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Effects of land use on soil erosion and nutrient loss in the Three Gorges Reservoir Area, China

Q.H. Meng[1], B.J. Fu[1]*& L.Z. Yang[2]

Abstract. By comparing field measurements from 1989, 1997, and 1998, the differences between farmland (sloping farmland, sloping farmland with contour cultivation, terraced farmland) and orchard (terraced orchard, unterraced orchard), in the Three Gorges Reservoir Area, were significant for runoff ($P<0.01$), erosion ($P<0.05$) and nutrient loss ($P<0.05$). Taking into account economic costs and environmental influences, reasonable and sustainable land use on slopes of 25° in the Three Gorges Reservoir Area should be unterraced orchard.

Keywords: Erosion, soil, losses from soil, nutrients, land use, China

INTRODUCTION

The Three Gorges Reservoir Area (TGRA) refers to the 20 counties along the Yangtze valley between Chongqing and Yichang; the land area is 55 800 km^2 and the population is about 16 million. Compared to other reservoirs in the world, soil erosion is an important factor affecting the safety of the Three Gorges Reservoir (Du *et al*. 1994). Sediment from farmland is responsible for 60% of the total soil erosion and 46% of the total sediments deposited in the Three Gorges Reservoir (Shi *et al*. 1992).

About 70% of farmland in TGRA is sloping land, and more than 25% is at approximately 25° (Chen 1992). With the forced reallocation of one million people, many may migrate upslope, so that the erosion hazard in the TGRA is likely to increase. The problem is how to utilize the sloping land at 25° in the TGRA while maintaining the safety of the Three Gorges Reservoir and an acceptable environmental quality.

Significant differences due to land use and types of management, in amounts of runoff ($P<0.05$), soil loss ($P<0.05$) and nutrient (N and P) loss ($P<0.05$) were observed (Thomas *et al*. 1992). On steeply sloping land, soil erosion is an important process influencing nutrient loss from the ecosystems (Fu & Chen 2000). Land use may accelerate the irreversible nutrient loss (Ripl 1995). The present study was designed to address the general need for basic information on the effects of land use at slopes of 25° on soil and nutrient loss and to address the specific need for information about the reasonable utilization of more steeply sloping land in the TGRA. So the objectives of this study were:

(1) To study the effect of land use on runoff and erosion at 25°.
(2) To study the effect of land use on nutrient (total N, P and K) loss at 25°.
(3) Based on (1) and (2), to suggest sustainable land use at 25° in the TGRA.

MATERIALS AND METHODS

Site Description

The field plots were located at Wangjiaqiao Soil and Water Conservation Station (31° 57′N, 110° 58′E). Wangjiaqiao experiences a subtropical monsoon climate; average annual temperature is 18 °C; mean annual precipitation is 1016 mm, and about 60–80% of rainfall falls between May and September. All the plots were on Lithic Eutrudepts, with a depth of less than 50 cm and pH of 8.0 to 8.9. The particle composition of the topsoil is shown in Table 1.

In 1986, five field plots (5 by 10 m) were established on a south-facing slope of 25°, and three years later field measurements were begun. To avoid the effects of position, all five plots were established in one line, and they were oriented parallel to the slope and adjacent to each other. A discharge ditch was created at the top of each plot to control runoff and sediments from the upper slope.

Land use was: Plot 1: terraced orchard (orange *Citrus sinensis* Osbeck); Plot 2: terraced arable; Plot 1 and Plot 2 were divided into three equal terraces. Each terrace was 5 m long by 2.05 m wide, with stone edges 25 cm wide. Plot 3: unterraced arable with contour cultivation; Plot 4: unterraced arable; Plot 5: unterraced orchard (orange *C. sinensis* Osbeck). In Plots 2, 3, 4, wheat, maize and soyabean were

[1]Department of Systems Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, P.O.BOX 2871, Beijing 100085, China.
[2]Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008, China.
*Corresponding author, E-mail: bfu@mail.rcees.ac.cn, Fax: +86–10–62923563

Table 1. Particle and aggregate composition of eroded sediment and topsoil (%) in the experimental area.

