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Response of tomatoes, a crop of indeterminate growth, to soil salinity

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Abstract

Tomatoes were grown in tanks filled with loam and clay, and were irrigated with waters of three different levels of salinity. Osmotic adjustment was determined by analysing the pressure-volume curves at four growth stages. Owing to the osmotic adjustment, tomatoes are able to maintain the turgor potential and the stomatal conductance at the same value for the lower values of the leaf-water potential. Salinity affected the pre-dawn leaf-water potential, stomata] conductance, evapotranspiration, leaf area and fruit yield on both soils. Soil texture only affected the fruit yield. The evapotranspiration showed a moderate decrease, owing to the small decrease in leaf area and the effect of osmotic adjustment on the stomatal conductance, whereas the fruit yield decreased strongly. The tomato plant apparently favours under saline conditions, the growth of foliage at the expense of fruit formation.

Keywords: Crop water stress; Crop water use efficiency; Leaf-water potential; Osmotic adjustment; Stornatal conductance; Salt tolerance; Tomato.
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1. Introduction

In the Mediterranean and arid climates, nearly 200 000 ha are under off-season protected cultivation. The tomato is the major protected crop (Hamdy and Lacirignola, 1993).

Under protected agriculture, the risk of soil salinization is relatively high as salt can accumulate at a higher rate and in a shorter period, than under outdoor conditions. Salinity is the major reason for the low yield and the quality deficiency of tomatoes (Mizrahi et al., 1988; Sonneveld and Welles, 1988; Mitchell et al., 1991; Mougou et al., 1993). Therefore, it appears useful to understand, first the reaction of tomatoes to salinity and then to analyse its consequences for the yield and water use efficiency of the crop.

This study is part of a long-term experiment on the use of saline water, started in 1989 at the Mediterranean Agronomic Institute at Bari, southern Italy. Previous papers (Katerji et al., 1992, 1996, 1997; Van Hoorn et al., 1993) described the experimental procedure and the effect of soil salinity on water stress, growth and yield of various crops (broadbeans, wheat, potatoes, maize, sunflower and sugar beets).

Tomato is the first crop of indeterminate growth to be studied in this experiment. The methodology is the same as for sugar beets: determination of the osmotic adjustment in combination with observations of the pre-dawn leaf-water potential, stomatal conductance, evapotranspiration, growth and yield.

2. Experimental procedure

2. 1. Set-up

The set-up consisted of 30 tanks of reinforced fibre glass with a diameter of 1.20 m and a depth of 1.20 m. A layer of coarse sand and gravel, 0. 10 m thick, was overlain by a repacked soil profile of I m. At the bottom of the tank, a pipe serving as a drainage outlet connected the tank to a drainage reservoir. The set-up was covered at a height of 4 m by a sheet of transparent plastic to protect the assembly against precipitation.

One series of 15 tanks was filled with loam and a second series of 15 tanks with clay.

The tanks were irrigated with water of three different qualities: the control treatment with fresh water containing 3.7 meq Cl/l and an electrical conductivity (EQ) of 0.9 dS/m, and two saline treatments containing 15 and 30 meq Cl/l and an EC of 2.3 and 3.6 dS/m, obtained by adding equivalent amounts of NaCl and $CaCl_2$ tO fresh water. For each water quality, five tanks were available.

At each irrigation, surplus water was added to provide a leaching fraction of about 0.2. Irrigation water was applied when the evaporation of the class A pan had attained about 80 mm. The evapotranspiration of the irrigation interval was calculated as the difference between the amounts of irrigation and drainage water.

For determining soil salinity, the average chloride concentration of soil water was calculated from the salt balance of irrigation and drainage water and converted into EC of soil water by the equation, established after the first 3 years, 1989-1992, In EC=0.824 In Cl - 1.42. This EC-value of soil water was divided by 2 for the conversion into EC_e. Owing to leaching at each water application, soil salinity remained almost constant from the start till the end of the growing period. According to measurements with soil water samplers, soil salinity slightly increased with depth.

