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Drip Irrigation Systems and Water Saving in Arid Climate: A Case Study from South Tunisia

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Abstract: Tunisia is a North Africa country where water resources are limited and often brackish notably in the south part. Competition for water between agricultural, industrial and urban consumers increases continually. Under these conditions of limited resources, trickle irrigation systems become an attractive alternative for conserving water. The objective of this paper was to study the feasibility of this system and to determine its impact on water use efficiency and production of pepper (*Capsicum annuum.* L) which is largely cropped plant of southern Tunisia arid part. Firstly, a study was carried out to determine the effects of different discharge values on wetting patterns under trickle source in a loamy sand soil. It was carried out in monoliths with two different discharges (4 and 1.5 liter per hour). With 4L/h discharge, wetting front reach a depth of 50cm after an application time of 4 hours and the largest moistened band at 20 cm depth under soil surface and measure 70 cm. With 1.5 L/h during 6hours application time the wetting front depth was 37cm and the largest band was observed at 15cm with 60 cm value. The second part of the study was undertaken on the field. Plants are planted and irrigated differently by trickle and surface irrigation in order to distinguish the differences in soil water content, crop production and applied water in relation with irrigation systems. Results showed that trickle irrigation used 60% less water than surface irrigation whereas production was respectively 17.755 Ton ha^{-1} and 10.715 Ton ha^{-1} for drip and surface.

Key words: Arid · Irrigation · Wetting front · Water use · Production · Pepper

INTRODUCTION

Located in the north of Africa and on southern of the Mediterranean Sea, Tunisia is a country dominated by an arid climate with a very strong variability. Approximately 85% of water resources of the country are allocated for irrigation sector. On another hand competition for water between agricultural, industrial and urban consumers increase continually.

In the arid south part, mean annual rainfall is less than 200 mm. irrigated agriculture is dominated by traditional methods of surface irrigation [1] which causes large percolation losses and restrains the increase in production due to soil frequent drought at irrigation intervals and poor irrigation management. In these arid climatic conditions, drip irrigation, in which water is applied directly to the roots zone of plants by different ways (orifices, emitters, porous tubing, or perforate pipe) and operated under low pressure [2] can help in conserving water by reducing evaporation and deep percolation if well managed [3]. Advantages of surface drip irrigation are the ease of installation, inspection, changing and cleaning emitters. It also permits the possibility of checking soil surface wetting patterns and measuring individual dripper.

MATERIALS AND METHODS

The first part of the study was undertaken in monolith with squared front (Fig. 1). Its main objective was to study the effect of application rate and water applied volume in relation with soil characteristics on the followings aspects:

- Lateral progress of the wetting front at the surface;
- Vertical progress of the wetting front under the dripper;
- Diagonal progress of the wetting front under the dripper;
- Wetted bulb volume at the end of irrigation.

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Table 1: Particules size distribution and rétention properties

Depth (cm)	0-20	20-40	40-60	60-80
Clay (%)	7.33	9.75	11.38	12.04
Silt (%)	6.78	10.25	12.13	13.41
Sand (%)	84.11	78.25	75.38	72.34
Field capacity (f_c) (cm^3/cm^3)	18.13	16.5	19.8	27.5
Wilting point (w_p) (cm^3/cm^3)	5.11	8.92	13.08	15.28

Table 2: Principles of water irrigation characteristics

Cations (méq/liter)			Anions (méq/liter)							
Na^+	K^+	Ca^{++}+Mg^{++}	So4⁻⁻	Hco3⁻	Co3⁻	Cl^-	Rs	EC	SAR	pH
31.52	0.41	17.16	20.67	0.63	0.1	35.1	2.94	4.28	10.76	7.9

