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Towards Sustainable Integrated Watershed Ecosystem Management: A Case Study in Dingxi on the Loess Plateau, China

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Abstract The Chinese government initiated a massive conservation program called "Grain-for-Green" in 1999 to reduce soil erosion and improve ecosystem function. Implementing practical sustainable development in the loess plateau still remains problematic, particularly in its eco-fragile areas. Here we discussed an approach for sustainable development at the watershed scale by integrating land use suitability, ecosystem services and public participation in the loess hilly area. We linked land use scenario analysis and economic modeling to compare the outcomes of three scenarios, CLU (Current Land Use), GOLU (Grain-production Oriented Land Use) and PSLU (Potential Sustainable Land Use). The results indicated that compared to PSLU, GOLU may provide a higher economic productivity in the short-term, but not in the long-term. CLU ranked lowest in terms of economic benefits and did not meet the daily needs of the local farmers. To reconcile the land use adjustments with farmers' basic needs, a labor-saving land use strategy is necessary. Since the PSLU scenario assumes that slope cropland should be converted to pastures or orchards, more time may be available for off-farm work and for more public participation in integrated ecosystem management. Financial support to the local farmers for environmental conservation should be modulated in function of their positive contribution to ecosystem management.

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Introduction

Ecosystem management addresses trans-boundary, interdisciplinary, and multi-party issues from an ecosystem perspective (Chuenpagdee and others 2006; Yaffee 1997; Berry and others 1998; Pavlikakis and Tsihrintzis 2000). Successful implementation of ecosystem management depends largely on stakeholders' acceptance and participation (Cervantes and others 2008; Chuenpagdee and others 2006; Prager and Freese 2009). The specific issue that challenges ecosystem management varies greatly globally, therefore no single formula, or institutional arrangement, is applicable to all situations (Ostrom 2007). Ecosystem management seeks to sustain multiple ecosystem services but often uses, as a reference point, historic conditions that are not achievable in a rapidly changing world (Chapin and others 2009; Christensen and others 1996). Since both ecosystems and human activities vary tremendously in heterogeneous environments, ecosystem management should be implemented adaptively (Chapin and others 2009). In the past decade, adaptive ecosystem management emerged as a new research area in ecosystem science and management, which shifts from the previous focus on static structures (stands, patches) to adaptive dynamic processes (Heinimann 2010). In addition, both ecosystem services and human needs are addressed, and ecosystem services become the cornerstone for meeting human needs and sustainable development. In ecosystem service assessments, ecologists focus on the ecosystem and organism characteristics that deliver services (Kremen

2005; Balvanera and others 2006) while economists prefer to exploring various techniques to determine the value of services to humanity (Knoche and Lupi, 2007; Swintona and others 2007; Tong and others 2007; Ingrahama and Foster 2008; Li and others 2008). Despite the booming interest in ecosystem services, up to now no standard methods exist to interpret and insert services in conservation assessments (Turner and Daily 2008).

This study addresses the ecosystem services related to soil and water conservation. These services are expected to lead to economic benefits by reducing soil erosion thereby preventing further decline in crop yield. With an increase in human activity and arable land losses, land use management agents often deliberately choose low-diversity options, such as single-species production forests or an economy largely based on a single industry, because these can be managed efficiently (Chapin and others 2009). Achieving a sustainable land use pattern by integrating ecosystem services in ecosystem management is especially important in fragile ecosystem.

Integrating environmental conservation with social and economic development is the objective of sustainable development. Transformation to a potentially more beneficial ecosystem state is the explicit goal of sustainable development programs in developing nations (Loorbach 2007). Assessing these issues must be based on a specific space scale, such as a watershed. Since the flow of services in ecosystems requires that they function as a whole system, the structure, composition and diversity of the ecosystem in a watershed are important components of the natural capital that gives service value. Therefore, integrated watershed ecosystem management becomes a foundation unit in sustainable development (German and others 2006).

As one of the most serious soil erosion areas in the world, the loess plateau has received a lot of attention in China and globally. Since 1980s, the idea of integrated watershed ecosystem management has been recommended and some technical measures are proposed (Chen and others 2007a; McVicar and others 2007a, 2010). In 1999, the afforestation project "Grain-for-Green" was initiated in China for soil erosion control and ecosystem improvement by converting the slope cropland into lands with ecosystem services. In this project, it is important to motivate local farmer to participate in the ecosystem management. In this study, we built an ecological–economic model to investigate whether a potential sustainable land use pattern in a watershed of the loess hilly area is economically viable. Part of this model is to determine the potential trade-off between soil and water conservation and economic earning.

The specific objectives of this study are to (1) evaluate watershed-scale land use suitability evaluation from the ecosystem health perspective; (2) compare the value of ecosystem services and economic benefits between different land use scenarios; and (3) propose an integrated watershed management scheme for sustainable development in the semi-arid loess hilly area.

