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Soil moisture regimes under point irrigation

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ABSTRACT

The main objective of this paper is determination of principal relationships influencing the distribution of moisture content in a soil profile under an emitter in point irrigation. Research was carried out by conducting field experiments. They determined geometry of wetted soil volume in a soil profile under point irrigation. Infiltration of water from a single emitter and the resulting spatial distribution is a typical feature of localized irrigation technology. The field experiments using different emitter discharges and various periods of irrigation on haplic Luvisol (ha LV) (ALFISOLS Udalfs) on loess were conducted in a soil profile 1 m deep.

Admissible duration of irrigation in relation to discharge rates has been calculated and illustrated in a graph. Incorrect irrigation practices can cause serious environmental damage. A method for determining the width and depth of the wetted soil volume under the point irrigation was developed. This method is rapid and simple, and it gives consistent results.

1. Introduction

Moistened soil volumes in surface and subsurface drip irrigation systems have been measured and/or theoretically analyzed by many authors. They include Brandt et al. (1971), Bresler et al. (1971), Goldberg et al. (1971, 1976), Lomen and Warrick (1974), Keller and Karmeli (1974), Roth (1974), Ben-Asher et al. (1978), Warrick et al. (1979), Roth (1982), Amoozegar-Fard et al. (1984), Trickle irrigation (1984), Vermeiren and Jobling (1984), Clothier et al. (1985), Zazueta et al. (1995), Shwartzmann and Zur (1986), Ungureanu (1986), Shein et al. (1987), Healy and Warrick (1988), Voronin et al. (1989), Clothier and Smettem (1990), Or (1996), Zur (1996), Or and Coelho (1996), Revol et al. (1997), Coelho and Or (1997), Hoang (1998), Thorburn et al. (2003), Skaggs et al. (2004), Šimůnek et al. (2006), Singh et al. (2006), Lazarovitch et al. (2007), Qiaosheng et al. (2007), Bhatnagar and Chauhan (2008), and Elmaloglou and Diamantopoulos (2007, 2010).

A localized irrigation system offers unique agronomic, agri-technical, and economic advantages for efficient use of water and labor. The distribution of water in localized irrigated soils is extremely important from an agri-technical point view since it determines the boundaries of the root zone and the concentration of water and salts (Goldberg et al., 1976).

In point irrigation, water is applied to soil surface in small drip flows from an opening with a point discharge rate more than that for drip irrigation but less than 140 l/h. Point irrigation was first designed in Czechoslovakia in the 1960s of the 20th century. Point irrigation system is very similar to the system of drip irrigation. The point irrigation has been named after the method of localized water application. The water outflow points (emitters) are located on lateral tubes on or beneath the soil surface. Point irrigation has lower quality requirements of irrigation water than drip irrigation. Blockade is minimized due to the large orifices of emitters, usually from 1.6 to 2.4 mm. Therefore, mesh filters are usually sufficient for point irrigation. Point irrigation systems are thus often preferred to drip irrigation from an economic point of view. However, due to low pressure, water slows in the point irrigation systems laterals (0.04–0.12 MPa), the disadvantage is that small differences in elevation have a big influence on the discharge rate of the emitters and on irrigation uniformity. Increased discharges of emitters require larger capacity of all elements of the system. In practice, this often leads to excessively high flows from the point emitters with negative impact on the soil. The rate at which water enters dry soil and the ability of a soil to conduct or transmit water determine the soil–water distribution patterns. Such patterns, however, can be modified by changing the rate and frequency of water application. Although water rates through the point systems are considered low, a puddle around the emitter can occur under field conditions when the discharge rate of emitter exceeds the ability of the soil to absorb the water. In such cases the horizontal movement of water increases as the puddle area increases in size. When water is applied

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in such a way that the puddle is minimal, soil aeration would be adequate because the soil will come near saturation only around the water source. Point irrigation systems must be designed to meet the crop water requirements while applying water at a rate no more than the soil can accept. As the rate of infiltration of soils typically decreases with time, the longer the point system is operated the greater the potential for creating puddles and subsequent run-off. In soils of very low infiltration rates, puddles can be avoided only by cycling the system at frequent intervals (pulse irrigation) within the duration of irrigation. To maintain high levels of water in the wetted zone and to avoid puddles and run-off, point irrigation systems should be operated as frequently as possible.

Water application through the point delivery system is based on moisture movement in a small area of the soil. To evaluate the effectiveness of a point source irrigation system, the wetted area, wetting pattern and vertical as well as horizontal water movement in the soil should be measured (Trickle irrigation, 1984). Field experiments are needed to evaluate the assumption of homogeneity, or to determine the largest units that can still be assumed homogeneous to enable modeling. To evaluate the generic design values for point source irrigation, field and laboratory experiments can be conducted and evaluated (Brandt et al., 1971). Although the statement obtained from the USDA-SCS National Engineering Handbook (1984) is true, research is trying to obtain knowledge on what variables affect the movement of water in the soil under point source irrigation, to enable more generic irrigation design values. The authors provide several relationships based on experimental work, applicable under the conditions that they had been developed for (yet generalizing for the heterogeneity of the soil and field conditions). Clothier et al. (1985) show that in some cases the hydraulic properties of soil can be so variable in time and space as to negate the utility of detailed theoretical analyses. Until reliable and easier mathematical methods have been developed, it is suggested that field experiments or empirical methods be used. The objective of the present work is to develop a guide for determining the geometry of the wetted soil volume under irrigation point sources. Furthermore, the experimental results obtained will help in testing the validity of mathematical models of infiltration from a point source.

