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Land degradation, government subsidy, and smallholders' conservation decision: the case of the loess plateau in China

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Abstract: Land degradation is one of the severe environmental problems in China. In order to combat land degradation, a soil conservation program was introduced since 2000 to reduce soil erosion by converting slope-cultivated land into forestry and pasture. This paper represents the first systematic attempt to investigate the impact of the soil conservation program on land degradation in the loess plateau. The results indicate that the soil conservation program to convert slope fields into forest or pasture is an effective way to combat soil erosion. However, a subsidy that is higher than profit of land use activity of slope fields before their conversion into forest and pasture is needed to encourage farmers to join the conservation program. A policy measure to encourage and assist farmers to develop sedentary livestock by using crops produced from fields as well as fodder and forage grass from the converted slope fields might contribute to combat soil erosion. Increase in off-farm job opportunities may encourage households to reduce cultivation in slope fields. That implies a policy measure to encourage rural urbanization might contribute to combat soil erosion.

Key words: Land degradation, Soil conservation program, Land conversion, Subsidy, Bioeconomic household model, Loess plateau
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INTRODUCTION

Land degradation has become one of the severe environmental problems in China. Approximately 5000 millions tons of soils are eroded each year. The total eroded area has reached to 1800 thousand km^2. The desertificated area has reached at 176 thousand km^2 and is increasing at an average rate of 2100 km^2 per year. Land degradation poses a serious threat to agricultural production and livelihood of rural residents, especially in the poor China's Western region where rural residents make up 82% of the population and agriculture provides 75% of household income. In order to combat land degradation, a new policy measure has been introduced since 2000 to reduce soil erosion by converting slope-cultivated land into forest and pasture. Farmers who participate in the soil conservation program and convert their slope field into forest or pasture can obtain in-kind subsidy from the government. It is unclear how this policy measure affects land degradation in rural China. This study is the first systematic attempt to investigate the impact of such policy change.

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Land degradation may be affected by various household activities (Heerink *et al*., 2001). In China households have become the basic units of decision-making of land use since the 1980s. The decision-making of smallholders that affect soil quality is influenced by various socio-economic factors, such as prices of output and input, and as well as economic policies. It is not easy to investigate the effects of policy measures on land degradation. Difficulties in identifying policy effects on land degradation stem not only from lack of suitable historical data, but also from the complexity of the interaction between policy measures and agro-ecological process (Barbier, 1998; Benhin and Barbier, 2001). To overcome these difficulties, it is necessary to develop models that integrate agro-ecological process and household behavior that responds to socio-economic circumstance (Barbier, 1998; Shiferaw and Holden, 1999). The objective of this paper is to develop such model to examine how the policy measure of converting slope fields into forest or pasture affects household activities, land use choice, and land degradation in China.

STUDY SITE AND ITS CROP-LIVESTOCK SYSTEM

Gezhenyan is a typical village in the loess plateau, located in Zhunger County of Inner Mongolia, about 150 km away from Huhhot. There are 21 households and 81 people in the village. The smallholders have average land of 17.8 mu (about 1.19 ha). There are three types of cultivated land, including flat fields and terrace and slope fields. Terrace is the field leveled artificially on slopes for preventing soil erosion. Main crops are maize, millet, sunflower, rapeseed, potato and beans. Maize is mainly grown in flat field and terrace for commercial use and feed. Millet is traditional staple food in this area, usually grown in slope field for self-consumption. The commercial crops are rapeseed and sunflower, usually in terrace and slope field. Potato and beans are for self-consumption (Table 1). However, livestock provides 70% of income for farm households in the site. Part of maize and all of maize straws produced are used for fodder. The most important livestock is goat. To reduce soil erosion associated with goat grazing, sedentary livestock such as pig- and sheep-raising has been increased in recent years.

To supplement their farming income, many farm households engage in off-farm employment. In 56 mainly labor jobs, 14 persons take various full time off-farm jobs. Ten of them are from part-time farm households and 4 are from full time farm households. There are 12 farm households whose income depends mainly on land use activities, and 9 part-time households who obtain more than 50% of income from off-farm activities. For farm households, on-farm activities provide 93% of income, while part-time farm households earn 73% of income from off-farm activities (Table 2).

