Application and problems of soil and water conservation measures for controlling land degradation and desertification in Yangtze River Basin

Liu Honghu
Changjiang River Scientific Research Institute,
Yangtze River Water Resource Commission,
Wuhan 430010, China
Honghu2005@gmail.com

Zhang Pingcang
Changjiang River Scientific Research Institute,
Yangtze River Water Resource Commission,
Wuhan 430010, China
Honghu2005@gmail.com

Jens Kiesel
Department of Hydrology and Water Resources Management, Kiel University, Olshausenstr. 75
24118 Kiel, Germany
jkiesel@hydrology.uni-kiel.de

Liu Xiaolu
Changjiang River Scientific Research Institute,
Yangtze River Water Resource Commission,
Wuhan 430010, China
liuxiaolu100@yahoo.com,cn

***Abstract*—The area where soil loss is occurring within the Yangtze River Basin is the largest in China's seven big river basins. Severe soil loss, in particular in the middle and upper reaches of Yangtze River, has damaged land resources, endangered food security and induced a high sediment input into the river and the three gorges reservoir. Thus, government and local farmers adopted soil and water conservation measures to control soil loss. This paper summarizes the characteristics of soil erosion and all soil and water conservation measures, and illustrates their roles on controlling soil loss and combating land degradation. It is indicated that soil loss in the whole Yangtze River Basin is increasingly severe due to higher rainfall intensities. Soil and water conservation measures, such as living hedgerow on sloping lands are practical. Some others are also effective, but very expensive so that they can not be adopted in the whole Yangtze River Basin. Most importantly, neither are suitable assessment methodologies and criteria applied to evaluate soil and water conservation measures, nor are measures selected to control soil loss and prevent land degradation.**

Keywords-soil loss; soil and water conservation measures; policy; soil erosion; Yangtze river

I. INTRODUCTION TO YANGTZE RIVER BASIN

Yangtze river is about 6380 km long and flows from Qinghai Province eastwards into the East China Sea at Shanghai. The Yangtze River Basin covers an area of about 1.72×10^6 km^2 with a population of approximately 40 million people. It is historically, culturally, and economically important to China.

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A. Precipitation

Annual rainfall in most parts of the river basin is 800 ~ 1600mm. Annual precipitation in the western and the eastern edge of Sichuan Basin, Jiangxi, Hunan and Hubei parts is higher than 1600m. The numbers indicate that rainfall in the Yangtze River Basin can induce severe rainfall erositivity.

B. Soil

Cultivated land in the Yangtze River Basin is about 173×10^8 hm^2, which is unevenly distributed in 52.6% of the upper reach region, 38.4% of the middle reach region and 9.0% in the downstream region. According to the classification of soil genesis, soil types include paddy soil, red soil, yellow soil, brown soil, purple soil, limestone soil and yellow brown soil. Red soil is mainly occurring from the Yangtze river southwards to Nanling Mountain, westwards to north-centeral Yunnan-Guizhou Plateau and to the southern edge of Sichuan Basin. Purple soil is mainly present in Sichuan, Yunnan, Guizhou and Hunan province and in a part of Hubei and Jiangxi province. Yellow soil is predominant in Sichuan, Guizhou, Hunan, Hubei, Jiangxi, Anhui and Zhejiang.

Table Ⅰ lists the average soil depth of sampling points in Yangtze River Basin. The table shows that: (1) diverse soil depths exist in the different districts. (2) soil depths are varying for the different slopes within each district. (3) mean soil depth is only 30-50 cm. Thus, soils are very vulnerable in Yangtze River Basin. Due to this, it is necessary to protect these limited soil resources.

