Chapter 1

Research and Practice of Water-Saving Irrigation for Rice in China

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Introduction

China is the biggest rice-producing country in the world. The planting area of rice is about 31 million hectares and makes up 30 percent of the total planting area of grain crops; the rice production per year is around 185 million tons and accounts for 44 percent of the total grain production in China. On the other hand, the availability of per capita freshwater in China is among the lowest in Asia. On average, there are only 2,260 m^3 of freshwater per year per head, which value is less than a quarter of the average value in the world. The distribution of precipitation in seasons and years is quite uneven and the water resources do not match with the distribution of farmlands. Though it is wet in the south of China, about 90 percent of the freshwater is used for rice production. The water shortage has been the bottleneck for both economic and agricultural development in China. Therefore, the need for more rice with less water is more urgent in China than in many other countries in the world. Increasing attention has been paid to improve irrigation water management of rice fields because of its importance in food production and its huge water use. In recent years, China has pioneered some water-saving policies and WSI techniques for rice production, aiming at increasing water and land productivity.

Traditionally, rice is grown under continuously flooded conditions in rice fields except for a short period of sun-drying at the late stage of rice tillering for adequately meeting the water needs of rice and the efficient supply of nutrients to the crop[2] (Liang 1983). Many studies have indicated that since the middle of the 1980s, significant savings in quantities of water used in traditional rice culture were possible without distinct reduction in rice yield (Fang 1989; Li et al. *Experiment study,* 1994; Tripathi et al. 1986; Zhu 1981; Zhu and Gao 1987). Some WSI techniques have been adopted widely in China (Li 1999; Liu and He 1996; Liu 1998; Mao 1997; Peng et al. 1997; Wang 1992; Xu et al. 1990).

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[2]In China, sun-drying was widely adopted in the late 1960s, so here, the "traditional way" refers to the practice before the mid-1980s. On the other hand, sun-drying was not originally developed for saving water.

In China, the term "WSI" has been used widely for any measure that leads to reducing irrigation water or increasing irrigation water productivity without distinct reduction in crop yield. There are many research papers on WSI for rice and a lot of success stories about application of WSI techniques that result in water savings at the farm level (Li et al. 1998; Li 1999; Li and Cui 1996; Peng et al. 1997; Wang 1992; Wu 1998). However, literature in such research in English is lacking. Such a situation not only limits international colleagues' understanding of the practice but also affects Chinese scientists' ability to learn through feedback from the insights of others. The objective of this paper is to describe the formation of the WSI techniques and to summarize the experiences on the WSI for rice in China.

Background of Development of the WSI Techniques for Rice

The experiment and research of WSI started in China in the 1950s (Ding 1961; Li et al. 1964; Xu 1963). But the direct purpose of the research was to improve the illumination and heat conditions of the rice fields and to control the ineffective tillering of rice. The irrigation theory and technique for sun-drying rice fields at the late stage of rice tillering and drying the fields immediately at ripening were gradually perfected in the 1960s. This saved a lot of irrigation water (Liang 1983; Shen 1985). In the 1970s, double- or triple-cropping rice spread throughout China to increase the supply of the staple food. Some drylands were changed to rice fields. Subsequently, the water shortage became more serious in many regions. Moreover, the temperature was too low in spring and autumn to grow double-cropped rice in many places. Experiments were conducted aiming at utilizing the rainfall and regulating the thermal capacity of rice fields through irrigation and drainage measures. The "shallow with frequent irrigation" and "shallow irrigation and deep storage" techniques were recommended (Shen 1985; Zhu and Gao 1987).

The systematic research on WSI techniques for rice in China started around 1985 (Fang 1989; Zhu and Gao 1987). The impetus came from different aspects. Along with the great economic reform in China at the beginning of the 1980s, electricity and food were in short supply and water demand from industrial, domestic and hydropower generation users increased sharply.

In east China, the shortage in electricity was the most important factor to limit the economic development. Here, most electric pumps supplied water for rice culture. The consumption of energy by agriculture has a lower economic return but the central government should ensure the supply of energy for food security. Therefore, local governments sponsored irrigation and agricultural scientists to study WSI for saving energy.