A recent paper (Van Hoorn et al., 1997) presents detailed information on soil properties, composition of irrigation water and soil salinity.

2.2. Crop

The tomato (Lycopersicum esculentum, variety ELKO 190) seedlings were transplanted on 22 June 1997 (day t) at the stage of 3 leaves and at a density of 11 plants per tank. Because of successive samplings to determine the growth parameters the number was reduced to 4 at harvest time, corresponding with a density of 35.000 plants per ha, the normal field density in Southern Italy.

Fertilizing was done twice, at the vegetative stage and at flowering, in total 150 kg N ha^{-1}, 110 kg P_2O_5 ha^{-1} and 240 kg K_2SO_4 ha^{-1}.

When 50% of the plants had attained a phenological stage, this date was noted: start of flowering t + 20; start of fruit formation t + 45; harvest t + 83.

2.3. Pressure-volume curve for determining osmotic and turgor potential.

The pressure-volume curves in this experiment were established from two replicates for all six treatments, following the procedure described in a previous publication (Katerji et al., 1997).

2.4. Water stress of the plant

The parameters used to characterize the water stress of the plant were the pre-dawn leaf-water potential and the stomatal conductance. The pre-dawn leaf-water potential was determined on the upper leaf surface of I leaf per tank (five leaves per treatment) and the stomatal conductance at midday on the lower leaf surface of 2 leaves per tank (10 leaves per treatment).

2.5. Growth and yield

The leaf area and the dry matter of leaf and stem were determined at the successive phenological stages on 5 plants, equally distributed over the 5 tanks per treatment, first the leaf area and afterwards the dry matter.

At harvest, the fruit yield, the number of fruits and the average weight of the fruits were determined.

3. Results

3.1. Osmotic adjustment to salinity

Table 1 presents the maximum osmotic potential (relative water content: 1), measured at four dates and shows that:

- The maximum osmotic potential of the control treatments, irrigated with fresh water, decreases with time. This means an osmotic adjustment occurs that is related to the phenological stage, already observed for other crops, such as sorghum. (Hsiao et al., 1976), sunflower (Cruiziat, 1989) and sugar beets (Katerji et al., 1997).

Table 1

Maximum osmotic potential at four growth stages of tomatoes (Mpa).

Time	Loam			Clay		
	Fresh	15 meq/1	30 meq/1	Fresh	15 meq/1	30 meq/1
t+24	-1.06	-1.10	-1.13	-1.08	-1.12	-1.20
t+52	-1.21	-1.25	-1.38	-1.19	-1.24	-1.44
t+66	-1.35	-1.43	-1.52	-1.37	-1.45	-1.61
t+80	-1.39	-1.47	-1.54	-1.44	-1.64	-1.71

F-values:
Linear time component 270, 40>8.18=F(1,19; 0.01);
Linear salinity component 58, 05>8.18-F(1,19; 0,01);
Linear time x linear salinity inter action component 3.15>2.99=F(1,19; 0.10);
soil texture 8.07>4.41-F(1,19; 0.05).

- The maximum osmotic potential decreases with increasing salinity, which means an osmotic adjustment to salinity.
- The osmotic adjustment to salinity increases with the time of exposure to salinity, as the differences between the control treatment and the saline treatments later on are larger than at the start (t+24);
- Soil texture also appears to affect the maximum osmotic potential.

3.2. Water stress

The pre-dawn leaf-water potential (Fig. 1) showed the normal trend of an increase after irrigation, followed by a decrease during the irrigation interval. Its value fluctuated between about -0.2 MPA and -0.6 MPA for the control treatment. The maximum differences between the control and the saline treatments were always observed before irrigation. Soil texture did not show a clear effect.

The stomatal conductance (Fig. 2) followed the same trend as the pre-dawn leaf-water potential, but the maximum differences between the control and the saline treatments always appeared immediately after irrigation. Soil texture did not show a clear effect.

