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Modeling the Soil Wetting Pattern under Pulse and Continuous Drip Irrigation

Samir Ismail, Tarek Zen EL-Abdeen, Abel Aziz Omara and E. Abdel-Tawab

Agricultural and Biosystems Eng. Dept., Faculty of Agric., Alexandria Univ., Egypt

Abstract: There were some problems that face continuous drip irrigation system in Egypt, such as emitter clogging, due to the narrow paths of water which give small discharge and in sandy soil, the depth of wetting pattern is relatively higher than the width. They cause deep percolation beyond root zone. Thus the need to increase the width of wetting pattern and use of high emitter discharge suggest the use of pulse drip irrigation. The information on depths and widths of wetted zone of soil plays the greatest role in design and management of drip irrigation system. There is a lack of models to predict wetting pattern under pulse and intermittent flow regime, since the applicability of the available models were limited to continuous flow regime only. Therefore, the objective of this research was to develop a dimensional analysis model to estimate both depth and width of wetting pattern under different flow regimes. Thus, a model was developed using semi-empirical approach and dimensional analysis method for determining geometry of wetted root zone under. The predicted values of wetted depth and width were compared with those obtained through laboratory experiments conducted in same soil. Experiment included determination of maximum depths and widths of wetted zone after 1, 2, 3, 4 h of water application under different flow regimes. Predicted and observed values were compared to test model applicability in laboratory conditions. On the basis of root mean square, mean error and model efficiency parameters model performance was found good. Thus, developed models can be used to predict wetting pattern under continuous, intermittent and pulse flow with line source of water application. Pulse flow results showed that the wetted width increased and wetted depth decreased as the operating on-time decreased for the same amount of applied water. As the pulsed flow was increased from six to twelve times the continuous flow, deep percolation was reduced and horizontal spread increased. This result shows the advantage of pulse flow, for reducing the deep percolation of water under the crop root zone, while obtaining a wide horizontal spread of wetting. This enables using a highly discharge emitter with the same amount of water.

Key words: Drip irrigation · Dimensional analysis · Soil wetting pattern · Pulse flow · Intermittent flow · Continuous flow

INTROCTION

Egypt is located in a dry climate zone where rainfall is scarce and the desert covers most of the land. Egypt's main and almost exclusive resource of fresh water is the Nile River. In addition to its fixed Nile quota of 55.5 BCM, a deep groundwater reservoir, which is not renewable, may be utilized with a rate of 2.7 BCM/year over a period of 100 years. The current total area of irrigated land is approximately 3.53 million hectares and expected to reach about 4.62 million hectares by the year 2017 due to horizontal expansion and the implementation of the future mega projects. Consequently, the agriculture demand is expected to increase to 63.6 BCM taking into consideration the rising of irrigation efficiency by extending the irrigation improvement projects to cover most of the old lands and applying modern irrigation techniques, e.g., sprinkler and drip irrigation, in the new reclamation lands [1].

Meanwhile, water demand is continually increasing due to population growth, industrial development and the increase of living standards. Because of population growth, the per capita share of water has dropped dramatically to less than1000 (700 to 500) m^3/capita, which, by international standards, is considered the "Water poverty limit". Thus, the water shortage is the main constraint and a major limiting factor facing the implementation of the country’s future economic development plans.

Corresponding Author: Samir Ismail, Ag. Eng. Dept. Faculty of Agr. Alexandria Univ., Egypt.

Drip irrigation has the tendency to increase water use efficiency only if the system is designed to meet the soil and plant conditions. Information on wetting patterns width and depth under emitters is a pre-requisite for the design and operation of drip irrigation systems. This will ensure precise placement of water and fertilizer in the crop root zone. Among the various problems associated with the drip irrigation, emitter clogging is considered as the most serious problem in drip irrigation. Water losses from deep percolation and small horizontal wetted width in sandy soils are also considered as a problem in applying drip irrigation in sandy soils. An alternative approach to the clogging problem is to increase the size of the water passage in the emitters. However, this may increase the emitter discharge which in turn would change the pattern of wetting in the soil profile. Oron [2] reported that Continuous water application is associated with increased water percolation under the root zone. Using higher emitter discharge is termed pulse flow. The principles of pulsing were first set out by Karmelli and Peri[3]. They described a pulse as consisting of an operating phase, during which water is applied to the soil; and a resting phase when the flow is zero. The average pulsed discharge is equivalent to the continuous discharge. Thus the same amount of water would be applied with a continuous discharge as in the pulsed regime provided the irrigation period or cycle is the sum of operating phase and resting phase.

