth could be reduced duplicately by exploitation, while the soil erosion was enhanced duplicately during the first 2 years after exploitation. Subsequently, soil erosion tended to be stable. Soil erosion was high positively correlated with land slope, i.e. soil erosion was increased by 120t/(km^2 • a) with a slope increase of 1°. On the contrary, soil erosion was high negatively correlated with vegetative coverage, i.e. soil erosion was limited at below 200t/(km^2 • a), when the vegetative coverage exceeded 60%. Furthermore, soil erosion was highly related with planting patterns, i.e. soil erosion in contour cropping pattern would be one sixth of that in straight cropping. Based on the view of soil nutrient balance, we first suggested that the acceptable soil erosion in Q_2 red clay derived red-earth should be lower than 300t/(km^2 • a). Contour cropping and contour plant hedgerow might be effective practices to control soil erosion at below 100t/(km^2 • a). For the relative poor farmers, to use dry rice hedgerow will gain both short-term benefits and long-term benefits.
Keywords: soil-water losses, run off coefficient, vegetative coverage, permissible soil erosion, hilly red-earth region

1 Introduction

Zhejiang province is one of the most serious provinces in conflict with population growth and arable land decrease in China. For long time, the unreasonable exploitation of natural resources has resulted in the aggravation of soil-water losses and soil degradation as well as serious reduction of soil fertility, especially in the hilly region. Red-earth is the main soil species in hilly region, whose area to be above 40% of total land area in Zhejiang Province. The landscape feature in hilly region is a transitional landscape of "Mountain to Hill to Valley", whose altitude mostly is at below 400m. The hilly region is the most serious in soil-water losses and fragile in ecological balance in Zhejiang Province, which has directly limited the normal development of agricultural production in the region. Facing on this problem, a long-term investigation on the regularity of soil-water losses in hilly red-earth has been conducted since 1986 in order to address the simple, easy and effective practices for soil-water conservation. This paper summarized the main research results from 14-yr long-term experiment.

2 Materials & methods

2.1 Experimental location

The experimental area was located near Lan-xi city of Zhejiang Province (39° 19′ N, 119° 24′ E; 40m—70m altitude; slope 6° —15°) with annual precipitation of 1,676.7mm, annual evaporation of 838.6mm and annual average air temperature of 17.7℃, which indicated the typical monsoon climate in subtropics. Experimental soil was degraded Q_2 red-earth derived from Q_2 red clay with high acidity and low fertility, which with a pH(H_2O) of 4.5—5.3, total N of 0.19g/kg—0.45g/kg, total P_2O_5 of 0.3g/kg—0.6 g/kg, total K_2O of 8.8g/kg—25.1g/kg and exchangeable Al of 2.7cmol/kg—8.7cmol/kg. The experimental soil was serious in soil erosion.

2.2 Experimental design

This long-term experiment established 20 investigating plots according to the original land slope and slope direction. Brick-concrete walls with 30cm high aboveground and 80cm depth underground separated the plots, and the top of wall was made as a 45° angle-shaped watershed. The cropping pattern in the plots was designed as transverse planting on natural slope. Its planting density was 2m by 2m for forest, 4(3.5) m by 3m for fruit tree and 1.4m by 0.3m for tea tree, respectively. Farmland established the straight cropping pattern and contour cropping pattern, and natural virgin sloping land was grown sporadic pine trees (*Pinus massoniana lamb.*). The planting in all the treatments was finished before Nov.1986, and the investigation began on 1.Jan1987. All treatments were displayed in Table 1.

Table 1 Design and treatment of experimental plots

Use mode	Slope (°)	Aspect	Slope length (m)	Slope width (m)	Area (m^2)	Plant species	Planting time
Farmland SC*	15	NS	20.7	10	200	Cereals	Nov.1986
Farmland CC*	15	NS	20.7	10	200	Cereals	Nov.1986
Fruitland SC*	15	EW	25.9	16	400	Citrus	Nov.1986
Woodland SC*	15	EW	25.9	16	400	Chinese Fir	Feb.1985
Teagarden SC*	8	EW	132	80	1,120	Tea	Mar.1986
Natural slope	8	EW	175	100	1,220	Scattered pine	Nature
Wasteland	13	EW	200	5	100	None	Nature