Study Area and Methodology

Study Area

The study area is located in Longtan watershed in Dingxi of Gansu Province, China (35°43′-35°46′N and 104°27′–104°31′E), covering 16.14 km^2 with an average elevation of 1900 m a.s.l.. The watershed belongs to a typical semi-arid loess hilly area and is characterized by a highly fragmented landscape. The annual mean (1961–2006) temperature is about 6.8°C and annual mean rainfall is about 386 mm with most rainfall occurring as high intensity rainstorms in summer (e.g., July to September). The annual mean potential evaporation (pan evaporation) is about 1649 mm. Soils are mainly composed of loess soil with low organic matter, low fertility, and partially sierozem. The predominant land use types are rain-fed cropland and sparse natural grassland, and then pasture grassland, shrubland, woodland, residential land and fallow cropland (Table 1). The natural vegetation includes *Stipa bungeana*, *Leymus secalinus*, *Heteropappus attaicus*. The vegetation planted by human includes *Medicago sativa*, *Caragana korshinskii*, *Armeniaca sibirica*, *Platycladus orientalis*, *Pinus tabuliformis*. As the climate is semi-arid, water shortage is the major constraint to vegetation growth and agricultural production, and therefore sustainable development. There are about 401 households with 1,545 people resided in the watershed in 2009.

Table 1 Current land use in the study area (2009)

Land use type		Area (ha)	Area percentage (%)
Agricultural production	Rain-fed cropland	519.32	32.17
Commercial purpose	Fallow cropland	36.56	2.26
	Pasture grassland	221.81	13.74
Ecosystem services purpose	Woodland	95.03	5.89
	Shrubland	104.18	6.45
	Sparse natural grassland	582.66	36.09
Others	Residential land	54.80	3.39
Total		1614.36	100

Data Processing and Methods

Digital topographic data was used to derive slopes and aspects data that were used for land use suitability evaluation. ALOS images were used for delineating current land use (Huang and others 2010). Face-to-face interviews identified the key issues faced by local farmers and their daily needs.

Land Use Suitability Evaluation

Land use suitability assessment offers a basis for sustainable land use planning and ecosystem management. In general, land use suitability is affected by landscape features, soil types and climate factors. However, given a very small study site, the spatial difference of land use suitability was predominantly influenced by landscape and soil factors because of the small variation of precipitation and dramatic change of evapotranspiration related to landscape position (McVicar and others 2007b). We use landforms, soil, slope and aspect to build a deterministic model for land use suitability evaluation (Table 2).

In the ecosystem service valuation model, the ecosystem service on soil and water conservation was specifically examined because the other services (e.g., carbon sequestration, water supply, timber production and recreation) were relatively less important. The minimum area to be used for maintaining ecosystem functions was identified in terms of soil and water conservation. The economic value of ecosystem service was evaluated by comparing the following three land use scenarios.

(I) CLU (Current Land Use): The current land use pattern in the catchment is maintained. In this case, the economic benefits and ecosystem services are examined based on the productivity of all land use type and total inputs in watershed scale. Because the agricultural management varies from farm to farm, thus the total agricultural input in general in the watershed was considered.

(II) GOLU (Grain-production oriented land use): All areas (including the steep land) in the watershed are simulated to be used for agricultural production. This means that land suitable to ecosystem services will be converted into cropland.

(III) PSLU (Potential sustainable land use): Steep slope land (i.e., >25°) will be used for ecosystem service purposes, and cropland (<15°) or commercial woodland (15°–25°) that have gentle slopes where terraces are built for soil erosion control.

The economic productivity of the three land use scenarios can be calculated as:

$$EP_i = AC_i \times UY_i \times MP_i \quad (1)$$

where, EP_i is the economic productivity obtained from the ith crop plantation (or other on-farm products) ($), AC_i is the planted area of ith crop (ha), UY_i is the unit yield of ith crop (kg/ha), and MP_i is the market price of ith crop plantation ($/kg).

Ecosystem Service Assessment

In the loess hilly area, planting shrubs in the steep slope may function as buffer to protect the terrace cropland from destruction due to soil erosion (Fu and Chen 2000; Wang and others 2000). The terrace croplands can be used for 30 years in the case that soil erosion in both steep hill-slopes and gully-slopes is controlled properly (Jiao and Wang 1999; Liu and Zhu 1996). However, the lifetime of terrace croplands is about ten rather than 30 years if serious soil erosion does happen. Therefore, the economic value of shrub plantation in the steep slope can be estimated by comparing the difference of economic productivity and loss for the above scenarios. Hereby, a period of 30 years was examined. In GOLU, the total economic productivity obtained from on-farm work is calculated as the economic earning from the crop plantation minus the cost of terrace-building of its dysfunction due to soil erosion. In general, the unit yield of

Table 2 Land use suitability evaluation model

Factors	Purpose of land use			
	Land for ecosystem services purposes		Land for commercial purpose, e.g., orchard/pasture	Land for agricultural production
Landforms	Gully, gully slope, steep hill-slope		Mod-steep hill slope	Mod-steep to gentle hill-slope
Soil	Sierozem	Loessial soil	Loessial soil	Loessial soil
Slope degree (°)[a]	All	>25	15–25	<15
Slope aspect (°)[b]	All	All	90–270	90–270

[a] The degree is that from horizontal

[b] The degree is that (clockwise) from north

the terrace cropland is 3 times of that of steep slope cropland (Ma 2003; Chen and others 2003). Thus the crop yield of the terrace cropland is about 3 times of steep slope cropland at the beginning and tends to a same value of slope cropland at the year of terrace dysfunction, although Wei and others (1998) reported that the benefits of the agroforestry system in terraced slopes is more than four times that of the slope cropland. Therefore, the total economic productivity of GOLU is estimated by

$$EP_i = \sum_{i=1}^{m}\sum_{j=1}^{10} 3 \times AC_i \times UY_i \times MP_i \times (1-r)^{j-1} - 3 \times UC_t \times \sum_{i=1}^{m} AC_i \quad (2)$$

where, r is the decrease rate of crop yield each year due to the dysfunction of terrace, j is the jth year after terrace-building, m is the number of crops, UC_t is unit cost of terrace building which is to be built three times in the period of 30 years. We assume that crop yield from terrace is maximum just after terrace construction and decreases linearly through time to a minimum value (defined as the crop yield from slope cropland) when the terrace is thoroughly dysfunctioned (i.e., 10 years).

