Effect of application rate and applied volume on moisture distribution pattern under drip irrigation by using HYDRUS -2D

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ABSTRACT

Drip irrigation has gained widespread popularity as an economically viable method of applying water. A constraint of drip irrigation is the number of emitters and laterals required to adequately deliver water to plantroots. During irrigation the water content in the soil changes spatially and temporally. Water distribution in the soil is strongly dependent on the design parameters of the irrigation. For effective design of drip irrigation systems, the water dynamics in soil needs to be predicted using all design parameters.

Richard's equation was solved using HYDRUS and vGM parameters obtained by using ROSETTA were used as input for HYDRUS. The HYDRUS model was calibrated and validated for different discharge rate and volume application combination. The modeling results showed that the HYDRUS-2D simulated the soil moisture satisfactorilyin terms of statistical parameters R^2 and RMSE.

Effect of different discharge of emitter with combination of different volume on moisture distribution pattern was also studied and results showed that as discharge rate and volume of water increased wetted diameter also increased upto 30 hours and decreased after 30 hours from time of application.

For Akola station, it was observed that the distance between two emitters should not be more than 48 and 52 cm in case of 4 lph and 8 lph emitter respectively.

Keywords: HYDRUS, Soil moisture, Modeling

INTRODUCTION

The emitters sometimes interact, for instance, for irrigation of row crops, emitters have to be closely spaced along the laterals to maintain the necessary strip of wetted soil along the row. During irrigation the water content in the soil changes spatially and temporally. Water distribution in the soil is strongly dependent on the design parameters of the irrigation system (drip lateral spacing, system pressure, flow rate, trickle emitter type), climatic conditions, root distribution, soil type, rates of water application and vegetation. For effective design of drip irrigation systems, the water dynamics in the soil needs to be predicted using all above mentioned variables.

Factors affecting the spread of water from drip sources include various soil physical properties such as texture and structure (e.g., Warrick, 1974; Bresler, 1975; Cote *et al.* 2003; Thorburn *et al.* 2003). It has also been suggested that certain management techniques such as pulsed applications, high application rates, and preirrigation of soil beds may increase horizontal spreading of water (e.g. Li *et al.* 2004). For example, some irrigation guidelines indicate that the emitter rate will significantly affect the horizontal/vertical ratio of the wetted soil, with a higher emitter rate increasing the ratio. These guidelines are developed based on surface drip irrigation systems in which high application rates cause water to pond and spread across the soil surface (Brandt *et al.* 1971; Bresler, 1978). When two adjacent wetting patterns begin to overlap, however, the problem becomes a fully three-dimensional problem and hence needs to be solved using a three-dimensional numerical simulator. Depending on emitter spacing, irrigation duration, initial water content, and soil properties, the wetting patterns of two adjacent emitters will eventually overlap to such extent that the water distribution between two emitters along a lateral becomes relatively uniform (Skaggs *et al.* 2004).

The modeling of water movement in soil requires the knowledge of the soil hydrological properties especially soil water retention curve and hydraulic conductivity-water content relationship. These two basic hydrological characteristics must be defined experimentally before it is possible to carry out numerical analysis of water movement in unsaturated and saturated soils. In virtually all studies of saturated and unsaturated zone, the fluid motion is assumed to obey the classical Richard's equation. The HYDRUS program numerically solves the Richard's equation for variably saturated water flow. The flow equation includes sink term to account for water uptake by plant roots. HYDRUS can be used to analyze water movement in unsaturated, partially saturated or fully saturated porous media.

MATERIAL AND METHODS

The experiment was conducted during 21st March 2018 to 11th April 2018 at Research Farm of Department of Irrigation and Drainage Engineering, Dr. PDKV, Akola.

Average annual precipitation of Akola is 760 mm. The minimum temperature over the period of study varied from 17.2° to 26°C whereas maximum temperature varied from 36.4° to 45°C and Evaporation varied from 8.2 to 13.9 mmday^{-1}respectively.The field experiment was conducted with the help of micro-irrigation set up and with various combinations of emitter discharge. Two variables affecting water flow namely application rate and applied volume were considered. Investigation was carried out with 6 different combinations. A coordinate system was established on the profile with the origin at the soil surface exactly below the emitter. During application of each irrigation combination, soil samples were collected after 12 hrs for determination of soil water content. Study was carried out with the objective as effect of application rate and applied volume on moisture distribution pattern under drip irrigation.