The main task for agricultural development in the central part of China was to improve the low yield from rice fields with subsurface waterlogging and cold groundwater. The characteristics of these fields are poor soil aeration and low temperatures of water and soil. In the fields, the fertilizers are transformed slowly to efficient nutrients, and rice assimilates the nutrients with difficulty (Liang 1983). Combined with the engineering measures, such as building surface or subsurface drainage systems and rehabilitating irrigation systems to control the irrigation water diversion, and following successful experiments, the alternate wetting and drying (AWD) irrigation technique spread (Liu 1998; Zhu and Gao 1987).

In south China, developing cash crops in hilly areas was restricted because of the water shortage. WSI techniques for rice were researched and applied to save water for cash crops. In other regions, the water shortage was more serious. More research on WSI techniques was undertaken to reduce irrigation water use for rice (Li 1999; Liu 1998; Peng et al. 1997; Xu et al. 1990). As a result, a similar theory on WSI for rice was found from different motives; i.e., higher rice yields could be obtained without the need for continuously flooded irrigation, and the water content in the root zone of rice could be as low as 70 percent to 80 percent of saturated moisture (Li 1999; Li and Cui 1996; Li et al. *Experiment study,* 1994; Mao 1997; Peng et al. 1997; Wang 1992; Xu et al. 1990; Zhang et al. 1994).

In the beginning of the 1990s, the AWD irrigation practice for rice was promoted in most rice-growing areas of China. During the demonstration and implementation, the terms "shallow-wet-exposure," "intermittent submerged irrigation," and "thin-shallow-wet-exposure" were used in different Provinces of China for farmers to understand and remember the techniques easily. Remarkable benefits from real water saving were reported (Feng 1998; Li 1999; Liu and He 1996; Liu 1998; Mao 1997; Peng et al. 1997). Meanwhile, the central government attached great importance to agriculture and water saving, and some scientists engaged in WSI research were cited and awarded for their work. This encouraged more people to do research on WSI and more organizations to sponsor the WSI research.

The AWD irrigation technique for rice just concerned the on-farm level water saving but not the requirements for irrigation conveyance and labor input. In practice, some problems resulted from low irrigation duty and frequent irrigation applications. Because of this, the intermittent submerged irrigation (ISI) method for rice fields is promoted nowadays. This practice is the AWD, which allows rice fields to reach a very dry condition prior to receipt of further water and to store more water after rainfall. So the utilization of rainfall is facilitated, irrigation water management of the canal system is eased, irrigation events are reduced greatly and percolation and seepage losses from rice fields are reduced (Feng 1998; Li 1999; Li and He 1999; Wu 1998; Wu et al. 1995).

Theoretic Research of WSI for Rice

Policies and Conditions for the Research

The central government recognized the severity of the water shortage very early, and national conferences on WSI have been held quite often in recent years. Water saving has been one of the basic national policies and has been generally perceived to be a "revolutionary measure" for sustainable increases in the economy and agriculture in China (Feng 1998; Liu and He 1996; Zhang 1997). Both the Scientific and Technical Ministry and local governments were required to increase funds for sponsoring the research enthusiastically and organizing the application of advanced experiences energetically (Zhao 1997).

There are more than 500 stations for irrigation experiments in China and experimental research on WSI for rice has been the main work at more than 150 stations for many years. These stations do irrigation experiments with lysimeters and controlled plots collaborating with professional institutes or universities and then demonstrate the WSI practices to farmers at the field level.

Theoretic Research

The systematic research on WSI was started for drought-tolerant rice in Hubei and Anhui Provinces at the beginning of the 1980s (Fang 1989; Li 1999). The results could not bring to light the relationships between water input and the rice yield but indicated that a slight water stress did not reduce rice yields (Fang 1989; Li 1999; Zhu and Gao 1987). Since the 1990s, some advanced research projects have been sponsored by the Natural Scientific Foundation Committee of China and other organizations, and systematic achievements have been obtained. The main issues that have been addressed are as follows:

- *Impacts of WSI on the physiological mechanism of rice.* More attention was paid to comparing and analyzing the rice physiological indexes such as the root parameters, tiller, leaf area index (LAI), stomata behavior and yields with different water supplies (Fang 1989; Fang et al. 1996; Li 1999; Zhang et al. 1994).

- *Changing of the environmental conditions in rice fields with WSI.* The changes of soil aeration, temperatures, diseases, insect pests, cultures and population of weeds in rice fields with different water regimes were compared and analyzed (Li et al. *Experiment study,* 1994; Mao 1993; Zhang et al. 1994).

