



Resolving ecological and economic challenges: An application of sustainable ecological agriculture on the Chinese Loess Plateau

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Abstract

Resolving ecological and economic challenges is an international topic. On the Loess Plateau of China, the local people have been struggling on low incomes to guarantee their food security, and contend with some of the most serious soil erosion problems in the world. This paper discusses the application, over ten years, of an ecosystem recovery plan based on the sustainable eco-agricultural theories, introduced in the Yan'gou watershed in 1998, including meso-scale eco-agricultural construction and re-vegetation projects intended to control soil and water losses, increase agricultural production and rise income levels. The socio-economic and ecological benefits achieved during this period of reconstruction are analyzed. The evidence indicates that the combination of comprehensive measures to prevent eco-environmental degradation and the application of eco-agricultural models was appropriate. The eco-environment has been substantially improved and the local people are now having higher incomes and much better living conditions. This watershed provides scientific evidence, and is an exemplary illustration of what may be accomplished by investing in eco-environmental and eco-agricultural construction on the Loess Plateau.

Key words: Yan'gou watershed, eco-agricultural systems, construction models, ecological benefits, socio-economic benefits, sustainability, model implantation.

Introduction

Over past decades, the economic growth has happened globally at the cost of the environment¹⁻⁴, particularly, in the Chinese Loess Plateau the local people have been farming and grazing on hill slopes to raise their income that had resulted in large areas devoid of vegetative cover (3% to 6.5% forest cover and 25% to 65% grass cover) and very severe erosion problems (the average soil loss was between 2000 and 2500 t/km²/a)^{5,6}. How to deal with the dilemma brought about by the nexus between economic development and environmental protection has become an internationally challenging topic^{7,8}. Some measures have been tried in many countries, the plastic shelters were used to protect soil and plant surface from rainfall to raise farmers' income in Belize⁹, limitation of expansion of sugarcane, banning of sugarcane burning, and protection of streams and riparian ecosystems in Brazil were recommended to help product sugarcane ethanol in environmentally sustainable and economically fair ways¹⁰, and ecological and sustainable agricultural construction to improve the environment and rural communities^{11,12}.

In China, the Loess Plateau covers an extensive region (530,000 km²—larger than Spain and almost as large as France) and marks the boundary where an eastern developed economy transitions

to a western undeveloped one¹³. The environmental health of this region is critical to the well-being of the areas to the east, in that water and wind erosion originating here can severely affect the water quality of the Yellow River, which supplies water for 12% (159 million) Chinese people with only 2.5% of national water resources, and the amount of dust and sand in the air over vast areas, including Beijing¹⁴. Geographically, it constitutes a unique zone characterized by a fragile eco-environment that is the scene of an intense conflict between human beings and nature¹⁵. For example, the hill-and-gullied loess areas located around Yan'an, Shaanxi Province, support poverty-stricken villages and have a disastrous eco-environmental record, which includes human-induced water deficits (728.8 m³ water resources per capita, which was 26.7% of that in China and only 8.8% of that over the world), very low soil fertility (the average organic matter content was 0.66%), and severe soil and water losses (the average soil erosion modulus was 5,000-10,000 t/km²/a)¹⁶⁻¹⁸. Even though several decades of comprehensive measures in micro-scale watershed (less than 10 km²) to control erosion have made great progress¹⁹⁻²¹, it is insufficient, and inefficient to deal with the serious soil and water losses and low incomes problems in the large area. Thus, there is still great pressure for further efforts to improve

the eco-environment and economy on the Chinese Loess Plateau^{22, 23}. In 1998, a project with a budget of 7 million RMB (about 0.85 million US dollar in 1998) to study the potential for eco-agricultural construction on the Loess Plateau was initiated. A typical eco-agricultural zone was selected for research located on the Yan'gou watershed in Yan'an, Shaanxi Province.

The objectives of this study were (i) to assess the nature and extent of the benefits achieved after ten years of research and construction; (ii) to determine if the comprehensive management plan and implementation of the eco-agricultural models were effective, appropriate and sustainable; (iii) to ascertain if there was a good balance between the ecological and socio-economic benefits. The results of practical eco-agricultural construction in meso-scale (10 km² to 1000 km²) will provide a scientific basis for ecological restoration in macro-scale (bigger than 1000 km²) on Chinese Loess Plateau, and be a beneficial reference for other countries in dealing with contradiction between environment and economy.

Study Area

Geography: The Yan'gou Watershed is located between latitudes N36°28'00" and N36°32'00" and between longitudes E109°20'00" and E109°35'00", 3 km from the city of Yan'an (Fig. 1). The watershed is in the center of the hill-and-gullied loess areas and has a total area of 46.88 km². The main gully is 8.6 km long. The geomorphology is very complicated with many gullies resulting in various types of land utilization, e.g. farming on steep slopes, animal grazing, forestry, etc. The watershed slopes from the southeast to the northwest. Its elevation is 986-1425 m a.s.l., with a maximum elevation difference of 439 m. The whole watershed is located in a climate transition zone between warm temperate semi-humid and semi-arid. The mean annual air temperature is 9.8°C; maximum and minimum temperatures have been recorded at 39.7°C and -25.4°C. The average precipitation is about 560 mm, of which 70% falls mainly in the period from June to September in intense storms. The soil parent material is loess. Loessial soil accounts for more than 90% of the soils in the area. Soil organic matter content is typically very low (< 1%).

