25 *Egypt. J. Soil Sci*. **Vol**. **54**, No. 4, pp. 337-354 (2014)

WET Sensor Technique to Evaluate Soil Moisture Distribution Patterns under Different Discharge Rates

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INSURANCE precise placement of water and fertilizer in active root zone is based on suitable moisture distribution pattern under point source emitter, consequently, is affected by some soil properties and emitter discharge rate. This investigation aims to evaluate the patterns of soil moisture distribution under different discharge rates for two different soils (sandy and loamy). The studied discharge rates were 1.8, 4.6 and 8 L h^{-1}, in addition to flooding application for comparison. Study also aims to detect the reliability of applying equivalent water depth equation particularly when water is trickling. For all treatments, soil moisture was measured using a moisture meter called "WET sensor" which calibrated in Lab. for both soils before field work. Validation of Schwartzman and Zur's model as a simplified semi-empirical method to determine the geometry of wetted soil volume was to detect both studied soils as an additional objective. The obtained results showed a high correlation between sensor reading and oven-dried value, introduced high R^2 values equaled 0.999 and 0.9804 for sandy and loamy soil, respectively. Based on the designed wetted soil volume, results showed that the best moisture distribution was recorded under 4.6 L h^{-1} and flooding treatment for sandy soil, while recorded under 1.8 and 4.6 L h^{-1} rates for loamy soil. Generally, the application rate of 4.6 L h^{-1} could achieved the desired moisture distribution in both soils, therefore, this trickling rate should be selected in such soils than the other. Applying of equivalent water depth equation, showed that desired progression of wetting front appeared to be closely achieved under flooding treatment in sandy soil than in loamy. So, flooding irrigation could be successfully applied on sandy soil with rationally water amounts. Therefore, from view point of wastewater, nutrients loss and soil contamination, flooding could be more safety compared to the other treatments. On the other hand, applying the same equation for loamy soil could only achieved by 87 % and 67 % of the desired moisture for a given depth under 8.0 L h^{-1} and flooding treatments, respectively. So, 8.0 L h^{-1} and flooding treatments are not recommended for such soil. Regarding to both irrigation scheduling and design, statistically analysis indicated that the most suitable wetted depth and width could be obtained under 4.6 L h^{-1} for sandy soil and under 1.8 and 4.6 L h^{-1} for loamy soil, therefore, an economic emitters distance and reduction of salt accumulation around the plant could be achieved. According to soil hydraulic conductivity, wetted width to witted depth ratio could be used as a decision support aid to determine the emitter distance and numbers, consequently, avoid wastewater and cost. Considering the difficult in measuring both laterally and vertically water movement, obtained results showed a good agreement between simulated of Schwartzman-Zur's model and field observations particularly for loamy soil than sandy.

Keywords: Emitter discharge, Equivalent water depth, Moisture pattern, Wetted soil volume.

Moisture distribution patterns under point source trickle emitters are an important factor for the design and operation of trickle irrigation system. Nutrients uptake and fertilizer unit efficiency are related closely to soil moisture distribution, consequently, affecting plant growth and quality. This consideration should provide high water use efficiency but only if the system is designed to meet the soil and plant condition, *i.e*., texture and root distribution, respectively. The wetted soil volume and moisture patterns under a point source trickle system is important to be known and considered as a function of soil texture, amount of applied water and discharge rate (Schwartzman and Zur, 1986, Phene, 1995, Watson *et al*., 1995, Lubana *et al*., 2002, Moncef *et al*., 2002, Cook *et al*., 2006, Ainechee *et al*., 2009 and Omran *et al*., 2012). Ainechee *et al*. (2009) concluded that an increased in the value of soil hydraulic conductivity representing a shift to lighter soils results in an increase in the ratio of the wetted soil depth to the wetted soil width. Therefore, more transmissive soil has greater wetted depth and smaller wetted width than more slowly permeable soil. Their results showed that extension application of water the value of wetted width changes little in sandy soil but is still increasing in silt clay loamy soil, therefore, doubling the value of emitter discharge tends to increase the surface wetted radius and depth.

Soil particle size is a significant factor in how water moves through soil. Water moves more rapidly in the sandy soil because the capillary conductivity of the larger pores is greater. On the other hand, clay soil has small pores and attracts water more strongly than the sandy soil with large pores, but transmits it more slowly. Generally, short duration time will minimize deep percolation of applied water, but may also confine the lateral distribution of water near the dripper. On the other hand, when longer run time is used with the same discharge rate, the distribution of applied water will be increased. In fine textured soils, the horizontal and vertical extension of wetting front moves with approximately similar velocity, but in coarse textured soils, the vertical velocity component of wetting front is more than the horizontal component, which causes more deep percolation in such soils under point source application of water (Fletcher and Wilson, 1983, Clark, 1992, Al-Qinna and Awwad, 2001, and Nafchi *et al*., 2011).

The major objective of this study was to provide the irrigation designer with a clear description of the moisture distribution takes place downward and sideways response to different emitter discharge rates on two different textural soils. In traditional irrigation practice (where non-rational water amount applied to soil) it is propaganda that flooding irrigation lead to the lowest water use efficiency due to a large amount of wasted water, especially for coarse soil compared to the fine one. According to Hokam *et al*. (2011) when irrigation water calculated based on the equivalent water depth equation, and applied using a drip irrigation system double wetted depth of irrigated soil could be reached to the desired moisture content. They reported that this finding may resulted because of the water amounts were applied to a limited point (under emitter), while the calculation was based on a specific area. Therefore, a second important objective of this study was to detect the feasibility to apply equivalent water depth equation, EWDE, successfully for all discharge rates on both studied soils, where the maximum allowable depletion technique used as a management method for irrigation scheduling.

