Artificial Rainwater Harvesting System and the Using for Agriculture on Loess Plateau of China*

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Abstract: Artificial rainwater harvesting system (ARHS) is a new way to increase water supply in semi-arid area, and has developed rapidly recent years in northwestern China. Not only it used in domestic supply, but also in agricultural as supply irrigation. More than 2 million water cellars have been built in Loess Plateau of China. In this paper, based on 5 years' related experiments, field engineering and trails, the author showed a case of practice research results in Dingxi experimental station, Gansu province. It was selected two kinds of material using land surface treatment for rainwater collecting, High strength and water stability Earth Consolidator (HEC) and asphalt fiberglass felt, which water harvesting efficiency (WHE) reached to 86%—91% and 85%—90%, respectively. It analyzed three kinds of water cellar structure, roundness shape, column shape and flask shape with red pastern mud. According to theory of limited irrigation, the experiments indicated that drip irrigation under plastic film (DIUP) is the best method at key stage of water requirement of crops. The yield and water use efficiency (WUE) of spring wheat at jointing stage with DIUP was 1900kg/hm^2 and 6.03kg/hm^2 • mm, respectively, which is higher 111.1 % and 69.4% than that of control, the effect on corn was more markedly. On the other hand, it gave out a practice demonstration for artificial rainwater harvesting system in slope land area, and showed the benefit of the model.
Keywords: Artificial rainwater harvesting system (ARHS), water harvesting efficiency(WHE) water cellar, water use efficiency(WUE), semi-arid, China

1 Introduction

Loess Plateau is located in Northwestern of China, 6.28×10^5 km^2, a typical and central area of rainfed farming in China. It includes most or parts counties of Guansu, Ningxia, Shanxi, Shaanxi, Qinghai, Inner Mogoliya and Henan provinces. The annual precipitation is 250mm—550mm in most area. However, only 5%—10% of annual rainfall is formed runoff, most of others is lost in evaporation from soil (Zhu Qiang *et al*., 2000). The average amount of runoff per capita and per hm^2 on Loess Plateau are only 541m^3 and 2,625m^3, respectively, which is only 4.2% and 8.8% average amount of the world (Z.B.Huang *et al*., 1997). Annual drought damage area from 1949 to 1985 has reached 7.3×10^7 hm^2 on Loess Plateau. The grain loss amount caused by drought and shortage of water has reached to 25×10^{10} kg over the China.

Meanwhile, rainwater is a major water resource of agricultural production and has a great potential to use. Annual average rainfall depth over Loess Plateau is 443mm, that means the annual rainwater amount is 275.7 billion m^3, which is about 9.2 times of the total annual consumption amount of surface and underground water.

Artificial rainwater harvesting system (ARHS), or rainwater catchment system (RCS), has been practiced over the world. Many countries have making rainwater use as a strategic way for sustainable development. It has formed various types of rainwater harvesting system for different purpose. Rainwater harvesting system for domestic supply is widely and rapidly in many countries (Boers, 1982, J.Gould,

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1999). Jordan and some countries built earth dams and water reservoir to increase water supply by floodwater harvesting (Majed, 2000). In Australia and India, it was to collect runoff of slope land into terrace field in low place, or store the water in a pool or tank to supply irrigation (Brian H., 1992). In Israel, the system made the farmland to supply rainwater 300mm—500mm where annual precipitation is only about 100mm. In America, 500hm^2 land surface is treated by sodium salt for supply rainwater for 50hm^2 farmland, the yield of crop in the farmland increased 1—2 times. These practices can be divided two aspects: ARHS and RCS. To RCS, most are related with field tillage, such as micro-basin planting (Garder, 1975, Z.B. Huang *et al*., 2000). To ARHS, the typical practice is in China.