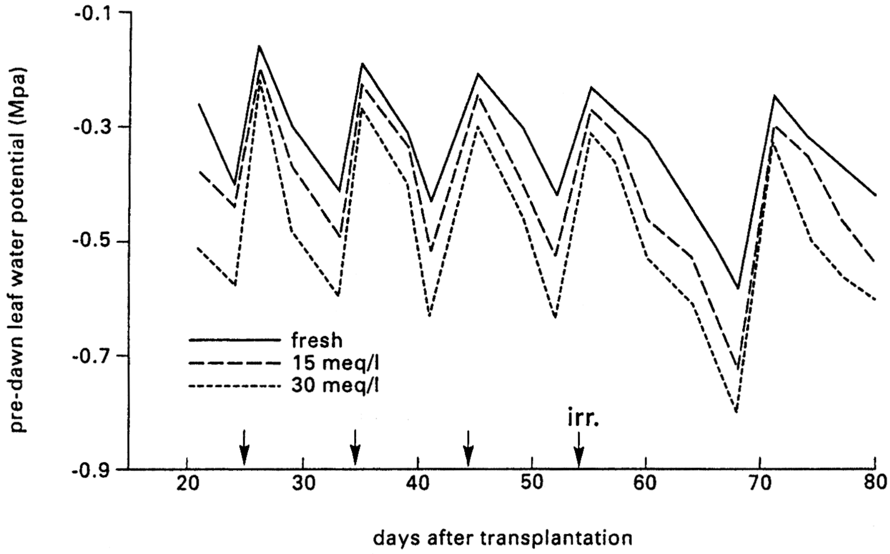

***Fig. 1**. Pre-dawn leaf water potential vs. days after transplantation on loam.*

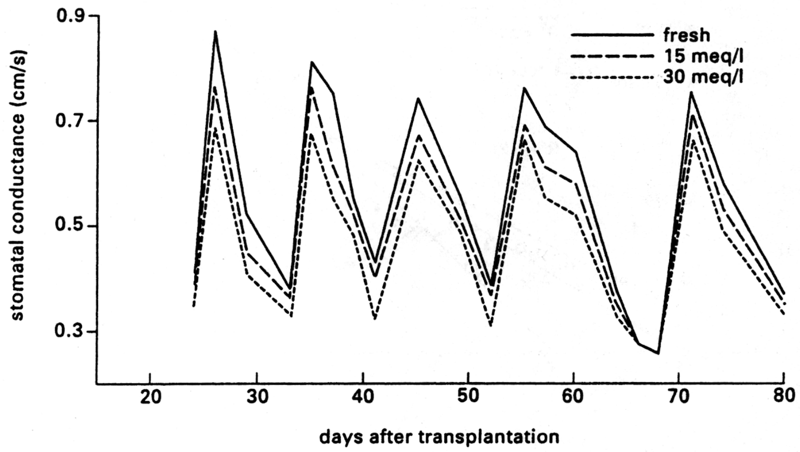

***Fig. 2.** Stomatal conductance vs. days after transplantion on loam.*

Fig. 3 presents the relationship between the stomatal conductance at noon and the predawn leaf-water potential. The slope of the control treatment is about twice the slope of the saline treatments. The pre-dawn leaf-water potential corresponding to zero stomatal conductance (about 0.1 cm s-1 according to Milburn, 1979) decreases with increasing salinity. This means that the plants, grown under saline conditions, maintain the stomatal conductance at higher values of water stress (lower pre-dawn leaf-water potential) than the control plants, owing to the osmotic adjustment.

