

Effects of irrigation regime and salinity on soil characteristics and yield of tomato

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Abstract

A field experiment was conducted in Mediterranean conditions to evaluate the effects of different irrigation volumes and water quality on yield performance of tomato crop. The tomato crop was irrigated re-establishing 50 (I1), 75 (I2) and 100% (I3) of the crop evapotranspiration (ETc) with two water quality: fresh water with EC 0.9 dS m⁻¹ (FW) and saline water with EC 6 dS m⁻¹ (SW). At harvest, total and marketable yield, weight, number, total soluble solids (TSS) and dry matter of fruit were calculated. The results showed no statistical differences among the three different irrigation volumes on tomato yield and quality. The salinity treatment did not affect yield, probably because the soil salinity in the root zone on average remained below the threshold of tomato salt tolerance. Instead, salinity improved fruit quality parameters as dry matter and TSS by 13 and 8%, respectively. After the first field application of saline water, soil saturated extract cations (SSEC), electrical conductivity of soil paste extract (ECe),

sodium absorption ratio (SAR) and exchangeable sodium percentage (ESP) cations increased; the largest increase of cations, in particular of Na, occurred in the top layer.

At the end of the experiment, the absolute value of SSEC, ECe and SAR, for all the effects studied, were lower than those recorded in 2007. This behavior was suitable to the reduced volumes of treatments administered in 2009 in respect to the 2007. Furthermore, the higher total rainfall recorded in 2009 increased the leaching and downward movement of salts out of the sampling depth.

Introduction

Tomato (*Lycopersicon esculentum* Mill.) is one of the most widely grown vegetables in the world. The quality of the fruits is controlled by the interaction of genetic, environmental, and agronomic factors, including plant nutrition (Dorais *et al.*, 2001). Nutrients concentration and water salinity have a great influence on yields and fruit quality of tomato (Dorais and Papadopoulos, 2000). The plant is classified as *moderately sensitive* to salinity which means that it tolerates an electrical conductivity of the saturated soil extract (ECe) up to 2.5 dS m⁻¹ without any yield reduction (Maas, 1986). Tomato crop is already grown in large areas where saline conditions are a problem (Reina-Sanchez *et al.*, 2005).

An increase in tomato fruit quality with salinity, as total soluble solids content, titratable acidity and perceived fruit flavour, has been observed in several studies (e.g. Sonneveld and van der Burg, 1991; Cuartero and Fernández-Muñoz, 1999; Eltez *et al.*, 2002; Magàn *et al.*, 2008). Fruit size was the only qualitative parameter negatively affected by increasing salinity.

In a field research carried out in Southern Italy, Maggio *et al.* (2004) found, for tomato irrigated with saline water for more than 10 years, increase of fruit quality (higher acidity, increased soluble solids and higher sugar content), although tomato fruits were smaller than non-salinized control fruits.

In Mediterranean environments, the water resources are limited, the fresh water for agriculture in many regions is little available, so the saline water utilization for irrigation purposes should be developed with optimal management strategies. Such water may contain large quantities of soluble salts, predominately Ca, and Na ions. The presence of certain cations such as Na in the irrigation water may create some environmental problems and needs evaluation prior to its use in agriculture. Irrigation with waters that have high concentrations of Na relative to divalent cations may cause an accumulation of exchangeable Na on soil colloids (Jalali and Merrikhpour, 2008). The successful use of low-quality water depends on soil type and requires the adoption

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of salt tolerant crops or cultivars but also appropriate agronomic practices such as irrigation scheduling, choice of irrigation method, mixture of waters with different salinity or their alternate use. Low-quality water irrigation can affect soil fertility and its physical condition.

In many parts of the world, tomato is cultivated under irrigation (Grange and Andrews, 1994). However, due to the global expansion of irrigated areas and the limited availability of irrigation water, there is need to optimize water use in order to maximize crop yields under water deficit conditions (Fereris and Soriano, 2007). The cultivation without irrigation is possible when the species resistance to abiotic stress (high temperatures and water deficit) was adopted. In fact, Kassam and Smith (2001) reported that several genetically improved varieties, more productive and tolerant to water deficit, have been introduced. Nevertheless, water deficit decreased tomato growth, yield and quality (Byari and Al-Sayed, 1999) therefore, a proper water management is important for sustainable crop production. Candido *et al.* (1999) found that water application positively influenced tomato productivity, and in particular the supplementary irrigation increased the marketable yield of 284%, and this value reached 578 and 1327% with the 50 and 100% of the maximum crop evapotranspiration. On the contrary, the maximum irrigation rate negatively influences the quality, since it induces reductions in soluble solids and dry matter content of tomato crop.