	2–0.2 mm		0.2–0.02 mm		0.02–0.002 mm		<0.002 mm	
	Particle	Aggregate	Particle	Aggregate	Particle	Aggregate	Particle	Aggregate
Topsoil	5.0	23.8	34.8	35.3	25.5	24.7	31.2	16.1

intercropped between 1997 and 1998 to maintain high plant cover; in Plots 1 & 5, mature trees were pruned each year in order not to influence the adjacent plots (Plots 2,3,4),

Methods
The gaseous loss of nitrogen was ignored since the area of each plot was only 50 m^2; because the trees were mature, the nutrient storage in stock every year was ignored.

Runoff and sediments were collected in two volumetrically calibrated tanks arranged in series at the base of each plot. The depth of runoff in each tank was measured and sampled as soon as each event ended. Then every tank was cleared of sediment and water. Using the USEPA sampling and analysis methods (Keith 1996), water (including runoff and rainfall), soil (including sediments) and plant (including crop and fruit) samples were analysed for total N, total P, and total K.

Nutrient loss in runoff and rainfall was expressed by the following equation:

$$\text{Total load} = \sum_{i=1}^{n} \text{nutrient conc.}(\text{mg l}^{-1}) \times \text{Flow (mm)} \times 10^{-2}$$

Nutrient loss in sediment was expressed by the following equation:

$$\text{Total load} = \sum_{i=1}^{n} \text{nutrient conc.}(\text{mg l}^{-1}) \times \text{Weight(kg)}$$

where n is the total number of erosive storms in each year.

Nutrient loss in crop and fruit was expressed by the following equation:

$$\text{Total load} = [\text{nutrient conc.}(\text{mg l}^{-1}) \times \text{Weight(kg)}]$$

Percentage of nutrient loss in runoff and sediments was expressed as:

$$\frac{\text{Nutrient loss}}{\text{Total nutrient output}} \times 100$$

Statistical analyses were performed to make treatment comparisons of runoff, soil loss, and nutrient (N, P and K) loss, using one-way ANOVA and the mean comparisons procedure from SPSS (SPSS Inc. 1993).

RESULTS AND DISCUSSION

Effects of land use on soil loss and runoff
There were fourteen erosive storms in 1997 and 1998. The total amount of erosive rainfall in 1997 was less than that in 1998, but the intensity in 1997 was greater than that in 1998 (Figures 1 and 2).

The amount of soil erosion was in the order: unterraced arable (Plot 4) > unterraced arable with contour cultivation (Plot 3) > terraced arable (Plot 2) > unterraced orchard (Plot 5) > terraced orchard (Plot 1) (Figures 3, 4, 5).

In 1989, the amount of runoff was: arable with contour cultivation (Plot 3) > unterraced arable (Plot 4) > unterraced orchard (Plot 5) > terraced arable (Plot 2) > terraced orchard (Plot 1), but in 1998 and 1997, it became: unterraced arable (Plot 4) > arable with contour cultivation (Plot 3) > terraced arable (Plot 2) > unterraced orchard (Plot 5) > terraced orchard (Plot 1).

Changes of runoff with time on terraced arable (Plot 2) shows that the effect of terraces on steep slope land (25°) is to retain soil, not to reduce runoff. Differences in runoff between Plot 3 and Plot 4 showed that contour cultivation is useful for retaining water on unterraced arable.

Effects of land use on runoff and sediment
The differences between arable (Plots 2, 3, 4) and orchard (Plots 1 & 5) were significant for runoff (P<0.01) and sediment content (P<0.05) (Table 2). This indicated that on steep slopes, orchards (Plots 1 & 5) conserved soil better than arable (Plots 2, 3, 4) in the TGRA.

In agreement with other researchers (Maas 1988; Stott 1999), dense plant cover, good soil structure, high soil

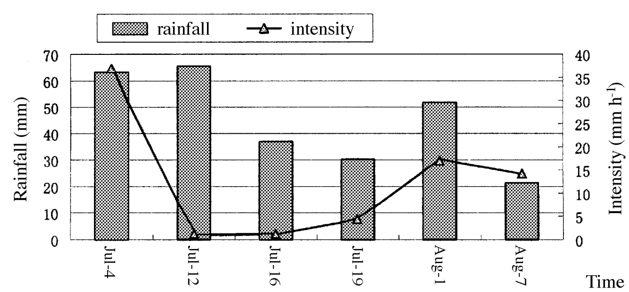

Figure 1. Rainfall and intensity in 1997.

