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Lateral hydraulic performance of subsurface drip irrigation based on spatial variability of soil: experiment

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ABSTRACT

Under the zero slope conditions of surface drip irrigation the emitter discharge along the lateral is also decreased for non-compensating emitters. However, in subsurface drip irrigation the lateral emitter is buried in the soil and the pressure of the emitter outlets is affected by soil physical properties. Because of the spatial variability of soil physical properties, the emitter discharge along the lateral is complex; the traditional discharge equation could not show the influence of soil properties on emitter discharge. A new emitter discharge formula is established that has soil initial water content, soil bulk density, mass fractal dimension, and head pressure as factors, and a nonlinear mathematical model of lateral hydraulics based on the emitter discharge formula is created. Experiments were then conducted to: verify the model, compare the HEPING emitter (with an inside diameter of 12 mm and outside diameter of 13 mm) and PLASSIM emitter (with an inside diameter of 14 mm and outside diameter of 15.2 mm), and assess the relative contribution of various factors to emitter discharge. The results of the experiments indicate that: ① the emitter discharge along the lateral head in the direction of flow followed a decline law in homogeneous soil, and decreased in a fluctuating manner in heterogeneous soil; ② the larger standard deviation of soil initial water content, bulk density, mass fractal dimension when each factor remained the same, the more disperse the emitter discharge along lateral.

1. Introduction

Subsurface drip irrigation(SDI) has many advantages. Compared with surface irrigation, the main advantages of SDI are related to water savings because water is applied directly to the crop's root zone's not only reduces soil water evaporation losses (Jordan et al., 2014), but also reduces water use (Mansour et al., 2010), reduces pollution (Song et al., 2006), increases farmland and irrigation efficiency (Crookston and Tullis, 2013), and enhances productivity and product quality. A further advantage of SDI is more efficient fertilization (Zhang et al., 2011) as a result of improved water application uniformity. Thus, SDI has become a common method for the irrigation of field crops (Jordan et al., 2014), orchards (Pisciotta et al., 2018), landscaping (Zhang et al., 2016), and greenhouse vegetables (Bozkurt and Mansuroglu, 2018).

From the 1990s to the start of this decade, the influence of irrigation network parameters was studied. In general, the design of irrigation systems is based on the assigned uniformity of flow rates. It must consider the flow regime, the inside diameter, pipe slope, pipe length, the inlet discharge, and the pressure head at the inlet and out terminal of the lateral (Khemaies et al., 2013). Previous continuous-uniform outlet discharge approaches for the hydraulic analysis of irrigation laterals are generally valid for large infinite number of outlets. However, for a finite number of outlets, these approaches may lead to errors in hydraulic computation, Valiantzas (2002) presented a new continuous-uniform outflow approach that takes into account the effect of the number of outlets on the lateral hydraulics, which the effect of ground slope and velocity head on hydraulic computation is considered. Khemaies et al. (2013) provided an analytical method to design evenly sloping, pressurized, nontapered, multiple-outlet pipes, the approach was derived from the solution of analytical nonlinear differential equations. Holzapfel et al. (2014) developed a classic nonlinear optimization model for the design and management of drip irrigation systems that takes into account: lateral diameter, lateral length, number of lateral emitters, number of laterals, total number of subunits, irrigation time. This approach was better applied to heterogeneous soil. However, the hydraulic performance of laterals is not only impacted by pipe material, network parameters (inlet pressure, pipeline diameter, slope, flow regime, and emitter spacing) but also by soil physical properties (Warrick and Shani, 1996), and is thus a complex issue. Lazarovitch et al. (2006) suggest that the pressure head of the soil water adjacent to

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the source outlet increases to become positive when the subsurface discharge rate is higher than the soil infiltration capacity. This is because a buildup of pressure in the soil restricts water transmission away from the dripper (Hu and Cheng, 2014).

The effects of positive water pressure created by soil conditions influence the performance of SDI systems. The obvious effect is such that emitter discharge (ED) decrease in soils with low infiltration (Shani et al., 1996). Because of the heterogeneity of soil hydraulic properties, there will be variability of dripper discharge (Lazarovitch et al., 2006), which will subsequently cause the following. First, due to the soil physical properties follow a normal distribution in nature (Hua and Nianpeng, 2016), each point in the field has different physical properties (SIWC, SBD and MFD), and there has a different effects on each emitter discharge. When the designer often deal with the irrigation systems that took the physical properties as homogeneous soil, as a result, there will be a great error between measured value and the calculated value of ED. Second, there will be spatial variability of water application in the field, i.e., localized over or under irrigation (Yıldırım, 2014). Third, influenced by irrigation uniformity, there will be strong spatial variability of soil hydraulic properties, with corresponding reductions of SDI uniformity (Ren et al., 2017).

In short, the combination of soil and the drip system hydraulic properties affect the local discharge rather than just the properties of the drip system. Researchers usually ignore the impact of soil physical properties and their spatial variability on ED to simplify calculations (Lamm et al., 2017). Thus, the error between measured and calculated values can be considerable. To address this knowledge gap, the hydraulic performance of laterals for SDI based on the spatial variability of soil physical characteristics will be addressed by this paper.

The specific objectives of this paper are to: 1) design a method to measure the ED of a lateral; 2) establish a new nonlinear hydraulic mathematical model of flow through a lateral, taking into account inlet pressure head, end flow in the lateral, number of emitters, emitter spacing, lateral slope, head losses, lateral diameter, and the soil parameters: soil bulk density(SBD), soil initial water content (SIWC), and mass fractal dimension(MFD); and 3) analyze the effect of spatial variability of soil on discharge distribution.