In general, wetting pattern can be obtained by measuring moisture contents either in laterally or vertically direction. Considering the difficult in deeper downward direction, a simulation model could be conducted to predict the water movement in two direction. The model of Schwartzman and Zur (1986) was developed as a simplified semi-empirical method for determining the geometry of wetted soil zone under line source of water application placed on soil surface. They assumed that the geometry of wetted soil (wetted width and depth) at the end of irrigation depends on soil type, emitter discharge and total amount of water. So, an additional objective of this study was to detect the validation of the semi-empirical method of Schwartzman and Zur for determining the geometry of wetted soil volume under point sources in the two soil types.

Material and Methods

The experiment was conducted in five stages as following: 1) Calibration for moisture meter (WET sensor), has been carried out in Soil and Water lab. (Faculty of Agr., Suez-Canal Uni.), 2) Evaluation of emitter discharge, in the same lab., 3) Planning of irrigation scheduling, 4) Applying water and field measurements of soil moisture distribution under different discharge rates and 5) Detection the validation of Schwartzman-Zur's model to predict the geometry of wetted soil volume.

Theories

WET sensor

WET sensor is a portable instrument used to measure soil Water content, Electrical conductivity and Temperature. It works respond to the soil dielectric constant ε, which is strongly dependent on the water content. Soil water content could be calculated from the soil dielectric (ε) reading, using two factors: factor a0 is an offset factor and a1 is a scaling factor, they are available for many soil types. When WET sensor inserted into soil for reading, it generates a 20MHz signal applied to the central rod, and produces a small electromagnetic field within the soil. Water content, electrical conductivity and composition of the soil surrounding the rods will determine its dielectric properties. Then the WET sensor detects these dielectric properties from their influence on the electromagnetic field and sends this data to the moisture meter. The moisture meter calculates Soil Moisture using its calibration tables (water has a dielectric constant ε ~ 81, compared to soil ~ 4, and air ~ 1). Whally (1993) and White *et al.* (1994) have shown that there is a simple relationship between the complex refractive index (equivalent to the square root of ε) and the volumetric water content, θ, as following:

$$\sqrt{\varepsilon} = a0 + a1 * \theta \quad (1)$$

$$\theta = (\sqrt{\varepsilon} - a0) / a1 \quad (2)$$

Where a0 and a1 are specific parameters of soil. They could be obtained experimentally and are unique for each soil type. These parameters are used with a linearization table, in the Meter, to convert the sensor output (in mV) into soil moisture readings. For mineral soil the a0 and a1 coefficients are permanently installed in the Moisture Meter as 1.6 and 8.4 for a0 and a1, respectively, according to Roth *et al.* (1992).

Irrigation scheduling: maximum allowable depletion (MAD)

There are several possible approaches could be used for irrigation scheduling or rational applied water, each one may be adapted or no adapted according to many conditions. The most precise one is the process to determine exactly when and how much water to apply to a defined soil profile, consequently, soil profile will be returned to field capacity. Maximum allowable depletion (MAD) technique may provides an average 35 % savings in water and energy (Sassenrath, 2011). Theoretically, Figure 1 illustrate that the rational water amount is that allowable amount of water can be withdrawn from the soil between two irrigations without stressing the crop to the point where significant reduction in crop yield or quality (*i.e.*, MAD = $\theta_{f\,c} - \theta_i$, where θ_i is initial moisture content). However and for successful apply of MAD-theory, easy monitoring for soil moisture under field conditions using the portable moisture meter, accuracy irrigation scheduling could be achieved by application of Equivalent Water Depth equation, EWDE:

$$D_{eq} = \int_0^z \theta_v(z)\, d(z) = \sum_{i=0}^{i=n} (\theta v\ i\ \Delta z\ i) \quad (3)$$

Where D_{eq} is the equivalent water depth in unit length, that represented water amount θ_v required to return a defined soil depth Z to field capacity, Δ_z is the soil depth interval. The units of D_{eq} should converted in L m^{-2}. This equation shows that D_{eq} can be calculated by the product of the volumetric water content and the depth interval Δ_z for each soil layer *i,* which differs in its field capacity.

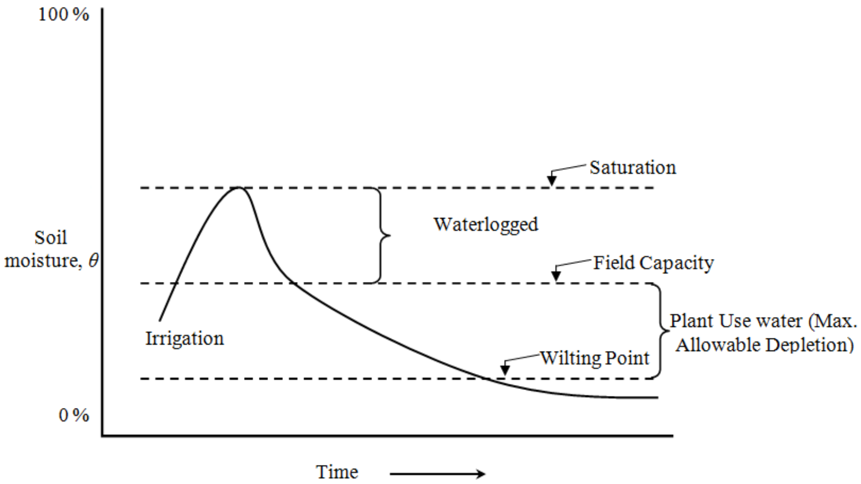


Fig. 1. A graph of θ_v versus z for a given soil profile to illustrate maximum allowable depletion (MAD) technique as scheduling theory for the current study.