Soil erosion is the most serious environmental problem in the loess plateau. Unfortunately, there is few observational data about soil erosion values between various crops in fields. Results from model EPIC (Erosion Productivity Impact Calculator) simulation show that soil erosion values differ between field types and various crops (Table 3). The most severe soil erosion occurs in slope fields

Table 1 Land use and cropping system

	Total		Flat field		Terrace field		Slope field	
	Sown area (ha)	Yield (kg/ha)	Sown area (ha)	Yield (kg/ha)	Sown area (ha)	Yield (kg/ha)	Sown area (ha)	Yield (kg/ha)
Corn	7.67	6660	4.27	9250	1.27	5100	2.13	3750
Millet	6.87	1819			1.47	1850	5.41	1808
Rapeseed	3.07	580			2.00	660	1.07	500
Sunflower	2.43	885			0.73	1000	1.69	836
Potato	2.80	7500			1.07	7125	1.73	7725
Beans	0.87	1400			0.47	1500	0.40	1300
Total	23.70		4.27		7.00		12.43	

Table 2 Farm economic characteristics

Farm type	Unit	Total	Farm household	Part-time household
Household	person	21	12	9
Population	person	81	49	32
Labor	person	56	34	22
Off-farm labor	person	14	4	10
Monthly off-farm labor	person	9	3	6
Yearly off-farm labor	person	5	1	4
Population per household	person per household	3.86	4.08	3.56
Cultivated land	ha per household	1.19	1.43	0.87
Family income	Yuan per household	8904	9645	7998
Farm income	Yuan per household	5945	9018	2188
Off-farm income	Yuan per household	2,960	627	5810
Ratio of off-farm income	%	33%	7%	73%
Ratio of livestock income within farm income	%	66%	69%	51%

Table 3 Soil erosion values derived from EPIC Model

Field type	Slope	Soil erosion values (ton/ha)					
		Maize	Millet	Sunflower	Rapeseed	Potato	Beans
Flat field	0%	0.430	0.550	0.510	0.460	0.200	0.460
Terrace	5%	4.400	5.620	5.220	4.670	2.070	4.670
Slope field	10%	12.520	15.770	15.090	13.090	5.880	13.090

Note: Simulation results are means of ten years

where millet or sunflower is grown, while there is rarely soil erosion in maize flat fields. Soil conservation technologies mainly include contour plowing, fish-scale pits and leveling slope field into terrace. Contour plowing technology has been widely adopted by the farmers in this area. Fish-scale pits dug on slopes may diminish stream, hold water and reduce soil erosion, but requires more labor input. According to the new policy measure to convert slope into forest or pasture, 0.5 Yuan is provided by government for digging one pit as food-for-work aid. Leveling slope field into terrace needs much more labor and material inputs and it is somehow difficult for individual small-households to adopt. In this village about 7 ha of slope fields has been changed into terrace.

ANALYTICAL FRAMEWORK AND MODEL BUILD-UP

Heerink *et al.*(2001) provided a conceptual framework for analyzing effects of policy reform on land degradation. Farm household decisions on land use activities and technological choice affect the soil quality and play an important role in aggravating or reducing land degradation process. Farm household decisions are dependent on relative prices of output, input and production factors, and other socio-economic circumstances that are influenced by macroeconomic and agricultural policy. Agricultural policies affect soil degradation by influencing the socio-economic environment of farm households. To measure such impact, several bioeconomic household models that incorporated bioeconomic model with household model have been developed (Singh *et al*., 1986; Kruseman *et al*., 1995; Kruseman and Bade, 1998; Barbier, 1998; Shiferaw and Holden, 1999; Shiferaw *et al*., 2001; Mullen *et al*., 2003; Fleming and Milne, 2003). A bioeconomic household model that incorporates household behavior and agro-ecological process has been developed as the base of analytical framework.