Vegetation: The primary zonal vegetation was forest but this has been completely eradicated. Although the Yan'gou watershed is adjacent to the natural secondary forest, e.g. *Quercus liaodungensis*, *Populus davidiana*, etc. of southern Yan'an, the

forest boundary has retreated rapidly over the past sixty years due to uncontrolled tree felling before 1997. In 1997, the surviving secondary forest coverage was less than 10% of the watershed. There was also 666.9 ha of artificially regenerated forest, e.g. *Robinia pseudoacacia*, *Pinus tobulaeformis*, *Platycladus orientalis*, etc. and 174.1 ha of commercial forests occupying 14.2% and 3.7% of the total area, respectively. Collectively, these areas covered only 27.2% of the total land area. The problems due to low levels of vegetation preservation and replanting were very serious, resulting in soil and water losses from exposed areas, and, consequently, this had a deleterious effect on the full development of the agricultural economy.

Soil and water loss: In 1997, the area affected by soil erosion in the Yan'gou watershed was 42.55 km², accounting for 90.7% of the total land area. The gully density was 4.8 km/km². Big gullies and small gullies occupied an area of 534.47 ha, or 11.4% of the total land area. Wild slope land and arable slope land covered 2636.83 ha, or 56.2% of the total land area. The steepness of slope was characterized by the following four divisions of gradient: lower than or equal to 5°, 5°-15°, 15°-25° and greater than 25°, accounting for 5.5%, 17.4%, 27.8% and 49.3% of the total land area, respectively. Most cropland (94.8%) occupied slopes with a gradient greater than 15°²⁴. The intensity of soil erosion, or the soil erosion modulus, of up to 6000-9000 t/km²/a was typical for this area of severe soil and water losses. Measures to prevent soil and water erosion, such as increasing vegetative cover, constructing dams, etc. were in place over an area of 1094.6 ha but had only succeeded in reducing soil losses to set standards in 23.9% of that area²⁵.

Population and economy: In 1997, the Yan'gou watershed included 14 villages with 693 families and 2932 persons. The population density was 64 persons/km². Per capita basic farmland, i.e. land officially designated for cultivation, amounted to only 0.06 ha. Most food was produced on slopes due to the terrain. The mean yield was 109.5 kg/ha, and the village per capita income was 763 RMB per year.

Methods

Eco-agricultural construction measures: Based on the principle of ecological agriculture a series of eco-agricultural construction measures for the Yan'gou watershed was launched in 1998. There are three key concerns for eco-agricultural construction in rural China: (i) the need to increase absolute levels of agricultural output to ensure food security; (ii) strengthening the rural economy and increasing rural income; and (iii) dealing with manifest rural environmental problems^{26, 27}. According to these, all cultivation on slopes steeper than 15° was to be abandoned, on the basis of China's self-supporting food policy, and terraces were to be constructed instead, thus compensating for the shortage of basic farmland; soil erosion would be controlled by increasing the vegetative cover of the abandoned land; and the average income per capita would be increased to eradicate poverty by expanding cash crops and commercial stockbreeding, e.g. shed breeding; advanced agricultural technologies in planting and management and good varieties of agricultural products were introduced to enhance yields.

To implement these measures, the difficulties caused by underestimating vegetative cover, using standard management

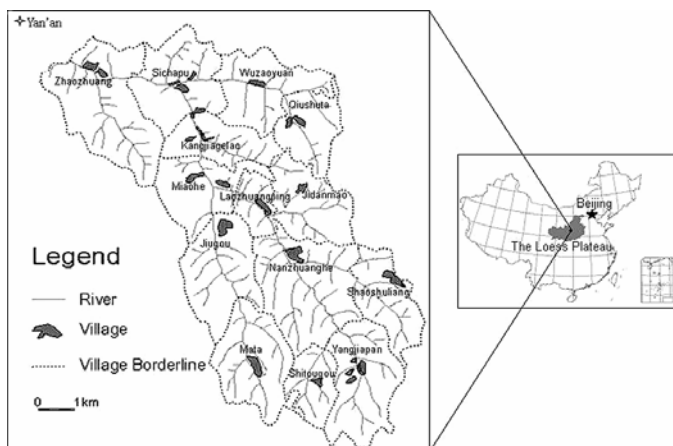


Figure 1. Map of the rural administration and the water system of the Yan'gou watershed, China.

practices without regard for local conditions, and the lack of coordination between measures were addressed first. Thus, the soil and water conservation system was planned taking into account the characteristics of soil and water loss in Yan'gou. Establishing vegetation was selected as the most important measure on slope farmland together with forest, shrub and grass recovery. The proposed vegetation recovery model was built upon the prevailing vegetation problems and conditions. The issue of immediately reducing the losses of forest and grasses caused by human activity and unmanaged grazing was addressed by issuing closure orders for the hillsides, prohibiting livestock grazing and unauthorized wood cutting, which also permitted natural self-propagation, renewal, and succession of vegetation in the abandoned gullies and on barren land.

Three models of eco-agricultural management and construction were developed for the region on the basis of a survey of the available local natural resources, existing agricultural infrastructure and expertise, and socio-economic conditions. These included the concepts of developing secondary agricultural products, integrating basic agriculture with fruit production, and developing stockbreeding programs alongside the establishment of forests and grasslands. These models were presented to the local people and were demonstrated in selected villages.

