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Rainwater harvesting for agricultural production in the semiarid loess region of China

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Abstract
Precipitation is the major water source for agricultural production in the semiarid region of China. Limited and erratic precipitation often results in low crop yields and sometimes in total crop failure. In recent years, rainwater harvesting was promoted to solve water problem for agricultural and domestic uses. Implementation of rainwater harvesting has been successfully solved drinking water problem, and is being adopted to improve crop production and promoted to adjust agricultural structure to increase farm's income and improve living environment. Rainwater harvesting has great potential to achieve sustainable agriculture in semiarid regions.

Key words: Rainwater harvesting, agriculture, semi arid, China.

Introduction

Water harvesting implies collection and storage of the precipitation runoff for a variety of purposes in arid and semiarid regions when common sources, such as streams, springs, or wells, fail[1]. In addition to supplying drinking water for people, livestock, and wildlife, water harvesting systems can provide supplemental water for growing food and fiber crops[1]. In a large area of the Loess Plateau of China, surface and groundwater resources are often either unavailable or too saline and brackish for human consumption and irrigation. Precipitation is the major water source for agricultural production; however, limited and erratic precipitation often results in low crop yields and sometimes in total crop failure. Crop production in the region is only 25-33% of the potential productivity, and water use efficiency is between 0.5 and 0.6 kg m^{-3} due to water stress.[2] Since 1990s, a so-called "rainwater harvesting agriculture (RAH)" has been promoted to solve the problem of water shortages for agricultural production. The implementation of RAH has improved crop performance in rainfed farming system and addressed some environmental problems such as soil erosion. Due to simple operation, high adaptation and low cost, rainwater-harvesting techniques have been used in many aspects and become a living, sustainable entity in the Loess Plateau. The objective of this paper is to review rainwater harvesting development and its uses for agricultural production in the semiarid loess region of northwest China.

Figure 1. Rainwater storage tanks with concrete catchment for greenhouse irrigation, Dingxi County, Gansu Province.

Brief History of Rainwater Harvesting in Semiarid Loess Region of China

Rainwater harvesting is an old technique that may be dated back to as long ago as 4500 B.C. by people of Ur and other places in the Middle East[1]. Water-harvesting system was used for runoff farming in Israel's Negev Desert 4000 years ago[3]. American Indians used similar systems 700 to 900 years ago in the southwestern United States[4]. China also 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 (2700 years ago). Underground clay-lined earthen water storage tanks have been used in Gansu of northwest China to supply water for household use since the Ming Dynasty (over 600 years ago). Other early rainwater harvesting techniques included mini-dams, terraced fields, and circular bunds on hillsides, which were constructed 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. Modern rainwater harvesting system using modern materials (e.g. concrete) and engineering designs to increase the longevity and storage capacity of water tanks, 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 Gansu provincial government as a solution to the problem of water shortages for agricultural production and has been termed rainwater harvesting agriculture (RHA)[5]. Rainwater harvesting systems are also practiced in other northwestern provinces such as Ningxia Autonomous Region, Shanxi, Shaanxi and Inner Mongolia Autonomous Region as well as southwestern and southeastern provinces such as Guangxi Autonomous Region and Guizhou Province. The implementation of rainwater harvesting has a profound impact on the development of semiarid rural areas. 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 now, this program has helped farmers construct 2.18 million storage tanks, supplying 1.97 million rural residents in Gansu Province. Statistics shows that in the whole country rainwater-harvesting practice has solved drinking water problem of about 23.80 million rural residents and 17.30 million livestock. Rainwater harvesting also has improved agricultural production. At present, 236,400 ha farmland is irrigated using supplemental water from runoff collection in Gansu Province and 1.51 million ha in the whole country.