Table 1. Field experiment - Treatment details

Combination Number	Discharge rate of emitter, lph	Volume to be applied, lits	Time required for application, hrs
T_1	4	8	2
T_2	4	12	3
T_3	4	16	4
T_4	8	8	1
T_5	8	12	1.5
T_6	8	16	2

Following data on movement of wetting front was observed

i. Surface wetted radius (cm) as function of applied time (min) for different application rates.

ii. Vertical wetted depth (cm) after redistribution of 48 hrs for two discharge rates (q).

Laying of gypsum block sensors in the soil

Gypsum block sensors were used to determine soil water content at different depth and distance from the emitter, placed at the centre of experimental plot. Before installation, gypsum blocks were soaked in the water for two hours. In all four direction at every 10 cm gypsum blocks were inserted at 10 and 30cm depth below the soil surface in accordance to soil profile study carried out .In each maximum distance from emitter was 30cm.

Modeling of moisture distribution using HYDRUS-2D

HYDRUS-2D is an extension of SWMS-2D and Chain- 2D. It is a finite element model which solves the Richard's equation for variably saturated water flow. The flow equation includes sink term to account for water uptake by plant roots. HYDRUS can be used to analyze water movement in unsaturated, partially saturated or fully saturated porous media. The program can handle flow regions delineated by irregular boundries. The flow region itself may be composed of non uniform soils having an arbitrary degree of local anisotropy. Flow and transport can occur in the two-dimensional vertical or horizontal plane, a three-dimensional region exhibiting radial symmetry about vertical axis, or fully three dimensional domain.

Following parameters were required by HYDRUS- 2Dmodel.

i. Residual water content (θr)

ii. Saturated water content (θs)

iii. Air entry potential parameter (α)

iv. Pore size distribution parameter (n)

v. Saturated hydraulic conductivity (Ks)

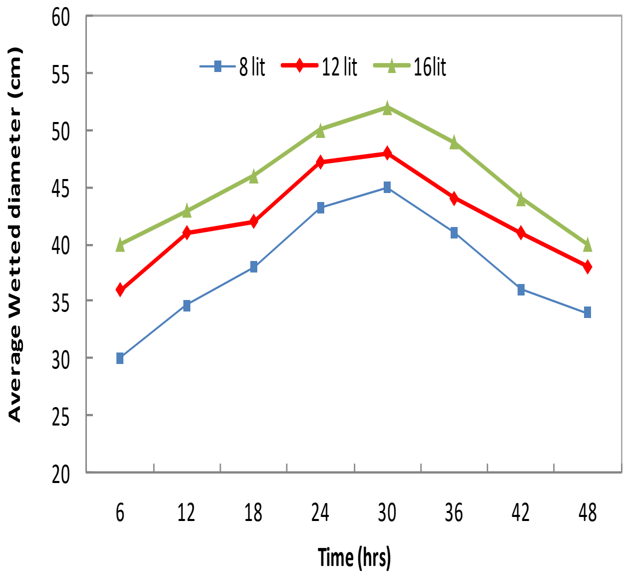

Fig. 1 Variation of average wetted diameter with respect to time for treatment T_1, T_2 and T_3

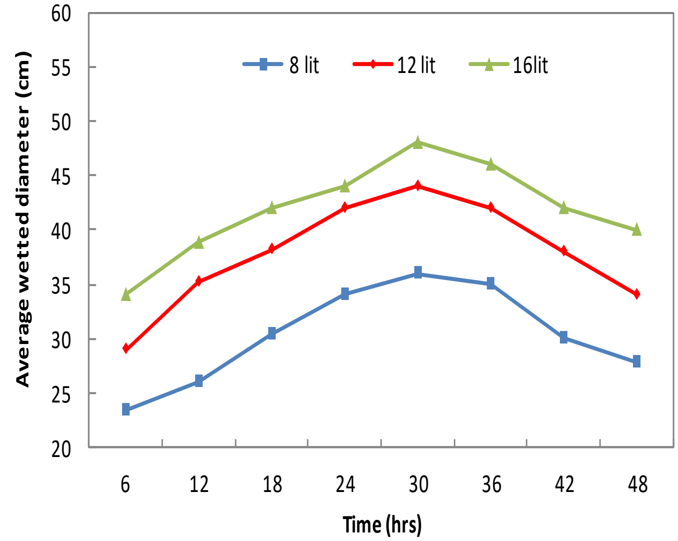

Fig. 2.Variation of average wetted diameter with respect to time for treatment T_4,T_5 and T_6

vi. Pore connectivity parameter (l)

vii. Evaporation

RESULTS AND DISCUSSION

The field experiment was conducted using drip irrigation layout and gypsum block sensors for different discharge rate and volumes combination.