It showed that the technology of ARHS used very long history in China y. Pool-dam appeared in about 2,700 years ago, and the water cellar about 620 years. Presently, small reservoir, terrace separated by slope land, water cellar and so on are also belonged to the range of ARHS. Recent years, as drought increasing and water shortage problem becoming serious, many projects, engineering and development of ARHS practices became more extensive and develop rapidly on Loess Plateau. These have formed a new way of rainfed farming. There are about two million new water cellars, volume 37.8×10^7 m^3 on Loess Plateau.

The objective of the paper is to show some research results of national project based on 5 years' related experiments, field engineering and trails. It also proved a demonstration on slope land of rainwater harvesting system.

2 Rainwater harvesting material and the WHE

Artificial rainwater harvesting system (ARHS) is consisted of three parts: rainwater collecting, rainwater cleaning and storing, rainwater using.

To rainwater collecting, the center is the water harvesting efficiency (WHE) of ground surface material. WHE is the ratio of runoff volume to precipitation volume. It is an integrated index, and related closely with characteristics of meteorology and hydrology, material of runoff collecting surface, water content before rainfall, and land types. Because the meteorology and hydrology are difficult to control, and the materials become more important.

By plot experiment on slope land field and indoor experiment in rainfall simulation hall, we found the materials were not the same influenced by precipitation, rainfall intensity, rainfall time and so on, and can be divided into two groups. To water infiltrating material, HEC, High strength and water stability Earth Consolidator, is a special material for treat land surface. The WHE was closely with maximum rainfall in thirty minutes ($WHE=16.19Ln(I_{30})+52.44$). To water preventing materials, such as plastic film, felt, asphalt fiberglass felt, concrete, the WHE was markedly related precipitation (P).

Indoor experiment in rainfall simulation hall showed that WHE of the HEC with sandy soil is 80%—95%, and asphalt fiberglass felt 72%—96% that all higher than that in field experiment (Table 1).

Table 1 WHE of different materials under rainfall simulation hall

Rang	Rain mm	Inten-sity (mm/min)	Rain time (min)	HEC Clay soil	HEC Sandy soil	C15 Concrete	Plastic film	Asphalt fiberglass felt
MIN	2.85	0.09	30.0	84.3	79.5	63.8	69.7	71.6
MAX	76.32	1.356	61.0	96.9	94.7	96.6	94.2	96.2
Average	39.6	0.732	45.5	90.7	87.6	80.0	78.3	83.7

Selection of materials is closely with local farm's economic and society. Owing to complex climate and poor economic condition, the surface area for ARHS should be good quality with cheaper price. For the present condition on Loess Plateau, the polythene plastic film is useful and used widely. Although the usage is about one year, but the price is only RMB 1yuan/m^2. For the long term benefit, it is recommended HEC and asphalt fiberglass felt.

HEC is a kind of solidify agent in powder material. The characteristic is high intensity, water resistant and extensive application. It can be mixed with many materials. Our experimental results showed that the optimum water content to proportion HEC and loess soil 1:6 and 1:8 is 19.0% and 19.2%, maximum dry density(ρ_{dmax}) at thickness 5cm are 1.67 g/m^3 and 1.65g/m^3, the anti-pressure intensity 2.04Mpa and 1.16MPa after building 3 days, the water infiltration coefficient was 4.99×10^{-8} and 1.44×10^{-8} on 3 days, respectively. These results are nearly same to parameters of concrete. Asphalt fiberglass felt, it made fiberglass covered with improved asphalt. The characteristic is high intensity, anti-pull, no water infiltrating, and aging resistance, and suitable to use in house proof, anti-infiltration material in reservoir and cannel. The WHE of asphalt fiberglass felt reached over 90%, 0.5mm—1mm thickness, the usage over 10 years.

3 The rainwater storing and cleaning

Rainwater storing is an important process to make water re-distribution and efficient use on place and time. The center is water storing facility, because its technology is complex, and investment of money is most.

