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Response of Onion to Salinity

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ABSTRACT

Germination responses to salinity levels were evaluated for eight days using the most frequently cultivated onion (*Allium cepa* L.) cultivar in Tunisia 'Merveille de Pompeï', an early white European variety with a flat bulb and small neck. Five salt levels were used with electrical conductivities (EC) ranging from 1.21 to 9.51 dS.m^{-1}. Germination percentage after 8 days was not significantly reduced at any salt level. These test results confirm that salt effects during germination are not related to later responses of the whole plant to salt. Screening onion for salt tolerance would best be done at the vegetative stage. In a second experiment, onion growth responses to salinity levels were evaluated in a greenhouse study in which the same range of salt levels was tested. Total number, height, fresh and dry weight of the leaves, fresh and dry weight of bulbs and fresh and dry weight of roots were measured during the growing season. Onion was sensitive to low salt levels. In the field, continuous irrigation of onion with water having electrical conductivities of 1.21, 1.45, 3.70, 6.21 and 9.51 dS.m^{-1} resulted in severe die-off of transplanted seedlings in the salinized plots during the first 60 days of growth and consequently, in reduced yields of bulbs. Significant differences in both foliage and bulb weight were found due to the interaction between treatments and plant age. Observations of plant morphological and physiological behaviour under saline conditions were used to explain the effects of brackish water irrigation on onion yield.
Keywords: *Allium cepa* L., crop response, irrigation water, soil

INTRODUCTION

Insufficient water supply for farmers cultivating crop plants has become a serious problem both in economic and biological aspects. Vegetables are very susceptible to water deficit, some due to shallow root systems, and others like celery, onion and cabbage, because of their high demand (Rumasz-Rudnicka *et al*. 2005). Onion water requirement varies depending on location and irrigation system (Al-jamal *et al*. 2000). Ollala *et al*. (2004) reported that the water requirements in Albacette (Spain) for optimum yield (75 t ha^{-1}) were 662 mm of water when using drip irrigation. The period most sensitive to lack of soil water is bulb growth (Kadayifci *et al*. 2005). Some studies give clear proof that the water requirements for onions are very high, restricting expansion to regions with limited water resources (Bandyopadhyay *et al.* 2003; Rajput and Patel 2006; Kumar *et al.* 2007).

Irregular natural rainfall can also result in inadequate water supply during vegetative growth. For these reasons supplemental irrigation is considered to be one of the most important factors for increasing vegetable production and giving crops of good quality. On the other hand, an increasing demand for water calls for farmers and researchers to seek new water sources. Farms might use saline water. In the Mediterranean coastal area of Tunisia, as well as in the vast desert lands, agricultural development depends upon artesian water. The scattered wells contain appreciable amount of salts ranging between 2-6 g.l^{-1} (about 3.0 to 9.5 dS.m^{-1}) with sodium as the predominant cation (Stino *et al*. 1972). The length of the period of germination might be an important determinant of the effective salt tolerance of onion, since the faster the radicle emerges, the faster the seedlings will escape the high salinity of the upper soil layer (De Malach *et al*. 1989). Onion is more affected by salinity than other vegetables (Brewster 1997).

This study was designed to determine yield response to continuous irrigation with brackish/saline water in Tunisia and the effect of salinity upon some morphological characters and dry weight of plant organs of onion cv. 'Merveille de Pompeï' (the most cultivated onion in Tunisia) growth and development. This cultivar is white skinned, rather flat and bulbs rapidly when day length reaches 12.7 to 13.4 hours or more. It has fairly low dry matter content and does not store well (Sta Baba *et al.* 2004). Much of the progress made in use of saline water for crop production has resulted from the formulation of appropriate irrigation management procedures (Pasternak 1987). To develop these procedures, we have to understand the anatomy, morphology and physiology of yield formation of the crop being studied, particularly when salinity is added as another variable (Pasternak *et al*. 1979). Since many crops are especially sensitive to salinity at specific growth stages (Pasternak *et al.* 1985), it is also important to determine at which stages the crop under investigation is more or less salt sensitive, so as to be able to devise management procedures accordingly.