Jackson and Kay [4] showed that the effect of pulsing depends not only on the soil type but also on the discharge and operating and resting times chosen. A major factor limiting high pulsed discharges is surface water ponding. Once this exceeds the local infiltration capacity of the soil, ponding spreads rapidly. This may not only change the wetting pattern significantly but may also result in run-off losses and soil erosion. Although pulsing may reduce clogging it will increase the cost of the system as larger pipes will be required to supply the larger flows and automatic sequencing valves may be needed to pulse the flows. However, this cost can be offset by reduced maintenance and cleaning/replacing emitters. The costs of pumping should not be affected provided the pulsed discharge is similar to that required in a continuous flow system. This can be achieved by careful choice of the number of trickle laterals operated during each pulse.

Mostaghimi and Mitchell [5] showed that pulsing drip irrigation significantly reduced the water losses from deep percolation in sandy soils and increased the lateral spread of water in the soil. Levin and Van Rooyen [6] reported similar advantages in reducing percolation losses but also showed that wetting patterns for pulsed and continuous flow applications were almost identical at very low discharges for point sources. Intermittent irrigation strategy based on discharge pulses followed by breaks could improve water management in the field and increase irrigation efficiency. Intermittent water application allows reducing mean irrigation rate to a level which coincides with soil's hydraulic conductivity and minimizes percolation below the main root zone [2].

Schwartzman and Zur [7] developed a simplified semi empirical method for determining the geometry of wetted soil zone under line sources of water application placed on surface for continuous flow regime. 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 soil water content in the soil. The soil type was represented by the saturated hydraulic conductivity. They used dimensional analysis approach to develop this model. This model predicts wetting front position under surface drip irrigation system only as a function of applied water and simple soil properties such as saturated hydraulic conductivity. Therefore, reducing the complexities encountered in numerical and analytical methods for designing purpose. The information on distribution of matric potential or water content within wetted soil zone is not required for most of field conditions. But, information on depths and widths of the wetted zone of soil will serve the purpose [8]. There is a lack of such available model to predict wetting pattern under pulse and intermittent flow regime, since the applicability of above model was limited to prediction under continuous flow regime only. Therefore, strong need is felt to develop new model to predict wetting pattern under different flow regime with line source of water application.

Therefore, the objective of this research was to develop a dimensional analysis model to predict wetted soil depth and width under different flow regimes.

Laboratory Experiments: Laboratory experiments were conducted on a 100 × 100 × 15 cm soil box that had transparent front wall and was filled with a sandy soil (99% fine sand, a bulk density (BD)of 1.53 gm/cm^3 and saturated hydraulic conductivity of 0.24 cm/min) as shown in Fig. 1. The box was packed with a soil which was air-dried and passed through a 2 mm (No. 10) sieve. Uniform BD was assured by packing 5 cm layers of pre-weighed soil. To prevent preferential flow along the walls, the walls were first treated with glue and sprayed

Table 1: Flow regime treatments.

Treatments	Continuous discharge Q_c, (L/hr)	Pulsed discharge Q_p, (L/hr)	Operating time t_o, minutes in every hour	Rest time t_r,minutes in every hour	Irrigation period(hr)
Continuous	0.6	-	60	0	4
Intermittent		0.6	60	60	8
Pulse (30 min-on)		1.2	30	30	4
Pulse (20 min-on)		1.8	20	40	4
Pulse (15 min-on)		2.4	15	45	4
Pulse (10 min-on)		3.6	10	50	4
Pulse (5 min-on)		7.2	5	55	4

