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Effects of Terracing and Agroforestry on Soil and Water Loss in Hilly Areas of the Sichuan Basin, China

J.H. ZHANG[1,2 *], Z.A. SU[2,3] , and G.C. LIU[1,2]

[1] *Key Laboratory of Mountain Hazards and Earth Surface Processes, Chinese Academy of Sciences, 610041, China*

[2] *Institute of Mountain Hazards and Environment, Chinese Academy of Sciences & Ministry of Water Conservancy, Chengdu 610041, China*

[3] *The Graduate School of the Chinese Academy of Sciences, Beijing 100049, China*

* *Corresponding author, e-mail: zjh@imde.ac.cn*

Abstract: Soil erosion in hilly areas of the Sichuan Basin is a serious concern over sustainable crop production and sound ecosystem. A 3-year experiment was conducted using the method of runoff plots to examine the effects of terracing and agroforestry in farmland systems on soil and water conservation of slope fields in the hilly areas in Jianyang County, Sichuan Province, Southwestern China. A power function (Y = aX^b) can statistically describe the relationship between water runoff (Y) and rainfall (X). The regression equation for the treatment of sloping terraces with crops (Plot 2) is remarkably different from that for the treatment of sloping terraces with grasses and trees (Plot 1) and the conventional up- and down-slope crop system (Plot 3) regarding equation coefficients, while regression equations are similar between Plot 1 and Plot 3. Water runoff amount and runoff coefficient of slope fields increased by 21.5~41.0 % and 27.5 ~ 69.7 % respectively, compared to those of sloping terraces, suggesting that terracing notably reduced the water runoff in the field. In the case of sloping terraces, lower amount of water runoff was observed on sloping terraces with crops than on sloping terraces with grasses and trees. Sediment yields on the slope fields in the normal year of rainfall distribution were notably higher (34.41 ~ 331.67 % and 37.06 ~ 403.44 % for Plot 1 and Plot 2, respectively) than those on sloping terraces, implying that terracing also plays a significant role in the reduction in soil erosion. It is suggested that terracing with crops is significantly effective for soil and water conservation in cultivated farmland, while the conventional practice of up- and down- slope cultivation creates high rates of water runoff and soil sediment transport. Terracing with grasses and fruit trees shows a less reduction in water runoff than terracing with crops, which was observed in the 3-year experiments.

Keywords: Agroforestry; sediment transport; runoff; sloping terrace; soil and water conservation

Introduction

The hilly areas of the eastern part of Sichuan Province, Southwestern China, covering an area of 121,000 km², are important agricultural production base for Sichuan Province. Yet, the hilly areas are facing the serious problem of environment degradation owing to conventional agricultural practices. In this region, there are 5,491,000 ha slope fields of severe soil and water losses that account for 62.8 % of the total area of farmland, one fifth of which is of steep land with slope gradients over 25 degrees. The Central Government of China has initiated “Ecological reconstruction in the Upper Yangtze River Basin” (including hilly areas of the Sichuan Basin) and enacted an afforestation / reforestation bill, i.e., converting cultivated slope fields with over 25 degrees into forestland and grassland. If all the steep sloping farmland is forested from cultivation, the local people’s life will be adversely affected and

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furthermore, the gully erosion may be intensified (ZHANG et al. 2003). Terracing divides the long slope into short slopes, resulting in the reduction in sheet and rill erosion. Meanwhile, terracing that changes landform and reduces the slope gradient may reduce runoff amount and rate (ZHANG et al. 1999). Therefore, in addition to afforestation / reforestation in the cultivated slope fields with over 25 degrees in severe soil erosion regions, terracing in steep farmland is an alternative way for soil and water conservation. However, research results showed large differences in the effectiveness of soil and water conservation among different regions. A 80 % and 90 % reduction in water runoff and sediment transport, respectively with terraces was reported on purple soil of southwestern China (ZHU 1988), while there was only a 10~20 % reduction in water runoff and sediment transport in the Loess Plateau of China (JIANG et al. 1989). Few researches have contributed to the understanding of the effects of terracing in combination with agroforestry on water runoff and soil erosion. Furthermore, level terrace construction has been recommended for controlling soil erosion, yet it spends much more labour and is lower cost-effective than sloping terrace construction. As a consequence, the effects of sloping terraces on reducing soil and water losses need to be identified.