In this work, artificially salinized water of different concentrations was used and salt level accumulation in the vicinity of plant roots was evaluated at different growth stages of the plant.

MATERIALS AND METHODS

The physical and chemical soil properties were determined according to standard methods (Richards and USSL Staff 1954). The soil is clayey sand more than 140 cm in depth (Xerochrepts; Soil Conservation Service 1975). It is rich in organic matter in the surface layer and has calcareous material starting from 80 cm. It is slightly saline (**Table 1**). The electrical conductivity of the saturated soil extract (ECe) did not exceed 2 dS.m^{-1}.

The irrigation water comes from Nebhana dam. This water is slightly saline; the EC is 1.21 dS.m^{-1} and the sodicity is low; the SAR is approximately 1.6. This water was used as the control treatment (**Table 2**). For the other treatments pure sodium chloride

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Table 1 Physical-chemical soil characteristics (28/12; average of three sites).

Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Organic matter (%)	Total carbonates (%)	Fine carbonates (%)	pH (soil/water: 1/5)	ECe ($dS.m^{-1}$)
0-20	17.3	16.5	60.3	1.6	2.0		8.2	1.9
20-40	18.5	17.0	59.0	1.4	2.9		8.2	1.7
40-60	23.0	16.0	55.5	1.0	3.9		8.5	1.8
60-80	22.2	16.7	57.5	0.8	3.0		8.5	1.5
80-100	24.7	14.3	54.5	0.7	11.7	6.0	8.6	1.0
100-120	23.8	16.2	55.3	0.7	14.5	6.0	8.6	1.8
120-140	21.5	18.8	54.2	0.7	18.3	8.0	8.6	2.0

Fine Carbonates: Fraction inferior to 2 µm Organic mater: determinate from carbon content.

Table 2 Chemical characteristics of the irrigation water of Nebhana dam. Control (28/12; pH for soil/water=1/2.5).

Na^+ (me/l)	Ca^{2+} (me/l)	Mg^{2+} (me/l)	K^+ (me/l)	Cl^- (me/l)	SO_4^{2-} (me/l)	HCO_3^- (me/l)	pH	EC (dS/m)	TDS (g/l)	SAR
4.0	5.0	7.0	0.1	6.0	7.0	3.0	7.8	1.21	1.0	1.6

(NaCl 99%, Panreac quimica SA) was added to the water to produce the following concentrations in terms of EC: S1: 1.41 $dS.m^{-1}$, S2: 3.70 $dS.m^{-1}$, S3: 6.21 $dS.m^{-1}$, S4: 9.51 $dS.m^{-1}$.

Germination study

A test was conducted to study the effect of salt on onion seed germination. Five different salt concentration treatments ranging from 1.41 to 9.51 $dS.m^{-1}$ were applied to the seeds of onion cv. 'Merveille de Pompeï' (Petoseed) and replicated four times. Treatment solutions were made using distilled water and appropriate quantities by weight of NaCl to achieve the various salt levels. The control solution was distilled water and had an EC of 1.21 $dS.m^{-1}$. Three layers of filter paper were placed in each Petri dish and 5 ml of solution were pipeted into each dish. One hundred seeds were placed in individual Petri dishes using a completely randomized block design with three replicates. The dishes were sealed with plastic film to prevent evaporation and placed in the dark at a constant temperature of 23°C. Germinated seeds were counted each morning for 8 days. Germination was defined as the first sign of radicle emergence. Statistical analyses were performed following a completely randomized block design with four replicates. Analysis of variance (ANOVA) with Duncan's multiple range tests was made at P = 0.05 to determine significant differences of salt treatments.

Plant growth study

The field trials were conducted under a PVC (polyvinyl chloride) greenhouse at Chott Meriem Experimental Agriculture Station (35°5 lat, 10°33 long, 15 m asl). The main variable was the salinity of the irrigation waters, with five levels of EC: 1.21, 1.45, 3.70, 6.21 and 9.51 $dS.m^{-1}$.