The total economic productivity of PSLU scenario is calculated as

$$EP_i = \sum_{j=1}^{30}\sum_{i=1}^{m} AC_i \times UY_i \times MP_i \times (1-a)^{j-1} - UC_t \times \sum_{i=1}^{m} AC_i \quad (3)$$

here, the a is the decrease rate of the ith crop yield due to soil erosion with terrace dysfunction, and the other parameters have the same meaning to Eq. 2. In this case, we assume that the yield of the terrace cropland linearly tends to the same value of steep slope cropland 30 year after the terrace is constructed (i.e., a terrace lasts 30 years before becoming dysfunctional due to the stabilization of planting shrubs), and a is a constant of yield decline.

Public Participation and Analysis

An interview of the agricultural activities undertaken by local farmers was conducted in the summer of 2009. The following data was obtained for statistical analysis: (i) population, (ii) labor, (iii) education, (iv) cropland plantation area, (v) plantation type, (vi) animal breeding, (vii) energy source and utilization, (viii) income from on-farm and off-farm work, (ix) daily expenditure, (x) agricultural input and output, (xi) environmental awareness. Based on interview, the total annual expenditure of local farmers is obtained.

Results

Current Land Use Pattern and Land Use Suitability

Sparse natural grassland and rain-fed cropland are the predominant land use types, followed by pasture grassland, shrubland, woodland, residential land and follow cropland (Table 1). All the land use types are distributed with respect to aspect, but irregularly according to slope (Figs. 1, 2). Since the semi-sunny aspect is the largest group in the catchment, each land use type is located predominantly in these areas, which is about 40–50% of the total study area. Rain-fed cropland and residential land are mainly distributed in the slopes between 8 and 25°. However, the other land use types, such as fallow cropland, pasture grassland, woodland, shrubland, sparse natural grassland dominated slopes of 15–25°, then 8–15° and >25°. As expected, the land use types with more human footprint are generally located on gentle slopes, while the land use types less affected by human are mostly situated on steep slopes. This implies that the human effect is decreasing with an increasing in slope.

The suitable area for agricultural production is about 461 ha or 29%, and the suitable area for commercial purpose accounts for approximately 30%, i.e. 482.2 ha (Fig. 3). In contrast, as much as 41% of the study area, i.e. 670.7 ha, is unsuitable for both agricultural use and commercial purpose. These areas should be used for ecosystem services including soil and water conservation. However, more than 37.8% of the study area is currently used for agricultural production, and only about 14.0% of the land is used for pasture grassland (Table 1; Fig. 3). Although a large amount of land was used for land uses with less human disturbance, the largest group is sparse natural grassland which gives less ecosystem services value than the woodland/shrubland (Chen and others 2007b, 2010). Thus, opportunities exist to improve the current land use pattern for ecosystem health and management.

Economic Productivity of Current Land Use and Two Land Use Scenarios

Annual economic productivity of farm work is calculated by considering the yield and market price of each agricultural product, and the cost of yearly terrace maintenance (Table 3). The total annual economic productivity of the entire catchment is $827,614, and the annual income per capita is about $516. These results are based on the assumption that the current terrace cropland can be used for 30 years.

The economic productivity of two land use scenarios of deforestation and afforestation are provided in Tables 4 and 5, respectively. GOLU assumes that all the land on