On the light of these considerations, a field research was carried out to evaluate the effects of irrigation regime and water salinity on soil properties and tomato yield in the a Mediterranean environment of Southern Italy.

Materials and methods

The field experiments were carried out at Metaponto (MT) in Southern Italy (40°24' N; 16°48' E) from 2007 to 2010 in a private farm and adopting a two-year rotation of tomato and maize. In this paper we reported the results of the summer 2007 and 2009 related to tomato crop. The soil had low content of both nitrogen (N) (1.03 g kg⁻¹) and organic matter (12.1 g kg⁻¹). The clay, silt and sand contents were 28.3, 40.4 and 31.3%, respectively; the soil water content at water field capacity (-0.03 MPa) and at permanent wilting point (-1.5 MPa) was 25.6 and 12.3% (percentage of soil dry weight), respectively.

The climate is *accentuated thermomediterranean*, according to UNESCO-FAO (1963) classification, with winter temperatures which can fall below 0°C and summer ones which can rise above 40°C, rainfall unevenly distributed during the year, being concentrated mainly in the winter months. During the 2007 tomato growing period the total rainfall was lower than 2009 (63.8 mm and 128 mm respectively) especially during the fruit set and maturity phases.

The *class A* pan evaporation rates were greatest during the months of June, July and August, with mean monthly rates of the two years of 242, 333 and 290 mm, respectively. During the experimental trials the average mean temperatures were 24°C. Four-leaf tomato plants (cv Tomito) were transplanted by hand on the 7th of May of both years on single row (plant densities were of 2 plants m⁻²). The following water quality treatments were compared: fresh water with EC 0.9 dS m⁻¹ (FW) and saline water with EC 6 dS m⁻¹ (SW). The following irrigation treatments were compared: re-establishing 50 (I1), 75 (I2) and 100% (I3) of the crop evapotranspiration (ETc). The salinity was imposed by irrigating with water artificially salinized, using commercial sea salt (97% of NaCl). The experimental layout was a split plot with three replications. Water quality treatments were allocated to the main plots, irrigation rates treatments were arranged in the sub-plots. For statistical analysis the year was considered as strip factor. In all treatments water irrigation was supplied by localized method. The ETc was calculated on the

basis of evaporation rate from *class A* pan (E) (Doorenbos and Pruitt, 1977) and the crop coefficients (Kc) applied according to FAO-56 paper (Allen *et al.*, 1998). The E and meteorological data were recorded on hourly basis by an automated data-logger close to the farm. The waterings were carried out when cumulated ETc reached 17.9 mm from transplanting to blooming and 35.8 mm from full bloom to fruit ripening corresponding to 40% of available soil water for a soil depth of 25 cm from transplanting to blooming and of 50 cm from full bloom to fruit ripening. The N dose (180 kg ha⁻¹) was applied in two times as ammonium sulphate: at transplanting time (60 kg of N ha⁻¹) and about one month after transplanting time (120 kg of N ha⁻¹). All other agronomic practices were followed as per the recommended package.

Determinations on plant and soil

Plant

At harvested (107 and 97 days after transplanting in 2007 and 2009 years, respectively) from each, plot 1 m² of tomato plants (central row) were collected and the number of fruits, fruit weight, dry matter (48 h at 70°C) and total soluble solids (refractometric index °Brix) were determined.

Soil sampling

For each unit plot three soil sub-samples were collected, within interrows, for 0-25 cm and 26-50 cm layers at the end of each crop cycle (August 2007 and 2009). The three sub-samples, pooled in one sample for replication, treatment and depth, were air dried, ground to pass a 2-mm sieve and then analysed.

The saturated soil paste extract (SSPE) was prepared using about 120 g of soil with suitable quantity of distilled water, so that the soil flows from spatula without sticking and then extracted by applying vacuum. The concentration of K, Na, Ca and Mg on SSPE were determined by ICP-OES (VARIAN Australia Pty Ltd 679 Springvale Road Mulgrave Victoria), whereas, the ECE was determined with a Conductimeter GPL32 CRISON (Crison Strumenti Spa, Carpi, Italy).

The exchangeable cations were determined by extraction in a barium chloride-triethanolamine buffered solution (pH=8.2), followed ICP-OES determination. The Capacity exchangeable cations (CEC) analysis was performed by the compulsive method, based on saturation with barium-chloride at pH 8.2, displacement of adsorbed barium by excess magnesium (0.05M MgSO₄) and titration of the Mg remaining in solution with 0.025M EDTA (Ethylenediaminetetraacetic acid) (Page *et al.*, 1982).

The sodium adsorption ratio ($SAR = (Na^+ / (Ca^{2+} + Mg^{2+}))^{0.5}$) and exchangeable sodium percentage ($ESP = 100 \times \text{exchangeable } Na^+ / CEC$) were also calculated.