*SC=straight cropping; CC=contour cropping

2.3 Runoff investigating area

The underground investigating rooms were constructed under each experimental plot, in which the bottle-connecting sand-sinking pool was constructed. The pool volume was designed by the local maximum precipitations once 50 years. A "V" shaped thin-wall triangle weir was set in the pool outlet, and a water-stage recorder ("SW40" type) and enamel-made water standard scale were disposed. The recording unit of investigating was designed as every precipitation period. The volume and density of precipitation, runoff and vegetative coverage were measured at each precipitation. [1]

2.4 Sampling and analysis

Once the raining stopped, first to stir the pool water, then to collect water sample for analysis of suspended substances and nutrient contents. Subsequently, to remove the pool water and collect three sand-soil samples for the measurement of dry weight and nutrient elements. Finally, to weight the total sand-soil (wet weight). The recording method and soil-water analysis method were referenced from the book named 《Forest Soil Analysis Method》published by State Forest Bureau (LY/T1210-1275-1999).

3 Results & analysis

3.1 The timing changes of soil erosion and surface runoff

3.1.1 The timing change of surface runoff

The observations from 14-yr long-term investigation indicated that: surface runoff was significantly correlated with surface rough degree. Once the land to be exploited, surface runoff coefficient will be rapidly reduced year by year, i.e. the runoff rates in the first, second and third years will be one half, one third and one eighth of that in natural conditions, respectively. In general, regardless of exploitation mode, the surface runoff will be higher during the first 2 years, and since the third year it has tended to be stable. The annual runoff coefficients were estimated at about 5% for farmland straight cropping, 2% for farmland contour cropping, below 2%for fruit garden, nearly 2%for woodland, roughly 4% for tea garden, about 23% for natural sloping land and nearly 33% for fallow virgin land (Fig.1)

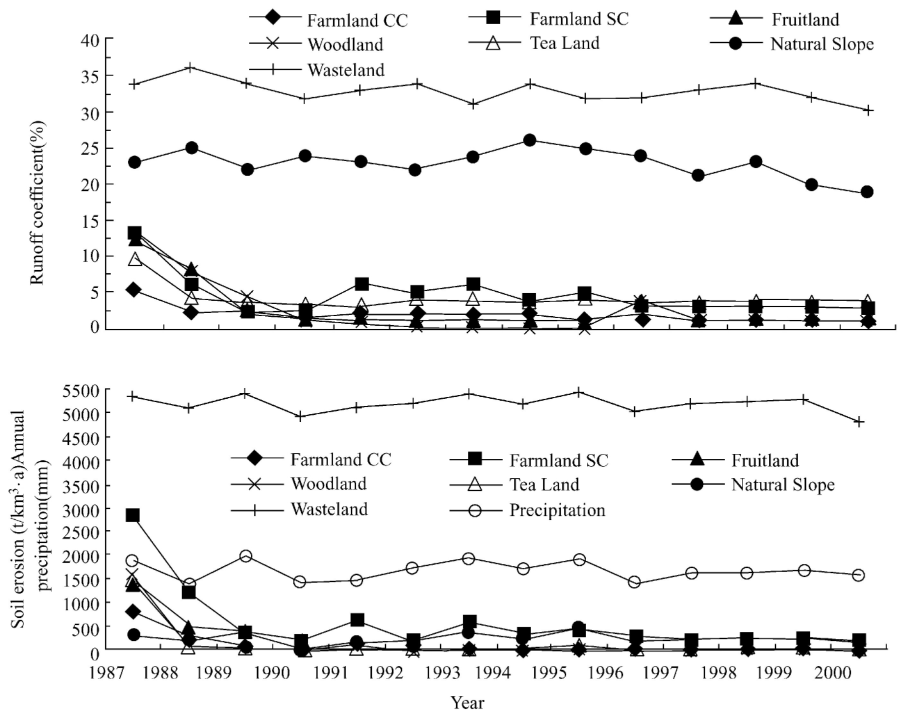

Fig.1 Timing changes of precipitation, surface runoff coefficient and soil erosion for different ecological modes in sloping red-earth

3.1.2 The timing changes of soil erosion

As we known, there are various types of soil degradation. However, the most essential, serious and extensive type might be caused by soil-water losses. As shown in Fig.1, once the sloping red-earth to be exploited, its soil-water losses will be increased duplicately. At the same time, the soil-water losses will significantly vary with different ecological modes[1]. In the first year, the soil-water losses for all the testing modes were rather high ranged from 1,380t/(km^2 • a) to 2,841 t/(km^2 • a). In the second year, significant different modes, i.e. the farmland was the highest up to 1,234 t/(km^2 • a), next was fruit garden (519 t/(km^2 • a)), and the woodland and tea garden were less than 100 t/(km^2 • a); After the third year, the soil-water losses showed obvious decrease but tended to be stable, i.e. farmland still was the highest at about 300 t/(km^2 • a)—400 t/(km^2 • a), the others all to be nearly 50 t/(km^2 • a). As a summary from 14-yr investigation, once the sloping red-earth to be exploited, the soil-water losses was the highest in the first year; then the significant modes in the second year; since the third year, it will be rather low at nearly 50 t/km^2, except farmland modes (300 t/(km^2 • a)—600 t/(km^2 • a)).