- (i) Secondary agricultural products model is mainly intended for villagers living near towns and cities who can take advantage of the location of a readily accessible, lucrative, market for their produce. The intent of the model is to push eco-agriculture construction forward rapidly with a view to raising the income of the farmers by optimizing crop production, planting cash crops on the limited land resources to generate higher incomes, and managing multiple enterprises such as animal husbandry, e.g. pig, cattle and fish, and food processing, e.g. tofu, bean sprout and meat foods.
- (ii) Mixed basic agriculture-fruit production model is mainly intended for villages with a large area of arable land and a strong foundation in fruit production. Considering the large area of newly built terraces and pre-existing fruit orchards, a stable and high yield of crops on the terraces should be possible. Therefore, this plan's intent is to improve the planting system, to expand the use of mature cultivation techniques, and to increase the fertility of the soil. Concurrently, the scientific management of fruit orchards will also be improved, and investment in agriculture and fruit production optimized.
- (iii) The intention of forest and grassland stock-breeding model is to develop animal husbandry as a source of revenue despite the apparent current conflict between it and the aim of forest preservation. This model is mainly intended for villages that are relatively far from cities and towns, and have poor natural conditions, such as low soil fertility, but a large land area per capita. Areas of artificial grassland and forest will be developed, with the inclusion of water conservation practices, as the source of a habitat and/or sustainable food supply for animals. A management program will be developed in order to optimize herd structure and grazing according to the local conditions with a view to maximize the production value of stockbreeding and to thereby increase the income of farmers. Emphasis will be placed on integrating the development of the forests and grasslands with stockbreeding.

Data collection and processing: This study integrated both qualitative and quantitative methods. Data were collected from three sources: published and unpublished government documents, survey from informal/semi-structured interviews and field observations. The most important government documents used in this study is the Baota District Gazetteer, published by Baota District Gazetteer Compilation Committee in 2002. Unpublished documents were provided by the government of Baota district. They provide details of the social and economic changes and historical events of the implementation of ecological agriculture in the Yan'gou watershed. Major quantitative data, especially demographic, economic and agricultural data, were derived from officially published statistics. Recognizing that many research questions cannot be addressed if analysis is based solely on official data, the authors conducted field observations and informal/semi-structured interviews in the Yan'gou watershed between 1998 and 2007. Regression analysis was undertaken to determine the relationship between population and year by the SPSS 16.0. As a result, the study is complemented by the incorporation of a qualitative analysis, which is based on data assembled through a combination of interviews, field observation and library research.

Results and Discussion

Achievements of eco-agricultural construction: Based on the master plan, eco-agricultural construction of the watershed was conducted between the years 1998 and 2007. Through close cooperation with engineers and the local government, the project's main objectives were completed efficiently. By 2007, 78.0% of the area was under effective management. The engineering tasks required to transform the slopes of the major gullies into terraces had been completed. Taking the watershed as a whole, the land utilization structure has now been rationalized (Fig. 2). A large number of engineering projects that will assist in erosion prevention and increase water use efficiency have been implemented (Table 1). Hence, good results have been achieved which are evident to the local population. Farmers have also been encouraged, by the practical soil and water conservation, and eco-economic benefits to assist in the eco-agricultural construction projects.

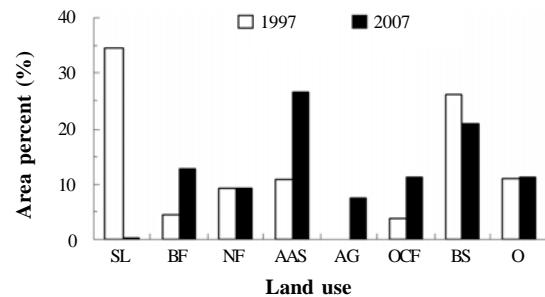


Figure 2. Comparison of land use in 1997 and 2007 in the Yan'gou watershed: SL steep land, farming on gradients >15°; BF basic farmland; NF natural forest; AAS artificial arbors and shrubs; AG artificial grassland, pastures; OCF orchard + commercial forests; BS barren slopes; O others.

Table 1. Eco-agricultural construction measures and investments in the Yan'gou watershed.

Measures	Pre-existing	Newly built	Investments (10 thousand RMB)
Terraces	94.8 ha	485.6 ha	410.34
Artificial arbors	255.0 ha	709.1 ha	85.00
Artificial shrubs	252.8 ha	32.5 ha	2.44
Artificial grasses	0 ha	349.7 ha	20.98
Orchard	174.1 ha	259.9 ha	46.78
Economic forest	0 ha	96.2 ha	17.31
Grassed roadway	0 km	40 km	30.00
Water utilization projects	0	4	13.40
Dams	2 (out of service)	3 (1 newly built, 2 repaired)	9.80
Water-harvesting cisterns	0	9	7.20
Sunlit greenhouses	4.2 ha	12.6 ha	38.35
Sunlit sheds	0	133	24.80
Others			12.36
Total			718.76

Training in and demonstration of the eco-agriculture models:

Secondary agricultural products model: The village of Zhaozhuang was selected as the experimental demonstration site for this model. The village, which is close to Yan'an city, is located at the dammed gully exit of the Yan'gou watershed. The villagers have a long tradition of managing multiple enterprises. First the infra-structure of the village was modified by constructing 26 ha of terraces for raising grain yields and 2.1 ha of sunlit greenhouses for planting off-season vegetables and seasonal fruits, e.g. cucumbers, vegetable marrow, tomatoes, strawberries and grapes. Using water from below the dry river bed, efficiently using water in drip irrigation systems in the greenhouses, and raising crop productivity has been widely implemented. Due to the higher efficiency of crop production, 65% of laborers (156 persons) were transferred to the industry from animal husbandry and food processing. The results are grain crops produced per capita having increased by 31.5% from 400 to 525.8 kg and net income per capita having greatly increased from 900 RMB in 1997 to 3680 RMB in 2007. The contribution of basic food crops and secondary agricultural products to the increase of net income was 8.7% and 65.3%, respectively. Thus, the secondary agricultural products model is proving to be highly effective.

