Effects of Rainwater Harvesting on the Regional Development and Environmental Conservation in the Semiarid Loess Region of Northwest China

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Abstract: Water is the major limiting factor for farming, forestry and animal husbandry in the Loess Plateau of northwest China and it is also the key factor for environmental improvement. Precipitation is the major water source for use in this region. However, limited and erratic precipitation often results in crop failure as well as serious soil and water loss. Rainfall harvesting can change the distribution pattern of rainfall runoff in time and space, which would supply humankind with steady water sources to some extent. Characterized by simple operation, high adaptation and low cost, rainwater-harvesting techniques have a great potential to be used in many aspects. Rainwater harvesting would provide the possibilities of setting up new agricultural ecological system and whereby improve ecological environments in the semiarid regions. This paper deals with the major environmental issues in the Loess Plateau and evaluates the influence of rainwater harvesting implemented since 1980s on the regional development and environment conservation. Based on the experiment on rainfall harvesting and field investigation, microcatchment model for ecosystem construction was proposed to improve regional environment. The Microcatchment rainfall-harvesting model with small watershed as a unit is characterized by incorporation of rainfall harvesting with yard economy and environmental construction. ≥25° sloping land is protected as water conservancy zone by prevent human and livestock interference; tree (or shrub) and grass can be planted in the gentle slope by means of microcatchment water harvesting techniques. The natural slope can also be treated as catchment for collecting runoff into the cistern for supplemental irrigation for farmland, which is the main part of the system for supply food to farmer by various water-saving agriculture techniques. The village and yard is the center of human activity, which can be regarded as an economic zone by using harvested water to develop greenhouse and animal husbandry.

1 Introduction

Conservation of the environment and sustainable utilization of natural resources are major issues of concern with in the international community (Li *et al*., 1999, Li, 2000a). Land degradation is a serious environmental problem worldwide and a major threat to the sustainability of agriculture and economic development. In the case of China, the total area subjected to soil erosion has reached 3,670,000 km^2, i.e. 38.2% of the total land area, of which land area subjected to wind erosion accounts for 1,880,000 km^2 and water erosion accounts for 1,790,000 km^2 (Feng *et al*., 1999; Chen, 2000). In China's semiarid regions, severe soil erosion by water mainly occurs in the Loess Plateau. The Loess Plateau of northwest China is situated in the upper and middle reaches of the Yellow River (33°43—41°16′N and 100°54—114°33′E). It covers a total area of 624,000 km^2. Annual precipitation ranges from 200 mm to 750 mm, with 70% rainfall falling between June and September, often in the form of heavy thunderstorms. This not only causes tremendous amounts of erosion, but also problems of inadequate availability of water for crops. The major soil type in the cultivated land area is sandy loam of loess origin, which is loosely structured and highly susceptible to wind and water erosion (Chen *et al*., 1996).

In a large area of the Loess Plateau, surface and groundwater resources are often either unavailable or too saline and brackish for human consumption and irrigation, the most widespread land-use system is rainfed farming. Rainfed cropland occupies about 80% of the total cultivated land. Crop production in the region is only 25%—33% of the potential productivity, and water use efficiency is between 0.5 kg • m^{-3} and 0.6 kg • m^{-3} due to water stress (Li *et al*., 2000c; Li *et al*., 2001a). Since the beginning of the century, particularly over the last several decades, the rapidly growing human population has placed heavy pressure on productive soil resources, forcing farmers to convert more and more forest land and grassland into cropland and at the same time to increase cultivation of steep erodible slopes. Consequently, this has led to an increase in the scale and severity of soil erosion and a reduction in soil fertility, which are major threats to the sustainability of agroecosystems in the region (Li *et al*., 2000b). This agricultural production pattern exacerbates erosion and locks farmers into a vicious cycle of land degradation and poverty. It is estimated that each year, on average, 40 million tons of nitrogen, phosphorus and potassium nutrients are lost from the region through soil erosion (Feng *et al*., 1999). The Loess Plateau suffers from the most severe soil erosion in the world, affecting 45% of the plateau, with an average annual soil loss of 3,720 t • km^{-2}. This is 14 times that of the Yangzi River region, China, 38 times that of the Mississippi River region, USA, and 49 times that of the Nile River region, Egypt (Liu, 1999).