Schwartzman-Zur model

According to Schwartzman and Zur (1986) their model should be used for surface drip irrigation to predict the geometry of wetted soil volume: width (W) and depth (Z) at the end of drip irrigation technique. The wetted soil volume was assumed to be dependent on emitter discharge (q), total amount of applied water (V) and saturated hydraulic conductivity (Ks) of soil. So, the functional relationship for these parameters can be written as following:

$$W = f_1 (V, q, Ks) \quad \text{and} \quad Z = f_2 (V, q, Ks) \qquad (4)$$

Three dimensional terms were developed using dimensional analysis and are represented as following:

$$V^* = V \left(\frac{K_s}{q}\right)^{3/2} , \quad Z^* = Z \left(\frac{K_s}{q}\right)^{1/2} \text{and} \quad W^* = W \left(\frac{K_s}{q}\right)^{1/2} \qquad (5)$$

Using experimental V, Z and W and estimated values of V*, Z* and W* the graphical relationships between dimensionless parameters V* versus Z*, and V* versus W* could be obtained, then data will fitted to obtain the optimum regression equation from which the exponents n_1 and n_2, and the constants A_1 and A_2 could be extracted and putted in the following relationships to obtain wetted width and depth:

$$W = A_1 V^{n1} \left(\frac{K_s}{q}\right)^{\frac{3n1-1}{2}} \qquad Z = A_2 V^{n2} \left(\frac{K_s}{q}\right)^{\frac{3n2-1}{2}}$$

and (6)

Experiments

WET sensor calibration

Sensor readings had found to give over/under-values for soil moisture content compared to that oven-dried. To convert the sensor readings to reliable values, a calibration process was carried out in Soil and Water Lab., for which ten different moist soil samples were involved for both studied soils. After that the relationship between WET-Readings and its corresponded soil moisture contents (oven-dried) was studied using simple regression equations analysis. This analysis was used to determine an equation used to obtain the correct soil moisture content measured either in the Lab. or field. Directly before oven drying, WET sensor inserted and readings were recorded in the same ten soil samples. The correlation coefficients of both data (*i.e*., WET readings versus gravimetric values) were also computed to select the most fitted equation.

Water applications and field measurements

Table 1 showed some physical properties for the tow soil types used, on which the different application treatments were conducted. The emitters used in this investigation (Self compensation, Euro Key – class) were evaluated in Lab. to provide three various rates of water discharge (1.8, 4.6 and 8 L h^{-1}). The used emitters were placed on the top of soil surface and connected to water reservoir of 2 m in height. The three different emitter discharges were used to give the same water volume, 8.25 and 63.25 L which represented the water depleted from soil to bring 0.25 and 0.5 m^2 of soil by 0.4 m depth back to its field capacity for sandy and loamy soil, respectively. At the end of application duration, evaporation from wetted soil surface has been prevented.

TABLE 1. Some physical properties of studied soils.

Soil	**Sand, %**	**Silt, %**	**Clay, %**	**Texture**	***H C, cm d^{-1}**	****Field Capacity, %**	**Swilling, %**
A	95.2	1.8	3.0	Sandy	742.6	9 – 13	0
B	51.9	29.9	18.2	Loamy	14.8	8	15

*H C = Hydraulic conductivity.
** volumetric percent. The deeper 10 cm layer had $\Theta_{f.c.}$ of 9 %.

One day before water application soils were sampled through 0 to 40 cm depth to get the initial moisture contents and bulk density. Each emitter was worked to apply the same total water amount. After 24 hr of irrigation termination, soil moisture content has been measured with WET sensor device.

The measurements were achieved each 5 cm increments horizontally and 10 cm vertically. Where the limitation of WET usage is the difficulty to be inserted deeper than 8 cm, so, measuring in next 10 cm soil layer required the removal of previous layer. For each soil layer surface wetting diameter has been measured. Water distribution pattern and uniformity was assessed using the software Surfer program version 8.

Results and Discussion

Sensor calibration

Calibration of WET sensor showed that its readings were over/under-values for soil moisture content in comparison to that oven-dried samples. Calibration processes was conducted using 10 different moist soil samples (varied from air dry to saturated) for both studied soils. Appling the simple regression equations indicated that optimum equation to represent the relationship between device-readings and soil moisture (oven dried) were exponential and polynomial (third order) regression equations, which gave good accuracy with R^2 of 0.9997 and 0.9804 for sandy and loamy soil respectively. Figure 2 showed the calibration curves could be used directly to obtain the corrected moisture content or using the regression equation. The results showed that the sensor is suitable for moisture monitoring at different distances and depths. It is quick responses time, but the limitation is the difficulty to be inserted deeper than 8 cm.

Wetting front progression

Irrigation scheduling applied here was based on equivalent water depth equation, EWDE, represented the most precision and timely-work low cost. The feasibility to apply EWDE was an important objective of this investigation. Hokam *et al*. (2011) reported that soil moisture content resulted from irrigation water (calculated based on EWDE) applied by drip irrigation system, penetrated the soil to a double depth of that calculated, and brought it back to soil field capacity. They attributed this finding to the fact that the water amounts were applied for a limited point, while it was planned for one plant area.

