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Simulation of Soil Wetting Pattern Under Point Source Trickle Irrigation

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Abstract: Information on moisture distribution patterns under point source trickle emitters is a pre-requisite for the design and operation of trickle irrigation systems. This will ensure precise placement of water and fertilizer in the active root zone. The distribution pattern is influenced by the soil properties and the behavior of applied water. In this study, water movement in three soil types from a surface point source was investigated. Experimentation included determination of maximum depths and widths of wetted zone after one hour time interval of water application. The surface wetted radius increased with an increase in application rate. A good relationship was found between the surface wetted radius and the volume of water applied. This suggested that for a certain volume of water applied, a corresponding wetted surface radius can be predicted. The numerical values of wetted surface radius for each flow rate group were compared with those predicted by the suggested equations. Predictability of model was estimated as 96.8 and 95.3%, respectively, for prediction of wetted width and depth. The results showed good agreement for all application rates.

Key words: Trickle irrigation, dimensional analysis, model efficiency, simulation model, wetting pattern

INTRODUCTION

The last decade has seen major advances in the design, technology and management of trickle irrigation system. This is due, in the large part, to a better understanding of the movement of water in soil in response to a surface point source like the trickle emitter. One of the important aspects of planning and management of drip irrigation system is soil moisture movement pattern under it.

In trickle irrigation, the soil serves less as a reservoir for water than for conventional irrigation because the water that is withdrawn from the root zone is continually replenished. As a result, soil type does not play much role in irrigation scheduling in trickle irrigation (Lubana *et al*., 2002). However, the soil type and the application rate of water, both influence the pattern of water movement in the soil. The distances between emitters would determine the degree of overlap between neighboring wetted circles. In addition, the cost of a unit length of a lateral is influenced by the number of emitters on it. The volume of soil wetted from a point source is primarily a function of the soil texture, soil structure, application rate and the total volume of water applied (Ekhmaj *et al*., 2005; Lubana *et al*., 2002).

Present design procedures recommend the use of empirical coefficients to calculate optimal emitter spacing. These coefficients vary with emitter discharge and soil texture. Clearly, the volume of water applied per irrigation also affects the width and depth of the wetted soil volume and therefore influences the optimal emitter spacing. Wetting pattern can be obtained by either direct measurement of soil wetting in field, which is site-specific, or by simulation using some numerical or analytical models. In most of models, the Richards equation governing water flow under unsaturated flow conditions have been used to simulate soil water matrix potential or water content distribution in wetted soil. Also, the hydraulic conductivity in unsaturated flow equations is highly nonlinear and show high spatial variable (Warrick and Nielson, 1980). Numerical and analytical methods have been used to solve unsaturated flow equations. These methods call for detailed information on the physical properties of the soil and for an access to computers (Battam *et al*., 2003).

Schwartzman and Zur (1986) developed a simplified semi-empirical method for determining the geometry of wetted soil zone under line sources of water application placed on surface. They assumed that the geometry of wetted soil, the width and depth of wetting at the end of irrigation depends on the soil type, emitter discharge per unit length of laterals and total amount of water in the soil. The objectives of the present study were to develop and test the simplified semi-empirical method of Schwartzman and Zur (1986) for determining the geometry of the wetted soil volume under point sources in three type soil.

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DESCRIPTION OF MODEL

Schwartzman and Zur (1986) model can be applied for use under surface drip irrigation from point source. The geometry of wetted soil volume, width (W) and depth (Z) under this method of water application at the end of an irrigation event was assumed to depend on emitter discharge (q), total amount of water (V), saturated hydraulic conductivity of soil (Ks). Therefore, the functional relationships among these parameters may be written as:

$$W = f_1(V, q, K_s) \qquad Z = f_2(V, q, K_s) \tag{1}$$

Using dimensional analysis method, three dimensional independent terms were developed which are represented as follows:

$$V^* = V\left(\frac{K_s}{q}\right)^{3/2} \qquad Z^* = Z\left(\frac{K_s}{q}\right)^{1/2} \qquad W^* = W\left(\frac{K_s}{q}\right)^{1/2} \tag{2}$$

