Integration of Cash Crop Hedgerows and Balanced Fertilizers to Control Soil and Water Losses from Sloping Farmlands in the Southwest China

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Abstract: Located in southwest China, the upper reaches of Yangtze River are characterized by broken geology and a fragile ecology, and prevail in sloping upland agriculture, serious soil erosion, leading to a backward economy and large poverty. Experts consider that soil erosion is the origin of poverty, since it washes away the fertile top soil that crops grow on, and along with it, moisture and plant nutrients that support plant life. Adopting cash crop hedgerows and balanced fertilizer technology to combat soil erosion has proven very practical and applicable on a large scale. It not only reduces soil erosion from sloping farmlands, but also increases crop yield and farmers' income. This integrated new technology has realized the goal combining social, ecological and economic benefits, and can thus safeguard the sustainable agriculture on sloping lands.

Key Words: cash crop hedgerow (CCH); sloping farmland; upper reaches of Yangtze River; soil erosion

1. Sloping farmlands and status of soil erosion in the upper reaches of Yangtze River

The upper reaches of Yangtze River prevailing in uplands with large population becomes one of the regions serious in soil erosion in China due to high cultivation index, overstocking, high modulus of soil erosion and fragile ecology. According to the survey and research in many years conducted by the Ministry of Agriculture (MOA), the Ministry of Water Resources and the Ministry of Forestry, sloping farmland is considered as the main origin of sediments in the upper reaches of Yangtze River.

The upper reaches of Yangtze River (above Yichang City) have an area of 1 million km^2, 55.8% of the catchments. It is situated in the transition zone between the first level and the second level of the topographic platforms and onto the second platform, and consists of 2/3 of plateau, 1/3 of hills and mountains and less than 10,000 km^2 of the Chengdu Plain. The area is characteristic of broken geology, complex geological structure, and thus suffers from intense earthquakes, frequent landslides and mud-rock flows and results in serious soil erosion affecting several provinces (Yunnan, Guizhou, Sichuan, Ganshu, Shanxi, Hubei and Chongqing) with an area of 351,000 km^2. Subtropical monsoon climate brings ample rainfalls and offers mild temperature and high humidity to most areas. Mean annual precipitation is 800-1000mm, 70%-90% of which falls between May and August. On steep slopes, fierce rainstorms lead to much severer soil erosion.

The average run-off and silt discharge from the upper reaches of Yangtze River streams were recorded as 440 billion m^3 and 530 million tons (M t) by the Yichang Hydrologic Station. Suspended silt particles, accounting for 72.8% of the total amount in the river, are mainly form Jinsha River (45.8%) and Jialing River (27.0%). The erosive regions have an area of 189,000 km^2 (53.9% of total farmlands) with an annual soil loss by 880 M t, 58% of total loss in upper reaches and more than 1/3 of the whole catchments. The sloping farmlands only have an area of about 5.5 million ha (15.6% of the total farmlands), but contribute to 380 M t of soil loss or 43.5% of total erosion. It is obvious that these regions are the major origin of sediments feeding to the water courses in the upper reaches of Yangtze River. Therefore, research on practical and applicable agricultural measures to prevent soil erosion from sloping farmlands is of great significance.

2. Development and evolvement of soil and water conservation technology for sloping farmlands

The essence of traditional technology for soil and water conservation on sloping lands is engineering terracing (ET) , viz. using engineering technique in combination with relevant agricultural measures such as contour cropping (CC), ridge tillage and chain water ponds to intercept run-offs on sloping lands. In recent 20 years, ET becomes a major effective practice to control soil erosion on sloping lands and to improve soil fertility and productivity. Despite its merits abovementioned, it needs considerable engineering work, technical supervision and construction cost. Cost usually ranges from US $75/ha to US $375/ha varying with specific landforms, slope gradient and bunds building materials. High cost of ET makes it difficult for farmers to follow suit without continuous financial support from governments.

