小流域における侵食抑止と農業開発に関する研究

Approach to Erosion Control and Agricultural Development Techniques in Small Watershed

A Case Study in Huangjiaercha Small Watershed in Loess Gullied-Hilly Area

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キーワード：黄土丘陵ガリ区，土壌侵食，水土保全，小流域管理，農業開発

Key words : loess gullied- hilly area, soil erosion, soil and water conservation, small watershed management, agricultural development

Summary

The loess gullied-hilly area of China is one of the most eroded areas. Soil erosion, along with semiarid to arid climate, dissected topography and fragile ecological environment, makes land productivity very low and the livelihood of rural people even hard. In order to promote appropriate strategies for soil erosion control and small watershed agricultural development techniques, long-term research has been carried out by Beijing Forestry University sponsored by the China government since 1981, in a small watershed, Huangjiaercha, of Xiji County in Ningxia Hui Nationality Autonomous Prefecture. These efforts have resulted in identifying appropriate technologies in relation to resource level, these strategies could be extended to similar agro-ecological situations. Soil and water conservation practices adopted in the watershed revealed that with investment level and continuous adjustment, soil losses of small watershed could be reduced by 98%, apart from increasing crop yield and per capita net income by 526% and 566% respectively. The impact of soil erosion control measures and its benefits will be discussed in this paper.

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Introduction

Need and approach

Loess plateau, as one of the most seriously eroded large plateau in the world, which produces 90% of sediment of Yellow River (S.Gong, 1988), is one of the areas for centuries with serious soil erosion, low and unstable agriculture production, undeveloped economy and culture, and very poor livelihood of inhabitants. Thus, it is always one of the main tasks for the government to conserve the soil and water resources for the development of agriculture, and to develop the regional economy for improving the living level there. From the end of 1970s, the government began to appeal for implementing comprehensive control of soil and water losses in small watershed. At the beginning of 1980's when the contract tillage system started, the National Committee of Science and Technology designated 11 research & demonstration areas of soil erosion control and agricultural development in small watershed scale, aiming at summing-up a series of method and technology for sustainable agricultural development in Loess Plateau. Huangjiaercha small watershed is one of the research & demonstration areas in loess gullied-hilly area, imputed by Beijing Forestry University. During the period of Ⅵ Five-year Plan for the National Economic Development (from 1981 to 1985, similar to the Ⅶ and Ⅷ Five-year Plan period), the researches of soil loss and it's control measures, and some erosion control measures for demonstration which is to enhance the soil and water conservation consciousness of inhabitants have been mainly conducted. While during Ⅶ and Ⅷ Five-year Plan periods, the implement of erosion control measures and agriculture improving measures have been carried out. In total, 2 reservoirs (one of it was built