On the other hand, forage and fruit trees are an important source of cash income for local farmers, as an increasing demand for sources of protein (meat and milk) and fruit has been evident with the improvement of the people's living standards. Therefore, there is a need to develop forage for animal breeding and fruit trees in farmland systems. Incorporation of trees or grasses in farming systems could maximize the use of resources, enhance land productivity, and protect the environment (LIU B. et al. 2001). Due to the influence of vegetation cover, the relationship between rainfall and erosion is non-linear and complex. The greater the annual precipitation and the higher the rain intensity, the stronger erosivity is due to rainfall and rainstorm runoff. Thus, there is a positive correlation between rainfall and erosivity (Langbein and Schumm 1958, Wilson 1973). On the other hand, high annual precipitation creates a large biomass of vegetation, thereby leading to strong protection of vegetation against rainfall and water erosion, or high erosion resistance of vegetation (XU 2005). Vegetation cover increases soil anti-scourability, favorable to soil and water conservation (ZHANG et al. 2003). As a result, there is a negative correlation between precipitation and erosion resistance due to vegetation cover. These diametrically opposed views indicate that the relationship between precipitation and erosion becomes uncertain due to the influence of vegetation, and therefore, there is a need to investigate the relationship between them for sustainable soil management strategies.

In this study, a 3-year experiment was conducted to examine the effects of sloping terraces with agroforestry and sloping terraces with crops on soil erosion and overland water flow to maintain sustainable land productivity and sound ecosystems in hilly areas of Sichuan. The objectives of this study were (1) to examine the effects of terracing on runoff and sediment transport in farming systems, and (2) to identify the influence of sloping terraces with agroforestry on soil and water conservation.

1 Research Area and Methodology

1.1 Description of research area

The study area was located in Jianyang County (30°04'28" ~ 30°39'00" N and 104°11'34" ~ 104°53'36" E), Sichuan, China. The elevation ranges from 400 to 587 m asl. The study area has a humid subtropical climate with distinct seasons. Temperature averages 17°C with the highest 38.7°C and the lowest –5.4°C. The annual accumulative temperature of ≥0°C is averagely 5,421°C. Mean annual precipitation is 872.2 mm, over 80 % of which occurs between April and October. Mean annual sunlight radiation is 90 kc/cm^2 and mean annual sunlight 1,240.6 hours. In the hilly areas, only a small part of vegetation is natural, while large part of vegetation is planted. Dominant crops are wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), sweet potato (*Ipomoea batatas* (L.) Lam), peanut (*Arachis hypogaea* L.) and rape (*Brassica napus* L.). The soil in the study area, derived from purple mudstone and sandstone of the *Jurassic* Age is classified as Regosols in the FAO soil taxonomy (FAO 1988).

1.2 Research methods

1.2.1 Set-up of runoff plots

Three plots of runoff observation with an area of 20 m × 5 m each were established in the study area in the 2002 winter season. Three treatments performed in the three runoff plots were as follows.

Plot 1: 3-year-old fruit tree (pear) seedlings were planted in rows at spacing of 3 m × 1 m, and grasses (*Medicago sativa*) were planted between tree rows on sloping terraces (3 steps in total) with a 4° slope gradient.

Plot 2: Crops (wheat – maize/sweet potato rotation) were planted on sloping terraces (3 steps in total) with a 4° slope gradient.

Plot 3: Crops (wheat – maize/sweet potato rotation) were planted in slope fields with a 9° slope gradient.

1.2.2 Sample collection

Each plot was bound on all sides by concrete borders except for the down-slope end. A baffle was installed at the down-slope end of each plot to block the runoff and direct it to a sediment collection tank of 5 m × 0.4 m × 0.6 m volume. A one-tenth aliquot of possible overflow from the sediment collection tank was separated by a multi-slot divisor and collected in a second collection tank of 1 m^3 volume. Following each rainstorm event, the amount of runoff in the respective tanks was measured after the sediments were settled down. Soil sediment was measured by manually stirring the dip in each tank and collecting 1000 ml samples of the mixture. The mass of soil sediment was determined following sediment samples precipitated with alum, water decanted, and then oven dried at 105 °C. The dataset from auto-rain recorder set up nearby the runoff plots gave the variation of rainfall amount during the rainfall event.

1.2.3 Soil baseline sampling and determination

The baseline soil physicochemical properties of runoff plots were determined to retain consistent experimental conditions. Core samples were collected with 6 replicates at 0~15 cm depth and 4 replicates at 15~30 cm for each plot prior to the experiment to determine soil bulk density. A composite sample for determination of physicochemical properties at the depth of 0~15 cm was taken from each treatment in April 2003. Each composite soil sample consisted of 10 augers.

