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Pepper (*Capsicum annuum* L.) responses to surface and drip irrigation in southern Tunisia

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Abstract

Field experiments were performed to study the impact of two different irrigation systems (surface drip and surface) on water use efficiency and yield components of a pepper crop (*Capsicum annum.* L). Irrigation scheduling was carried out based on estimated crop evapotranspiration (ETc) using crop coefficients for pepper and reference evapotranspiration ETo calculated using the Penman-Monteith equation (Allen *et al.*, 1998). The crop received total water needs computed according to Veirmeiren and Jobling (1983) procedure for surface drip irrigation. Border irrigation was scheduled by Cropwat model (Smith, 1992). Experimental plots were irrigated simultaneously during the appropriate duration for each one and received the same nutrients (N, P, and K) ratio. Comparison was made on fruit number per plant, fruit weight, fruit weight by harvest and yield per unit surface. The results showed that compared with surface irrigation, drip irrigation presented a significant difference in total fruit yield and water use during cropping season (May to September). With drip irrigation, average yield was 19.73 kg m^{-2} which was 68% greater than that irrigated with surface irrigation (11.90 kg m^{-2}). Applied water volume by unit production (m^3/kg) was 0.38 for drip and 1.05 for border, respectively. Drip irrigation increased fresh pepper fruit yield with a reduction of 60% in water use compared to traditional surface irrigation.

Key words: Arid, drip irrigation, border irrigation, yield, *Capsicum annum.*L, water use.

Introduction

In near future, the main constraint to agricultural development of arid and semi arid areas will be the availability of water resources rather than soils. Under these conditions of limited water 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 which has increased the search for technology with improved water use efficiency.

In Tunisia, where rainfall is erratic and water demand increase steadily, a national water saving strategy for an efficient management of available water resource was undertaken with following objectives: safeguarding water resources to meet necessary needs for different uses; minimizing water losses; improving water use efficiency especially in agriculture which use 80% of total resources.

In the arid southern part of the country, where water resources are finite, irrigated agriculture is dominated by traditional methods of surface irrigation (Thabet *et al.,* 1999) 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 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 (Spellman, 2008). This can help in conserving water by reducing evaporation and deep percolation, if well managed (Tanji and Hanson, 1990). Advantage 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 discharge rates.

In order to conserve precious water resources and maximize plant performance, farmers are incited to use this method for a subsidy which can reach 60 % of irrigation materials cost.

The main objective of this study was to evaluate the effects of surface drip and surface irrigation on yield components of pepper which is a widely cropped vegetable in summer and used as condiment in North Africa countries. Major studied factors during irrigation season were gas exchange, water consumption, crop yield and soil salinity.

Materials and methods

The experiments were carried out in the experimental field of Aridoculture and Oases Laboratory 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 summarised 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.1).

Irrigation water characteristics are given 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