Three modeling approaches of bio-economic household models have been developed, including econometric estimation approach, mathematical programming approach and decision rule approach (Kruseman, 2001; Bontkes, 2001). Econometric approach is based on statistical analysis of historical and/or cross-sectional data so that it can provide a fairly accurate description of the behavior in the past. Such estimation is usually very demanding in terms of data, which are rarely available in developing countries. Decision rules approach regards household behavior as the outcome of the interplay between the householder and his 'disposition to act', his resources and external context. It only estimates a statistical relationship between exogenous variables and relevant endogenous variables. Mathematical programming approach allows determination of an optimal allocation of land, labor and capital, given a set of goals and constraints. A major advantage of mathematical programming approach is that it may combine economic behavior and biophysical process in an integrated framework. The use of Leontief input-output coefficients permits the combination of incompatible economic and biophysical production function (Kruseman and van Keulen, 2001). However a disadvantage of the mathematical programming model is that it generates vast amount of results with 'what-if' analysis when some of parameters of the model are not known with great accuracy. In this paper emphasis is placed on combining household behavior with biophysical process. A linear programming model (LP) is applied to describe the relationship between policy change and land degradation. Several features of the LP model introduced in the paper are as follows:

1) The model is designed to maximize net income, simultaneously incorporating both crop and livestock activities, subject to constraints on land, labor and capital resources. The objective function is to maximize net income as follows:

$$\mathrm{Max}M=\sum_{c=1}^{C}\left\{p_c\left(\sum_{g=1}^{G}A_{cg}y_{cg}(x)-b_c-s_c\right)-\sum_{g=1}^{G}\sum_{i=1}^{n}A_{cg}e_{icg}x_{icg}\right\} +\sum_{v=1}^{V}\left\{p_v(L_v y_v(x)-b_v-s_v)-\sum_{i=1}^{n}e_{iv}x_{iv}\right\} -\sum_{j=1}^{J}p_j f_j+\sum_{o}^{O}w_o z_o-\sum_{k}^{K}w_k h_k \quad (1)$$

subject to

$$A=\sum_{c}^{C}\sum_{g}^{G}A_{cg} \quad (2)$$

$$Z_h=z_f+z_o \quad (3)$$

$$Z_f=z_f+\sum_{k}^{K}h_k \quad (4)$$

all the variable definitions are shown in Table 4.

Table 4 Variable definition

Variables	Explanation
M	Household net income
c	Crop
g	Land type
A	Land endowment
v	Livestock
w_o	Off-farm wage
Z_h	Family labor
w_k	Hiring labor wage
h	The hiring labor supply
s	The crop or livestock output y used for self-supply, such as fodder, draft animal
z_o	The off-farm labor supply
A_{cg}	The area of crop c produced on land type g
p	The price of crop or livestock output
y	The yield function for production of crop c or livestock v
x_i	A vector of inputs used in production of crop c or livestock v
e_i	The per unit input price for input x_i
L	The production of units of livestock v
b	The crop or livestock output y used for self-consumption
z_f	Family labor input for farm activities
Z_f	Total labor input for farm activities

2) The LP model is specified at the village level using the data collected at Gezhenyan village. The model is specified at the village level because in China many natural resources such as grazing land and fuel wood are managed at the village level. As such soil degradation processes occur at a more aggregate level rather than at household level. Moreover, mutual labor exchange often occurs between individual households so that labor constraint cannot be bound strictly at the household level (Barbier, 1998).

3) Three forms of market imperfection exist in rural China. First, with increasing income, many

farm households in upland areas have started to purchase rice or wheat for staple food as well as to sell their products such as maize (Shi, 1996). Due to the high transaction costs in the agricultural product market an obvious price band exists between farm gate prices and purchasing prices of farm products. As a result, disappearance of farm products includes simultaneously for sale and self-consumption or self-supply for feed. The LP model includes sale processes of tradable goods and self-consumption processes of non-tradable goods. Second, as off-farm job opportunities for rural residents are limited under an imperfect labor market, in the LP model we place the constraints of off-farm job opportunities and divide part-time labor into constantly off-farm labor and seasonally off-farm labor so as to define off-farm job constraints more meticulously. Third, as there is rarely mobility of land management right between households, land market is missing, so that no module related to land market is introduced in the model.

4) Crop production processes are constituted by three types of land and six kinds of crops. Crop production functions are Leontief type. Yields depend on land type, level of various inputs such as labor, fertilizer, seeds, pesticides and manure. Livestock includes three kinds of animals: goat, sedentary sheep and pig. Animal numbers depend mainly on feed availability that stems from grassland and self-supplied fodder.

