Agricultural Systems 153 (2017) 109–117

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Short communication

Impact of alternative cropping systems on groundwater use and grain yields in the North China Plain Region

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ARTICLE INFO

Article history:
Received 16 June 2016
Received in revised form 24 January 2017
Accepted 25 January 2017
Available online xxxx

Keywords:
Irrigation
Maize
Wheat
Groundwater
China

ABSTRACT

Excessive use of groundwater in irrigation (mainly for production of winter wheat) in the North China Plain (NCP) has resulted in markedly decreased groundwater levels. Alternative cropping systems may have potential to reduce groundwater use in the region. The APSIM (Agricultural Production System Simulator) farming systems model was used to simulate long-term (1981–2015) water use, net overdraft and crop yield for eight cropping systems. The wheat-maize double cropping system (WW–SM) in the study area resulted in overdrafts of 258 mm yr^{-1}, about 100 mm yr^{-1} more than estimated groundwater recharge. Although six of eight simulated systems reduced overdrafts below the estimated recharge value of 150 mm yr^{-1}, a triple-cropping system consisting of winter wheat/summer maize followed by fallow and early maize (WW–SM/F–EM) in two years appears to be the most viable alternative. Annual grain yield under the triple cropping system was only 13% less than that under the current WW–SM double cropping system. Groundwater overdrafts under triple-cropping system were about equal to lateral recharge from the mountains, water brought in via the South-North Water Transfer (SNWT) project and water from other water-saving measures (e.g. plastic film mulching) in the region.
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1. Introduction

The North China Plain (NCP) is one of the most important grain-producing areas in China. Comprising only 136, 000 km^2 of arable land, NCP produces some 20% of China's food grains (Yuan and Shen, 2013). Since the 1970s, crop production in NCP has shifted from two or three crops in two years to two crops per year with a winter wheat and summer maize (WW–SM) crop rotation as the dominant system (Xiao et al., 2013). Shifts in cropping systems, plant cultivars and management practices in NCP have significantly increased grain yield over the past decades (Wang et al., 2012; Xiao and Tao, 2014). Although this has enhanced grain production, it also has led to severe groundwater depletion in the plain (Wang et al., 2008; Sun et al., 2011; Meng et al., 2012; Gao et al., 2015; van Oort et al., 2016), because natural precipitation is less than crop water requirements (Yuan et al., 2016). This is especially due to winter wheat, for which the average crop water demand of 450 mm yr^{-1} substantially exceeds the average annual precipitation of 280 mm yr^{-1} (Sun et al., 2006; Fang et al., 2010; Yuan et al., 2016). About 200–450 mm yr^{-1} irrigation water is required to maintain high crop yields under the WW–SM system (Sun et al., 2006). Because surface water resources are scarce in the region, groundwater is almost the only source of irrigation water (Liu et al., 2011; Xiao and Tao, 2014).

With the advent of mechanized pumping wells in the 1960s, the number of wells dug for irrigation increased from 20 in 1953 to 9558 in 2000 (Mao et al., 2005). This rapid increase has led to the intensification of crop cultivation (Kendy et al., 2004; Yuan and Shen, 2013; Sun et al., 2015). Water use for crop (total evapotranspiration (ET) in the lifecycle of a crop) is the main factor driving groundwater depletion in NCP (Zhang et al., 2013). It accounts for over 70% of total groundwater use in the floodplains and 87.2% in the piedmont regions of the plain (Yang et al., 2010; Hu et al., 2010). Due to the continuous over-pumping, groundwater level in the region has dropped on the average of 0.8 m yr^{-1} from 10 m since the 1970s to 40 m today (Yuan and Shen, 2013; Min et al., 2015). Groundwater depletion at this rate has posed a significant challenge to sustainable utilization of regional groundwater resource (Liu et al., 2001; Moiwo et al., 2010; Hu et al., 2010; Pei et al., 2015).

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http://dx.doi.org/10.1016/j.agsy.2017.01.018
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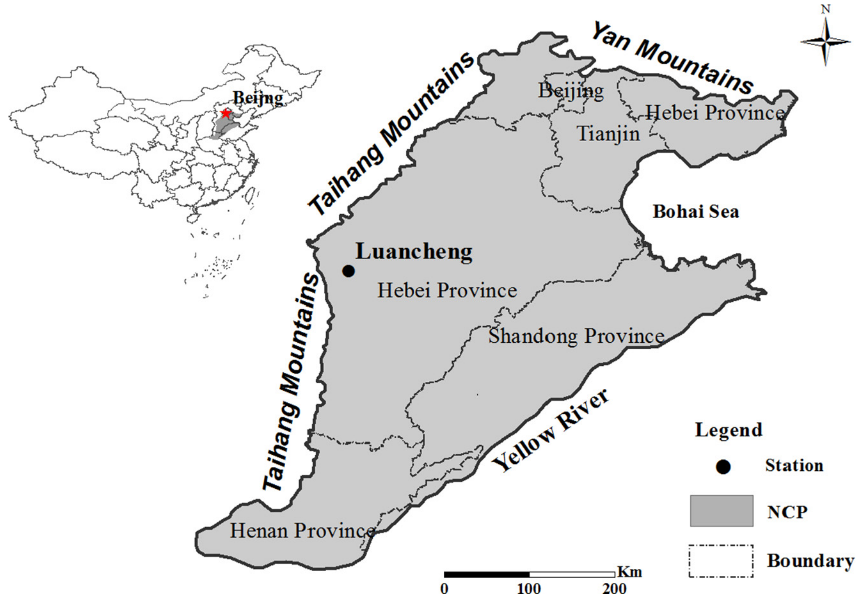

Fig. 1. A map depicting the location of North China Plain (NCP) in China (inset plate on the left) and Luancheng Agro-Ecological Experimental Station (LAES) (main plate on the left) in the plain.