TABLE I. AVERAGE SOIL DEPTH OF SAMPLING POINTS IN YANGTZE RIVER BASIN

County	Mean (cm)	Upper (cm)	Middle (cm)	Lower (cm)
YuanMou, Yunan	30-40	10-30	30-50	50-70
QianXi, Yunan	30-60	20-30	30-50	60-90
Guangan, Sichuan	30-50	20-30	30-50	70-110
Wanzhou, Chongqin	30-50	10-30	30-50	50-120
Chengxian, Gansu	50-80	30-50	50-80	80-150
Yongshun, Hunan	40-60	20-50	50-80	80-150
Xinzhao, Hubei	60-90	30-70	70-90	90-150
Ganxian, Jiangxi	70-90	50-70	70-90	90-150

C. *Agriculture*

In Yangtze River Basin nearly half of China's crops are produced, including more than two-thirds of China's rice yield. Other crop types include cotton, wheat, barley, corn (maize), beans, and hemp. Due to appropriate temperatures, local farmers cultivate their land without interruption. Such farming in high densities promotes soil loss in the basin.

II. SEVERE SOIL LOSS IN YANGTZE RIVER BASIN

A. *Soil erosion types*

Soil erosion types occurring in Yangtze River Basin mainly include water erosion, wind erosion, freeze-thaw erosion, Benggang (a special type of gully erosion) and debris. Water erosion affects an area of 52.41×10^4 km^2, which is 82.2% of the total soil loss area. For comparison, wind erosion covers 0.67×10^4 km^2. More than 1.6×10^4 landslides and debris canals are present in the basin and nearly 2.39×10^5 gullies (or benggang) are distributed in the deep weathered granite area.

B. *Characteristics of soil erosion*

1) *Severe soil loss*

Several methods are used to measure and compute soil loss rate in Yangtze River Basin which are described in the following: (1) The runoff plot method: Purple soil loss rate in different districts is displayed in table Ⅱ[1]. Downslope tillage reached 4.11 t km^{-1} mm^{-1} and results in severe soil loss than cross-slope tillage and no-tillage. No-tillage and cross-slope tillage plays an important role in preventing soil loss. No-tillage is more effective than cross-slope tillage to reduce soil loss. Runoff plot data in slope gradients of 15° was used to compute soil loss rate[2]. Soil loss rate was related to rainfall and had a poor relationship with rainfall intensity. But soil loss rate increased with increasing rainfall and rainfall intensity. Average soil loss rate of every rainfall event was more than 20 t km^{-2} mm^{-1}. (2) Artificial simulated rainfall: Xin et al.[3] simulated the runoff process on three slope gradients (5°, 10°, 15°) and for five rainfall intensities (19.62, 37.42, 53.95, 74.02, 111.69 mm/h). They concluded that surface runoff had a positive relationship with rainfall intensity and slope gradient. For the same rainfall intensity, transported sediment increased with increasing slope gradient. Wang et al.[4] simulated the soil erosion process for five rainfall intensities (18.06, 37.27, 53.40, 67.26, 106.57mm/h) and five slope gradients (5°, 10°, 15°, 20°, 25°). They found that soil loss rate was linearly correlated with high rainfall intensity (106.57mm/h), but steady at low rainfall intensity. Yuan et al.[5] studied the effects of slope gradients and rainfall intensity on runoff and built single-factor and multiple-factor regression equations for runoff predictions under different land uses. (3) The nuclide tracer method: Wen et al.[6] measured soil loss rate in the upper reach of Yangtze river using the ^{137}Cs tracer method and found that yearly soil loss rate had reached up to 9854 t km^{-2} a^{-1} (range: 758 - 9854 t km^{-2} a^{-1}).

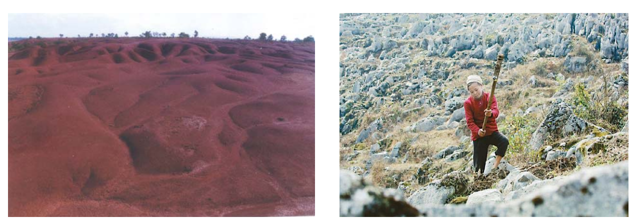
2) Surface runoff and interflow

Table Ⅰ shows that soils are generally thin in Yangtze River Basin. Its textures support water infiltration. High infiltration rates and thin soil depths cause losses of soil nutrients. However, an impermeable layer exists under thin purple soil. It impedes further infiltration of soil water so that most of the infiltrated water returns to the surface and causes a degration of water quality[7]. Shan et al.[8] reported that surface runoff volume was less than interflow. Phosphorus concentration during the rainfall event was 3 to 4 times higher in surface runoff. Despite the fact that surface runoff was the primary source of phosphorus transfer during rainstorms, interflow was one of the main contributors in normal rainfall conditions.