Mixed basic agriculture-fruit production model: The two villages chosen to demonstrate this model were Wuzao yuan and Jidanmao in the middle reaches of the watershed. Wuzao yuan village had a large area of mountain land, and the farmers depended mainly on agriculture for their income. Implementing the mixed basic agriculture and fruit production model resulted in a transformation of the traditional practice of extensive planting which delivered low incomes. Currently, the newly built terraces cover 36.6 ha, and basic farmland per capita has increased from 0.07 ha to 0.21 ha. New orchards have been established and cover 17.6% of the original farmland area. The rehabilitated forest and grassland area totals 48.7 ha, 57.0% of the original farmland area. Food produced per capita has increased from 412 kg in 1997 to 723.5 kg in 2007. Net income per capita now stands at 2612 RMB, which is 3.73 times the 1997 value.

Jidanmao village had a small land area and began to develop fruit production in the mid-1990s. Although the orchard area per capita totaled 0.167 ha, due to poor management and low returns,

the farmers were very poor. Per capita income in 1997 was only 640 RMB. Horticultural management of the fruit orchards aimed at achieving high yields of good quality fruit efficiently by, for example, preventing diseases and pests, has been improved through on-site training and guidance. Now Jidanmao has become a famous fruit-specialty village. In 2007, income per capita was 3301 RMB, 5.16 times the 1997 value, of which more than half derives from fruit. The application of the mixed agriculture-fruit production model, with Wuzao yuan and Jidanmao villages at the hub of a circle of neighboring villages is proving to be highly effective.

Forest and grassland stock-breeding model: Mata village was selected to demonstrate this model. As an example, the development of artificial grass lands or pasture, and both indoor and outdoor animal production were practiced at Mata. The local plan was to produce grassland, sheep, pigs, methane, and fruit as an integrated agro-industry. New fodder crop varieties were introduced to solve the existing problem of low forage yields. A new alfalfa variety, Ar-4, from Canada was planted on 43.33 ha of mountain terrace (92.3% of the total terrace area) and on 23.33 ha of rehabilitated slope land. A further 10 maize and sorghum varieties of fodder, or food-fodder, were introduced resulting in a 50% increase in grass yield. A series of engineering projects including high quality herd stocks to increase breeding potential and to raise their production value, 25 sunlit sheds for breeding sheep and pigs, facilities for utilizing the methane produced from the animal wastes, and 80 storage pits for silage, fresh forage, etc. have been built. In 2007, 57 of 63 families in Mata village engaged in shed breeding, and there were total 1053 white cashmere goats. The net income per capita in Mata village has been greatly increased from 500 RMB in 1997 to 2864 RMB in 2007. The efficiency of the breeding program has been recognized with the granting of the title of "demonstration village for shed breeding" by the program and the Baota district.

Benefits analysis of eco-agricultural construction:

Eco-environmental benefits: The first target pursued in the Yan'gou watershed development was to improve the eco-environment. In 1999, the hill slopes of the Yan'gou watershed were closed off entirely. This has effectively increased the preservation rate of artificial forests and grasslands, and encouraged the restoration and succession of natural vegetation. Currently, the proportion of forest and grassland in the landscape is fully consistent with the guideline that the mountains "should be beautiful and the water clear". Forests now cover 44.1% of the area. If the closed area, representing potential forest and grasslands, was included in this figure, forests and grasslands would cover 75.0%. If the orchards were also added, the area covered would be 84.3%. Even taking into account the land actually covered by roads, buildings, rivers, etc., within these areas, vegetative cover in the Yan'gou watershed still covers 70.0% (Table 2). Slope farmland in the Yan'gou watershed has effectively been restored. The once yellow wild mountains are now flourishing green.

Engineering and biological measures such as the construction of major dams and terraces, the establishment of orchards, and the planting of forests, shrub- and grasslands in the Yan'gou watershed have substantially reduced surface soil losses. With

Table 2. Benefit indices for the Yan'gou watershed.

Year	Ecological benefits			Economical benefits		
	Management area (%)	Vegetation coverage (%)	Soil erosion modulus (t/km ² /a)	Income per capita (RMB)	Basic farmland per capita (ha)	Yield (kg/ha)
1997	23.9	27.2	6000	763	0.066	1095
2007	78.0	70.0	33	3214	0.194	4389

the large increase in the area under management control, the obvious benefits of soil and water conservation have been achieved. According to monitoring data collected by the hydrological station at the exit of the Yan'gou watershed, sediment loads have declined by 91.4% during the study period. Reducing soil losses have greatly improved the eco-environment in the watershed and promoted productivity while at the same time improving the water quality of the river.