To reduce the cost, Dr. Sam Portch, former vice President of Potash and Phosphate Institute of Canada (PPIC), Dr. Adisak Sajjaponse who formerly worked for the International Board of Soil Research and Management (IBSRAM) and Ms. Zhu Zhonglin, former President of Sichuan Academy of Agricultural Sciences, proposed a new concept of 'cash crop hedgerows' (CCH) on the basis of international work on plant hedgerows. Field experiments and demonstrations were carried out to verify the effect of cash crop hedgerows on controlling soil erosion in the provinces of Sichuan, Yunnan and Guizhou. It demonstrated through the field work that this technology resulted in both good environmental and socio-economic benefits which were well recognized by farmers and local governments. The provincial government supported the extension. In 2001, a national project was offered by the Ministry of Agriculture（MOA）and extended further to eight counties in Sichuan and Chongqing. In 2002, Sichuan Agricultural Development Office stopped implementation of ET and initiated using the new CCH technology in sloping land management program. It was regarded as a key technology in sloping land management by the Guizhou government. Under sponsorship of governments of Guizhou and Yunnan, good progresses were achieved during the same period of time.

3 Effect of cash crop hedgerows on soil erosion control in the upper reaches of Yangtze River

3.1 Relationships between rainfalls and soil erosion from sloping farmlands

Rainstorm is the main cause for soil erosion from sloping lands. Amounts of soil eroded depend not only on rain quantity and intensity, but also on landforms, slope gradient and length, soil texture, organic matter content, nature of vegetation and coverage. At the same location with the same farming practice, soil eroded is observed to be mainly governed by rain quantity and intensity as well as plant coverage (Table 1).

Table 1 Determination results of soil erosion under farmers practice (FP) and precipitation in Luodian, Guizhou Province, 2001.

Month	April	May	June	July	August	September	Total
Rainfalls (mm)	225	1,569	6,420	444	1,514	308	10,479
% of total Rainfalls	2.1	15	61.3	4.2	14.4	2.9	100
Run-off (kg/ha)	22,575	660,615	2,258,130	36,000	162,000	27,750	3,167,070
% of total run-off	0.7	20.9	71.3	1.1	5.1	8.8	100
Soil loss (kg/ha)	150	25,845	76,335	0	0	0	102,330
% of total soil loss	0.1	25.3	74.6	0	0	0	100

Amounts of run-off and soil loss from the corn field with FP were regularly measured. Before July when soil surface was not totally covered by crop canopy, amounts of run-off and soil loss were closely correlated to intensity and quantity of each rainfall and both reached the peak value in June. After July though rainfalls produced rather large run-off, soil loss was not observed. This may be attributed to two reasons: (1) soils were loose and susceptible to erosion by rainfalls at early crop growing stages. With time, top soil becomes compact due to roots growing and increase soil cohesion at later stages, resulting in reduced probability of soil loss. (2) flourishing crop growth provides fully shading that prevents raindrops from directly hitting soil surface and further avoids soil loss.

3.2 Impact of cash crop hedgerows and balanced fertilizer technology on controlling soil erosion from sloping farmlands

Since fully plant coverage and extensive rooting system are key factors to prevent soil from erosion, any factors reinforcing them could have effective impact. In order to validate the roles and effects of these factors, from late 1990s to now Potash & Phosphate Institute/ Potash & Phosphate Institute of Canada has supported Soil and Fertilizer Institutes of Sichuan, Yunnan and Guizhou Academy of Agricultural Sciences which lies in the upper reaches of Yangtze River to conduct research and delightful progress has achieved. Field research results are shown in Table 2 and 3.

In Yunnan, field experiments were conducted at two locations, i.e., Xiangyun and Fuming County, representing two typical erosive soils in the province. Experiments consists of five treatments including farmers practice (down-sloping cultivation (FP)), FP + BF, FP+BF+CCH (Chinese prickly ash tree+Chinese day lily), contour cropping (CC) + BF, CC+BF+ CCH(Chinese prickly ash tree +Chinese day lily) (Table 2). Results showed that there were large discrepancies among the amounts of soil lost in different years that fluctuated with annual rainfalls, the higher the rainfalls in a year, the higher the soil losses. The results also showed that any practice that could maximize soil coverage and stabilize top soil could significantly reduce soil erosion. On average, FP+BF reduced soil loss by 21%, and further 52% decrease plus CCH in 4 years experiments in Xiangyun County. Compared to FP, soil loss was reduced by 81.98% with CC+BF and by 87.89% with CC+BF+CCH. At Fuming site the same trend was observed but with less soil losses.

