Agricultural Water Management 190 (2017) 42–54

Contents lists available at ScienceDirect

Agricultural Water Management

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

Research Paper

Impacts of varied irrigation on field water budegts and crop yields in the North China Plain: Rainfed vs. irrigated double cropping system

Hongwei Pei[a,b,c], Leilei Min[a], Yongqing Qi[a], Xingran Liu[a,c], Yugui Jia[b], Yanjun Shen[a,*], Changming Liu[a]

[a] Key Laboratory of Agricultural Water Resources, The Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, The Chinese Academy of Sciences, 286 Huaizhong Road, Shijiazhuang 050021, Hebei, China
[b] Hebei University of Architecture, Zhangjiakou 075000, Hebei, China
[c] University of Chinese Academy of Sciences, Beijing 100049, China

ARTICLE INFO

Article history:
Received 4 October 2015
Received in revised form 14 April 2017
Accepted 16 May 2017

Keywords:
North China Plain
Irrigation
Rainfed
Deep percolation
Yield

ABSTRACT

Groundwater irrigation has supported intensive agriculture in the North China Plain during the past four decades, but resulted in continued aquifer depletion. Reduce irrigation amount would be one of the actions to control the groundwater depletion. However, the impacts of reducing irrigation on the soil moisture and deep percolation have not been studied broadly. Therefore, this study employed long-term experiments via two irrigation plots (rainfed and irrigated) to assess the impacts of reducing irrigation on the soil water dynamics and percolation process in the double cropping fields. The following conclusions were reached in this study: (1) Irrigation reducing decreased the soil moisture in the unsaturated zone within the root zone, but increased the variations of soil moisture in the layer deeper than 500 cm below the land surface. Meanwhile, there was a new dried soil layer in the 160–180 cm depth below land surface for the irrigated double cropping field. (2) Irrigation increased mean annual deep percolation (Oct. 2011–Sep. 2015) from 1.3 mm yr^{-1} to 116 mm yr^{-1} compared to rainfed. At the same time, the maximum percolation rate for the rainfed crops was 0.03 mm d^{-1} while the irrigated crops reached to 2.69 mm d^{-1}. The percolation decreased significantly from 140 to 190 mm yr^{-1} to 40–89 mm yr^{-1} as a result of water-saved irrigation strategy. (3) Irrigation has increased actual evapotranspiration and accelerated the field water cycle: mean annual evapotranspiration (double cropping system) increased from 454 mm yr^{-1} beneath rainfed cropland to 671 mm yr^{-1} beneath irrigated cropland during Oct. 2011–Sep. 2015, but decreased from 752 to 757 mm yr^{-1} to 565–610 mm yr^{-1} as a result of water-saved irrigation strategy. Overall, this research presents a multi-year visualization of the dynamics for soil moisture and deep percolation beneath rainfed and irrigated through the deep vadose zone. The assessments of irrigation and water-saved irrigation impacts on soil water profile and percolation are valuable for agricultural water management in these semi-arid regions fed by groundwater irrigation, globally.

1. Introduction

The irrigated agriculture has played a crucial role in crop yield increasing during the past 50–60 years (Taylor et al., 2013; Wada et al., 2012) and stabilize agricultural productivity by mitigating the effects of rainfall vagaries (Vico and Porporato, 2015). In fact, the irrigated agriculture produces ∼40% of food production only based on 20% of the cropland by consuming ∼90% of the global fresh water supply (Jury and Vaux, 2005; Scanlon et al., 2012; Shiklomanov, 2000). Among the period, groundwater-fed agriculture has expended quickly especially in the latest couple of decades at the cost of groundwater overexploiting, resulting in long-term aquifer depletion in most semiarid regions globally, such as the North China Plain (NCP, Fig. 1) (Cao et al., 2013; Chen et al., 2005; Le Coz et al., 2013; Liu et al., 2001; Rodell et al., 2009; Scanlon et al., 2010, 2012; Siebert et al., 2005, 2010). In the piedmont of the NCP, as a result of the excessive exploitation of groundwater resources for irrigation, the depth to water table has declined continuously from ∼10 m in 1970s to 46 m in 2015 (Fig. 2) and lead to deep vadose zone, while the field water cycle was changed accordingly. Therefore, alternative cropping (Yuan and Shen, 2013; Xiao et al., 2017) and water-saved irrigation method (Zhang et al., 2013)