Furthermore, the soil erosion rate in natural sloping land was always stable at nearly 256 t/km^2, and the very big soil erosion was found in barren sloping land (average 5193 t/(km^2• a)). It is worthy to point out that the entire contour cropping modes could duplicately reduce the soil erosion rate, e.g. the effect of farmland contour cropping mode to control soil erosion almost to be equal to that of fruit garden and woodland modes.

3.2 Relationship of vegetative coverage and soil erosion

As we known, the mulching of vegetation on land surface could weaken the intensity of raining scouring, and block the rain flow then to make it permeate enter the underground. Consequently, the vegetative coverage on the sloping red-earth must give an obvious affect on the soil erosion rate. The summarized results from 14-yr long-term experiment indicated that: the soil erosion rates for the vegetable coverage of 35.1%, 48.3%, 60.9%, 69.2% and 83.1% were estimated at 927.8,587.2,207.6,103.2 and 32.0 t/(km^2 • a), respectively. Clearly, the soil erosion rate will be duplicately reduced with a vegetative coverage increase of 10% in sloping red-earth. The soil erosion could be limited at below 200 t/(km^2 • a), when the vegetative coverage to be more than 60%, i.e. soil erosion was high negatively correlated with vegetative coverage (Fig.2)

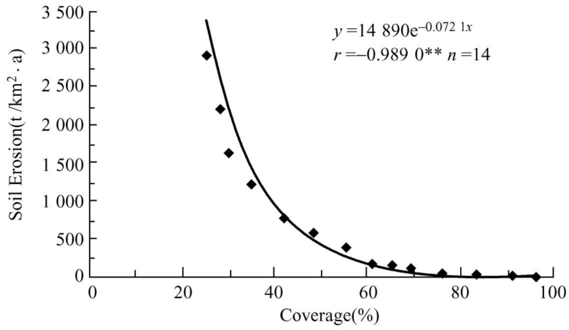

Fig.2 Relationship of soil erosion and vegetative coverage in sloping red-earth

Under the contour-cropping pattern, the soil erosion rates for the vegetative coverage of 35.2%, 38.6%, 56.1% and 70.4% were estimated at No.5 102.4, 25.8 and 18.4 t/(km^2 • a), respectively. Obviously, to use contour cropping mode can reduce significantly the soil erosion, and its effect will be more than six times as large as that of straight cropping mode. Thus, the vegetative coverage plays a key role for the soil-water conservation.

3.3 Relationship of land slope and soil erosion

As we known, land slope is the most essential factor to soil erosion, when the precipitation and vegetative coverage to be the given values. The water on the sloping surface has both mobility and permeability, due to the gravity action. Under the other conditions to be equal, the water on the surface of rapid slope will essentially show the mobility, whereas if will be governed by the permeability, thus the soil-water losses will be reduced. The statistical data for years indicated that, the soil erosion rate will be increased by 120 t/(km^2 • a) with a slope increase of 1° . There is a high positively correlation between soil erosion and land slope (Fig.3).