Onion seed germination began in an outdoor seedbed on November 20. Thirty-four plants were transplanted on February 28 into each plot at the 2-to-3 leaf stage using a completely randomized block design with three replicates. Prior to planting, the field was irrigated with fresh water to obtain a uniformly leached soil profile. Number, height and fresh and dry weights of onion foliage, bulbs and root were determined by periodical harvests of 3 plants per plot, starting 35 days after transplanting and ending 10 days before harvest. For each date, ANOVA was applied. Means were compared by Fisher's multiple range tests at the 5% level followed by multiple comparison of means by Newman and Keul's test when means equality hypothesis was rejected in accordance with Steel Robert (1980) and Dagnélie (1986).

The onions were harvested when 75% of the tops of the bulbs in a plot bent over.

Irrigation management

Plots were irrigated with approximately 20 liters of the salinized water every week corresponding to 11.4 mm of water. The total number of irrigations was 18. Irrigation was stopped on May 30 and the onions were harvested 10 days later (the soil was not treated with any pesticide before planting).

Soil salinity control

Taking into account the homogeneity of the plots, the soil was sampled initially (09/03) on three sites of the greenhouse. A highly significant relationship was obtained between the electrical conductivity of the saturated soil extract (ECe) and the aqueous soil/water extract 1/5 (EC1:5) according to the method of Richards *et al.* (1954) and was used for the soil salinity control: $ECe = 7.85*CE_{1:5}$; $R^2 = 0.873$; n = 67.

After this initial sampling, sampling was performed twice more after the establishment of the onion crop; during vegetative growth (09/04) and at harvest (09/06). Sampling took place for 0-20 and 20-40 cm soil layers in each replication, 9 sites per treatment. Accordingly, the homogeneity of soil salinity in the beginning of the experiment, ECe, was determined. At the end of the experiment, the number of soil samples was so high, caused by the different treatments. In the first step, the relationship between ECe and EC 1:5 was established for 30 soil samples. This relationship was used for about 100 soil samples.

RESULTS AND DISCUSSION

Germination study

No significant differences in germination percentage occurred between salt levels in the 1.21 to 9.51 $dS.m^{-1}$ treatments (**Fig. 1**). Germination percentages after 8 days were not significantly different between the concentrations. These results suggest that onion is quite tolerant to salt during germination; this is in agreement with results obtained by Wannamaker and Pike (1987). Similar results were reported by De Malach *et al.* (1989), who found that onions are very tolerant to salinity during germination *in vitro*. Under drip irrigation with 6 $dS.m^{-1}$ water, germination of onion in the field might still be reduced by salinity, because of the very high salt concentration in the seed bed (top 5 cm of the soil) due to the need to keep the soil wet until germination is

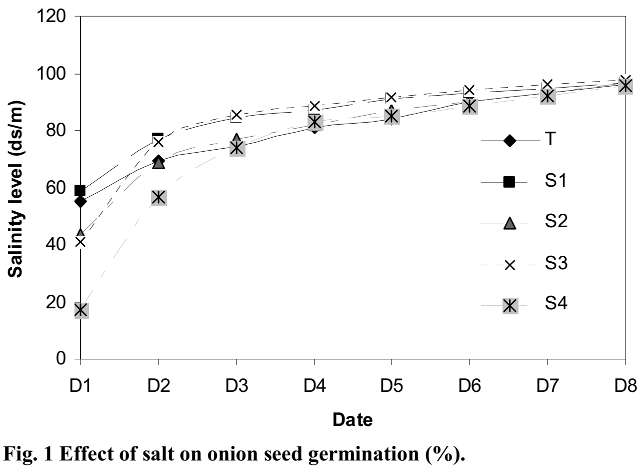

Fig. 1 Effect of salt on onion seed germination (%).

Table 3 Effect of different salt concentration on the number, height and fresh weight of the foliage, on the bulb and neck diameter and on the bulb fresh weight.

Salinity (dSm^{-1})	Leaf number	Leaf height (cm)	Leaf fresh weight (g)	Bub diameter (cm)	Neck diameter (cm)	Bulb fresh weight (g)
1.21	9.55 a	45.71 a	57.23 a	4.32 a	1.70 a	49.94 a
1.45	6.45 b	38.45 b	20.62 b	4.06 a	1.08 b	42.21 b
3.70	5.80 c	33.36 c	13.90 c	3.30 b	1.02 b	25.63 c
6.21	3.80 d	26.47 d	6.13 d	2.70 c	0.80 c	13.48 d
9.51	2.47 e	18.83 e	1.55 d	1.57 d	0.49 d	4.65 e

*Values in a column with the same letter are not significantly different at $P < 0.001$

Table 4A Effect of different saline irrigation treatments on the leaf fresh weight (LFW) independently of date.