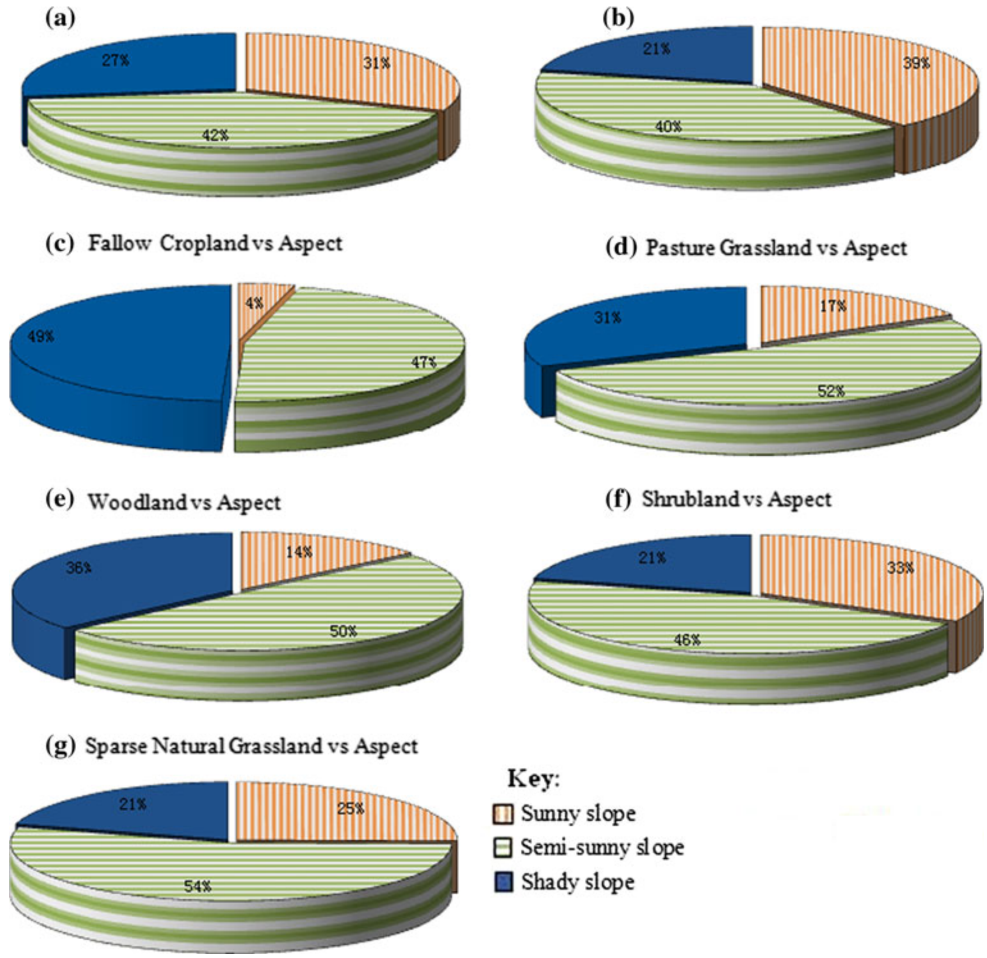

Fig. 1 The relationship between current land use and aspect

steep slopes is used for agricultural production, as was common in the 1970s. PSLU assumes the slopes with a gradient >25° will be afforested. Even if no much difference on the economic productivity exists between these two scenarios in the short-term, the PSLU scenario has a better economic productivity than GOLU in the long-term. The results imply that ecosystem services from converting the slope cropland into woodland/shrubland in the steep slopes awards $66,546 annually. We also found that the plausible future economic scenario to change slope cropland into woodland/orchard/pasture grassland may result in economic losses initially (i.e., the first 5 years). It is necessary to refine this scenario to safeguard both ecological benefits and economic benefits in the longer term (Tables 4, 5). In addition, PSLU promises a more favorable landscape in contrast to the landscape that farmers faced in the 1970s and might face in GOLU as a result of severe soil erosion.

In terms of annual economic productivity, PSLU is more optimal, then GOLU, and the current land use is the lest optimal in the long-term. The lower economic productivity of current land use compared to PSLU is largely due to the reduction of orchard, and the conversion of much land to sparse natural grassland. Compared with GOLU, there is less agricultural production in current land use. However, unlike PSLU, GOLU may result in serious soil erosion and poor ecosystem services. Although far from being perfect, this comparison may help make improved decisions in regulating land use structure and investing in ecosystem services.

Annual Expenditure of Local Farmer for Daily Life

Table 6 indicates the total economic income and daily expenditure of the local farmers based on interview data. Some difference exists between the interview results and calculation results (Tables 3, 6). This is because the income from on-farm work is calculated at best cases. In fact, the crop yield may not reach the average value in the years, and not all the planted crop produce outcome. However, comparing the annual economic income and annual consumption of the study area, we found that the production from on-farm work can not sustain human needs (Table 6). This implies that on-farm work only is not economically viable. Based on the interview with local farmers, we also found that off-farm income played a pivotal role in improving their quality of life, and the