As water depletion or water scarcity in NCP has drawn significant global concern (Liu et al., 2011; Lu et al., 2011; Huang et al., 2015), calls to limit or halt groundwater withdrawals to ensure water balance or recovery in the plain have increased (Kendy et al., 2004; Meng et al., 2012; Gao et al., 2015). Sun et al. (2015) found that even a minimum of one irrigation event per crop life cycle with current cropping systems can cause water table decline. This suggests that there is the need to shift to alternative cropping systems (e.g. dryland wheat-maize, single wheat or single maize cropping system) in the region. The current WW–SM cropping system is probably not sustainable because under any irrigation system precipitation is not sufficient for groundwater recharge (Wang et al., 2008; Gao et al., 2015).

Foregoing production of winter wheat in one or two seasons in the conventional double cropping system is a potential option for sustainable groundwater use in NCP (Gao et al., 2015; van Oort et al., 2016). Previous studies examined the possibility of replacing the conventional WW-SM System with the alternative cropping system, including winter wheat/summer maize-spring maize (W/M–M) and spring maize monosystem (SM). Compared to conventional WW–SM double cropping, both alternatives reduced irrigation water by 35% and 61%, respectively. They had higher water use efficiency that resulted in estimated water balance (Meng et al., 2012). Gao et al. (2015) also recommended the W/M–M management package as an alternative option to maintain grain yields while mitigating the decrease in the groundwater level.

Despite these previous studies, there is still the need for a further analysis of the long-term effects of the irrigation water required for different cropping systems for a regional water balance (Sun et al., 2011; Meng et al., 2012; Gao et al., 2015). For sustainable groundwater development in the NCP, improved knowledge is required on water-yield trade-offs for the various cropping systems (van Oort et al., 2016). Crop models can be used to evaluate the effects of different cropping systems on crop productivity and water use (Xiao and Tao, 2014). In this study, the Agricultural Production System Simulator (APSIM) farming systems model, calibrated and validated by experimental field data, was used to simulate the long-term (1981–2015) characteristics of water use and crop productivity under different cropping systems in the NCP.

Thus, the main objectives in this study were to: 1) determine historical agricultural irrigation characteristics and crop yields under different cropping systems in the NCP; and 2) investigate the effects of irrigation on groundwater use under different cropping systems in the NCP. The results of the study will add to existing data for the development of sustainable water resources management in the NCP study area. This is critical for future crop production and social stability in the region.

2. Materials and methods

2.1. Study site, climate and crop data

The NCP study area (Fig. 1) is delimited in the north by the Yan Mountains, the west by Taihang Mountains, the south by the Yellow River and the northeast by the Bohai Gulf (Shen et al., 2013). With an area of 136, 000 km^2 and a population of 111 million, the NCP is one of the main agricultural regions in China. Rainfall is only 135 mm during the normal wheat growing season (Fig. 2). Observed crop yields in the region are supported by intensive irrigation (Sun et al., 2015).

This study was conducted at Luancheng Agro-Ecological Experimental Station (LAES) (37° 53′ N, 114° 41′ E, altitude 50.1 m a.s.l., and water table depth of 20–45 m), located in the high-yield zone of NCP (Fig. 1). Loam of aeolian origin is the dominant soil type. The climate is temperate semi-arid monsoon type, with mean annual temperature of 12.2 °C, radiation of 524 kJ cm^{-2} and precipitation of 488 mm yr^{-1}, 50 to 80% of

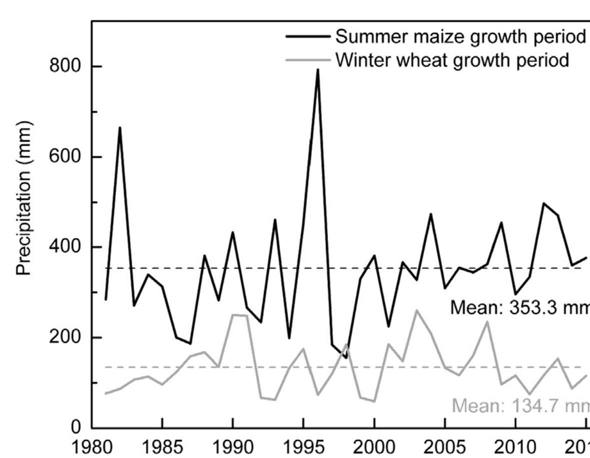

Fig. 2. Variations in precipitation during winter wheat and summer maize growth periods in 1981–2015 at Luancheng Agro-Experimental Station (LAES) in North China Plain.

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