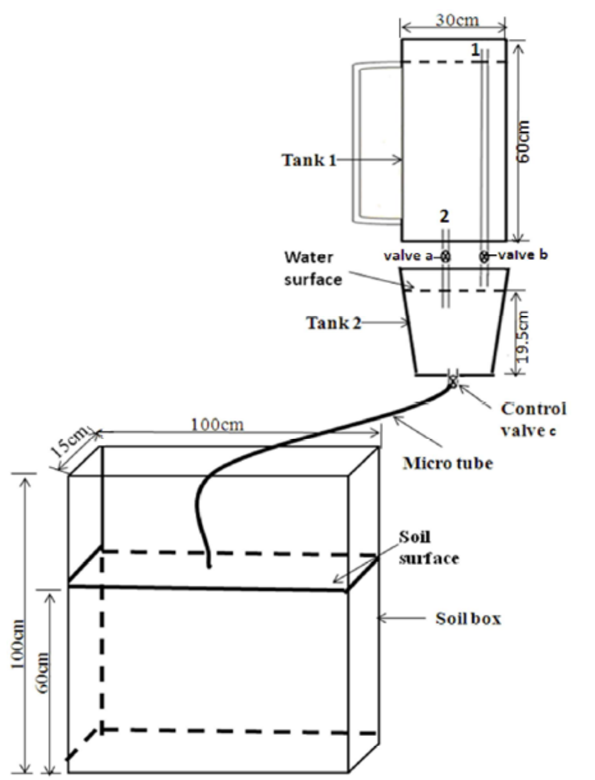


Fig. 1: Schematic diagram of experimental apparatus.

with sand to create a course surface. The position of wetting front was marked on the transparent wall of the box at fixed time intervals (1 h) until the end of irrigation. If many emitters are close together on a line, the result is an effective line or strip source and the pattern of wetting will be in two dimensional (horizontal in the direction perpendicular to the line-source and vertical) rather than in three dimensional.

Irrigation Timing:

- If in-line emitter is used (GR) with a discharge of 2 L/hr at a 50 cm spacing, then; the discharge of linear meter for drip irrigation line = 4 L/hr.
- The soil slice used in the experiment was 15 cm. So, the discharge was (4 x 0.15= 0.6L/hr).
- Experiment was carried out during a period of 4 hours, which represents four cycles, (cycle time = 1 hr).
- Water volume = 0.6× 4= 2.4 L. (water volume is constant for all treatments)

Five pulses and intermittent flow regimes were selected within the range of most commercially available trickle equipment for comparison with a continuous flow of 2L/hr (according to the laboratory experiment, the continuous discharge is constant at 0.6L/hr). The flow rates used are shown in Table 1.

Model Development

Continuous Flow: Dimensional analysis is used to estimate the wetted soil geometry. As one of the methods of establishing numerical models in physics, dimensional analysis determines the relationship among physical variables using the information provided by dimensions of physical variables according to the consistency in dimension theory (Montero *et al*. [9]). More specifically, Buckingham's π-theorem is used for analysis of consistency in dimensions. The theorem states as:" If there are n variables (dependent and independent ones) in a dimensionally homogeneous equation and if these variables contain m fundamental dimensions, then the variables are arranged into (n-m) dimensionless terms and these dimensionless terms are called π-terms".

The dimensions of wetted pattern depend on water discharge rate, soil saturated hydraulic conductivity and irrigation time.

There were two separate functional relationships of a wetted soil volume, one for wetted soil depth (z) and the other for wetted soil width (d) the two functions can be written as follows:

$$z = f_1(Q_c, k_s, T) \tag{1}$$

$$d = f_2(Q_c, k_s, T) \tag{2}$$

where f_1 and f_2 are function signs;

- Z Is the wetted soil depth (cm).
- d Is the wetted soil width (cm)
- Q_c Is the discharge rate of continuous drip irrigation ($cm^3\ min^{-1}$).
- K_s Is the saturated hydraulic conductivity of soil (cm min^{-1})
- T Is irrigation time (min)

The basic dimension of each variable can be expressed as follows:

$z = L$, d = L,

$Q_c = L^3T^{-1}$,

$k_s = LT^{-1}$, and

$T = T$

The number of π terms (free variables) is equal to (n-m), where n = 4 which is the total number of variables in the experiment (z, Q_c, k_s, T) and m=2 which is the number of reference dimensions (L, T).

Free variables = n-m = 4-2 =2

$$F(\pi_1, \pi_2) = 0 \tag{3}$$

The dependent variables (repeating variables) were selected as k_s and Q_c, which involve all fundamental dimensions. The π term was formed by grouping one of the free variables with all dependent variables, starting with the free variable, z, the first π term can be formed by combining z with the dependent variables such that

$$\pi_{1z} = k_s^{a1}.Q_c^{b1}.z \tag{4}$$

Estimating a1, b1, so that the combination is dimensionless

$(LT^{-1})^{a1}.(L^3T^{-1})^{b1}.\ L = L^0.\ T^0$

So: a1+3b1= 0 (for L)
-a1-b1= 0 (for T)