Table 2 Soil losses in XiangYun and Fuming counties,Yunnan from May to October in 2000-2003.

Site	Year	Rainfall (mm)	FP (T_1)	FP+BF (T2)	FP+BF CCH(T_3)	CC+BF (T_4)	CC+BF +CCH(T_5)
Xiangyun	2000	826.8	5,607.4	2,327.6	3,226.9	1,639.9	952.2
	2001	1,078.4	42,841.0	37,382.0	14,775.0	6,884.0	6,498.0
	2002	959.0	18,828.0	11,884.5	4,837.5	2,056.5	1,501.5
	2003	982.2	50,164.3	41,105.4	9,273.2	10,580.4	5,266.1
	mean	961.6	29,360.2	23,174.9	8,028.2	5,290.2	3,554.5
	reduction vs T1	kg/ha	-	-6,185.3	-21,332.1	-24070.0	25,805.8
	Soil loss	(%)	-	-21.07	-72.66	-81.98	-87.89
Fuming	2000	775.4	12,058.5	11,886.5	13,305.0	723.0	1,036.5
	2001	879.3	5,775.0	3,753.0	2,304.0	2,665.5	471.0
	2002	777.2	11,697.7	8,969.6	8,527.1	4,248.0	1,554.3
	2003	664.9	2,321.6	852.9	565.4	552.6	237.9
	mean	774.2	7,963.2	6365.5	6,175.4	2047.3	824.9
	reduction vs T1	kg/ha	-	-1597.7	-1,787.8	-5915.9	-7138.3
	Soil loss	(%)	-	-20.06	-22.45	-74.29	-89.64

In Guizhou, field experiments were conducted in Luodian County, including five treatments (FP, FP+BF, CCH(polygonum cymosum Trev+plum tree), CCH (Chinese day lily +Chinese prickly ash tree) and ET) (Table 3). Results showed the trend similar to Yunnan that amounts of soil loss varied but coincided with rainfalls in different years. Application of CCH technology and other measures improving crop growth and vegetative coverage could effectively control soil erosion. Effectiveness of the different treatments on reduction of run-off was in an order of polygonum cymosum Trev+plum tree+BF> ET+BF> BF> FP, and on reduction of soil losses was in an order of polygonum cymosum Trev+plum tree +BF> ET+BF> Chinese day lily +Chinese prickly ash tree +BF > BF> FP. Results illustrate that BF integrated with CCH technology can maintain sustainable agriculture on sloping farmlands.

Table 3 Soil losses in Luodian County, Guizhou from May to October in 2000-2003

Year	FP	CCH1	CCH2	ET	BF
			kg/ha		
2000	10233	3518	4749	3797	5352
2001	4,395	255	255	1,530	1755
2002	7,335	3,353	3,375	3,980	5925
2003	2,494	633	440	502	1282
Average	6,114	1,940	2,205	2,452	3579
Decrease Vs. FP	-	-4,174	-3,909	-3,662	-2536
Decrease Vs. FP (%)	-	-68.27	-63.94	-59.89	-41.47

In Sichuan, a number of cash crop hedgerow patterns were selected and tested in the field trials, including Chinese toon, loquat tree+Chinese day lily, pear tree+ Chinese day lily, Chinese prickly ash tree, mulberry tree, Eulaliopsis (a raw material for paper-making) and honeysuckle. At Jianyang site, the CCHs were pear tree + Chinese day lily. Similar to Yunnan and Guizhou, this hedgerow pattern had significantly reduced soil loss sine 1997. Combination of BF with CCH could further improve its effect on soil and water conservation. It was observed that effect of different types of CCHs on reduction of soil and water losses varied from year to year, the higher the rainfalls, the better the effect.

4. Impact of cash crop hedgerows and balanced fertilizer technology on crop yield

The crop belt width and hedgerow width used in the sloping farmlands in Yunnan, Sichuan and Guizhou are given in Table 4.

