Field Crops Research 210 (2017) 47–51

Contents lists available at ScienceDirect

Field Crops Research

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

Short Communication

Value of groundwater used for producing extra grain in North China Plain

Zhigan Zhao[a,b], Xin Qin[a], Hecang Zang[c], Chao Chen[d], Yinghua Zhang[a,*], Zhimin Wang[a,*]

[a] Department of Agronomy and Biotechnology, China Agricultural University, Yuanmingyuan West Road 2, Beijing 100193, China
[b] CSIRO Agriculture & Food, GPO Box 1700, Canberra, ACT 2601, Australia
[c] Agricultural Economy & Information Research Center, Henan Academy of Agricultural Science, Zhengzhou 450002, China
[d] CSIRO Agriculture & Food, Private Bag 5, PO Wembley, WA 6913, Australia

ARTICLE INFO

Keywords:
Wheat-maize rotation
Yield
Water use efficiency
Water pricing
APSIM

ABSTRACT

Irrigation has led to increased crop productivity in the North China Plain (NCP) in the past three decades, but also caused quick depletion of groundwater resources with potentially severe hydrological consequences. Future policy development needs to balance crop production and groundwater use for increased sustainability. This requires an understanding of how crop production can be impacted by reduced irrigation and the value of the groundwater used for producing extra grains across NCP. We used cropping systems modelling to assess how the productivity of the wheat-maize system are influenced by spatial climate variability and changes in irrigation water supply across a north-south rainfall gradient in NCP. Our results show that irrigation has minimised the north-south difference in crop productivity, leading to a production gain as large as 9 t/ha/year grain with a total value of up to 19,000 CNY/ha/year in the north. The high water use efficiency (WUE) of irrigation water in the north was similar to the WUE of natural rainfall in the south, allowing the farmers at dry sites to obtain very similar production value to those at the wet sites. The value of groundwater used for producing the extra grains was estimated to be 1.8–8.6 CNY m^{-3} water. The results provide the scientific basis for the design of future policies for water pricing and sustainable agricultural development in NCP.

1. Introduction

North China Plain (NCP) is one of the largest agricultural production area in China. The dominant winter wheat–summer maize double cropping system has been highly productive, and played an essential role for China's food security in the past 30 years. However, in large part of the NCP, the high productivity has been achieved with irrigation using groundwater at the cost of depleting groundwater resources (Kendy, 2003; Kendy et al., 2004; Wang et al., 2008), potentially leading to severe hydrological consequences in the future. Recent policy development has encouraged measures to restrict groundwater use such as through controlling electricity used for pumping ground water or stopping irrigation for certain crops. To quantify the potential implications of such measures requires an understanding of how crop production can be impacted by reduced irrigation and the value of the groundwater used for producing extra grains across NCP.

Considerable studies have been conducted to explore possible ways to reduce groundwater use such as developing a water pricing mechanism to charge for irrigation use of groundwater in NCP (Brown and Halweil, 1998; Jin and Young, 2001; Webber et al., 2008; Yang and Zehnder, 2001; Yang et al., 2003; Zheng et al., 2010). Water pricing needs to be based on the potential production gain caused by irrigation using the water. Due to great spatial variations of climate (particularly rainfall) across the NCP, crop yield increase caused by using certain amount of irrigation water can be very different. While such information is critical for policy development to balance productivity and water use, a systematic analysis on the impact of irrigation on crop productivity and the value of groundwater used to produce grains across different rainfall areas in NCP is lacking. Such an analysis with the current wheat-maize double cropping systems can provide a scientific basis for development of sustainable management practices and future water pricing policy.

The objective of this paper is to use a simulation modelling approach to quantify how the productivity of the wheat-maize system can be influenced by spatial climate variability and impacted by changes in irrigation water supply across a rainfall gradient in NCP. We further analyse the total value of irrigation and assess the value of groundwater used for producing extra grains across NCP, with the aim to provide a scientific basis for future policy development to balance crop productivity and groundwater use.

* Corresponding authors at: 2 Yuanmingyuan West Road, Beijing, 100193, China.
E-mail addresses: yhzhang@cau.edu.cn (Y. Zhang), Zhimin206@263.net (Z. Wang).

http://dx.doi.org/10.1016/j.fcr.2017.05.022
Received 7 May 2017; Received in revised form 27 May 2017; Accepted 27 May 2017
0378-4290/