Effect of application rate and applied volume on moisture distribution pattern under drip irrigation

The variation of wetted diameter in respect to applied volume and emitter discharge for the combination of different application rate of emitter (4lph and 8lph) and applied volume (8,12,16 lit*) i.e.* for treatments T_1, T_2, T3, T4, T5 and T6 are depicted in Fig.1and 2 respectively.

From Fig.1 it is observed that for 4 lph emitter with 8 lit volume combination, the average wetted diameter increases gradually to 24 cm after 6 hours of application of water and it increased to 30 cm after 30 hours. Later on it gradually decreased to 28 cm at 48 hours after application of water. Whereas in case of 4 lph emitter with 12 lit volume combination and 4 lph emitter with 16 lit volume combination, the average wetted diameter reached to maximum *i.e.* 44 and 48 cm, respectively, after 30 hours of water application. In these both cases, it decreased gradually to 34 and 40 cm after 30 hours of water application.

Likewise from Fig. 2 it is observed that for 8 lph emitter with 8, 12, 16 lit volume combination the average wetted diameters increased gradually after 6 hours of water application to 30, 36, 40 cm and it was maximum at 30 hours of water application *i.e.* 45, 44, 52 cm and it gradually decreased to 34, 38, 40 cm at 48 hours of water application.

In general, it is observed that as the discharge rate and volume of water increases, the average wetted diameter also increases upto 30hrs after application of water. It is observed that the average wetted diameter decreases gradually after 30hrsfrom time of application of water. Thus for soil at experimental site, the distance between two emitters should not be more than 48 and 52 cm in case of 4 lph and 8 lph emitter respectively considering the wetted diameter.

Modeling of moisture distribution using HYDRUS-2D

HYDRUS 2D model set up

HYDRUS-2D is a widely used physically based model for soil moisture simulation. In the present study HYDRUS was used for the determination of K-ϴ relationship. HYDRUS requires the value of saturated moisture content (Θ_s), residual moisture content (Θ_r), saturated hydraulic conductivity (K_s) and vanGenuchten's water retention curve parameters *i.e.* α and n.Saturated moisture content was considered equals to total porosity of soil. The saturated moisture content varies from soil to soil and with soil depth. From Table4.1 it is understood that the value of $\Theta_s$is 0.40 cm³ cm⁻³ for 0-18 depth and 0.38 cm³ cm⁻³ for 18-42cm soil depth.

Determination of soil residual water content, Θ_r is difficult to determine in the laboratory. K-ϴ relationship is influenced by the choice of Θ_s and Θ_r. In the present investigation Θ_r was estimated using ROSETTA software. It was found that the value of Θ_r ranges from 0.1050 to 0.1051 cm³ cm⁻³ at different depths for soil under study. α, n and m are independent parameters of vGM. α and n were estimated by ROSETTA software (Art.3.3.1.1.3)and are presented in the Table 4.1. These parameters were used to obtain K-ϴ relationship.

Table 2. Hydraulic properties and vGM parameters for soil at the experimental plot using ROSETTA

Soil depth, cm	Saturated moisture content, $cm^3\ cm^{-3}$	Residual moisture content $cm^3\ cm^{-3}$	Saturated hydraulic conductivity, $cm\ h^{-1}$	vGM parameters	
				α, cm^{-1}	n
0-18	0.40	0.1050	1.07	0.0187	1.2872
18-42	0.38	0.1051	1.06	0.0189	1.2809

Calibration of HYDRUS-2D model

Calibration of HYDRUS-2D was carried out for the combination of 4lph discharge rate with 12 lit volume of water. The selected model parameters were varied, *i.e.* the manual calibration procedure based on trial and error process of parameter adjustment was used, and several simulations were performed to get an adequately calibrated model. After each parameter adjustment, the simulated and observed soil moisture was compared to judge the improvement in predictions. The performance of model for simulating the soil moisture was evaluated using graphical presentation and evaluation of statistical parameters *i.e.* R^2 and RMSE.