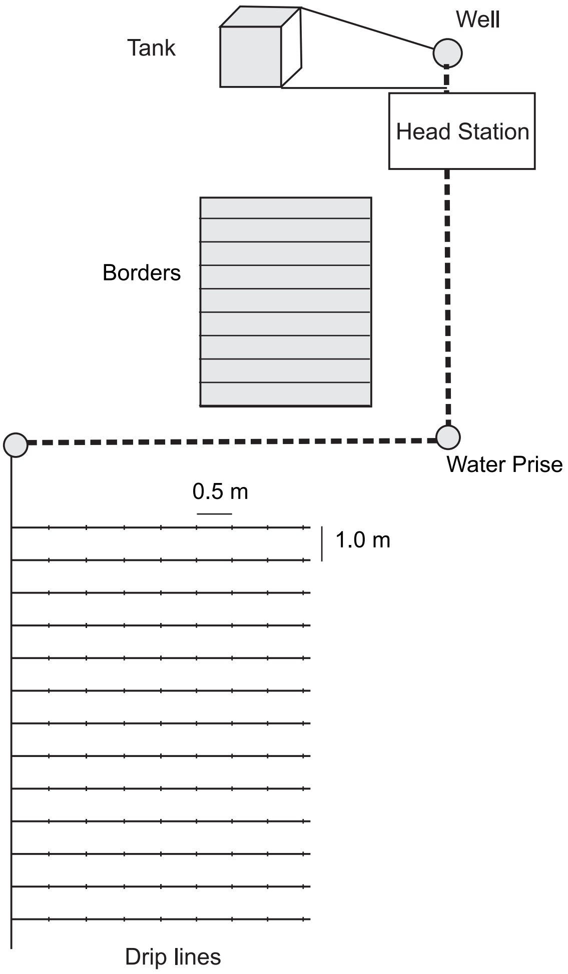

Fig. 1. Experimental layout

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 (Dirks and Tan, 1988; Gough, 2001). 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.

The total available water (TAW) which is water that soil can hold between field capacity and permanent wilting point for a given depth is calculated as:

$$TAW = Z_r * \frac{(\theta_{fc} - \theta_{pwp})}{100} \quad (1)$$

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:

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

Where:

θ_v: measured volumetric soil moisture [%];

θ_{pwp}: volumetric soil moisture at permanent wilting point [%] ;

Zr : root zone depth [mm].

These two variables were used to calculate the percent of total available water stored in the root zone depth which equals:

$$SW = 100 * \frac{AW}{TAW} \quad (3)$$

As pepper is considered one of the most susceptible crops to water stress (Smittle *et al.*, 1994; Delfine *et al.*, 2001; Antony and Singandhupe, 2004; Sezen *et al.*, 2006), the critical value of stored water (SW_c) was taken 50% and equation (3) was used to calculate water stress factor (S_f) computed as :

$$S_f = 100 * \frac{SW}{SW_c} \text{ for } SW < SW_c \quad (4)$$
$$= 1 \quad \text{if } SW \geq SW_c$$

Gas exchange measurements were conducted weekly at 10 plants per treatment one day after irrigation using a portable LCi Ultra Compact Photosynthesis System (ADC BioSientific Ltd, UK). These measurements were conducted in leaves of the same physiological stage (two well-developed leaves per plant) at the same time of the day (9-11a.m.). Measured parameters were:

transpiration rate: E [mmol $m^{-2}s^{-1}$] ;
stomatal conductance : g_s [mol $m^{-2}s^{-1}$] ;
photosynthetic rate : A [µmol $m^{-2}s^{-1}$] ;
substomatal CO_2 : C_i [vpm].

During irrigation season, all plots received the same amount of fertilizer (130-35-75). Yield was determined by hand harvesting of each plot depending on physiological maturity of plants.

Results and discussion

Soil water content: Fig. 2 and 4 illustrates the time course of soil available water content (AW) calculated weekly, 24 hours

Table 1. Soil particle size and water retention properties

Soil depth (cm)	Particle size distribution (%)			Bulk density (g cm^{-3})	Volumetric moisture content (cm^3 cm^{-3})	
	Clay	Silt	Sand		θ_{fc}	θ_{pwp}
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

Table 2. Irrigation water characteristics

Cations (méq L^{-1})			Anions (méq L^{-1})				Rs (g L^{-1})	EC (ds m^{-1})	SAR	pH
Na^+	K^+	Ca^{++}+Mg^{++}	SO_4^{--}	HCO_3^-	CO_3^-	Cl^-				
31.52	0.41	17.16	20.67	0.63	0.1	35.1	2.94	4.28	10.76	7.9

after irrigation. For surface irrigation, soil available water was evaluated from three gravimetric measurements of soil moisture at three points as cited in "materials and methods". During the cropping season, soil moisture ranged from 8 to 14 % with an average of 11.2%.