* Corresponding author.
E-mail addresses: yjshen@sjziam.ac.cn, yj.shen@gmail.com (Y. Shen).

http://dx.doi.org/10.1016/j.agwat.2017.05.007
0378-3774/

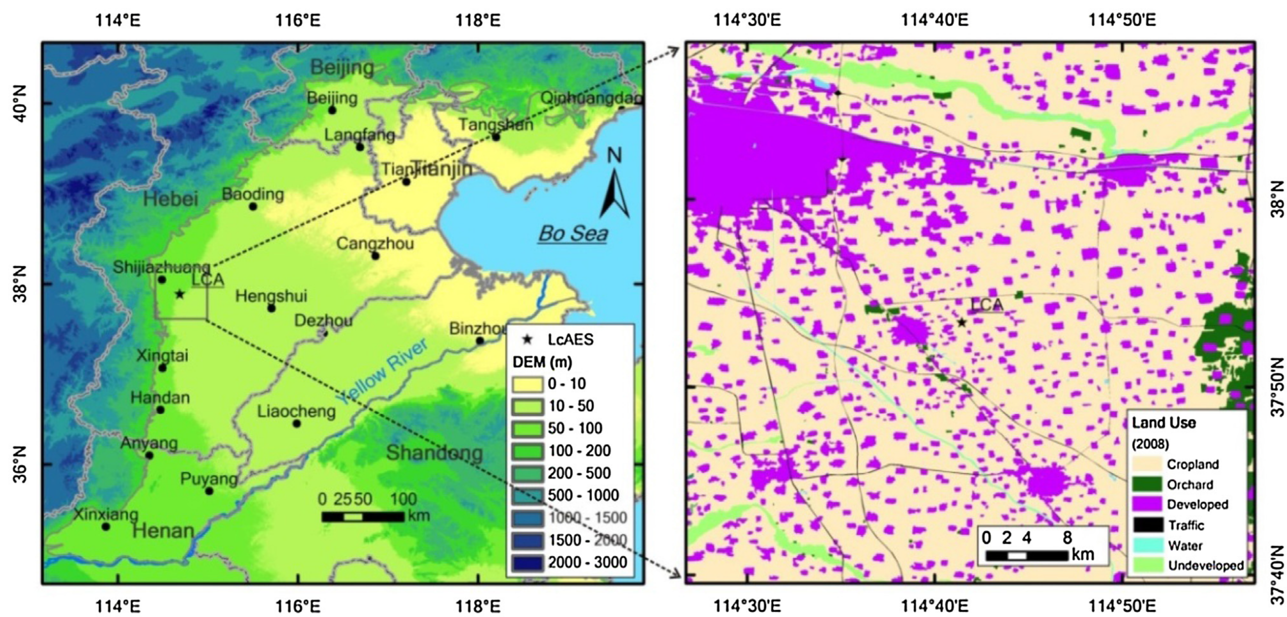

Fig. 1. Location map of the North China Plain (NCP) and the Lucheng Agricultural Station (LCA).

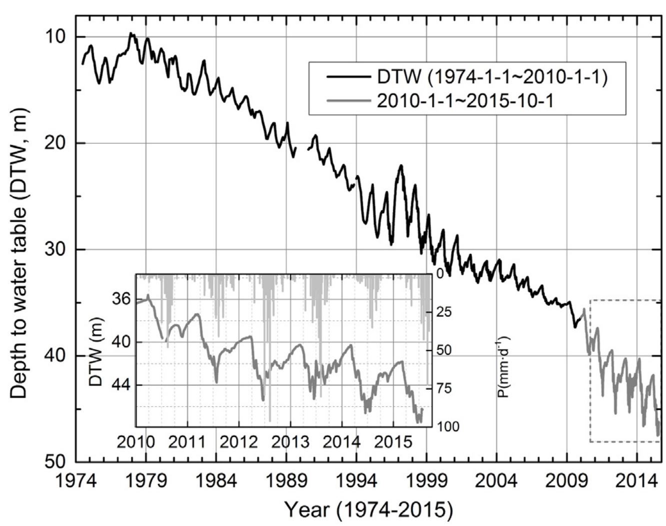

Fig. 2. Depth to water table (DTW) with seasonal fluctuation in the Lucheng Agricultural Station (LCA).

