Improving agricultural water productivity to ensure food security in China under changing environment: From research to practice

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ABSTRACT

Irrigation is an important measure for increasing grain production. Improving water use efficiency in agriculture is expected to play a very important role in ensuring food and water security in China, since there is a serious problem between food supply and limited water resources in China. The present state and future trend of water and food security in China were analyzed, while the importance of irrigation in ensuring China food security was highlighted based on the analysis of the evolution of irrigation water productivity in recent 60 years and its relationships with changes of crop yield, cropping pattern, fertilization and irrigation water use. Research progresses and practical application on high-efficient agricultural water use in China were introduced, and two successful cases of improving agricultural water productivity in China were presented, one was to improve crop water use efficiency by the novel irrigation method based on crop physiological responses, and the other was to improve the regional water productivity by the integrative methods in the Shiyang River Basin of Northwest China. The major research areas needed to focus on in the future were discussed, which include responses of crop water demand to changing environment and associated spatio-temporal optimization of water allocation, multi-processes hydrologic cycle of irrigated land under strong influences of human activities, integrated measures for improving multi-scale agricultural water use efficiency, and interactions between grain production, water resources and ecological system and its sustainability analysis in a systematic way.

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1. Introduction

Increases in greenhouses gas concentrations have resulted in the increases in globally-averaged mean annual air temperature and variations in regional precipitation and these changes are expected to continue and intensify in the future (Solomon et al., 2007). Climate change poses serious threats to global food security due to changes in water supply and demand by altering the spatial and temporal distribution of rainfall, the availability of water, and other agricultural production factors (Alcamo et al., 2007; Hanjra and Qureshi, 2010). Sustainable use of water resources and food security are essential for ensuring sustainable social and economic development. Worsening resources and climate crises, water and soil resources scarcity, and extreme weather events such as severe drought and flooding have been affecting global agricultural production in a negative way (Turrall et al., 2001). Ensuring food security has become the most important challenge the human society has ever faced.

Water security is the basis for food security. Water resource scarcity will lead to the variable grain production, which is considered as the source of real food crisis. Water management is the key to ensuring that more food can be produced for the growing population. “There is no food security without water security,” said José Graziano da Silva, Director-General, Food and Agriculture Organization of the United Nations. (Bertilsson, 2012). Agriculture is the sector responsible for most water use, consuming 70% of total water use in the world. Therefore, improving agricultural water productivity is an important measure for ensuring global water safety and food security. Rosegrant and Cline (2003) stated in an article published in Science that “Although the economic and environmental costs of irrigation make many investment unprofitable, much could be achieved by water conservation and increased efficiency in existing systems and by increased crop productivity per unit of water used”. Norman Borlaug said in 2000, “how can we continue to expand food production for a growing world population within the parameters of likely water availability? The inevitable conclu-
sion is that humankind in the 21st century will need to bring about a ‘Blue Revolution—more crop for every drop’ to complement the so-called ‘Green Revolution’ of the 20th Century. Water productivity must be wedded to land use productivity. Science and technology will be called upon to show the way (Borlaug and Dowswell, 2000).

Irrigation water productivity (IWP), defined as the production per irrigation water amount (Molden, 1997), reflects the relationship between irrigating input and output, i.e. how much value is being obtained from irrigation water, and could be used as a useful indicator for assessing irrigation and crop management level (Zoel, 2006). Improvement in IWP can reflect the comprehensive improvement in crop production and irrigation water use efficiency. Therefore, how to reduce the irrigation water use while maintaining or even increasing agricultural production with available irrigation water is essential for improving irrigation water productivity.

At present, agriculture in China encounters immense challenges. How to secure supply of agricultural products and improve the sustainability of agricultural development under the constraints of limited resources and environmental sustainability is the most important challenge that has to be overcome. Water is a vital factor in agricultural production, and water shortage has seriously affected China’s agricultural production (Brown and Halweil, 1998; Oweis and Hachum, 2003). Owing to extensive use of irrigation, China is able to feed 21% of world population with only 6% of world freshwater resource and 9% of arable land. However, there is severe water shortage in China, with annual average water resource of 2100 m³ per capita (28% of world average), and 21,000 m³ ha⁻¹ area (about 50% of world average). Water shortage is one prominent factor shaping the food security picture of China. The total water use in China was 618.34 billion m³ in 2013, in which 63.4%, i.e. 392.03 billion m³ was used by agriculture. To make things worse, irrigation water delivery efficiency in China is only 52%, far lower than that in the developed countries of 70–80%. To mitigate the water shortage problem, there is a great need to reduce irrigation water use. However, simply reducing irrigation water without diligent planning will lead to the reduction in local agricultural production, thus pose great risk to national food security. Consequently, how to improve irrigation water productivity becomes the key factor that strikes the balance between alleviating water shortage and maintaining high and stable agricultural production.

To solve the current water crisis and ensure agricultural sustainable development and food security in China, it is essential to (1) identify the key issues related to highly-efficient water utilization in agriculture (2) understand the mechanisms of water transformation and consumption in grain production at different scales, and (3) improve water use efficiency through scientific and technological advancements and management reform. Therefore, this paper has four main objectives; (1) to analyze the present state and future trend of water and food security in China (2) to analyze the evolution of irrigation water productivity in recent 60 years and its relationships with changes of crop yield, cropping pattern, fertilization and irrigation water use in China, and to demonstrate the importance of irrigation in ensuring China food security (3) to present the research progresses and practical experience on improving agricultural water use efficiency in China, and (4) to discuss the major research areas that need further study for improving agricultural water productivity in the future.

2. The state of water and food security under changing environment in China

Water security state is closely linked to sustainable development of human economic society and ecosystem. Rapidly increasing water consumption, worsening water pollution and excessive extraction of water resources due to competition of different sectors aggravated the water shortage problem and deteriorated water ecosystem around the world, threatening the development of social economy and human well-being (UNESCO, 2006). Ever-diminishing water supply poses great risks to national security, economic development and social stability and adversely affects human health, energy reserve, and food supply across the globe (UNESCO, 2012).

The normal annual total water resource of China is about 2840.5 billion m³, the sixth highest of the world. However, average water resource per capita is less than one-third of the world average. Moreover, there is mismatch spatially between water resources and other social resources. For example, about 64% of total land area, 46% of cultivated land area, and 60% of population are in the northern part of China, where there is only 19% of total water resource of China. Groundwater in the Northern China Plain has been severely over-extracted. As a result, there are more than 160 regions with groundwater over-extracted for many years. Also groundwater depth in the Northern China Plain has declined from 10 m in 1970s to 32 m in 2001, and continues to decline annually at the rate of 1 m (Hu et al., 2010). Climate change has great impacts on water resources of China (Piao et al., 2010). Relative to the period of 1956–2000, surface water and total water resources

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