5) Food expenditure stems from self-consumption of farm products and food purchased. Food expenditure decision is based upon linear consumption choices that combine nutrition values with prices of food products under the constraints of basic requirement of nutrition intake and preference of the households.

6) Soil erosion results from land use activities of the households. Only eroded soil is used as index of impact of production on soil erosion in the model. Parameters of soil erosion value are derived from simulation results of EPIC (Williams *et al*., 1987). As the policy measure of converting slope fields into forest or pasture has been put into effect since 2000, conversion of slope field is modeled as soil conservation process. Soil erosion will reduce soil depth and soil organic matter (SOM), and then deplete natural resource stock. Since we are interested in what will happen within a short period along with the implementation of the policy measure of converting slope field into forest or pasture, a short-run effect is emphasized so that the effects of soil erosion on production activities cannot be easily recognized. Due to lack of the data related to change in soil depth and SOM, the feedback process of soil erosion to production activities is not introduced in the model.

RESULTS

The base run results are largely close to the actual situation in 2002 (Table 5). Due to potential errors associated with data collection, the levels of input purchase and self-supply in the actual situation are lower than those of the base run. The results suggest that households can raise more shed sheep by using maize and straw as fodder instead of selling maize, and grow more cash crops such as sunflower and rapeseeds instead of millet to earn cash income. One of the reasons for those gaps is the lack of investment constraint in the model. In reality, due to their poor income, smallholders are likely to face a shortage of investment when they want to raise more livestock animals. Another reason may be the risk averting behavior of households. Planting more cash crops and raising shed livestock bring home higher income, though they also have to face sharp prices influence and high risk as the agricultural market is imperfect. As a result, farmers prefer to grow millet for staple food and to sell maize to earn cash income.

Impact of price change

Fig.1 shows simulation results on land use choice due to the price change. The results show that changes in prices of livestock products mainly affect livestock production choice and have no significant effects on land use choice and soil erosion. However, changes in relative prices of commercial crops may affect land use choice, especially land use choice of slope fields. Due to difference in erosion, modulus exists between crops of interest, and as a result, changes in prices of commercial crops have significant impact on soil erosion (Fig.2).

Table 5 Comparison between actual situation and base run results

	Items	Unit	Actual situation in 2002	Base run
	Total family income	Yuan	139141	194403
	On-farm income	Yuan	106232	174082
	Off-farm income	Yuan	59190	52200
Crop production	Corn flat	mu	64.0	0.0
	Corn terrace	mu	19.0	7.4
	Corn slope	mu	32.0	0.0
	Feed corn flat	mu	n.a	66.0
	Feed corn terrace	mu	n.a	53.1
	Feed corn slope	mu	n.a	34.9
	Millet Terrace	mu	22.0	0.0
	Millet Slope	mu	81.1	46.6
	Potato terrace	mu	16.0	6.8
	Potato slope	mu	26.0	0.0
	Sunflower terrace	mu	11.0	0.0
	Sunflower slope	mu	25.4	60.7
	Rapeseed terrace	mu	30.0	53.7
	Rapeseed slope	mu	16.0	0.0
	Bean	mu	13.0	20.7
Livestock	Goat family labor	head	377.0	348.4
	Shed sheep	head	123.0	734.9
	Hog	head	39.0	0.0
	Grazing cattle	head	4.0	4.0
Sale	Corn	kg	18900.0	0.0
	Sunflower	kg	1750.0	3382.7
	Rapeseed	kg	1704.0	2444.5
	Cashmere	kg	30.8	87.1
	Goat	head	177.0	348.4
	Sheep	head	32.0	734.9
	Hog	head	39.0	0.0
Self-consumption	Corn	kg	7450.0	2000.0
	Millet	kg	4450.0	5000.0
	Potato	kg	22850.0	2770.4
	Bean	kg	1320.0	1449.8
	Mutton	kg	480.0	0.0
	Pork	kg	755.0	0.0
Land supply	Flat field	mu	67.7	66.0
	Terrace field	mu	121.0	121.0
	Slope field	mu	171.0	162.9
	Converting land	mu	159.1	167.2
	Grazing land	mu	407.0	407.0
Land degradation	Soil erosion	ton per year	200.1	194.5