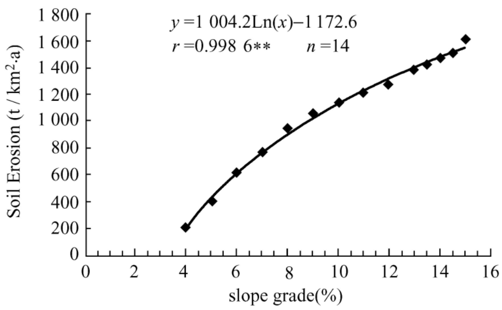

Fig.3 Relationship of soil erosion and land slope in sloping red-earth

3.4 Determination of permissible soil erosion

The permissible soil erosion is defined as the permissible maximum soil erosion density to maintain the soil fertility and land productivity for long time. When the soil erosion exceeds this limit value, the land productivity will be obviously reduced and have to correct it by using soil-water conservation practices. The permissible soil erosion is the boundary line to distinct the adverse erosion and harmless erosion, so it should be determined reasonably and precisely. The overestimation of permissible soil erosion must result in the exaggeration of the project scale of soil-water conservation then to waste the construction capital. Whereas, it will result in the aggravation of soil erosion and soil fertility reduction then to raise the production cost. From “ The Classification standard of Soil Erosion Type & Soil Erosion Density” announced by the State Water Conservancy Ministry in 1984, the permissible soil erosion should be 500 t/(km^2 • a) for Southern China and 1,000 t/(km^2 • a) for Northern China[2]. In the red-earth region of Southern China, the permissible soil erosion in the granite derived red-earth should be less than 200 t/(km^2 • a) for Southern China and 1,000 t/(km^2 • a) for Northern China. In the red-earth region of Southern China, the permissible soil erosion in the granite derived red-earth should be less than 200 t/(km^2 • a) suggested by Ruan Fu shui (1995)[3]. Soil erosion is depended on the joint effects of many factors including precipitation, soil, vegetation and landscape, so that the permissible soil erosion should be varied with the local conditions. As we known, the basis of sustainable agriculture is the soil fertility balance, while nitrogen is the most important factor in soil fertility[4]. From the data of long-term investigation on the precipitation and soil-water-nutrient losses in different ecological modes, we suggested the soil erosion to maintain the balance of nutrient input from precipitation with nutrient output by soil-water losses should be 997 t/(km^2 • a)—1,828 t/(km^2 • a). Pang Ting bai (1999) reported that: the soil organic matter and corn yield will be reduced by one half and one fourth, respectively, with a topsoil loss of 1mm[5]. The summarized analysis result of soil N indicated that the enrichment coefficient of soil nutrient in soil-water losses of red-earth was as high as nearly 2. This implied that the soil nutrient loss is a significant nutrient enrichment process rather than a simple physical transportation. Obviously, the proportion of fine particle in the runoff soil was rather large, while the fine particles has higher absorption ability then to remove more nutrients. Under the present scientific level and production conditions, we suggested the permissible soil erosion limit in the Q_2 derived red-earth should be less than 300 t/(km^2 • a) in order to maintain the higher soil fertility and give maximum economic benefits for long time (Talble 2). Furthermore, in the present experiment the actual soil erosion of natural virgin red-earth was as high as 256 t/(km^2 • a), which exceeded 20% of the permissible soil erosion. This implied that the natural red-earth still has been in degradation.

Table 2 The balance of input and output of soil N in the sloping red-earth

Treatment	N NIP (Nkg/hm^2) ①	N soil (N g/kg) ②	N NOSWL (N kg /t) ③	N NNER [6] (N g/kg) ④	N NECSWL ⑤	N NERC ⑥	Soil erosion (t/(km^2• a))	
							Balance ⑦	restoration⑧
Barren Land	17.55	0.41	0.96	>1.5	2.34	3.66	1,828	213
Woodland	17.55	0.72	1.26	>1.5	1.75	2.08	1,392	382
Bamboo Land	17.55	0.75	1.32	>1.5	1.76	2.00	1,330	377
Fruitland	17.55	0.82	1.68	>1.5	2.04	1.83	1,044	280
Tea Garden	17.55	0.85	1.72	>1.5	2.02	1.76	1,020	287
Farmland	17.55	0.86	1.76	>1.5	2.04	1.74	997	281
Average	17.55	0.735	1.45	>1.5	1.99	2.17	1,268	303

Note: N output by soil-water losses were estimated by the average values for virgin land, woodland, bamboo garden, tea garden and farmland; The term⑤=③/②, ⑥=④/②, ⑦=①/③*100, ⑧=⑦/⑤/⑥. NIP= Nitrogen Input from Precipitation; NOSWL=Nitrogen Output Soil-Water Losses; NNER=Nitrogen Need for Ecological Restoration; NECSWL=Nitrogen Enrichment Coefficient in Soil-Water Losses ; NECRC=Nitrogen Ecological Restoration Coefficient

3.5 Control practices of soil erosion

3.5.1 Contour cropping

Land slope is the most essential factor for the soil-water losses, thus to modify the landscape could significantly reduce the soil erosion. From the results of long-term experiment, to use contour cultivation could reduce soil erosion by 199 t/(km^2 • a)—388 t/(km^2 • a), i.e. the soil erosion reduction at average 67.5%(Table 3).

