A Review of Researches on Efficient Agricultural Water Use in China

CUI Yuanlai & HUANG Jiesheng

State Key Laboratory of Water Resources and Hydropower Engineering Sciences, Wuhan University, Wuhan, Hubei 430072, China

1. Introduction

China is a large agricultural country. According to statistics in 2009, the amount of agricultural irrigation water use accounted for about 62% of the total water consumption of the national economy. With increasing population and fast growing food demand in the future, irrigated areas will be further expanded, yet the total agricultural water use will not increase or will continue to fall. It is estimated that the national irrigation efficiency in 2009 was about 49.3%, which is very lower than the irrigation efficiency of developed countries. As a result, China has the huge potential for agricultural water saving. Based on the *National Planning of Water-saving Irrigation*, China's irrigation efficiency will be raised to over 55% by 2020. It is forecast that, by 2020, China's population will reach 1.4 billion and there will be a food shortage of 45 million tons. In 2009, China put forward the goal that "the country's grain production capacity will be improved by 50 million tons". Therefore, sequel and auxiliary construction and infrastructure improvement to increase water use efficiency for irrigation scheme as well as research and extension of water-saving irrigation technology with water saving and grain increasing as the core will be a strategic task for China in the long run. The research and extension of the theory and technology of efficient agricultural water use is of great significance to ensure China's food and water security.

Since the 1980s, China has made prominent contributions to the research and extension of the theory and technologies of efficient agricultural water use, including major crops' variation of evapotranspiration and the calculation method under the circumstances of sufficient or deficit irrigation, theory of spatial variability of evapotranspiration, crop water production function and its temporal and spatial variability theory, the movement regulation and control mechanisms of water and fertilizer under the condition of water saving irrigation, theory of efficient use of irrigation water at different scales, models

CUI Yuanlai, professor in irrigation and drainage at Wuhan University. His areas of expertise are water saving irrigation principles and techniques, optimization of irrigation and drainage system, and optimum management of water resources. Prof. Cui has published more than 200 papers and 5 books. He is a winner of the Second Award of National Science & Technology Progress in 1996.
E-mail: cuiyuanlai@263.net

and schedules of water saving irrigation, methods and technologies of water saving surface irrigation, theory and technologies of sprinkle irrigation and micro irrigation, models and methods of optimal distribution of irrigation water at different stages of the same crop, of different crops and of different regions under a limited water supply, *etc*.

2. Progress of researches on agricultural water use

2.1 Variation regulation of evapotranspiration and its calculation method in the condition of water saving irrigation

Crop evapotranspiration (ET) is the major water consumption in farmland, its variation regulation and estimation method have remained one of the most important research in the field of irrigation and drainage. The research of crop ET and its variation regulation under insufficient water in farmland is the basis for water saving irrigation. Over the past 20 years, China's scholars have used various methods such as lysimeter plot and farm land to carry out systematic observation of ET experiments, targeting at the major grain crops in different regions as rice, corn, wheat, cotton, *etc*. They have already ascertained the variation regulation and reasons of ET at different time scales (hour, day by day, ten days, growth stage, whole growth period, inter-annual period) in the conditions of sufficient and deficit irrigation (including different levels of drought tolerance, drought tolerance at different times and different combinations of drought tolerance conditions) (Li Y.H *et al*, 2003; Kang S.Z *et al*, 2009). In addition, they have also systematically analyzed the major factors influencing crop ET as well as how these factors have influenced ET, including meteorological, soil and crop factors (Li Y H. *et al*, 2003).

Based on the measured values of crop ET of the same species at different spatial points and the spatial variations of the major factors influencing ET (weather, soil, crops), they have worked out the spatial variation regulation of reference crop ET and major crop ET (Wang J.L. *et al*, 2004). The isogram of Chinese reference crop and major crop ET have been drawn (Chen Y.M. *et al*, 1995).

The analysis of the adaptability of the calculation methods of different reference crop evapotranspiration (ET0) demonstrated that the Penman-Montieth equation is adaptive to most parts of China (Liu Y. *et al*, 1997; Wang X.H. *et al*, 2006). The Penman-Montieth equation has been applied to the calculation of ET0 and the analysis of spatial and temporal variation regulations. Meanwhile, scholars have proposed appropriate ET0 calculation and analysis methods with less weather data, and have established forecasting model and methods on the basis of a small amount of forecast of meteorological factors (Cui Y.L. *et al*, 2005; Luo Y.F. *et al*, 2005; Cai J.B. *et al*, 2005).