Dissolved phosphorus from interflow can account for a high percentage of phosphorus losses. When comparing nitrogen concentrations in surface runoff and interflow, it is found that soil infiltration causes nutrient decay especially for particulate nitrogen[9].

C. *Damages caused by soil erosion*

Land degradation is very serious in Yangtze River Basin. Soil erosion is be the most important reason for land degradation and desertification. In the red soil region, "red desertification" is caused by water erosion (Fig. 1a). In the southwestern rocky mountain region, "stone desertification" is also formed by water erosion (Fig. 1b). Both have been the most serious land degradation phenomenon in Yangtze River Basin. Local farmers nevertheless continue to plough for crop production which intensifies serious soil loss and land degradation.



a red desertificatioin　　b stone desertification

Figure 1. Red desertification (a) and stone desertification (b) in the Yangtze River Basin

Sediment transport is about 5×10^8 t/a in the Yangtze River Basin. Based on this sediment yield, soil loss is nearly 0.4mm/a. In fact, actual soil loss is much higher than the sediment being transported to the river network. Considering the soil depth data shown in Table Ⅰ and a constant loss rate of 0.4mm/a, soil depth would be decreased to less than 20cm within the next one hundred years. Thus, it is very important to protect soil resources in Yangtze River Basin.

III. HISTORY OF SOIL AND WATER CONSERVATION PROJECTS

Local farmers apply a series of effective soil and water conservation measures for controlling soil loss and land degradation. In fact, soil and water conservation in the Yangtze River Basin started in the 1930s. Especially, after the new Chinese government was built, a series of soil and water conservation projects were adopted. Also in the Yangtze River Basin, some projects on soil and water conservation were applied. In table Ⅱ eight important projects are displayed which show the invested amount, the according soil and water conservation measures and their benefits.

The total invested amount for every project was high and closely related to the treated area and duration. However, average investment of most projects was very little. In all projects different soil and water conservation measures were adopted, such as level terrace. Soil and water conservation measures are explained in detail in the following section. Socio-economical benefits of all projects concerning soil and water conservation mainly refer to the following points: (1) Improving land productivity for agriculture; (2) Increasing the local farmers' income and supporting the local economy. Major environmental benefits of all projects are: (1) An increase in forest and grassland area as well as vegetation cover; (2) These projects have reduced soil loss (Table Ⅱ) and have also (3) decreased the input of sediment to the river network.

IV. SOIL AND WATER CONSERVATION MEASURES AND BENEFITS

Five groups of soil and water conservation measures were adopted in Yangtze River Basin (Table Ⅲ). They are tillage measures, biological measures, engineering measures, auxiliary measures and relevant policies. Every group was subdivided into subtypes of controlling measures according to actual conditions. Every group of soil and water conservation measure is described in the following sections.

TABLE II. SOIL AND WATER CONSERVATION MEASURES IN THE YANGTZE RIVER BASIN

No	Measure classification	Measures
1	Tillage measures	Contour tillage
		Contour furrow
		Ridge with no-tillage
		Ridge tillage and pitting field
		Contaur trench cropping
		Contour strip intercropping
		Level trench
		Minimum/No-tillage
2	Biological measures	Living hedgerow
		Plant for protecting terrace ridge
		Intercropping, mixed cultivation
		Rotation
3	Engineerging measures	Level terrace
		Sloping terrace
4	Auxiliary measures	Drainage ditch
		Impounding reservoir
		Road
5	Relevant policies	Fenced off for afforestation

