Rainwater Harvesting Irrigation—A Strategic Measure for Integrated Rural Development in the Dry Mountainous Areas of Gansu Province, China

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Abstract The loess plateau and hilly areas of Gansu Province are one of the driest areas of China. In the past, water scarcity caused domestic water supply insecurity, low levels of agricultural production, land degradation and impoverishment of the population. For many people, rainfall is the only practicable source of water. Since 1996, the rainwater harvesting (RWH) project has been used to provide supplementary irrigation. By 2005, formerly rainfed farmland irrigated using RWH systems totaled about 80,000 ha. An approach known as "low-rate irrigation (LORI)" has been developed in which irrigation is only applied at critical periods of crop growth. Highly efficient simplified irrigation methods developed locally along with drip systems have been widely adopted. Water application is targeted at the root zone to reduce evaporation loss. With only very small amounts of irrigation, crop yield has been raised by between 22–88% and 40% on average. Furthermore, RWH enables farmers to modify their agriculture patterns according to market needs. Farmers can now grow high-value cash crops, greatly decreasing poverty levels. Simple low-cost greenhouses have also been widely replicated, further boosting household incomes. The project, outlined in this chapter, has also benefited ecological restoration and the local environment as a whole.

Keywords Water scarcity · Rainwater harvesting · Low-rate irrigation
Water use efficiency · Poverty alleviation

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1 Introduction

The objective of this chapter is to give a comprehensive overview of the development of rainwater harvesting irrigation in Gansu Province, China, over the past 25 years. Many of the findings from field tests and research were undertaken by the Gansu Research Institute for Water Conservancy (GRIWAC). The large scale of the program and multiple investigations conducted over this period precludes the inclusion of details of specific experimental methodologies and results. A more detailed account of the whole RWH program in Gansu can be found in the book Every Last Drop (Zhu et al. 2012).

Rainwater harvesting (RWH) for supplemental irrigation has been practiced for at least 3000 years, and evidence of ancient systems from the Negev Desert in Israel has been documented in areas with mean annual rainfall as low as 100 mm (Evenari et al. 1961). India too has been the home of many ancient water harvesting systems (Agarwal and Narain 1997). China also has a very long history of using rainwater harvesting for both water supply and irrigation (Li et al. 2000).

Despite the long history of using RWH for supplementary irrigation and renewed interest in this approach in some parts of the world, there is a growing concern that opportunities for using this approach are being missed, especially in regions such as sub-Saharan Africa where food security issues are most acute (Rockström et al. 2007; Falkenmark and Rockstrom 2015). The urgent need to harvest and utilize more rainwater to address hunger and poverty also received considerable publicity following an announcement by prominent scientists at the 2014 World Water Week in Stockholm, (Falkenmark 2014). Preliminary investigations indicate significant potential for utilizing and managing rainwater better for improving agricultural production in Africa (Rockström and Falkenmark 2015) and in other semiarid regions. This makes the successful experiences with RWH in China, particularly relevant to demonstrating how they can enhance both food and water security globally (Zhu and Li 2003; Gould et al. 2014; Zhu et al. 2015).

China is ranked sixth largest in the world in terms of its total water resources. However, due to its huge population, the annual renewable water resources per capita is little more than 2000 m^3 which is less than a third of the global average and rank it 143rd out of 193 countries (UNESCO 2006). China is thus a country with some serious water shortages due to the uneven spatial and temporary distribution of water resources, especially in its arid interior (MWEP 1987).

Gansu, located in Northwestern China, is one of the driest and poorest provinces in the country (Fig. 1). The mean annual rainfall is only 280 mm, and the annual renewable water resources per capita are 1150 m^3, less than half of the national average. Water shortages have become an increasingly major restraint to agricultural production (Xu 2007). According to historical records, 749 droughts occurred over a period of 2155 years from 206 BC to 1949 AD, averaging about three droughts per decade. While in the 41 years from 1949 to 1990, there were 26 droughts or more than six per decade. The loess plateau and hilly areas in the middle and eastern part of Gansu Province suffered most (Yu et al. 1996). This part of the basin has an area of 107,800 km^2 and population of 17.7 million, of which 13.3 million are rural (GRIWAC 2005). In the loess plateau and hilly region, the average annual rainfall is about 440 mm and the annual renewable water resources are about 300 m^3 per capita (GRIWAC 2005). Although the Yellow River and its tributaries flow through this area, most of the land lies hundreds of meters above the river, so using this water for irrigation is very difficult. Another limitation is that the base flow in some tributaries has a high mineral content and cannot be used either for domestic purposes or irrigation. Groundwater sources are also frequently of poor quality and often located at depths of hundreds of meters (GRIWAC 2005; Zhu et al. 2012, 2015). The plateau is also crisscrossed with numerous gullies and ravines, which makes building canals and pipelines difficult. More than 80% of cropland is rainfed (GRIWAC 2005). However, the rainfall distribution is unfavorable to crop growth as the rainfall in May and June, when the crops need the most water, accounts for only around 19–24% of the yearly total (Zhu et al. 2012). More than 65% of the rain falls at the end of the growing season in July to October period (Zhu et al. 2012). The sparse vegetation and the hilly topography cause serious soil erosion which can be as high as 5000–10,000 t/km^2/y, equivalent to a surface layer of 5–10 mm being stripped off annually, causing great loss of soil nutrients and land degradation (Zhu et al. 2012, 2015). Water scarcity has resulted in low agricultural productivity, mono-cultural agriculture, and widespread poverty. Low productivity has forced farmers to cultivate as much land as possible including on steep slopes, thus accelerating soil erosion and land degradation. Millions of people lacked easy access to water and many hours were wasted daily fetching water from rivers in deep valley bottoms. The only other option was to use water of poor quality from ponds shared with animals (GRIWAC 2005; Zhu et al. 2012).