For drip irrigated plots, soil moisture was measured at two different points: one at 10 cm from the dripper and the other at 25 cm (middle point between two successive drippers). Near the dripper, soil moisture ranged from 14.4 % to 16.6 % with an average of 15.25 %. According to formula (4), Figs. 3 and 5 showed a water stress factor equal to 1 for the point near the dripper during all the cropping season however at 25 cm from dripper, its average was 0.97. In surface irrigation, the average of this water stress factor was 0.61. These results show that the nearest the point from dripper the more the soil moisture. It also show that even at 25 cm from dripper, the average soil moisture was more than that in surface irrigation. This behaviour may be attributed to evaporation losses caused by important evaporative area in surface irrigation added to percolation losses due to land levelling and distribution uniformity, however the reduced area of the slowly applied water in the case of surface drip irrigation decreased water losses by evaporation and deep percolation and so increased soil water content.

Fruit number and yield: Different measured parameters for each irrigation treatment are summarized in Table 3. Graphics and curve fitting were performed using Microsoft Excel 2000 software (Microsoft Corporation).

Analysis of variance (ANOVA test) indicated that irrigation

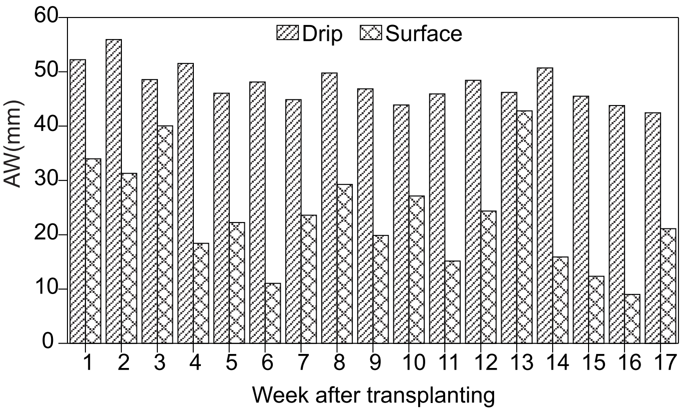

Fig. 2. Available water in 0-60 cm soil depth for surface and at 10 cm from dripper

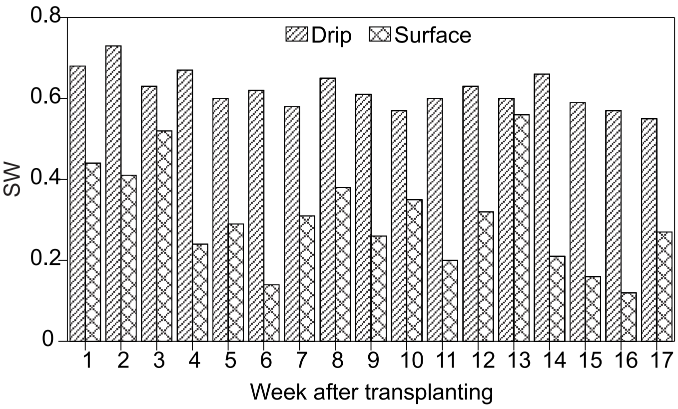

Fig. 3. Total available water ratio in 0-60 cm for surface and at 10 cm from dripper

Table 3. Yield parameters for different irrigation techniques

Parameters	Drip	Surface
Total yield per plant (g)	986.42a	396.86b
Number of fruits per plant	57.43a	28.61b
Average fruit weight (g)	17.18a	13.87a
Yield by square meter (g)	1972.84a	1190.58b
Irrigation water amount (m^3 m^{-2})	0.75a	1.25b

(a), (b): For each row, values with the same letter were not significantly different ($P < 0.05$)

Table 4. Correlation coefficients between net CO_2 assimilation rate (A) and stomatal conductance (g_s) under drip and surface irrigation.

Type of irrigation	Stage 2	Stage 3	Stage 4
Surface drip	0.57	0.66	0.64
Surface	0.60	0.49	0.58

technique did not affect average fruit weight factor, while fruit number was significantly affected by irrigation system. The highest fruit number was obtained at dripped plants with a significant difference so they had higher total mass of fresh fruit than those surface irrigated.

