Rainwater harvesting – an alternative for securing food production under climate variability

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Abstract
Food insecurity is still a challenge in some remote and mountainous areas in China. When studying the impact of climate variability on food production, we should pay even more attention to the rainfed area. This is because the larger part of agriculture is the rainfed one and climate variability has more negative impacts on the rainfed agriculture than on the irrigated one. The traditional dry farming practices based on the principle of storing as much rain in the soil as possible and making best use of soil water could not bridge the gap between the time that the crop needs water and the time that rain occurs, so its effects on enhancing food production under climate variability is limited. Combining artificial water supply from rainwater harvesting systems with the traditional dry farming practices is an innovation in water management in rainfed agriculture. Experiences in the recent two decades indicate that rainwater harvesting irrigation can well mitigate the drought caused by the climate variability and bring the rainfed agriculture to a new level.

Keywords
Climate variability; food security; irrigation; rainfed agriculture; rainwater harvesting

Introduction
Entering the new millennium, the world is facing serious challenges of food security. In China, it seems that food production has basically met the demand on the whole country basis at the present time. However, it is clear that national food security does not imply food security for all the regions and people in the nation because of the unbalanced conditions in nature and economy. Also, food security should take into account the variety of food. In some mountainous areas in China there exist 23.3 million people living under the poverty line. Most of them are still suffering from lack of food. Besides, some factors could become a latent threat to food supply for the huge population in the future. Along with the rapid process of urbanization, the area of cultivated land has been dropping increasingly. To the year of 2000, cultivated land per capita is less than 0.1 hm² and would be further decreased in the future 20–30 years. The potential of extending cultivated land is small because most of the reclaimable wasteland is concentrated in West China and the priority for this area will be on rebuilding the ecosystem. With the implementation of the Land Conversion Programme more and more cultivated land will be shifted to afforestation and grass planting. Low, even negative, benefit of food production in some areas has driven farmers to abandon their lands and to find city jobs. To keep a balance between the growing demand for food supply on the one hand and the increased population as well as the reducing land for grain cropping on the other hand, the only way is to enhance the agricultural productivity.

Impact of climate variation on the agriculture production
Food production is closely related to water condition. When studying the climate impact on agriculture production, we should not only pay attention to the irrigated agriculture, but also pay even more attention to the rainfed area. The rainfed lands occupy about 81% in the world. Even in China, a country with an irrigation history of more than two thousand years, the proportion of irrigated land is still less than half. If effective measures were taken for
enhancing production in the rainfed areas, the potential for increasing grain yield could be considerable. Climate variation has more impacts on the agriculture yield in the rainfed areas than that in the irrigated areas. Particularly in the semi-arid areas with traditional dry farming practices, like the loess plateau of Gansu, China, climate variation has caused frequent drought, which is the permanent threat to food production and also the root cause of poverty as well as land degradation and environmental deterioration. According to the governmental statistics for the period from 1950 to 1990, in this area where 90% of the agriculture is rainfed, droughts happened in 26 years, of which heavy droughts (grain production reduced by 30–50% compared with the normal year) amount to eleven, while in the western region of the province where 80% of land is irrigated by a perfect irrigation system, only 21 light droughts (production reduction 10–30%) happened in the same period and no heavy drought occurred. These figures clearly indicate that the food production in the rainfed agriculture area suffers much more from climate variation.

The central and eastern part of Gansu is a semi-arid loess plateau with altitude ranging from 1,800 m to 2,200 m. The annual precipitation is 360 mm and, owing to geographical and hydrological reasons, an irrigation system is very difficult to build. According to the definition of Britannica, this area belongs to a typical dry farming area. To study the impact of climate variation on food production in a more specific way, we will take Huining County for a case study. The annual precipitation is 368.8 mm in the County while the crop water demand of spring wheat, a main crop in the area, is 380.9 mm. Here the crop water demand refers to water consumption of the crop under the condition of sufficient water supply. So the annual precipitation is the same magnitude as the crop water demand of spring wheat in the whole growing period. However, the conclusion is entirely different if comparing the rainfall hydrograph with the water demand distribution curve. In the critical period from May to June, water demand amounts to 322.4 mm (85% of the total), while rainfall in the two months averages only 88.4 mm in the past 44 years, 27.4% of the crop water demand. The recorded maximum rainfall from May to June is 156 mm, only 48.4% of the crop demand, indicating the dominance of water shortage in the area. So we can conclude that the crop water deficit is mainly caused by the timely inadaptability of crop demand to natural rainfall distribution rather than by the insufficiency of yearly rainfall. Besides, based on a statistical analysis of the rainfall data, the variation coefficient of rainfall from May to June is about 1.5 times that of the yearly rainfall. The higher variability of rainfall in the critical period causes unstable food production.