To solve these problems, local farmers and water technicians put great effort into leveling the land by building terraces and contour strips and adopting the use of mulching, plastic sheeting, and modifying agricultural practices. Since 1970s,

Fig. 1 Map of Gansu Province and the project area

corn has increasingly been planted instead of wheat, as it is better adapted to the low-rainfall conditions. All these measures have been effective in reducing soil erosion, retaining rainfall in the field, cutting soil evaporation loss, and to a certain extent raising crop yields. Nevertheless, the overall impact of these measures on improving agriculture productivity was relatively limited as the crops still suffered water shortages resulting in low yields (Zhu et al. 2012, 2015).

An example was terracing which was used as one of the principle measures against drought in the area. Figure 2 shows the terraces in Zhuanglang County. After terracing, much of the runoff was retained and soil erosion and the associated nutrient loss were significantly reduced. The yield of terraced land in a normal year was increased by 40–50% compared to un-terraced slopes (GSWCB 1994). However, the moisture captured in the soil mainly during the rainy season (July–September) can only be used for seeding in the following spring. Over this 6–7 month period, most of the moisture was lost by evaporation during dry weather so when sowing takes place soil moisture is usually too low for seed germination and survival of the young plants (GRIWAC 2002; Zhu et al. 2012). Since 1970, plastic sheeting has also been widely used in Gansu. A 3-year study found that with this method the crop yield could be increased by 20–30% (GRIWAC 2002).

Planting more corn to replace wheat is also an important measure in terms of raising the yield, as corn has a longer growing period and can use more of the natural rainfall in July and early August (GRIWAC 2002). Thus, corn yields more

Fig. 2 Terrace land in the Zhuanglang County, given the name "Terrace County" by the State. *Photo* Qiang Zhu (2010)

than double that of wheat. However, water deficit in late May and June can cause significant loss in corn yield (GRIWAC 2002; Zhu et al. 2015).

Long-term studies have shown that water shortages in the critical growing periods of crops are the main cause for low productivity in this region (GRIWAC 2002; Zhu et al. 2012). It has long been known that May and June are the most critical period for both wheat and corn, and drought is common in this period. In May and June, wheat goes through the growing stages of jointing, booting, and heading, while corn goes through jointing, early flowering, and sprouting (Zhu et al. 2012). Analysis of the rainfall data from Huining Gauge and water demand for corn and wheat (Zhu et al. 2015) showed that the rainfall in May and June in a normal year accounts for only 11–12% of the yearly total. Meanwhile, the crop demand for wheat and corn in the same period is 75 and 34% of that for the whole growing season, respectively. The rainfall and estimated water demand and water deficit for wheat and corn in Huining County, Gansu, for different periods are listed in Table 1.

It can be seen from Table 1 that wheat and corn suffer water stress during most of the growing season, but the most significant water shortage is in June, which is the most critical growing period for both crops (GRIWAC 2002). From the above analysis, it can be concluded that water deficit always occurs in the critical crop-growing period. Thus, supplying crops with supplemental irrigation in this critical period is the most effective way to enhance the yield. The challenge was finding a suitable water source. One of the conventional approaches utilized has been to build inter-basin water transfer projects. These kinds of projects require a huge investment and have high operational and maintenance costs making them unaffordable to both local authorities and farmers. Furthermore, the loess plateau and hilly area are crisscrossed by numerous gullies, which make the construction of water conveyance systems very difficult. The environment is also not conducive to the building of such projects due to problems like ground subsidence and landslips (Zhu 2003).

Only in the mid-1990s, with the implementation of the 1-2-1 rainwater harvesting project did the community get access to a water source it could use for

Table 1 Rainfall, water demand, and deficit of wheat and corn in different periods in Huining, Gansu

Item		Mar	Apr	May	Jun	Jul	Aug	Sept	Year
Mean rainfall mm		7.5	25.0	41.7	46.8	79.9	79.3	49.6	373
Water demand mm	Wheat	10	57	133	152	28			380
	Corn		10	46	112	138	136	18	460
Water deficit mm	Wheat	−2.5	32.0	91.3	105.2	−51.9	−69.3		
	Corn		−15.0	4.3	65.2	58.1	56.7	−31.6	

Note Negative number in "water deficit" means the monthly rainfall is larger than the crop water demand supplemental irrigation (Zhu and Li 2000; Zhu et al. 2012). The 1-2-1 project initially focused on addressing the severe domestic water shortages faced by a rural population. This was due to the absence of both surface and groundwater sources, leaving rainwater harvesting as the only viable water source. The 1-2-1 project provided households with one catchment area, two large subsurface tanks (20–30 m^3), and one irrigated plot. Within just 18 months, the project met its goal of providing about 1.2 million people with water. Tiled roofs and concrete-lined courtyards provided catchments, and traditional water cellars were upgraded for storing rainwater, ensuring a safe, reliable, and affordable domestic water source (Zhu and Li 2000; Zhu et al. 2012). At the same time, rainwater was used to irrigate small pieces of land for planting vegetables and fruit trees in order to improve the community's diet and to produce additional income (Zhu and Li 2000; Zhu et al. 2012). The most significant outcome of the 1-2-1 project was that for the first time, the local people and the authorities recognized the enormous value of rain, as the only potential and accessible water source in the region. Due to the success of the 1-2-1 Project, the Gansu Government decided to initiate the rainwater harvesting irrigation project in 1996 (Zhu and Li 2000, 2006).

2 Description of the RWH Irrigation Systems

The RWH irrigation system is composed of three parts, the catchment, the storage tank, and the irrigation equipment (Zhu et al. 2015).

2.1 The Rainwater Catchment

Runoff from the catchment provides the water source for the RWH irrigation system. A catchment with an adequate area and high rainwater collection efficiency (RCE) will help to guarantee enough water for the system to meet demand. The catchments used in Gansu can be classified into three kinds: the surface of an existing structure, a natural slope, or a purposed-built catchment (Zhu et al. 2015).