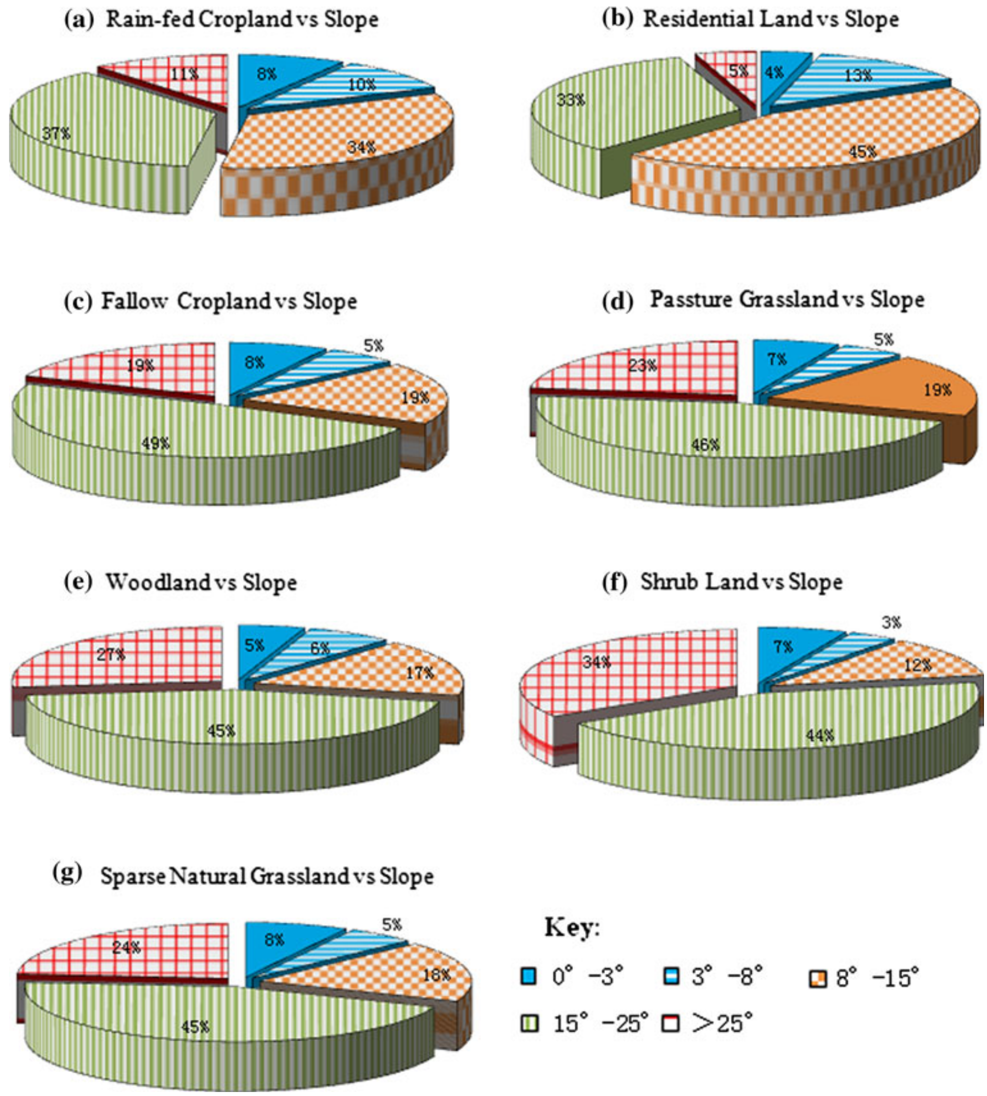

Fig. 2 The relationship between current land use and slope

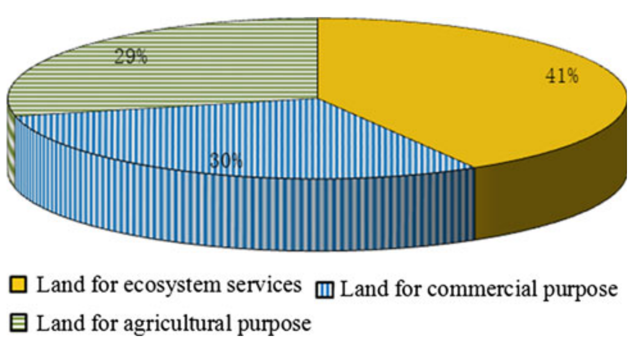

Fig. 3 Land use suitability in the study area

income from off-farm work contributed positively to the total income per capita (Fig. 4d). The income from the other sources, for example grain production, pasture grassland, and husbandry has a negative relationship with the income per capita (Fig. 4b, c), or unclear relationship (Fig. 4a). This means that external assistance (export of labor services, state subsistence) was required to reach long-term economic development.

Discussion

Role of Soil Erosion Control in Sustainable Land Use Planning

A large part of the study watershed, such as areas with slopes exceeding 25° and the sierozem area, was unsuitable for agricultural production. Although slope croplands may produce some productivity in the short-term, the transformation of these areas from crop to ecosystem services use would give better outcome in the long-term for the whole watershed (Table 5). The loess plateau has been suffering from soil erosion for a long time due to human activities. In

Table 3 The economic productivity of current land use (2009)

Land use type		Area (ha)	Unit yield (kg/ha)	Unit price ($/kg)[a]	Annual total economic income ($)
Terrace building		519.34	13,953/once	7246,605/30a	241,553/each year
Agricultural production	Total area	519.34			
	Residential land	54.8	–	–	–
	Potato	209.04	22,500	0.093	437,532
	Maize	69.68	9,000	0.248	155,567
	Wheat	69.68	2,250	0.310	48,615
	Others	116.13	1,500	0.558	97,229
Commercial purpose	Pastureland	221.87	12,000	0.124	330,225
Ecosystem service	Woodland	95.03			–
	Shrubland	304.02	22,500		–
	Sparse natural grassland	101.34	9,000	–	–
Annual total income from on-farm work ($)					1069,167
Annual net income by subtracting the cost of terrace maintenance($)					827,614
Annual income per capita ($)[b]					536

[a] $100 = ¥645 (Chinese currency unit)

[b] The population used in the study area is 1,545

Table 4 The economic productivity of the scenario of grain-production oriented land use (GOLU)