Soil bulk densities were determined using oven-dried weight and sample volume. Soil particle size fractions were determined in 1,000 ml soil solution with the pipette method following H_2O_2 treatment to destroy organic matter and dispersion of soil suspensions by Na-hexametaphosphate. Soil pH was measured in a 2.5:1 soil-water suspension and calcium carbonate in soil was measured using the CO_2 mass method (Nanjing Institute of Soil Science, Chinese Academy of Sciences 1978). Soil organic matter (SOM) was determined using wet oxidation with $K_2Cr_2O_7$. Total nitrogen analysis followed the Micro-Kjeldahl digestion method. The determination of total P was carried out using NaOH digestion method. Other measurements included available nitrogen (N) (NaOH extraction and distilling) and available phosphorous (NaOH extraction method). Total potassium and available potassium were determined with NaOH digestion and ammonia acetic extraction, respectively (LIU 1996).

1.2.4 Data statistics

Paired-samples T test was used to detect the differences in runoff among the treatments. Runoff and erosion data for each rainfall event were analyzed by the linear or non-linear correlation utilizing SPSS statistic package. The level of significance, if not otherwise indicated, reflects a statistical significant correlation ($P < 0.05$).

2 Results and Discussion

2.1 Baseline soil physical and chemical properties of the runoff plots

The baseline soil physical and chemical properties of runoff plots are presented in Table 1. The physical properties among the three treatments were highly consistent, with Coefficient of Variance (CV) values of 2.0~6.7 %. Differences in total P and K contents and pH values were also small with CV values of 1.6~4.3 %, while Organic Matter (OM) and available nutrient contents showed higher CV values (10.4~18.5 %). The CV values of soil particle size fractions and bulk density were small compared with soil OM and nutrient contents, showing that soil physical properties were more similar than chemical properties. The similarity of the baseline physical property among different plots was favorable to compare the experimental results on water runoff and soil sediment transport, as physical properties exerted an important impact on soil erodibility.

Table 1 Soil physicochemical properties of the runoff plots

Treatment	OM (g/kg)	Total N (g/kg)	Total P (g/kg)	Total K (g/kg)	Available N (mg/kg)	Available P (mg/kg)	Available K (mg/kg)	pH		Particle size fraction (USA system) (%)			Bulk density (Mg/m^3)	
								KCl	H_2O	Sand	Silt	Clay	0~15 cm depth	15~30 cm depth
Plot 1	14.4	0.75	0.87	22.3	68.5	19.1	187	6.50	7.19	18	48	34	1.26	1.37
Plot 2	10.9	0.92	0.92	20.5	75.3	24.6	194	6.87	7.3	16	46	38	1.23	1.31
Plot 3	12.1	0.72	0.91	21.7	61.1	17.4	239	6.64	7.42	18	46	36	1.28	1.30
Mean	12.47	0.80	0.90	21.50	68.30	20.37	206.67	6.67	7.30	17	47	36	1.26	1.33
SE	1.78	0.11	0.03	0.92	7.10	3.76	28.22	0.19	0.12	1.15	1.15	2.00	0.03	0.04
CV (%)	14.27	13.54	2.94	4.26	10.40	18.48	13.65	2.80	1.58	6.66	2.47	5.56	2.00	2.85

Sampling date: April 7, 2003

Table 2 Rainfall temporal distribution in the study area (mm)

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
2003	0	0	0	0	82.3	32.7	38.3	106.7	47.3	10.6	6.2	7.2	331.3
2004	10.5	24.5	78.9	33.5	54.1	131.0	49.8	149.2	61.5	45.2	10.9	7.0	656.1
2005	0	0	0	0.3	61.8	178.0	190.2	223.1	70.3	22.4	19.9	9.7	775.7
Mean (3 yrs)	3.5	8.2	26.3	11.3	66.1	113.9	92.8	159.7	59.7	26.1	12.3	8.0	587.7
Annual mean (30 yrs)	9.8	11.7	17.9	44.7	74.7	128.9	199.7	181.4	132.6	44.0	18.6	8.2	872.2

2.2 Rainfall and runoff

2.2.1 Temporal distribution of rainfall

During the period of the 3-year experiment, on the whole, the distribution of erosive rainfall between May and September (62.33 % of the total rainfall) was similar to that of mean annual rainfall (58.47 % of the total rainfall). Annual precipitation was recorded as 331.3 and 775.7, respectively for the years of 2003 and 2005. The rainfalls causing runoff and/or erosion between May and September were 276 mm and 298 mm (data not shown), taking up 83 % and 38 % of annual precipitation, respectively in 2003 and 2005. However, compared to the distribution of erosive rainfall generally occurring between May and September, the rainfall in 2004 appeared to be abnormal, i.e., a rain storm event occurred in April. The 3 years' mean annual rainfall was 32.62 % lower than the long-term mean annual rainfall, and the 3 years' mean rainfall between May and September decreased by 28.16 % compared to the long-term mean rainfall, showing that there is a drought tendency in recent years.