Rainwater Harvesting Agriculture and its Technological Systems

The RWH system consists of a synergetic combination of different technological components including a rainwater harvesting system, a water-saving irrigation system, and a highly effective crop production system[6]. Among these 3 components, the rainwater harvesting system is the core, its function is to provide water for domestic and agricultural needs. An effective water-saving irrigation system is crucial for the economical and effective use of water. The rainwater harvesting system consists mainly of catchemnt, runoff channel, sediment tank and storage facilities. The catchments selected for runoff inducement will depend, in large part, upon the rainfall parameters, cost and availability of materials and labor. The popular catchments in the Loess Plateau include rooftops, courtyards, paved and unpaved roads, cleared and smoothed hillsides[7]. Moreover, some barrier-type materials (e.g., concrete, soil cement, asphalt-fabric membranes and plastic film), mechanical treatments (smoothing and compacting) and chemical treatments have been employed to establish artificial catchments to increase precipitation runoff. The catchments are usually built in courtyards for household use and surrounding or above agricultural fields for irrigation purpose. A photograph showing 900 m^2 concrete catchment for harvesting rainwater is presented in Figure 1. Table 1 presents some of the common catchment treatments being used and an estimate of the installation costs, longevity, and runoff efficiencies of each. The popular water storage facilities in the Loess Plateau are underground tanks, which are treated with cement or traditional red clay. The shapes of water tanks are vase-like, ball-like or column-like, the diameters ranges from 2 to 4 m and depths varies between 4 and 5 m. The capacity of these tanks is usually between 15 and 60 m^3 depending on locality and purpose. A volume of 20-30 m^3 tank cost about 1200 RMB (Chinese currency yuan) including labor cost 500 RMB in most cases. The tanks are often situated around yard to collect runoff from rooftops and courtyards for domestic use, livestock watering or limited irrigation. Also they are distributed in field near both sides of paved and unpaved road to store runoff for irrigation purpose (Figure 2).

Figure 2. Water storage tanks distributed in the wheat field for supplemental irrigation.

Effects of RHA Practices on Agricultural Production

Water stress is a crucial factor limiting crop production in the semiarid region of China. Using historical data of precipitation, Li[8] analyzed the occurrence frequency of water stress for some crops and found that the occurrence frequency of water stress was 60% for corn and 92% for winter wheat, among which about 90% of water stress events took place in spring. According to the study of Li et al. [6], the relative water satisfaction for winter wheat (defined as the percentage of growing-season precipitation relative to crop water requirements for full yield) is 62% in terms of the whole phenology and only 35%, 41 % and 40 % for the three critical growth stages of jointing, heading and grain-filling. The relative water satisfaction of corn is 87% for the whole phenology, but only 55% and 79% for the two critical growth stages of jointing and earring. The period of water stress for both winter and summer crops coincide with their heading and grain-filling growth stages and it is extremely unfavorable for grain production. For this reason, providing supplemental irrigation to crops during their water-stress periods is essential to achieve a high sustainable yield in rainfed conditions[9]. Due to limited water from runoff collection system, supplemental irrigation must be used efficiently. Large demand and low water availability often result in deficit irrigation. As a rule of thumb, for the RWH system, supplemental irrigations often occur in early spring or at the seedling stage and other serious water deficit stages such as heading and grain-filling growth stages. For wheat and corn, one to three supplemental irrigations of 10-27 m^3 each can be applied to 1 *Mu* (667 m^2) farmland (Table 2)[10], hence a 30 m^3 water tank can provide water for irrigation for 1-2 *Mu* farmland in the whole season of crop growth. Supplemental irrigation has obvious effects on crop yields. Table 2 shows that supplemental irrigation can increase crop yields by 10-120%. Small-scale runoff collection and supplemental irrigation system shows promise for increasing and stabilizing crop production, this spurs farmer's incentives to maximize profits of the limited supplemental water. Due to the fact that high cash crops such as vegetables offer higher net returns than conventional crops under supplementally irrigated conditions, farmers have been adjusting the structure of agricultural production by shifting land out of grain production into high-value cash crops to increase incomes. This involves planting vegetables, tobacco, herbs, flowers and fruit trees using advanced irrigation methods such as drip and micro-sprinkler irrigation. Statistics show that among the total area of the irrigated land using water from rainwater harvesting, the area of orchards and cash crop covers 17% and 19% respectively[11]. Table 3 shows irrigation frequency, amount, and yields for greenhouse vegetable production in Gansu Province, the economic profit of vegetables is about 65-240 RMB m^{-3}, which is significantly higher than economic profit of wheat and corn of about 2.9-6.3 RMB m^{-3} (Table 3 and 4). Moreover, water from rainwater harvesting system was also used to raise poultry, livestock or rare animals to increase income. Table 4 compares net profits among different water use patterns. Raising scorpion animal has the highest net return from the supplemental water due to low water consumption, followed in decreasing order by greenhouse vegetables and flowers, fruit trees and field grain crops. The combination of greenhouse mushroom cultivation with rainwater harvesting has a great potential to develop in the mountainous areas where water is scarce, because it requires small amount of water and has high market values as compared to the other crops. It is apparent that RHA has been a new technology that is more than to increase crop production but change farmer's thinking and increase economic activity. Rainwater harvesting would provide the possibilities of setting up new agricultural ecological system in the semiarid region of China.