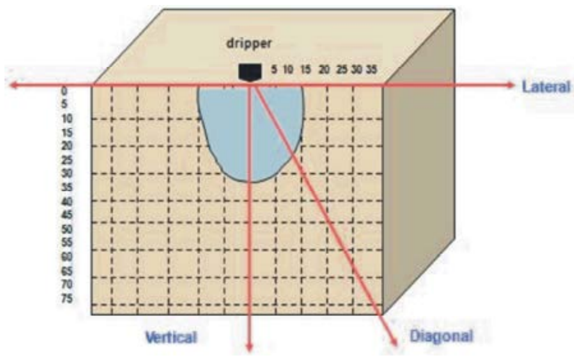

Fig. 1: Schema of used monolith

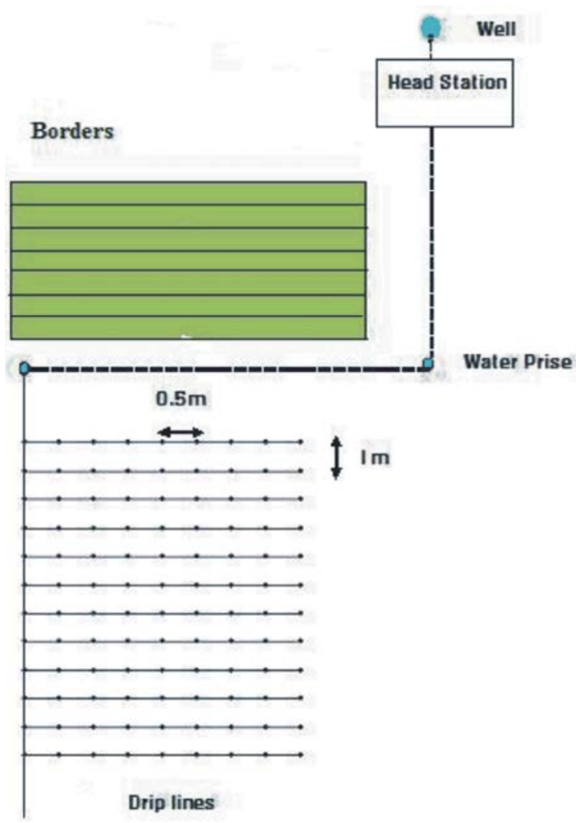

Fig. 2: Schematic representation of experimental layout in field

The second part was carried out in the experimental field of Aridoculture and Oases Laboratory [4] in the Institute of Arid Regions (33°3' N, 10°3'E). Climate is typically Mediterranean with dry and hot summers and precipitations irregularly distributed throughout the year. The soil at the study site is loamy sand and almost flat. Major soil characteristics of trial plots are summarized in Table 1.

One month old seedlings of a local green pepper cultivar were transplanted in 60x50 cm spacing for border irrigation and in 100x50 cm for surface trickle irrigation. Borders were 2 m wide and 8 m in length, while the drip lines length was 20 m where drippers were spaced out at 50 cm (Fig. 2).

Irrigation water characteristics are included in Table 2. It was applied from a well by a pump in drip irrigated plots and by gravity from the basin for borders. A drip irrigation system was used, with 4L/h PVC emitters. Irrigation frequency was three days for each trial. It was chosen to be the nearest of farmer's practices.

Soil water content data were collected from each experimental plot, once a week one day after irrigation. It was calculated by gravimetric method for surface irrigation where three samples were taken at the head, the middle and the end of the border with a step of 20 cm until 60 cm considered as a maximum root depth for pepper [5, 6]. Gravimetric method was also used to determine soil moisture at the point of middle distance between drippers. Near the dripper, soil water content was measured by mean of 4 densitometers placed around the dripper at a 10 cm circumference at 15, 30, 45 and 60 cm depths. Statistical treatment was performed with Excel [7] by the mean of an analysis of variance (ANOVA test).

RESULTS AND DISCUSSION

Moistened Bulb Shape in Sandy Soil: In the first part, experiment was devoted to study water patterns under trickle for the soil, largely dominated by sand fraction. For this objective two water discharge (4 and 1.5 liter/hour) were used. Wetting front coordinates were measured into three directions as shown in monolith schema. In the end of experiment which has taken six hours for 1.5 liter per hour and four hours for 4 liter per hour, collected data permit to draw the bulb shape at the end of irrigation (Figure3).

For 4 Liter per hour dripper discharge (Q), wetting front reach a depth of 50cm after an application time (T) of 4 hours. The largest moistened band measuring 70cm was observed at 20 cm depth under soil surface. With 1.5 Liter per hour dripper and during 6hours application time the wetting front depth was 37cm and the largest moistened band was observed at 15cm with 60 cm value.