The degree of reduction in sediment levels was influenced by two key factors: the amount of vegetative surface cover and rainfall^{28, 29}. Annual rainfall was relatively low during the implementation of the management plan but it has now increased to levels that are higher than those in 1997, i.e. before the project began (Fig. 3). Even so, both soil loss intensity and sediment concentration showed a declining trend (Fig. 3), implying that the reduction in soil erosion was mainly due to human control of soil and water losses.

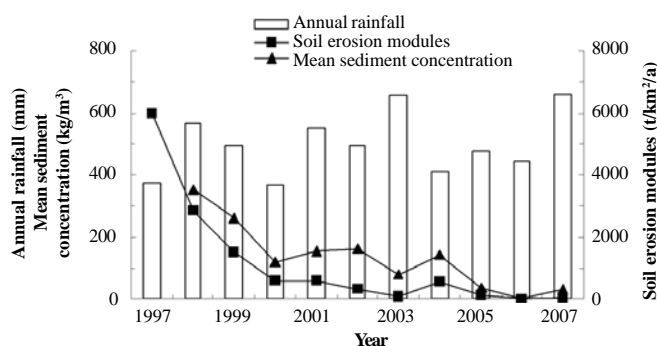


Figure 3. Annual rainfall, soil erosion modulus and average sediment concentration for the Yan'gou watershed for 1997-2007.

Economic benefits: Through investments in eco-agricultural construction in the Yan'gou watershed (Table 1), the total crop yield for the area is now steady at 1600 ton or 511 kg per capita per year, the carrying capacity of the vegetation grew from 2500 sheep units in 1997 to 7500 sheep units in 2007, and the mean income per farmer rose from 763 RMB in 1997 to 3214 RMB in 2007 (Fig. 4). The structure of per capita income has changed (Table 3), and the increase of income is derived mainly from

Table 3. Structure of per capita income in the Yan'gou watershed before and after eco-agricultural construction.

Income source	1997		2007		Changes (+ increase, - decrease)	
	Income per capita (RMB)	Percentage (%)	Income per capita (RMB)	Percentage (%)	Income per capita (RMB)	Percentage (%)
Grain crops	293.0	38.4	573.0	19.8	+ 280	- 18.6
Cash crops	68.8	9.0	810.3	28.0	+ 741.5	+ 19.0
Animal husbandry	116.7	15.3	538.3	18.6	+ 421.6	+ 3.3
Off-farm job	284.5	37.3	972.4	33.6	+ 687.9	- 3.7
Total	763.0	100	2894.0	100	+ 2131.0	0

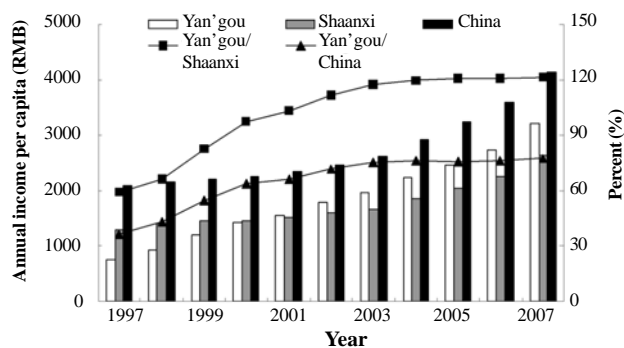


Figure 4. Per capita income of farmer in the Yan'gou watershed and Shaanxi Province and China, and the ratio of income per farmer in the Yan'gou watershed versus it in Shaanxi Province and China, 1997-2007.

agriculture including grain crops, cash crops and animal husbandry, although the off-farm job contributes 32.3% to the increase. That was caused by the chief investments in terraces, artificial vegetation, orchard and economic forest, and the average investments were respectively 8450, 990 and 1800 RMB/ha (Table 1). Although the average investments are much less than the estimated values of 9750, 1381 and 6120 RMB/ha³⁰, the eco-agricultural construction projects in Yan'gou watershed have achieved the ecological and economic aims successfully.

Fig. 4 shows that the mean income per farmer in Yan'gou watershed, Shaanxi Province and China was increasing from 1997 to 2007. The ratio of income per farmer in Yan'gou watershed versus it in Shaanxi Province and China were also increasing, especially, from 59.4% and 36.5% in 1997 to 117.4% and 75.1% in 2003. From 2004 to 2007, the increase of the ratio slowed down. On one hand, because 90% of infrastructure including terraces (438 ha), orchards (226 ha), sunlit greenhouses (12.6 ha), artificial grass (310 ha) and sunlit sheds (117) had been completed in past six years and been put into use, the input in construction decreased in late three years. On another, a series of benefiting-farmers policies had been carried out by the Chinese government from 2004 to 2007, the mean income per farmer in Shaanxi Province and China rose faster than past six years. We can conclude that the eco-agricultural construction brought up the income of farmer and kept it at a higher standard in research area than in Shaanxi Province, but it was also lower than that in China. Therefore, the new economic growth points should be developed.

On the other hand, not all benefits have an easily quantifiable financial value. The obvious immediate financial benefit is in the increased incomes of the local people. It is more difficult to put a price on preserving the ecosystem. Soil is considered to be a non-renewable resource and so, preserving it by preventing

erosion, could be regarded as priceless. Improvements to the environmental health and the aesthetic quality of the landscape can lead to a general sense of well-being among the people resulting in lowered health costs and higher productivity. Greatly reduced sediment loads help protect the downstream

water system with subsequent savings on expenditures for dredging and water purification, etc. There also existed a need for the investment in order to protect the heritage for future generations by designing and implementing a sustainable eco-agricultural system and to satisfy other perceived moral obligations of this present generation. In the end, it remains in the hands of those who can invest such sums of money (e.g. governments, international organizations, business consortiums, charities) as to whether such investment is worth it.

