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Inter-dripper variation of soil water and salt in a mulched drip irrigated cotton field: Advantages of 3-D modelling

Xianwen Li[a,b,c], Menggui Jin[b,*], Nianqing Zhou[c], Simin Jiang[c], Yaxian Hu[d]

[a] Key Laboratory of Agricultural Soil and Water Engineering in Arid and Semiarid Areas, Ministry of Education, Northwest A&F University, Yangling, Shaanxi 712100, China

[b] State Key Laboratory of Biogeology and Environmental Geology & School of Environmental Studies, China University of Geosciences, Wuhan 430074, China

[c] Department of Hydraulic Engineering, Tongji University, Shanghai 200092, China

[d] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Northwest A&F University, Yangling, Shaanxi 712100, China

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ABSTRACT

Two-dimensional (2-D) numerical models have been widely used to predict soil water-salt transport under mulched drip irrigation. However, conventional 2-D models often neglect the spatial variation of soil water-salt transport along drip lines and over-simplifies it by averaging values. This calls for a more robust model to better reflect the actual spatial and temporal variation of soil water-salt distribution in the field, especially in arid regions using brackish water with additional salt. In this study, mulched drip irrigation with brackish water was applied to a cotton field with loam soil in an arid region of southern Xinjiang, northwest China. The changes of soil water potential and total dissolved solid (TDS) of soil water over two irrigation events were intensively measured on hourly base to establish and calibrate a 3-D model, and another five irrigation cycles were monitored on daily base to validate the 3-D model. The mean absolute relative errors between measured and calculated soil water potential and TDS of soil water were 13.7% and 10.7% during hourly-based model calibration, even though there might be bias inevitably introduced by pre-determined sampling intervals and volumes. The calculated values during model validation were reasonably in line with the temporal patterns of soil moisture and TDS before and after irrigation at different irrigation cycles. This 3-D model was then applied to predict the spatial and temporal variations of soil water-salt transport during and after irrigation. Our results show that (1) the 3-D model with additional consideration on point-source discharge from individual drippers effectively reflected the wet front interferences along the drip lines. (2) A semi-elliptic cylindrical wet bulb together with relatively low salinity was formed along the drip lines, which matched well with the cotton layout (one mulch, two drip lines and four rows). However, the uneven overlapping of wet front interferences among individual drippers required to optimize the design of dripper intervals and irrigation regime to provide desirable soil water-salt conditions for cotton growth in this loam soil. (3) During the 96 h after irrigation, the TDS of soil water was always greatest in the dense root zone, increasing from approximately 3.8 $g\,L^{-1}$ to 7.0 $g\,L^{-1}$ as a result of root water uptake. Such localized re-salinization patterns demand repeated leaching in continued irrigation cycles to ensure cotton growth. Our study suggests that a smaller interspace between drippers with short but more frequent irrigation cycles would be much more helpful to timely and spatial-precisely meet plant water demanding.

1. Introduction

Water resource shortages and soil salinization are crucial limitations hindering the sustainable development of agriculture in arid regions (Chen et al., 2010; Danierhan et al., 2013). For example, in Xinjiang, a region of northwestern China, more than 50% of rivers have been exploited for agricultural irrigation (Li, 2003), which has in general caused downstream rivers and lakes to dry up and desert expansion (Li, 2003). With drip irrigation, it can potentially reduce soil water evaporation and deep-water percolation, hence effectively conserving water and enhancing water use efficiency. When further combined with field surface mulching (namely mulched drip irrigation), it has great potential to be applied in arid regions (Assouline et al., 2006; Sezen et al., 2006; Vázquez et al., 2006; Marouelli and Silva, 2007; Bhattarai

* Corresponding author.
E-mail address: mgjin@cug.edu.cn (M. Jin).

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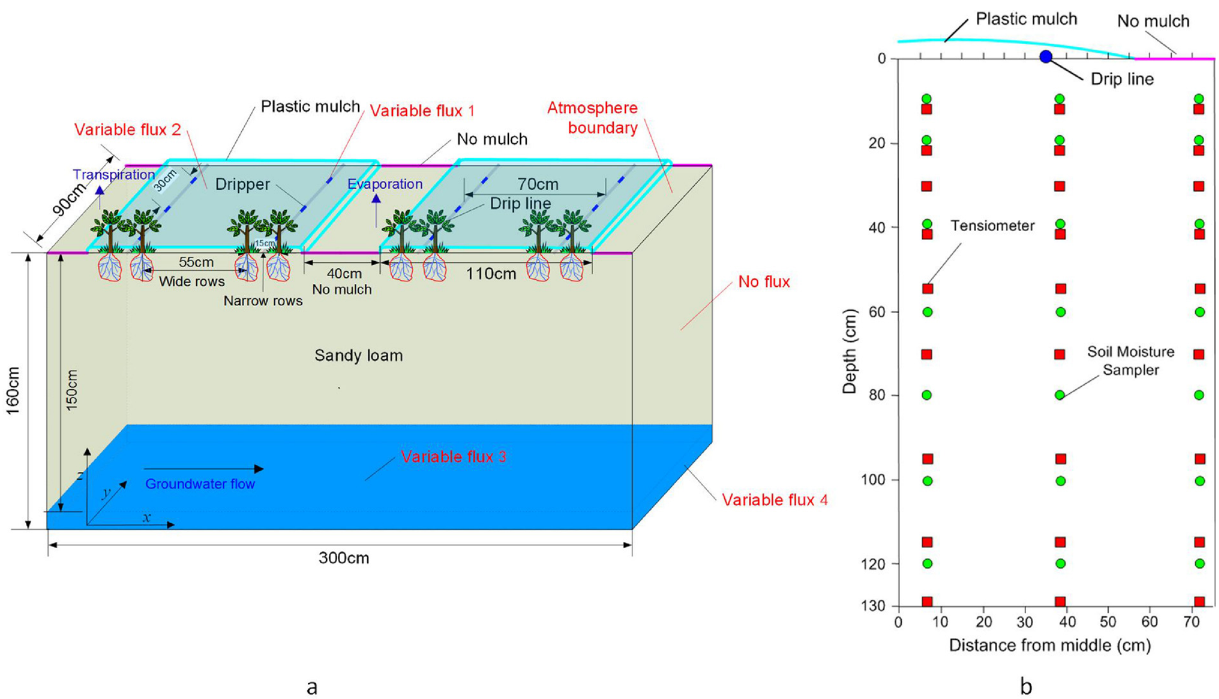