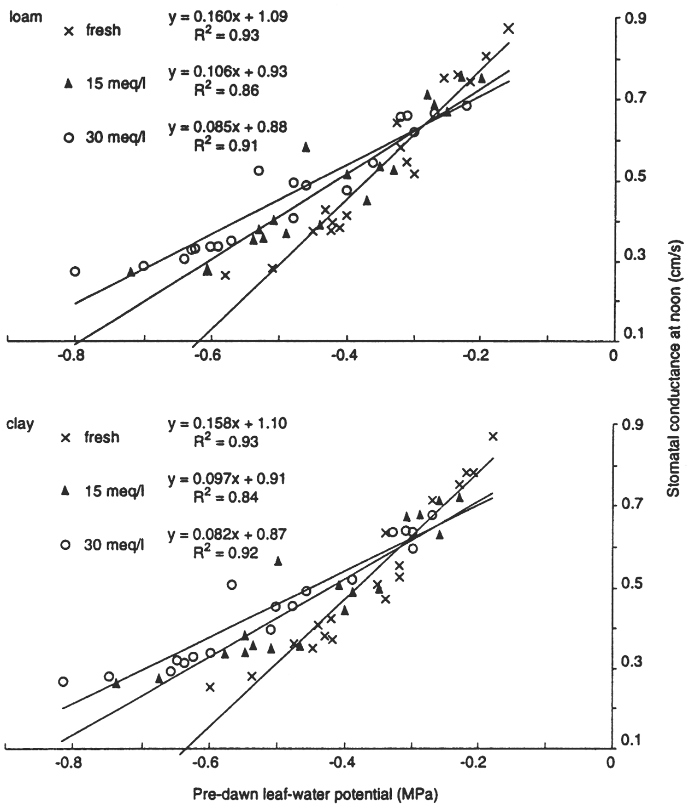

Fig. 3. *Stomatal conductance vs. pre-dawn leaf-water potential.*

3.3. Evapotranspiration

Evapotranspiration, presented in Table 2, showed the effect of salinity, a decrease of about 10% for the treatment of 15 meq l-1 and about 20-25% for the most saline treatment. Soil texture did not show an effect, corresponding with the observations of the pre-dawn leaf-water potential and the stomatal conductance.

3.4. Growth and yield

The leaf area (Fig. 4) developed rapidly until 59 days after transplantation, then its growth slowed down and finally the leaf area decreased owing to senescence. Salinity affected the leaf area, but its effect was not strong and decreased with time, for the most saline treatment from about 50% reduction till 10%, as is shown in Table 3. Soil texture did not show a clear effect.

Table 2

Evapotranspiration of tomatoes (mm day^{-1})

Period	Loam			Clay		
(during the year 1996)	Fresh	15 meql^{-1}	30 meql^{-1}	Fresh	15 meql^{-1}	30 meql^{-1}
17.06-30.06	3.2	2	2.7	2.9	2.6	2.5
30.06-10.07	5.1	5.1	4.9	5.3	5.0	4.9
10.07-17.07	7.5	6.9	6.7	7.5	7.1	6.5
17.07-26.07	10.3	8.1	6.2	9.5	8.2	5.8
26.07-04.08	12.0	11.0	8.6	11.9	11.2	8.5
04.08-14.08	11.8	11.6	9.2	11.9	11.7	9.0
14.08-30.08	11.0	9.0	8.1	9.3	8.9	7.5
30.08-11.09	5.7	5.1	4.5	5.3	5.0	4.9
Total period (mm)	708	630	540	667	628	523
(%)	100	89	76	100	94	78