Social benefits: The control of soil and water losses and the various eco-agricultural construction projects have led to a conspicuous improvement in production and living conditions. The efficiency of both land and labor production has been significantly enhanced. The switch from the former labor intensive, extensive planting system with its low yields to more efficiently managed, higher yielding systems have released a large amount of labor for the development of land resources and eco-environmental construction. This greatly promotes the prosperity of the village economies and the subsequent development of education, health care, and cultural activities. From 1997 to 2007, attendance rate of school-age children in the nine-year compulsory education program increased from 92.3% to 98.8%. Meanwhile, the ratio of expenditure on education, health care, and cultural activities in family consumption rose from 6.9%, 4.2% and 0.8% to 10.7%, 11.8% and 4.6%, respectively. Eco-environmental construction in the Yan'gou watershed has been acknowledged as a prime example of eco-agricultural construction models and integrated key technologies. In 2000, the Chinese Ministry of Water Resources named it as one of the first national "ten-hundred-thousand" demonstration engineering projects. The national media has given extensive coverage to the Yan'gou watershed case; this interest has spread information on the construction models and technologies used in the Yan'gou watershed on the Loess Plateau.

Sustainability: On the assumption that in the future land utilization structure will be kept as same as in 2007 (Fig. 2), namely the agricultural and economic development will not threaten the virtuous circle of established ecosystem. Sustainability of ecological agriculture could be evaluated by per capita area of basic farmland and orchard, and per capita sheep units with increasing population. The regression analysis found it out that the best fitting between population (P) in Yan'gou watershed and year (Y) from 1957 to 2007 (Fig. 5) could be obtained with the following logarithmic equation:

$$P = 74151 \ln(Y) - 560561 \quad (n = 25, R^2 = 0.9958)$$

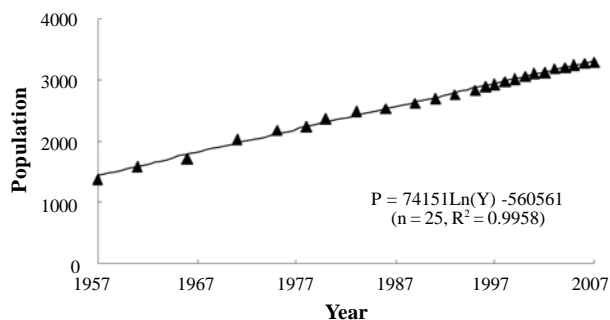


Figure 5. Population growth in the Yan'gou watershed, 1957-2007.

The population in the future could be calculated by this equation (Table 4). Table 4 shows that if the total area of basic farmland and orchard and the total number of sheep units do not change, the population in 2047 will increase by 45.1% from 3293 in 2007 to 4777 in 2047, but per capita area of basic farmland and orchard, and per capita sheep units will respectively decrease by 30.1%, 31.1% and 31.1% in 2047 than in 2007. Without regard to improvement of productivity and the population flow which is caused by urbanization and increasing of off-farm job, the local people will also live at higher standards in 2047 than in 1997 (before eco-construction). Therefore, a sustainable eco-agricultural mechanism has been established that will provide long-term ecological and economic benefits for the Yan'gou watershed.

Table 4. Changing of evaluation indices for sustainability with time in Yan'gou watershed.

Indices	1997	2007	2017	2027	2037	2047
Population	2932	3293	3682	4049	4414	4777
Per capita area of basic farmland	0.066	0.194	0.173	0.158	0.145	0.134
Per capita area of orchard	0.059	0.132	0.118	0.107	0.098	0.091
Per capita sheep unit	0.852	2.28	2.04	1.85	1.70	1.57

The environmental protection policies in China prohibit reducing natural vegetation area, so the ratio of it in land use will not decrease. Thus, soil erosion could be controlled effectively at a level much lower than the local soil loss tolerance (1000 t/km²/a). However, with the increase of population in Yan'gou watershed, per capita means of production will decrease (Table 4). The contradiction between limited agricultural land area and economic development will appear. To deal with the problem, the productivity should be improved, for example, advanced agricultural technologies in planting and management and good varieties of agricultural products were introduced to enhance yields; aggregating agricultural production to enhance the degree of agricultural mechanization, to transfer labors to off-farm job. On the other side, investing on industry of agricultural products processing will not only solve the problem of farmers on agricultural products sales but will also provide plenty of off-farm jobs. With the economic development, local people will invest more in education, health care, and cultural activities.

The chemical fertilizers and pesticides were mostly used in farmlands, orchard and greenhouses. Although the chemical fertilizers used in three land use types increased in per hectare, the amount of them in Yan'gou watershed decreased in last ten years (Table 5). The decrease of chemical fertilizers was due to, firstly, the planting areas decrease; secondly, the basic farmlands having higher fertility without soil erosion than slope land; thirdly, more organic fertilizers used which were from developed shed breeding; finally, advanced agricultural technologies in planting and management, such as, film, straw returning and rotation, introduced to keep and supply fertility. Although the yields of secondary agricultural products increased, the utilization pesticides also decreased, because a series of advanced technologies and fine management measures were introduced. Films and sunlit greenhouses were used to enhance water content, temperature and fertilizer of soil to improve antiviral ability

Table 5. The fertilizer and pesticides used in Yan'gou watershed before and after eco-agricultural construction.