		Area (ha)	Unit yield (kg/ha)	Unit price ($/kg)[a]	Total income in the first year ($)	Total income in 30 years ($)
Terrace building in the slope less than 15°		461.38	3 times	$13,953/ha	6437,635/once	19,312,905
Agricultural production	Total area	461.38				
	Residential land	54.80	–	–	–	
	Potato	182.96	22,500	0.093	382,945	7045,507
	Maize	60.99	9,000	0.248	136,158	2505,069
	Wheat	60.99	2,250	0.310	42,550	782,834
	Others	101.65	1,500	0.558	85,099	1565,668
Commercial purpose	Total area	477.37				
	Orchard	159.12	15,000	0.310	740,103	13465,847
	Pastureland	318.24	12,000	0.124	473,666	8618,142
Ecosystem services	Total area	675.61				
	Potato	304.02	22,500	0.093	212,110	6363,301
	Maize	101.34	9,000	0.248	75,417	2262,507
	Wheat	101.34	2,250	0.310	23,568	707,034
	Others	168.90	1,500	0.558	47,136	1414,067
Total income from on-farm work ($)					2218,751	44729,977
Total net economic income from on-farm work in the 30 years ($)[b]					25417,071	
Annual net economic income from on-farm work ($)					847,236	
Annual economic income per capita from on-farm work ($)[c]					548	

[a] $100 = ¥645 (Chinese currency unit)

[b] The total economic income in the 30 years is result of total income from on-farm work subtracts the cost of terrace building

[c] The population in the study area used is 1,545

the past decades, much effort has been spent to control soil erosion by improving vegetation coverage and ecosystem function (e.g., Chen and others 2007a; Tian 2010; Wang and others 2010; Zhang and Liu 2007). Unfortunately, how to define sustainable land use pattern at a watershed scale is still not clear in the loess hilly area. Our study suggests that

Table 5 The economic productivity of the scenario of potential sustainable land use (PSLU)

		Area (ha)	Unit yield (kg/ha)	Unit price ($/kg)[a]	Total income the first year ($)	Total income in 30 years ($)
Terrace building in the slope less than 15°		461.38	1 times	$13,953/ha	–	64,37918
Agricultural production	Total area	461.38				
	Residential land	54.80	–	–	–	
	Potato	182.96	22,500	0.093	382,945	696,7527
	Maize	60.99	9,000	0.248	136,158	24,77343
	Wheat	60.99	2,250	0.310	42,550	774169.6
	Others	101.65	1,500	0.558	85,099	1548,339
Commercial purpose	Total area	477.37			–	–
	Orchard	159.12	15,000	0.310	740,103	13465,847
	Pastureland	318.24	12,000	0.124	473,666	8618,142
Ecosystem services	Total area	675.61				
	Woodland	225.20322	–	–	–	–
	Natural grassland	450.40644	–	–	–	–
Total income from on-farm work ($)					1860,521	33851,368
Total net economic income from on-farm work 30 years ($)[b]					27413,450	
Annual net economic income from on-farm work ($)					913,782	
Annual economic income per capita from on-farm work ($)[c]					591	

[a] $100 = ¥645 (Chinese currency unit)

[b] The total economic income in the 30 years is result of total income from on-farm work subtracts the cost of terrace building

[c] The population in the study area used is 1,545

Table 6 Comparison on income and expenditure of local farmers based on interview data

Income				Expenditure			
Items	In total ($)[a]	Per capita ($)	Percent (%)		In total ($)	Per capita ($)	Percent (%)
Crop plantation	117,778	229.1	37.40	Grain consumption	75,952	150.7	25.17
Orchard	1,886	3.7	0.60	Agricultural input	30,212	59.9	10.01
Pasture grassland	7,458	14.5	2.37	Dining spices	19,499	38.7	6.46
Animal breeding	8,576	16.7	2.72	Education	20,479	40.6	6.79
Labor export	117,039	227.7	37.16	Social and daily life	122,004	242.1	40.43
Manufacture	2,583	5.0	0.82	Life improvement	33,652	66.8	11.15
State subsistence	59,633	116.0	18.93				
In total	314,953	612.8	100	In total	301,797	598.8	100

[a] $100 = ¥ 645 (Chinese currency unit). The households interviewed in this study are 129, and the people interviewed are 514

a suitable land use pattern should have a land distribution of 40% for ecosystem services use, 30% for orchard/pasture grassland, and 30% for agricultural production.

In order to realize sustainable land use in the loess hilly area, the following measures should be considered. First, soil erosion risk due to human activities must be evaluated. Previous studies indicate that the slope cropland produces much more soil loss than pasture grassland, shrubland and woodland (e.g., Huang and others 2006; Wei and others 2007). Magnitude and spatial distribution of areas sensitive to soil erosion needs to be identified for a specific region. In land use planning, these areas are to be designated as area for ecosystem services (McVicar and others 2010). Second, the trade-off between economic loss due to soil erosion and economic benefits obtained from crop plantation needs to be examined in the long-term rather than the short term. In our study, GOLU of planting crops in the steep slopes may give a higher annual economic productivity at the beginning than PSLU. However, the economic earning of reclaiming the steep slopes is economically