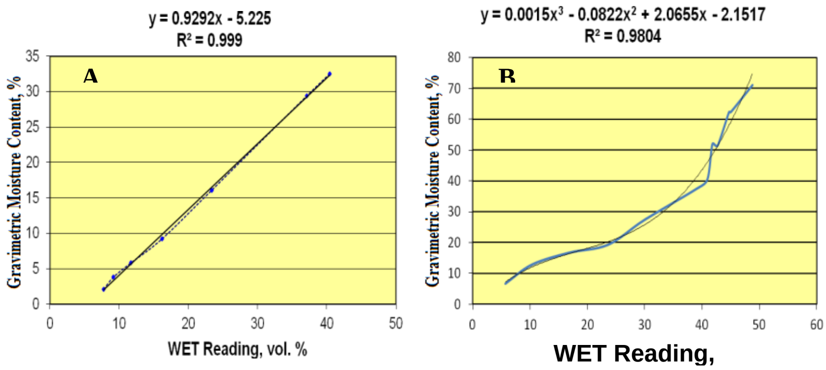


Fig. 2. Calibration curves: WET – Readings versus and gravimetric moisture values, for both sandy (A) and loamy (B) soils.

Therefore, the applied water amounts were calculated using EWDE to bring 40 cm soil depth to its field capacity, then checked the moisture pattern under the three different discharges and flooding application. Figure 3 illustrates the progression of wetting front in both studied soils under flooding application. The Figure showed that wetting front was progressed closely to the desired depth (40 cm) in sandy soil, while it reached only 27 cm in loamy soil (*i.e.*, achieved 67.5 % of the desired or planed depth). This result indicated good agreement between the calculated soil depth wetted to field capacity and that found experimentally. Consequently, in sandy soil, irrigation process could be successfully achieved under flooding application when water amounts are rationally calculated using EWDE. Additionally, field observations showed that wetting front (with small diameters) progressed deeper than 50 cm in sandy soil under the three emitters, therefore, wastewater, nutrients loss and soil contamination are expected. Therefore, while flooding application for rationally water amount are more safety in sandy soil, it is not recommended for loamy soil. This declination to achieve EWDE for irrigation scheduling in loamy soil may be attributed to the dominance of lateral movement of water rather than the downward gravity force, which plays a main role in moisture distribution. Also, the declination may be associated somewhat to the swelling phenomena found in such soil (*i. e*., 15 %, Table 1).

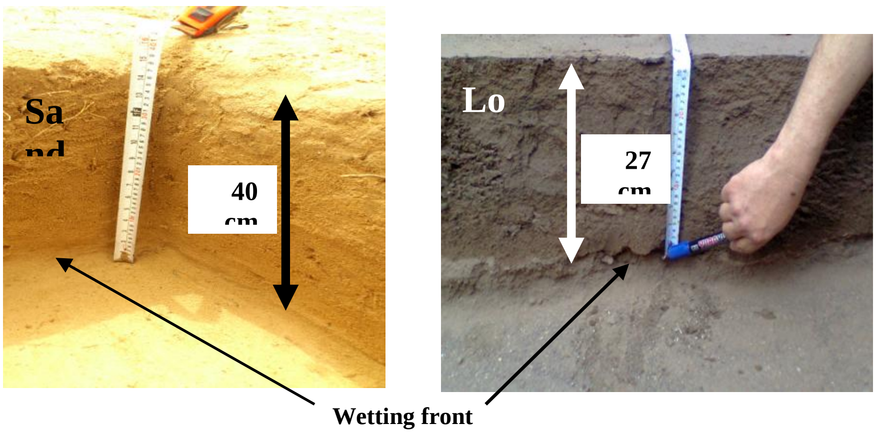


Fig. 3. Progression of wetting front in both studied soils under surface flooded treatment.

Moisture pattern

Water trickling from a point source takes place in the soil and moves downwards and sideways. To detect the dimensional transit flows occur differentially based on the discharge rate and soil texture, the three different discharge rates (*i.e*., 1.8, 4.6 and 8.0 L h^{-1}) were applied on each soil type (*i.e.* Sandy and loamy). Where the main problem in such situation is how to express moisture distributed radial in two dimensions, the software surfer program (version 8) has been used to produce the wetting patterns. Moisture meter data obtained from field experiment (where measurements were taken 5 cm increments horizontally and 10 cm vertically) were involved in surfer program. The obtained results showed that soil moisture distribution values under each emitter discharge were varied from each to other either in the same soil or from soil to other under the same rate. The smallest wetting diameter was related to the discharge rate of 1.8 L h^{-1}, this is in good agreement with that found by Ainechee *et al*. (2009) and Nafchi *et al*. (2011). Generally, Figures 4 and 5 indicated that soil moisture distribution and its uniformity within the soil profile under surface drip was to great extent affected by soil texture rather than emitter discharge, while the factor dominantly affected the moisture pattern was the emitter discharge under the same texture. Also, the results showed that the treatments to be recommended as they resulted in the most suitable moisture distribution are 4.6 L h^{-1} and flooding application compared to the other two discharges.

