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Tomato plant growth as affected by horizontally unequal osmotic concentrations in rock-wool

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Summary

Tomato plants were grown in rock-wool in a split-root system with equal or different osmotic concentrations. Yield reduction correlated with the average electrical conductivity (EC) values, calculated as the mean EC values of both parts of the system.

In treatments with different EC values in the root zone, root development was better in the part with the low EC. Water uptake from the part with the low EC was also higher. Nutrient concentrations showed an increase in the part with the low EC when differences in EC between both parts were 4 mS/cm or more. One of several possible explanations for this is that solutes move through the roots from the part with high to the part with the low osmotic concentration.

Introduction

In intensive tomato culture, water and nutrients are normally applied in liberal quantities by various systems. Part of the root system may be exposed to high, and another part to low osmotic conditions. This may alter water and nutrient uptake, thereby affecting plant growth.

In water cultures with corn and tomato plants with their root system divided between two or more solutions that differed in concentration and in type of added salts, Eaton (1941) showed that root growth and water uptake was greater in

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dilute than in concentrated solutions. Lunin & Gallatin (1965), Shalhevet & Bernstein (1968), and Bingham & Garber (1970), using layers of soil separated by sand or wax membranes, studied the effect of non-uniform salinity with depth on plant growth and water uptake in tomato, lucerne and maize. The results will be discussed later.

All these experiments are characterized by a uniform root distribution and a root system that had fully developed before salinization was started. The present study was designed to evaluate the effect on plant growth, root development, and nutrient uptake of horizontally unequal osmotic concentrations by using a split-root system. Rock-wool was used as substrate, a new material utilized for growing vegetable crops on a commercial scale in various European countries. For details about chemical and physical characteristics of rock-wool, see Sonneveld (1980).

Materials and methods

Four rock-wool pieces of 22 cm × 17 cm × 17.5 cm were placed in polystyrene boxes. Each piece was covered with a white plastic sheet to maintain mutual separation and to avoid drainage and evaporation losses. Four EC levels ranging from 2 to 10 mS/cm at 25 °C were established in various combinations to give ten different treatments, replicated three times. Details about the treatments are given in the tables. In each treatment, two rock-wool pieces had an EC value equal to or different from the other two. In the latter case the two pieces with the same EC values were placed diagonally.

The EC levels were obtained by adding the appropriate amounts of two stock solutions A and B, taking into account that one litre of solution A plus one litre of solution B, diluted 100 times, gave an EC value of 2 mS/cm. The composition of both solutions is given in Table 1.

Tomato (*Lycopersicon esculentum* Mill., cv. Moneydor) was used as the experimental plant. The seeds were germinated in sand; on 2 May 1980, when the

Table 1. Composition of stock solutions A and B.

Stock solution A			
Ca (NO_3)	68.2 g/l	$NH_4(NO_3)$	4.0 g/l
$K(NO_3)$	15.0 g/l	Fe-EDTA 330 (9% Fe)	0.56 g/l
Stock solution B			
$K(NO_3)$	10.2 g/l	$MnSO_4 \cdot H_2O$	0.16 g/l
KH_2PO_4	20.4 g/l	$ZnSO_4 \cdot 7H_2O$	0.11 g/l
K_2SO_4	30.4 g/l	$CuSO_4 \cdot 5H_2O$	0.012 g/l
$MgSO_4 \cdot 7H_2O$	24.6 g/l	$Na_2MoO_4 \cdot 2H_2O$	0.012 g/l
		$Na_2B_4O_7 \cdot 10H_2O$	0.18 g/l

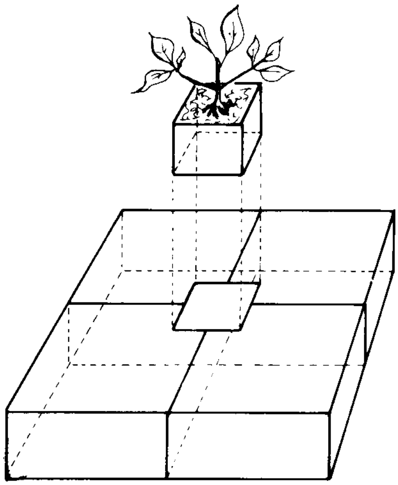

Fig. 1. The experimental set-up.

plants were about 5-6 cm high, they were transferred to cubic rock-wool blocks of 7.5 cm, of which the sides were covered with a black plastic sheet. The plants were allowed to grow until the roots reached the bottom of the rock-wool block. During this period the plants were irrigated daily with the nutrient solution of 2 mS/cm diluted with demineralized water (1:2).

On 24 May, each plant in the rock-wool block was placed in the centre of one box, having a fourth of its bottom surface on each rock-wool piece as is shown in Fig. 1. Previously, on the spot where the block had to be placed, the plastic sheet was removed so that the roots could penetrate the rock-wool pieces.

It was attempted to maintain a constant EC level in each piece of rock-wool throughout the experimental period, although this was not always possible. One replicate was checked daily; either water or nutrient solution was added as required. The other replicates were checked at least twice a week. The samples were taken with a plastic syringe. Two weeks before the conclusion of the experiment, and before adding water or solution, samples were taken for macronutrient analysis.

On 17 July the plants were topped; each bore 6 clusters. The next day four leaves were taken from the middle section of the plant, and chemically analysed. After 8 pickings of fruit, the experiment was terminated on 18 August. Total weight and number of fruits, weight per fruit, number of fruits with blossom-end rot (BER), percentage of fruits with even colour, and dry weight of the plants were recorded. The rock-wool pieces were uncovered and the roots of each plant were separated from the rock-wool for weight measurements according to the method described by Brouwer & van Noordwijk (1978). The yield data were statistically analysed, except the number of fruits affected by BER, the number being too low for meaningful analysis.

