Agricultural Water Management 191 (2017) 85–97

Contents lists available at ScienceDirect

Agricultural Water Management

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

Quantification of lateral seepage from farmland during maize growing season in arid region

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ARTICLE INFO

Article history:
Received 8 March 2017
Received in revised form 10 June 2017
Accepted 12 June 2017

Keywords:
Lateral seepage ratio
Soil moisture
HYDRUS-2D
The middle reaches of Heihe River Basin

ABSTRACT

Quantification of lateral seepage from farmland under basin irrigation in arid region is essential for the evaluation of irrigation water use efficiency and for understanding its contribution to local natural vegetation. Field monitoring and numerical simulation of soil water dynamics were conducted by HYDRUS-2D in the oasis of middle reaches of Heihe River Basin during maize growing seasons in 2012 and 2013. The monitored results demonstrate that there was a sharp increase of soil moisture in the adjacent area of the farmland after each irrigation event, indicating there was noticeable lateral seepage from the farmland after irrigation. HYDRUS-2D model calibration/validation results compared well with the monitored data, with $r = 0.71/0.67$, RMSE = 3.63%/4.62%, RE = 0.12/0.14. Further scenario simulations showed that the lateral seepage ratio (i.e., the ratio of total lateral seepage to the total irrigation in the studied farmland) increased with the increase of irrigation quota and decreased with the increase of the farmland area. Lateral seepage ratio would increase in case of fine-textured soil under the root zone and decrease with coarse-textured soil underneath the root zone. In terms of the general irrigation schedule, farmland area and soil texture in the middle reaches of Heihe River Basin, the annual later seepage from the farmlands were estimated to be about 1.13×10^5 m^3 to 6.98×10^6 m^3.

1. Introduction

Agricultural irrigation generally takes over 90% of the total water resources in the northwest China (Sun et al., 2012). Conventionally except root water uptake, the irrigation water consumptions, e.g., soil evaporation, deep percolation and lateral water seepage are regarded as inefficient irrigation water use (i.e., water losses) (Wright et al., 2014). Quantification of each item of the irrigation water losses is essential for efficient agricultural water management in regions with water shortage. Although soil evaporation and deep percolation have been thoroughly investigated, there are few studies on the lateral seepage, always considering it as a negligible term in the field water balance. However, with the promotion of precision irrigation it is necessary to learn the fate of every drop of irrigation water. Under such circumstance, the quantification of lateral seepage could not be avoided, especially in the arid land area where irrigation in the farmland may serve as a source item to the surrounding area. Besides, current arid land hydrological process simulations generally consider only the vertical flow in vadose zone, assuming the lateral water movement negligible. Without thorough study on the lateral water seepage from the farmland, it is hard to learn how *in situ* information, e.g., the soil texture, the farmland area and the irrigation manor would affect the lateral seepage and how much error it may bring into the hydrological model under various circumstances. On the other hand, lateral water seepage can supply water for the adjacent land use units (e.g., tree belts and pastures) and help maintain local farmland ecosystems in arid land with limited precipitations (Dan et al., 2004) showing its potential ecological value rather than the previous negative view as unbeneficial water consumption. Therefore, quantification of lateral seepage from irrigation can provide critical data support for improving agriculture water use efficiency, for accurate simulation of regional hydrological processes, and for protection of the arid land ecosystems.

Previous studies on irrigation water use/loss have been mainly conducted by water balance method (Sun et al., 2006; Abid Karray et al., 2008; Wang et al., 2012). Irrigation/precipitation, surface runoff, evaporation, transpiration, deep percolation, variation of

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http://dx.doi.org/10.1016/j.agwat.2017.06.006
0378-3774/

soil water storage, and lateral seepage to adjacent land, are the main components of the soil water balance (Zhao and Zhao, 2014). Precipitation, irrigation, surface runoff and the variation of water storage are often obtained by field monitoring. The evapotranspiration, including soil water evaporation and crop transpiration, can be obtained by field measurements (e.g., weighing lysimeters, eddy covariance systems and Bowen ratio systems), calculations based on the crop coefficient and reference crop evapotranspiration, or numerical simulations (Li et al., 2016). Deep percolation is generally estimated by the variation of underground water level (Sun et al., 2006), by its empirical relationships with the field capacity and water storage in root zone (Allen et al., 1998), or obtained by numerical simulations (Jabro et al., 1998). Soil water storage is usually obtained by measuring the soil water content at different depths, using neutron detector, time-domain reflectometer, etc (Evett et al., 2012) or by oven drying method with soil samples collected from the field site. However, the lateral water movement/lateral seepage is usually neglected, because the water movement in the vadose zone is mainly in a vertical direction (Li et al., 2015).

Although soil water movement in horizontal direction in farmland is not as prominent as it is in vertical direction, there are still hydrological interactions between different land use types in an ecosystem (Smith et al., 1997; Zhao et al., 2012). The combination of land use or vegetation types (e.g., farmland, forest, grassland or desert) makes the hydrological processes more complex than that in a single land use unit because of the lateral water flow and the extended root system (Ong et al., 2002; Ruiz-Sinoga et al., 2011).