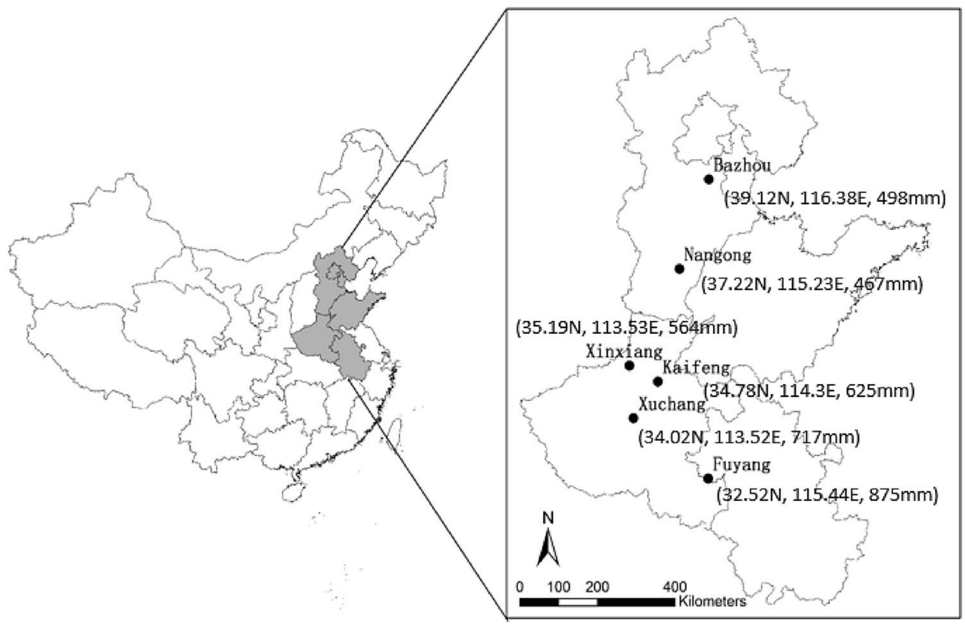

Fig. 1. The six study sites selected based on annual rainfall across the North China Plain (NCP), with latitude, longitude and annual rainfall amount shown in brackets close to the site names.

2. Method

2.1. Study sites, cropping system and climate

Six sites (Fig. 1) were selected based on annual rainfall to represent a north-south rainfall gradient across NCP. The typical soil in this study area is a loam like soil with light loam texture in surface layers, changing to clay loam in the deeper layers to a depth of 2 m at least. For the wheat–maize double cropping system, the growing season of wheat is from mid-October to early June, and of maize from mid-June to early October. The study region was characterised by a summer monsoon climate, with > 70% of the annual rainfall concentrated in the summer maize growing season from Jun-Sep.

Historical daily climate data from 1961 to 2012, including daily maximum and minimum temperatures, sunshine hours, and precipitation, were obtained from China Meteorological Administration (CMA). Sunshine duration was converted into daily solar radiation using the Angstrom formula (Angstrom, 1924).

2.2. The agricultural systems model APSIM and its parameterization

The APSIM model (Holzworth et al., 2014; Keating et al., 2003; Wang et al., 2002) version 7.5 was used to simulate above-ground biomass, grain yield, and water use of the wheat-maize double cropping rotation at the study sites. In APSIM, phenological development of wheat and maize crop is driven by accumulation of thermal time, which is also modified by response to photoperiod and vernalisation (wheat only) at early stages. Daily growth of aboveground biomass is simulated as the smaller one as determined by transpiration efficiency (TE) together with soil water supply (Wang et al., 2004) or a stage-dependent radiation use efficiency (RUE) together with the intercepted radiation. Grain yield of both crops is simulated based on grain number and grain filling rate. A detailed description of APSIM can be found at http://www.apsim.info

APSIM has been extensively validated for wheat and maize in NCP. For general performance of APSIM, we rely on the model validation (> 32 sites across NCP) of previous studies (Chen et al., 2010a,b,c; Gaydon et al., 2017; Sun et al., 2015; Wang et al., 2012; Zhao et al., 2014a), which showed that the APSIM model was able to predict the crop biomass growth, grain yield, crop water and nitrogen uptake of wheat and maize in response to water and nitrogen supply in NCP.

During the past fifty years, cultivars of both wheat and maize were changed frequently. For the long-term simulations described below, to eliminate the impact of cultivar changes, the modern summer maize cultivar 'ZD958' and the modern wheat cultivars 'JM22' were used with cultivar parameters obtained from Chen et al. (2010a) and Zhao et al. (2014b), respectively. The two cultivars are widely grown across NCP. In all simulations, maximum root depth of wheat and maize were set to 2 m and 1.2 m respectively, based on the finding of Zhou et al. (2008) and Wu et al. (2009). This gives a potential available water capacity (PAWC) of 410 mm for wheat and 245 mm for maize.

2.3. Modelling the system performances across rainfall gradient in NCP

The wheat-maize double cropping system was simulated continuously from 1961 to 2012 at the six sites using long-term daily climate data under two scenarios: (a) irrigation and (b) no irrigation (i.e. rainfed condition). For each scenario, the optimal rates of N applications were derived for both wheat and maize crops at each study site, using the same approach as in Zhao et al. (2015). This was done by running simulations with nitrogen application rates ranging from 0 to 300 kg/ha (15 kg/ha interval) to determine the optimal N rate as the N rates leading to 95% of maximum yield. For the scenario of irrigation, irrigation was applied to fill the soil to the drained upper limit (DUL) if soil water content in the top 600 mm soil layer was below 70% of DUL, which closely mimicked the irrigation amount applied by farmers. On the day before wheat sowing date each year, all maize residue was incorporated into 200 mm soil depth. Wheat residue was left on the soil surface after harvesting. Representative sowing dates for wheat and maize at each location were used. Grain yield, optimal N rate and irrigation water use amount of both wheat and maize were calculated to analyse the systems productivity, water use and water use efficiency (WUE).

2.4. Impact and benefit of irrigation with groundwater

Impact of irrigation on productivity was represented by the increase in crop yield compared to rainfed conditions. The water use efficiency (WUE) for irrigation water was calculated as the yield increase divided by the irrigation water amount.

The economic value of the grain production of wheat and maize was calculated as

$$ProductionValue(CNYha^{-1}) = \mathrm{Y} \times \mathrm{PY} - N \times \mathrm{PN} - \mathrm{I} \times \mathrm{PI} - \mathrm{CO} \quad (1)$$