If available, using the surface of an existing structure is the most economical solution. The most commonly used structures include: roofs, paved highways, courtyards, country roads, sport grounds (Zhu et al. 2015). While household roofs and courtyards are commonly used as catchments for domestic water supply, paved highways are widely used for collecting rainwater for irrigation and their RCE can be as high as 0.6–0.7 (Zhu et al. 2012).

Usually, there is a drainage ditch by the side of the highway that has already been constructed by the transport department. To divert the runoff from the highway to the tank, it only needs construction of a small dike and ditch (Zhu et al. 2015). Rural roads can also serve as a catchment but can only collect water for one or two tanks due to the low RCE of their earthen surface (Zhu et al. 2015).

In recent years, many thousands of simplified greenhouses have been built in this loess plateau region as a result of the development of RWH. The plastic-film greenhouse roof has a very high RCE. Roof runoff is generally stored in a water cellar to irrigate crops inside the greenhouse (Zhu et al. 2012). Figure 3 shows some of the different existing structures used for catchments.

In the past, people used the ground surface for collecting rainwater, but nowadays, it is seldom used as a catchment, as a compacted loess soil surface has a very low RCE ranging from 0.13–0.25 (Zhu et al. 2012). In places where crops are planted far from the nearest road, a purposed-built catchment can be constructed using impermeable materials like concrete, cement soil, or a plastic-film covering (Zhu et al. 2012, 2015). The most commonly used material is concrete with a thickness around 4 cm (Zhu et al. 2015). Figure 4 shows a concrete-lined catchment used for irrigating orchards in the Qin'an County.

2.2 *Rainwater Storage Tank*

In Gansu, a traditional underground tank with the local name of *Shuijiao* (water cellar) has long been used for rainwater storage. An underground tank has many advantages (Zhu et al. 2012, 2015), these include:

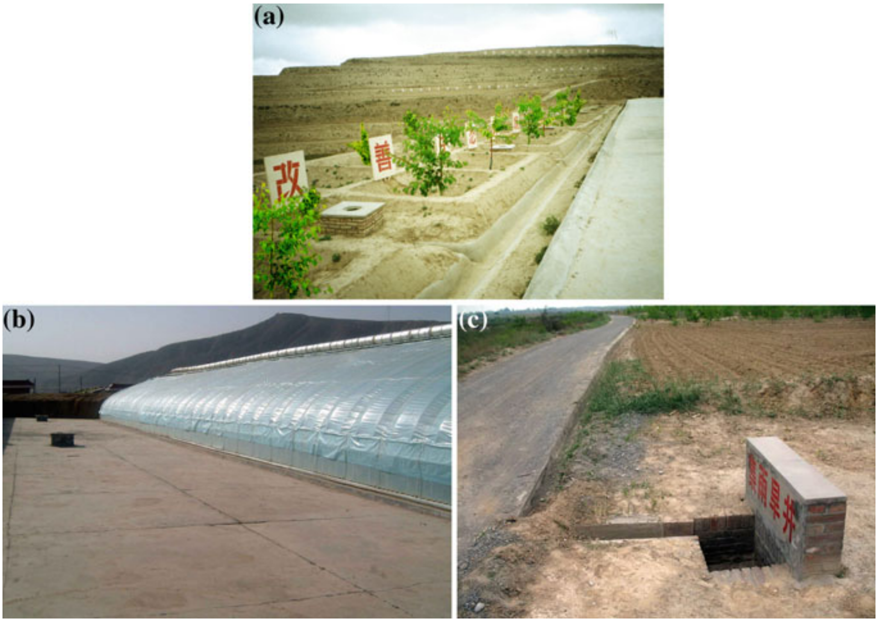

Fig. 3 Existing structures used for catchments: **a** paved highway, **b** greenhouse roof, **c** country road. *Photo* Li Yuanhong (2000)

Fig. 4 Concrete-lined catchment for irrigating orchards in Qin'an County. *Photo* Zhu (2003)

- Ease of collection of surface runoff
- Water quality can be maintained for a long time because of its low temperature and exclusion of all light by the tank cover
- Water remains unfrozen even in cold winters
- Reduces evaporation loss
- Reduced material requirements and cost as soil helps to stabilize the tank structure.

The water cellar can have a rectangular or circular cross section (Zhu et al. 2015). The circular design has a bottle shape with a volume ranging between 30 and 80 m^3 (Zhu et al. 2012). Depending on the soil properties, the circular water cellar consists of three distinct types, namely, the thin walled, the top domed, and the cylinder type. Of these, the most commonly used is the top-domed water cellar which has a bottom slab constructed with concrete and a 3 cm thick wall plastered with cement mortar, see Fig. 5. The rectangular underground tank can have a volume up to 1000 m^3. To keep the silt and debris out the runoff, water should first pass through a sediment basin, see Fig. 6.