To study the susceptibility of yield of staple food to the climate variation, a correlation analysis was made. It was found that the grain yield has a close correlation with the rainfall from May to July. Here the critical period seems to be May to July. This is because corn, another main crop in the area, needs water most in June and July. The correlation is significant at confidence level \( \alpha = 0.01 \) by the F-test. The regression equation between food production and rainfall from May to July is shown as follows.

\[
Y = 0.1806R + 114.8
\]  

(1)

where \( Y \) is the yearly yield of staple food in the County, \( 10^3 \) t, \( R \) is the rainfall from May to July, mm.

In a recent period of 5 years, the average yield from 1997 to 2001 was 144,416 t per year, which corresponded to grain production per capita of 278 kg (about 70% of the State level) when shared among the population in the County. In Eq. (1) this yield corresponds to rainfall from May to July of 163 mm, placed on the 53% percentile on the empirical frequency distribution curve (1957–2000). If we take the average yield in the recent 5 years as a critical yield for ensuring minimum food supply at the county level, then the food security
has reliability of a little more than 50%. In Eq. (1) the regression coefficient of 0.1806 implies a slight impact of rainfall on the yield. For example when rainfall in the period of May to July drops from 163 mm to 90 mm (from 50% to 90% percentile) yield decreases from 144.4 t to 131 t, i.e. decreases by 9.3%. However, considering that the food consumption of local inhabitants is mainly grain (wheat and corn), from the nutrition point of view, the food consumption level at the moment is not enough for the real meaning of food security.

Analysis of rainfall data in the past 44 years shows that the rainfall has a trend of light decrease with oscillation versus time. The reduction tendency is more apparent (correlation significant at confidence factor $\alpha = 0.01$ by F-test) in the 5-year mean of the rainfall hydrograph, see Figure 1.

Figure 1 shows that there is about a half percent reduction for each year on average over the past forty years. Since the rainfall series in Huining County is not long enough, we cannot say at the moment whether the reduction trend in the area is a section of the natural hydrological cycle or a result of climate change. However, people in this area have complained more and more of suffering from recurrent droughts in the 1990s, it at least indicates the necessity to prepare more steps to mitigate the negative impact of climate variability.

If the rainfall continues to decline as Figure 1 shows and the population continues to increase then steps should be taken to enhance the land productivity for securing food production.

**Traditional adaptation to climate variability for food security**

In past decades, people in this area have made numerous efforts to mitigate the frequent drought for enhancing the agriculture level. However, before the 1980s, these efforts were in the category of conventional dry farming (Zhu Qiang and Li Yuanhong, 2001). They included the following measures:

- reforming the land to retain more rainfall, such as terracing, contour planting;
- cultivation measures to keep soil moisture from evaporation such as deep plough, harrowing and tillage, mulching, etc.;
- fertilizing to increase resistance of crop to water stress;
- breeding new varieties that can have higher resistance to water stress and adaptability to the rainfall condition; and
- floodwater harvesting and spate irrigation.

All these measures are based on the principle of water management for dry farming, that is, to store as much rainwater in the soil as possible and to make best use of soil water. They were proved to be effective in mitigating the water deficit of the crop but the effects were limited. This can be further explained through an analysis of the water balance from July 1975 to June 1976 (year with rainfall from May to July locating at the 75% percentile of the
frequency distribution curve) for a spring wheat field. The results are illustrated in Figure 2. The analysis was done with an optimum assumption that all the natural rain could be absorbed in the soil (except when the storm exceeds the infiltration capacity of soil). The crop water demand in the analysis is for the spring wheat under plastic sheeting, with which the crop water demand can be reduced by 15–38%, as indicated in some field tests. Here the reduction rate of 30% is adopted. The crop water demand was determined by field tests.