Salinity (dSm^{-1})	Means of LFW (g)	Ecart type
1.21	57.23 a	17.58
1.45	20.62 b	4.49
3.70	13.90 c	6.52
6.21	6.13 d	3.42
9.51	1.55 d	0.97

* Values in a column with the same letter are not significantly different at $P < 0.001$.

Table 4B effect of different saline irrigation treatments at different stages of plant growth on the leaf fresh weight.

Salinity (dSm^{-1})	15-04	02-05	20-05
1.21	28.60 a	28.62 a	114.47 a
1.45	11.52 b	12.02 b	38.30 b
3.70	8.51 c	13.48 c	19.71 c
6.21	5.01 d	4.89 d	8.50 d
9.51	2.00 e	1.16 e	1.49 e

* Values in a column with the same letter are not significantly different at $P < 0.001$.

Table 5A Effect of different saline irrigation treatments on the leaf height independently of date.

Salinity (dSm^{-1})	Means of leaf height (cm)	Ecart type
1.21	45.71 a	3.52
1.45	38.45 b	4.34
3.70	33.36 c	4.95
6.21	26.47 d	4.25
9.51	18.83 e	3.35

* Values in a column with the same letter are not significantly different at $P < 0.001$.

Table 5B effect of different saline irrigation treatments at different stages of plant growth on leaf height.

Salinity (dSm^{-1})	15-04	02-05	20-05
1.21	35.74 a	38.40 a	62.99 a
1.45	31.58 b	36.48 b	47.29 b
3.70	29.24 c	33.37 c	37.46 c
6.21	28.19 d	25.02 d	26.20 d
9.51	19.98 e	15.28 e	21.22 e

* Values in a column with the same letter are not significantly different at $P < 0.001$.

complete (De Malach *et al*. 1989). Abdel-Fattah *et al.* (1972) reported that emergence was slightly stimulated by low concentrations of NaCl (2000 ppm), whereas it declined considerably with increasing salinity levels (4000, 8000 and 16,000 ppm). 700 ppm is about equal to 1 $dS.m^{-1}$. Malik *et al*. (1977) also reported that emergence was stimulated at low concentrations of Na Cl, $CaCl_2$ and $MgCl_2$ (4 $dS.m^{-1}$), but depressed at higher salt solutions (7.5 and 11.0 $dS.m^{-1}$). Therefore, the stage of sensitivity to salt damage appears to be emergence rather than germination. Penetration by the embryo through its seed coat is inhibited at very high salt concentrations (Wannamaker and Pike 1987).

Plant growth study

Table 3 shows the effects of salinity on the number, height and fresh weight of the foliage, on the bulb and neck diameter and on the bulb weight of the onion plant. The data indicate that all these parameters were affected by the various levels of salinity of the irrigation water used in this experiment. Differences in fresh weight were highly significant due to the interaction between the different treatments and plant age (**Table 4A, 4B**). In general, the onions exhibited an initial decline in growth at 3.7 $dS.m^{-1}$ and above. A ~22% reduction in plant weight, 35 days after transplanting, occurred in this treatment in comparison to the plants irrigated with the control solution. Other observations were noted at the 3.7 $dS.m^{-1}$ level. After 45 days, there were about 50% fewer leaves, a 50% reduction in bulb weight (**Fig. 2**) and a 21% reduction in height (**Table 5A, 5B**). The average number of leaves and leaf diameter were noticeably lower than those in the control plants. At higher salt concentrations the decline in growth rate was very gradual. The rate of leaf production declined, about 5 leaves per plant were present in the 3.70 and 6.21 $dS.m^{-1}$ treatments, whereas only three leaves per plant were generally present in the 9.51 $dS.m^{-1}$ plots. In the 9.51 $dS.m^{-1}$ solution plots, bulb and leaf weight were generally 80% less than that of the control,

Fig. 2 Onion bulbs at harvest of different treatments. From left to right: T: Control, EC = 1.21 dSm^{-1}; S1: EC = 1.45 dSm^{-1}; S2: EC = 3.70 dSm^{-1}; S3: EC = 6.21 dSm^{-1}; S4: EC = 9.51 dSm^{-1}.