Therefore:

a1= 1/2 and b1= -1/2

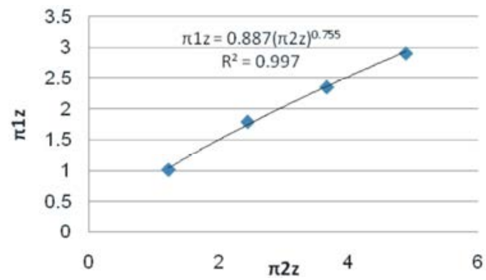


Fig. 2: Relation between π_{1z} and $\pi_{2z}$of continuous drip irrigation

The π term them becomes

$$\pi_{1z} = z\sqrt{\frac{K_s}{Q_c}} \tag{5}$$

Repeating the preceding steps, the second π term can be obtained as follows:

$$\pi_{2z} = k_s^{a2}.Q_c^{b2}.\ T = (LT^{-1})^{a2}.\ (L^3T^{-1})^{b2}.\ T \tag{6}$$

a2+3b2=0 (for L)
-a2-b2+1=0 (for T)
a2= 3/2, b2= -1/2

$$\pi_{2z} = T\sqrt{\frac{K_s^3}{Q_c}} \tag{7}$$

$$\pi_{1z} = f(\pi_{2z}) \tag{8}$$

$$\pi_{1z} = \varphi_z.\ \pi_{2z}^{\alpha z} \tag{9}$$

The relationship between the two π terms can be solved with curve fitting techniques, as shown in Fig. 2.

$$\pi_{1z} = 0.887(\pi_{2z})^{0.755} \tag{10}$$

The final equation which estimates the depth of wetted pattern can be written as follows:

$$z = 0.887\ k_s^{0.6325}T^{0.755}Q_c^{0.1225} \tag{11}$$

The previous steps were repeated in order to estimate the values of soil width d. The values of $\alpha_d = 0.463$ and $\varphi_d = 0.769$ were obtained from Fig. 3 as follows;

$$II_{1d} = 0.769\ (II_{2d})^{0.463} \tag{12}$$

The final equation for calculating the soil width can be written as follows;

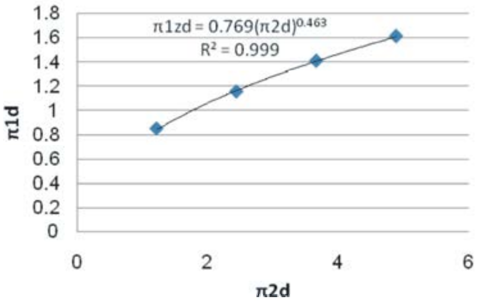


Fig. 3: Relation between π_{1d} and π_{2d} of continuous drip irrigation

$$d = 0.769\, k_s^{\,0.1945} T^{0.463} Q_c^{\,0.2685} \quad (13)$$

Pulse and Intermittent Flow: The dimensions of wetted pattern of pulse and intermittent drip irrigation depend on water discharge rate, soil saturated hydraulic conductivity and accumulated cycle times.

There were two separate functional relationships of pulse and intermittent drip irrigation, one for wetted soil depth (z) and the other for wetted soil width (d). The two functions can be written as follows:

$$z = f_1(Q_p, Q_c, k_s, T) \quad (14)$$

$$d = f_2(Q_p, Q_c, k_s, T) \quad (15)$$

where f_1 and f_2 are function signs;

- Z Is the wetted soil depth (cm).
- d Is the wetted soil width (cm)
- Q_p Is the discharge rate of pulse drip irrigation which changes according to the pulse ration on/off, ($cm^3\ min^{-1}$).
- Qc Is the equivalent discharge rate of continuous drip irrigation which is equal to 2L/hr(33.33 cm3/min) in the present laboratory study, in case of intermittent flow regime $Q_c = Q_p$.
- K_s Is the soil saturated hydraulic conductivity (cm min^{-1}).
- T Is the elapsed time (min), which is a multiple of cycle time = n.(Ton+Toff).
- n Is number of cycles.