Gas exchange: Transpiration rate (E), net CO_2 assimilation rate (A) and stomatal conductance (g_s) were measured in order to compare the effect of soil water availability difference between the two irrigation systems during different cropping stages (Katerji *et al.,* 1993). Analysis of variance (ANOVA) of collected data was performed with Microsoft Excel 2000 software considering irrigation system and crop stages factors. The first conclusion was the high correlation between net CO_2 assimilation rate (A) and stomatal conductance (g_s) especially for drip irrigation. During different crop stages, analysis of variance (ANOVA) indicated that irrigation technique affect stomatal conductance (g_s), photosynthetic rate (A), substomatal CO_2 (C_i) and water use efficiency defined as A/g_s.

Spatial changes in soil salinity: Salinity is an environmental stress which limits plants growth and development. Plants response to excess NaCl is complex and involves changes in their morphology, physiology and metabolism (Hilal *et al.*, 1998). Pepper (*Capsicum annuum* L.) is generally considered salt sensitive (Maas and Hoffman, 1977; Navarro *et al.*, 2002). As any irrigation water supplies contain a substantial amount of salt, soil electrical conductivity was measured at the beginning and the end of the trial in order to evaluate salt accumulation in the root zone for each irrigation system. There are two processes

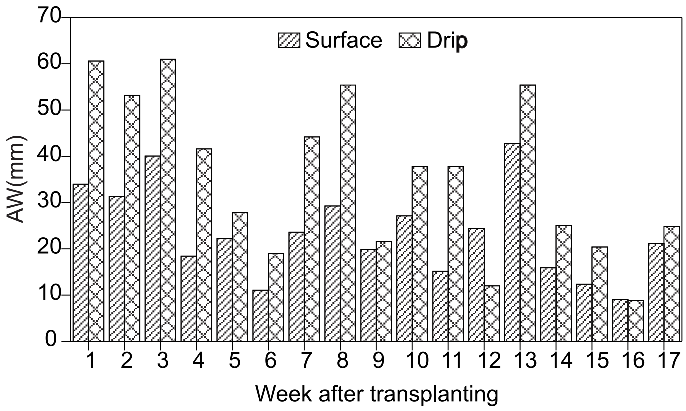

Fig. 4. Available water in 0-60 cm soil depth for surface and at 25 cm from dripper

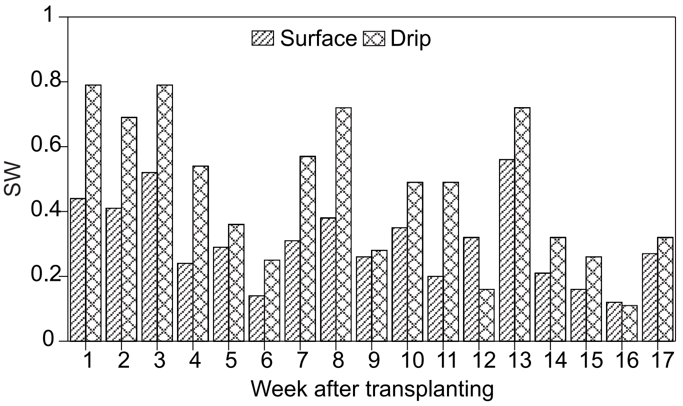

Fig. 5. Total available water ratio in 0-60 cm for surface and at 25 cm from dripper

by which salt accumulates in the root zone. The first one is the upward movement of a shallow saline-water table and the second is salts left in the soil due to insufficient leaching which is the process of applying more water to the field than can be held by the soil in the crop root zone such that the excess water drains below the root system, carrying salts with it**.** In the present case salinity was due to leaching efficiency only. Soil salinity was evaluated by the electrical conductivity of its saturated paste taken in a 10 cm grid along surface and depth. Results showed that high salt concentration was at the bulb periphery and decreased towards the middle. For surface irrigation, as water was distributed over more surface, average soil electrical conductivity values where less than in wetted bulb.

Application of water by drip irrigation system increased fresh pepper fruit yield compared to traditional surface irrigation. Yield data analysis indicated a significant difference between surface drip and traditional surface irrigation systems. One kg of fresh pepper fruit was obtained with 0.38 m^3 for drip and 1.05 m^3 for surface irrigated water and the average water use efficiency along cropping season was 59 and 46%, respectively.

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