Fig. 3 Onions plants of different treatments (harvested 20 May). T: Control (far right), EC = 1.21 $dS.m^{-1}$; S1: EC = 1.45 dSm^{-1}; S2: EC = 3.70 dSm^{-1}; S3: EC = 6.21 dSm^{-1}; S4: EC = 9.51 dSm^{-1}.

and height was reduced by 66%.

With higher salt levels, the plants' leaves were dull green. Leaf diameter was visibly smaller in plants in the 9.51 $dS.m^{-1}$ treatment (**Fig. 3**). These results are in accor-

Table 6 Effect of salt on bulbing ratio.

Salinity (dSm^{-1})	15-04	02-05	20-05
1.21	1.91	3.45	2.39
1.45	2.24	4.83	4.13
3.70	2.43	3.79	2.06
6.21	2.21	4.24	3.67
9.51	2.58	2.43	4.73

*Values in a column with the same letter are not significantly different at $P < 0.001$.

Table 7 Effect of salt on bulb fresh weight independently of date.

Salinity (dSm^{-1})	Means of bulb fresh weight (g)	Ecart type
1.21	49.94 a	10.64
1.45	42.21 b	9.46
3.70	25.63 c	12.21
6.21	13.48 d	4.68
9.51	4.65 e	1.54

* Values in a column with the same letter are not significantly different at $P < 0.001$.

dance with those of Bernstein and Ayers (1953) who found that there was 50% less growth at an EC value of 4.1 $dS.m^{-1}$ in onions in field plots in Riverside, California. This pronounced effect at advanced stages of plant growth was due to the increase in both salt accumulation and total moisture stress.

Forty-five days after transplanting, the onions had started bulbing in the salinized plots (**Table 6**). On the other hand, the bulbing ratio (maximum bulb diameter/minimum sheath diameter) of the control plants had not yet reached 2; they were undergoing normal vegetative growth at this time. This shows that salts influence bulbing. Bulb initiation take place when the bulbing ratio attains 2 (Brewster 1994).

In fact, to achieve high production a vigorous foliage during the vegetative cycle is needed (Bosch Serra and Casanova 2000; Sta Baba *et al.* 2004). An important foliage carry late maturity and consequently the onions are harvested tardily (Legrand 2003).

Table 7 shows the effect of water salinity on the fresh weight of onion bulbs. Yield in the control group was relatively high. There were highly significant differences in fresh weight of bulbs due to the effect of different saline irrigation treatments at different stages of plant growth. These effects were more pronounced as the plants matured. Generally, the data indicate that continuous irrigation of onion plants with saline water resulted in a significant reduction of both foliage and bulb weights.

The increase of salts in the root zone of the sandy loam soil used in this study depends on the salt content of the irrigation water and the number of water applications. Increased application of water leads to an increase in the salt content at the soil surface (0-20 cm depth) at higher rates due to capillary rise and escape of water as vapor in the process of evaporation. At a depth of 20-40 cm salt accumulation was much lower as compared with the accumulation on the soil surface, due to leaching of salts to deeper levels. It has been reported that doubling the concentration of salts in the irrigation water resulted in doubling of the salt accumulation at the soil surface (0-20 cm depth) (Assed and Warid 1977).

In previous studies De Malach *et al*. (1989) showed that early-season seedling death was the greatest limitation to onion yield under saline water irrigation. This seedling death resulted from prolonged exposure of the shallow root system of onions to the high salt concentration found in the upper 5 cm of soil, during plant establishment. Transplanting larger seedlings raised with better quality water might therefore be one way to improve their survival.