Statistical analysis

Data was analyzed using the SAS package (SAS, 1998). The effects of the treatments were assessed through the General Linear Model procedure. The means of the experimental treatments were compared using the Student-Newman-Keuls (SNK) tests for two and more than two mean comparisons at $P \leq 0.05$.

For SAR and ESP data, the statistical analysis was carried out by year and considering the soil depth as strip factor.

Results and discussion

Meteorological conditions

In Table 1 the irrigation scheduling is reported. The effective rain was 25 mm and 62 mm in 2007 and 2009, respectively. In 2009 lower irrigation volumes were due to shorter tomato crop cycle, lower evapo-

ration rate (-12% compared to 2007, *data not shown*) and higher effective rainfall (62 mm respect to 25 mm).

Yield and quality performances of tomato

In Tables 2, 3 and 4 the main effects on tomato yield performance of irrigation volumes (*I*), water quality (*WQ*) and years (*Y*) are reported with the indications of statistical significance for the following interactions: irrigation volume-year (*IxY*), water quality-year (*WQxY*), irrigation volume-water quality (*IxWQ*), and irrigation volume-water quality-year (*IxWQxY*). No significant differences for all quantitative parameters were observed among irrigation and water quality treatments. The average total and marketable yields were 104.3 and 92.4 t ha⁻¹ respectively (Table 2). For the fruit quality irrigation treatments did not affect any parameters.

The lack in reduction of yield as expected in saline treatments is in agreement with the ECe values measured at the end of crop cycles, 4.95 and 2.99 dS m⁻¹ in 2007 and 2009, respectively (Table 5). In fact, the mean ECe of whole crop cycle, probably was around 2-3 dS m⁻¹ in 2007 and 2 dS m⁻¹ in 2009. These values are slightly lower or higher than

tomato threshold (Maas, 1986). The salinity of irrigation water reduced significantly the mean weight of marketable fruit (-7.6 %) (Table 3).

These results are in general agreement with the finding reported by Olympios *et al.* (2003). Cuartero and Fernández-Muñoz (1999) indicated that the tomato yield can be reduced by decreased average fruit weight and/or by the reduced number of fruits. At relatively low soil electrical conductivity (ECs), the yield reduction observed is caused mainly by a reduction in the average fruit weight whilst the fruit number remains unchanged; the declining number of fruits explains the main portion of yield reduction at higher ECs (van Ieperen, 1996; Cuartero and Soria, 1997). The number of tomato fruits/plant depends on the number of trusses/plant, the number of flowers/truss and the fruit set index (number of fruit/number of flowers) at each truss. The number of trusses/plant is reduced with highly saline irrigation water and with long salinisation periods (Cuartero and Fernández-Muñoz, 1999). Furthermore, in our case overripe fruits harvested in saline treatments resulted significantly higher (+34%) than in fresh irrigation water treatment (Table 3).

Significant increases in fruit dry matter percentage were observed in the saline treatment (SW): ripe and green fruit dry matter percent-

Table 1. Waterings and irrigation volumes during tomato growth stages in the two years and for the irrigation treatments.

Treatments	I period		II period		III period		Total	
	Waterings	Irrigation volume	Waterings	Irrigation volume	Waterings	Irrigation volume	Waterings	Irrigation volume
	n	m ³ ha ⁻¹	n	m ³ ha ⁻¹	n	m ³ ha ⁻¹	n	m ³ ha ⁻¹
2007								
I1	4	337	7	1270	5	1036	16	2643
I2	4	505	7	1905	5	1554	16	3964
I3	4	674	7	2540	5	2072	16	5286
2009								
I1	5	483	4	764	3	522	12	1769
I2	5	724	4	1147	3	783	12	2654
I3	5	965	4	1527	3	1044	12	3536

I period, from transplanting to first fruit cluster formation; II period, from first fruit cluster formation to 10% of fruits with fully ripe colour; III period, from 10% of fruits with fully ripe colour to fully ripe.

Table 2. Effects of irrigation volumes, water quality, years, and related interactions on yield performance of tomato.

Treatments	Total yield	Marketable yield	Ripe fruit t ha ⁻¹	Turn dark-coloured fruits	Overripe fruits
Irrigation (I)					
I1	104.2	92.4	89.0	3.4	7.1
I2	101.3	90.5	86.4	4.1	5.4
I3	107.2	94.3	90.8	3.5	6.7
	ns	ns	ns	ns	ns
Water quality (WQ)					
SW	102.3	89.8	86.6	3.2	7.4
FW	106.3	95.0	90.8	4.2	5.5
	ns	ns	ns	ns	*
Years (Y)					
2007	88.2	71.7	66.0	5.7	10.6
2009	120.3	113.1	111.4	1.7	2.2
	*	**	**	**	*
IxY					
WQxY	ns	ns	ns	ns	ns
IxWQ	ns	ns	ns	ns	ns
IxWQxY	ns	ns	ns	*	ns

SW, saline water; FW, fresh water. *P≤0.05; **P≤0.01; ***P≤0.001; ns, not significant.