Table 4 Different dimensions of crop belt and hedgerows in Yunnan, Guizhou and Sichuan

Site	Crop belt width (m)	Hedgerow width (m)	CCH area account % of total farmland
Yunnan	9-10	1	10
Guizhou	6	1	16.7
Sichuan	7	1.3	18.7

Effects of different CCHs on crop yield are shown in Table 5, 6 and 7. Because planting hedgerows took up some area for conventional crops in the field, all the treatments with CCHs influenced grain crop yields. The magnitude of the influence depended on types and varieties of hedgerow crops introduced. In Yunnan Province, crop yields with BF in both Xiangyun and Fuming sites were significantly increased in 4 years straight (Table 5). Contour cropping (CC) increased more yield than FP for its effectiveness in reducing soil erosion and maintaining soil fertility. Although CCHs occupied 10% of total land area, it did not reduce the crop yield at all, but just the contrary, crop yield increased.

Table5 Impact of different treatments on crop yield in CCH field experiment in Yunnan, 2000-2003 (kg/ha)

Site	Treatment	FP (T1)	FP+BF (T2)	FP+BF+CCH(T3)	CC+BF (T4)	CC+BF+CCH(T5)
Xiangyun	2000	6,090.0	7,035.0	6,120.0	7,155.0	7,065.0
	2001	6,075.0	6,315.0	6,870.0	6,900.0	7,020.0
	2002	6,973.5	7,174.6	6,836.0	7,857.1	7,529.1
	2003	5,661.4	6,137.6	6,071.4	6,719.6	6,904.8
	Average yield	6,200.0	6,665.6	6,474.4	7,157.9	7,129.7
	Yield increase Vs. T1 (kg/ha)	-	465.5	274.4	957.9	929.7
	Yield increase Vs. T1(%)	-	7.51	4.43	15.45	15.00
Fuming	2000	4,760.0	6,012.8	5,459.7	10,248.3	9,840.3
	2001	3,790.5	4,482.0	4,824.0	4,648.5	5,136.0
	2002	7,623.8	7,728.6	6,842.9	8,752.4	8,628.6
	2003	5,904.8	6,442.9	5,185.2	6,895.2	6,783.1
	Average yield	5,519.8	6,166.6	5,578.0	7,636.1	7,597.0
	Yield increase Vs. T1 (kg/ha)	-	2,784.4	2,195.8	4,253.9	4,214.8
	Yield increase Vs. T1(%)	-	82.32	64.92	125.77	124.62

Effect of BF on crop yield tends at Luodian site, Guizhou was observed similar to that in Yunnan, but differed in yield quantity. Although Chinese day lily + Chinese prickly ash tree occupied 16.7% of land area, this treatment produced higher corn yield than FP treatment in 4 years straight (Table 6). Corn yield started to fall from the third year for the treatment with polygonum cymosum Trev + plum tree. This could be attributed to a larger canopy and a more extensive rooting system of plum tree that imposed more shading on corn and grabbed more nutrients from soil profile in the competition with corn. Thus, the influences became more pronounced as plum trees grew bigger. When sloping farmland was terraced by ET, corn yield still increased despite a land area decrease compared with FP.

Table 6 Corn yield response to different treatments of CCH on sloping farmlands in Luodian, Guizhou,2000-2003.

Year	Treatment	Corn yield (kg/ha)	Yield increase Vs. FP	
			kg/ha	%
2000	FP	3,588.8	-	-
	CCH1（polygonum cymosum Trev +plum tree）	4,852.5	1,263.8	35.2
	CCH2（Chinese day lily+Chinese prickly ash tree ）	4,841.3	1,252.5	34.9
	ET	3,978.8	390.0	10.9
	BF	4,867.5	1,278.8	35.6
2001	FP	5,066.3	-	-
	CCH1（polygonum cymosum Trev +plum tree）	5,993.8	927.5	18.3
	CCH2（Chinese day lily+Chinese prickly ash tree ）	6,215.0	1,148.8	22.7
	ET	5,229.3	163.0	3.2
	BF	6,045.8	979.5	19.3
2002	FP	3,220.5	-	-
	CCH1（polygonum cymosum Trev +plum tree）	2,859.0	-361.5	-11.2
	CCH2（Chinese day lily+Chinese prickly ash tree ）	4,355.3	1,134.8	35.2
	ET	3,888.4	667.9	20.7
	BF	4,266.4	1,045.9	32.5
2003	FP	3,414.3	-	-
	CCH1（polygonum cymosum Trev +plum tree）	3,329.4	-2.5	0
	CCH2（Chinese day lily+Chinese prickly ash tree ）	4,934.0	44.5	1.3
	ET	3,672.9	7.6	0.2
	BF	4,365.0	27.8	0.8