Owing to poor economic condition, it is not permitted to use water tank made of metal on Loess Plateau. However, the people used to build water cellar for water storing hundreds years, and accumulated rich experience. The key is to deal with infiltration problem and select suitable size and shape of water cellar. To the infiltration, the characteristic is the same to land surface treatment, and closely related with design and shape selection.

Based on analysis using limited buck method of elasticity mechanics, and practice investigating, it was recommended three types of water cellar, roundness water cellar, column water cellar and flask water cellar (Fig. 1).

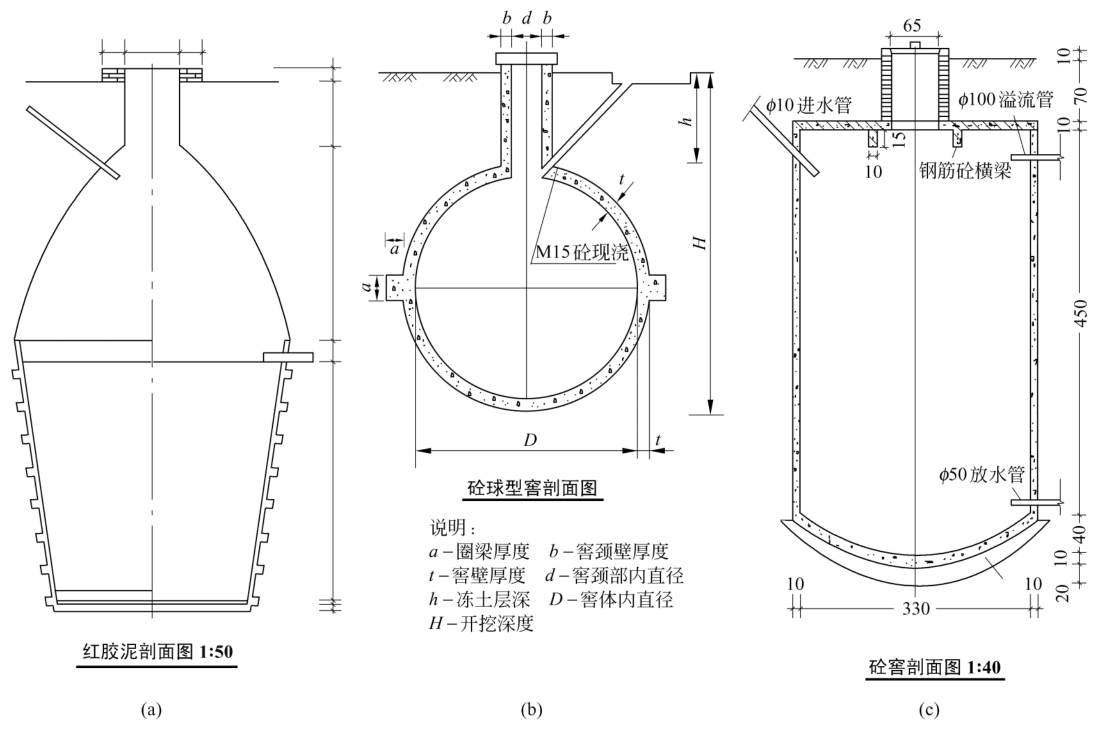

Fig. 1 Three shapes of water cellars. (a) Flask water by red pastern mud, (b) Roundness water cellar, (c) Column water cellar by concrete

Roundness water cellar suited to various land types and made of concrete, the volume 10m^3—25m^3, thickness of the wall 4cm—5cm. Column water cellar is suited to intensity soil or land area. The structure is simple, wall thickness 7cm, cheaper and engineering process easy, the volume generally $30m^3$—$60m^3$. Flask water cellar made of red pastern mud, one kind of local special soil with red color, and contains a lot of paste material. The wall thickness is 8cm—10cm, the volume $15m^3$—$50m^3$.