Table 3. Effects of irrigation volumes, water quality, years, and related interactions on average marketable fruit weight and fruit number of tomato.

Treatments	Marketable fruit mean weight g	Ripe fruit n m ⁻²	Turn dark-coloured fruits n m ⁻²	Overripe fruits n m ⁻²
Irrigation (I)				
I1	15.4	563.5	39.4	64.1
I2	15.3	552.8	41.7	55.6
I3	14.7	610.8	34.9	64.4
	ns	ns	ns	ns
Water quality (WQ)				
SW	14.5	585.9	35.6	69.7
FW	15.7	565.4	41.7	53.1
	*	ns	ns	ns
Years (Y)				
2007	14.7	434.2	58.4	98.8
2009	15.5	717.2	18.8	23.9
	ns	**	**	*
IxY				
WQxY	ns	ns	ns	ns
IxWQ	*	ns	ns	ns
IxWQxY	ns	ns	ns	ns

SW, saline water; FW, fresh water. *P≤0.05; **P≤0.01; ***P≤0.001; ns, not significant.

age increased of 5 and 11%, respectively, compared to fresh water treatment (FW). SW treatment showed the same total fruit dry biomass of FW (Table 4), then the salinity influenced only fruit size whereas it did not reduce the assimilates into the fruits. This reduction of fruit is a consequence of reduction in water content, the low water content of fruit then appears to be the result of an osmotic effect.

SW treatment showed the highest TSS (total soluble solids) content with an increase of about 8 % compared with FW (Table 4) that is the most important quality criterion for tomato, confirming the results of many Authors about the positive relationship between brackish water irrigation and quality of tomato (Cuartero and Fernández-Muñoz, 1999; Cucci *et al.*, 2000; Machado *et al.*, 2003; Yurtseven *et al.*, 2005). TSS tends to increase with salinity and hence the use of moderately saline irrigation water (3-6 dS m⁻¹) is recommended to improve fruit quality (Mizrahi *et al.*, 1988). The yield performance showed significant differences in the two years. In particular, the total and marketable yields (Table 2) were lower (88.2 and 71.7 t ha⁻¹) in 2007, because of both low rainfall occurred during fruit setting and maturity phases and a higher temperature recorded during fruit setting. In 2009, higher marketable yield was determined by higher ripe fruit production, due to higher number of ripe fruits and not to average fruit weight. In the same year, the turn dark-coloured fruits and overripe fruits resulted significantly lower compared to 2007, probably due to less ripening variability.

The results of the analysis of variance for the mean weight of marketable fruit indicated a significant *I*×*WQ* interaction (Table 3). In fact, this parameter increased with increasing irrigation volumes in the treatment with fresh water, whereas it reduced with enhancing irrigation volumes in the treatment with saline water (Figure 1). In particular, the treatment with re-establishing of 100 % of the ET_c (I3) and irrigation with saline water (SW) showed the lowest average marketable fruit (13.3 g). The treatment with re-establishing of 50% of the ET_c (I1) and irrigation with saline water presented an increase of about 16% compared to I3-SW. This increase was probably due to lower amount of salt supplied in soil with low irrigation volumes.

The results of the analysis of variance for the ripe fruit dry matter percentage showed a significant *I*×*WQ* interaction (Table 4). In fact,

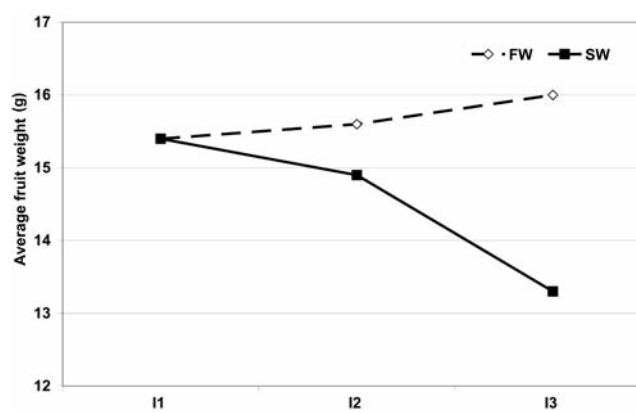


Figure 1. Effect of interaction *water quality* × *irrigation* on mean weight of fruits.