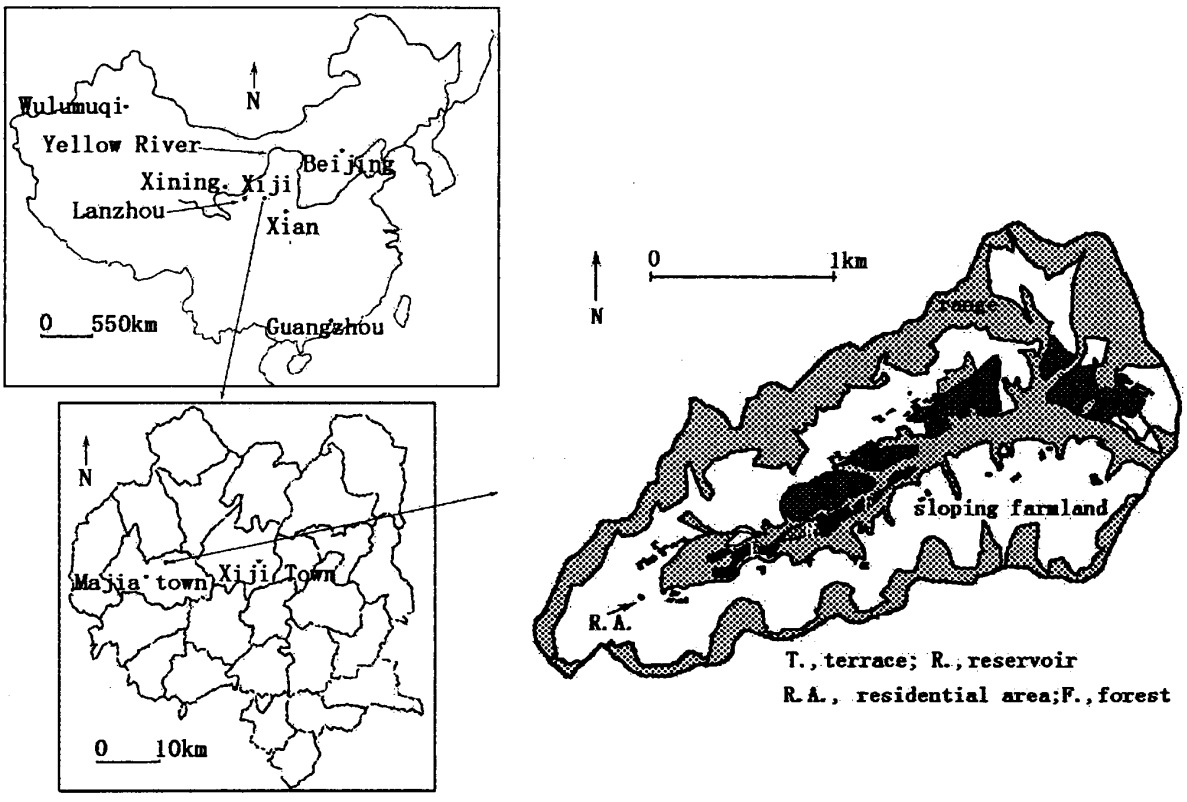


Fig. 1 Study area in Xiji County, China

outside of the watershed considering of the condition of dam site), 63 check dams and 230 ha of flat cultivated terrace to practise the measures of improving yield have been constructed, and the rest of sloping areas including gully slope have also been transformed into types of bench terraces or fish-scale pit for plantation and grass sowing.

Study Area

The Huangjiaercha watershed, part of Dawan village of Majian town in the west of Xiji County, is located in the central range of loess plateau representing the middle reaches of Yellow River between 105° 29′ and 105° 31′ 40″ East longitude, 35° 17′ 18″ and 35° 18′ 40″ North latitude respectively (Fig.1). The area of the watershed is 5.7 ㎢ and it is located between the altitudes of 1,860 and 2,135m above mean sea level (L. Sun et al., 1987).

Natural Resources

Mean annual temperature is 5.8℃, average minimum and maximum temperatures monthly are -13.9℃ and 24.3℃ respectively. The area receives a maximum and minimum precipitation of 611.1 mm and 240.3 mm respectively with an average of 402.2 mm (Fig.2). The coefficient of variation for the precipitation is 26%. The ground water is mainly the still-water which come from the upper layer of loess, its capacity is completely controlled by precipitation and micro-geomorphology. The annual total evaporation on water surface is 1,490 mm, especially highest in May and June. The annual relative humidity is 65% and the annual climate aridity varies between 1.21 and 1.54, is of semi-drought zone.

The soils of the watershed are mainly derived from loess of Quaternary Period of 20~50m in depth with the red soil of Tertiary Period underlying the loess. Bedrock is mainly mud sandstone of Cretaceous Period. Its geomorphology is of loess gullied-hilly area with gully density of 1.23 ㎞／㎢ (Fig.3). Three kinds of soils, i.e. *Xianghuangtu* soil, *Qianheilutu* soil and *Baiyantu* soil are met in the watershed. *Xianghuangtu* soil, the infertile eroded loess with light brown colour, is occurred on the farmland and waste range on slope; *Qianheilutu* soil, the slightly fertile cultivated loess with brown or dark brow colour, is mainly noticed on the terraces distributed on the both side of principally gully at the lower reach of the watershed; *Baiyantu* soil, the salinized soil pale in colour having 3% salts is mainly observed at the bottom of the gully with higher groundwater table.