A. *Tillage measures*

Traditional agriculture was gradually formed in long-term agro-production practices. Soil loss rate and nutrient loss in traditional agriculture was very high due to downslope cultivation[30]. To reduce soil loss and protect limited soil resources, some suitable soil and water conservation measures were adopted in Yangtze River Basin including contour tillage, contour furrow, ridge tillage, pitting field, contour trench cropping, contour strip intercropping, level trench and minimum/no-tillage. Yuan et al.[30] concluded that contour tillage and contour furrow is better than downslope cultivation to reduce soil loss and nutriental loss. Liu Liguang and Wu Bozhi[31] discovered that the percolation of water and nutrients in contour planting is 64% and 79% higher than in straight planting along the slope. Zuo and Ma[32] found that contour tillage is better than downslope cultivation to reduce soil loss.

The cost of tillage measures was relatively low. They were implemented in the cultivation process by local farmers. Farmers often used tillage measures to control soil loss because tillage measures are only labor extensive and cheap. Thus, it is advantageous to apply the available tillage measures in the Yangtze River Basin.

B. *Biological measures*

Biological measures include living hedgerows, vegetation for protecting terrace ridge, intercropping, mixed cultivation, and crop rotations in Yangtze River Basin. Few studies were conducted on the benefits of intercropping, mixed cultivation, and rotation while more studies were carried out investigating the functions and benefits of living hedgerows and plants for protecting ridges of terraces. Sun et al.[33] studied living hedgerows planted 4 m apart on sloped land. This could reduce runoff by 49.6%. Topsoil organic matter content and total nitrogen at areas treated with hedgerows of nitrogen fixing plants was respectively increased by 20%-40% and 80%-130% in 3-6a. Exchangeable potassium and cation exchange capacity were also improved [34]. Zhu et al.[35] concluded that the social, economic and ecological benefits of hedgerow intercropping is superior to that of traditional sloping cultivation. Wu et al.[36] found that hedgerows play an important role in conserving soil macrofauna diversity. Zhang et al.[37] stressed that contour hedgerow system were one of the most favorable measures for soil and water conservation, and vital to control agricultural non-point source pollution. However, competition appeared between hedgerows and crops concerning nutrients, light, water and air. In general, costs of biological measures were rather low. It can reduce soil loss and improve crop production. Thus, it was important to adopt these suitable biological measures in Yangtze River Basin.

C. Engineering and auxiliary measures

Main engineering measures included level terrace and sloping terrace. In addition, in small catchments roads and engineering measures for improving runoff were constructed. Ma et al.[38] indicated that the maximum stable height of a ridge was 2.62 m. After the construction of the terraces, changes of soil bulk density and soil porosity were the main cause of an increase in soil infiltration capacity. According to the field survey and questionnaire, it was very expensive to transform a hillside or sloping lawn into terraces, in particular rock ridge terraces. The price of rocky ridge terraces was 2500 yuan/acre in 1995, but 7000-8000 yuan/acre in 2008.

Auxiliary measures for terraces mainly refer to drainage, collection and storage of runoff including drainage ditches and impoundment reservoirs. Engineering measures and auxiliary measures increased the conservation of water and soil by 37.4% and 71.2% respectively. Such measures can increase maize yield by 36.4%. Therefore, it plays an important role in the sustainable development of eco-environmental food production on rocky slopes which are prone to desertification[39]. The price of such engineering measures was very high. Consequently, in severe soil loss regions with little agricultural land, engineering measures should be adopted, otherwise they should be avoided.