Low water resources (230 m^3 per capita), high population pressure (130 head km^{-2}) and vulnerable ecosystem are the pressing issues constraining the sustainability of agriculture and economic development in the loess plateau. Since precipitation is the major water source for agricultural production and environmental improvement, To maximize rainfall utilization is the appropriate approach to cope with the existed problems in the area. Water harvesting techniques would be a promising way to set up new agricultural ecological system and whereby improve ecological environments in the loess plateau.

2 Brief history of rainwater harvesting in northwest China

Water harvesting, defined as the collection of rainfall runoff for domestic purpose or livestock watering (Frasier, 1983), and for fruit and crop production (Reij *et al*., 1988, Grewal *et al*., 1989; Gupta, 1989), has been used successfully in arid and semiarid regions of the world for thousands of years. China has a long history of rainwater harvesting. One very old but still common flood diversion technique called “warping” (harvesting water as well as sediment) has been extensively applied in China’s loess areas since the Spring and Autumn period (2,700 years ago). Underground clay-lined earthen water storage tanks have been used in Gansu to supply water for household use since the Ming Dynasty (over 600 years ago) (Li *et al*., 2000a, Li *et al*., 2001b). Other early rainwater harvesting techniques include construction of terraced fields, fish-scale pits on hillsides and mini-dams to retain runoff and prevent soil erosion. However, a growing awareness of the potential of rainwater harvesting for improving crop production arose with widespread droughts in the 1980s followed by serious shortages of drinking water and crop failures (Li, 2000b). Modern rainwater harvesting system was first practiced in Gansu Province, and aimed at solving drinking water problem for human beings and livestock. Since 1995, rainwater harvesting has been promoted by the government as a solution to the problem of water shortages for agricultural production and has been termed rainwater harvesting agriculture (RHA). (Cook *et al*., 2000; Li *et al*., 2000b). The RHA system consists of collection surface (catchment), water storage tank and supplemental irrigation system. The main innovations of modern rainwater harvesting system include: the use of modern materials (e.g. concrete) and engineering designs to increase the longevity and storage capacity of water tanks, utilizing stored water for irrigation rather than simply for household use; the construction of efficient catchment systems; the adoption of water-saving irrigation techniques; and the combination of rainwater harvesting with a comprehensive, highly efficient crop production system. At present, rainwater harvesting has successfully implemented not only in the semiarid areas in north and northwest China but also in the semi-humid and humid areas covering one half of the total provinces in the whole country (Li *et al*., 2000b).

3 Advantages and benefits of rainwater harvesting practices

3.1 Advantages

Rainwater harvesting has superior qualities of small-scale, simple operation, high adaptation and low cost; and therefore is ideally suited to the socioeconomic and biophysical conditions of semiarid rural areas. In contrast with large-scale water development projects, rainwater harvesting is well suited to complex mountainous topography and individual household use. Moreover, one notable advantage of rainwater is its good water quality due to softness.

3.2 Benefits of rainwater harvesting practices

The implementation of rainwater harvesting has a profound impact on the development of semiarid rural areas. First it has basically solved the drinking water problems of people lived in the semiarid mountainous areas. The successful example is the 1-2-1 rainwater harvesting program launched by the Gansu provincial government to assist each rural households to build about 100 m^2 of concrete catchment, two concrete storage tanks and irrigate one mu (1/15 ha) of cropland for production of high market value cash crops. Up to 2000, this program has helped farmers construct 2.18 million storage tanks, supplying 1.97 million rural residents in Gansu Province. Rainwater harvesting systems are also practiced in other northwestern provinces such as Ningxia Autonomous Region, Shanxi, Shanxi and Inner Mongolia Autonomous Region as well as southwestern and southeastern provinces such as Guangxi Autonomous Region and Guizhou Province. Statistics shows that in the whole China rainwater-harvesting practice has solved drink water problem of about 23.80 million rural residents and 17.30 million livestock.