- *Rice evapotranspiration (ET) with different water supplies.* All experiment stations in rice-growing areas have been asked to do research on the changing patterns, influencing factors, estimation and forecasting of rice ET to meet the requirements for planning and design of irrigation projects, planning of developing water resources of basins, irrigation scheduling and irrigation water allocation.

- *Irrigation regimes for effective water and nutrient use by rice.* The field contrast experiments for approaching the optimum irrigation regime for effective water use by rice were started in many stations in the beginning of the 1980s (Li et al. *Experiment study,* 1994; Liu 1998; Peng et al. 1997; Wang 1992; Wu et al. 1995; Xu et al. 1990; Zhu and Gao 1987). From 1996, the research was combined with effective nitrogen (N), phosphorus (P) and potassium (K) use by rice, and the assimilation, transportation and escape of N, P and K in rice fields with different water regimes were addressed (Lu et al. 1997; Lu et al. 2000; Wu 1998).

- *Rice water-production functions (WPF) and the application.* Based on experimental data, WPF for different rice varieties (early, middle or late rice) and in different regions have been recommended, and the regularity of the variation of water sensitivity parameters in various models has been analyzed (Cui et al. 1998; Li 1999; Mao and Cui 1998). In some regions, the optimum irrigation regimes for rice fields were obtained in line with the WPF (Cui et al. 1995; Cui et al. 1997; Li 1999).

Findings

- Normally, it is necessary to keep shallow ponded water until the middle stage of rice tillering. Afterwards, AWD irrigation does not give negative impacts on the growth of rice if the water content in the root zone is not lower than 80 percent of the saturated moisture (Li 1999; Li et al. *Experiment study,* 1994; Zhang et al. 1994). Sometimes, there is an advantage in getting bumper crops with the well-developed rice roots resulting from the oxidized conditions and bigger area of upper rice leaves resulting, in turn, from an "overshoot" of growth after slight water stress in a short period (Fang et al. 1996; Li 1999; Lu et al. 1997; Wang 1992; Zhang et al. 1994).

- Some weeds grew well under continuously submerged conditions but others emerged when there was no deep-ponded water layer. Neither continuously flooding nor long-time drying controlled weeds effectively. The alternate flooding and drying was good for weed control in rice fields.

- ET is mainly affected by climatic factors and, to some extent, is controlled by physiological functions of rice under submerged conditions. However, the physiological characters of rice are considerably different before, during and after water stress. ET is lower than normal treatments during the period of stress and for several days following re-watering because of both a lower LAI and a leaf stomatal resistance, but ET will surpass that of continuous submerged treatments in later periods because of the "overshoot" (Li and Cui 1996). Therefore, the contribution of rice plant to ET should be considered separately before, during and after water stress when estimating ET with the Penman-Monteith method. The effects of soil factor should be considered according to the soil-moisture content of rice fields as well (Li 1999; Li and Cui 1996; Li et al. *Patterns and affected factors* 1994; Li et al. 1995).

- The AWD increases available nitrogen and phosphorus remarkably. Especially, the nitrogen nutrient could be transferred to the rice plant-growth center under AWD conditions in light of the experiments, and the nitrogen content in an ear of rice with AWD practice was always much higher than that under continuously flooded conditions. On the other hand, the uptake efficiency of potassium by rice might be lower with AWD practice (Lu et al. 1997; Lu et al. 2000; Wu 1998).

- The Jensen model is the applicable model of WPF for rice in China (Mao and Cui 1998). For early rice and middle rice, the water sensitivity index in the Jensen model always reaches the highest value at the growth stage of heading and flowering. For late rice, it reaches the highest value at the growth stage of elongating and booting (Cui et al. 1998; Li 1999; Mao and Cui 1998).

- In general, serious water stress during the tillering stage leads to the reduction of the panicle number but results in an increase of filled grain number and the weight of thousand-grain. Both the panicle number and filled grain number are slightly decreased if water is short in the booting stage. The filled grain number will be evidently reduced if rice suffers serious drought during the heading and flowering stage. The degree of drought stage when rice suffers water stress and the duration all give expression to the rice yields, and the reduction of rice yield is most sensitive to the duration of the drought (Li 1999; Zhang et al. 1994).