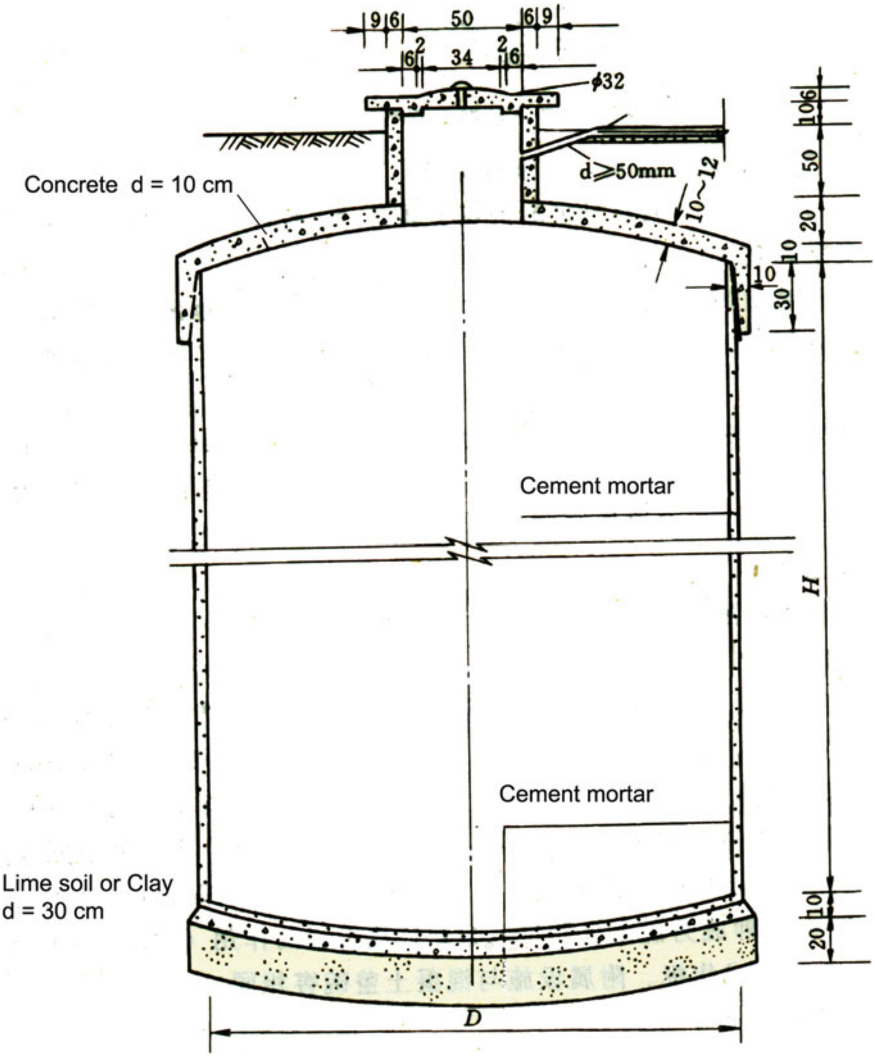

Fig. 5 Illustration of a section of a domed water cellar

2.3 High-Efficiency Irrigation Equipment

In Gansu, there are two kinds of RWH irrigation system: simple irrigation methods developed by local farmers and modern micro-irrigation methods mostly involving drip systems. The modern methods are used by the wealthier farmers with access to small loans from a bank or local cooperative (Zhu and Li 2000; Zhu et al. 2012, 2015). The locally developed simple irrigation methods include the following types as outlined below (Zhu and Li 2000; Zhu et al. 2012).

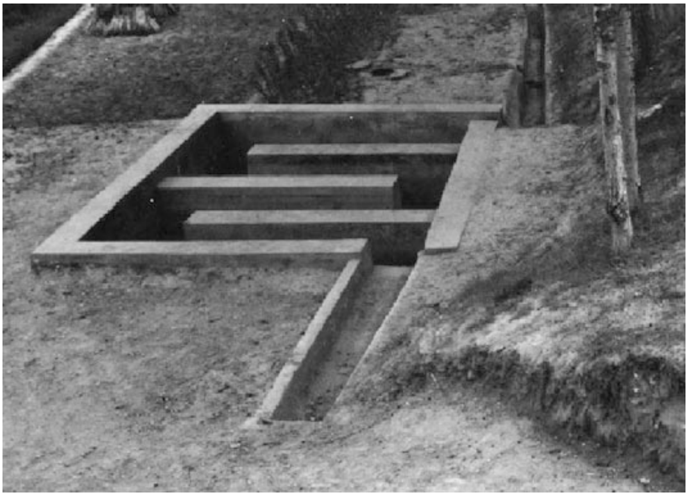

Fig. 6 A photo of the sediment basin. *Photo* Li Yuanhong (2000)

(a) **Irrigation during seeding:** During sowing, a small amount of water (about one liter) is poured in the hole just before the seed is dropped in. Fertilizer may also be added at the same time, and the soil is then covered with plastic film. Although this operation can be done manually, integrated machinery has been developed to simultaneously undertake watering, seeding, fertilizing, laying the drip line, laying the plastic film, and compacting the soil (Cheng et al. 2009; Zhu et al. 2012, 2015). Irrigation during seeding uses only a small amount of water about 50–75 m^3/ha which can moisten the soil around a 25-cm-diameter zone surrounding the seeds. This can enhance the germination rate and help the healthy growth of young plants during a period of 30–40 days without rain (Cheng et al. 2009). Figure 7 shows an integrated machine for sowing and irrigation during seeding.

(b) **Irrigation through plastic sheeting:** After sowing, the soil is covered with plastic film. When the young seedlings emerge, cross-shaped cuts are made manually in the film to allow the plants grow and allow irrigation water and rainfall to flow in. Irrigation is done manually using a bucket or sometimes a hose from the tank, (Cheng et al. 2009; Zhu et al. 2012, 2015). Figure 8 shows the irrigation water being applied through the holes in the plastic sheeting.

This simple manual irrigation method is popular because it is low cost and easily managed. A bucket or hose is connected from the tank to water the crop root zone, see Fig. 9.

Fig. 7 An integrated machine with a water tank mounted on a sowing machine for supplying a small amount of water in the seeding ditch. *Photo* Li Yuanhong (2000)

Fig. 8 Illustration showing irrigation through holes in the plastic sheeting. *Photo* Xiaojuan Tang (2003)

(c) **Modern micro-irrigation methods:** Modern micro-irrigation methods include drip, micro-sprinkler, and bubble irrigation systems, of which the drip system is most commonly used for RWH irrigation in China (Cheng et al. 2009; Zhu et al. 2012). The micro-irrigation system is composed of three parts: the water source, the pivot, and the piping. In RWH irrigation, the water source is the

Fig. 9 Manual irrigation using a hose connected to a rainwater tank. *Photo* Manjin Cheng (2009)

rainwater tank with a pump to produce pressurized flow (Zhu and Zhang 2001; Zhu et al. 2012). When the tank is located at a position high enough to produce the necessary pressure for the micro-irrigation, a pump is not needed. The pivot includes the valves, meters (water and pressure), fertilizer container (optional), and very importantly the filter. Since any silt settles at the bottom of the tank and due to the small scale of the system, a screen-type filter is used. The RWH-based pipe system includes the main pipe and the drip lines. To save costs, a movable drip system is used. After finishing irrigation, the whole drip system including the pump can be moved to another tank (Zhu and Zhang 2001; Zhu et al. 2012). Figure 10 shows an example of a drip system irrigation using rainwater.