The results could be attributed to the fact that just as sandy soil included large pores, water moves downward more quickly than through smaller pores. When the soil becomes saturated as happened under 8 L h^{-1} discharge rate, gravity becomes the dominant force moving water downward, therefore, water moved and penetrated more deeply in the sandy soil, while under 4.6 L h^{-1} the discharge rate brought the soil high moisture content but was not so as rapid to prepare the opportunity for air trapped, consequently, increasing the laterally water movement. The results also shown that increasing the emitter discharge from 1.6 L h^{-1} to 4.6 L h^{-1} tends to increase the wetted soil width from 35 to 50 cm, respectively, as shown in Table 2, a similar result was obtained by Ainechee *et al*. (2009) who found that the surface wetted radius and depth increased with an increase in application rates of emitters from 1.38, 2.17 and 3.46 L h^{-1}. Therefore, sandy soils under drip irrigation should irrigated under discharge rate not more than 4 or 5 L h^{-1} to maintain adequate water pattern and maintain the plant nutrition with minimum losses below the root zone, this result is agreed with that reported by Watson *et al*. (1995). In other words, when the same soil irrigated with 4.6 L h^{-1} discharge, soil pores are not open to free water (as the case occurred under 8 L h^{-1}), so water moves primarily by capillary action around the voids until the soil become saturated, so gravity dominates and causing to move downward. However, the two forces that make water move through soil (*i. e*., gravitational and capillary) act simultaneously in soils.

Figure 5 illustrate the moisture patterns occurred in loamy soil under the different application rates. The patterns showed that very little gravitational or free water moves through pore spaces due to its small size and shape of the pores (where hydraulic conductivity was equaled 14.8 cm day^{-1} (Table 1), so the ability to hold water in such soil increased additionally to high forces of adhesion and cohesion. As found under all treatments, particularly under 8 L h^{-1} and flooding treatments, water eventually rises and retained in the upper layers and can move in any direction (compared to that in the coarse soil). These both treatments, may resulted in ponded conditions into the soil surface, so, under such condition when water is applied with high rate, it moves outward almost as far as it moves downward.

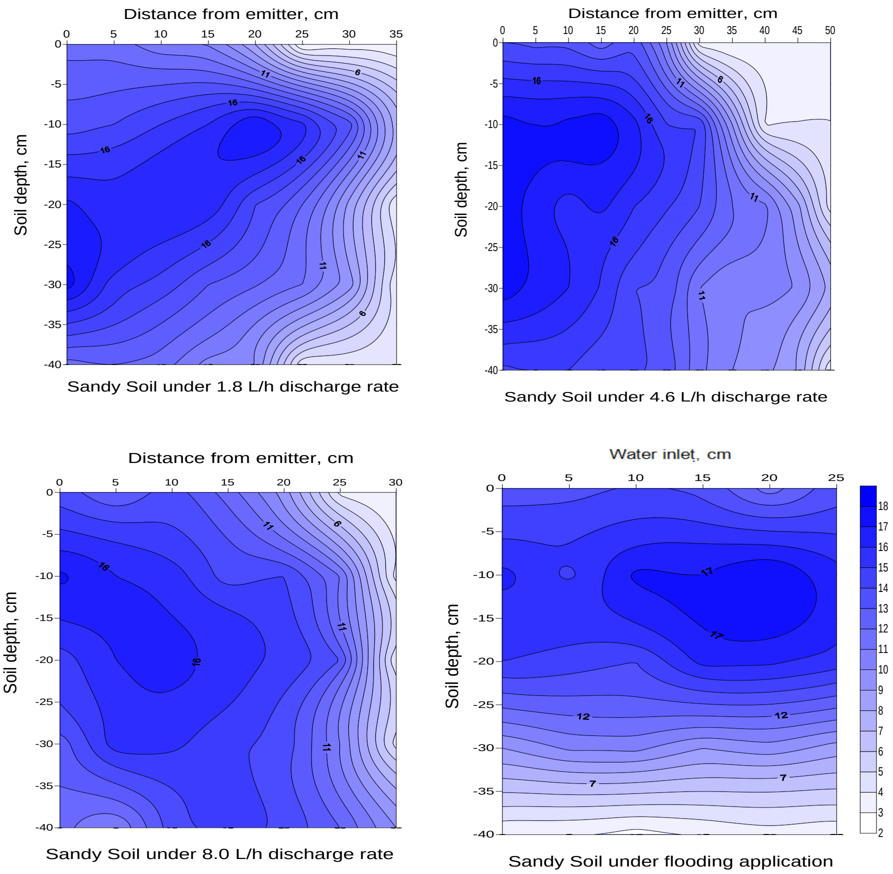
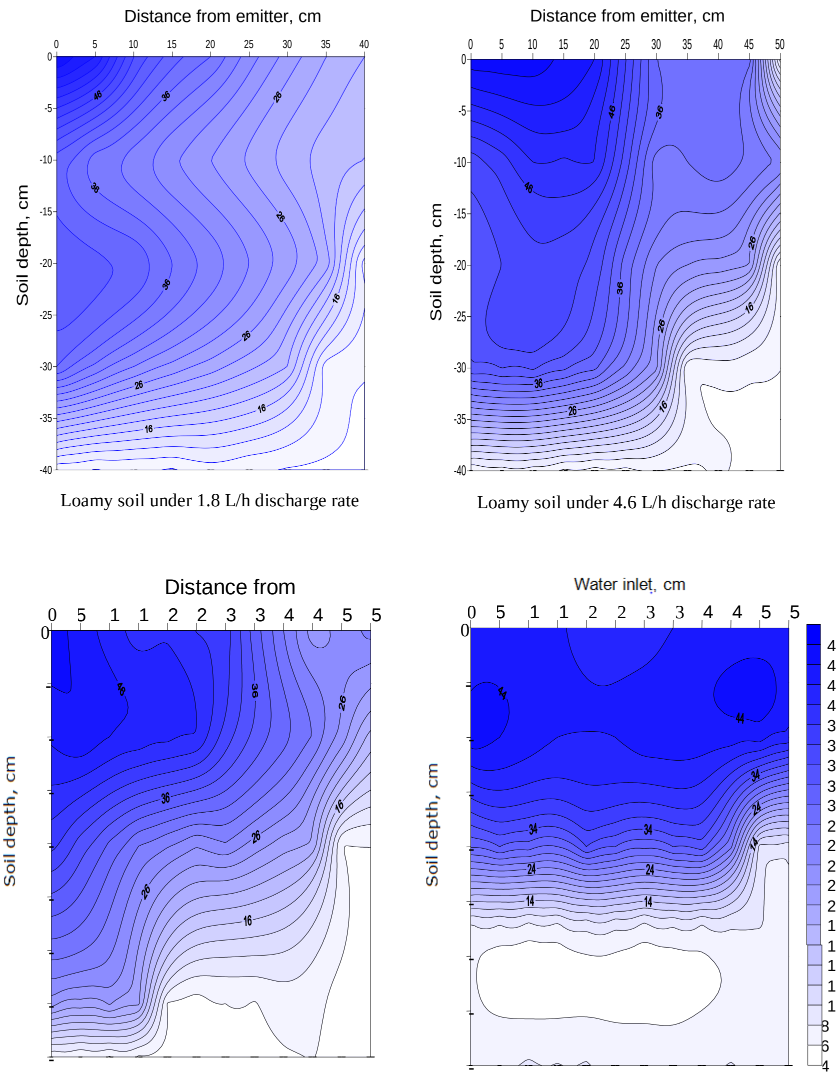