On distribution of water cellars in field, there are three kinds of type, series connection, parallel connection and scatter. The series type often used with big water collecting area. The parallel type most built in road line or big irrigation area, and often 3—8 water cellars parallelling for concentrating supply water. The cellars for life and courtyard plants are constructed around houses or nearly yards, to get water often is used hand pump. The cellars for irrigation of green houses or farmlands are built in side of fields or road, to get water usually is micro-electricity pump. In some places, irrigation depends on natural pressure of high position of water tank.

The appendix installation of water cellar is water cannel, sediment tank, block filter net and water-entering pipe, water power-wasting tank and water-meter and so on.

4 High efficient use of rainwater and limited irrigation

To agricultural use of ARHS, the center problem is how to get limited water for high efficient use. Rainwater amount by ARHS is very limited, can not be used as flood irrigation or adequate irrigation, and suitable to limited irrigation based on the water requirement rule of crops and culture ways. The research results showed that water requirement among crops is not same. Water stress does not always make crop yield decreased. Under suitable water stress, the crop yield may increase, and the quality is better (Turner, 1990). Therefore, the main use way of ARHS is as supply irrigation at key water requirement stages of crop or at serious drought seasons. In general, the supply irrigation is 1—2 times in whole growth stages, and irrigation amount is limited compared with irrigation farming.

It has indicated the water requirement of spring wheat is 300mm, but precipitation at same time only 182.2mm, water shortage reached about 40%, and in jointing stage water balance difference is 82%(Zhao Songling, 1996). Under furrow irrigation 60mm at jointing stage, the grain yields of spring wheat increased 24.5%, 48.2% and 53.4% for the species suited to dryland, dry or irrigation land, and irrigation land, respectively.

To the method of limited irrigation, there is hole irrigation at young growth stage, planting with water, irrigation in hole of plastic film, ditch irrigation, drip irrigation and permeating irrigation etc. In which, the most water-saving method is drip irrigation. Using drip irrigation under plastic film (DIUP), the yield and water use efficiency (WUE) are all best (Table2). Under DIUP way to supply 300 m^3/hm^2, the grain yield)of maize was 3,323kg/ hm^2, nearly to that under furrow irrigation 900mm, and irrigation water use efficiency IWUE reached 4.44 kg/(mm • hm^2), 1.76 times of that under furrow irrigation 900mm.

Table 2 Effect on yield and WUE of Spring wheat to different irrigation methods

Irri. Method	No irri.	Surf. Irri.	Irr.on P.F.	DIUP
Grain yield(kg/hm^2)	899.0	1,498.5	1,758.2	1,900.1
Increasing (%)	—	66.7	95.6	111.4
Weight 1000 grain (g)	39.5	39.6	40.8	36.7
WUE(kg/(hm^2 • mm))	3.56	4.60	5.58	6.03
Increasing (%)	—	29.2	56.7	69.4

(Data from DingXi experimental station).

5 A demonstration of rainwater harvesting system on slope land

According to the local water resource, land type and people's economic condition, it is built an integration model in Dingxi experimental station. The model characteristic was " planting grain crop or grass upon slope land in summer, then covering the land surfaces by plastic film for collecting rainwater in autumn, building water cellars below edge of the slope land, and irrigating terrace crop under the slope land". The test area of the slope land is 0.28 hm^2, the covering material is plastic film, the type of ten water cellars, volume $30m^3$ and a set of drip irrigation system with auto-pressure, the supply irrigation area is $0.73hm^2$ (Fig.2).

The test showed that the WHE of plastic film reached 93.0%, the yield of maize in terrace using drip irrigation was 3,150kg/hm^2, which is higher 40% than that of the control. Meanwhile, the yield of spring wheat on slope land is 2,502kg/hm^2, higher 25.1% than that of the control.