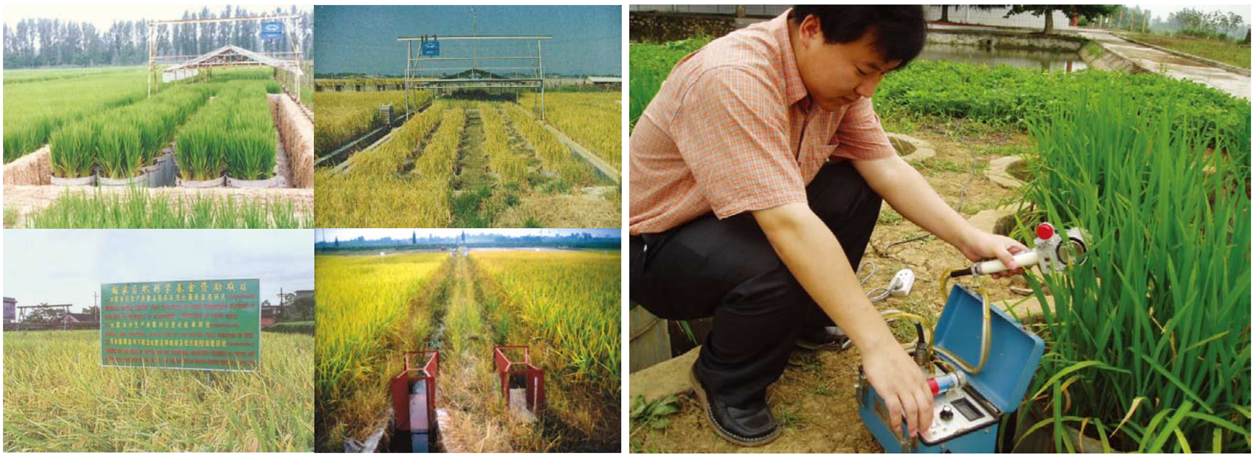
The calculation method of crop coefficient and soil water stress coefficient has been brought out under the condition of deficit irrigation (Li Y. H.*et al*, 2003; Kang S.Z. *et al*, 2009). In light of it, the theory and method of calculation and forecast of ET0 under the condition of deficit irrigation has also been formulated (Li Y.H. *et al*, 2003; Peng S.Z. *et al*, 2009). The research of variation regulation and forecasting model of economic crop ET has been initiated under the conditions of sufficient and deficit irrigation (Dong B. *et al*, 2009; Ge J.K. *et al*, 2009).

2.2 Theories and technologies of deficit irrigation

Some scholars have studied the regulations and mechanisms of how different water stresses have influenced the physiological activity of crops and the yields (Li Y.H. *et al*, 2003; Kang S.Z. *et al*, 2009). The indicator and model of regulated deficit irrigation and relevant techniques (such as interval furrow alternate irrigation technique, micro irrigation technique) as well as the irrigation schedule of major crops in the condition of deficit irrigation have been created (Kang S.Z. *et al*, 2009).

2.3 Crop water production function and its temporal and spatial variation regulation

Since crop water production function reveals how crop yield varies with the water variation, it has served as the basis for scientific water saving irrigation. As a matter of fact, crop water production function has always been the research focus. Since the early 1980s, Chinese scholars have been working on the crop water production function models suitable to the local conditions with the targets of major upland crops as wheat, corn and cotton (Mao Z. *et al*, 2003). Since the 1990s, Wuhan University has conducted specific field experiments of crop water production function of northern middle season rice, southern early rice and late rice and central middle season rice in Tangshan



Researchers conducting experiments for rice water saving irrigation.

City of Hebei Province, Guilin City of the Guangxi Zhuang Autonomous Region, Jinmen City of Hubei Province and have thus proposed the crop water production function suitable to major rice strains in China's different regions, which has filled the gap in this area both at home and abroad (Mao Z. *et al*, 2003).

As for the temporal and spatial regulation of rice water production function, the concept has been introduced that rice water production function varies regularly with the weather and soil conditions, which leads to the establishment of relevant model and the formulation of theory and methods concerning the interpolation and extension of water production function in different hydrological years and in different regions. The principles and methods of formulating the isogram of rice water production function have been worked out and for the first time, provincial or autonomous regional isograms of rice water production function have been worked out and applied to guide production (Cui Y.L. *et al*, 2002; Mao Z. *et al*, 2003).