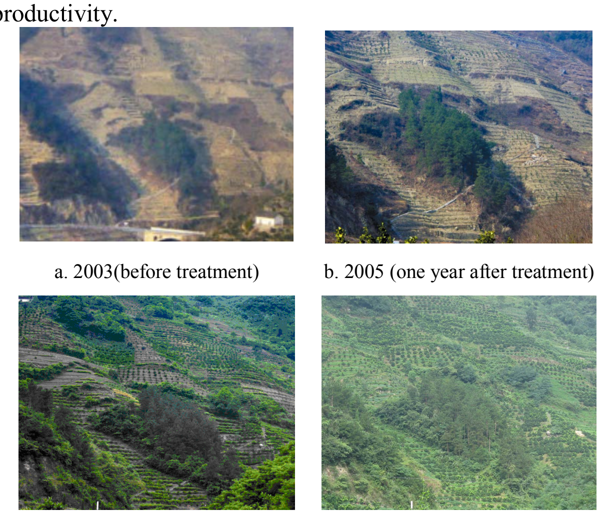
D. Relevant policies

Correct policies are important for controlling soil loss and land degradation. Apart from providing funds to support a series of soil and water conservation projects, policies like fencing of areas for reforestation should be implemented for protecting vegetation and controlling soil loss. It is very effective to restore vegetation and a successful way to control soil loss.

V. ACHIEVEMENTS OF SOIL AND WATER CONSERVATION IMPLEMENTATION

A series of projects of soil and water conservation were implemented in Yangtze River Basin. Among them some suitable measures were adopted which proved that soil loss can be controlled. Figure 2a shows the vegetation status before planting fruit trees and hedgerows. Vegetation cover in 2003 was very little and most of the surface soil was exposed. This meant that serious soil loss happened. Figure 2b displays that vegetation was still very sparse. In 2005 fruit trees and living hedgerows were used to cut off runoff and prevent soil loss from slopes. Orange trees in between the hedgerows were planted for supporting the local economy. The change in vegetation cover between 2005 and 2003 can not prove that these measures were very helpful to prevent soil loss. Until 2007, vegetation coverage got denser, but surface soil can still be seen (Figure 2c). In 2010, the sloping land was covered with orange tree and living hedgerows (Figure 2d). The four photographs in Figure 2 prove that vegetation cover gradually increased during the past eight years from 2003 to 2010.

According to the field investigation, it was very helpful that living hedgerows intercepted the sediment which resulted in sediment deposition and decreased sediment transport to the river network. In addition, orange trees grew quickly, supported by fertile soil. They did not only improved vegetation cover and reduced soil loss, but also increased local farmers' income and supported the local economy. The vegetation change, displayed in Figure 2 is one example from the region as there were more soil and water conservation measures which reduced soil loss and improved land productivity.



a. 2003(before treatment)

b. 2005 (one year after treatment)

c. 2007 (three years after treatment)

d. 2010 (six years after treatment)

Figure 2. Comparison of vegetation status before and after treatment

VI. PROBLEMS OF SOIL AND WATER CONSERVATION

The aims of application of soil and water conservation measures were as follows: (1) reduce soil loss; (2) regulate soil water content and runoff; (3) preserve and improve soil fertility; (4) improve output of agriculture and support the development of local economy; (5) low cost.

For serious soil loss regions such as the red desertification and stone desertification region, local farmers have to cultivate crops for living. Thus, measures must be adopted to control soil loss and improve land productivity there. Terraces can cut natural drainage lines, reduce concentrated runoff quantities and thus, result in a reduction of soil loss and protection of soil. It is very unfortunate that the labor and cost input to terraces is very high. Beyond that, terraces are not applicable in all regions. For example, in the stone desertification region thin topsoils can not supply the material necessary for the soil layers and the terraces.

It is important to note that (a) rarely does a single type of soil and water conservation measure prove effective if it is not framed by an enabling institutional environment and if it is not coordinated with and complemented by other types of measures applied for the same or other purposes, (b) similar types of measures do not prove successful in all the Yangtze River Basin and, thus, (c) how well soil and water conservation measures respond to the soil loss and land degradaton in Yangtze River basin depends on how well they are accepted and implemented. Currently no uniform assessment criteria and method for soil and water conservation exists. The most suitable soil and water conservation measures in the Yangtze River Basin was not formed. Thus, currently a suitable assessment criteria and method should be studied.