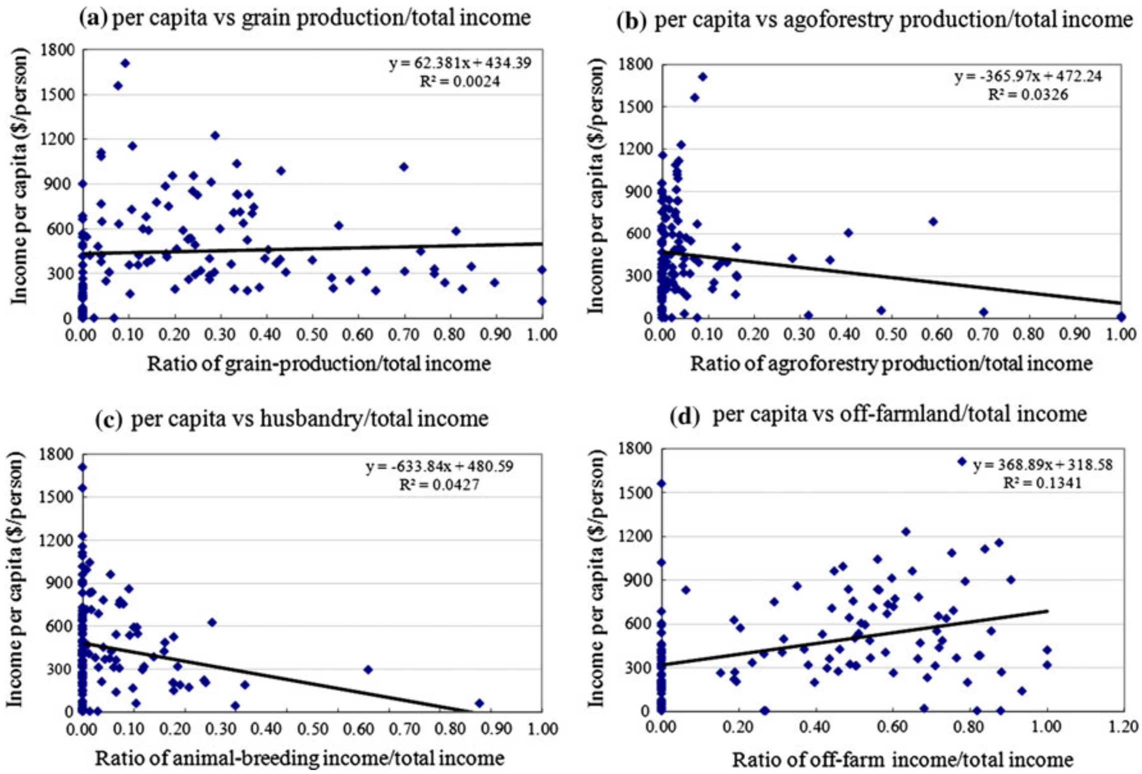

Fig. 4 The relationship between income sources and per capita income

unsustainable in the long-term when the cost of terrace construction and maintenance is taken into account. This means that ecosystem management by integrating ecosystem services is necessary. However, it is challenging for both local farmers and governments to make decisions on sustainable land use planning by integrating ecosystem services at the watershed scale. Third, public participation in soil erosion control and watershed ecosystem management is to be fostered. Integrated watershed management for soil and water conservation has proven to be a useful means to reduce soil erosion and to reinforce ecosystem functions in the loess plateau (Chen and others 2007a; Mu and others 2007). However, it was not widely implemented in the loess plateau since it requires large financial and human resources. Since integrated watershed management for soil and water conservation is ultimately borne by local farmers, their cooperation will be important. However, most farmers consider the government to be in full charge of soil and water conservation. This means that looking for a feasible way to encourage public participation in integrated watershed ecosystem management is an important task in the loess plateau. We suggest that subsistence be given to the local farmers in proportion to their direct involvement in the integrated ecosystem management. This is much better than the direct compensation without cross-compliance, as is currently implemented in China (Liu and Yao 2010).

Role of Ecosystem Services in Ecosystem Management at Watershed Scale

Integrating ecosystem services in watershed management is crucial for sustainable development. In general, ecosystem services can be defined as the benefits that humans obtain from nature (Costanza and Daly 1992; Daly and Farley 2003; Daily 1997; de Groot and others 2002; Ekins and others 2003). They are classified into four categories: (I) provisioning services; (II) regulatory services; (III) cultural services; and (IV) supporting services (MEA 2005). This concept offers a general framework for ecosystem services assessment, however, the approach to estimate economic value of ecosystem services varies according to the regions and the ecosystems. Although potential trade-offs between carbon sequestration and other ecosystem services are important in the regions with scarce water resource (Chisholm 2010), only the ecosystem services of soil and water conservation are considered in our study. This is because the flow of services from ecosystems requires that they function as a whole system: structure, composition and diversity of the ecosystem are important components of natural capital that cannot be separated. Because of the scarce water resource in the semi-arid loess hilly area, vegetation growth is slow and ecosystems are vulnerable (e.g., McVicar and others 2007a, 2010). The other ecosystem services such as firewood provisioning and recreation may not enact in practice if the services on soil and water conservation is kept except for biodiversity conservation which is, however, not as important as soil and water conservation in the loess hilly area.

The reduction of genetic, stand and landscape biodiversity is usually intentional when land is used by human to enhance the productivity of a particular ecosystem service. Such phenomenon occurred in the loess plateau in the 1970s when, driven by population explosion, a large amount of slope land was converted to agricultural production. Consequently, the local economy was not improved and the ecosystem services were widely degraded. Acknowledging ecosystems and convincing land use stakeholders of their importance is often not considered by local governments, because it is difficult to evaluate them quantitatively. A strong demand on more ecosystem-service research and practice exists in the undeveloped regions of China, largely because widespread poverty implies that any expenditure on environmental programs from state government must be justified in economic and social terms. Quantification of ecosystems providing services is a prerequisite for economic valuation, but unfortunately this has systematically been done in ecology only until recently (Chisholm 2010). In watershed ecosystem management, key question is how to incorporate the ecosystem services into ecosystem management for sustainable development of a region. In our study, scenario analysis was employed and the trade-off between scenarios was compared in the long-term. We found that integrated watershed ecosystem management by implementation of ecosystem services in land use planning is promising. However, it is often ignored in the decision on land use planning in China.