The temporal variations of observed and simulated soil moisture for soil under study for 0-10 cm and 10-30 cm depth are presented in Fig.3. and 4 respectively.

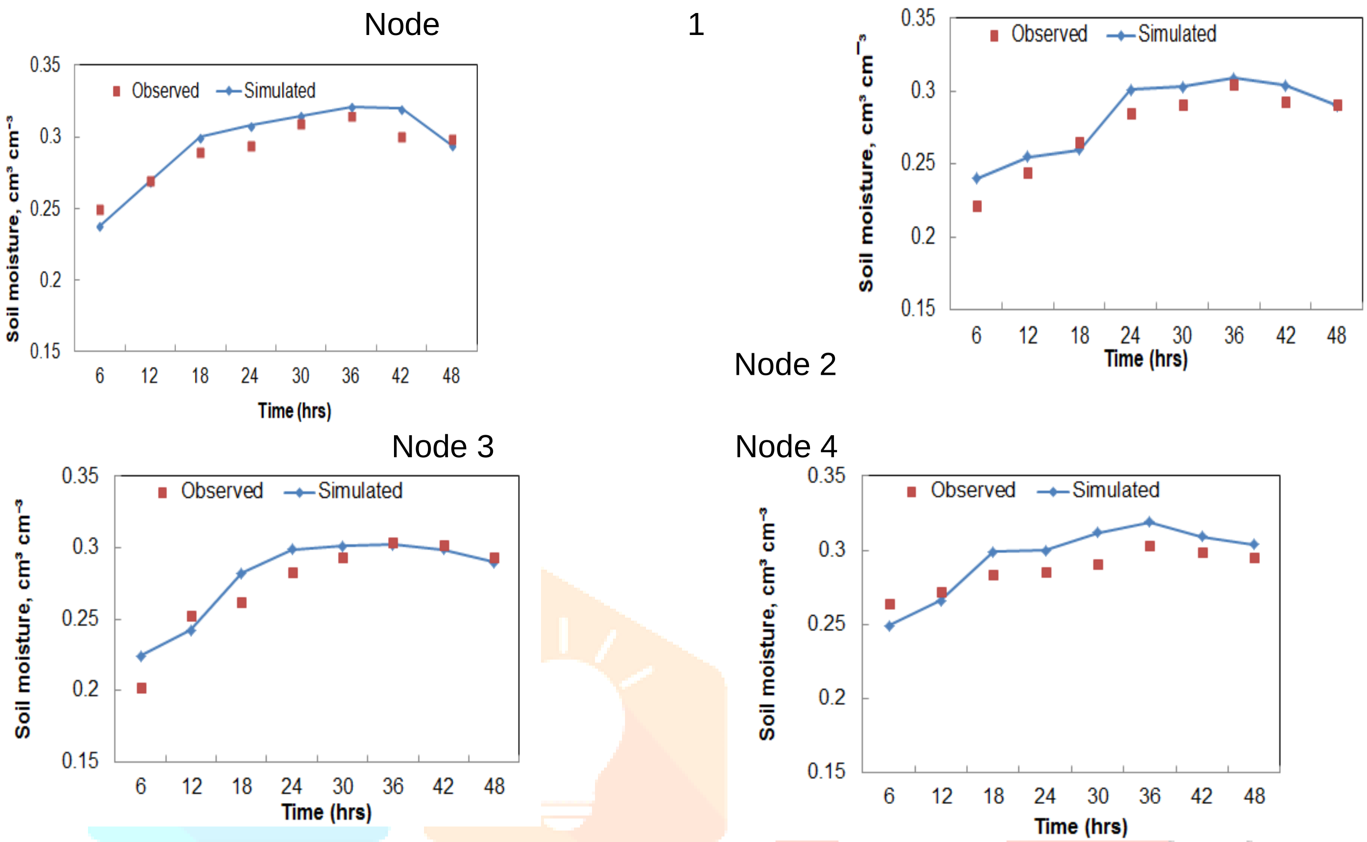

Fig. 3 .Temporal variation in observed and simulated soil moisture at 0-10 cm depth

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The temporal variations of observed and simulated soil moisture for soil under study for 0-10 cm and 10-30 cm depth are presented in Fig. 3. and 4 respectively.

As evident from the Fig. 3 and 4, the simulated and observed soil moisture matches well for both soil depths. Statistical parameters for variation in soil moisture at each node were evaluated.