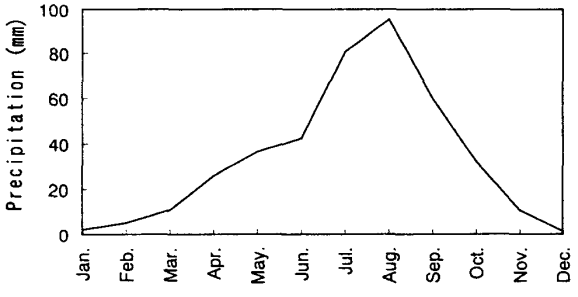


Fig. 2 Annual precipitation monthly in Huangjiaercha small watershed

The watershed was devoid of vegetation with only 10.02 ha under *Poplus simonii* around the reservoir. The trees such as *Salix matsudana, Ulmus pumila, Ailanthus altissima* and *Pyrus betuleaforlia* are planted around the houses. The staple crops are spring wheat (*Triticum aesivum*), pea (*Pisum satium*), oriental sesame (*Sesanum indicum*), naked oats (

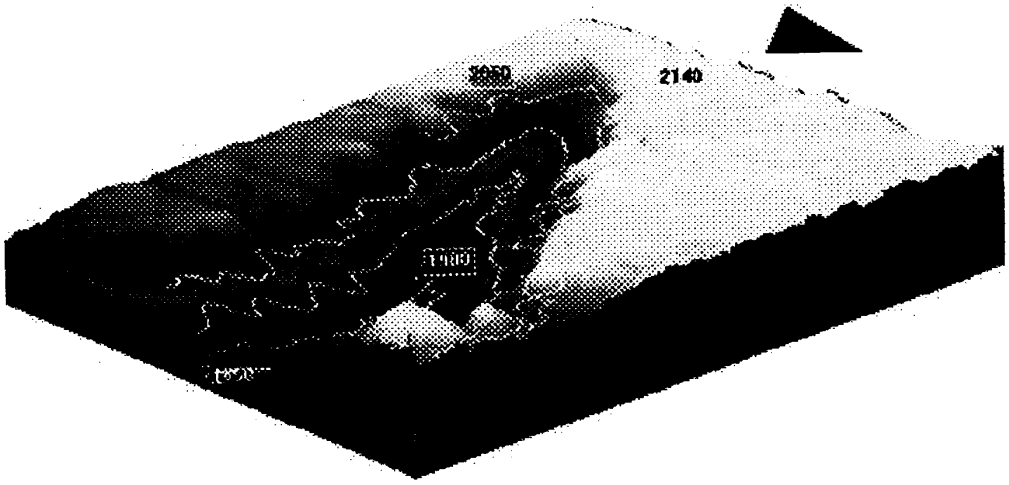


Fig. 3 Digital terrain map of Huangjiaercha small watershed

Avena nuda), buckwheat (*Fagopyrum esculentum*), oats (*Avena sativa*) and potato (*Solanum tubero*). The major natural grass species are *Stipa grandi, Roegneria purpurascens, Potentilla chinensis, Plantago major, Trigonella ruthenica, Taraxacum mongolicum and Leonurus sibiricus.*