From the analysis, we can see that a serious water deficit exists, amounting to 93.7 mm, 34.4% of the total water demand. Water shortage occurs in the wheat growing stages of heading and milking, during which water shortage would have a large influence on the yield. The storage capacity of soil is not enough for mitigating water shortage. For loam and sandy loam, the maximum available soil water that can be held in the root zone approximately 0.8 m deep is in the range of 90–120 mm. It is only about 54–71% of the water shortage in May and July. Besides, the evaporation loss on the bare land in the period after harvest to next seeding amounted to 138 mm, 67% of the stored moisture, indicating a low utilization rate of the natural rain.

The inadequacy of the adaptation capability of the conventional measures of rainfed agriculture to the climate variability is mainly due to it not being able to bridge the gap between the time that the crop needs water and the time that rain occurs. Usually the gap would extend to 6–8 months. So the grain yield in the area remained at a low level of about 1.0 to 1.5 t/ha in a normal year and would drop seriously under an unfavorable rain distribution. Experiences and studies in past decades forced people in the area to come to the conclusion that only adding artificial water supply to the natural rain would enable a stable and high level of crop yield in the rainfed agriculture.

The problem is how to get water. The surface and ground water resources are both very scarce in the area. Since the 1960s, a scheme to divert water from Taohe River, the largest tributary of Yellow River in the Province, to the loess plateau has been planned. But owing to the geographic and topographic condition, this project is very costly. According to a recent budget estimation, to develop each hectare of irrigated land the investment will reach US$ 15,000. Although the State Government has approved support for this project there is still a large fund gap and furthermore, the water users would be unable to afford the high O&M fees. The big amount of work would need a long time to bring the project into play. Besides, there would also be many environmental issues associated with the large project. For instance, the loess soil characterized by wet subsiding in the project area might sink seriously owing to too much water being brought to the land after a long-term operation. Furthermore, the decentralized local inhabitants with their lands scattered in the vast mountainous areas can hardly get access to this concentrated water delivery project.

**Figure 2** Water balance for the spring wheat, July 1975–June 1976, Huining
Innovation

The most easy-to-use water resource in the area is rainwater, which is available everywhere. The rainwater harvesting (RWH) developed in the last 20 years in the area has provided a way to promote the rainfed agriculture to a new level. In 1996, after successful implementation of the 1-2-1 RWH Project that has succeeded in supplying water for domestic purposes for 1.2 million people in the area, a RWH irrigation project was initiated, aiming at supplying water for agriculture production. To the end of year 2000, 2.3 million tanks were built, which enabled 236,000 ha of land to receive 2–3 supplemental water applications in the crop growing season. The water use was very efficient. Firstly, water supply to the crop took place only at critical periods of crop growing. The critical periods for different crops were identified through numerous field tests by comparing the effect on the yield increase and the water supply efficiency (WSE = water amount applied/yield increase). For instance, the optimum periods of water supply for spring wheat were found to be at the jointing and heading stages and for corn it is at the stage of flowering and heading. Besides, water supply during seeding is necessary for all crops to ensure emergence and normal growth of the young plant. Secondly, water-saving and indigenously innovated methods were adopted for supplying water to the crops. These include bunch irrigation, seepage irrigation, water injection to the root zone, irrigation through holes in plastic films, etc. All these methods have the feature of limiting the watering area only at the crop root zone and to avoid evaporation loss from the soil as much as possible. For cash crops and irrigation in the greenhouse, drip and micro sprinklers are used. The following table quotes part of the recommendation on the irrigation frequency and quota by the “National Code of Practice for Rainwater Collection, Storage and Utilization” issued by the Ministry of Water Resources in April 2001.

The figures in Table 1 represent the practical experiences of the RWH irrigation in China. The water supply from the RWH system to the grain crops in the whole growing season is about 300–450 m$^3$/ha. It only provides less than 15% of the total crop water consumption but its effect is promising. According to an investigation in the area, with these water applications, yield can be increased by 40% on average in a normal year and by much more in a dry year. Table 2 lists results of the effect of artificial water supply on crop yield based on some testing and demonstration projects in recent years.

