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Wetting Patterns under Trickle Source in a Loamy Sand Soil of South Tunisia

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Abstract: This study was carried out to determine the effect of different discharge values on the wetting patterns of a loamy sand soil under trickle source. The experiment was conducted in two undisturbed monoliths, equipped with a transparent Plexiglas front to make easy learning and measuring the wetting front coordinates (wet radius at the surface, diagonal wetting front and the depth of the wetting front under the dripper). Irrigation treatments consisted of two different discharges (1.5 and 4 Lh^{-1}). Application time was six hours for the first treatment and four hours for the second one. Monitoring of the wetting front movement revealed that low application rate leads to water distribution in the horizontal direction, while higher application rate favours the vertical direction of water for a given applied volume. The increase in vertical and diagonal wetting front was represented by a power function expressed as $Z(t) = a.t^b$,whereas lateral wetted radius increase was represented by an exponential model as follows: $R_f(t) = a.(1\text{-}e^{-b.t})^c$ which expressed the steady value for $R_f(t)$ at long time. R_f and Z_f measurements versus time leads to wetting front speed calculation in the two directions. It makes the estimation of the wetted bulb volume easier under the emitter at the end of any irrigation application. Mathematical models were developed for the horizontal, diagonal and vertical wetting fronts in relation to the application rates. Such results can help in design procedure (emitters spacing, lines spacing and application time) and improveing the water use efficiency.

Key words: Arid · drip irrigation · wetting front · discharge rate · wetting bulb

INTRODUCTION

As everywhere in North Africa and Middle East, water is a scarce source in Tunisia. Competition for water between agricultural, industrial and urban consumers increases continually [1]. The arid climate requires that cultivated crops be intensively irrigated. Under these conditions of limited resources, crop production must be maintained at expense of minimum inputs but aiming at achieving maximum incomes. In order to achieve that goal, improvement of irrigation water use efficiency is necessary. The dominant irrigation methods are furrow and basin irrigation, which cause a large percolation losses and restrains the production increase in due to the frequent drought of soil at the irrigation intervals and under poor irrigation management. In the arid southern part of the country, water resources are finite and irrigated agriculture is dominated by traditional methods of surface irrigation [2]. In order to preserve this resource and to improve its use efficiency, drip irrigation is considered as a good way to achieve that. In fact, drip irrigation allows a large degree of water application control, enabling accurate application of irrigation amounts according to crop water requirements. If properly managed, drip irrigation will reduce the water losses caused by evaporation and by deep percolation [3]. Furthermore, chemicals can be added to the irrigation water, thereby accurately placing plant nutrients near to the plant roots. When using low quality water, drip irrigation has several advantages as compared to other irrigation methods; where the possible damage of the foliage because of the salts accumulation at the wetting front is prevented [4], in addition that the soil salinity around the root area stays near by the irrigation water [5] when the irrigation is managed properly [6].

Nevertheless, the use of this technique is relatively recent and little information is known about the movement of water in these permeable soils in response to this drip irrigation contrary to other soil types [7-9]. In this part of Tunisia, irrigation is mainly practiced around shallow wells with a salinity varying from 3 to 10 dS m^{-1}

The objective of the present research was to study the effect of application rate and volume applied on the followings aspects: 1) the lateral progress of the wetting front at the surface R_f (t); 2) the vertical progress of the wetting front under the dripper Z_f (t); 3) the diagonal

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progress of the wetting front under the dripper Z_d (t); 4) the speed of wetting front movement in lateral and vertical direction and 5) the wetted bulb volume at the end of irrigation.

MATERIALS ET METHODS

The experiments were carried out in the laboratory using two parallelepipedic containers (monolith) with a transparent Plexiglas front. They are 100 cm height and 90 cm wide with some drainage apertures at the bottom to prevent water stagnation. A sandy loam soil profile was prepared along eight months for a natural ramming [10]. Table 1 summarizes water holding capacity and particle size distribution of the soil.

θ_{fc} : Volumetric water content at the field capacity;
θ_{pwp}: Volumetric water content at the permanent wilting point.

The vertical Plexiglas front was 5cm on 5cm squared in order to observe wetting front advance in every direction (Fig. 1).

The surface was evened to a favour axisymmetric water distribution. Water was applied to the soil surface by a constant level reservoir connected to a capillary tube. Alike device is usually used [11-13] to study water movement, wetting bulb shape under emitters and nitrogen distribution from a surface point source.