There were 477 people of Hui nationality habitants in the watershed during 1982 representing a density of 93 persons/km². The details pertaining to land use and income are presented in Table1. The area of sloping farmland accounted for 92.42% of the total farmland, while the terrace area was 7.58%. The per capita available land for farming and economic activities were 0.65 and 1.93 ha respectively. The yield from terrace lands was 825 kg/ha, while only 345 kg/ha was realised from sloping lands. The total grain production of watershed was 111,200 kg, with per capita yields of 217.86 kg, of which only 125 kg was food grain. Hence the watershed required 7,000 kg of relief food grain annually. About 1.7% of the land is considered to be the forest area and barren. The sloping area without crops is considered as grass lands producing only 180 and 600 kg/ha of fresh grass. In the watershed there were 30 bulls, 40 donkeys, 15 mules, 2 horses and 94 low-quality sheep, which could only earn 222 US$ annually. An annual relief fund of 217 US$ had to be provided by the government for meeting the minimum demands of inhabitants. The fuel wood collected by per head annually was only 439 kg, including crop residuals and dump. To meet the demand, they dug up the roots of the perennial grasses and trees so as to enable them to cook one time and have one warm meal every day.

Table 1. Land use in Huangjiaercha small watershed

Item	Agriculture	Forestry	Animal husbandry	Sideline production	Total
Land area (ha)	342.7	10.20	207.5	9.6	570.0
	(60.1)*	(1.7)	(36.4)	(1.8)	(100)
Total gross income (US$)	8,416	132	311	0	8,859
	(95)*	(1.5)	(3.5)	(0)	(100)
Per capita net income (US$)	21.2	1.0	1.8	0	24

* Figs in the parenthesis is percent value.

Soil Erosion

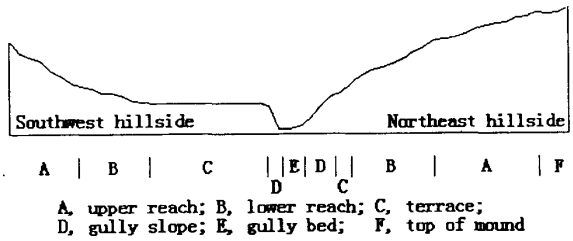
According to on-site investigations, area subjected to erosion was 536.45 ha (Table2), and accounted for 94.11% of the watershed area. Annual soil losses were estimated to 73.8 t/ha/year.

Table 2. Soil erosion situations in Huangjiaercha samll watershed

Erosion degree	Erosion rate (t/ha/yr.)	Location and land form	Area (ha)	Percent to total area (%)
Slight erosion	<10	sheet erosion on farmland	59.27	10.4
		sheet erosion on forest and range	13.08	2.3
Low erosion	10~25	sheet erosion on farmland with gentle slope	9.99	1.7
		sheet erosion on range slope of mound	112.34	19.7
Moderate erosion	25~50	sheet erosion on sloping farmland	47.06	8.2
		sheet erosion on range slope of mound	59.42	10.4
Heavy	50~100	sheet erosion on steeper farmland	143.99	25.3
		breakdown	20.18	3.5
Heavier	100~200	sheet erosion and shallow gully erosion	71.12	12.5

Erosion Control Measures

Based on the investigations made and considering the agricultural developmental activities, plant succession rules along with the present conditions of the forest, a programme to develop the area on sustainable basis was developed and implemented during the Ⅵ, Ⅶ and Ⅷ Five-year Plan periods. The major programmes consisted of formation of flat cultivated terraces on slopes less than 15° , returning areas with gradients ranging from 15° to 25° as forest and pasture lands and planting with suitable grasses species using recommended techniques for conserving soil and water, adoption of improved farming practices for increasing the yields. In addition to the above appropriate animal husbandry programmes were undertaken for increasing the household incomes. The major conservation programmes that were undertaken in the watershed are given as below (Fig.4):



A, upper reach; B, lower reach; C, terrace; D, gully slope; E, gully bed; F, top of mound

Fig. 4 land form cross-section at lower reach of Huangjiaercha small watershed

Bio-engineering measures on slope

1. Shifting sloping farmland to forest and grass. Halting farming progressively on the lands with slopes more than 15° ;
2. Constructing flat cultivated terraces on fields with slope ranging from 5° ~15° and to reduce the area of farmland progressively to areas having slope less than 15° . Planting shrubs on the outward slope of the terraces bank with species of *Tamarix ramosissima* and *Salix mongolica*, and along the bank toe of the terraces, one line of tree planting with either *Poplus hopeiensis* or *Poplus bolleana* so as to protect the slope (Fig.5). In case of abandoned farmland and the middle reach of gentle slope, protective belts of forest

consisting of trees mixed with shrubs and grasses, combined with land management practices suitable to the terrain conditions to conserve soil and water were organised.