The effect of hedgerows on crop yields in Sichuan was somewhat different from the other two provinces possibly due to two crop harvests a year in Sichuan. In the first two years of the experiment, the treatment pear tree+ Chinese day lily increased yields of all crops in study, but from the third year (1999), the total annual crop yield started to decline, a similar trend as observed in Guizhou. A considerable yield reduction was observed on summer corn and sweet potato rather than winter wheat and barley (Table 7). This was also due to the canopy shading and competition for nutrients from pear tree with summer crops. Since the trees are in dormancy in winter and blooming in spring, they affect winter crops only to a minor extent. In the sixth year, both summer and winter crop yields were more influenced by the CCH as the trees grew bigger, but addition of BF minimized this influence. In 2003 yields of three crops with the CCH decreased by 6% compared with FP, but CCH+BF increased yield by 3%.

Table7 Crop yield response to different treatments in Jianyang, Sichuan Province, 1997-2003

year	Crop	FP(CK) kg/ha	CCH + CC		CCH+ CC+BF	
			Yield kg/ha	Vs. CK±%	Yield kg/ha	VS.CK±%
1997-2000	Corn	5,067	4,267	-15.8	4,833	-4.6
	Sweet potato	11,367	9,800	-13.8	11,717	+3.1
	Wheat +barley	2,167	2,534	+16.9	3,333	+53.8
	Total yield	18,601	16,601	-10.2	19,883	+6.9
2001	Peanut	3,250	2,700	-16.92	2,750	-15.38
	Wheat +barley	2,375	2,475	4.21	2,525	6.32
	Chinese day lily	-	513	-	914	-
	Pear tree	-	4,250	-	5,000	-
2002	Peanut	3,255	1,575	-51.61	2,400	-26.27
	Wheat +barley	2,925	2,400	-17.95	2,625	-10.26
	Chinese day lily	-	390	-	420	-
	Pear tree	-	6,900	-	8,655	-
2003	Peanut	3,104	2,157	-30.51	2,344	-24.48
	Wheat	3,240	2,791	-13.86	2,996	-7.53
	Sweet potato	13,436	10,041	-25.27	11,258	-16.21
	Chinese day lily	—	373	-	400	-
	Pear tree	—	6810	-	8,900	-

5. Economic benefit of cash crop hedgerows

Adopting the CCH technology not only effectively prevents soil erosion but also obtains considerable economic profit, which is completely different from other agricultural measures such as ET and non-cash crop hedgerows. The combination of social, ecological and economic benefits is the goal and ensures for sustainable agricultural on sloping farmlands.

In order to assess the economic benefit of CCH without bias, Dr. Adisak Sajjaponse from IBSRAM was invited by PPIC to undertake the job in 2003, and results are shown in Table 8, 9 and 10.

Table 8 Net income in Jianyang, Sichuan,1997-2003.

Year	Net income（US$/ha）		
	FP	CCH	CCH+BF
1997	446	-1665	-1646
1998	1144	834	1052
1999	686	889	1018
2000	790	1587	1771
2001	900	1625	1895
2002	1013	1719	2415
2003	998	2721	2832
Total net income	5978	7709	9336
Increase Vs. FP (US$)	-	1731	3359
Increase Vs. FP (%)	-	28.96	56.19

Table 9 Net income in Luodian, Guizhou, 2000-2003.

Year	Net income（US$/ha）				
	FP	ET	CCH 1	CCH2	CC+BF
2000	-144	-635	-639	-542	-48
2001	55	47	623	292	154
2002	-159	-108	459	133	-57
2003	-8	14	326	630	128
Total net income	-256	-683	768	514	176
Increase Vs. FP (US$)	-	-427	1024	770	432
Increase Vs. FP(%)	-	-166.92	400.45	300.92	169.01

Table 10 Net income in Fuming, Yunnan, 2000-2003.