Land use types	1997				2007			
	area (ha)	organic fertilizer (t/ha)	chemical fertilizer (kg/ha)	pesticides (kg/ha)	area (ha)	organic fertilizer (t/ha)	chemical fertilizer (kg/ha)	pesticides (kg/ha)
Farmlands	1099.0	9.6	369.8	3.2	642.3	15.0	380.2	2.6
Orchard	174.1	24.1	402.7	15.3	434.0	37.5	411.3	9.2
Sunlit greenhouses	4.2	55.4	1086.6	14.7	16.8	73.1	1123.1	5.2
Total	1277.3 ha	14978.89 t	481084.0 kg	6242.3 kg	1093.1 ha	27542.6 t	439216.2 kg	5750.1 kg

of plant. The new resistant varieties, soilless culture, non-pollution cultivation, physical and biologic prevention measures were also introduced. As a result, the development of eco-environment was sustainable.

However, there were also many public environmental problems which need to be solved, for example, absence of wastewater treatment plants and garbage collection systems; the haphazard drainage of domestic sewage polluting soil and rivers; odor and parasitic diseases caused by stockbreeding and free toss of rubbish; environmental pollution due to residue films, etc. To solve such environmental problems, more investment, technology and labor force are needed.

Model implantation: In the past ten years, three exemplary eco-agricultural construction models have been implanted to other villages in Yan'gou watershed. According to the demonstration in Yan'gou watershed, an eco-agricultural construction plan has been implemented in 120 km² area of Baota district, Yan'an City. After that, based on the five models from Yan'gou watershed, Zhifanggou watershed and Yanhe watershed in Yan'an City and exemplary research results of three watersheds, an eco-environmental construction project to accelerate the ecological restoration in 707 km² of Yan'an City has been initiated. In 2002, on the basis of the successful experiences from meso-scale demonstrations including Yan'gou watershed, Ministry of Water Resources and Chinese Academy of Sciences combined with the government of Shaanxi Province started construction of a macro-scale demonstration area (80,600 km²) of soil and water conservation and eco-agricultural construction in Yulin and Yan'an City, north of Shaanxi Province. It has been proved that the models developed in Yan'gou watershed could be implanted to other places in a large area.

However, given the diverse conditions, the path towards sustainable agricultural development and ecological protection will vary substantially and solutions will be highly location-specific³¹⁻³³. It should be kept in mind that research in other areas must account for relevant local conditions, especially when implanting the models to other agricultural systems, e.g. European, North American or Australian farming regions, which are far different in population and agricultural practices.

Conclusions

Through the application of a master plan that integrated scientifically-based eco-environmental and eco-agricultural construction projects with the needs of local communities, substantial ecological and economic benefits have been achieved in the Yan'gou watershed. Successful soil and water conservation measures and the implementation of various, efficient, eco-agricultural projects have resulted in large increases in production

and improvement in the living conditions of local farmers. Whereas, before the project began, the environment was heavily degraded and the prospects of the communities on the watershed were poor, the eco-economic system now shows signs of healthy improvement and the prospects that this will continue are good.

The achievements of Yan'gou eco-agricultural construction have provided scientific evidence and an exemplary demonstration for exploring effective means of management, taking into account the local limiting factors and devising a strategy for sustainable development on the Loess Plateau, especially in regard to eco-agriculture.

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References

- Rees, W. 2003. Economic development and environmental protection: An ecological economics perspective. *Environmental Monitoring and Assessment* **86**:29-45.
- Anonymous 2004. Soil and trouble. *Science* **304**:1614-1615.
- Chianu, J. N., Tsujii, H. and Awange, J. 2006. Environmental impact of agricultural production practices in the savannas of northern Nigeria. *Journal of Food Agriculture & Environment* **4**(2):255-260.
- Ogunlela, V. B. and Ogunlela, Y. I. 2008. The challenge of rural poverty alleviation in Nigeria: The role of the national agricultural research system. *Journal of Food Agriculture & Environment* **6**(3&4):439-499.
- Shi, H. and Shao, M. A. 2000. Soil and water loss from the Loess Plateau in China. *Journal of Arid Environments* **45**:9-20.
- Chen, L. D., Messing, I., Zhang, S. R., Fu, B. J. and Ledin, S. 2003. Land use evaluation and scenario analysis towards sustainable planning on the Loess Plateau in China – Case study in a small catchment. *Catena* **54**:303-316.
- Bolorunduro, P. I., Adesehinwa, A. O. K. and Bolorunduro, O. M. 2005. Policy options in managing the crisis of environmental degradation and the prevalence of poverty in urban Nigeria. *Journal of Food Agriculture & Environment* **3**(1):216-219.
- Ablaza, E. C., Takeda, N. and Ishikawa, K. 2006. Quartz porphyry (Bakuhan-seki) as soil amendment in improving soil quality and yield of soybean (*Glycine max* (L.) Merr.). *Journal of Food Agriculture & Environment* **4**(3&4):252-256.
- Arya, L. M., Pulver, E. L. and Th. van Genuchten, M. 2001. Economic, environmental, and natural resource benefits of plastic shelters in vegetable production in humid tropical environment. *Journal of Sustainable Agriculture* **17**:123-143.

