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Research Paper

Field assessment of basin irrigation performance and water saving in Hetao, Yellow River basin: Issues to support irrigation systems modernisation

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Water-saving irrigation needs to be implemented in Hetao irrigation district to help satisfying the demand by other users in the Yellow River basin. Aiming at assessing the potential irrigation performance and water saving at farm level, a set of traditional basins and another of precision-levelled basins cropped with maize, wheat and sunflower and managed by farmers were evaluated. Data were collected to characterise the basin sizes, microtopography, inflow rates, advance and recession times, cut-off time and soil water content. In addition, families of infiltration curves were derived from field observations and subsequent use of model SIRMOD. Infiltration was higher for the precision-levelled basins and decreased from the first to the next irrigation events. Infiltration data were used to support the computation of distribution uniformity (DU), beneficial water use fraction (BWUF) and deep percolation (DP). For traditional basins, DU and BWUF were low and DP was high. When precise land levelling was practised, DU increased greatly to near 94% but BWUF improved little, because irrigation scheduling was inadequate leading to excessive water application; however, non-negligible water saving was achieved for maize and wheat since they have higher irrigation demand. In contrast, simulating the application of an appropriate irrigation scheduling through adjusting the cut-off time led to an approximately unchanged DU but BWUF greatly increased and DP reduced to 10% on average. This condition represents a potential water saving of 34–39%; however its achievement requires improved design of farm systems, appropriate irrigation water deliveries and scheduling, and the support and training of farmers.

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1. Introduction

The Hetao irrigation district (Hetao), located in the upper reaches of the Yellow River, is one of the largest irrigation districts of China, with 570,000 ha of irrigated land. The average annual rainfall is near 200 mm, so only irrigated agriculture is feasible. The canal network is supplied directly from the Yellow river. The Yellow River Water Conservancy Commission (YRWCC) is reducing diversions of Yellow river water to irrigate this area from 5.2×10^9 m^3 year^{-1} to 4.0×10^9 m^3 year^{-1} (Qu et al., 2003; Wang, Gao, & Lu, 2005), which implies the adoption of various water-saving technologies. This reduction is due to the increased demand for non-agricultural sectors and to reduced precipitation, probably due to climate change (Zhao, Xu, Huang, & Li, 2008), and aims to control the water scarcity conditions occurring in the middle and lower reaches of the Yellow river. Forecast scenarios on water resources allocation and use in the basin point to the need to reduce irrigation water use (Xu, Takeuchi, Ishidaira, & Zhang, 2002; Yu, 2006).

A variety of water-saving technologies is considered by Hetao and Inner Mongolia water managers (IWC-IM, 1999) aiming to reduce the agricultural demand for water, to improve environmental conditions, and to increase water productivity and farmers' incomes. These technologies consider the improvement of: (a) the water conveyance service, mainly through upgrading water delivery and reducing operational runoff wastage; (b) farm water use when implementing improved crop irrigation schedules with low to moderate deficit irrigation; and (c) farm surface irrigation, mainly through precise land levelling and upgraded technologies for furrowed and flat level basin systems. Impacts of these technologies in terms of irrigation performance, water saving and salinity control were analysed in previous studies applied to Huinong and Hetao irrigation systems (e.g., Deng, Shan, Zhang, & Turner, 2006; Gonçalves, Pereira, Fang, & Dong, 2007; Pereira, Gonçalves, Dong, Mao, & Fang, 2007; Xu, Huang, Qu, & Pereira, 2010, 2011).

Surface irrigation is the most appropriate irrigation method for Hetao because irrigation water is diverted from the Yellow River, which has a very high sediment concentration, averaging 3.1 kg m^{-3} at Dengkou, but reaching 5.17 kg m^{-3} (Wang & Cheng, 1993). These water quality conditions make it impossible to use sprinkler or microirrigation systems. In addition, favouring basin irrigation, land is flat, the conveyance and distribution network is designed and operated for surface irrigation, this method is appropriate to leach salts, and farmers have a good knowledge of the irrigation method they use. Modern technologies of surface irrigation, such as modernised furrowed and flat basin systems, precise land levelling and improved cut-off times, may well adapt to improve current practices and farmers have been shown to easily adopt them. The excessive use of water to control soil salinity is a major issue because farmers often over-irrigate for this purpose, despite it being known that autumn irrigation is generally sufficient to control salinity (Li et al., 2010).

Modern surface irrigation design applies simulation models, providing an increased quality of procedure because models allow the quantification of the integrated effect of numerous factors, such as field length and slope, soil infiltration and roughness, inflow discharge, land shape and surface microtopography (Clemmens, Walker, Fangmeier, & Hardy, 2007; Reddy, 2013; Strelkoff & Clemmens, 2007; Walker & Skogerboe, 1987). Nevertheless, in addition to hydraulics simulation, there is the need for a combined application of a variety of model tools for irrigation scheduling, land levelling, field distribution systems, and economic and environmental impacts analysis. Data requirements are therefore high and these data should be obtained as close as possible to actual field conditions, namely relative to infiltration characteristics. Benefits of modern surface irrigation could only be achieved if improvements in system design and irrigation scheduling were to be implemented together (Darouich, Gonçalves, Muga, & Pereira, 2012; Pereira, Oweis, & Zairi, 2002).

Land levelling plays a determinant role in the performance of surface irrigation, particularly in basin irrigation (Abdullaev, Hassan, & Jumaboev, 2007; Clemmens, Dedrick, Sousa, & Pereira, 1995; Dedrick, Gaddis, Clark, & Moore, 2007; Playan, Faci, & Serreta, 1996). Applications have been studied for North China and Hetao (Bai, Xu, Li, & Pereira, 2010, 2011; Li, Xu, & Li, 2001; Zheng, Shi, Guo, & Hao, 2011). Precise land levelling is particularly appropriate because it provides for significant reduction of the irrigation advance time and promotes uniformity of infiltration (Bai et al., 2010, 2011), thus favouring water saving and crop growth and yield; however, related benefits are not always tangible in terms of farm profitability, which explains why farmers may prefer the simpler and cheaper traditional land smoothing. Land levelling is traditionally performed in Hetao using rudimentary equipment and practices, with low quality and performance. Assessing present and improved land levelling conditions and related impacts on irrigation performance is therefore required to evaluate possible water savings and to base further decisions on irrigation improvements.

The performance of basin irrigation systems depends on the design, land levelling and farmers management, including the irrigation scheduling adopted, the inflow rate applied and the appropriateness of adopted cut-off time (Clemmens et al., 2007; Clyma & Clemmens, 2000; Pereira, 1999; Pereira et al., 2002). The importance of appropriate delivery schedules needs also to be considered as they constrain farm irrigation scheduling (Pereira et al., 2002). The traditional practice of over-irrigation in Hetao is explained by the need for salts leaching and to avoid any water deficits resulting from undesirable delays in water delivery, which are out of farmers' control; in addition, because the water fee relates to the field size and does not depend upon the volume of water use, there is no incentive for water saving. In contrast, adopting a limited deep percolation is desirable for maintaining the salts concentration at an appropriate level as previously analysed for the neighbouring areas of Huinong (Pereira et al., 2007; Xu et al., 2013). It is therefore also necessary to assess impacts of inflow rate control to support further improvements in Hetao.

Soil infiltration is a crucial factor impacting surface irrigation design and operation, namely the advance and recession and the distribution uniformity. Surface irrigation design