Moistened Bulb Dimensions: Admitting moistened bulb symmetry to Oz axis, wetted bulb volume V can be expressed as:

$$V = \pi \int_{z=0}^{z} r^2(z)\,dz \qquad (1)$$

Estimation of integral (1) was carried out by using trapeze method [8] and results are reported in Table (3).

As shown in Figure 3, moistened bulb radius observed at soil surface was successively 25 cm for 4liter per hour and 28 cm for 1.5 liter per hour. Quotient radius/depth was successively 0.46 and 0.70.

Table 3: Wetted bulb volumes recorded after irrigation

	Q= 4 L.h^{-1}			Q = 1.5 L.h^{-1}	
T (hour)	Depth (cm)	V (cm^3)	T (hour)	Depth (cm)	V (cm^3)
4	50	167987	6	37	80639

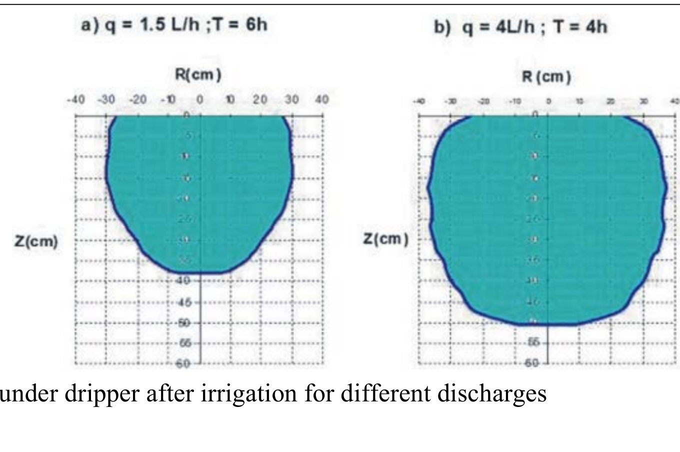

Fig. 3: Moistened bulb under dripper after irrigation for different discharges

Water Status in Soil: Total available water (TAW) is water that soil can hold between field capacity (fc) and permanent wilting point (pwp). For a given depth, this total available water is calculated by the mean of following equation:

$$TAW = Z_r * \frac{(\theta_{fc} - \theta_{pwp})}{100} \quad (2)$$

where:

TAW : Total available water (mm);
θ_{fc} : Volumetric soil moisture at field capacity (%);
θ_{pwp} : Volumetric soil moisture at permanent wilting point (%);
Z_r : Root zone depth [mm].

When soil moisture is less then field capacity, the available water (AW) stored in the root zone is computed as:

$$AW = Z * \frac{(\theta_v - \theta_{pwp})}{100} \quad (3)$$

where:

θ_v : Measured volumetric soil moisture (%);
θ_{pwp} : Volumetric soil moisture at permanent wilting point(%);
Z : Root zone depth (mm).

These two factors permitted to calculate the ratio of total available water stored in the root zone depth expressed as:

$$SW = 100 * \frac{AW}{TAW} \quad (4)$$

In order to compare between drip and surface irrigation, parameters defined in equations 2, 3 and 4 were measured in borders and around drippers during irrigation season. Comparison was made between border and two points (10 and 15wm) around dripper for 60cm soil depth. Results are presented in followings figures.