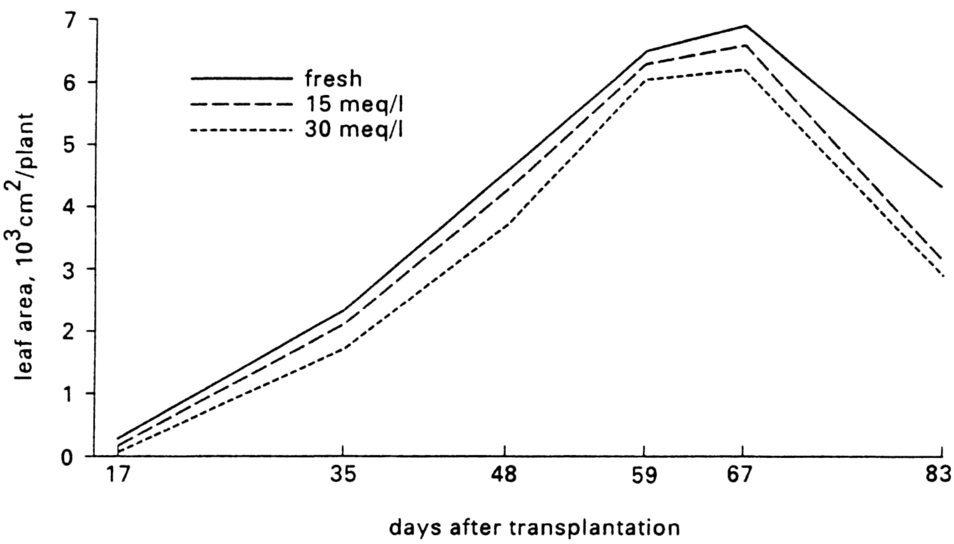

Fig. 4. *Leaf area vs. days after transplantation on loam.*

Table 3

Ratio between the leaf areas of the most saline and control treatments

t,days	17	35	48	59	67
Loam	0.44	0.75	0.81	0.92	0.90
Clay	0.64	0.55	0.83	0.80	0.89

Dry matter of leaves and stems (Fig. 5) developed regularly from transplantation till harvest and was affected by salinity, but not by soil texture.

Table 4 presents the tomato yield, its components, the water use efficiency and the average soil salinity of the layer 0-100 cm, which remained nearly constant during the growing season. The yield of 6.1 kg/m2 on loam and 5.3 kg/m2 on clay is in the same order of 7.1 kg/m2 reported by Hamdy and Lacirignola (1993) for protected tomatoes in Italy. The slight difference may be attributed to the fact that the tomatoes were harvested only once in this experiment, whereas farmers are generally harvesting twice.

The effect of salinity on the fresh weight yield, on the number of fruit per plant and on the average fruit weight was highly significant ($p<0.01$) and the effect of soil texture on the fresh weight yield was significant ($p<0.05$). No interaction appeared between salinity and soil texture. As shown in Fig. 6, the salinity effect is somewhat stronger than appears from the data of Ayers and Westcot (1985). The fact that texture had no effect during the growing period, but only at the end on the fresh weight yield, could be atttributed to the rather short irrigation interval between 7 and 10 days from the start of July till the middle of August.

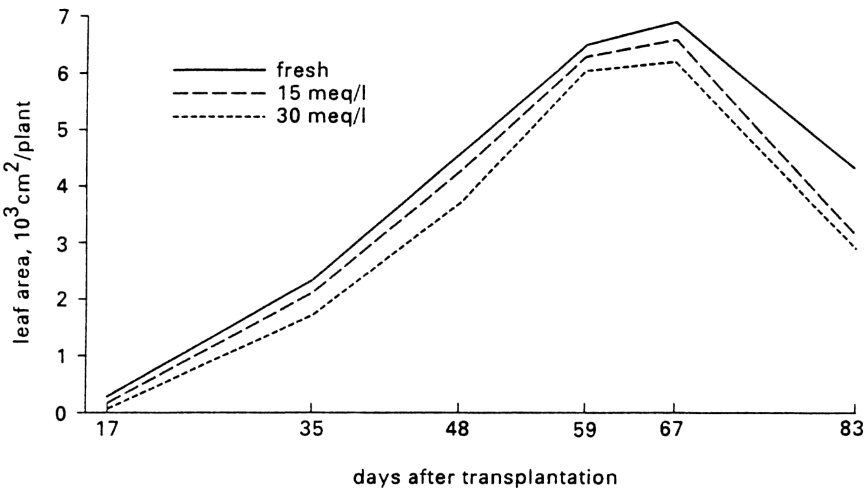

Fig. 5. *Dry matter of leaves and stems vs. days after transplantation on loam.*

Table 4

Yield of tomatoes, water use efficiency and soil salinity.

	Loam			Clay		
	Fresh	15 (meql^{-1})	30 (meql^{-1})	Fresh	15 (meql^{-1})	30 (meq)
Fresh weight (kg m^{-2})	6.12	4.46	2.42	5.31	3.85	2.29
Number of fruit per plant	48.0	45.8	33.3	45.2	44.1	35.0
Average fruit weight (g)	36.0	27.5	20.5	33.2	24.7	18.5
Water use efficiency(kg m^{-3})	8.65	7.07	4.47	7.96	6.13	4.60
EC, (dS/m)	0.8	4.5	6.4	0.8	4.0	5.4

4. Discussion and conclusion

The tomato is a plant of indeterminate growth. Bunches of flowers are formed along the stem again and again after about three leaves. The results of this experiment allow to analyse and understand the reaction of the tomato plant to saline stress and the consequence of this reaction for its yield and water use efficiency.