Sustainable Development Thorough Integrated Ecosystem Management at a Watershed Scale

Our results show that it is impossible to realize sustainable land use or sustainable development in the semi-arid loess hilly area by using the local resource only (Table 6). Thereby, adopting an integrated ecosystem management at the watershed scale is of special importance. Our study recommend following measures for the sustainability in land use and ecosystem management.

(1) Adjustment of the land use pattern is required in line with the need to transform the labor-intensive farming system to a labor-saving one. Based on the results of scenario analysis, the current land use pattern gives rise to the lowest economic productivity compared with the other two scenarios (Tables 3, 4, 5), and the daily demand of the local farmers can't be met by on-farm work. It was also indicated that the income from off-farm work contributes largely to the total income of household (Table 6). Thus, finding a labor-saving farming system may help improve income-generation and the sustainability of likelihood since more income may be obtained by extricating the local farmers from on-farm work. We also found that under the three land use scenarios, afforestation is associated with large future economic gains, suggesting a need for greater future use of more land for ecosystem services and commercial purpose.

(2) Diversification of agricultural income and low risk on agricultural production is required for sustainable development. Private landholders, motivated primarily by profit, might choose to manage their lands for a single ecosystem service. However, a region in which the economy depends entirely on one extractive industry is poorly buffered against market fluctuations (Chapin and others 2009). In general, the risks of unfavorable land use adjustment outcomes can be minimized through careful planning by multiple user groups to assess the risks of good and bad outcomes; transparent navigation of the transformation process; and fostering resilience of those outcomes that meet broad societal goals (Nettle and Romaine 2000).

(3) The public participation in integrated watershed ecosystem management should be encouraged in the semi-arid loess hilly area. There is a growing awareness that successful erosion control and sustainable land use requires consideration of the local farmer's needs and willingness (Fagerström and others 2003). It is hard to control soil erosion without farmers' participation and cooperation. However, environmental awareness of local farmers in the loess plateau is currently poor. For most farmers, grain production is considered much more important than environmental conservation (Chen and others 2007a; Hu and others 2006). In order to ensure effectiveness and sustainability of soil and water conservation, education on environmental conservation to local farmers should be reinforced. Above all, the local people should be encouraged to participate in sustainable land use planning and vegetation restoration. Because sometimes local people understand the nature better than scientists and politicians, their solution to soil erosion control and vegetation restoration is pertinent (Fagerström and others 2003; Stolte and others 2005). Usually, nature is exploited by the local people with little thinking about its environmental effects. It is urgent to tell the people that to protect nature may help improving their own life as the PSLU shows. Third, financial means are necessary to encourage local people to participate in environmental conservation, and in integrated watershed ecosystem management. Although some compensation is given to the local farmers for their converting the slope cropland into the other uses (Zhang and Liu 2007; Wang and others 2010), at present little financial

encouragement is given as payment for the other environmental protection actions (Chen and others 2007a).

Conclusion

Ecosystem management that can address trans-boundary, interdisciplinary, and multi-party issues from an ecosystem perspective should be evaluated in the long-term by incorporating public opinion, preferences, and the ecosystem service values. Although ecosystem management has been proposed for many years and promoted in many regions, it is still conceptual in most developing nations. Integrated ecosystem management is difficult to understand for stakeholders such as local officials and local farmers, and in many cases scientists face problems in developing a workable scheme for a specific region. However, integrated ecosystem management is extremely important for sustainable development because of its holistic and sustainability approach.

Scenario analysis is a useful approach in the integrated ecosystem management. In our study, it was employed to compare the economic productivity of three land use scenarios. The trade-off between them becomes visible when factors such as land use suitability, economic earning, and ecosystem services were combined in the analysis. Our study suggests that ecosystem services should be examined in the long-term rather than in the short-term when ecosystem management scheme is planned. It was found that the Grain-production Oriented Land Use has a better economic benefit than Potential Sustainable Land Use in the short-term, but not in the long-term. This implies that integrated ecosystem management for sustainable development requires viewing nature and sustainability in a future perspective. However, it is challenging to implement such principles in a resource-poor region, such as the semi-arid loess hilly area.

Development of integrated ecosystem management for sustainable development takes time in the semi-arid loess hilly area. We found that both the current and the potential sustainable land use are not able to afford the daily needs of the local farmers based on on-farm work only. Thus, external financial assistance is necessary. There are two ways to proceed. The first is compensation directly from the state government. We suggest that it should be given to the local farmers based on their involvement in ecosystem management rather than directly providing them with cash. The second is increasing off-farm employment for local farmers because it is the major contribution of the total income. To reach this goal, transformation from the current land use system to a new one that may partially relieve the local farmers from farming only is needed. In light of these issues, the loess plateau region has much to do to achieve the desired sustainable development.

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