Fig. 10 Drip system using rainwater for irrigating corn. *Photo* Manjin Cheng (2009)

3 Enhancing Rainwater Irrigation Efficiency

Since stored rainwater is usually limited, its use in an efficient and beneficial way is the key to the success of any RWH irrigation project.

3.1 Development of the Low-Rate Irrigation (LORI) Approach

With RWH-based irrigation in the loess area, a very low irrigation quota is used with each application. This ranges from between 50 and 225 m^3/ha, depending on the method used. The times of application are also limited. For grain crops (wheat and corn), irrigation usually takes place 2–3 times over the growing season: once during seeding followed by one or two further applications. Only when irrigating vegetables and fruit trees, water is applied more frequently (GBWR 1997; MWR 2001; Zhu et al. 2012). Investigations have shown that irrigation amounts for wheat, corn, millet, linseed, and potato amount to 225–400 m^3/ha using RWH-based methods, while for conventional irrigation 1500–2500 m^3/ha is required (GRIWAC 2002; Zhu et al. 2012).

Careful field tests have shown that these small amounts of water can be effective in enhancing crop yield. Demonstration projects have shown that yields of grain crops can be raised by 11–88% for wheat and 20–88% for corn. For each m^3 of rainwater used for irrigation, yields increase 1.7–3.9 kg for wheat and 3.1–5.7 kg for corn, respectively (GRIWAC 2002; Zhu et al. 2012).

This then raises the question of why RWH-based irrigation is so effective and efficient? Following long-term investigations and field testing, the GRIWAC developed a new approach to RWH irrigation called “low-rate irrigation” or LORI (Zhu et al. 2012). This involves using very small amounts of irrigation water at critical times and can significantly enhance crop yields. The current practices show that RWH irrigation only accounts for 10–15% of the crop water consumption over the whole growing season with regular rainfall providing the rest. The limited supplementary irrigation water from the RWH system just helps to tide the crop over periods of water stress during critical growth stages, thus avoiding serious crop damage. This maintains the crops health, so that later in the growing season natural rainfall can be used effectively (Zhu et al. 2012, 2015). Without this limited amount of water applied at critical periods, the crop would be damaged or wither completely. In this event, even if there were subsequent abundant rainfall, crop failure would be inevitable. The LORI water consists of natural rainfall that is stored and used at the most critical times. In Gansu, most RWH-irrigated land is still a form of rainfed agriculture dependent on in situ rainfall but supplemented with a further 10–15% of stored rainwater collected ex situ and applied at times when the crops need it most.

The LORI approach is based on the three following principles:

First, the adoption of a deficit irrigation approach to RWH irrigation; water stored in the tank is applied only at the critical periods of crop growth when it is most sensitive to water stress (Zhu and Li 2004; Zhu et al. 2012). The critical periods for crops vary with different climatic and soil conditions and can be identified from field experiments or by consulting with local farmers (GRIWAC 2002).

Second, the amount applied should be appropriate to get a higher water supply efficiency (WSE) and water use efficiency (WUE). The WSE is the crop yield increase as compared to pure rainfed production divided by the total irrigation water applied, and the WUE is the crop yield divided by the total crop water consumption including rainfall, soil moisture, and supplementary irrigation. While higher water application may produce a higher yield per unit area, it may not produce a higher WSE and WUE (Zhu et al. 2012; GRIWAC 2002). Obviously, in the loess area of Gansu where water for agriculture is limited but land is abundant, a prudent rainwater management strategy should endeavor to increase the WSE.

Third, reducing the evaporation loss can raise the rainwater irrigation efficiency. To achieve this, irrigation methods that apply water only to the crop root zone should be adopted. When irrigating, only a small part of soil around the plant needs to be moistened. Another measure for reducing evaporation loss is the adoption of plastic sheeting (Zhu et al. 2012). The land is covered with plastic film in the growing stages, and drip lines are usually installed under the plastic to reduce evaporation loss (GRIWAC 2002; Zhu et al. 2012). Figure 11 shows plastic sheeting and the covered drip line.

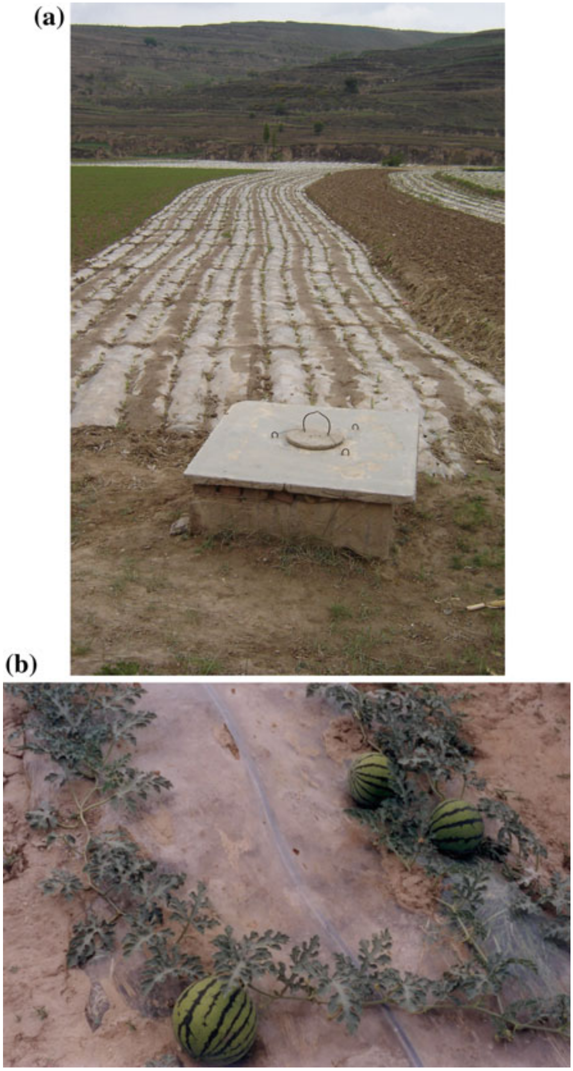

Fig. 11 Plastic sheeting in Gansu **a** Plastic-sheeted field and water cellar, **b** Sheeted drip line for melon irrigation. *Photos* Li Yuanhong and Ziyong Huang (2000)