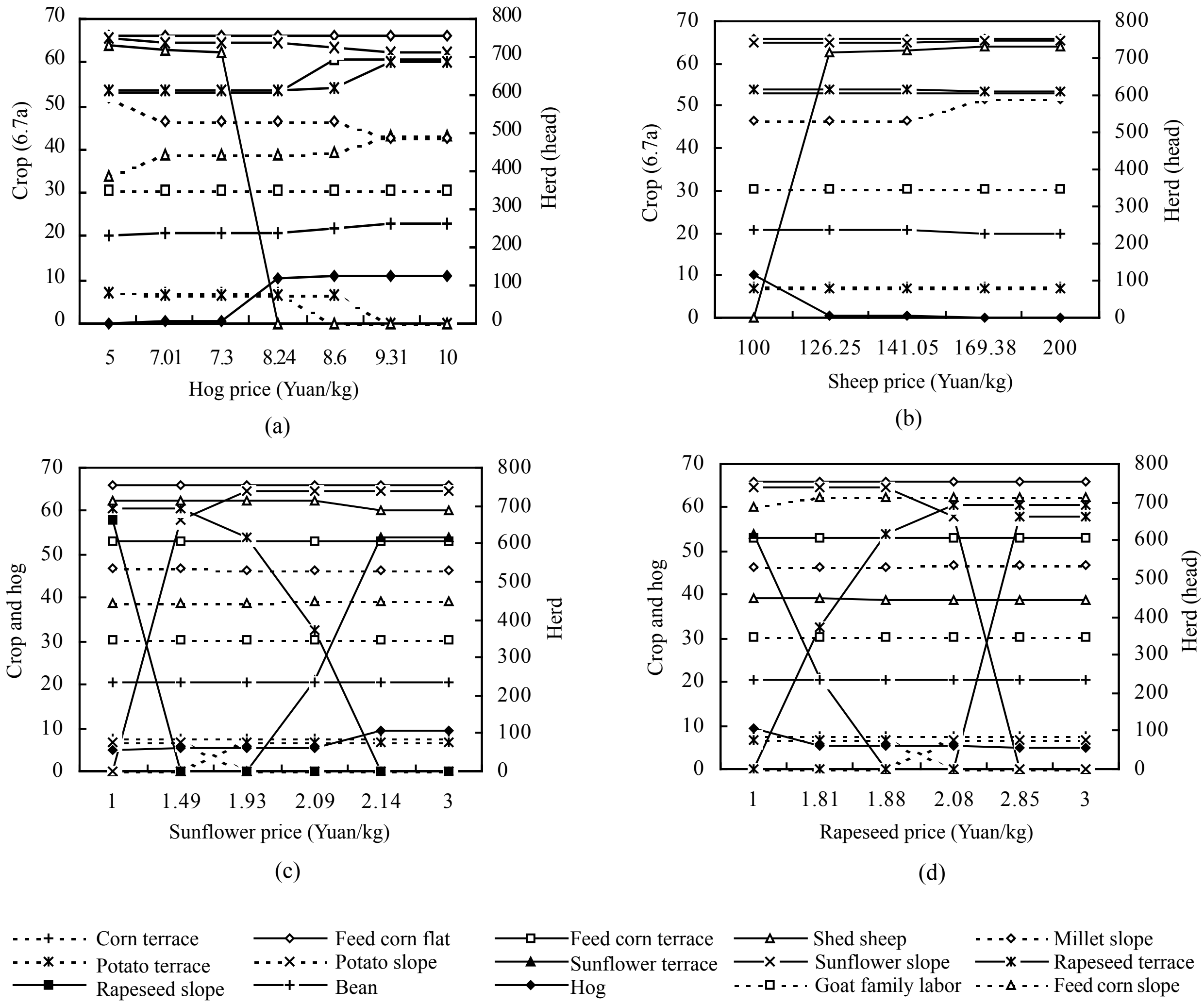

Fig.1 Hog (a); sheep (b); sunflower (c); rapeseed (d) price change and land use change