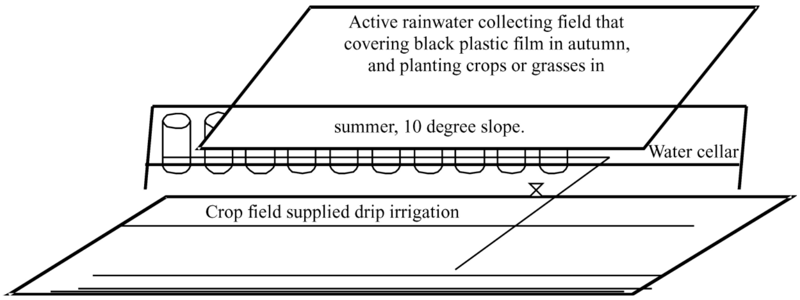

Fig. 2 A demonstration model for artificial rainwater harvesting system(ARHS) on slope land

References

[1] Boers Th.M. and J.Ben-Asher, 1982, a review of rainwater harvesting, Agri. Water Manage., 5:145-158.

[2] Brian H., 1992, Water harvesting—improving the reliability of farm dams in the Western Australia wheat-belt, Chief executive office of the department of agriculture, Western Australia.

[3] Huang Zhanbin Shan Lun *et al*., 1997, Correlation between rainwater use and agriculture. sustainable development of the loess Plateau of China, In: Proceedings of the 8th international conference on rainwater catchment system, April 25-29, Tehran, IRAN, 1048-1054.

[4] Z.B.Huang S.Assouline J.Zilberman and Meni Ben-hur, 2000, Tillage and saline irrigation on water and salt distribution in a sloping field, Soil Sci. Soc. Am. J., 64, 2096-2102.

[5] Frasier, G.W. Myers,L.E., 1983. Hand book of water harvesting, U.S.Department of Agriculture. Handbook No.600, pp.45.

[6] Gould J. and Erik N.P., 1999, Rainwater catchment system for domestic supply, Intermediate Technology Publications, London, UK.

[7] Garder, H.R., 1975, An analysis of the efficiency of microwatershed system. Proc. Water Harvesting Symp., Phoenix, AZ, ARS W-22. USDA, pp.244-250.

[8] Li Xiaoyan Gong Jiadong Gao Qianzhao and Wei Xinghu, 2000, Rainfall interception loss by pebble much in the semiarid region of China, J.of Hydrology, 228:165-173.

[9] D.C.Nielsen, 1998, Snow catch and soil water recharge in standing sunflower residue, J.prod.Agric., vol.**11**:476-480.

[10] Majed Abu-Zreig, Mousa Attom, Nisreen Hamasha, 2000, Rainfall harvesting using sand ditches in Jordan, Agri. Water Manage., 46, 183-192.

[11] Ojasvi P.P., R.K.Goyal, J.P.Gupta, 1999, The micro-catchment water harvesting technique for the plantation of jujube (Zizphus mauritiana) in an agroforestry system under arid conditions, Agricultural Water Management 41,139-147.

[12] Shaozhong Kang Yinhua Pan *et al*., 2000, Alternate furrow irrigation for maize production in an arid area, Agri. Water Manag. 45, 267±274.

[13] Shan Lun, 1994, Water use efficiency of plant and agricultural water use in semi-arid area, Plant physiology communications, 30(1), 61-66 (in Chinese).

[14] Turner, NC,1990, Plant water relation and irrigation management, Agric. Water Manage., 17:5973.

[15] Zhao Songling,1996, introduction to catchment agriculture, Shaanxi Scientific and Technological Press, Xian China (in chinese).

[16] Zhu Qiang Li Quanhong, 2000, Rainwater harvesting project in Gansu Province, In edited by Huang Guanhua, Theiry and Practice of Water-saving Agriculture, Proceedings of Chinese-Israeli Bilateral International Workshop on Water-saving Agriculture, Chinese Water Conservancy and Electricity Press, Beijing, China, pp.18-27.

[17] Luis S. Pereira, 1999, Higher performance through combined improvements in irrigation methods and scheduling: a discussion, Agri. Water Manag. 40, 153-169.