The basic dimension of each variables can be expressed as follows:

$z = L$, d = L,

$Q_p = L^3T^{-1}$, $Q_c = L^3T^{-1}$

$ks = LT^{-1}$

And $T = T$

The number of π terms (free variables) is equal to (n-m), where n=5 which is the total number of variables in the experiment (z, Q_c, k_s, Q_p, T) and m=2 which is the number of reference dimensions (L, T).
free variables = n-m = 5-2 =3

$$F(\pi_1, \pi_2, \pi_3) = 0 \quad (16)$$

The dependent variables (repeating variables) were selected as k_s and Q_c, which involve all fundamental dimensions. The π term was formed by grouping one of the free variables with all dependent variables, starting with the free variable, z, the first π term can be formed by combining z with the dependent variables such that

$$\pi_{1z} = k_s^{a1}.Q_c^{b1}.z. \quad (17)$$

Estimating a1, b1 so that the combination is dimensionless

$(LT^{-1})^{a1}.(L^3T^{-1})^{b1}.\ L = L^0.\ T^0$

So: a1+3b1= 0 (for L)
-a1-b1= 0 (for T)

Therefore:
a1= 1/2 and b1= -1/2

The π term them becomes

$$\pi_{1z} = z\sqrt{\frac{K_s}{Q_c}} \quad (18)$$

Repeating the preceding steps, the second π term can be obtained as follows:

$$\pi_{2z} = k_s^{a2}.Q_c^{b2}.Q_p = (LT^{-1})^{a2}.\ (L^3T^{-1})^{b2}.\ (L^3T^{-1}) \quad (19)$$

a2+3b2+3=0 (for L)
-a2-b2-1=0 (for T)
a2=0, b2=-1

$$\pi_{2z} = \frac{Q_p}{Q_c} \quad (20)$$

Repeating the preceding steps, the third π term can be obtained as follows:

$\pi_{3z} = k_s^{a3}.Q_c^{b3}.T = (LT^{-1})^{a3}.(L^3T^{-1})^{b3}.T$ (21)

a3+3b3=0 (for L)
-a3-b3+1=0 (for T)
a3= 3/2, b3=-1/2

$$\pi_{3z} = T\sqrt{\frac{k_s^3}{Q_c}} \quad (22)$$

$\pi_{1z}=(\pi_{2z}, \pi_{3z})$
$\pi_{1z}=\varphi_z.\ \pi_{2z}^{\alpha z}.\ \pi_{3z}^{\beta z}$ (23)

The values of unknowns α_z, β_z and φ_z were estimated using the data of the laboratory experiments with curve fitting techniques which yields:
$\pi_{1z}=1.183\ \pi_{2z}^{-0.0275}.\ \pi_{3z}^{0.465}$ (24)

Substituting; $\pi_{1z} = \left(z\sqrt{\frac{k_s}{Q_c}}\right)$, $\pi_{2z} = \left(\frac{Q_p}{Q_c}\right)$ and $\pi_{3z} = \left(T\sqrt{\frac{k_s^3}{Q_c}}\right)$ then the final equation which estimates the depth of wetted pattern can be written as follows:

$$z = 1.183\ k_s^{0.196}T^{0.465}Q_p^{-0.028}Q_c^{0.295} \quad (25)$$

In case of pulse flow, Q_c can be calculated as follow;

$$Q_c = CR.Q_p \quad (26)$$

where the cycle ratio is the ratio between the on time and the cycle time, cycle ratio can be calculated as follow;

$$CR = \frac{T_{on}}{T_{on}+T_{off}} \quad (27)$$

By substituting in Eq.(25) in order to replace the term Q_c by the previous equation (CR. Q_p) then, the following equation can be deduced;

$$z = 1.183\ k_s^{0.196}T^{\,0.465}Q_p^{\,0.267}CR^{0.295} \quad (28)$$

By applying the above equation for pulse drip irrigation, the results are in the acceptable range. This means that, the previous equation can be used to estimate the depth of wetted pattern in pulse drip irrigation correctly.

The intermittent irrigation is a special case of pulse drip irrigation which $Q_c = Q_p$. By substituting in Eq.(25), the following equation can be obtained;

$$z = 1.183\ k_s^{0.196}T^{\,0.465}Q_p^{\,0.267} \quad (29)$$

The previous equation can be used in order to estimate the depth of wetted pattern in case of intermittent irrigation and the result will be in acceptable range.

The previous steps were repeated in order to estimate the values of soil width (d). The final equation for calculating the soil width can be written as follows;

$$d = 1.202\ k_s^{-0.2}T^{\,0.2}Q_p^{\,0.031}Q_c^{\,0.369} \quad (30)$$

By substituting in Eq.(30) in order to replace the term Q_c by the previous equation (CR. Q_p) then, the following equation can be deduced;

$$d = 1.202\ k_s^{-0.2}T^{\,0.2}Q_p^{\,0.4}CR^{0.369} \quad (31)$$

By applying this equation in case of pulse drip irrigation, the results are in the acceptable range. This means that, the previous equation can be used to estimate the width of wetted pattern in pulse drip irrigation correctly.