2. Materials and methods

The field experiments using different emitter discharges and various periods of irrigation on haplic Luvisol (ha LV) (ALFISOLS Udalfs) on loess were conducted in order to determine horizontal and vertical water movements in a soil profile.

The initial design application volume was calculated using the required wetted soil volume, based on the root zone depth and the emitter spacing, and the available soil water storage, based on the initial soil water content and the theoretically maximum soil water content held against gravity (field capacity). Field experiments were carried out in a dry period during the growing season with the natural water content in the soil profile.

The following equipment was used (listed in the order of the water flow path) to carry out the field experiments (Fig. 1): 1 – a water tank vehicle, which was used for water supply; 2 – a gate valve of the tank; 3 – a mesh filter to prevent clogging of the emitter which was connected to the outlet of the gate valve of the tank; 4 – a water meter for water rate control which was connected to the outlet of the screen filter; 6 – a reservoir with a float valve for maintaining a constant water level, which was placed beside the tank on a metal prolongated stand (7) and connected to the water meter by means of a 1.0 m long PE tube (5); 8 – a PE tube with a diameter of 12 mm and length of 10 m connected to the bottom of the reservoir (6); a PE tube (8) was fitted with the emitter (10) for the application of water rate, placed between the needle valve (9) with regulation according to the discharge rate, and a flush valve (11) for a periodic washing device. The PE pipe end is provided with a plastic stabilizing pin (13). Under the emitter (10) a large bowl (12) is placed on the soil surface for trapping the outgoing water from the emitter and also for controlling the discharge rate of the emitter. Furthermore, it is necessary to have a pump for pumping water from the large bowl into barrels in setting the discharge rates at 50–140 l/h using a needle valve, a pyramidal horn, a graduated cylinder and a stop-watch for the measurement and control of the emitter discharge; a soil coring tube, sampling rings for taking the undisturbed soil samples, a circular brass sieve with a diameter of 70 mm to prevent the destruction of the soil under the emitter, a knife, aluminum containers for soil samples, a laboratory balance and a soil oven, two intake cylinders for measuring the intake rate; a hoe, spade, shovel and a folding rule.

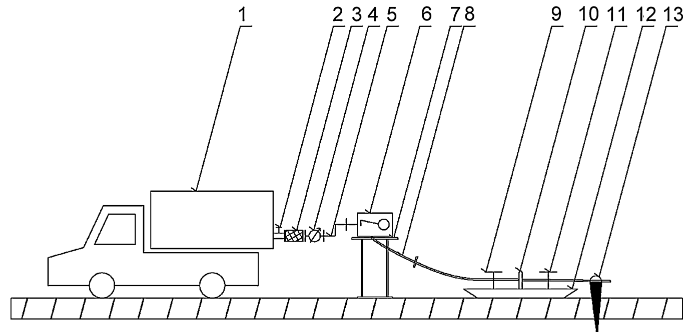

Fig. 1. Equipment used for field experiments: 1 – water tank vehicle, 2 – gate valve, 3 – mesh filter, 4 – water meter, 5 – 1 m long PE tube, 6 – reservoir with float valve, 7 – metal prolongated stand, 8 – PE tube D = 12 mm, L = 10 m, 9 – needle valve, 10 – emitter, 11 – flush valve, 12 – large bowl, 13 – stabilizing pin.

The water rate is determined on the basis of the root zone depth with the moisture content in the soil at the time of the experiment and the moisture content at field capacity. The experiment was performed as follows: before starting the experiment near the location where it was to be carried out the initial water content in the soil profile in the control (non-irrigated) soil samples was determined using the gravimetric method. Soil samples for the determination of initial soil moisture (w_i) were taken at 0.1 m increments, down to a depth of z = 1.0 m, along equally spaced distances (0.1 m) from the emitter in the (r) directions with three successive recurrences.

Before starting the experiment, it is necessary to establish the necessary equipment on a particular point of the field. After positioning the device for carrying out field experiments (Fig. 1) the equipment was used for the appropriate calibrated emitter discharge rate through the needle valve (for example 50 l/h). After opening the gate valve (2), water begins to flow from the emitter (10) into the large bowl (12). By adjusting the needle valve (9) on the discharge rate e.g. 50 l/h check the emitter leak at 25 l of water for 30 min. Depending on the speed of filling the large bowl, the water should be pumped into plastic barrels. After 30 min close the gate valve (2) to stop the water inflow into the emitter (10). Measuring the water rate from the emitter (10) 25 l, the discharge rate of the emitter sets the water application rate at 50 l/h. The water rate volume is checked by the water meter (4). For the measurement and control of the emitter discharge a calibrated cylinder and a stop-watch are used.

After calibrating the emitter by measuring its discharge rate and removing the large bowl under the emitter, a circular brass sieve with a diameter of 70 mm was put on the soil surface and, the water rate was applied.

The irrigation duration was 1 h, 1.5 h, 2 h, 2.5 h, 3 h, and 4 h for the emitter discharges from 50 to 70 l/h. For the emitter discharges