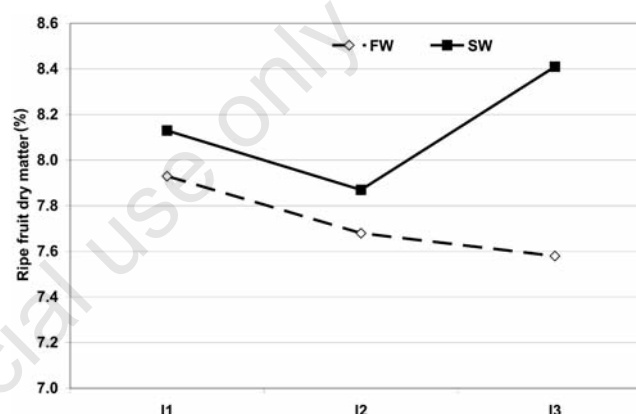


Figure 2. Effect of interaction *water quality* × *irrigation* on fruit dry matter percentage.

Table 4. Effects of irrigation volumes, water quality, years, and related interactions on dry matter and total soluble solids of tomato fruits.

Treatments	Ripe	Fruit dry matter Turn dark-coloured %	Green	Dry biomass t ha ⁻¹	Total soluble solids °Brix
<i>Irrigation (I)</i>					
I1	8.0	8.7	8.5	7.5	6.6
I2	7.8	7.9	8.2	7.1	6.4
I3	8.0	9.0	8.2	7.6	6.4
	ns	ns	ns	ns	ns
<i>Water quality (WQ)</i>					
SW	8.1	9.1	8.7	7.4	6.7
FW	7.7	7.9	7.8	7.4	6.2
	*	ns	**	ns	*
<i>Years (Y)</i>					
2007	7.5	7.4	7.9	5.3	6.4
2009	8.4	9.6	8.7	9.5	6.5
	**	ns	*	**	ns
I×Y	ns	ns	ns	ns	ns
WQ×Y	ns	ns	ns	ns	ns
I×WQ	*	ns	ns	ns	ns
I×WQ×Y	ns	ns	ns	ns	ns

TSW, saline water; FW, fresh water. *P≤0.05; **P≤0.01; ***P≤0.001; ns, not significant.

Figure 2 shows that this parameter increased with increasing irrigation volumes in the saline water treatment, whereas it reduced with enhancing irrigation volumes in the fresh water one. In particular, the treatment with re-establishing of 100 % of the ETc (I3) and irrigation with saline water (SW) showed the highest ripe fruit dry matter percentage (8.4%).

As a consequence of the Figures 1 and 2, the fruit average dry matter accumulation was not affected by salinity, in fact the ripe fruit dry percentage increased with increasing irrigation volumes in the treatment with saline water, which probably reduced the fruit water content. Fruits from salt-treated plants seem to grow normally during the cell division phase while deleterious effects of salt are observed during the cell expansion phase (Cuartero and Fernández-Muñoz, 1999). The reduction of the mean weight of marketable fruit could be due to the reduction in water content in the fruit (osmotic effect) and the reduction of the nutrient assimilation caused by a competition among Na^+ , Cl^- and K^+ , Ca^{2+} , Mg^{2+} and NO_3^- (nutritional effect). In fact, I3 treatment reached the highest EC and SAR values in the 2009 with an increase of about 30 % and 36 % compared to I1 (Table 5).

The treatments I1, I2 and I3 showed the same marketable yield because number of fruits did not show significant differences and the lower mean weight of marketable fruit in the treatment with re-establishing of 100 % of the ETc (I3) and irrigation with saline water (SW) was compensated by the treatment with re-establishing of 100% of the ETc (I3) and irrigation with fresh water (FW).

Effects on soil

SSPE analysis and exchangeable properties of soil are shown in Table 5 by years (2007 and 2009) in function of soil depth (D), water quality (WQ), and irrigation regime (I). The statistical significance of the following interactions are also reported: $\text{D} \times \text{WQ}$, $\text{D} \times \text{I}$, $\text{WQ} \times \text{I}$ and $\text{D} \times \text{WQ} \times \text{I}$. In 2007, no significant differences between depths were found for all SSPE cations except for Na that decreased (-11.4%) in the deeper layer compared to the top one. This could be mainly due to higher Na solubility compared to other cations and to higher irrigation supplied in 2007 (Table 1). Calcium dominated the exchangeable complex followed by magnesium, sodium and potassium. The high exchangeable Ca and Mg content was due to a preferential and stronger adsorption of these divalent cations over monovalent (Na and K). However, also in this case, exchangeable Na value decreased in the deeper layer in respect to the top one, as well as the ESP value (25.3 and 29.1%, respectively). The CEC showed an increase in the deeper layer of 4.4% in respect to the top one. This result is in agreement with that reported by Sunitha *et al.* (2010).