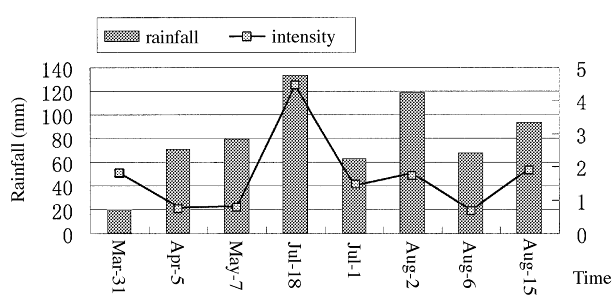

Figure 2. Rainfall and intensity in 1998.

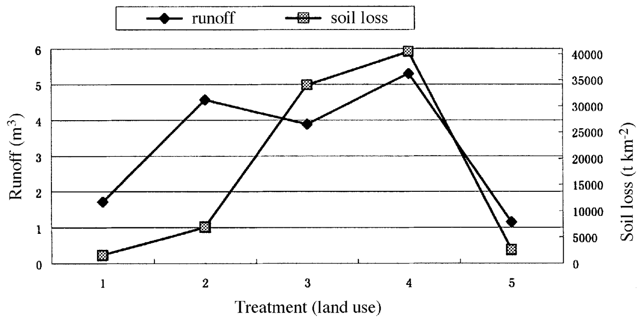

Figure 3. Runoff and soil loss in 1997. See Table 2 for treatment key.

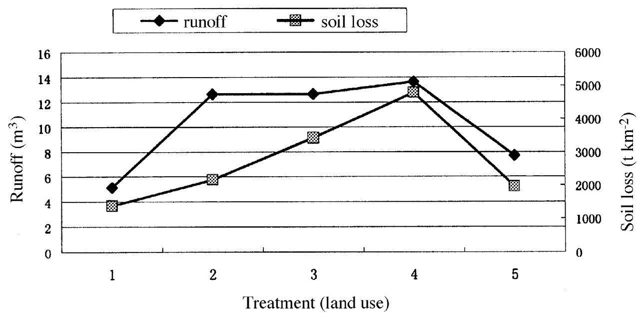

Figure 4. Runoff and soil loss in 1998. See Table 2 for treatment key.

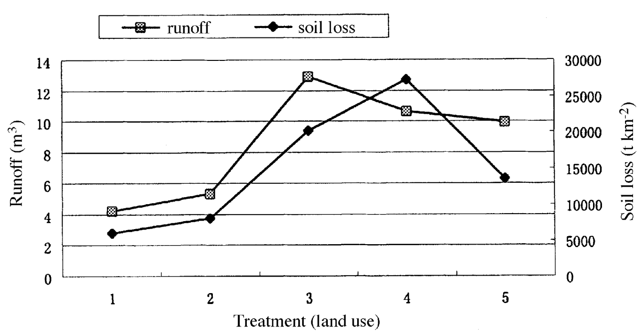

Figure 5. Runoff and soil loss in 1989. See Table 2 for treatment key.

organic matter and biological activity were the probable cause of significantly less soil loss and runoff from the orchard plots (1 & 5) than from the arable plots (2, 3, 4).

Effects of land use on nutrient loss

The amount of nutrient (N, P and K) loss was: unterraced arable (Plot 4) > arable with contour cultivation (Plot 3) > terraced arable (Plot 2) > unterraced orchard (Plot 5) > terraced orchard (Plot 1) (Table 3). Percentage of nutrient (N, P and K) loss in runoff and erosion from the orchard plots was less than 20%, whereas it was from 50% to 99% from the arable plots, showing that conserving soil and water is the first priority on arable fields, whereas, in orchards, adequate fertilizers should be applied to maintain high production.

Table 2. Multiple comparison of runoff, sediment, and nutrient output.