Second, rainwater harvesting has improved agricultural production. Once the benefits of the rainwater harvesting became evident in solving drink water problem, such technique has shifted to the use for supplemental irrigation of crops since 1995. Water tanks or mini-dams have been built adjacent to fields, with roads and hillsides serving as catchments. A 30 m^3 concrete tank cost 1000—1500 RMB Yuan, which can usually irrigate 2—3 mu (1/15 ha) farmland. Due to the fact that rainwater harvesting can addresses the temporal discontinuity between the availability of rainfall and the water requirements of crops, supplemental irrigation in the critical of the crops can significantly improve crop yield and water use efficiency (Gao *et al*., 2001) (Table 1). At present, 236,400 ha farmland is irrigated using harvested water in Gansu Province and 1.51 million ha in the whole country.

Third, rainwater harvesting has adjusted agricultural structure and improved incomes. Rainwater harvesting has been used in combination with cash crop planting and animal husbandry to increase incomes. The economic analysis of rainwater harvesting and supplemental irrigation indicated that the highest net economic benefit was 60, 000 Yuan ha^{-1} for planting vegetable in greenhouse, followed by fruit trees with 19, 914 Yuan ha^{-1}. Zhu and Li (2001) reported that, among the total area of rainwater-harvesting irrigated land, the area of orchards and cash crops accounted for 17% and 19% respectively in Gansu Province. Besides, farmers have built a total area of 1, 567 ha greenhouses for increasing incomes.

Table 1 Effects of rainwater harvesting for supplemental irrigation on crop yields and water use efficiency

Crop	Irrigation amount $m^3 \cdot ha^{-1}$	Yield ($kg \cdot ha^{-1}$)	Yield increase percentage (%)	WUE ($kg \cdot m^{-3}$)
Spring wheat	225—300	897—6,843	10.5—88.3	0.7—5.2
Corn	375—400	2,940—9,050	19.6—88.4	1.5—5.7
Millet	300	2,583—2,750	20.5	0.9—1.6
Flax	225	530—2,505	44.7—120.6	0.9—2.9

Fourth, rainwater harvesting played a significant role in promoting the ecological and environmental conservation. Rainwater harvesting is in itself a useful measure in soil and water conservation by capturing and storing runoff, which can directly contribute to the reduction of soil and water erosion. Moreover, rainwater harvesting has indirect beneficial effects on eco-environmental improvement by its feedback mechanism in the comprehensive agricultural management system. As mentioned above, rainwater harvesting can increase crop production by implementing supplemental irrigation. Increased productivity in flat and terraced fields can help reduce the incentives of farmers to cultivate steep slopes, thus converting more steep cultivated land into forest or grass land, which would reduce soil erosion.

4 Rainwater harvesting mode in the Loess Plateau

Rainwater harvesting needs to be integrated within a comprehensive agricultural management system. Watershed-scale comprehensive management systems in the Loess Plateau are an example of integrated system of soil erosion control and sustainable agriculture development.

The watershed can be divided into three distinct morphological units: mountain, farmland and courtyard unit. Large area of mountain with sparse vegetation should be afforestted by means of rainwater harvesting with natural loess slope as catchments. ≥25° sloping land is protected as water conservancy zone by prevent human and livestock interference; tree (or shrub) and grass can be planted in the gentle slope by means of microcatchment water harvesting techniques. Farmland is the main part of the watershed for supplying food to farmer, which needs combine rainwater harvesting with other agricultural technologies such as water-saving techniques, crop management and soil fertility management to improve crop yield. The village and yard is the center of human activity, which can be regarded as an economic zone by using harvested water to develop greenhouse and stock raising. These three parts are interacted with each other and often influenced by human being activities. Only if farmers have enough food and better economic incomes can prevent them from cultivating steep erodible slopes and converting forest land and grassland into cropland. Therefore, more research is needed to assess the hydrological, ecological, social and economic aspects of rainwater harvesting from a plurality of perspectives in a wide range of different localities.

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