3. In the middle to upper reaches silvipasture was adopted by either levelling land into narrow strips of level bench or forming narrow bands of level bench, so as to increase fuel and fodder yields.

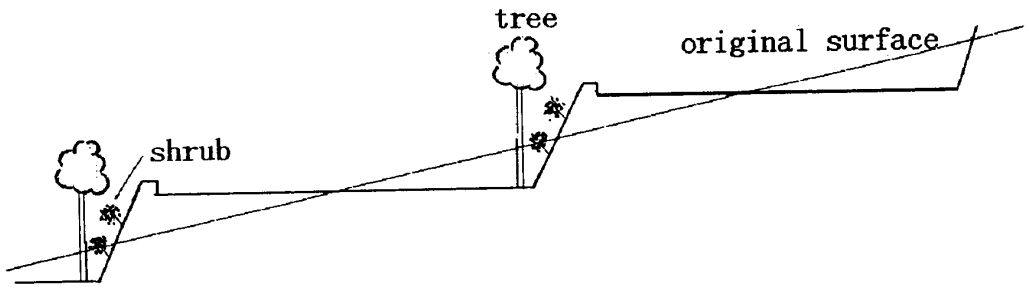


Fig. 5 Sketch of flat cultivated terrace

Bio-engineering measures in gully

1. In branch gullies, especially in the branch gullies with steeper gully bed on the northwest half of the watershed, a large number of small scale check dams with willow and earth were constructed to control runoff and sediment step by step.
2. Trees were planted in gully head to check gully.
3. Slope-cutting measures were taken up to transform gully slope and steeper precipice into narrow strips of level bench, suitable species of shrubs and grasses with deep root system and higher ability to fix earth were planted to attain the goal of solidifying gully with biological measures.
4. In the primary gully, reservoirs were constructed at appropriate place to monitor the floods and to alleviate the harmful effects in the lower reaches. This has helped to develop water resources for pisciculture and regulated surface runoff and percolating fowl, served the domestic needs. At the same time the fast-growing timber forests were established at appropriate places having better conditions to solidify gully and to provide small-diameter timbers.

The Results of Agricultural Development

Agricultural Improvement Measures

1. Soil moisture in the flat cultivated terraces increased by 12 to 34.8% when compared to that of sloping areas. As a result, yield of wheat, pea and potato increased by 62.2%, 50.4% and 32.3% respectively. Among the crops tried the average yield increment ratio is 48.3% (D. Liu et al., 1995).
2. Most suitable crop is spring wheat, fertilizer requirement is 45,450 kg/ha of farmyard manure, 223 kg/ha of ammonia sulfate, and 120 kg/ha of phosphate, and the appropriate seeds rate is 200 kg/ha. The appropriate seeds rates and optimum fertilizer levels for crops growth in the area are 45 kg/ha seeds and 75 kg/ha of phosphate for pea,

while 525 kg/ha tuber, 97.5 kg/ha of nitrogen fertilizer, 76.5 kg/ha of phosphate, 127.5 kg/ha potassium fertilizer and 49,500 kg/ha of farmyard for potato.

3. Using plant growth regulating substance and micro element fertilizer improved yield by 4.7 to 24.5%.
4. Sowing spring wheat and oriental sesame by machines helped establishment of stand and improved grain yield by 20% when compared to hand sowing.
5. Intercropping with potato and pea improved the yields by 67 to 114% when compared to mono cropping.
6. Deep plowing improved yield by 17.3% while cultivated with time. Cultivator / disc improved yields by 11.1%.
7. Replacement of traditional varieties with improved varieties of crops brought an increase of grain yield in ranging from 10 to 36.4%.