Soil salinity evolution

The amount of irrigation water is approximately 206 mm in total for each treatment. This water transported a variable quantity of salt depending on the treatment: 206, 232, 458, 732 and 1973 $g.m^{-2}$ respectively for the treatments T, S1, S2, S3 and S4. Towards the half way cycle of the crop in mid-April, only 5 irrigations out of a total of 18 had been applied. The quantities of salt imported by irrigation were very limited; they had only a moderate effect on the increase of soil salinity especially on the 20-40 cm layer (**Figs. 4, 5**). The 0-20 cm layer had a greater increase in salinity than the 20-40 cm layer (**Fig. 6**). The saline profile is thus ascending. The salinities reached at the end of the crop cycle in the 0-20 cm layer appear lower than those which would have been expected if in equilibrium with the irrigation water. With an appropriate irrigation and clayey sandy soil, ECe must be normally equal to 1.5 of EC of irrigation water. In fact, the ECe between 0 and 20 cm is an average value of the whole layer. In the upper centimeters of this layer, saline efflorescence is visible, indicating stronger salt contents in these levels. This salinity distribution was very obviously uneven within the top layer. However, the overall spatial variability of the salinity was generally moderate. The coefficient of variation varied between 20 and 27% for the 0-20 cm layer and 13 and 32% for the 20-40 cm layer. This increase in soil salinity affected the onion crop. Thus, for the fresh weight of bulbs, we observed at the 4^{th} sample taken a relative decrease, which exceeded 50% for ECw, equal to 3.7 dSm^{-1}. This is clear evidence of the sensitivity of onion to salinity. The evolution of fresh weight of the bulbs presents a decreasing slope (**Fig. 7**) and might be adjusted to a power curve or a linear curve by eliminating the control (**Fig. 8**). According to Ayers and Westcot (1985), onion yield potential is 100% until ECw = 0.8 $dS.m^{-1}$, 90% for 1.2 $dS.m^{-1}$, 75% for 1.8 $dS.m^{-1}$, 50% for 2.9 $dS.m^{-1}$ and about 0% for 5.0 $dS.m^{-1}$. According to our observations in

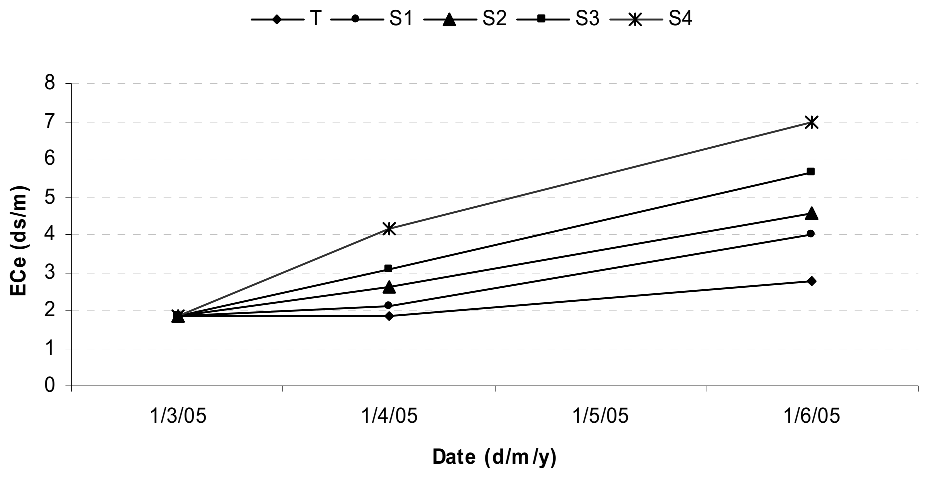

Fig. 4 Soil salinity evolution (ECe) for each treatment for the 0-20 cm layer.