As expected, significant differences were found for WQ for Na, ECe and SAR of soil saturated extract. In particular in SW Na increased by 4.4 times, ECe and SAR by 3.7 times compared to FW. Again this behavior was confirmed for exchangeable Na and ESP value. Moreover in SW Ca and Mg showed a decrease of 16 and 26%, respectively, compared to FW treatment. These results are in agreement with those reported by Jalali and Merrikhpour (2008). They found that the addition of the poor

Table 5. Effects of depth, water quality and irrigation on saturation extract and exchangeable properties of soil.

Effect	levels	K mg L ⁻¹	Na	Ca	Soil solution Mg ECe dS m ⁻¹		SAR	K	Exchangeable cations Na Ca Mg meq 100 g ⁻¹ %				CEC	ESP
2007														
Depth (D)	0-25	35.8	485.7	139.6	31.0	3.07	10.17	1.45	2.61	11.37	2.58	19.07	13.80	
	26-50	48.6	430.1	162.9	34.7	3.22	7.87	1.45	1.95	11.55	2.34	19.92	9.79	
		ns	*	ns	ns	ns	ns	ns	*	ns	*	*	*	
Water quality (WQ)	FW	30.1	167.9	106.5	25.3	1.34	3.84	1.35	0.71	12.46	2.83	19.46	3.66	
	SW	54.3	747.8	196.1	40.4	4.95	14.20	1.55	3.85	10.46	2.09	19.52	19.93	
		*	***	ns	ns	**	**	ns	**	**	**	ns	***	
Irrigation (I)	I1	43.1	521.5	155.6	32.9	3.52	9.87	1.41	2.64a	11.38	2.35	18.88	14.27a	
	I2	39.9	467.1	133.6	29.4	3.33	9.81	1.40	2.59a	11.63	2.49	19.55	13.23a	
	I3	43.6	385.1	164.5	36.3	2.59	7.38	1.54	1.61b	11.36	2.53	20.05	7.88b	
		ns	ns	ns	ns	ns	ns	ns	**	ns	ns	ns	***	
DxWQ		ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	*	
DxI		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	
WQxI		ns	ns	ns	ns	ns	ns	ns	*	*	ns	ns	***	
DxWQxI		ns	ns	ns	ns	ns	ns	ns	ns	ns	**	ns	*	
2009														
Depth (D)	0-25	44.3	251.4	98.2	22.5	1.76	5.63	1.94	1.22	12.34	2.87	13.83	12.02	
	26-50	35.7	269.5	89.7	19.4	2.06	6.28	1.52	1.31	11.74	2.70	12.86	11.55	
		ns	*	ns	ns	*	**	*	**	**	ns	ns	ns	
Water quality (WQ)	FW	27.6	83.9	70.5	16.4	0.82	2.36	1.56	0.40	12.68	2.99	12.14	4.97	
	SW	52.5	437.1	117.3	25.6	2.99	9.56	1.90	2.13	11.40	2.58	14.54	18.60	
		ns	*	ns	ns	*	**	ns	*	***	***	ns	*	
Irrigation (I)	I1	37.1	221.2	92.7	21.1	1.69	5.12b	1.62	1.03	12.03	2.79	13.44	9.21	
	I2	42.1	249.9	93.2	20.6	1.85	5.79b	1.84	1.22	12.40	2.85	13.38	11.09	
	I3	40.9	310.3	95.9	21.3	2.19	6.96a	1.73	1.55	11.69	2.71	13.20	15.06	
		ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	
DxWQ		ns	*	***	***	**	*	**	*	ns	ns	*	ns	
DxI		ns	ns	ns	ns	ns	ns	ns	ns	**	ns	ns	ns	
WQxI		ns	ns	ns	ns	ns	*	ns	ns	ns	ns	*	ns	
DxWQxI		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	

* $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$; ns, not significant. ^{a,b}Values in each column followed by a different letter are significantly different at $P < 0.05$ (SNK).

quality water resulted in increased exchangeable Na on the exchange complex at the expense of exchangeable Ca and Mg.

No significant differences were observed for all SSPE cations, ECE and SAR. Significant differences were found also for exchangeable Na and ESP value. In particular, for exchangeable Na, the I3 treatment showed a decrease of 22% compared to the average of I1 and I2. Even if the I3 treatment applied a major rate of Na, the higher water volume improved the mobility of this cation enhancing the leaching effect.