Fig. 4: Moisture distribution patterns in sandy soil under different application rates.

Furthermore, because of fine soil (loamy soil) exhibited the swelling phenomena (determined value = 15 %, Table 1), a similar conclusion was reported by Gal *et al.* (1990). This means that soil may included expended clay minerals which hinders the downward water movement. Under both 8.0 L h^{-1} and flooding applications the wetting front did not reached the desired soildepth (*i.e.*, 40 cm) for which irrigation amount was calculated, therefore the recommended discharge for such soil are 1.8 and 4.6 L h^{-1}. However, application duration which known as the time needed to apply the water consumed since previous irrigation must be considered for energy cost. Generally, and in traditional drip irrigation practice, it may ranged between 1 and 16 hr and should not be continuous. If more than 16 hr are needed, the number of emitters should be increased and at the same time water pounding or runoff may be starts (Marsh *et al*., 1982). According to the major aim of this investigation, and to overcome the extend application duration, doubling of 1.8 L h^{-1} emitters may be acceptable for both soil types, but not acceptable for 4.6 L h^{-1} emitters, because it resulted in poor soil moisture distribution either for sandy or loamy soil**.** So, selection of emitter with appropriate discharge for a particular soil is essentially to insure appropriate irrigation management, consequence, achieving high water- and nutrient-use efficiency.



Loamy soil under 1.8 L/h discharge rate

Loamy soil under 4.6 L/h discharge rate

Loamy soil under 8.0 L/h discharge rate

Loamy soil under flooding application

Fig. 5. Moisture distribution patterns in Loamy soil under different application rates.

Ratio of wetted width to wetted depth

Data listed in Table 2 revealed that the most important properties contributed to the geometry of wetted soil volume (represented by the ratio of wetted width to wetted depth) were soil texture emitter discharge. For both soils, the results showed that not these characters were correlated with wetted width and depth in the same manner. For example, wetted width to depth ratio was increased from upper to lower layers in sandy soil, while this ratio was decreased from upper to lower in loamy soil. On the other hand, the same ratio was increased as discharge increased in loamy for all layers, while in sandy soil ratio was increased from 1.8 to 4.6 L h^{-1}, then decreased under 8.0 l h^{-1}. Therefore, bubbler application may be not recommende either for sandy or loamy soils. Assuming that desired wetted depth for both soil was 40 cm, and the desired width was 50 and 70 cm for sandy and loamy soil, respectively, then the width/depth ratio will be 0.5 and 0.7 for sandy and loamy soil, respectively. Therefore, data in Table 2 indicated that 4.6 L h^{-1} and flooding treatments on sandy soil may achieved the designed ratio than the other two discharges. On the other hand, 8.0 L h^{-1} and flooding treatments for loamy soil could achieve the designed ratio but not for the desired depth, therefore, 1.8 and 4.6 are the recommended discharges for such loamy soil. Values of soil saturated hydraulic conductivity, Ks, listed in Table 1 indicated that an decreased in Ks-value from 742.6 cm d^{-1} to 14.8 cm d^{-1} representing a shift from coarse to fine soil resulted in an decrease in the wetted ratio, particularly in the upper two layers, these results are in agreement with those found by this is good agreed with that found by Clark (1992) and Ainechee *et al*. (2009). Generally, doubling the value emitter discharge on loamy soil tends to increase the wetted soil width more than to decrease the wetted depth, while in the case of sandy soil, it tends to increase the wetted depth more than to increase the wetted width. Clearly, and because the irrigation was scheduled to obtain a wetted widths of 0.50 and 0.70 m for sandy and loamy soil, respectively, with 0.4 m soil depth, the average wetted diameter (Table 2) could be used to make a decision support. So, 47.5cm (represented 0.8 L h^{-1} on sandy soil) and 85 cm – 103.3 cm extended to depth shorter than 0.4 m (represented 0.8 L h^{-1} and flooding treatment for loamy soil) must be excluded at irrigation management.