Data in Table 2 show that the effect of RWH irrigation on increasing the yield is very significant. The mechanism of the high effect of the low rate water supply is not quite clear so far. But we notice that the WUE with the artificial water supply from the RWH system is much higher than that without the supply. It would be reasonable to assume that the low rate water supply in the critical period is just to help the crop to tide over the serious water stress to avoid the crop from fatal damage. Then in the rainy season the crop could use the rain efficiently. Indeed, most of the crop water consumption is still from the natural rain. So in order to use the natural rain efficiently, under the condition of artificial water supply from

<table>
<thead>
<tr>
<th>Crop</th>
<th>Irrigation method</th>
<th>Application frequency in area with annual rainfall (mm)</th>
<th>Application quota (m$^3$/ha$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>250–500</td>
<td>&gt;500</td>
</tr>
<tr>
<td>Wheat, corn</td>
<td>Watering when seeding</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Bunch irrigation</td>
<td>2–3</td>
<td>2–3</td>
</tr>
<tr>
<td></td>
<td>Irrigation through holes in plastic film</td>
<td>1–2</td>
<td>1–2</td>
</tr>
<tr>
<td></td>
<td>Injection to root zone</td>
<td>2–3</td>
<td>1–2</td>
</tr>
<tr>
<td></td>
<td>Drip, furrow with plastic sheeting</td>
<td>1–2</td>
<td>2–3</td>
</tr>
</tbody>
</table>

(Quoted from Code of Practice for Rainwater Collection, Storage and Utilization SL267-2001)
the RWH system, we should still use the traditional rainfed agriculture practices that were proved effective. This can also explain why with the same amount of water supply the WUE of corn is much higher than spring wheat because the natural rain that can be utilized by wheat is less than corn in the growing period.

As Zhao Songlin (1996) suggested, it seems an over-compensation effect of the limited water complement by the RWH system exists. The compensation effect of the water supply is identified by the following measurement:

If \( \text{WSE} / \text{WUE} > 1 \), over-compensation exists;
If \( \text{WSE} / \text{WUE} = 1 \), exact compensation exists;
If \( \text{WSE} / \text{WUE} < 1 \), under-compensation exists;
If \( \text{WSE} / \text{WUE} = 0 \), no compensation exists.

Data in Table 2 strongly suggest the phenomenon of over-compensation by the artificial water supply from the RWH system. In the conventional irrigated area (canal, reservoir, pumping plant, etc.) in Gansu, where the irrigation quota is as high as 300 to 600 mm, WSE is usually less than 20 kg/ha-mm. The fact of a higher WSE in RWH irrigation implies the possibility of increasing productivity in the rainfed area and also the potential of agriculture water conservation that has not yet been explored. Adding the measure of artificial water supply (with a small amount) to the conventional dry farming to fight climate variability is an innovation in water resource management in the rainfed areas. Experiences of RWH in semi-arid Gansu in the last two decades have proved this conclusion, and those in the sub-humid and humid areas in China have also come to it.

Owing to the decentralized aspect of the RWH system, it can help to secure food production on a household basis. The affordable input and O&M fees, the indigenous and appropriate technique and the household ownership of a RWH system make the RWH acceptable to