2.2.2 Runoff amount and coefficient

The conventional crop system in slope fields (Plot 3) yielded the highest runoff amount (206.6 mm) (Table 3), while the lowest runoff amount (122.2 mm) was found in the treatment of sloping terraces with crops (Plot 2) among the three treatments during the 3 years' experiment. A moderate amount of runoff (162.2 mm) was observed in the treatment of sloping terraces with grasses and trees (Plot 1). Compared to Plot 3, the runoff amounts in Plot 1 and Plot 2 decreased by 21.5% and 41.0%, respectively. Among the three treatments, the highest runoff coefficient (0.250) was also observed in Plot 3, being 27.5 % and 69.7 % more than that of Plot 1 (0.193) and Plot 2 (0.145). Statistics showed that there were significant differences among the three treatments ($P \leq 0.05$; Table 4). As a result, runoff would occur more easily in Plot 3 than in Plots 1 and 2.

The reduction in runoff was significant in Plots 1 and 2, compared to Plot 3. This indicates that terracing is an effective approach for reducing overland water flow, as a result of the conversion from long slope into short one and the decrease in slope gradient. The runoff amounts and runoff coefficients were both higher in Plot 1 than in Plot 2, showing that sloping terraces with crops play a more effective role in reducing runoff than sloping terraces with grasses and trees. Better effectiveness of alfalfa (*Medicago sativa*) on reducing runoff cannot be observed in the present context, which does not agree with previous studies indicating that grass and tree planting has better water conservation effectiveness than cropping (LIU *et al.* 2005). This difference was attributed to tillage performed in crop systems (Plot 2). No tillage practices were conducted in Plot 1, while major tillage was preformed once each year in Plot 2. Tillage increases soil porosity, thereby increasing soil infiltration rate and water holding capacity. As a result, more runoff was observed in Plot 1 than in Plot 2.

2.2.3 Relationship between runoff and rainfall

The relationship between runoff (Y) and rainfall (X) can be described by function $Y=aX^b$ for the three treatments and significant correlations between rainfall and runoff were found for each plot (Table 5). Accordingly, rainfall exerts an important impact on overland water flow. The regression equation for Plot 2 is remarkably different from that for Plots 1 and 3 with respect to equation coefficients, while regression equations are of a similarity between in Plot 1 and Plot 3. The mean equation coefficient for Plots 1 and 3 is 2.3 times higher than that for Plot 2 when equation powers are of small differences, showing that runoff in Plot 2 increases with rainfall much more slightly than the others. Although the regression equations are similar between Plot 1 and 3, the rationale on the influence of rainfall on runoff is different from each other. Sharp increase in runoff with rainfall in Plot 1 is attributed to the reduction in soil porosity due to no-till treatment during the period of 3-year experiments; whereas such a change in Plot 3 is closely linked to slope steepness and length.

2.3 Sediment transport

Unlike runoff, sediment transport was not significantly correlated with rainfall ($P>0.1$), even not in the conventional crop system (Plot 3). The results might be linked to vegetation cover of the treatment plots. The cover of crops or alfalfa (*M. sativa*) directly reduces splash erosion and sheet erosion. And the plant roots improve the aggregate degree of topsoil (Cassel 1985, SHI et al. 2005), which enhances soil anti-scourability (ZHANG et al. 2003), thereby diminishing soil erosion.

Sloping terraces with grasses and trees (Plot 1) created larger amount of sediments than the other two treatments (Plot 2, 3) in the year 2004 (Figure 1). The main reason for this is that the first event of erosive rainfall occurred earlier (in April) in 2004 than in the rest years, so that alfalfa (*M. sativa*) had not yet grown up and therefore the land surface had not been covered with leaves at that time, resulting in a great deal of sediment transport. The vegetation coverage was different between Plot 1 and Plot 2 in different periods of time in an annual cycle. Alfalfa (*M. sativa*) is a perennial plant and there is a low cover in winter and early spring, whereas crops, such as wheat, maize/sweet potato have a dense cover in such a period. From the 2004 observations, it can be found that vegetation cover has an important impact on reducing sediment transport.