Table 3 Effects of various farming practices on the soil-water losses in sloping red-earth

Use mode	Cropping pattern	Average slope (°)	Hedgerows species	Soil erosion (t/(km^2.a))	Erosion reduction	
					(t/(km^2 • a))	(%)
Farmland	SC	15		570	0	0
	CC	15		182	388	68.1
	SC	15	CR; IAC	196	374	65.6
Citrus garden	SC	15		395	0	0
	CC	15		96	199	67.4
	CC	15	PTR; MBC	41	254	86.1
Pear garden	SC	13		280	0	0
	SC	13	Dry rice	68	212	75.7
Bamboo garden	SC	13		111	0	0
	SC	13	BLM	55	56	50.4
Woodland	SC	13		94	0	0
	SC	13	PNF	32	62	65.9
Barren land	Natural slope	8		262	0	0
	Natural slope	8	VZ	129	133	50.7

Note: CR = Cassia Rotundifolia; IAC = Indigofera Amblyantha Craib.;PTR = Poncirus Trifoliata(L.);MBC = Mohonia Bealei(Fort.) Carr;BLM = Bosa Laevigata Michx.;VZ = Vetiveria Zizanioides;PNF = Paspalam Notatum Flugge.

3.5.2 Plant hedgerows

The plant hedgerows can block both water-flew retardation and sink originally the soil in site. The observation of three years study showed that use plant hedgerows can decrease soil erosion by 56 t/(km^2 • a)—374 t/(km^2 • a), i.e., the average soil loss rate to reduce by 60.8%, its effect was next to contour cultivate (Table 3).

3.5.3 Preservation in developing process

From the results for 14-yr long-term experiment, we concluded that the strategy "Preservation in Developing Process" will be ideal way in hilly red-earth region. To use the contour cultivation or plant hedgerow technique could effectively limit the soil loss rate within the permissible soil erosion (200 t/(km^2 • a)) (Fig.1).

4 Conclusions & discussion

(1) The annual average runoff coefficients for the different ecological modes were estimated at 33% for fallow virgin land, 23% for natural sloping land, 4% for tea garden and farmland, nearly 2% for contour cropped farmland and fruit garden. The annual average soil erosion for various ecological modes were estimated at 5,193 t/(km^2 • a) for fallow virgin land, 256 t/(km^2 • a) for natural sloping land,

157 t/(km^2 • a) for woodland, tea garden and fruit garden, 107 t/(km^2 • a) for contour cropped farmland, and 591 t/(km^2 • a) for straight cropped farmland. The contour-cropping mode will be specially recommended to farmers in hilly red-earth region for its easy operation and good effects.

(2) From the data of 14-yr long-term investigation on the precipitation and soil-water losses, and based on the view of soil fertility balance, we suggest the permissible soil erosion should be less than 300 t/(km^2 • a) in order recover the ecological balance and gain abundant economic benefits for long time.

(3) The soil-water losses in sloping red-earth was closely related with plant coverage, i.e. soil erosion will increase by 120 t/(km^2 • a) with a slope rise of 1° ; and soil erosion will increase duplicately with a vegetative coverage increase of 10%: as well as the soil erosion will be limited within the permissible soil erosion 200 t/(km^2 • a), so , It is necessary to maintain the vegetative coverage in wet season to be above 60%.

(4) The contour cultivation mode will be the best way to control soil-water losses, and next is the plant hedgerow technique. The "Preservation in developing process" is more advantageous than natural ecological restoration.

References

[1] Shui Jianguo, Kong Fangen, Zheng Junchen. Effects of different uses of red soil slopes on soil and water loss. Journal of soil and water conservation.1989,**3**(1):84-90.

[2] Chen Qibo,Qi Shi,Sun Lida. Process and trend of soil loss tolerance research. Bulletion of Soil and water Conservation,2000,**20**(1):9-13.

[3] Luan Fushui, Wu Xianghai, Shi Yuezhong et.al.. Study on permissible soil erosion in Granite area of Fujian province. Soil and water conservation in Fujian.1995,No.2,p.26-31.

[4] He Dianyuan. Nutrient balance of agro-ecosystem is the important condition for sustainable agriculture. Research of agricultural modernization. 1999,**20** (4) :241-243.

[5] Peng Tingbai, Huang Daoyou, Chen Huiping,et.al.. Establishment of the harmonious mechanism of water and soil to ensure the sustainable development of agriculture. Eco-agriculture research. 1999, **7** (1) :36-39.

[6] Shi Deming, Wei Qinfan, Liang Yin,et.al.. Study on degradation index system of eroded soils in Southern China. Journal of soil and water conservation, 2000,**14**(3):1-9