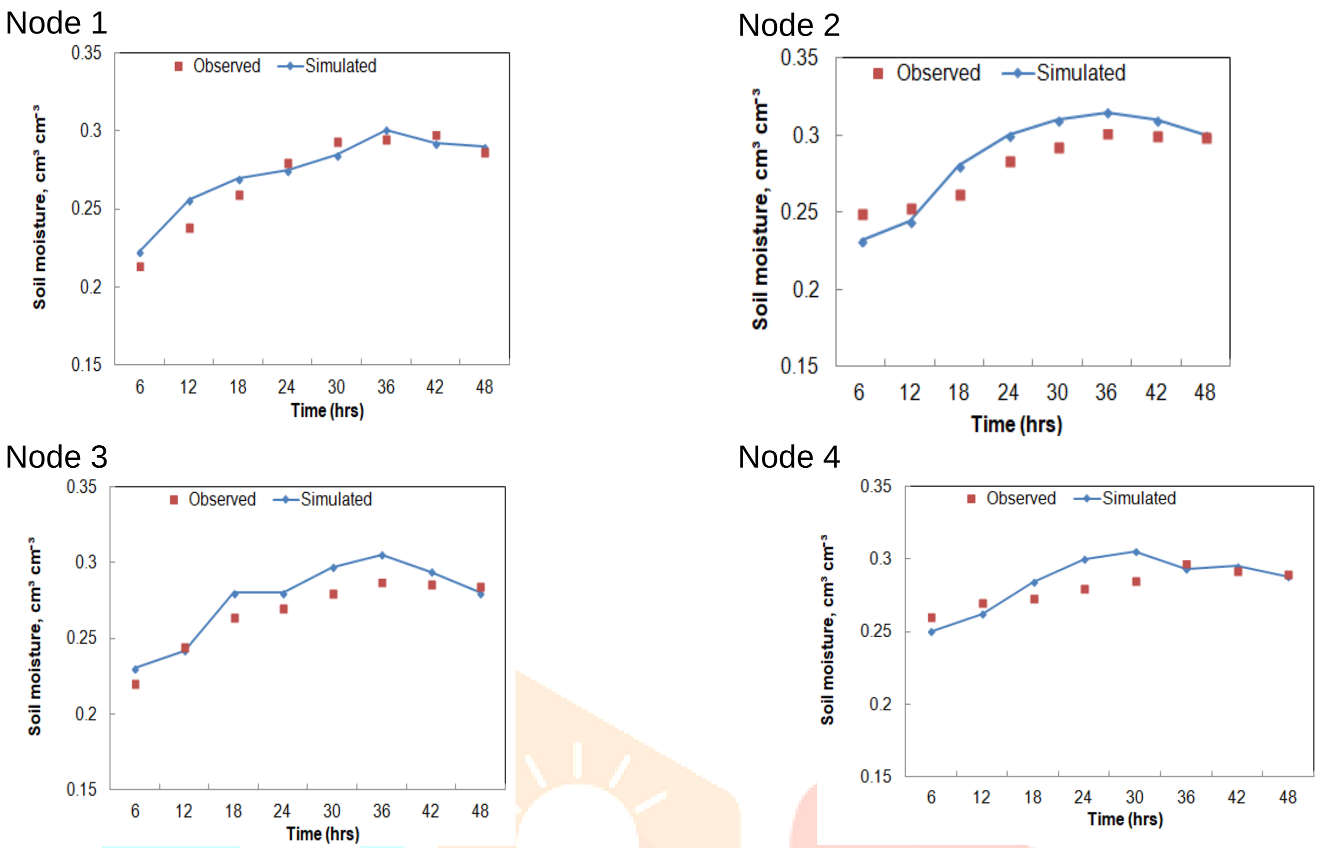

Fig 4 .Temporal variation in observed and simulated soil moisture at 10-30cm depth

CONCLUSIONS:

- Effect of different discharge of emitter in combination of different volume on moisture distribution pattern was also studied and results showed that as discharge rate and volume of water increased, average wetted diameter also increased upto 30 hours and later on decreased gradually.
- Calibration and validation results of HYDRUS for the soil show that the model simulates the soil moisture satisfactorily. The calibrated values of Ks α, n were finalized as simulated and observed soil moistures matches for 0-10 and 10-30 cm depth below soil surface. Also the performance of model in terms of statistical parameters is good.

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