<table>
<thead>
<tr>
<th>Crop</th>
<th>Irrigation Frequency</th>
<th>Amount</th>
<th>Irrigation Period</th>
<th>Yield</th>
<th>Increase Rate %</th>
<th>WUE</th>
<th>WSE</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>Without irrigation</td>
<td></td>
<td></td>
<td>1,334</td>
<td>3.91</td>
<td></td>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>W</td>
<td>1</td>
<td>45</td>
<td>J</td>
<td>1,934</td>
<td>45</td>
<td>6.52</td>
<td>13.3</td>
<td>(1)</td>
</tr>
<tr>
<td>W</td>
<td>2</td>
<td>45</td>
<td>J and B</td>
<td>2,270</td>
<td>70.2</td>
<td>5.92</td>
<td>20.8</td>
<td>(1)</td>
</tr>
<tr>
<td>C</td>
<td>Without irrigation</td>
<td></td>
<td></td>
<td>7,131</td>
<td>17.7</td>
<td></td>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>60</td>
<td>J</td>
<td>9,270</td>
<td>30</td>
<td>20.1</td>
<td>35.8</td>
<td>(1)</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>60</td>
<td>F</td>
<td>9,440</td>
<td>32.4</td>
<td>19.7</td>
<td>38.6</td>
<td>(1)</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>120</td>
<td>F</td>
<td>10,000</td>
<td>40.2</td>
<td>19.6</td>
<td>24.0</td>
<td>(1)</td>
</tr>
<tr>
<td>W &amp; C</td>
<td>Without irrigation</td>
<td></td>
<td></td>
<td>4,088</td>
<td>9.7</td>
<td></td>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>W &amp; C</td>
<td>1</td>
<td>43</td>
<td>Wheat B</td>
<td>6,467</td>
<td>58.2</td>
<td>13.6</td>
<td>55.2</td>
<td>(1)</td>
</tr>
<tr>
<td>W &amp; C</td>
<td>3</td>
<td>95</td>
<td>Wheat B and J, B</td>
<td>7,127</td>
<td>74.3</td>
<td>12.4</td>
<td>32.0</td>
<td>(1)</td>
</tr>
<tr>
<td>W &amp; C</td>
<td>4</td>
<td>135</td>
<td>Wheat J, B, M</td>
<td>7,394</td>
<td>80.9</td>
<td>13.2</td>
<td>24.5</td>
<td>(1)</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>75</td>
<td>F</td>
<td>9,051</td>
<td>88.4</td>
<td>11.1</td>
<td>56.6</td>
<td>(2)</td>
</tr>
<tr>
<td>C</td>
<td>Without irrigation</td>
<td></td>
<td></td>
<td>3,900</td>
<td></td>
<td></td>
<td></td>
<td>(3)</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>29.6</td>
<td>S &amp; H</td>
<td>9,160</td>
<td>134</td>
<td>177.6</td>
<td></td>
<td>(3)</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>43.5</td>
<td>S, J, H</td>
<td>10,710</td>
<td>175</td>
<td>156.6</td>
<td></td>
<td>(3)</td>
</tr>
<tr>
<td>D-W</td>
<td>2–3</td>
<td>23–30</td>
<td></td>
<td>1,990–6,843</td>
<td>10.5–88</td>
<td>16–39</td>
<td>25–58</td>
<td>(1)</td>
</tr>
<tr>
<td>D-C</td>
<td>2–3</td>
<td>38–41</td>
<td></td>
<td>2,940–9,050</td>
<td>20–88</td>
<td>31–57</td>
<td>46–85</td>
<td>(1)</td>
</tr>
</tbody>
</table>

Note:
1. Data source: (1) Gansu Research Institute for Water Conservancy et al., 2002 (2) Zhao Songlin, 1996 (3) Water Resources Research Institute of Inner Mongolia, 1997
3. D-W and D-C are results of demonstration projects

Table 2 Test and demonstration results of the effect of RWH irrigation on crop yield (Unit: yield, kg/ha, application amount mm, WUE and WSE, kg/hm²-mm)
the mass of farmers in China. During the implementation of RWH projects, to mobilize the farmers to accept the RWH system for domestic water use was easier than for enhancing production. Time will be needed to increase the awareness building related to the benefits of RWH to production as well as the ways to bring about profit. Since there have already been hundreds of thousands of households in Gansu and millions of households in China adopting this approach, RWH will be accepted by more and more farmers. It will play a greater role in mitigating drought to secure food production in the near future.

Conclusions

1. The rainfed agriculture suffers more from climate variability. For securing food production, we should not only pay attention to the irrigated area but also pay even more attention to the rainfed areas.

2. Adaptation of traditional rainfed agriculture to the climate variability can be effective but its effect is limited when serious and/or recurrent droughts occur.

3. Combining RWH with the traditional rainfed agriculture practice is an innovative approach to adapt to the climate variability. It is hoped to bring this traditional agriculture practice to a much higher level and even into a breakthrough.

References