The intermittent irrigation is a special case of pulse drip irrigation which $Q_c = Q_p$ in this type of flow. By substituting in Eq.(25), the following equation can be obtained;

$$d = 1.202\ k_s^{-0.2}T^{\,0.2}Q_p^{\,0.4} \quad (32)$$

Eq. (32) can be used to estimate the width of wetted pattern in case of intermittent irrigation and the result will be in acceptable range.

Model Performance: The performance evaluation of the model was also based on comparison of statistical parameters of estimated data with that of the observed data. The parameters used were mean error (ME) and root mean square error (RMSE) and model efficiency (EF) which was calculated using following relationships (Willmut [10]):

$$ME = \left[\frac{1}{N}\sum_{i=1}^{N}(C_{Si} - C_{Oi})\right] \quad (33)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(C_{Si} - C_{Oi})^2\right]^{1/2} \quad (34)$$

$$EF = 1 - \frac{\sum_{i=1}^{N}(C_{Si}-C_{Oi})^2}{\sum_{i=1}^{N}(C_{Si}-C_{O})^2} \quad (35)$$

where N is the total number of data, C_{Si} the *i*th predicted data and C_{oi} the *i*th observed data. RMSE and ME values were compared separately for wetted width and depth of soil. For better performance of model, criteria adopted was: lower the value of RMSE and absolute value of ME and greater the value of EF.

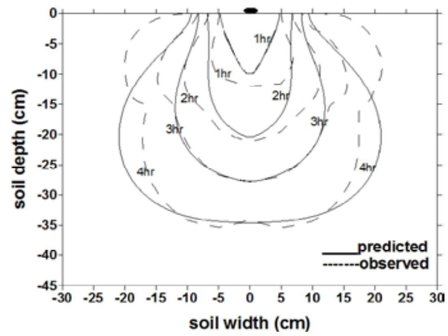
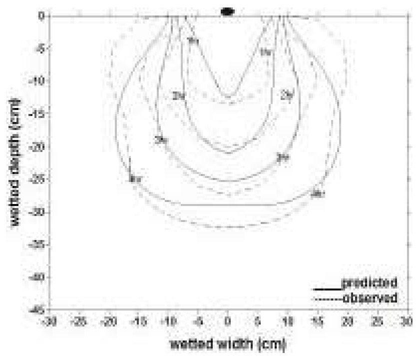
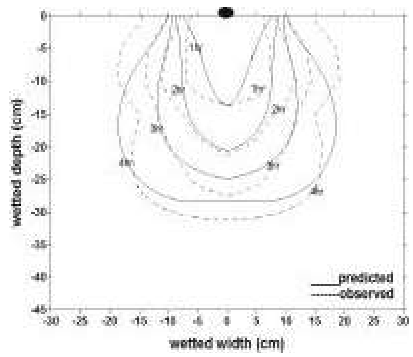


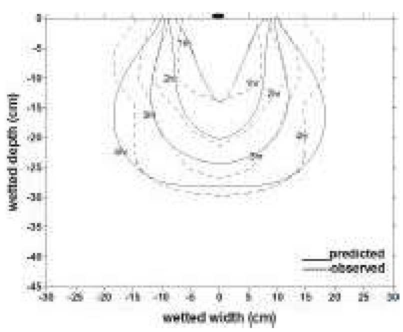
Fig. 4: The predicted and observed wetted bulb as a function of time for continuous flow.



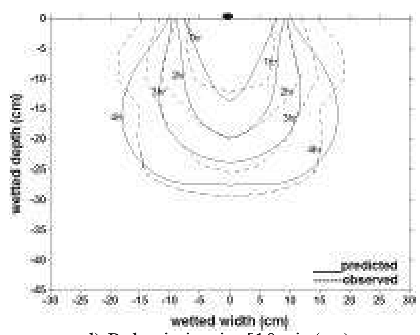
a) Pulse irrigation [30min(on) 30min(off)]