Relevant studies have reported that lateral percolation from farmland irrigation is important water source for the growth of adjacent tree belts or desert plants. For instance, experimental methods (Dan et al., 2004) and HYDRUS-2D model (Wang et al., 2011) were used to investigate lateral water flow in agroforestry systems. They found that soil water content in the deeper layers of farmland may decrease because of the existence of nearby forest root systems, and forest soil may be rewet under soil water potential gradients when farmlands was irrigated. The same conclusions were obtained by the other researchers (Shen et al., 2014; Yi et al., 2015) according to the experimental observations in farmland-forest-desert transition zones. They concluded that the soil water may move from the irrigated land use unit to the nearby non-irrigated unit under soil water potential gradients through physical diffusion in the upper soil layer or under groundwater level gradients through groundwater flow in the deep soil layers. However, from our knowledge there is little effort on the quantification of lateral seepage from farmland yet.

Heihe River Basin is the second largest inland River Basin in China and historically one of the major grain production areas. With limited precipitation in this region, Heihe River is the main water source for economic development and for the maintenance of a sustainable ecosystem. The water consumption in the middle reaches comprises 86% of total available water resources of Heihe River, of which 96% is used for irrigation (Chen et al., 2003). Therefore understanding the irrigation water losses, including quantification of the lateral water seepage from farmland, is essential for the sustainable water utilization in this region.

In this study, we conducted two years' (2012–2013) field monitoring on the soil water dynamics in order to quantify the lateral seepage from a farmland to its adjacent area during maize growing season in Yingke Irrigation District, middle reaches of Heihe River Basin. The corresponding processes were simulated and evaluated using HYDRUS-2D. The main objectives of the study are to (1) predict the response of soil water dynamics and lateral seepage on irrigation/precipitation events, (2) quantify the irrigation loss induced by lateral seepage, (3) identify the main influencing factors on lateral seepage, and (4) estimate the annual lateral seepage from the farmlands in the oasis of middle reaches of Heihe River.

2. Materials and methods

2.1. Study area

The study area was in Yingke Irrigation District, located in the middle reaches of Heihe River Basin (Fig. 1). The landuse in the middle reaches of Heihe River Basin includes bare soil, building lot land, farmland, forest, grassland and surface water. Most of the farmland is concentrated in the middle of the region with bare soil around it. The irrigated fields are commonly adjacent to other irrigated fields, except for those on the margins of the farmland. It

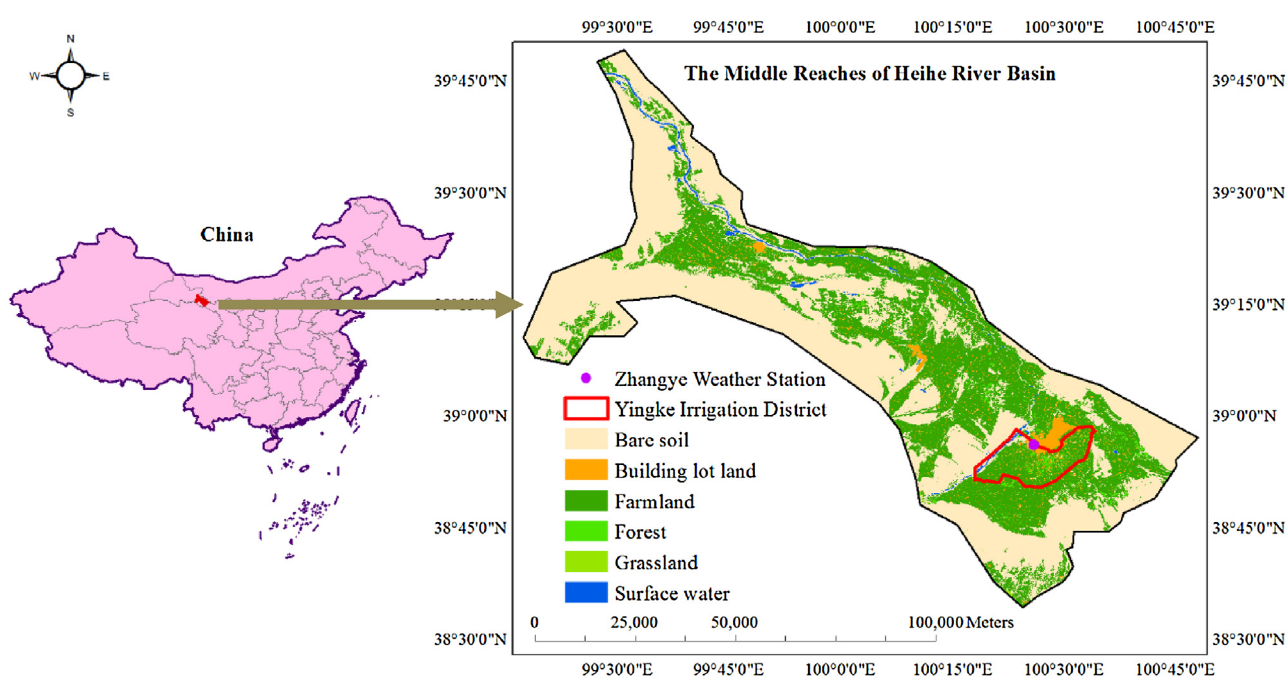

Fig. 1. The location of Yingke Irrigation District and the landuse of middle reaches of Heihe River Basin.