3.2 Modified Agricultural Practice

Before the RWH irrigation project started, more than 97% of the land had been planted with low-value cereal crops. Using rainwater stored in tanks for irrigation, farmers now grow a wide range of crops and adapt production according to the needs of the market, thereby greatly increasing their incomes (Zhu et al. 2012).

Tests have shown that supplementary irrigation with rainwater can increase cereal yields by 1.5–2 kg per m^3 (GRIWAC 2002), worth an additional 3–4 CNY (US$0.46–0.62, *Exchange rate US$1 = 6.5 CNY, February, 2016, and used* *hereafter*). However, for growing vegetables and other cash crops, each m^3 of rainwater can generate with a value of 10 times than that of grain crops. For example, for each cubic meter of irrigation water, cucumbers and tomatoes in greenhouses would yield 29 kg valued at 58 CNY (US$8.9) and 38 kg valued at 76 CNY (US$11.7), respectively (GRIWAC 2002).

3.3 Role of Greenhouses in Enhancing the Benefits of RWH Irrigation Project

Greenhouses have played an important role in enhancing the economic value of RWH irrigation. Before the RWH project, there were no greenhouses in this dry, mountainous area due to the lack of water. After the implementation of the RWH irrigation project, the use of low-cost greenhouses developed rapidly (Zhu and Li 2006; Zhu et al. 2012). By 2005, it was estimated that their number had reached about 100,000. Most of the greenhouses were simple and affordable. There are two kinds of greenhouses: the walled greenhouse with an earthen wall located on the northern side and the arch-shaped greenhouse without a back wall as shown in Fig. 12 (Zhu et al. 2012). The walled greenhouse is the most common, as it can be used in extremely cold regions, where the nighttime temperatures can drop to −20 °C. The greenhouse roof is made of plastic film with thickness of 0.15 mm supported by steel rods and sometimes intermixed with bamboo (Zhu et al. 2012). A greenhouse with an earthen wall costs about 7000 CNY (US$1080) in the early 2000s, but could yield produce valued at between 2000 and 4000 CNY (US$300–600) annually depending on the crop type and management, thereby providing an excellent return on the investment (Zhu and Li 2006; Zhu et al. 2012).

The plastic-film greenhouse roof also provides a very efficient rainwater catchment. Tests have shown that RCE can be as high as 0.88. In the Dingxi County, where the annual rainfall is about 400 mm, the runoff from the roof can supply 83–89% of the water required to irrigate a crop of vegetables (GRIWAC 2002). According to Guo (2010), the percentage of roof water accounted for 42.3% of the total water use of an average greenhouse. Figure 13 shows a typical group of greenhouses.

The greenhouse is not only used for planting annual crops but even for fruit trees. Nectarines grown by villagers of Liuping Township in the Qin'an County could be harvested 2 months earlier than those planted outside, thereby securing a premium price. This early production translated to a value of 100–150 CNY (US$15–23) per cubic meter of irrigated rainwater (Zhu et al. 2012). The same strategy was also used for growing watermelons in the winter. The price of 6 CNY/kg (US$0.92/kg) obtained for the melons was three times of the normal price (Zhu et al. 2012). In an interesting trial, conducted by Gansu Academy of Agriculture Sciences, Enoki and White Elf mushrooms were grown in a greenhouse using a very limited amount of water. Yields for Enoki mushrooms

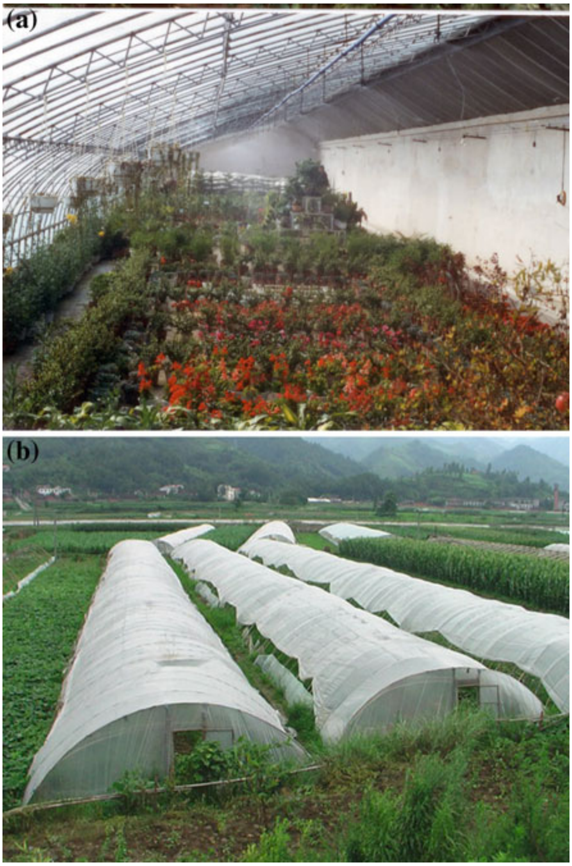

Fig. 12 Simple greenhouses **a** solar-heated earth-walled greenhouse, **b** arch-type plastic tunnel greenhouse. *Photos* Ziyong Huang and Guo (2010)

(*Flammulina velutipes*) and White Elf mushrooms (*Pleurotus Nebrodensis)* amounted to 180,000 kg/ha and 108,000 kg/ha, respectively. The water use was only equivalent to 80 m^3/ha. The production value per unit of water used amounted to 14,625 and 40,500 CNY/m^3, (US$2250/$m^3$ and US$6230/$m^3$), respectively (GRIWAC 2002). Figure 14 shows the fruit trees and mushrooms being cultivated in the greenhouses.