The relationships between dimensionless parameters; Z*, W* and V* in Eq. 2 could be extracted either from experimental or simulated results. The following relationships exist between dimensionless parameters:

$$W^* = A_1 V^{*n_1} \tag{3}$$

$$Z^* = A_2 V^{*n_2} \tag{4}$$

In Eq. 3 and 4, n_1 and n_2 are exponents and A_1 and A_2 are constants of equation, respectively. Now putting values of W* and V* in Eq. 3, the following relationship for wetted width was obtained:

$$W = A_1 V^{n_1}\left(\frac{K_s}{q}\right)^{\frac{3n_1-1}{2}} \tag{5}$$

Similarly putting values of Z* and V* in Eq. 4, yielded value for wetted depth as below:

$$Z = A_2 V^{n_2}\left(\frac{K_s}{q}\right)^{\frac{3n_2-1}{2}} \tag{6}$$

MATERIALS AND METHODS

Measurement of soil wetted front: The experiments were conducted in Physical Modeling Laboratory, Water Engineering Faculty, Shahid Chamran University, Ahwaz, Iran. The simulation experiments for the three-dimension used in the present study consisted of a Perspex transparent box 180 cm long, 150 cm wide and 120 cm deep which a quarter of that was eliminated (Fig. 1). The box was packed with a soil which was air-dried and passed through a 2 mm (No. 10) sieve. Uniform bulk density was assured by packing 5 cm layers of pre-weighed soil. Three soil types were used in this study. A silty clay loam packed to a bulk density of 1.36 g cm^{-3} and a loam packed to a density of 1.6 g cm^{-3} and a sandy packed to a density of 1.72 g cm^{-3}. The saturated hydraulic conductivity determined using Rosetta software (Version 1.0) (Schaap *et al*., 2001) was 32.1 cm day^{-1} for the silty clay loam and 23.8 cm day^{-1} for the loam and 99.52 cm day^{-1} for the sand. Water was applied from a calibrated emitter which was placed in the geometrical center at the top of the soil surface according to Fig. 1. Three emitter discharges of 3.46, 2.17 and 1.38 l h^{-1} with three replications were tested on each soil making a total of 27 experimental runs.

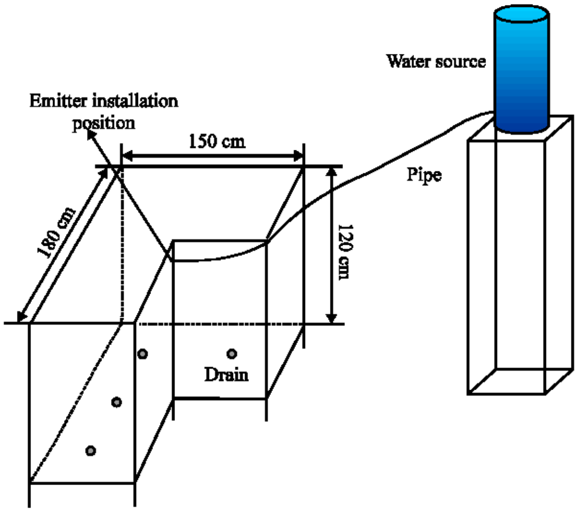

Fig. 1: Physical model for wetting front observations

The position of wetting front was marked on the transparent wall of the box at fixed time intervals (1 h). These lines were then copied on transparent drawing paper. The depth and width of the wetted soil volume at various times during infiltration was determined from these results. Then the results compared simulated values against observed values in field to ensure model applicability under field conditions.

Steps for simulation: The following steps were followed for simulation of wetted width, W and depth, Z of wetted soil zone around placed emitter with point source of water application:

- Values of Z and W were observed under given q and V for given soil of known value of K
- Values of V*, W* and Z* were estimated using Eq. 2 for different simulated values
- Values of W* and V* were presented graphically (Fig. 2)
- The best fit equations and correlation coefficients relating simulated V* to simulated W* was computed for each three soil types (Fig. 2)
- Values of Z* and V* were presented graphically (Fig. 3)
- The best fit equations and correlation coefficients relating simulated V* to simulated Z* was computed for each three soil types (Fig. 3)

Values of constant were put into Eq. 5 and 6. It yielded relationships for wetted depth, Z and wetted width, W of soil (Table 1).

The values of wetted widths and wetted depth of soil were simulated using top equations for different discharge rates and duration of water application.

Performance of simulation model: Performance of model was tested by comparing simulated values against observed values in field to ensure model applicability under field conditions. For this purpose null-hypotheses of equal variances and equal means at 0.05 significance level were tested using t-test. These tests were performed for comparing simulated values against observed values of wetted soil depth and width for given duration of water application.

Calculated values of t were found less than critical values. Therefore, null-hypotheses of equal variances and means, respectively, were accepted. It was then concluded that simulated values followed distribution not different than observed values at 0.05 significance level.