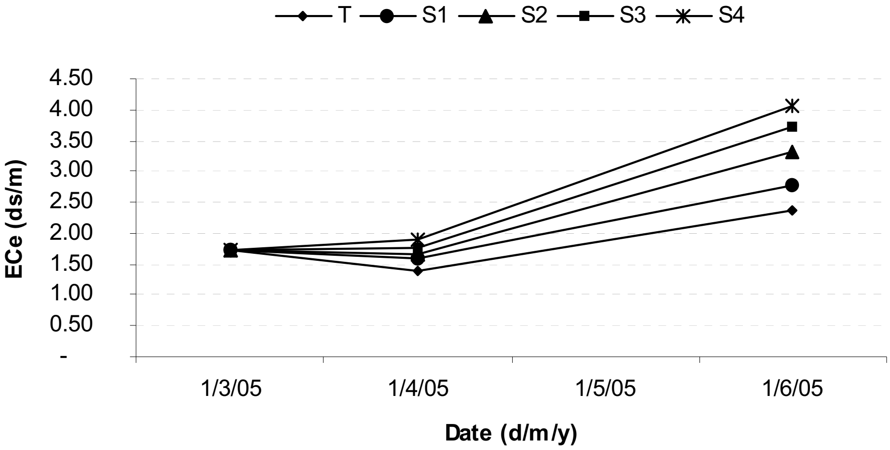

Fig. 5 Soil salinity evolution (ECe) for each treatment for the 20-40 cm layer.

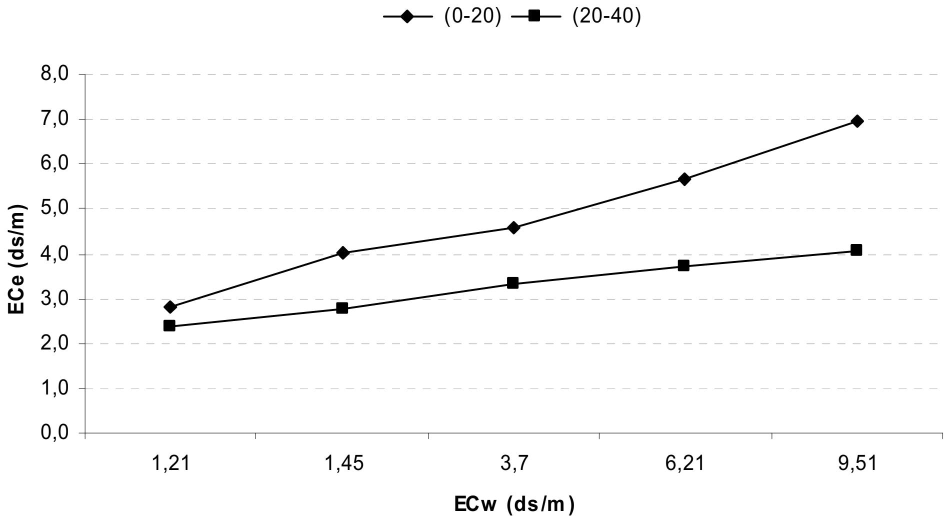

Fig. 6 Soil salinity evolution (ECe) versus water irrigation salinity (ECw) at the end of the experiment for each treatment and 0-20 and 20-40 cm layers.