Year	Net income（US$/ha）				
	FP	FP+BF	FP+CCH	CC+BF+CCH	CC+BF
2000	218	220	-149	847	287
2001	90	174	257	195	298
2002	130	145	209	285	336
2003	303	392	3067	4265	437
Total net income	740	933	3385	5592	1358
Increase Vs. FP (US$)	-	192	2645	4852	618
Increase Vs. FP(%)	-	25.95	357.23	655.34	83.47

The results of all provinces showed that all BF and the CCH treatments clearly increased farmers' income compared with FP. In Jianyang, Luodian and Fuming the increased net income resulting from BF was US$1628 / ha (27.23%)(Table 8), US$432 /ha(169.01%)（Table 9）and US$ 192 /ha (25.95%) （Table 10） over the FP, respectively. Although higher investment in young seedlings of cash crops and labors was needed in the first year for planting cash crops, net income increased obviously more than FP when cash crops brought about economic return. In the field experiments an increase in net income of US$ 1731 /ha (28.96%)（Table 8）, US$ 1024/ha (400.45%)（Table 9）and US$ 2645/ha (357.23%)（Table 10）was obtained respectively using CCH in Jianyang, Luodian and Fuming. More economic return resulted in the CCH combined with BF, i.e., in Sichuan and Yunnan CCH+BF increased net income by 56.19% and 655.34% compared with FP.

ET in Luodian decreased total income in 4 years by US$ 427 /ha (166.92%) instead of increasing more income than FP.

Among all experiment sites, net income with FP in Sichuan was the highest, followed by Yunnan and Guizhou (negative income). It could be a reflection of soil productivities and farmers' output/input ratio in the different locations so as a mirror of local rural economic income and living standard.

6. Patterns of cash crop hedgerows and extension

After several years of research, demonstrations and extension, experts in Sichuan, Yunan and Guizhou have worked out several hedgerow patterns and selected a number of crop varieties suitable for local climate, slope gradient and soils to meet local market. Presently, the CCH patterns such as pear tree+ Chinese day lily, Chinese toon, mulberry tree, Eulaliopsis （a paper making material）, honeysuckle, Chinese prickly ash trees are selected in Sichuan; pear tree+ Chinese day lily, Chinese prickly ash tree, plum tree+ polygonum cymosum

Trev and forage crops in Guizhou; and Chinese prickly ash tree+ Chinese day lily and forage crops are more suitable in Yunnan. Great progress in cash crop hedgerow research and demonstrations have been obtained, further efforts are needed to extend this technology to a larger scale to benefit more farmers and areas.

7. Summary and prospect

Cash crop hedgerows and balanced fertilizer technologies are proven more practical and applicable than the engineering terracing in controlling soil erosion from sloping farmlands. If proper shrub and herbage crops with small canopy and rooting system are used as the CCH, grain crop yield will not be negatively influenced. In general, grain yield will be affected remarkably from the third year if arbor trees with large canopy and extensive rooting systems are used. However, combination of the CCH and BF can make up this negative impact. Above all, the CCH increased farmers' income and achieved the goal of social and ecological benefits, so as to provide a new technology for safeguarding reconstruction of sloping farmland and sustainable agriculture.

Delightful development of research on the CCH technology has been achieved, but some problems need further investigation: (1) more patterns and varieties of the CCHs suitable for different areas need to be found out, and planting techniques need to be improved, (2) whether or not this technology can be extended to a large scale depends on its market share and how much profit it can produce, (3) it is necessary to conduct further research on how to orientate the direction of hedgerow crop root and canopy growth in the fields to achieve an ideal and mutual beneficial growing condition with grain crops, and thus safeguard yield increase and economic profit, (4) to explore more uses for hedgerow crops, and (5) to strengthen training of local agricultural technicians and farmers. Due to less educated and poor in taking in new knowledge, farmers in hilly areas need government's guidance and support through a seeing, learning and doing process to achieve the goal.

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