2. Materials and methods

2.1. Experiment principles

The experiment equipment has six major components: a water tank, pressure pump, pressure sensor, load cell, and soil box systems. The schematic diagram of the experimental set-up is shown in Fig. 1(a), and an illustration of the experimental facilities is shows in Fig. 1(b). The water tank level was 10 m and the pump head was 30 m. The head pressure can be controlled from 5 to 40 m by adjusting the inlet valve and draw-off valve. The head pressure can be controlled from 5 to 10 m by closing the pressure pump ⑨ and valve ④, and opening valves ①,②,③,⑤, and ⑥, and by finely adjusting valves ⑤ and ⑥.The head pressure can be controlled from 10 to 40 m by closing valve ③, and opening valves ① ②, ④, ⑤, and ⑥, and by finely adjusting valves ⑤ and ⑥.

2.2. Experiment test system

The experiment automatic data acquisition system (ADAS) consists of three main parts: PCI-1711 data acquisition (Advantech CO·LTD, Taiwan), HP34401A digital multimeters (Agilent Technologies Inc, USA), CDZ9-53P relays (Delixi electricity Limited company, China), DC switching power supply, ELE-801 pressure sensors (Elecall Electric CO·LTD, China), and MIK-LCS1S type load cell (Hangzhou Meacon Automation technology CO·LTD, China).A schematic representation of the test components is shown in Fig. 2.

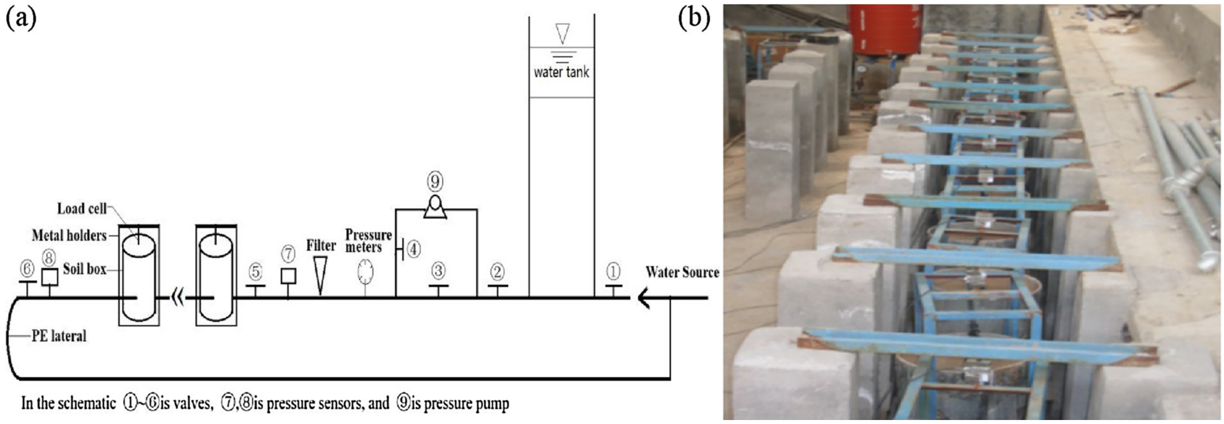
2.3. Experimental schemes

The experiment included two groups: experiments 1 and 2 (EP1, EP2) were test experiments with the inlet pressure at 25.47 m, and experiments 3 and 4 (EP3, EP4) were validation experiments with the inlet pressure at 20.17 m. Five soils with different textures for EP1 and EP2 were selected: sandy soil, loamy soil, sandy loam soil, and two mixed soils composed of loamy and sandy loam soil in different ratios. The soil types for EP3 and EP4 were fifteen mixed soils composed of loamy and sandy loam soil in different ratios. The soil particle size distribution and fractal dimension of the five soil types are shown in Table 1. The soil physical parameters of EP1 and EP2 are shown in Table 2. Because of the soil physical properties followed a normal distribution in nature (Hua and Nianpeng, 2016), to analyze lateral performance accordingly, the soil parameters of EP3 and EP4 were generated with a normal Gauss distribution (Eq. (1)), where $\theta = \mathrm{normrnd}~(14,~3,~[1,15])$, and $\gamma = (1.37, 0.06,~[1,15])$.The soil physical parameters of EP3 and EP4 are shown in Table 5.

$$v = \mathrm{normrnd}(\bar{v}, \delta, [1, n]) \tag{1}$$

where v = variables of soil, $\bar{v}$ = average of variables for soil; δ = standard deviation of variables; n = number of variables.

Two pressure non-compensating model labyrinth emitters were used: HEPING emitter (produced by Shaanxi peace technology industrial Co. Ltd in china), and PLASSIM emitter (produced by plassim technical plastics works for Agr.Ind. & Bldg.Ltd in Israeli). HEPING emitter with an inside diameter of 12 mm and an outside diameter of 13 mm; and PLASSIM emitter with an inside diameter of 14 mm and an outside diameter of 15.2 mm. To eliminate the influence of manufacturing deviations on ED, we chose 30 out of 300 emitters under a given pressure to ensure that the discharge of each emitter was as



In the schematic ①~⑥is valves, ⑦,⑧is pressure sensors, and ⑨is pressure pump

Fig. 1. (a) Schematic diagram of the SDI experimental set-up. (b) SDI experiment facilities.