In general, improved practices under rain-fed agriculture brought improvement in yield by more than 110%.

Afforestation Improvement Measures

The area in the watershed designed to be kept under afforestation was developed into inward sloping bench terraces, narrow strips or bands of level bench, and fish-scale pits (Fig.6). The details of that are presented in an earlier paper by T. Zhao, et al. 1992. The tree species planted and their suitable site, appropriate density are given in Table3. The land after planting with suitable species was weeded twice during first three years, and tree species are pruned five years just after autumn for getting normal growth. Although it seems some early to say that we succeed in forestry development because the trees are still young, at least we can say that some tree and shrub species such as *Larix principis-rupprechii, Poplus hopeiensis, Tamarix ramossima, Salix mongolica* etc. introduced look like successful which are growing normally and playing an important role for conserving soil and water. The coverage of tree, shrub and artificial grass increased to 42.3% in 1990 from 1.7% in 1982.

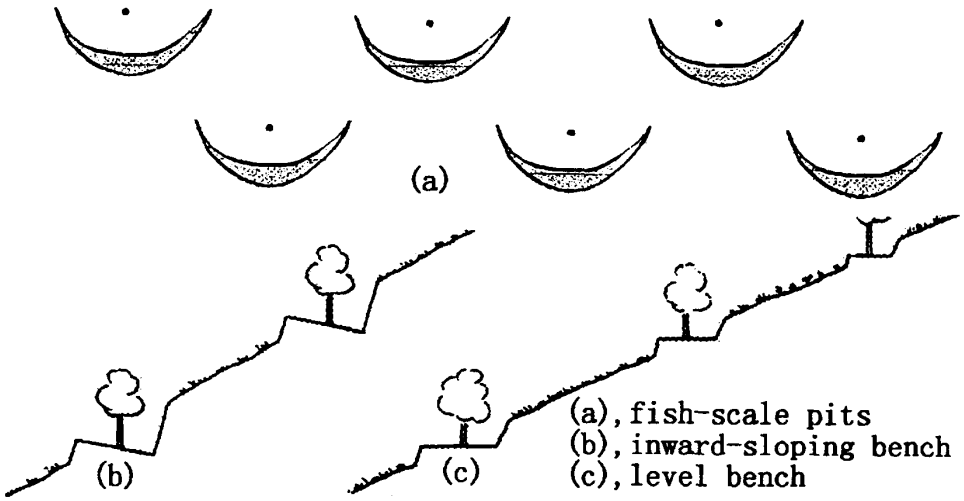


Fig. 6 Site preparation measures used in Huangjiaercha small watershed

Table 3. Tree species, suitable site and density for afforestation

Tree species	Suitable site	Density (stocks/ha)
Larix principis-rupprechii	abandoned farmland on south-east hillside	3,333
Pinus tabulaeformis	abandoned sloping farmland	3,333
Pinus sylvestris	abandoned farmland on north-west hillside	3,333
Poplus hopeiensis	mound slope or gentle slope of gully	2,500
	along the bank toe of flat cultivated terrace	one line of tree with 2m space
Poplus bolleana	gully head around	2,500
	along the bank toe of flat cultivated terrace	one line of tree with 2m space
Pyrus betulaefolia	mound slope	3,333
Prunus aremniaca var.ansu	slope on the south-east hillside	4,444
Prunus dividiana	slope on the south-east hillside	4,444
Hippophae rhamnoides	mound slope, gully slope and gully bed	6,666
Caragana korshinskii	mound slope and gully slope	4,444
Caragana microphylla	mound slope and gully slope	6,666
Tamarix ramosissima	gully bed	6,666
	bank slope of flat cultivated terrace	10,000
Salix mongolica	mound slope, gully slope	6,666
	bank slope of flat cultivated terrace	10000
Robinia pseudoacacia	leeward area on the south-east hillside	4444
Ulmus pumila	abandoned farmland with gentle gradient on the northwest hillside.	3333