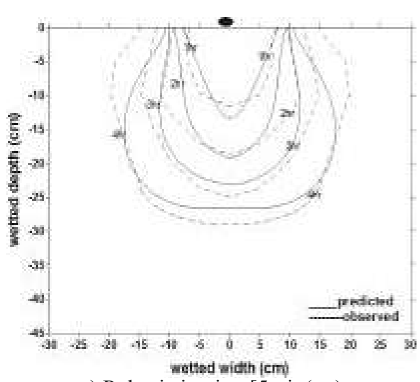
b) Pulse irrigation [20min(on) 40min(off)]



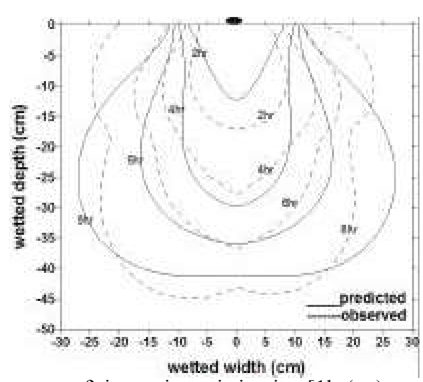
c) Pulse irrigation [15min(on) 45min(off)]



d) Pulse irrigation[10min(on) 50min(off)]



e) Pulse irrigation [5min(on) 50min(off)]



f) intermittent irrigation [1hr(on) 1hr(off)]

Fig. 5: The predicted and observed wetted bulb as a function of time for different levels of pulse and intermittent flow.

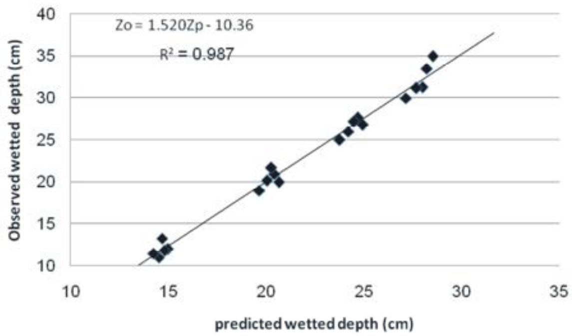


Fig. 6: Comparison between predicted and observed depth of wetted bulb

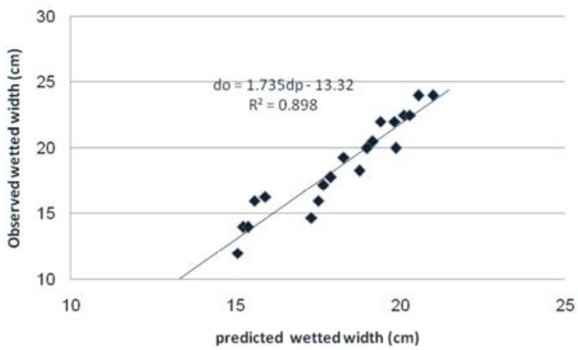


Fig. 7: Comparison between predicted and observed width of wetted bulb

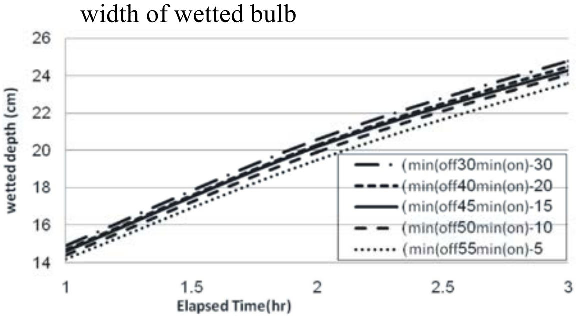


Fig. 8: Effect of on-time period as a function of elapsed time(hr) on the wetted depth for pulse flow in sand soil.

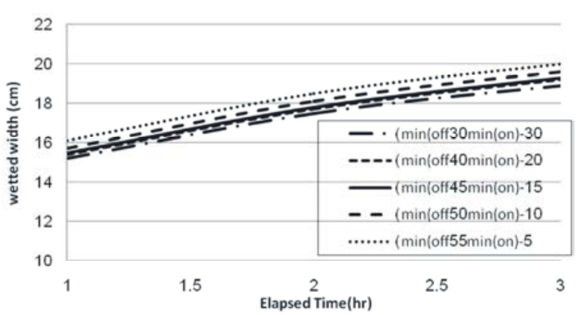


Fig. 9: Effect of on-time period as a function of elapsed time(hr) on the wetted width for pulse flow in sand soil.

Figs. 7 and 8 show both predicted and observed wetted bulb dimensions for continuous, pulse and intermittent drip irrigation.