The amount of water stored in the root zone represented by its width and depth, showed that the wetted depth should coincide with the depth of the root system while its width dimension should be related to the spacing between emitters and lines. In the case of row crops, where distance between emitters would determine the degree of overlap between neighboring wetted circles, data presented in Table 2 could be used to avoid the cost of a unit length of lateral, on which a defined number of emitters are laid, a similar conclusion was reported by Lubana *et al*. (2002). The one way randomized blocks was use as statistically analysis to detect the significantly difference between the wetted diameter (in average through the 40 cm soil depth) under all studied discharge for both soils (Table 2). For sandy soil, the results showed that 4.6 L h^{-1} discharge rate had the most wetted width (significantly increased) compared to the other treatments, therefore it could be provide the economic emitters distance. On the other side, although the most wetted width was obtained under 8.0 L h^{-1} and flooding application, both 1.8 and 4.6 L h^{-1} discharges with accepted wetted width could reached the desired soil depth in the regard of irrigation scheduling.

TABLE 2. Values of wetted width to wetted depth ratio for both soils recorded under different treatments. Total applied water, V, was 8.2 and 63.25 L for sandy and loamy soil, respectively.

Soil	Soil depth, cm	Emitter discharge rates, L h^{-1}			Surface flooding
		1.8	4.6	8.0	
Sandy	10	3.5	5.0	4.0	5.0
	20	7.0	7.0	5.0	6.5
	30	6.0	9.0	5.0	6.5
	40	6.0	10.5	5.0	5.0
Average wetted diameter, cm		5.6 [b]	7.87 [a]	4.75 [b]	5.75 [b]
loamy	10	8.0	8.5	11.0	11.0
	20	8.0	9.5	9.7	9.5
	30	6.5	8.5	7.0	8.0 **
	40	5.5	5.5	2.0 *	0
Average wetted diameter, cm		7.0 [a]	8.0 [a]	8.5 [a]	10.4 ***

For sandy soil: LSD 0.05 = 1.89
For loamy soil: LSD 0.05 = 3.01

* Depth of wetted layer was only 5 cm, so, the average of wetted diameter was based on 35 cm soil depth.

** Depth of wetted layer was only 7 cm, so, the average of wetted diameter was based on 27 cm soil depth.

*** While this wetted width could provide an economic emitters distance, the desired depth will not be wetted.

Simulated and observed data

Field observations showed that the most transmissive soil (*i.e*., sandy where K = 742 cm d^{-1}) showed greater wetted depth, Z, and smaller values of wetted width, W, compared to the other more slowly soil (loamy soil where Ks= 14.8 cm d^{-1}). Generally, and due to the difference among discharges, values of W and Z observably changed. Practically, these changes are strongly related either to laterally and vertically roots distribution or emitter spacing. Schwartzman-Zur model has been developed to predict these wetted parameter (*i.e*., W and Z) and tested in this study to detect its precision to use for field detections. The simulated values of W and Z obtained using Schwartzman-Zur's model were computed and compared with those measured in the field. Data listed in Table 3, showed that there was good agreement (particularly, for loamy soil) between the simulated values and observed values strengthens our confidence in the validity of this empirical equation, to use for point source water application. There was a poor relationship between simulated W and that observed for sandy soil. This poor relation between the model-Values for sandy soil have been found also either by Ekhmaj *et al*. (2006) using Hydrus 2D model or Ainechee *et al*. (2009) using Schwartzman-Zur model. The regulated manner in the relation between wetted volume (represented by W and Z) in loamy soil compared to that hysterically in sandy, may be attributed to the different in Ks values. In the case of loamy soil, the absolutely increasing the laterally wetting compared to vertical direction may be due to that all different discharges were more than water penetrating through the soil. Thus water will be accumulated in upper layers leads to horizontally movement as well as a chance for capillary rise of water, So, cone moisture appears delightful rather than length (Fig. 5).

TABLE 3. Comparison between observed and simulated values of wetted width, W and wetted depth, Z according to Schwartzman-Zur model, Eq. 6, in which V values were 8.2 and 63.25 and Ks were 742.6 and 14.8 cm d^{-1} for sandy and loamy soil, respectively.

Soil	Model's constants				Applied discharge, L h^{-1}	Simulated value, cm		Observed value, cm	
	A_1	n_1	A_2	n_2		W	Z	W	Z**
Sandy	27.672	0.3400	19.838	0.3333	1.9	60.0	40.0	56.3	40.0
					4.6	59.5	40.0	78.8	40.0
					8.0	59.5	40.0	47.5	40.0
					492*	56.8	40.0	57.5	40.0
Loamy	23.358	0.3037	7.8465	0.3668	1.9	74.9	40.0	70.0	40.0
					4.6	78.1	38.1	80.0	39.0
					8.0	80.1	37.0	85.0	35.0
					3795*	105.3	27.2	103.7	27.0

*These values assumed that total water amounts, *V*, for each soil, applied in one mint to represent the flooding application.

**Actual wetted depth in sandy soil excised 40 cm, while the observed depth was limited here to 40 cm because the irrigation scheduling was achieved to this depth back to its field capacity.

Conclusion

Irrigation decision-making must be depended on a good description of soil moisture patterns in both laterally and vertically directions. Assessing of soil moisture status under surface drip irrigation systems, is a function of soil texture and discharge rate, thus it is a pre-requisite successful irrigation management. Both WET sensor meter and Surfer program could be used as reliably techniques for detection of laterally and vertically soil moisture pattern. Obtained results indicated that soil moisture distribution and its uniformity within the soil profile under surface drip was greatly affected by emitter discharge and soil texture. Regarding to appropriate moisture distribution, it is preferably to use discharge rates of 1.8 and 4.6 L h^{-1} for both soils, while bubbler application (8 L h^{-1}) may be not recommende either for sandy or loamy soil, because the last two techniques could not achieved the desired wetted volume (*i.e*., wetted width and wetted depth). Irrigation scheduling based on equivalent water depth equation was found to be successfully applicable for sand soil compared to the loamy. To quantify the geometry wetted volume in soil, Schwartzman-Zur's model could be reliably used particularly for loamy soil than the sandy, in which the model provides an accurate description about the wetted width and depth ratio.