Animal Husbandry Improvement Measures

Animal husbandry in this area has had a long history. In order to make better use of the resources developed in non-arable area, based on the principle of Leslie dispersion model, the linear planing method was used to optimise the structure of livestock for guiding the development of animal husbandry. For meeting the forage needs of livestock population, many good grass species were introduced from time to time to meet growing demands. The grass species introduced were *Astragalus adsurgens*, *Medicago sativa* and *Onobrychis viciaefolia* etc., their seeds rates were 7.5 kg/ha, 15 kg/ha and 30 kg/ha respectively.

Benefits from Erosion Control and Agricultural Development

The erosion control along with agricultural development programmes in the watershed resulted in spectacular benefits in all spheres (Table4). Across thirteen years from 1983 to 1995, the total investment (including inhabitant's labour) was 396,034 US$, of which, 56,345 US$ in Ⅵ Five-year Plan period, 227,586 US$ in Ⅶ Five-year Plan period, and 112,103 US$ in Ⅷ Five-year Plan period were invested respectively. The total comprehensive benefits (including economic and ecological benefits) were 740,396 US$ (among which, 51,776 US$ in Ⅵ Five-year Plan period, 240,517 US$ in Ⅶ Five-year Plan period, and 448,103 US$ in Ⅷ Five-year Plan period), which was 1.87 time of the total investment, suggesting continuous increase in the income from the watershed.

Table 4. Benefits from soil erosion control and agriculture development

Period	Erosion rate (t/ha/yr.)	Average yield of grain (kg/ha)	Total yield of grain (ton)	Per capita output of grain (kg)	Total net income (US$)	Per capita net income (US$)	Coverage of forest & range (%)	Domestic installation (US$)
1982	73.8	346	111.2	233.1	11,741	24.00	1.7	2,569
Ⅵ	10.4	1,320	156.8	358.1	17,258	36.00	54.9	11,483
Ⅶ	3.5	1,820	244.7	522.8	48,103	91.00	51.0	43,210
Ⅷ	2.40	2,250	560.8	916.4	89,620	138.00	42.3	62,069

As a result of resources development and it's scientific utilization, the ratio of land use changed from 1:0.03:0.61 in 1982 to 1:0.64:1.04 in 1990 for agriculture, forestry and animal husbandry respectively.

There have been significant changes in cattle population. The amount of big livestock in hand in 1990 was 263 as against 86 in 1982; the number of sheep increased from 93 to 450; the number of fowls increased from 120 to 1,540, and rabbits from 150 in 1982 to 2,480 in 1990.

Habitant's living improved greatly. The shortage of living fuel had been resolved. Consequent to development through effective management of natural resources on watershed basis, the living standard of the population in 1995 improved by 24.16 times to ones in 1982. Almost all of the households rebuilt their house, some of them even had bought electric equipment and transportation vehicles. The rate of starting school among children at school ages reached to 90%.

The watershed management programmes helped to evade drought and brought stability to the area. The year 1992 was extremely dry, and the average yield in Xiji County was only 1,077 kg/ha, where as the average yield in Huangjiaercha, was as high as 2,198 kg/ha; further 1995 was the driest year in the last one hundred years, the summer grain was almost not harvested in Xiji County except in Huangjiaercha watershed yielding 148.5 kg/ha and 144 kg/ha of spring wheat and pea respectively. The watershed recorded an average yield of 519.8 kg/ha during 1995 as against a yield of 381 kg/ha in 1982.