4 Achievements and Challenges

4.1 Achievements

An evaluation of the RWH irrigation project by GRIWAC (2005), reported that by the end of 2004, two million storage tanks had already been built. The project enabled about 80,000 ha of originally purely rainfed land to be irrigated using

Fig. 13 Greenhouse group with tanks by the side of the greenhouses. *Source* Guo (2010)

stored rainwater (GRIWAC 2005). The main benefits from the RWH irrigation project included:

(a) Enhancement of yields by providing supplementary irrigation for crops that had previously been purely rainfed. Many farmers greatly increased food production. Mr. Luo Zhengjun in Luoma Village, Huining County, is a striking example. Luo's grain production increased by 270% after he built six water cellars with a capacity of 120 m^3, introduced plastic sheeting, and switched to growing corn instead of wheat (Zhu and Li 2003).

(b) Alleviation of poverty by diversifying agricultural production. With stored rainwater for supplementary irrigation, farmers were able to adjust their production and shifted away from mono-cultural grain production to more market-oriented crops. This has allowed them to grow vegetables, fruit trees, and even raise animals in their greenhouses, greatly increasing household incomes. The use of greenhouses and plastic sheeting has thus helped to rid this region of poverty and replace it with relative prosperity. The case of Mr. Bao Haiji from Zhengguo Chuan Village, Qingran Township, illustrates this point well, see Fig. 15. Before the RWH project, his village was one of the poorest villages, but by diverting runoff from a nearby highway and building nine rainwater tanks, Bao Haiji managed to boost farm yield and saved 160,000 CNY (US$24,615) within 10 years, a small fortune in the context of rural China (Zhu et al. 2012).

Fig. 14 Photo showing **a** fruit trees, **b** mushroom growing in greenhouses. *Photos* Qiang Zhu (2010) and Li Yuanhong (2000)

(c) Improvement of the environment. With enhanced grain production and improved economic conditions, the trend of clearing more land for cultivation, even on steep slopes ceased. Instead, more and more farmers started to participate in the State initiated "Land Conversion" program that encouraged farmers to shift from crop cultivation on marginal sloping land to planting trees and grasses. These trees and pastures would then belong to the farmers, who got compensated with wheat and cash from the government for a period of 8–10 years. RWH irrigation helps to encourage the restoration of the environment in the region (Zhu et al. 2012).

(d) Creating an innovative approach to rainfed agriculture which enhances overall rainwater use efficiency. A key principle in rainfed agriculture is to enhance the WUE. This can be expressed as the output (either the amount or value of production) per unit of rainwater used. The practice of RWH irrigation includes retaining the in situ runoff in the soil and collecting and storing the ex situ runoff to irrigate crops when they need water most. Field trials have shown that by irrigating crops at the critical growing stages with limited amounts of stored rainwater, the overall WUE (kg/m^3) can be enhanced by 29–59% and 15–35% for wheat and corn, respectively (GRIWAC 2002).

Fig. 15 Bao Haiji's **a** new house, **b** greenhouse, **c** corn field. *Photos* Xiaojuan Tang (2009)

4.2 Challenges Facing the RWH Irrigation Project

The main challenge faced by the project is that many of the RWH tanks for irrigation are not being efficiently used. The reason is in part due to a miss-match between tank capacity and the size of their catchments. Some of the tanks receive insufficient runoff due to either inadequate catchment area or the low RCE of the catchment (GRIWAC 2005). Some technicians and farmers neglect the importance of ensuring a properly sized catchment to adequately supply the system. This is due to the poor awareness and lack of training of farmers and the agricultural extension service (Zhu et al. 2012). It is also not uncommon to find a rainwater tank full of water next to land that is not being irrigated. This is usually because of one or more of the following reasons (GRIWAC 2005; Zhu et al. 2012):

(a) Farmers are unaware of the benefits that RWH irrigation can offer as positive experiences have not been demonstrated to them.
(b) Suitable irrigation methods such as drip systems are considered unaffordable or economically too risky by poorer farmers.
(c) Farmers have been used to rainfed agricultural practices for generations and are unfamiliar with or lack know-how about RWH irrigation techniques.
(d) The above shortcomings are indicative of insufficient support from the agricultural extension services. Indeed compared to the 1990s and early 2000s, far less attention is being been given to RWH by the authorities. Due to rapid

economic development, more financial resources are now available to build large inter-basin water transfer irrigation projects and the focus has shifted away from small-scale initiatives such as RWH.

While it is true that a large project can provide irrigation to thousands of hectares, these are not appropriate in remote and mountainous areas, where people live in scattered settlements. Large irrigation projects can only supply water to discrete locations and along distinct corridors and those living far away from these locations miss out (Zhu 2003; Zhu et al. 2012). To help people living in remote and mountainous areas to farm efficiently and profitably, there is no choice but to use the only available water source which is—rainwater. Promotion of RWH should therefore remain a key responsibility of the authorities at various levels even while they devote themselves to larger projects.