Conclusions

Rainwater harvesting is a relatively inexpensive, small-scale method of water supply that can be adapted to the indigenous resources and needs of rural community and small households. In the case of China, rainwater harvesting has been successfully solved drinking water problem, and is being adopted to improve crop production and promoted to adjust agricultural structure to increase farm's income and improve living environment. Undoubtedly, developing rainwater-harvesting agriculture is essential to achieve a productive, sustainable and high efficient agriculture in China's semiarid loess regions.

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Table 1. Estimated runoff efficiency, longevity and cost for various water harvesting treatments.

Catchment treatments	Runoff efficiency(%)	Estimated longevity (yr)	Initial cost (RMB m^{-2})*	Water cost (RMB m^{-3})
Land clearing	12-13	5-10	0.12	0.76-0.86
Compacted loess soil	7-22	4-6	0.25	1.66-3.90
Compacted red clay and loess soil	28-35	3-6	0.90	0.10-0.84
Plastic film	85-92	1-2	1.00	1.98-2.37
Concrete	70-80	10-20	4.80	1.80-3.00
Cement tile	67-75	20-25	4.96	1.50-2.60
Brick tile	29-40	15-20	3.00	2.30-4.80

* 1 US$ equals to about 8.3 RMB (Chinese yuan)

Table 2. Effect of supplemental irrigation on grain crop yield and water use efficiency.

Crops	Irrigation frequency	Irrigation amount(m^3 ha^{-1})	Grain yields (kg ha^{-3})	Yield increase percentage(%)	Water use efficiency(kg m^{-3})
Spring wheat	1-3	225-300	900-6840	10.5-88.3	0.75-5.2
Corn	2-3	375-405	2940-9045	19.6-88.4	1.5-5.7
Millet	1-2	300	2580-2745	20.5	0.89-1.7
Flax	1-2	225	1590-2505	44.7-120.6	0.89-2.8

Table 3. Effect of supplemental irrigation on greenhouse vegetable yield and water use efficiency.

Vegetables	Irrigation frequency	Irrigation amount(m^3 ha^{-1})	Yield (kg ha^{-1})	Water use efficiency(kg m^{-3})	Economic profits (RMB m^{-3})*
Cucumber	8-9	3600	1099950	30.5	92
Tomato	8-9	650-3750	91950-122025	42.8-47.6	65-86
Water melon	5-7	750	30000	40.0	240
Sweet melon	5-7	900	30000	33.3	200

* 1 US$ equals to about 8.3 RMB (Chinese yuan)

Table 4. Net profits of supplemental water from rainwater harvesting for different water use patterns.

Item	Total water supply(m^3 ha^{-1})	Net profit due to supplemental water (RMB m^{-3})*
Wheat	375-450	2.9-3.6
Corn	300-450	5.5-6.3
Field vegetables	675-900	15-50
Greenhouse vegetables	975-1200	65-240
Fruit trees	375-600	88-165
Greenhouse flowers	1000-3000	100-228
Greenhouse mushroom	750-1500	900-1200
Raise scorpion	714	2542

* 1 US$ equals to about 8.3 RMB (Chinese yuan)