Table 3 Erosive rainfall and runoff for the three treatments

Year	Plot 1		Plot 2		Plot 3		Rainfall (mm)
	Runoff (mm)	Runoff coefficient	Runoff (mm)	Runoff coefficient	Runoff （mm）	Runoff coefficient	
2003	9.5	0.03	4.8	0.02	10.0	0.04	275.7
2004	31.3	0.12	23.0	0.09	30.4	0.11	266.6
2005	121.4	0.41	94.4	0.32	166.2	0.56	298.4
Mean	54.1	0.19	40.7	0.14	68.9	0.24	280.2

Table 4 Paired-samples T test among the three treatments

Treatment	Plot 1			Plot 2		
	Runoff	d.f.	Sig.	Runoff	d.f.	Sig.
Plot 2	2.111	15	0.052			
Plot 3	2.517	15	0.024	2.743	15	0.015

Table 5 Regression equations of the relationship between runoff and rainfall

Treatment	Regression equation	R^2	Sig.
Plot 1	$Y = 0.0321X^{1.3678}$	0.5330	0.001
Plot 2	$Y = 0.0099X^{1.5935}$	0.6046	0.0001
Plot 3	$Y = 0.0338X^{1.3973}$	0.5120	0.002

The largest amount of sediment transport was observed in the crop system in slope fields (Plot 3) among the 3 treatments in 2003 and 2005 (Figure 1). The observations showed that the sediment transport in Plot 3 was 331.67% and 403.44 %, respectively more than that in Plot 1 and Plot 2 in 2005, and the increase in Plot 3 was 34.41 % and 37.06%, respectively more than Plot 1 and Plot 2 in 2003. Those differences can be attributed to terracing due to the reduction in slope length and gradient. This result agrees with the previous studies on terracing effects on soil sediment transport (Hammad et al. 2006). The soil sediment transport increased with increasing rainfall during the period of 3-year experiments in Plot 3, while no increasing trend with rainfall was found in Plot 1 and Plot 2, thus suggesting that the conservation practices (Plot 1 and 2) have apparent effectiveness of reducing soil loss, compared to the conventional practice (Plot 3).

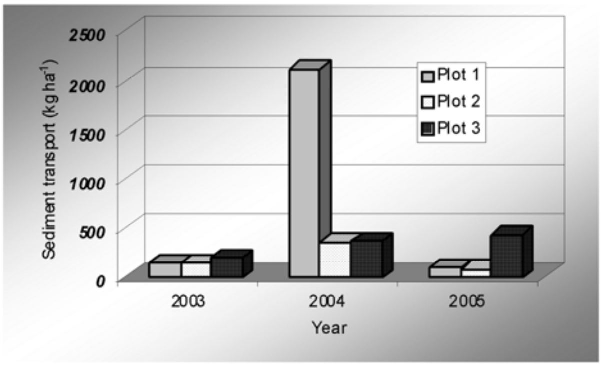

Figure 1 Comparison of sediment transports among the different treatments

3 Conclusions

A power function (Y=aX^b) can statistically describe the relationship between water runoff and rainfall. The regression equation for the treatment of sloping terraces with crops (Plot 2) is remarkably different from that for the treatment of sloping terraces with grasses and trees (Plot 1) and the conventional crop system (Plot 3) regarding equation coefficients, while regression equations are of a similarity between Plot 1 and Plot 3. The mean value of equation coefficients for Plots 1 and 3 is 2.3 times higher than that for Plot 2 when equation powers are of small differences, showing that the runoff in Plot 2 increases with rainfall much more slightly than the others. The water runoff amount and runoff coefficient in slope fields increased by 21.5~41 % and 27.5~69.7 %, respectively, compared to those of sloping terraces, showing that terracing notably reduces water runoff in the field. In the case of sloping terraces, lower amount of water runoff was observed on sloping terraces with crops than on sloping terraces with grasses and trees. Sediment yields in the slope fields, in the normal year of rainfall temporal distribution, were notably higher (34.41~331.67 % and 37.06~403.44%, respectively) than those in sloping terraces, suggesting that sloping terraces play a significant role in the reduction in soil erosion. It is suggested that sloping terraces with crops is significantly effective for soil and water conservation in cultivated farmland, while the conventional practice of up- and down- slope cultivation creates high rates of water runoff and soil sediment transport. Terracing with alfalfa (*M. sativa*) and fruit trees shows a less reduction in water runoff than terracing with crop systems during the period of the 3-year observation. An additional observation is required to identify the effects of grass and tree planting on water runoff and soil sediment transport. It is recommended that terracing in slope fields should be widely practiced in hilly areas of Sichuan.

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