Regarding the interactions, no significant effects were found for all SSPE cations, ECE and SAR. Instead significant differences were observed for the interactions $DxWQ$, $WQxI$ and $DxWQxI$ for some exchangeable cations. In particular, $DxWQ$ interaction for exchangeable Na and ESP showed, once again, that the highest increases were recorded in the top layer (486 and 499%, respectively, *data not shown*) compared to the deeper one. This behaviour is probably due to the lower Na affinity to the CEC compared to other exchangeable cations (Ca, Mg and K). This phenomenon leads to higher Na concentrations in soil solution and, consequently, to higher Na transport along the soil profile, as reported by Pereira Lael *et al.* (2009).

For exchangeable Na, $WQxI$ interaction showed a constant positive trend (around $0.71 \text{ meq } 100 \text{ g}^{-1}$, *data not shown*) in increasing irrigation volume FW regardless of irrigation treatment. However SW showed an increase from I1 to I2 in exchangeable Na with a maximum value of $4.5 \text{ meq } 100 \text{ g}^{-1}$ (data not shown), while the application of I3 treatment determined a sharp reduction of Na to $2.6 \text{ meq } 100 \text{ g}^{-1}$. Once again, this could be mainly due to a faster solute transport in the soil due to an higher leaching effect under I3.

The effect of $DxWQxI$ interaction for ESP is illustrated in Figure 3. In FW treatment, ESP showed low values in both layers regardless of the applied irrigation volumes. Instead, in SW, ESP values are quite constant from I1 to I2 and dramatically decrease in I3 for the top layer (14.4%). In the deeper layer the reduction of ESP was less effective than the top layer, with a value of 11%. These data confirmed that, due to irrigation and rainfall, the largest increase of cations, in particular of Na, occurred in the top layer. In 2009, the average values of SSPE cations, ECE and SAR were lower than those recorded in 2007. This result was due to the lower irrigation volumes supplied in 2009 compared to 2007 (Table 2) and to the higher rainfall recorded in 2009 (128 mm) that supported a greater solute leaching below the sampled soil layers.

Compared to the previous year, no particular differences were detected about the relationships between ion concentrations. Gloaguen *et al.* (2007) reported that the behavior of Na in the soil solution depends predominantly by the balance between evaporation and precipitation, as well as on adsorption and desorption processes in the CEC. The same Authors observed increasing concentrations of soluble Na and SAR up to a depth of 2 m in a tropical soil after treatment by sewage effluent with a high concentration of Na.

As regard the interactions, $DxWQ$ (Figure 4) shows that, compared to FW, the increase of EC value in SW was higher in the deeper layer than in the top one (307 and 222%, respectively). Similar results were observed, within the same interaction, for all SSPE cations, with the exception for K. This behavior was probably due to the higher rainfall recorded in 2009, that promoted the solute movement in deeper layer. These results are in agreement with those reported by Pereira Lael *et al.* (2009).

Figure 5 shows the effect of $WQxI$ on SAR. In FW treatment, SAR showed a constant trend with a mean value of 2.3 regardless of irrigation volumes. However, in SW, I3 recorded an increase of 34% compared to average of I1 and I2. This result is most likely to be linked to lower fruit weight of I3, shown in Figure 1, instead of higher amount of salts supplied with I3.

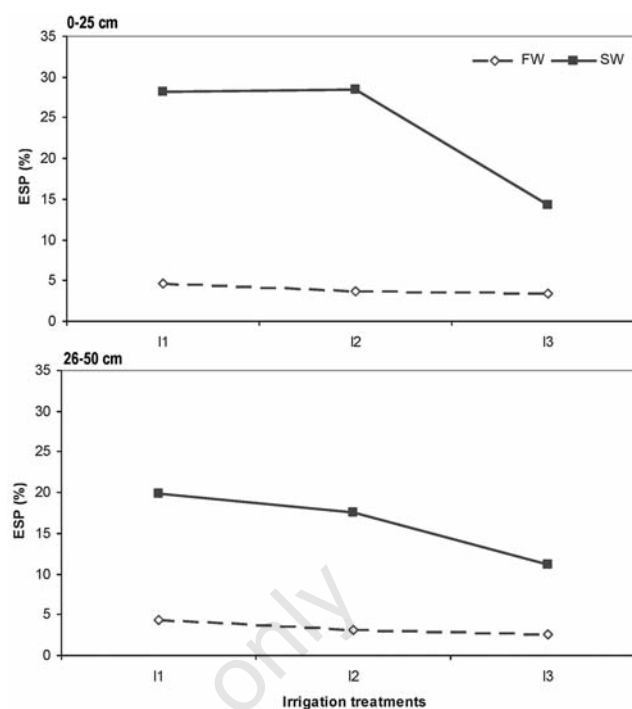


Figure 3. Effect of interaction *depth x water quality x irrigation* on ESP in 2007.