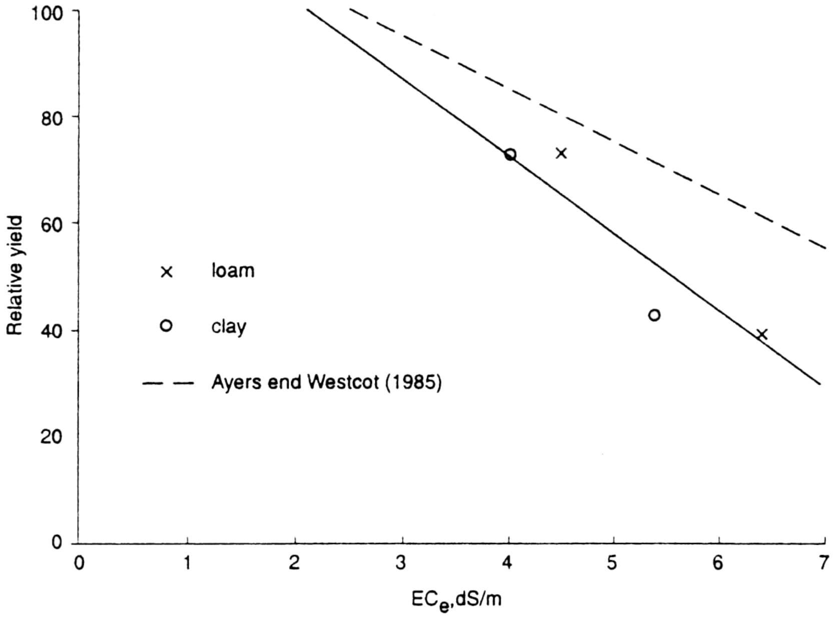

Fig. 6. *Relationship between relative yield of tomatoes and soil salinity.*

The tomato plant is able to adjust its osmotic potential to maintain the turgor potential and the stomatal conductance under saline conditions. The adjustment observed in this experiment of 15-20% is higher than the adjustment of 4-14% mentioned by Oosterhuis and Wullshlerger (1989). In their experiment saline stress was only applied during a few days, whereas in our experiment it was applied during the whole growing season.

Saline stress appears to affect in a different way the growth of foliage and flowering, the alternative growth processes of the tomato plant:

- The leaf area apparently makes up for the original loss, as the salinity effect decreases with time (Table 3), probably owing to the osmotic adjustment (Cutler et al., 1980), that increased with time (Table 1). The small difference in leaf area in combination with the capability to maintain the stomatal conductance under saline conditions, may explain the moderate decrease of the evapotranspiration, shown in Table 2.
- The reduction in fruit yield of the most saline treatment is about 60% against a reduction in leaves and stems of about 30%. The reduction in fruit yield corresponds with a reduction in fruit weight and in the number of fruit. We did not determine in this experiment the cause of the reduction in the number of fruit : less flowers, loss

of flowers before or after fecundation or delay in flowering (Dumbroff and Cooper, 1974).

The behaviour of the tomato plant under saline conditions appears to be similar to that under drought conditions. Fisher and Nel (1990) reported a lack of response of leaf growth to water stress, whereas yield and fruit size decreased. Gionquinto et al. (1990) did not observe a remarkable difference in vegetative growth, but in reduced yield and a decrease of the fruit weight in case of deficit irrigation. The tomato plant apparently favours under conditions of water stress, owing either to salinity or to moisture deficit, the growth of foliage at the expense of fruit formation, which is the cause of the low yield and water use efficiency. This may be improved by balancing growth of foliage and fruit formation, e.g. blocking the growth of foliage by suppressing the terminal shoot.

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