2.4 Couple of water and fertilizer and its regulating theory and technologies

The movement regulation and control mechanism of water and fertilizer under the condition of water saving irrigation have been investigated with rice and wheat as major targets (Liu J.S. *et al*, 2008; Yang J.C. *et al*, 1996). Since 1997, Wuhan University has cooperated with Huzhong University of Agriculture to conduct systematic experiments concerning the movement regulation of water and fertilizer and the mechanism and technology of efficient use of water and fertilizer under the conditions of water saving irrigation (Cui Y.L.*et al*, 2004; Li Y.H. *et al*, 2009). A series of achievements have been made in figuring out how rice has absorbed nitrogen (phosphorus, potassium) and the transformation and movement regulation of fertilizer nutrient in rice paddies under the condition of water saving irrigation, biological characteristics, yields and components of rice under different water and fertilizer management as well as the interactive effect of water and fertilizer and the optimal management model of water and fertilizer management. In particular, scholars have proposed the optimal management model of water and fertilizer concerning the main rice strains in major rice growing areas. At the same time, such management model of water and fertilizer have been widely extended in provinces like Hubei, Guangxi, Zhejiang, Jiangxi and so on, producing economic, social and environmental benefits.

In recent years, it has been a research hotspot as how to reduce non-point pollution of nitrogen and phosphorus through integrated management of water and fertilizer. The researches carried out by Wuhan University and Hohai University all suggest that the emission of nitrogen and

Research is carried out on rice growing under different water and fertilizer treatments.

phosphorus as well as COD loss could be significantly cut though the water saving irrigation combined with rational fertilization (Cui Y.L. *et al*, 2010; Peng S.Z. *et al*, 2009).

2.5 Methods and technologies of water saving surface irrigation

The last several years have witnessed the wide application of some advanced surface irrigation technologies of upland crops, such as improved furrow irrigation, border irrigation, surge flow irrigation, level border irrigation and drip irrigation under ground membrane(Qian Y.B. *et al*, 2002).

The research of rice water saving irrigation in China started in the early 1970s, with a major focus on the changing from traditional deep water irrigation to shallow irrigation. More than ten rice water saving irrigation models have been raised, including alternate wetting and drying irrigation, thin-shallow-wet-dry irrigation, controlled irrigation, thin-exposure irrigation and semi-dry cultivation etc. In the late 1990s, in addition to improving water use efficiency, studies have also been carried out in light of coupling of water and fertilizer for rice in combination with fertilizer and water saving. China has been in the leading position in the research of water saving irrigation for rice around the world and has exerted great international influence. Professor MAO Zhi of Wuhan University has thus won the second prize of the State Science and Technology Progress Award and the International WatSave Awards issued by International Committee on Irrigation and Drainage (ICID). Wuhan University has conducted several researches on water saving irrigation for rice in cooperation with a number of international research institutes such as International Rice Research Institute (IRRI), International Water Management Institute (IWMI), Commonwealth Scientific and Industrial Research Organization (CSIRO), and Australian Centre of International Agricultural Research (ACIAR).

2.6 Theory, technology and equipment of sprinkler and micro irrigation

Through the innovation of technologies and materials, great progress has been made in the sprinkler irrigation and micro irrigation techniques concerning investment costs, energy saving irrigation, water distribution uniformity and counter clogging capacity. Drip irrigation under ground membrane has been extended in large scale in Xinjiang. The research of subsurface drip irrigation has also gained significant progress (Qian Y.B. *et. al*, 2002).

International cooperation and exchanges have been conducted in the stuides of agricultural water use.

The research of sprinkler irrigation and micro irrigation is developing toward the goal of multi-objective utilization and operation and management automation. The new tendencies of the development of micro irrigation equipment are as follows: the new irrigator of improved counter clogging and pressure compensation capacity with a reduced cost, easily operated fertilizer injector with well mixed fertilizer and adjustable concentration, highly effective self-cleansing filtration system with low cost and high performance. Special platform has been developed to manufacture micro irrigation equipment featured with high precision and rapid prototyping, with the main focus on high precision, rapidity and the production of functional metal pieces. Currently, China is weak in the theory of designing sprinkler irrigation and micro irrigation. The hydraulics of micro flow channel and its description as well as numerical simulation techniques need further research so as to provide a theoretical basis for the design of irrigator.

In the field of water conveyance and allocation, the new type of canal seepage control and lining techniques as well as low pressure pipe techniques have been developed and extended to improve the water utility efficiency in the process of water conveyance and allocation.

2.7 Optimal distribution of water and land resources in irrigation districts under the condition of deficit water

One of the key issues in the optimal distribution of irrigation water under the condition of deficit irrigation is to work out the optimal distribution of limited water at different stages of the crop in accordance with the water production function to ensure maximum increase of crop production. Therefore, optimal irrigation schedule under the condition of deficit irrigation has become a research hotspot. Based on crop water production function and its temporal and spatial variation regulation, and by using systematic analysis, Wuhan University has proposed serial model and method of optimal distribution of water and land resources in irrigation districts under the condition of deficit water, which can systematically work out the optimal distribution of irrigation water in different regions, different crops in the same region, different growing stages of the same crop under the condition of deficit water and the optimal layout of different crops in different region adapted to the relevant water conditions so as to maximize the economic efficiency generated from water and land resources (Li Y. H, 2003).

