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# Modelling analysis of water-use efficiency of maize in Heihe River Basin

Guofeng Wang [a], Jiancheng Chen [a,*], Qing Zhou [b,c,d], Xi Chu [e], Xiaoxue Zhou [a]

[a] School of Economics and Management, Beijing Forestry University, Beijing 100083, China
[b] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[c] Center for Chinese Agricultural Policy, Chinese Academy of Sciences, Beijing 100101, China
[d] University of Chinese Academy of Sciences, Beijing 100049, China
[e] Faculty of Resources and Environment Science, Hubei University, Wuhan 430062, China

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ABSTRACT

Water, as an important resource in ecosystem, greatly influence human life. Increasing water use efficiency will save water resources, thus will lead to better ecosystem. Agricultural water resources are important production materials that will impinge the long-term agriculture development potential, while water use efficiency (WUE) is a key factor closely linked to agricultural production. In this study targeted at Heihe Agriculture Zone, we used a stochastic frontier production function to study agricultural production efficiency and WUE.

In particular, the effects of planting areas on farmers' WUE were investigated. The result show current farmers' WUE of Maize is 0.67 on average, which still can be improved largely. The farmers' planting scales largely affect WUE of Maize. The farmers with planting scales of 0–0.3 ha and over 1.3 ha paid high attention to WUE. The optimal planting scale of water use efficiency of maize is around 3.3 ha. This study provides a scientific basis for the water resource use in arid and semiarid regions



## 1. Introduction

Hydrological ecosystem is a system will be provided by water. Thus water use efficiency and water productivity is highly related to hydrological ecosystem (Terrado et al., 2014). The *Outline of National Agricultural Water Conservation Program (2012–2020)* issued in 2012 sets a top-level design for promotion of water-saving irrigation and development of agricultural water conservation (Tromboni et al., 2014; Yang and Liu, 2014). Along with the release of state-level and regional policies/measures and the gradual increment of investments, China has entered an unprecedented rapid orbit of water-saving irrigation development (Yan et al., 2014; Zhang et al., 2014). In recent years, the promotion of water conservation has been accelerated, with achievements including the construction of 100 state-level pilot water-saving social construction sites, and the release of 27 national standards on water quota and water-saving techniques (Liu et al., 2014; Shi et al., 2014). All these achievements would accelerate the promotion of agricultural water-saving irrigation (Qiu et al., 2015). For instance, the water consumption at the added-value level of ten thousand yuan nationwide was 59.5 $m^3$, with a drop of 31.9% from 2010, while the water use efficiency (WUE) coefficient of farmland irrigation was improved from 0.5 in 2010 to 0.531 in 2014 (Xue et al., 2015). During the 13th 5-Year Plan, China will earnestly promote the policy of “water conservation first”. The specific measures include: regional large-scale efficient water-saving irrigation (e.g. water conservation and grain production increment in Northeast China, water conservation and efficiency improvement in Northwest China, water conservation and groundwater extraction inhibition in North China, water conservation and emission reduction in South China; promotion of industrial water recycling (Jiang et al., 2014; Sun et al., 2013; Wang, 2013). Located in Northwest China, Gansu Province, connects Loess Plateau, Qinghai-Tibetan Plateau and Inner-Mongolia Plateau (Li et al., 2015). Its 353,700 $km^2$ covers 14 prefecture-level administrative regions, with 86 county-level administrative regions. In 2014, the total GDP was 106.83 billion US dollar, of which, 13.74% (14.67 billion US dollar) was the added values from the agriculture, forestry, husbandry and fishing. The climate in Gansu varies geographically and the eco-environment is

* Corresponding author.
*E-mail addresses:* wanggf_simlab@163.com (G. Wang), Chenjc_bjfu@hotmail.com, chenjc1963@163.com (J. Chen), chux_simlab@163.com (X. Chu).

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complex and diverse. The annual precipitation there changes spatially, as it gradually drops from southeast to northwest, and ranges from 36.6 to 734.9 mm, indicating the typical temperate monsoonal climate. The total grain yield of Gansu in 2015 was 11.71 million tons, including 2.75, 5.65 and 2.39 million tons of wheat, maize and potatoes, respectively, which contributed to 1.88% of agricultural production in China. Heihe River Basin in Gansu is a major production base of maize seed. In 2014, the area of maize seed base was 0.07 million ha and the maize seed yield was 0.478 billion kg, accounting for 42% of state-level total maize planting area and 48% of state-level total maize yield, respectively. A major part of water resource consumption in Heihe agriculture zone is due to agricultural use (Qin et al., 2013). Thus, how to improve WUE is a critical issue that affects Heihe sustainability and guarantees the agriculture security.