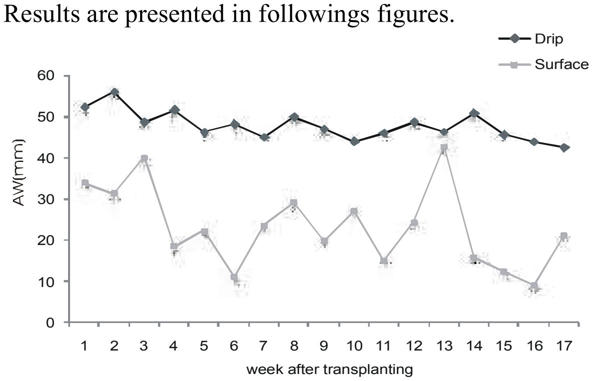

Fig. 4: Measured available water for surface and at 10 cm from dripper

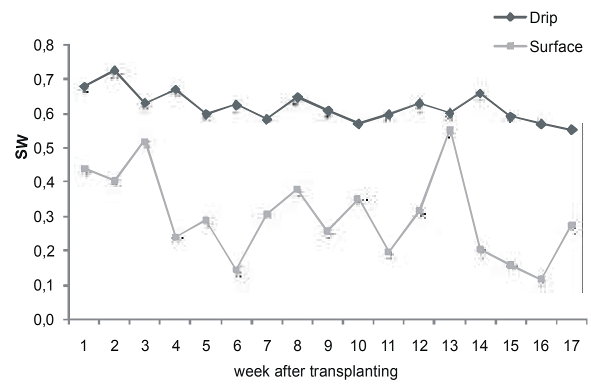

Fig. 5: Total available water ratio in borders and at 10cm from dripper

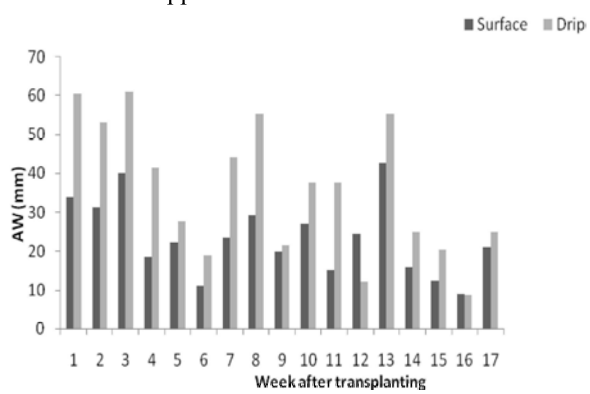

Fig. 6: Measured available water for surface and at 25 cm from dripper

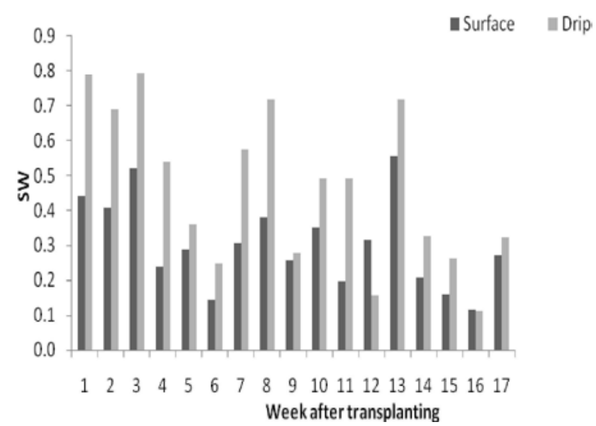

Fig. 7: Total available water ratio in borders and at 25cm from dripper

Figures 4 to 7 showed that soil moisture content was always more important with drip irrigation. At the end of irrigation season, calculus showed also that consumed water volume for one kilogram of fresh pepper was 0.38 m^3 for drip irrigation against 1.05 m^3 for surface irrigation. Others production parameters are included in the following table.

Table 4: Production parameters for pepper under drip and surface irrigation

Parameters	Drip irrigation	Surface irrigation
Fruits/plant	57.43(a)	28.61(b)
Average fruit weight (g)	17.18 (a)	13.87(a)
pepper weight (g/plant)	986.42(a)	396.86(b)
Yield/m^2 (g)	1972.84(a)	1190.58(b)
Applied volume/m^2	0.75	1.25
Consumed water/kg	0.38	1.05

*in line, data with same letter are not statically different

CONCLUSIONS

In order to conserve precious water resources and maximize crop performance, Tunisian farmers are incited to use drip irrigation method for a subsidy which can reach 60 % of irrigation materials cost. Irrigated agriculture is often practised on small plots of land around surface wells and dominated by traditional methods of surface irrigation [1] which causes large percolation losses. In these conditions, reconversion to drip irrigation is able to save considerably water resources and promoting irrigated agriculture. However, this improvement remains dependent of a good design of the system.

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