Plot	Runoff	Sediment	N	P	K
	P<0.01	P<0.05	P<0.01	P<0.05	P<0.05
4	A	a	A	A	a
3	A	a	A	A	a
2	A	b	B	A	b
5	B	b	B	B	b
1	B	b	B	B	b

A, B are significantly different at 99% level. Same letter is not significantly different. a, b are significantly different at 95% level. Same letter is not significantly different. Plot 1– terraced orchard; Plot 2 – terraced arable; Plot 3 – arable with contour cultivation; Plot 4 – unterraced arable; Plot 5 – unterraced orchard.

Table 3. Nutrient loss in runoff and sediment as % of total nutrient output.

Year	Nutrient	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5
	N	3.3	50.4	84.4	84.3	4.7
1997	P	2.8	58.5	92.1	91.7	4.8
	K	13.3	97.7	99.5	99.6	22.9
	N	3.0	51.3	54.2	59.8	7.3
1998	P	2.1	50.6	61.1	70.8	5.1
	K	9.8	96.8	97.9	98.7	20.9

For key to plot no. see Table 2.

Effect of land use on nutrient loss

The differences in nutrient (N, P, K) loss between arable and orchard were significant for total N (P<0.01) total P and total K (P<0.05) (Table 2). This difference indicated that, by adjusting land use, we can sustain highly productive ecosystems at the same time as good environmental quality.

The reason for these differences was attributed primarily to fertilization. Orchards maintain more soil organic matter (SOM) than arable because less harvested products are removed. More SOM content means better soil structure and greater biological activity (Stott *et al.* 1999). So orchards have significant beneficial effects on nutrient loss and the larger soil nutrient content enhances the benefits of this land use (Meng & Fu 2000).

CONCLUSION

Orchards were significantly better than arable land in retaining soil and nutrients. By extrapolating the results to TGRA, the sustainable land use should be terraced or unterraced orchard. But storms of short duration may destroy terraces and cause severe debris flow (Du *et al.* 1994). Furthermore the cost of building terraces is high. The differences between terraced and unterraced orchard were not significant, so we conclude that sustainable land use at slopes of 25° in TGRA should be unterraced orchard.

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REFERENCES

Chen Hongzhao 1992. Evaluation of impacts of the Three Gorges Project on soil environment. In: Changes of soil environment, ed. Gong Zitong, Chinese Science Technology Press Beijing (in Chinese) pp 227–231.

Du Ronghuan Shi Deming & Yuan Jianmo 1994. Effects of soil erosion on eco-environment in TGRA. Science Press, Beijing (in Chinese).

Fu Bojie & Chen Liding 2000. Agricultural landscape spatial analysis in the semi-arid hill area of the Loess Plateau, China. Journal of Arid Environments 44, 291–303.

Keith LH (eds) 1996. Compilation of EPA's sampling and analysis methods. Second Edition. CRC Press Inc.

Maas JM Jordan CF & Sarukhan J 1988. Soil erosion and nutrient loss in seasonal tropical agro-ecosystems under various management techniques. Journal of Applied Ecology 25, 595–607.

Meng Qinghua & Fu Bojie 2000. Relationship between landscape pattern and soil nutrient flow. Acta Consevationis Soli et Aquae Sinica 14, 116–121 (in Chinese).

Ripl W 1995. Management of water cycle and energy flow for ecosystem control: the energy-transport-reaction (ETR) model. Ecological Modelling 78, 61–76.

Shi DM YangYS Lu XX & Liang Y 1992. The analysis of soil erosion pattern and sediment sources in the Three Gorges Reservoir Area of Yangtze River. Acta Conservationis Soli et Aquae Sinica 5, 9–21 (in Chinese).

SPSS 1993. SPSS for windows base system user's guide release 6.0. Marjia J. Norusis / SPSS Inc.

Stott DE Hart GL Bradford JM Kung K-JS & Huang C 1999. Impact of soil organisms and organic matter on soil structure. In: Soil Quality and Soil Erosion, ed. R Lal, CRC Press Washington, D.C. pp 57–76.

Thomas ML Lal R Logan T & Fausey NR 1992. Land use and management effects on nonpoint loading from Miamian soil. Soil Science Society of American Journal 56, 1871–1875.

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