5 Conclusions

1. RWH has now been practiced for small-scale supplementary irrigation for more than 25 years and has proved to be both cost-effective and popular with local communities, who have rapidly adopted it without any negative impacts on the environment (GRIWAC 2005). The RWH irrigation has been an important innovation for providing resilience against drought, ensuring food and water security, alleviating poverty, and conserving the environment. With the world facing a serious shortage of water, it is vital to consider not only using surface and groundwater but also to focus on the most basic water source that the Earth offers, the rain.
2. RWH irrigation is a special kind of irrigation appropriate in semiarid areas such as on the loess plateau of Gansu where conditions for agriculture are extremely adverse. This method uses only small amounts of water to enhance the overall efficiency of rainwater use in areas dependent on rainfed agriculture. In China, RWH systems are owned by individual households and compared to publicly owned or community-owned water storage facilities are highly efficient and have proved very effective in mitigating the impact of drought (Zhu et al. 2012).
3. Good management of RWH projects is the key to maximizing their potential benefits. Attention should be paid to help farmers, who are the owners of the systems to better manage them. This approach should include promoting awareness of the benefits of RWH irrigation, training and capacity building, as well as the provision of any necessary financial support such as affordable loans by local authorities.

References

Agarwal A, Narain S (1997) Dying wisdom: rise, fall and potential of India's traditional water harvesting systems. Centre for Science and Environment, New Delhi, India. p 404.

Cheng M, Zheng D, Ma L (2009) Rainwater harvesting water saving irrigation and dry farming technology in the semi-arid loess hilly area of North China. Yellow River Water Resources Publications, Zhengzhou, China (in Chinese).

Evenari M, Shanan L, Tadmor N, Aharoni Y (1961) Ancient Agriculture in the Negev, Sci, pp 979–996.

Falkenmark M, Rockström J (2015) Double water blindness delaying sub-Saharan green revolution. In: Water for Development: Charting a Water Wise Path, SIWI Report 35, Stockholm, pp 64–68 Available at www.siwi.org.

Falkenmark M, Rockstrom J, Holmgren T (2014) Concerned scientists and experts declaration on Water, Hunger and Sustainable Development Goals, Managing rain: the key to eradicate poverty and hunger. SIWI, Stockholm.

GBWR, Gansu Bureau of water Resources and Gansu Bureau of Technical Supervision (GBTS) (1997) Technical standard for rainwater collection, storage and utilization in Gansu Province. Gansu Science and Technology Press, Lanzhou (in Chinese).

GSWCB, Gansu Soil and Water Conservation Bureau, Gansu Soil and Water Conservation Research Institute, Soil and Water Conservation Research Institute of Pingliang Prefecture and Soil and Water Conservation Research Institute of Dingxi Prefecture (1994) Experiment and research report on leveled terrace. Gansu Bureau of Water Resources, Lanzhou [Unpublished] (in Chinese).

Gould J, Zhu Q, and Li Y (2014) Using every last drop: rainwater harvesting and utilization in Gansu Province, China. Waterlines, 33(2), pp 107–119. Available at: http://www.developmentbookshelf.com/doi/abs/10.3362/1756-3488.2014.012.

GRIWAC Dryland Agriculture Institute of Gansu Academy of Agriculture Sciences, Gansu Agriculture University and Dingxi County Government (2002). Technology integration and innovation study on high efficient concentration of natural rainfall in the semi-arid mountainous area, GRIWAC, Lanzhou [Unpublished report] (in Chinese).

GRIWAC Gansu Research Institute for Water Conservancy (2005), Research on the post evaluation of the rainwater harvesting projects and its development pattern in the middle and eastern part of Gansu Province. GRIWAC, Lanzhou [Unpublished] (in Chinese).

Guo X (2010) Presentation on the Lanzhou International Training Course on Rainwater Harvesting and Utilization for the Developing Countries [Unpublished].

Li X, Gong J, Gao Q (2000) Rainfall harvesting and sustainable agriculture development in the Loess Plateau of China. J of Desert Res, 20(2), pp 150–153.

MWREP, Ministry of Water Resources and Electric Power, Hydrological Bureau (1987) Assessment of China's water resources. Water and Power Press, Beijing (in Chinese).

Ministry of Water Resources (2001) Technical code of practice for rainwater collection, storage and utilization. China Water and Power Publications, Beijing (in Chinese).

Rockström J, Falkenmark M (2015) Agriculture: Increase water harvesting in Africa. Commentary, N, 519: 283–285.

Rockström J, Lannerstad M, and Falkenmark M (2007) Assessing the water challenge of a new green revolution in developing countries. Proceedings of the National Academy of Sciences of the United States of America 104, pp 6253–6260.

UNESCO (2006) The United Nations World Water Development Report 2. Available at www.unesco.org/water/wwap.

Xu W, (2007) General survey of water resources and rainwater utilization in Gansu. In: Zhu Q, Li Y, Ma C [eds.] Rainwater Harvesting. Auhui Educational Publishing House, Hefei (in Chinese).

Yu Y, Zhang Y, Yang S, He R, Tian H, and Sa A (1996) Disaster of flood and drought in Gansu. Yellow River Water Resources Press, Zhengzhou, China (in Chinese).

Zhu Q (2003) Rainwater harvesting and poverty alleviation: A case study in Gansu, China, Intern J W Res Develop, V19 No. 4, 569–578.
Zhu Q, Li Y (2000) Rainwater harvesting for survival and development. Waterlines, 18(3), pp 11–14.
Zhu Q, and Li Y (2003) Drought-proofing villages in Gansu province. LEISA Magazine, Vol. 19.2, pp 14–16.
Zhu Q. Li Y (2004) Rainwater harvesting—An alternative for securing food production under climate variation. J W Sci & Tech V49, No.07 157–163.
Zhu Q, Li Y. (2006) Rainwater harvesting: The key to sustainable rural development in Gansu, China. Waterlines, 24(4), pp 4–6.
Zhu Q, Zhang G (2001) Concise book for rainwater harvesting in rural area. Water and Power Press, Beijing China (in Chinese).
Zhu Q, Li Y, and Gould J (2012) Every Last Drop: Rainwater harvesting and sustainable technologies in rural China, Practical Action Publications, Rugby, U.K., 142p.
Zhu Q, Gould J, Li Y, Ma C [eds.] (2015) Rainwater harvesting for water supply and agriculture. China Science Press/Springer, Beijing.