So, Eqs. (11)and(13) can be used to estimate both depth and width of wetted pattern correctly for continuous drip irrigation. In addition, Eqs. (25) and (30) can be used to estimate both depth and width of wetted pattern under pulse and intermittent drip irrigation.

The magnitude of RMSE values was indicative of performance of model but did not show any degree of over or underestimation of estimated values by the models. The statistical parameter, mean error (ME), was used for comparing quantification of accuracy of estimated and observed values of wetted soil depth and width. The positive value of ME is the indication of overestimation and negative value indicates underestimation. The absolute value of ME is an indicator of the performance of model. As presented in Table 2, the model showed slight under estimation. For the developed models RMSE and ME, values are also presented in Table 2. It was found that performances of the models are good. Therefore, the models can be used to describe the wetted depth and width for pulse drip irrigation.

Predictability of model was expressed in terms of model efficiency as presented in Table 2, which was estimated as 98% and 97%, respectively, for prediction of wetted depth and width under continuous flow regime. However, for intermittent flow regime, the model efficiency was estimated as 94% and 83%, respectively. At the same time, for pulse flow regime, the model efficiency was estimated as 86% and 79%, respectively. This shows that developed models can be used to predict wetting pattern under continuous, intermittent and pulse flow with line source of water application.

Model-based Studies

The Effect of On-Time Period on Wetted Soil Pattern: The effect of increasing the on-time period on both depth and width of wetted pattern is investigated using average discharge of 2L/hr with the same total amount of applied water (6L). The volume of applied water must be constant in all periods of on-time and the average discharge remains constant when the on-time decreases and Q_p increases simultaneously.

Fig. 8 shows that, the effect of on-time period on depth of wetted pattern is significant in sand and clay soils. As on-time decreases, the depth of wetted pattern also decreases in both sand and clay soils. This behavior appears significantly when the on-time reduced from 30 min to 5 min.

Table 2: Model performance parameters for depth and width of wetted soil

	Wetted soil depth			Wetted soil with		
Flow Regimes	ME	RMSE	EF	ME	RMSE	EF
Continuous	0.0266	0.3879	0.98	0.0299	0.08639	0.97
Pulse	1.07	2.8	0.86	0.183	1.57	0.79
Intermittent	0.654	2.103	0.94	0.46	1.82	0.83

It was found that when the same total amount of water (6liters) was added to the soil with different on-time a long 3hrs of elapsed time, the wetted depth increased as on-time increased. While the opposite happened for the soil wetted width, the wetted width increased as on-time decreased. It is clear that the increases in pulse flow up to twelve times to that of the equivalent continuous flow can decrease vertical spread and increase horizontal spread.

Fig. 9 shows that, the effect of on-time period on width of wetted pattern is significant. As on-time decreases, the width of wetted pattern increases. This behavior appears significantly when the on-time reduced from 30 min to 5 min.

The water deep percolation reduced and horizontal spread increased with an increase in the pulse flow. Using pulse flow allows the small widths of wetted pattern in continuous flow to be large and consequently the emitters spacing to be increased and finally the number of emitters to be reduced, which is considered as economic advantage. It will allow the use of large emitter size, reduce emitter clogging problems.

CONCLUSIONS

There is a lack of models to predict wetting pattern dimension under pulse and intermittent flow regime, since the applicability of the available models were limited to prediction under continuous flow regime only.

Laboratory results on sandy soil indicated that, in pulse flow, the wetted width increased and wetted depth decreased as the on-time decreased for the same amount of applied water volume. This result shows the advantage of pulse flow, for reducing the deep percolation of water under the crop root zone, while obtaining a wide horizontal spread of wetting. This enables using a large emitter discharge with the same amount of water. Using large emitter discharge reduces the emitter clogging.

The developed dimensional analysis models were able to predict soil wetted depth and width under continuous, intermittent and pulse flow with line source of water application. Predicted and observed values were compared to test models applicability in laboratory conditions. Predictability of model was expressed in terms of model efficiency, which was estimated as 98% and 97%, respectively, for prediction of wetted depth and width under continuous flow regime. However, the model efficiency was estimated as 94% and 83%, respectively, for prediction of wetted depth and width under intermittent flow regime. Under pulse flow regime, the model efficiency was estimated as 86% and 79%, respectively, for prediction of wetted depth and width. This shows that developed models can be used to predict wetting pattern under continuous, intermittent and pulse flow with line source of water application.

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