Discussion

1. It is very important to make a plan of erosion control and agricultural development based on a thoroughly analysis of the present situation of nature and social aspects, those features in the watershed could be summarised as serious natural conditions, over population, sparsity vegetation, serious soil and water losses, and undeveloped economy and culture, which affected each other. It is considered to be suitable that constructing flat cultivated terrace to implement rain-fed agriculture improving measures so as to produce plentiful food grain and straw, and alleviate the need of more farmland due to over populated pressure; and transforming the other sloping area into types of bench terrace or fish-scale pit for afforestation and sowing grass to afford enough fuel and forage resulting in a sustainable development of animal husbandry. Hence, the flat cultivated terraces firstly and then other bench terraces were constructed in time sequence.

2. When making and implementing the plan, funds have had to be considered. In the case of that the inhabitants had no money or they could not get loan for investment, the methods which peasants construct the erosion control works assisted by the government in ways of tax relief and affording necessary materials and funds including seedlings fees, chemical fertilizer fees to compensate the yield decline in new flat cultivated terrace and rent expense of bulldozers etc. had been adopted. It had been proved to be successful in such an area of poverty, although there are some successful cases which peasants made loans for erosion control and agricultural development in developing area of China.

3. Another important item is to persuade the inhabitants to agree with your plan,

which concerns whether the erosion control and agricultural development are sustainable. In 1983 when the flat cultivated terraces construction started, most of inhabitants objected till the village manager's sloping farmland was levelled and the yield was increased.

4. Whether the implement of the plan thoroughly depends on the land allocation and house estate distribution. In the watershed, land replotting and plan modification have been done in order to let every door have adequate area of flat cultivated terraces. As a result, some of them have to be constructed on the slopes between 15 to 25° .

5. There were two difficult things in implementing and maintaining the erosion control works, one of them was that inhabitants insisted on cultivating the slope between bench terraces for a food grain yield while where was reserved for grass growth and producing runoff to be used in the bench terrace below, the other was that some peasants secretly cut off the soil and water conservation trees planted in the village's land. Thus, the countermeasure of hiring forest guardsman, and the policy of relating the preservation of forest to village or town manager's promotion were undertaken.

6. In general, erosion control is not only a technical work, but also a management one. Present technique can reduce soil and water losses greatly, but it's application relates to many aspects such as politics, social features and economic constraints, hence a research on policy to assure soil and water conservation programmes implement seems to be much more significant. The erosion control and agricultural development practices contribute to those aspects mentioned above.

Conclusions

Bio-engineering measures of erosion control mainly including construction of reservoir and check dam, forming of flat cultivated terraces and other types of bench terraces controlled soil erosion in Huangjiaercha small watershed of loess gullied-hilly area are effective, which reduced soil losses by 98%. Agriculture improving measures helped to develop agriculture based on the adequate use of resources, and increased per capita yield out and per capita net income by 526% and 566% respectively. All of these brought in a comprehensive benefits of 129,894 US$／㎢ from 1983 to 1995 with an investment of 69,480 US$／㎢.

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小流域における侵食抑止と農業開発に関する研究

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要　約

黄土丘陵ガリ区は中国における侵食の激しい地域の一つである。激しい土壌侵食に半乾燥・乾燥気候、峻険な地形と悪化した生態環境に加えて、土地生産力は極めて低く、住民の生活も貧困である。このような自然・経済状況に鑑み適当な侵食防止策と農業開発技術を探討する為に、「黄土丘陵ガリ区における小流域の土壌侵食防止と農業開発技術に関する研究」を国家の指定研究課題とし、北京林業大学が寧夏回族自治区の西吉県の黄家二岔小流域において、1981年から一連の研究を行ってきた。採用された技術は該当地域の資源レベルと一致し、研究成果は類似な小流域にも適用・普及できる。黄家二岔小流域の侵食防止・農業開発の実際により、流域管理事業には連続的な資金・技術投入があれば、土砂流失は98%まで低減でき、食糧生産高と住民の年平均収入がそれぞれ526%と566%まで増加できるとされている。本研究は当該小流域の侵食防止措置と侵食防止事業の効果について検討するものである。

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