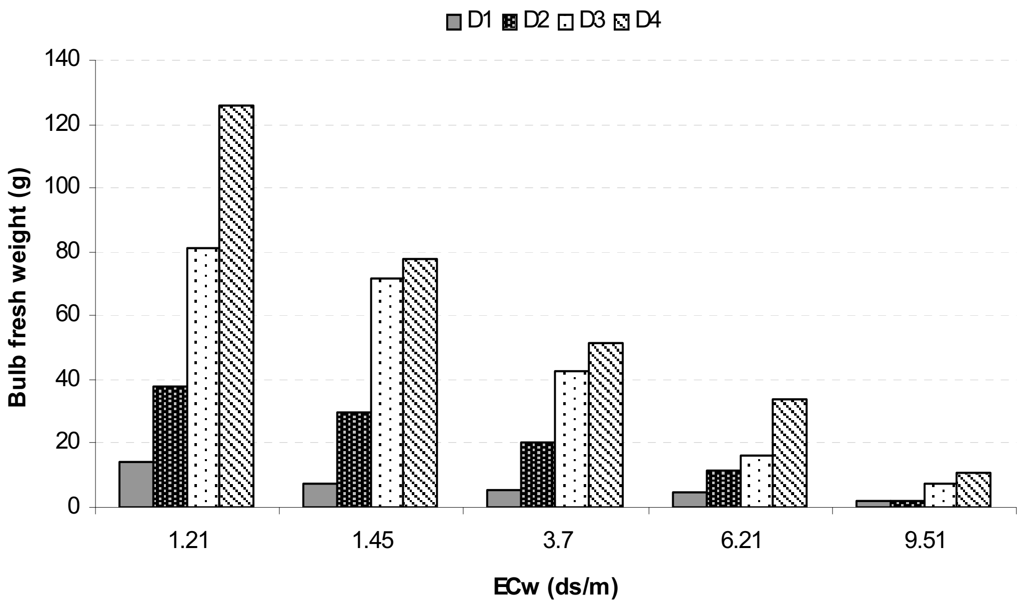

Fig. 7 Relative bulb fresh weight (%) versus EC of the irrigation water. D1:05/04; D2: 15/04; D3: 02/05; D4: 20/05.

our conditions and for the onion variety studied, if we use our linear relationship (Y = -6.437*ECw-68.2), our results show that for 75% of the relative yield, we obtained 2.0 $dS.m^{-1}$ in place of 1.8 $dS.m^{-1}$ (proposed by Ayers and Westcot 1985) and for 50%, 2.83 $dS.m^{-1}$ in place of 2.9 $dS.m^{-1}$. These results are very close to those of Ayers and Westcot (1985). For more saline water, yield reduction resulted mostly from fewer bulbs per unit area, but also from smaller bulb size. There was a severe die off of plants and for the few, which survived; bulb weight did not exceed 6% of the

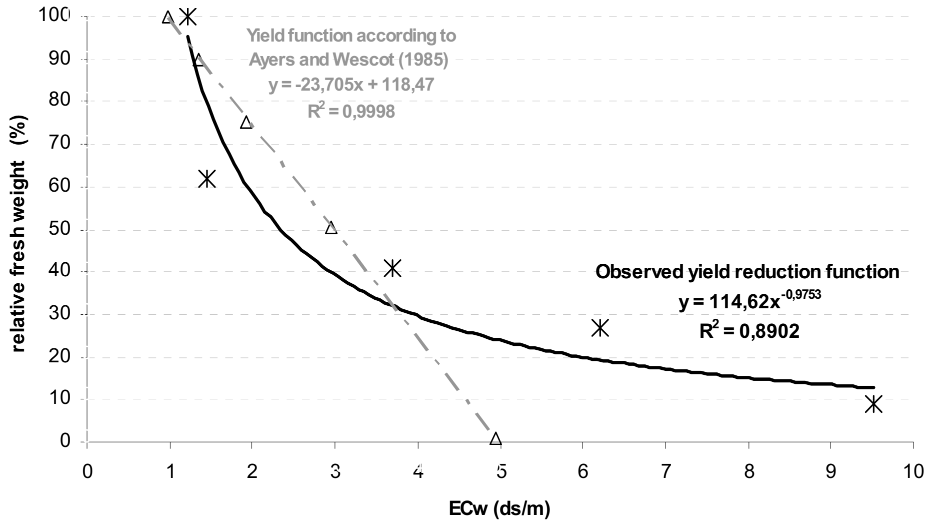

Fig. 8 Relative bulb fresh weight (%) versus EC of the irrigation water for D4 (harvest).

bulb weight of the control plots with a salinity of 9.51 $dS.m^{-1}$.

CONCLUSIONS

Salt effects during the first 8 days of onion germination are not related to later responses of the whole plant to salt. This study helps to demonstrate the complex interactions that occur between onion yield and the effects of water salinity, soil and plant morphology. Significant differences in both foliage and bulb weight were found, due to the interaction between treatments and plant age. Onion is a relatively salt-sensitive crop. Salts influence bulbing and the quality of the bulbs harvested. It thus appears that commercial production of onions with brackish/saline water requires delaying the application of saline water after the fourth leaf has appeared (parched leaves were not counted), when an ECw of 1.41 $dS.m^{-1}$. The relative yield function obtained in this study shows that we can irrigate later on with saline water and still have a crop yield. Certainly the yield decrease may be as much as 50% so this technique cannot be recommended as economically viable in large-scale agriculture but it may be acceptable in small-scale agriculture systems prevalent in small areas such as we have in Tunisia and in many third world countries.

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