were claimed as the groundwater depletion and water scarcity in the NCP. Among these researches, Zhang et al. (2011) reported the irrigation wetting depth can be reduced at least to 40 cm, rather than the traditional 100 cm, as a means of water conservation which based on the stable isotopic research conclusion that the main depths of root water uptake were 0–40 cm (Zhang et al., 2011). However, what's the impact to reduce irrigation water on soil moisture in the deep vadose zone and how much the deep percolation changed? Those key issues for field water management were still limited understood by now.

The deep percolation (also as same as vertical recharge, deep drainage) which was fed by groundwater irrigation was not only a great part of vertical recharge to the local groundwater (Scanlon et al., 2010), but also acts as a source of pollution in the intense agricultural regions (Pei et al., 2015a, 2015b; Min et al., 2017). Therefore, estimating groundwater recharge of the intensive agricultural lands and reduce the pollution risk of groundwater is so crucial for the sustainable agricultural water management. In fact, the estimations of recharge rate and soil moisture dynamics have attracted much more attentions (Dahan et al., 2009; Rimon et al., 2007). In recent couple of decades, the unsaturated zone methods (physical methods, tracer methods and numerical modeling et al.) for estimating groundwater recharge/field deep drainage have been applied broadly in the NCP (Min et al., 2015). A latest research showed that the deep percolation at 8 m depth for normal irrigated cropland was averagely ~200 mm yr^{-1} in the NCP during the past 4 decades (Min et al., 2015). Lin et al. (2013) estimated the recharge rate at non-irrigated woodland was 16.9–19.4 mm yr^{-1}, and the recharge rate under irrigated cropland was 65.9–126.8 mm yr^{-1} via environmental tracers: fluoride (F•), chloride (Cl•) and sulfate (SO_4^{2-}). Other scientists including Kendy et al. (2003), Tan et al. (2014), Wang et al. (2008) and Lu et al. (2011) addressed that the recharge from double cropping cropland were varied from 70 mm to 200 mm annually. However, multi-years on site research of the percolation process through the deep vadose zone was still very limited in the NCP, especially under the scenario of water-saved irrigation strategy.

On the other hand, the understanding about the impacts of irrigation on deep percolation and field water budget is pivotal in agricultural hydrology and assessing agricultural water management. The field water budget and variation of soil quality for the rainfed cropland and irrigated cropland have been compared in other semiarid regions such as Israel (Kurtzman and Scanlon, 2011), U.S. High Plains (Scanlon et al., 2010) and Niger (Le Coz et al., 2013) lately. Among these cases, irrigation has increased field recharge significantly from 1 to 3 mm yr^{-1} under rainfed cropland to 90–230 mm yr^{-1} under irrigated cropland with clay soil texture and deep groundwater level (~30 m) in Israel (Kurtzman and Scanlon, 2011). With the low-permeability, fine-grained soils, percolation rate beneath irrigated agro-ecosystems is 22–36 mm yr^{-1} in the deep water table zone (~30 m) but almost zero under rainfed condition in the northern part of southern U.S. High Plains; in contrast, with the high-permeability, coarser-grained soils, the percolation rate is ranged from 18 to 97 mm yr^{-1} beneath irrigated which is similar to the range beneath rainfed agro-ecosystems by 4.8–92 mm yr^{-1} (Scanlon et al., 2010). Another case with a shallow groundwater depth (3–4.5 m) in Niger showed the recharge rates were varied from −10–120 mm yr^{-1} of rainfed cropland to