The greatest challenge of agriculture production is to produce more food for humans, but this process may be affected by various factors (Deng et al., 2015; Huang et al., 2015). Agricultural water resources are a key factor that limits agricultural development. Along with the accelerated urbanization in China, especially the increment of ratio of industrial water to ecological water, the challenges and constraints encountered by agricultural water resources necessitate the further improvement of WUE (Sun et al., 2013; Wang, 2011). Agricultural WUE is also a research hotspot, but the computations of WUE largely differ among researchers (Song et al., 2015; Taylor, 2015; Wu et al., 2012). WUE, as an indicator of water resource input-output, is generally expressed as follows:

$$WUE = \frac{Y}{ET} \quad (1)$$

where, Y is the actual crop yield (kg/ha) and ET is the actual crop water consumption due to evapotranspiration ($m^3$/ha). This method can efficiently portray the amount of agricultural products per unit of water resource. It is mainly applied into agriculture, meteorology, ecology and hydrology (Dixon et al., 2011). The WUE deduced from this method can only discriminate the productivity evaluations of single factors, but cannot differentiate the relationships between different elements in the whole process (Kummu et al., 2010). Regarding this, some researchers adopted the WUE with economic meaning (Chirinko et al., 2011). This concept describes the difference between the real low-efficiency allocation state and the ideal high − efficiency allocation state of water resources, and reflects the maximum expansive degree under the rated output level or the rated input level. It is the ratio of effective input to real input, or the ratio of real output to effective output. Measure of agricultural WUE has already been studied (Sangare et al., 2012). WUE levels differ along with the irrigation status, management status or technical level. Agricultural WUEs largely differ among nations (Li et al., 2012). Agricultural WUEs in 2014 were as follows: Israel (87%), Australia (80%), France (73%), USA (54%), Egypt (57%), and India (44%). Clearly, agricultural WUE is not directly related with developed level, but is related with the attitude of local governments toward water resources (Tromboni et al., 2014). The analysis of WUEs in 30 provinces of China shows that WUEs are lowest in Central China, highest in East China, and are related with per capita income in an inverted-U way (Kuslu et al., 2014). The differences of WUE are mainly attributed to the differences of economic development levels. Other studies on China's 31 provinces show that agricultural WUEs in economically developed areas are high, and the proportion of agricultural water use in total water consumption, and the WUE per 10 thousand US dollar, are both positively correlated with WUE (Waraich et al., 2011). Agricultural WUE is slightly higher in South China versus North China. Moreover, agricultural WUE gradually drops from North to South China, mainly owing to the regional resource endowment (Onishi et al., 2009).

Agricultural WUE calculate using stochastic frontier analysis is also a hot spot (Tonini, 2012). Also, researchers propose an alternative measure of irrigation water efficiency based on concept of water use efficiency (Karagiannis et al., 2003). Agricultural WUE in Heihe River Basin has also been studied. From the perspective of farmers, the agricultural WUE in 2006 was studied. It was found the average farmers' WUE was only 0.3208, since all the investigated farmers wasted 68% of water. The WUEs largely differed among farmers. Clearly, the maximum farmer-level WUE was 89.67%, and the minimum was 5.21%, with a difference of 16.21 times (Singh, 2007). In this study, based on previous research, we measured the WUE of maize in the Heihe agricultural zone, aiming to provide scientific support for water resource conservation.

## 2. Study area

Heihe River is the second largest inland river in Northwest China. It is located in an important place on the ancient Silk Road and Central Eurasia. The upstream of Heihe River covers Qilian County of Qinghai and Sunan County of Gansu, which both depend on husbandry; the midstream contains Shandan County, Minle County, Ganzhou District, Linze County, and Gaotai County all in Gansu, which all rely on irrigated agriculture. The unique climate characteristics there lead to the formation of an oasis agriculture planting. Its downstream involves Jinta County in Gansu and Ejina Banner in Inner Mongolia, both partially dependent on irrigated agriculture. The Heihe agriculture zone (Fig. 1) is mainly located in Gansu and covers Shandan County, Minle County, Ganzhou District, Linze County, Gaotai County, and Jinta County.

In 2012, the county-level total grain output in the Heihe agriculture zone was highest in Ganzhou District (up to 400 million kg),

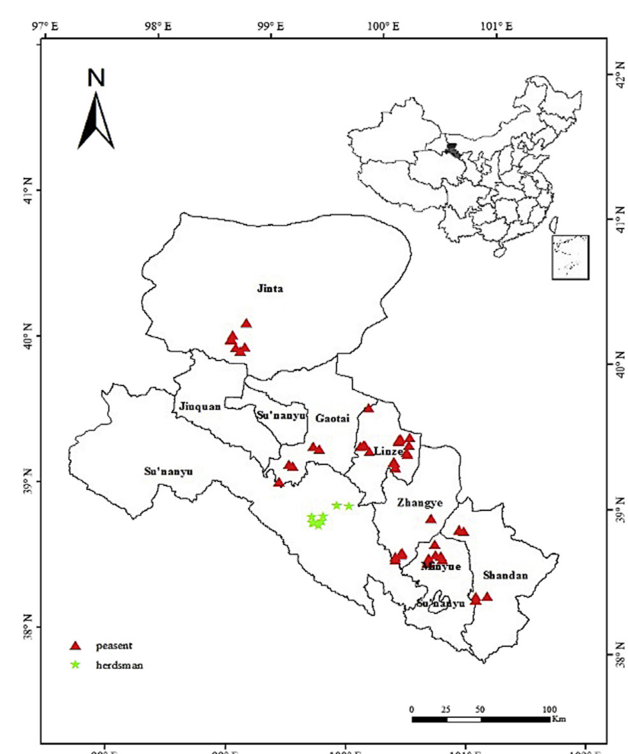


**Fig. 1.** Sketch map of villages and farmers for sampling and investigation.

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