Table 1: Particules size adistribution and rétention properties

depth (cm)	Clay (%)	Silt (%)	Sand (%)	Bulk density (g cm^{-3})	θ_{fc} ($cm^3.cm^{-3}$)	θ_{pwp} ($cm^3.cm^{-3}$)
0-20	7.33	6.78	84.11	1.48	18.13	5.11
20-40	9.75	10.25	78.25	1.53	16.5	8.92
40-60	11.38	12.13	75.38	1.49	19.8	13.08
60-80	12.04	13.41	72.34	1.46	27.5	15.28

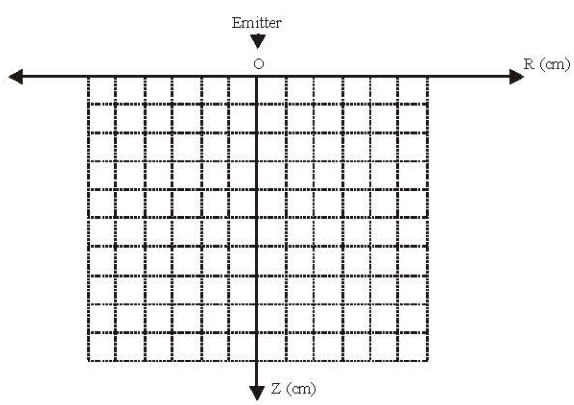

Fig. 1: Schematic description of the experimental device (axis and squared front)

The discharge rates 1.5 Lh^{-1} and 4 Lh^{-1} were used in the experiment. The infiltration time was successively 6 hours and 4 hours for the discharge flow rates of 1.5 and 4 Lh^{-1}. Initial soil water content was 0.05 $cm^3.cm^{-3}$. During each experiment, the positions of wetting front on the soil surface (or axis) and in the vertical plane (oz axis) were visually recorded every fifteen minutes. Two variables affecting water flow are considered: application rate and applied volume.

RESULTS AND DISCUSSION

The wetting patterns are characterized by the depth of wetting front (Z_f) under the point source (emitter) and the radial wetting front at the surface (R_f). These variables are influenced by the application rate and the applied volume. Nevertheless the knowledge of lateral and vertical coordinates of the wetting front makes it easy to calculate advance's speed in every direction.

Vertical wetting front advance (Z_f): A regression analysis showed that experimental data of the advance vertical wetting front (cm) exposed a power function in relation to time (min) as follows:

$$Z_f = kT^u \quad (1)$$

- $q = 4Lh^{-1}$: k = 5.004602 ; u = 0.419284 and r = 0.999
- $q = 1.5Lh^{-1}$: k = 1.093596 ; u = 0.609344 and r = 0.998

A similar regression was established by Merlo [14]; Guerdouh [15] and Laghrib [16].

Figure 2 which shows the vertical wetting front progression for every studied discharge, exhibits two curves with a similar shape. The deeper point of wetting front is located at 50 cm under the emitter for 4 Lh^{-1} discharge, while for 1.5 Lh^{-1} it doesn't overreach 40cm. It shows that the higher the emitter discharge the more the vertical advance which corroborate Montalvo [12] and Mostaghami *et al.* [9] results. Accordingly, the applied time must be optimised to prevent water loss by deep percolation, mainly with a long time scale, for the greater discharge, while for the small discharge it is run with the short time scale.

results. Accordingly, application time must be optimised to prevent water loss by deep percolation, mainly with a long time scale, for the greater discharge and under irrigation, mainly with a short time scale, for the small discharge.

Wetting front movement speed is given by derivating equation (1) to time which leads to followings results:

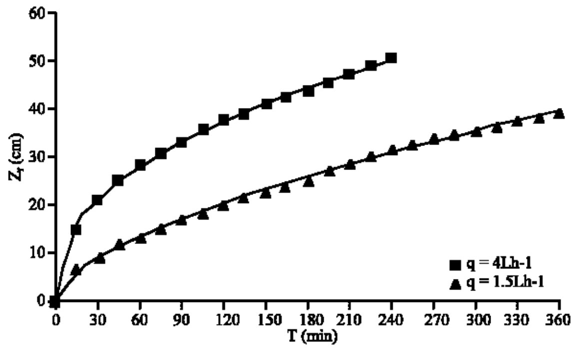

Fig. 2: Down advance of wetting front versus time under different discharges

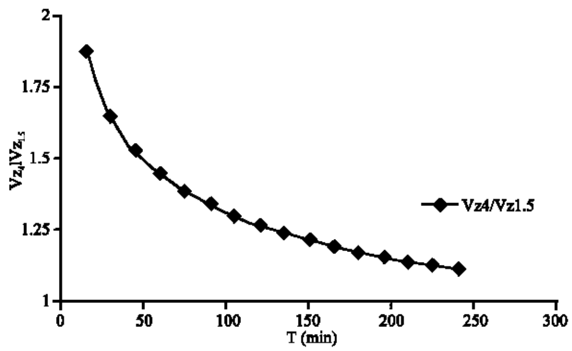

Fig. 3: Variation of the vertical speed ratio in relation to irrigation time

- $q = 4\ Lh^{-1}$: $V_4 = 2{,}098349 * T^{0{,}580716}$
- $q = 1.5\ Lh^{-1}$: $V_{1.5} = 0.666376 * T^{\ 0.390656}$

Where V is in $cm.min^{-1}$ and T in min.

As for the advance, speed is more important with the great discharge rate. At the beginning of the experiment, speed of the greater discharge is about twice (1.8) of that for the small discharge. This ratio decreases with time to reach a value near the unity (1.1) which means that at long time speed is independent from discharge value. This behaviour may be attributed to the predominance of the gravity effects in the long time.

Figure 3 shows the variation of the V4 / $V_{1.5}$ ratio in relation to time.

Lateral wetting front advance (R_f): Figure 4 represents the radial wetting front advance at the soil surface. Curves are obtained by fitting experimental data on an exponential function as followings:

$$R_f = A\ (1 - e^{-Bt})^C \qquad (2)$$

- $q = 4\ Lh^{-1}$: A = 24.22953 ; B = 0.008690 ; C = 0.318549 and r = 0.998

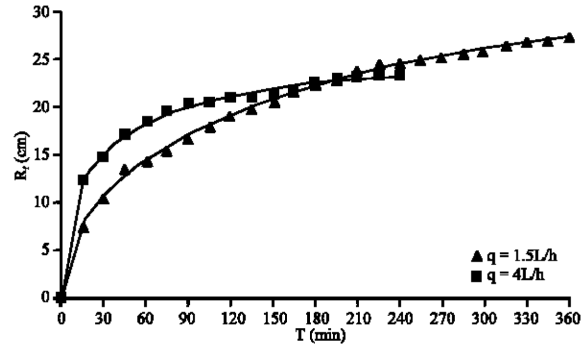

Fig. 4: Variation of the lateral wetting front advance in relation to irrigation time under two discharges

- $q = 1.5\ Lh^{-1}$: A = 33.15213; B = 0.002981; C = 0.457225 and r = 0.999

Where R_f is in cm and t in min.

Figure 4 shows that during the first 180 minutes, wet radius was more important with the great discharge ($4\ Lh^{-1}$), after what the behaviour will be inversed and the greatest wet radius was produced by the small discharge ($1.5\ Lh^{-1}$). It also shows the asymptotic tendency of the curve which means that at long time scale wet radius take a finite value (equal to limit $R_f(t)$ when $t \to \infty$). This lateral advance behaviour of wetting front is attributed to the capillary predominance effect for small discharge at the opposite of gravity effect which is more important with great discharge.

As for the vertical advance, derivation procedure enables the inference of lateral speed for every studied discharge. Nevertheless, for lateral increase, a higher speed was generated by small discharge as showed by the ratio $V_{1.5}/V_4$ curve in Figure 5:

Figure 5 shows that for this sandy loam soil, the lower the discharge rate, the higher the lateral speed. The ratio takes approximately the value 1at the beginning and reaches almost the double at the end of irrigation time. A similar result seems in favour to use of lower discharge rates. It corroborates the new world tendency to lower discharges in localised irrigation [17-19].

Diagonal wetting front advance (Z_d): Experimental data are well fitted on a power function for the vertical wetting front as follows:

$$Z_d = \lambda\ T^{\gamma} \qquad (3)$$

- $q = 1.5\ Lh^{-1}$: $\lambda = 2.014$; $\gamma = 0.5028$; r = 0.998
- $q = 4\ Lh^{-1}$: $\lambda = 4.921$; $\gamma = 0.4388$; r = 0.998