Fig. 1. Conceptual model of 3-D soil-water flow under mulched drip irrigation (a) and the layout of measurement tools (b) (after Li et al., 2016). Please be noted that the *z* axis in (a) was set as 0 at soil depth of 160 cm following the pre-determined settings of the 3D HYDRUS model, whilst the *z* axis in (b) starts from soil surface and extends downward until soil depth of 130 cm.

et al., 2008; Li et al., 2012; Panigrahi et al., 2013; Selim et al., 2013), especially in the arid region of Xinjiang, China (Liu et al., 2012).

Slightly salty water can provide another possibility to make up fresh water shortage in regions with limited irrigation resources (Oron et al., 2002; Letey et al., 2011). For instance, in regions such as the North China Plain, the midstream and upstream regions of the Yellow River and the northwestern regions with inland rivers, abundant brackish groundwater (in total 13 billion m^3 with salt concentration of 2–3 g L^{-1}) can be used as irrigation resources to meet the increasing water demanding (Yang and Cheng, 2004). Even though with great applicable potential in regions with limited fresh water resources, the possible impacts of mulched drip irrigation using brackish water on soil water-salt distribution are still far from being fully understood (Wang, 2013; Wang et al., 2014; Li et al., 2015, 2016). Mirjat et al. (2014) and Aragüés et al. (2015) reported that salt could accumulate in the root zone due to insufficient leaching, causing localized salinization. After comparing soil water content, salinity and root density between cotton fields irrigated with fresh and brackish water, Chen et al. (2018) reported that two-year trials with brackish water irrigation evidently increased soil water content and salinity in the root zones. The depth of soil salt accumulation also uplifted from 40 to 55 cm in fresh water irrigated field to 35–55 cm in brackish water irrigated field. This is mostly because evapotranspiration can exacerbate soil salinization, meanwhile partly related to the upward capillary transportation of salts from shallow groundwater with great saline (Hamed, 2008). In addition, the electrical conductivity of soil solution in the field with brackish water exceeded the threshold for cotton growth, posing great threat on cotton productivity (Chen et al., 2018). Therefore, it is essential to investigate soil water and salt distribution in soil profiles after irrigation with brackish water, so as to evaluate the applicability of brackish water irrigation at larger scale.

Even though field monitoring has been widely used to investigate soil water–salt distribution (Rameshwaran et al., 2016; Reyes-Cabrera, et al., 2016), systematic field investigations are often time-consuming and costly. Process-based numerical models have been used to simulate soil water-salt dynamics at any time point from a micro-spatiotemporal perspective (Müller et al., 2016). With presumed boundary conditions for future, process-based numerical models can also help to predict long-term effects of agricultural water management under different scenarios (Wang et al., 2014). For instance, HYDRUS has been widely used to simulate the movement of soil water, heat and solute, featuring various boundary conditions with a user-friendly input/output interface. In particular, root water uptake is also included in HYDRUS, which can reflect the soil water-salt distribution in root zone more effectively (Simunek et al., 2016). A great number of studies have employed HYDRUS to simulate water–salt transport under drip irrigation in various soil texture and weather conditions (e.g. Skaggs et al., 2004; Hanson et al., 2008; Kandelous et al., 2011; Bufon et al., 2012; Phogat et al., 2012; Wang et al., 2014; García Morillo et al., 2017). However, most of the previous studies treated drip irrigation regime as 2-D transects, and evenly distributed discharge rates over the entire drip line. In fact, irrigation water is not equally discharged at any place of the drip line but from distantly distributed drippers. Averaging discharge rates over drip lines, as often assumed in those 2-D models, failed to capture the boundary conditions of variable fluxes at spatially distributed drippers. Therefore, the objectives of this study are: (1) to build up a 3-D conceptual model to reflect the spatial variations of discharge rates along drip lines; (2) to apply the numerical 3-D model to capture the inter-dripper variations of soil water and salt transport when irrigated with brackish water.

2. Materials and methods

2.1. Study site

The study site is located on an alluvial plain of the Peacock River in the arid Xinjiang, northwest of China (41°35′N, 86°10′E, with average elevation of 900 m above sea level) (Li et al., 2015). It is classified as a continental desert climate with an average annual precipitation of only 58 mm, while the maximum potential evaporation is 2788 mm. The annual mean temperature is 11.5 °C, with a minimum of −30.9 °C and maximum of 42.2 °C. The study site featured loam soil with proportions