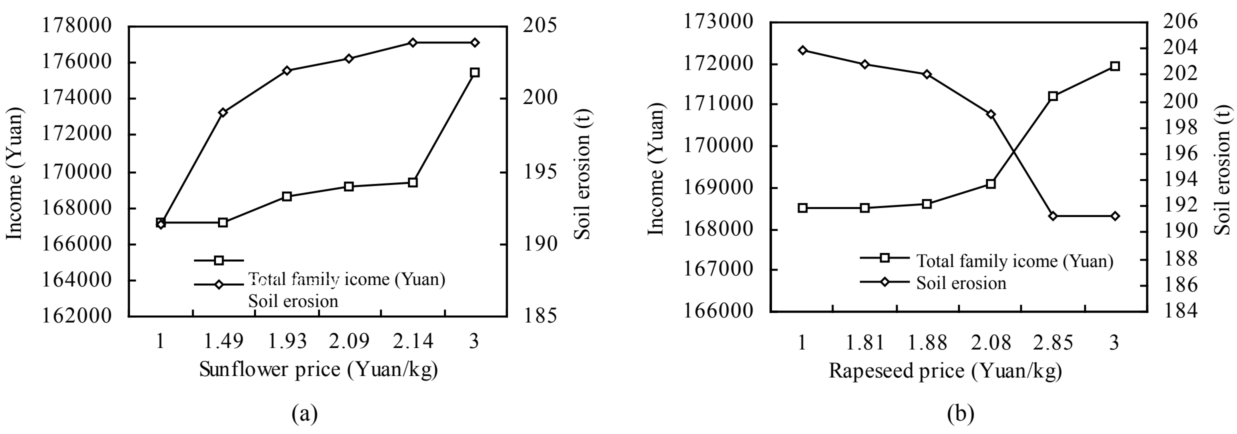

Fig.2 Sunflower (a) and rapeseed (b) price change and soil erosion

Land conversion and soil erosion

The policy measure of converting slope field into forest or pasture has significant effect on land use choices of slope fields and terrace fields (Fig.3a). and also causes concomitant changes in livestock production. Increase in slope fields converted into grassland tends to reduce soil erosion (Fig.4). Simulation results confirmed that the policy measure of converting slope fields into forest or pasture is an effective way to reduce soil erosion, but, if there is no subsidy for converting slope fields into forestry and pasture, farm income tends to decrease because of the cost for combating soil erosion.

Subsidy and soil erosion

Simulation results showed that, while allowance of more than 160 Yuan per mu (6.7a) was paid to farmers, households begin to convert part of their slope fields into pasture, as the profits of cultivation in these slope fields are less than the amount of the subsidy (Fig.3b). Land conversion results in significant reduction of soil erosion without decrease in household income (Fig.5). When subsidy of 160 Yuan per mu was paid to farmers, 167 mu (11.15 ha) of slope fields will be converted into pasture. According to the new policy measure to convert slope fields into forest or pasture, government will pay subsidy to farmers who join the soil conservation program and convert slope fields into forest or pasture. The subsidy for converted slope fields in loess plateau includes 100 kg grain per mu with a price of 1.4 Yuan per kg as compensation for income decrease following abandonment of slope cultivation, and 20 Yuan per mu as food-for-work aid for digging fish-scale pits, which is totally equal to 160 Yuan per mu. Actually 159 mu (10.6 ha) of slope fields has been converted into pasture up to