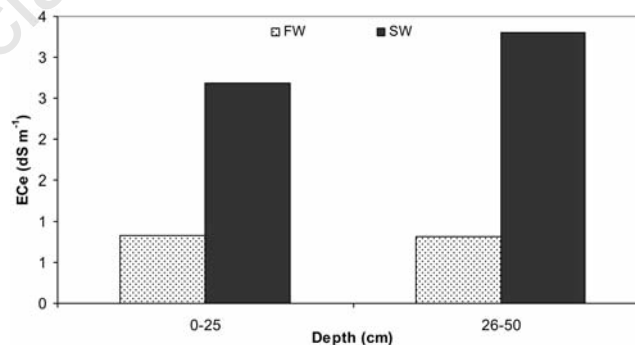


Figure 4. Effect of interaction *depth x water quality* on EC in 2009.

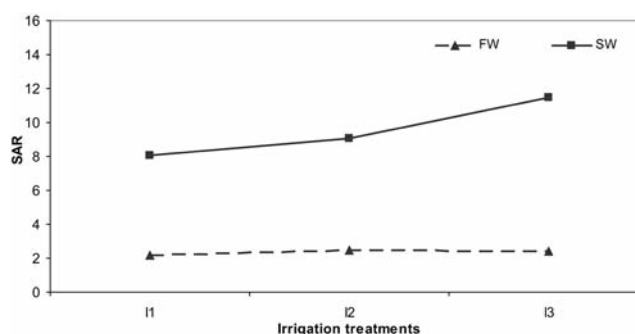


Figure 5. Effect of interaction of *water quality x irrigation* on SAR in 2009.

Conclusion

The principal goal of this research was to evaluate the possibility to use alternative water resources to irrigate a typical vegetable crop cultivated in Southern Italy. In the area where we carried out this research, it is common to have moderately saline water from wells that could be considered an important water resource. In a private farm two field researches were carried out with specific objectives in order to evaluate differential irrigation regimes and saline water effects. Two cycles of two-year rotation based on tomato and maize were cultivated and this paper reported the results obtained from tomato in the first and third year of continuous cultivation.

In general, the reduction of irrigation volume obtained decreasing by 25 and 50% of the water supplied respect to the optimum water requirement (100% Etc), did not determine significant effect of reducing tomato yield. Moreover, there were no significant effects on fruit quality and soil chemistry. These results, quite unexpected, are probably due to the presence of a shallow water-table at 100 cm which, through capillary rise, contributed to fulfil the crop water requirements under limited irrigation treatments.

The application of irrigation with saline water (EC_e of 6 dS m^{-1}) on tomato cv Tomito did not reduce significantly the total and marketable yields compared with fresh water irrigation. These yields were obtained with an soil electrical conductivity that at the end of the cropping cycle was 4.95 and 2.99 dS m^{-1} for 2007 and 2009, respectively, but the EC_e mean of whole crop cycle, probably was around $2-3 \text{ dS m}^{-1}$ in 2007 and 2 dS m^{-1} in 2009.

Moreover, the salinity of irrigation water reduced significantly the average marketable fruit weight (8%) whereas did not affect the number of fruits. In particular, the lowest fruit weight and the highest SAR value were recorded for the I3 treatment under SW, suggesting that the irrigation at 100% of ETm with saline water could determine a more deleterious effect compared to that detected at 50% of ETm, due to a major amount of applied salts. Dry biomass of fruits was not affected by salinity because the fruit size reduction was a consequence of reduction in water content in the fruit.

Finally, the TSS increased with salinity and hence the use of moderately saline irrigation water is recommended to improve fruit quality. In average, the continuous irrigation with saline water determined a soil EC_e of about 3 dS m^{-1} whereas the SAR and ESP were about 14% and 20%, respectively. EC_e value shows that the winter rains have been sufficient to leach significant amounts of salts avoiding that soil salinity could reaches salt stress threshold of the adopted tomato cultivar. The value of ESP of 20% can be taken to the limit of acceptability. However, the SAR and in particular the significant presence of Ca in the exchange complex reduces significantly the risk of deterioration of soil structure with particular reference to permeability hazard, as suggested by Rhoades *et al.* (1992).

Our results show that for the clay-loam soils widespread in the Jonical area of Metaponto it is possible to irrigate the Tomito cultivar with saline water up to 6 dS m^{-1} for a period of three years. However, we suggest that, especially when the winter rains are below the average, it should be necessary monitoring continuously the soil salinity before planting and, if the values of EC, SAR or ESP exceed the values achieved in this research, to stop the irrigation with saline water or adopt supplemental agronomic practices in order to reduce the risks to have lower crop production and to expose the soil to salinization processes.

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