2.8 Research of a decision support system of water use management combining crop water demand monitoring, real-time irrigation forecasting and dynamic water allocation channel

With the extensive application of hi-tech and the implementation of informationization in irrigation districts, efficient crop water use turns from static water use to dynamic water use. Modern information technologies have been developed and used to monitor soil moisture status, crop drought and agricultural weather data, which serve to forecast irrigation water demand for crops and to determine optimal water distribution and controlling in line with optimization principles. Decision support system of water use management has been developed, featured with a combination of dynamic monitoring of water demand, irrigation forecasting, dynamic water distribution, real-time irrigation decision-making of allocation and real-time controlling of buildings used for water conveyance and allocation.

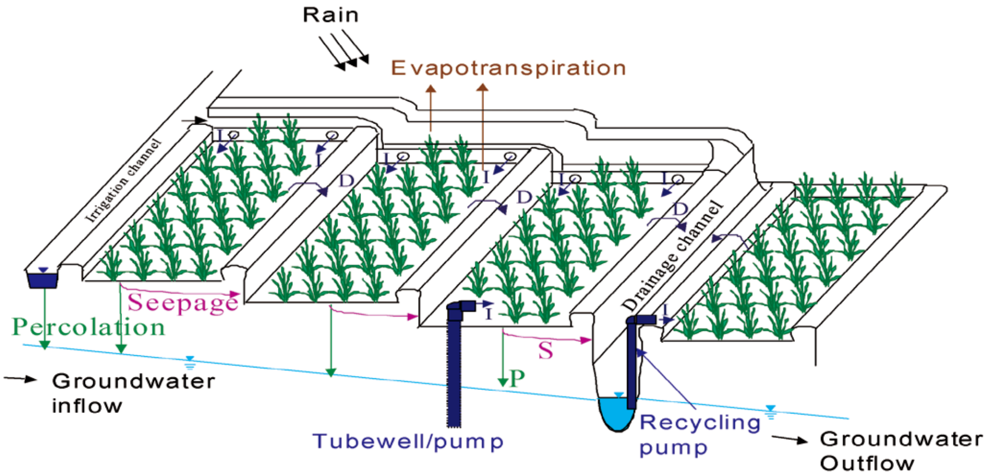
2.9 Agricultural water use efficiency at different scales

In field scale, the main research focus is on the management and controlling technologies of water demand for crops and field irrigation to fully use the water diverted to the field and to improve efficiency field water use.

As for the irrigation district scale, the research lies mainly in the following four aspects. Firstly, the water cycle model and mechanisms of irrigation districts; the combination of micro cycle at field scale and macro cycle at irrigation district scale; the cycling and conversion among atmospheric water, soil water, ground water, irrigation district surface water. Second, how to evaluate the irrigation water use efficiency in irrigation districts; different layouts of canals have been proposed in light of different canal classification; the impact of irrigation return flow on irrigation water use efficiency and relevant correction method; head-end measurement method and integrated measurement analysis have been worked out and applied to evaluate the irrigation water use efficiency at irrigation system, provincial and national scales. The scale transformation method of irrigation water use efficiency at irrigation district level is also under study (Li Y.H. *et. al*, 2009). Third, the influence of water saving irrigation districts on local economic and ecological system. Fourth, water saving potential and water saving standards of irrigation districts; a combination of prediction of rational water demand in irrigation districts, water resources management, water cycle, water saving project, the analysis of project efficiency and ecological efficiency under the management measures, and the efficiency assessment with the consumption of water resources as its core.

At the regional scale, full consideration has been given to the recycling of water resources. Macro-level studies have been conducted to work on the highly efficient use of water resources with the consideration of water use in regions or sectors. The research on water cycle has changed from the initial pilot study of single crop to field research of specific farmland/small areas, to irrigation districts/partial irrigation districts and the distributed hydrological model research of basin/region.

In the late 1990s, Wuhan University, for the first time, raised the question of scale effect of water saving irrigation and conducted systematic field observations and theoretical researches on the influence of different scales used in water saving irrigation technologies as well as the water conversion regulations at different scales. Thus, based on the scale effect of water saving irrigation and features of water cycles of irrigation districts, water saving irrigation strategies at different scales and in different types of irrigation districts have been proposed (Li Y.H. *et al*, 2009). And distributed hydrological models suitable for irrigation districts have been developed (Dai J.F. *et al*, 2009; Xie X.H. *et al*, 2011).



Water balance and recycling in rice irrigated area.

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