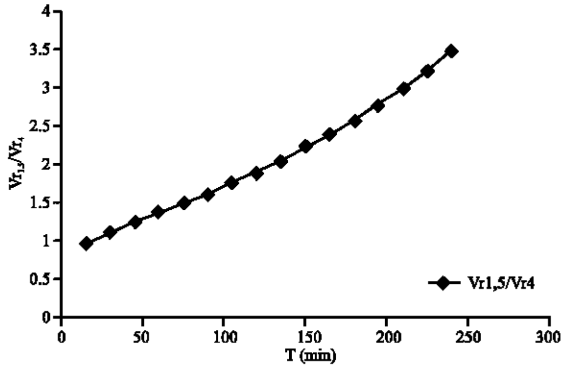

Fig. 5: Variation (evolution) of the $V_{1.5}/V_4$ ratio in relation to the irrigation time

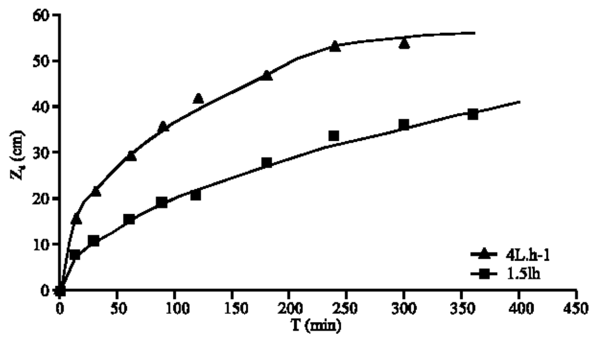

Fig. 6: Variation of the diagonal wetting front increase in relation to irrigation time

Diagonal wetting front « Z_d » increase versus time during irrigation time is presented in Figure 6. This figure shows two curves with a similar behaviour as the vertical wetting front advance (Z_f). So, the higher the discharge rate, the higher the diagonal advance is.

Bulb volume at the end of the infiltration: Figure 7 shows the bulb shape after irrigation leading to deduce the maximum width of the wet strip (L_h) under emitter for every discharge rate. The strip cote is as follows:

- q = 1.5 Lh^{-1}: L_h = 60 cm (at Z ≈ 15 cm);
- q = 4.0 Lh^{-1}: L_h = 72 cm (at Z ≈ 20 cm).

Where: T (h), Z_f (cm) and Vh (cm^3).

Admitting the bulb symmetry to Oz axis, wetted bulb volume V_h can be expressed as:

$$V_h = p\int_{z=0}^{z_f} r^2(z)dz \qquad (4)$$

Estimation of integral (4) was carried out by using trapeze method (Nougier, 1983). Computation of results are reported in Table 2.

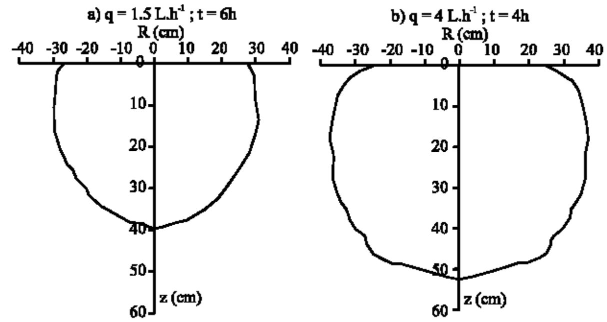

Fig. 7: Wetted bulbs at the end of irrigation

Table 2: Wetted bulb volumes recorded after irrigation

q = 4 $L.h^{-1}$			q = 1.5 $L.h^{-1}$		
T (h)	Z_f (cm)	V_h (cm^3)	T (h)	Z_f (cm)	V_h (cm^3)
4	52.5	167987	6	40	80639

After 6 hour's application time, the wetting front depth with 1.5 Lh^{-1} emitter was at 40 cm. For 4 Lh^{-1} and 4 hours application time, it was at 52.5 cm. After redistribution, wetting front depth will be certainly greater than these values. Accordingly, with crops roots depth, emitters and laterals spacing, discharge choice can be obtained and consequently application time optimisation to prevent water loss neither by deep percolation nor by under irrigation.

CONCLUSION

The influence of an emitter discharge on wetting patterns and distribution in arid sandy loam soil has been studied. Tow applications rate were tested for the measurement of the wetting advance front (lateral, diagonal and vertical) and wetted bulb volume after irrigation.

In these regions, where drip irrigation is recently used in field crops, wetting front advance knowledge is very important. It helps to design irrigation network: wetted radius (R_f) width indicates the optimum lines spacing and drippers spacing on a line whereas vertical wetting front (Z_f) advance with cultivated crops roots growth allows the calculation of the optimum time application to prevent nether deep percolation water nor the fertiliser loss or under irrigation.

This study was performed on a bare homogeneous loamy sand soil profile. Further research is needed for testing the suitability of the obtained results on other cropped soils of different types.

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