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(*Received* 19/ 2 /2014;
accepted 2 / 11 /2014)

تقييم أنماط توزيع رطوبة التربة تحت معدلات تصرف مختلفة بإستخدام محس الـ WET

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إن ضمان توصيل الماء والأسمدة بكفاءة عالية إلي منطقة الجذور النشطة للنباتات يتطلب فهم وإستيعاب جيد لنمط توزيع الرطوبة داخل التربة. ويتأثر نمط توزيع الرطوبة بكل من خصائص التربة ومعدل التصرف الذي يضاف به ماء الري. ويهدف هذا البحث إلي تقييم أنماط توزيع الرطوبة داخل التربة، والحادثة تحت معدلات تصرف مختلفة، وذلك في نوعين تربة مختلفين في القوام (إحداهما تربة رملية والأخري لومية). تمت الدراسة في الحقل، وذلك تحت أربعة معدلات إضافة مختلفة للمياه: ثلاث معدلات تنقيط وهي: 1,8، 4,6 و 8,0 لتر/ساعة، بالإضافة إلى تطبيق طريقة الغمر وذلك بغرض المقارنة ولتقييم مدي الإعتماد عليها في جدولة عملية الري، وذلك من خلال دراسة تقدم جبهة الإبتلال في كلا التلابتين. كما تهدف الدراسة أيضاً إلى معرفة إلي أي مدي يمكن تطبيق معادلة عمق الماء المكافئ بشكل موثوق فيه وذلك تحت نظام الري بالتنقيط. لقد تم قياس المحتوي الرطوبي بالتربة علي مسافات عديدة في الإتجاهين الأفقي والرأسي وذلك لجميع المعاملات، وقد إستخدم في ذلك جهاز لقياس رطوبة التربة يطلق عليه محس الـ WET Sensor، ووفقاً للإختبارات المبدئية التي تمت علي الجهاز وجدت ضرورة معايرته لكل نوع تربة علي حدا قبل إستخدامه في الحقل، وقد تمت المعايرة داخل المعمل. بما أن تتبع التوزيع الرطوبي علي أعماق ومسافات متعددة تحت الظروف الحقلية، قد ينتج عنه بعض العيوب، سواء من ناحية التربة أو النبات أو الوقت، فقد تم إختبار نموذج شفارتسمان-تسور كطريقة شبه تجريبية بسيطة يمكن من خلالها التنبوء بالشكل الهندسي لتوزيع الرطوبة بالتربة (حجم البلل)، وكان دراسة مدي صلاحية هذا النموذج لإستخدامه لكلا التربتين هدفاً إضافياً في هذه الدراسة.

أظهرت النتائج المتحصل عليها وجود إرتباط كبير بين قراءات الجهاز وقيم المحتوي الرطوبي المتحصل عليها بطريقة التجفيف والوزن، حيث بلغ معامل الإرتباط R^2 0,999 و 0,9804 وذلك للتربة الرملية واللومية علي التوالي، مما

يوضح أن هذا المقياس يمكن الإعتماد عليه لدراسة وتتبع توزيع الرطوبة داخل التربة. كما أظهرت النتائج أن أفضل توزيع رطوبي يمكن الحصول عليه بالنسبة للتربة الرملية كان تحت معاملتي معدل التصرف 4,6 لتر/ساعة ومعاملة الغمر وذلك مقارنة بالمعدلين 1,8 و 8,0 لتر/ساعة. أما بالنسبة للتربة اللومية فقد كان أفضل توزيع رطوبي تحت المعاملتين 1,8 و4,6 لتر/ساعة. كانت مرجعية الحكم علي أفضل توزيع رطوبي هو تعيين مساحة أفقية وعمق محددين، يتم علي أساسهما حساب كمية المياه المطلوب إضافتها. وقد دلت النتائج علي أن تقدم جبهة الإبتلال يمكن الحصول عليه بشكل جيد (مما يرفع من كفاءة إستخدام وحدة المياه وكذلك الوحدة السمادية) كما هو مرغوب في عملية الجدولة، وذلك عند إضافة المقنن المائي بطريقة الغمر في التربة الرملية بينما لم يتحقق ذلك بدرجة صحيحة في التربة اللومية، حيث تحقق فقط بنسبة 67 ٪ .

ومن ناحية التصميم والجدولة معاً، فقد دل التحليل الإحصائي علي أن أفضل قطر وعمق بلل يمكن الحصول عليهما تحت معدل تنقيط 4,6 لتر/ساعة في التربة الرملية، وتحت معدلين 1,8 و 4,6 لتر/ساعة في التربة اللومية، حيث يمكن مع تلك المعدلات الحصول علي منطقة تداخل بلل جيدة (مما قد يقلل من مشكلة تكون دوائر الأملاح حول النقاطات) كما يمكن أن تكون إقتصادية من ناحية عدد النقاطات علي الخط الواحد. وفقاً لخاصية التوصيل الهيدروليكي بالتربة، وكمية المياه المضافة ومعدل التصرف فقط . دلت نتائج إختبار نموذج شفارتسمان-تسور أن هناك توافق كبير بين قيم عرض وعمق البلل المحسوبة من النموذج وتلك المسجلة في تجربة الحقل، ويمكن إستخدامه للتربة اللومية مقارنة بالرملية.