- ¹⁰Martinelli, L. A. and Filoso, S. 2008. Expansion of sugarcane ethanol production in Brazil: Environmental and social challenges. *Ecological Applications* **18**:885-898.
- ¹¹Gullino, M. L., Camponogara, A., Capodagli, N., Yang, X. and Clini, C. 2006. Sustainable agriculture for environment protection: Cooperation between China and Italy. *Journal of Food Agriculture & Environment* **4**(2):265-273.
- ¹²Shi, T. 2002. Ecological agriculture in China bridging the gap between rhetoric and practice of sustainability. *Ecological Economics* **42**:359-368.
- ¹³Wu, H., Childress, W. M., Li, Y., Spence, R. D. and Ren, J. Z. 1996. An integrated simulation model for a semi-arid agroecosystem in the Loess Plateau of northwestern China. *Agricultural Systems* **52**:83-111.
- ¹⁴Editorial. 2003. Introduction: Soil erosion and participatory land use planning on the Loess Plateau in China. *Catena* **54**:1-5.
- ¹⁵Lu, C. H., van Ittersum, M. K. and Rabbinge, R. 2004. A scenario exploration of strategic land use options for the Loess Plateau in northern China. *Agricultural Systems* **79**:145-170.
- ¹⁶Fu, B. J. and Chen, L. D. 2000. Agricultural landscape spatial pattern analysis in the semi-arid hill area of the Loess Plateau, China. *Journal of Arid Environments* **44**:291-303.
- ¹⁷Wang, J. J., Liu, G. B., Xie, Y. S., Quan, S. A. and Zhang, G. L. 2005. Research on the development model of ecological agriculture in loess hilly-gully region of northern Shaanxi, China. *Ecological Economy* **1**:93-99.
- ¹⁸Xu, Y., Guo, T. Y. and Yang, G. A. 2005. A comparison between different ecological de-farming modes in the loess hilly-gully region in China. *Journal of Geographical Sciences* **15**:53-60.
- ¹⁹Chen, L. D., Wang, J., Fu, B. J. and Qiu, Y. 2001. Land-use change in a small catchment of northern Loess Plateau, China. *Agriculture, Ecosystems and Environment* **86**:163-172.
- ²⁰Qiao, Y. L., Wang, Y. and Tang, J. Y. 2004. Study of remote sensing monitoring of dynamic change of the Loess Plateau forest resources. *Advances in Space Research* **33**:302-306.
- ²¹Fu, B. J., Hu, C. X., Chen, L. D., Honnay, O. and Gulinck, H. 2006. Evaluating change in agricultural landscape pattern between 1980 and 2000 in the loess hilly region of Ansai County, China. *Agriculture, Ecosystems and Environment* **114**:387-396.
- ²²Hoang Fagerström, M. H., Messing, I., Wen, Z. M., Trouwborst, K. O., Xu, M. X., Zang, X. P., Olsson, C. and Andersson, C. 2003. A participatory approach for integrated conservation planning in a small catchment in Loess Plateau, China - Part II. Analysis and findings. *Catena* **54**(1):271-288.
- ²³Chen, H. and Cai, Q. G. 2006. Impact of hillslope vegetation restoration on gully erosion induced sediment yield. *Science in China: Series D Earth Sciences* **49**:176-192.
- ²⁴Jiao, F., Yang, Q. K. and Lei, H. Z. 1998. Present situation of land use and proposals for rational use at Yan'er Gully watershed. *Bulletin of Soil and Water Conservation* **18**:41-44.
- ²⁵Lei, H. Z., Yang, Q. K. and Jiao, F. 2000. Soil erosion and land utilization in loess hilly region. *Research of Soil and Water Conservation* **7**:48-51.
- ²⁶Cai, Y. and Smit, B. 1994. Sustainability in agriculture: A general review. *Agriculture, Ecosystems and Environment* **49**:299-307.
- ²⁷Sanders, R. (ed.) 2000. *Prospects for Sustainable Development in the Chinese Countryside: The Political Economy of Chinese Ecological Agriculture*. Ashgate, Aldershot.
- ²⁸Zhang, K., Li, S., Peng, W. and Yu, B. 2004. Erodibility of agricultural soils on the Loess Plateau of China. *Soil & Tillage Research* **76**:157-165.
- ²⁹Zheng, F. L. 2006. Effect of vegetation changes on soil erosion on the Loess Plateau. *Pedosphere* **16**:420-427.
- ³⁰Xu, Y. 2001. Discussion on the investment problem of rural industrial development based on soil and water conservation – taking middle hilly region of Loess Plateau for example. *Research of Soil and Water Conservation* **8**:143-146.
- ³¹Smith, C. S. and McDonald, G. T. 1998. Assessing the sustainability of agriculture at the planning stage. *Journal of Environmental Management* **52**:15-37.
- ³²Saysel, A. K., Barlas, Y. and Yenigün, O. 2002. Environmental sustainability in an agricultural development project: A system dynamics approach. *Journal of Environmental Management* **64**:247-260.
- ³³Fernandes, L. A. O. and Woodhouse P. J. 2008. Family farm sustainability in southern Brazil: An application of agri-environmental indicators. *Ecological Economics* **66**:243-357.