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TABLE III. SOIL AND WATER CONSERVATION PROJECTS RELATED TO CHANGJIANG RIVER BASIN

No	Project Name	Time (year)	Province	Treated Area (10^4 km^2)	Investment		Soil and water conservation measures	Social-economic benefits	Environmental benefits	Reference
					Total (10^8yuan)	Average (10^8yuan/(km^2×a))				
1	Major projects of National soil and water Conservation	1983-2009	Jiangxi, Fujian, Henan, Anhui, Shannxi and Gansu etc.	4.79	48.96	0.38	Small projects of soil and water conservation Fruit tree Return farmland to pasture or forest	Income every farmer is increased by 300 yuan every year. 1.0 $\times 10^7$ farmers breaks away from poor to rich.	Vegetation arises by 24%. Sediment is decreased by 2.8 $\times 10^8$ t every year. Sediment of small catchment is redued by 40%.	[10]
2	National agriculture comprehensive development projects of soil and water conservation	1989-2005	Jiangxi, Hubei, Chongqing, Sichun etc	4.8	12.04	0.15	Slopeland and channel Remediation, soil improvement, soil conservation of tillage measures, field road small projects of water conservancy and soil and water conservation Economic fruit, forest and grass for soil and water conservation spreading technology and technical training	3.60 $\times 10^5$ farmers breaks away from poor to rich. Crop yield is increased by 4.17$\times 10^8$ kg every year.	Coverage of forest and grassland was improved by 43%. Yearly soil loss was decreased by 1.22$\times 10^7$t.	[11-12]
3	major projects of soil and water Conservation in Yangtze River Basin	1989	Yunan, Guizhou, Sichuan,Gansu, Shannxi,Hubei,Chongqing,Hunan, Jiangxi and Henan province	9600	152	0.016	Level terrace Forest, fruit tree, Pasture, Grassland, Fence Tillage measures Reservoir, ponds for sediments or water storage, Channel for irrigation and drainage repair roads of township, village and field	Crop yield per capita increased from 376 kg to 530 kg. Net income every farmer was increased by 50%	Area of soil loss was decreased from 62 $\times 10^4$ km^2 to 53$\times 10^4$ km^2, which is decreased by 40%-60%. Vegetation coverage is improved by 30%.	[13]
4	Natural Forest Protection Project	1998	The upper reach of Yangtze River	68.2	962	14.11	Afforestation		Until 2010, area of forest is increased by 2.2 ×108 acre.	[14-15]
5	Projects of soil and water conservation in Danjiangkou reservoir and its upper reach region	2006-2010 (Recent period), 2011-2020 (Forward period)	shannxi, hubei, henan province	1.43 (recent period)	34.97 (recent period)	4.89	Slopeland control, Gully protection, Forest and grass Energy source substitution, Raising livestock and pasture reserve, Ecological migration		Vegetation coverage is increased by 15-20%. Soil loss was reduced by 30-40%. Yearly sediment to reseivor is decreased by 0.4-0.5 $\times 10^8$t Sediment is decreased by more than 60-70%.	[16]
6	The Changjiang/Pearl River Watershed Rehabilitation Project	2006-2012	yunan, guizhou,hubei and chongqing.	0.32	2.0	0.89	Vegetation constrution Small water conservancy and soil and water conservation projects Raising livestock and pasture reserve	Farmer's income is 30% more than before treated.	87.8% of soil loss area was controlled. Soil loss was decreased by 70%. Forest reaches more than 30%.	[17-24]
7	Construction of soil and water conservation monitoring network and information system	2002	175 Monitoring stations and 1065 monitoring points	-	2.48	-	Construct a preventing, supervising and monitoring system of soil and water conservation	Ameliorate environment and improve people life	promote society, economy and environment, zoology to coordinate development	[25-27]
8	A benchmark project of comprehensive erosion control of stony desertification in karst region	2008	Hunan, Hubei, Sichuan, Chongqing, Yunan, Guizhou etc	-	22	-	Afforestation Terrace Water cellars Methane pools	In 2009 farmers' income was increased by 1165 yuan per capita.	In 2009 coverage of forest and grass was improves by 24%. Soil loss is reduced by 165 × 10^4 t, which is 67% that was before	[28-29]