Table 1: Equations simulated and observed values

Equation	Sandy soil	Loam soil	Silty clay loam soil
Wetted width, (W) (simulated)	$W = 5.32V^{0.21}(\frac{K_s}{q})^{0.185}$	$W = 2.21V^{0.75}(\frac{K_s}{q})^{0.625}$	$W = 3.25V^{0.48}(\frac{K_s}{q})^{0.22}$
Wetted width, (W) (observed)	$W = 5.02V^{0.19}(\frac{K_s}{q})^{0.2}$	$W = 2.25V^{0.86}(\frac{K_s}{q})^{0.5}$	$W = 3.35V^{0.45}(\frac{K_s}{q})^{0.2}$
Wetted depth, (Z) (simulated)	$Z = 8.04V^{0.59}(\frac{K_s}{q})^{0.385}$	$Z = 2.23V^{0.52}(\frac{K_s}{q})^{0.28}$	$Z = 4.06V^{0.74}(\frac{K_s}{q})^{0.61}$
Wetted depth, (Z) (observed)	$Z = 8.1V^{0.57}(\frac{K_s}{q})^{0.396}$	$Z = 2.31V^{0.49}(\frac{K_s}{q})^{0.27}$	$Z = 3.98V^{0.70}(\frac{K_s}{q})^{0.68}$

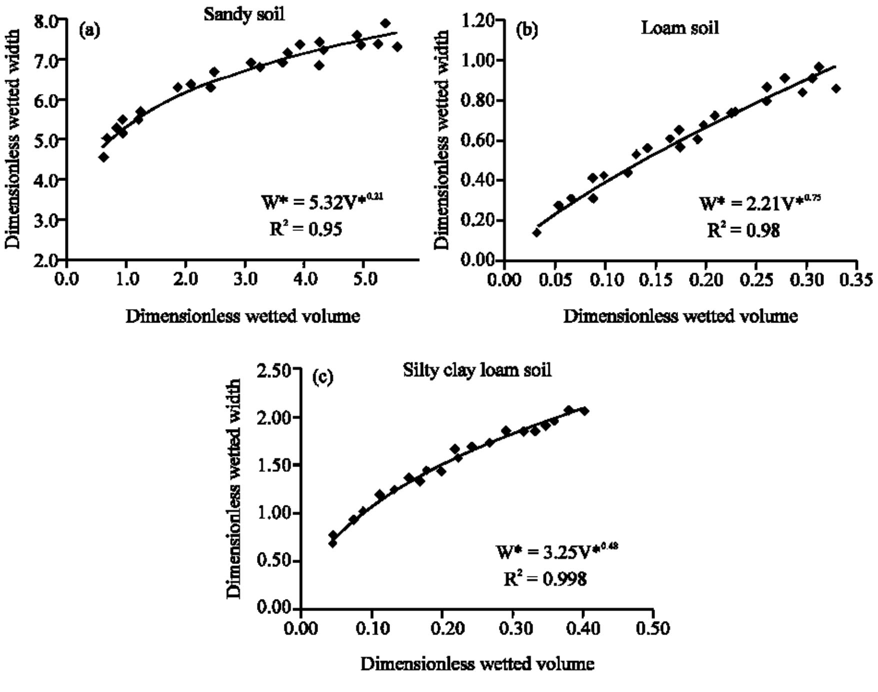

Fig. 2: Relationship between simulated dimensionless wetted soil width and simulated dimensionless wetted soil volume