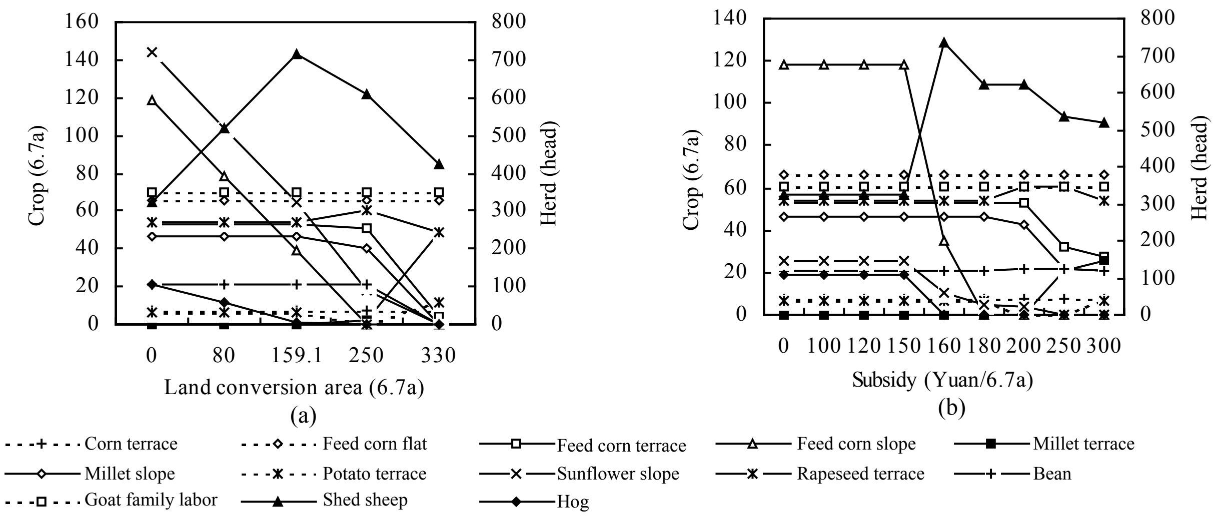

Fig.3 (a) Land conversion policy and land use change; (b) Subsidy and land use change

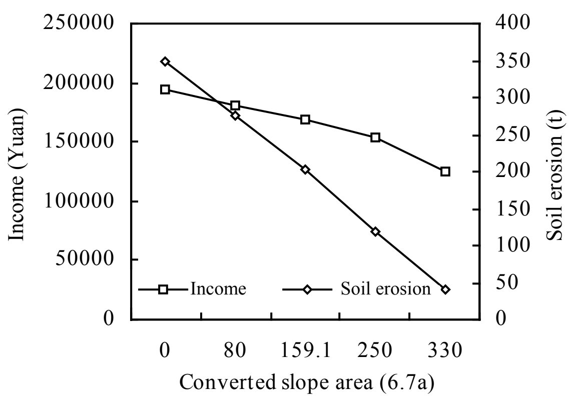

Fig.4 Land conversion policy and soil erosion

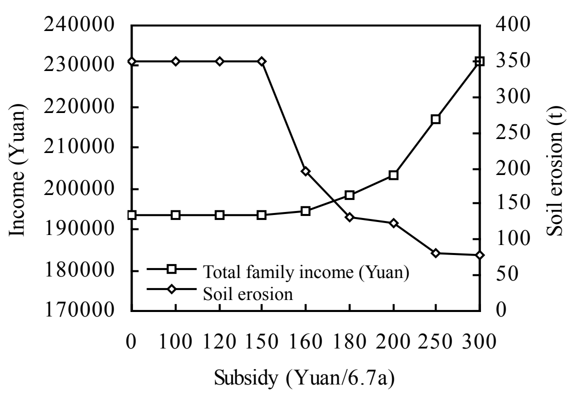

Fig.5 Subsidy slope and soil erosion

the year 2002. Simulation results were quite close to the actual situation and have confirmed the effectiveness of the subsidy in encouraging farmers to convert slope fields into pasture and reducing soil erosion.

With increase in subsidy for land conversion, more slope fields will be converted into pasture. For example, when 200 Yuan subsidy was paid to farmers, 16.3 ha of slope fields making up 74% of total slope fields might be converted into pasture, and when 300 Yuan subsidy was paid, 19.2 ha of slope fields making up 87% of total slope fields might be converted into pasture. Compared with base run result, soil erosion might be reduced from 194.5 tons to 123 tons when 200 Yuan of subsidy was paid and to 79.2 tons when 300 Yuan of subsidy was paid to farmers. The results indicate that if the government wants to reduce soil erosion furthermore by converting much more slope fields, a subsidy more than the profit of cultivation in slope fields should be paid to farmers to convert their slope fields into forest and/or pasture.