Application of WSI Techniques

Policies

A series of policies has been drawn up, such as Water Law, Water Resources Protection Law, Water Charge Rules, etc. "Pursuing WSI and taking shape a water-saving society" is one of the national basic policies, which is the highest law in China. Water shortage is not only the key problem in economic development but also one of the most important political topics. Professional or regional conferences on WSI are held often. The central government asked that WSI should be promoted as a revolutionary approach and the governor of province or county should be responsible for building advanced agriculture. The achievement in developing the sustainable agriculture and lightening the burden on farmers is one of the most important indexes for checking on cadres on different levels, which spurs leaders on to bring into line the benefits of farmer, irrigation agency, region and the state.

From 1980, irrigation agencies were asked to support themselves financially except for the infrastructure construction. The reform of water charge provided a basis for irrigation agencies to change the water allocation policy. Under the macroscopic control of the state, the provincial governments issued the water charge policies about rates and collection. The water rates for agriculture, industry, municipal and hydropower are quite different, and of these, the water rate for irrigation is the lowest. But irrigation claims first priority if water is lacking. Irrigation water is charged mainly based on the volume of water used.

Spreading of WSI Techniques

According to the Irrigation Experiment Rule in China, the research on WSI techniques should be carried out with more than 3 years of plot experiments, and then be demonstrated in typical fields. What has been applied successfully in trial rice fields will be spread in orderly fashion. First, policies for water saving and advantages for adopting WSI practice are propagandized widely via various media. Second, training courses and guidelines are given to heads of farmer groups and some farmers. Third, technicians direct farmers in rice fields. In addition, in some regions, such as the Guangxi Province, the responsibility records for spreading WSI techniques are signed level by level from province to village.

Incentives

After the reform of water charge, irrigation agencies have to improve management of irrigation water in order to transfer more water from agriculture to other purposes and increase the benefits from the same water quantity. They have incentive to do research on WSI techniques and help farmers to adopt WSI practices enthusiastically. Although farmers would pay less water fee if they use less water, this is often more than compensated by higher paying cities and industries. In humid areas, farmers believe WSI practices lead to higher rice yields because the aeration in rice fields is improved. In some regions, because the irrigation interval is longer and irrigation events are less, farmers are able to work a longer time in cities when they adopt the AWD technique for rice. Another reason for farmers to welcome WSI is that the application of WSI practices need a sound irrigation system and reliable water supply. Therefore, in areas practicing WSI, the central government and irrigation agencies will pay more attention to the modernization of irrigation systems.

Improvement of Irrigation Systems

On the one hand, there is a huge budget from the central government for the modernization of irrigation systems aiming at increasing water efficiency or water productivity and, on the other, irrigation agencies have the financial capacity for perfecting the irrigation system, especially the distribution systems, and strengthening the maintenance and operation after the reform of water charge. This is because they are able to transfer the savings from irrigation to more beneficial sectors. The "melons-on-the vine" irrigation system with functions of "big, medium, small; storing, diversion and lifting" is built, and the reliability of irrigation water supply is improved.

Combined with other measures, such as regulation of the cropping pattern, recycling of water, canal lining and introduction of small tanks to catch return flows, good results from the application of WSI techniques have been achieved. WSI techniques have been applied in more than 3.5 million hectares of rice fields, and the impacts of WSI on economic and agricultural development are profound (Feng 1998; Li et al. 1998; Liu and He 1996; Zhang 1997; Zhao 1997). Many reports in China (Li 1999; Liu and He 1996; Peng et al. 1997; Wu 1998) claim that the WSI techniques could increase on-farm water productivity by 20 percent to 35 percent compared with the traditional irrigation practices.

Conclusion

Gigantic efforts have been made for the research and practice of WSI for rice, and considerable benefit has been obtained in China. The WSI has struck root in the hearts of the people, which leads to a sound environment for both research and practice of the WSI techniques. However, there remain many scientific issues that have not been addressed. Research on efficient water use at system level or basin level is lacking. Real water savings at the system level cannot be quantified, and there is no systematic theory for modernization of irrigation systems. The field experiment is the weak link in China. Funds for experiments and demonstrations are always short, and the number of scientific research workers engaged in the fieldwork are not enough. In addition, the application of WSI techniques in some regions is still very difficult because of both physical and institutional problems. But farmers should never bear the responsibility for non-adoption of the WSI practices. Some irrigation agencies are not able to transfer water to domestic and industrial water users and are thus not interested in the application of WSI techniques. Therefore, scientific, policy and institutional issues related to the WSI practices are all important and increasing attention should be paid to them in the coming years. The cooperation of water and agricultural scientists is needed in the research and practice of WSI techniques. Technical support from international institutions is necessary.

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