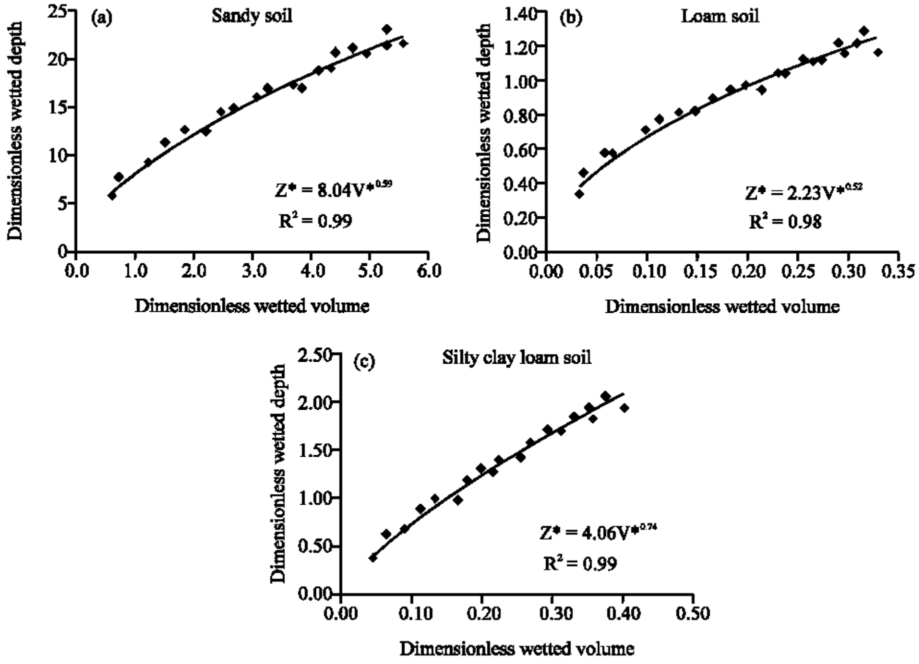

Fig. 3: Relationship between simulated dimensionless wetted soil depth and simulated dimensionless wetted soil volume

This indicated that model may be used for simulation of wetted soil depth and width in duration of water application.

RESULTS AND DISCUSSIONS

The wetted width and depth was affected by discharge rates of emitters. With increasing discharge rates of emitters depths and width of wetted zone of soil increased. The reason was that, with increasing discharge rate the volume of water supplied in a given duration increased which created higher volume of wetted soil zone.

It was observed that wetted width and depth of was affected by duration of water application. These increased with increased duration of water application for given discharge rate. Because, with increased duration of operation more volume of water is applied that was occupied by larger wetted volume of soil (Fig. 4).

An increased in the value of K representing a shift to lighter soils results in an increase in the ratio of the wetted soil depth to the wetted soil width (Fig. 4). It should be stated, wetting pattern was affected by soil structure (Peter *et al.*, 2003). As expected, more transmissive soil (silty clay loam, K = 32.1 cm day^{-1}) have greater values of Z and smaller values of W than more slowly permeable soil (loam, K = 23.8 cm day^{-1}). After extension application water value of W changes little in sandy soil but are still increasing in silty clay loam and loam soils.

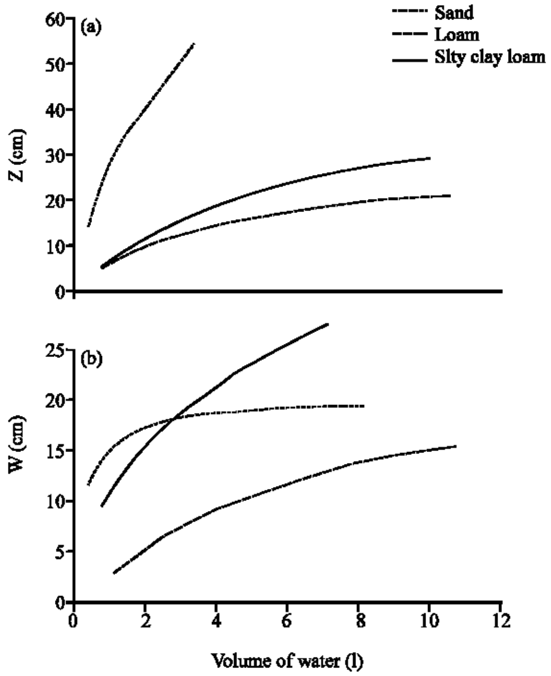

Fig. 4: Change in vertical distance and change in radius of the wetted volume of water applied for three contrasting soils

Doubling the value of emitter discharge tends to increase the wetted soil width more than to decrease the wetted depth.

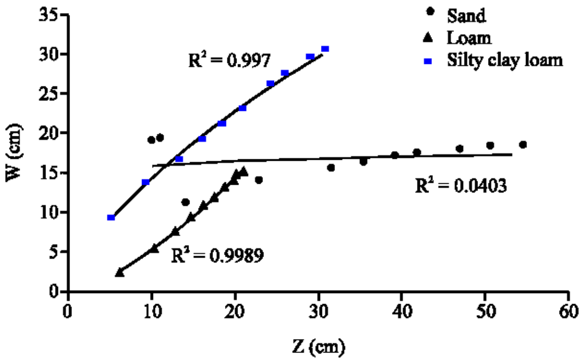

Fig. 5: Relationship between the radius (W) and depth (Z) of wetted volume

Good agreement between simulated values and observed values strengthens our confidence in the validity of the empirical equations developed for the case of a point source. However, it is still of critical importance to test these equations in the field.

There was a poor relationship between W and Z for sandy soil. Also, these values were well correlated in loam and silty clay loam soils ($R^2 = 0.99$) (Fig. 5).

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