The question is whether or not farmers will continue to abandon slope cultivation if the government stops the subsidy. The results show that farmers are not willing to abandon cultivation in slope fields and convert them into pasture if there is no subsidy or if the subsidy is less than 160 Yuan per mu. This raises concern as the subsidy in place is not paid indefinitely. How to develop alternative sectors to increase household income after converted slope fields are converted into pasture becomes a very important issue. One option for the government is to encourage farmers to develop sedentary livestock by using crops produced from fields as fodder and using forage grass from the converted slope fields.

Impact of off-farm job opportunity

Off-farm income provides 33% of total family income at present. In 14 off-farm laborers, 5 persons are engaged constantly in full time off-farm job so they have almost no time for agricultural activities. The others are seasonal part-time laborers who continue their agricultural activities at the same time while pursuing off-farm jobs, so that increase in off-farm job opportunities for seasonal part-time laborers has little effect on land use activities. The increase in number of constantly off-farm laborers will influence land use choice and have impact on land degradation. Simulation results showed that with increase in the number of constantly off-farm laborers part of the slope fields will be progressively used exclusively withdrawn for cultivation of crops, such as maize and sunflower (Fig.6). While the number of constant off-farm laborers continues to increase and exceeds 25 persons, cultivation of millet in slope fields will tend to decrease. When the number of constant off-farm laborers reaches 35 persons, cultivation in all slope fields will stop. As a result, soil erosion will tend to decrease due to halt in slope cultivation following the increase in full time off-farm job opportunities (Fig.7). Total family income will increase steadily and off-farm income will increase with the increase in the number of constant off-farm laborers.

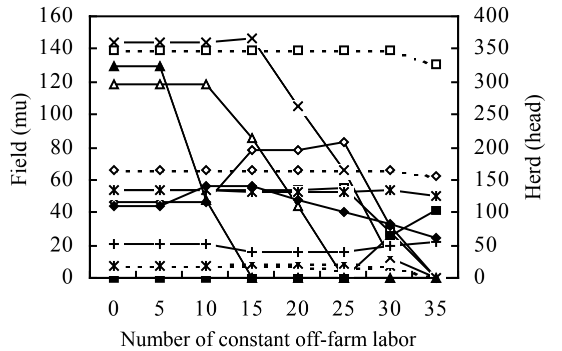

Fig.6 Off-farm labor and land use (these signs in the figure are same as Fig.3)

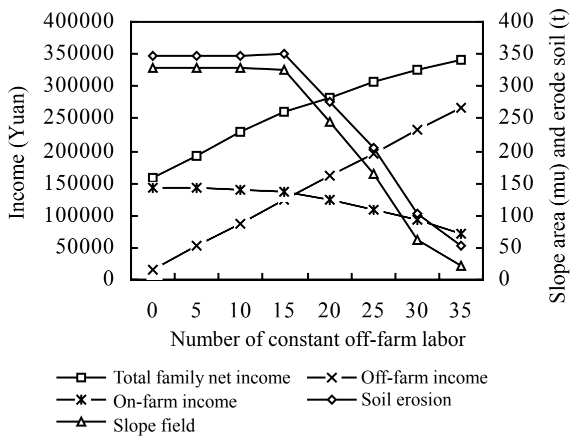

Fig.7 Off-farm labor and soil erosion

CONCLUDING COMMENTS

The simulation results illustrated that the soil conservation program to convert slope fields into forest or pasture is an effective way to combat soil erosion. However, a subsidy that is higher than the profit obtainable from slope fields is needed to encourage farmers to join the conservation program. The result of base run also showed that households can realize a significant increase in income without increase in soil erosion if they put much great weight on sedentary livestock such as pig and shed sheep. That implies a policy measure that gives financial assistance to develop sedentary livestock might contribute to combat soil erosion in the loess plateau. One policy option is to encourage and assist farmers to develop sedentary livestock by using crops produced from fields as well as fodder and forage grass from the converted slope fields.

The analysis result on the impact of off-farm job opportunity on soil erosion showed that households may reduce cultivation in slope fields if they have more constant off-farm job opportunities. That implies a policy measure to increase off-farm job opportunities and to encourage rural urbanization that might contribute to combat soil erosion in the loess plateau.

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