Results and discussion

Growth characteristics

The first visual effects of treatments were noted about one week after starting the treatments, viz a darker green leaf colour, narrower leaves, and necrosis symptoms especially at the edges of the leaves of plants growing at high EC levels (treatments T-8, T-9 and T-10). At later stages, the stems of plants growing at high EC levels were slender, without difference in length of internodes.

Nutrient solution concentrations

Table 2 shows the nutrient composition of the solution in the rock-wool. Most remarkable is the increase in EC and nutrient contents in the low-EC part in combination with a high EC. This increase is greater as the difference in EC between both parts is greater (compare T-1 to T-4). A definite explanation cannot be given. One possibility is that water was mainly taken up from the part where the EC increased most strongly. This is in agreement with our observation that more water or solution was needed in the part with the low EC. Another explanation could be that there was a movement of salts from the high-EC part to the low one through siphoning via the rock-wool block of the seedling. This could have taken place when the levels of the nutrient solution in the four rock-wool pieces were unequal. However, because the capillary activity of rock-wool is low, this could have happened only temporarily at high solution levels after suppletion. Thus, any transport of salts in this way should be of little or no importance.

Movement of salts can also taken place through the roots. Exact measurements were not made but the last time nutrient solution was added to the low-EC part of T-4 was 17 July; from then until the samples were taken (4 August) water was supplied every day and yet this part still had an EC of 6.5 mS/cm at that time. Although L. K. Wiersum (personal communication, 1980) considers transport of salts from on medium to another through roots unlikely, the indication of boron transport found in another experiment (Cerda & Roorda van Eysinga, 1981) supports the opinion of the authors. Eaton (1941) reported transport of chloride through roots of maize and tomatoes.

Yield components

Mean values of yield components are given in Table 3. Fig. 2 shows the linear regression of the shoot and fruit yields in relative figures on the average EC-values. $\overline{EC}$ is the average of the target EC value of both parts. The real EC values were not used for this calculation in view of their variation. The negative effect of increasing $\overline{EC}$ on fruit yields was greater than on shoot weight. The values of r^2 for both equations indicate that 81 % of fruit yield reduction is accounted for

Table 2. Composition of the solutions in the rock-wool, and of those applied.

Treatment			EC	mmol per litre								
code	EC level (mS/cm) aimed at	combined with	(mS/cm)	NH_4	K	Na	Ca	Mg	NO_3	Cl	SO_4	P
T-1	2	($-EC_2$)	2.4	0.0	11.2	2.8	6.3	2.1	14.7	0.7	6.3	1.3
T-2	2	($-EC_4$)	2.2	0.0	9.1	2.1	5.6	1.4	14.0	0.5	4.9	2.0
T-3	2	($-EC_6$)	5.2	0.0	28.0	3.5	14.7	4.9	42.7	1.4	11.9	4.7
T-4	2	($-EC_{10}$)	6.5	0.0	34.3	2.8	19.6	6.3	56.0	0.7	11.9	6.7
T-2	4	($-EC_2$)	3.6	0.1	18.2	2.1	9.1	2.8	26.6	0.7	6.3	3.3
T-5	4	($-EC_4$)	4.5	0.1	22.4	2.8	13.3	4.2	35.0	1.4	10.5	3.6
T-6	4	($-EC_6$)	5.0	0.1	24.5	2.1	14.7	4.2	42.0	0.5	9.8	5.0
T-7	4	($-EC_{10}$)	4.6	0.1	23.1	2.8	11.9	3.5	32.9	0.5	9.1	4.4
T-3	6	($-EC_2$)	5.8	1.4	30.1	2.1	15.4	5.6	46.9	2.1	11.2	5.8
T-6	6	($-EC_4$)	5.9	1.4	31.5	2.8	16.8	4.9	49.7	1.4	11.9	6.6
T-8	6	($-EC_6$)	6.0	1.4	31.5	2.1	16.8	5.6	47.8	2.1	12.6	5.8
T-9	6	($-EC_{10}$)	7.6	0.0	43.4	3.5	26.6	8.4	60.9	0.7	24.5	7.7
T-4	10	($-EC_2$)	7.6	2.8	43.4	3.5	24.5	7.0	69.3	2.1	15.4	9.6
T-7	10	($-EC_4$)	7.0	2.8	39.9	2.8	20.3	6.3	62.3	2.1	14.0	8.5
T-9	10	($-EC_6$)	7.2	2.8	40.6	2.8	20.3	6.3	63.7	1.4	14.0	8.4
T-10	10	($-EC_{10}$)	9.0	2.1	51.8	4.2	27.3	8.4	84.0	2.8	20.3	9.6
Nutrient solution applied												
EC_2			2.0	0.5	7.5	0.9	7.5	2.0	10.5	0.6	5.5	1.5
EC_{10}			8.3	2.5	37.5	1.5	37.5	10.0	52.5	2.0	27.5	7.5

Table 3. Yield components of tomato plants in relation to the EC levels in a split-root system.

Treatment		Fruit yield (g per plant)	Number of fruits per plant	Fruit weight (g)	Fruits evenly coloured (%)	Shoot (dry weight, g)
code	EC levels (target)					
T-1	EC_2-EC_2[a]	4033	81	50.2	68	186
T-2	EC_2-EC_4	3850	77	49.8	65	188
T-3	EC_2-EC_6	3984	75	53.0	84	188
T-4	EC_2-EC_{10}	3528	80	44.0	91	189
T-5	EC_4-EC_4	3517	74	47.2	92	205
T-6	EC_4-EC_6	3590	81	41.6	79	201
T-7	EC_4-EC_{10}	3492	72	47.9	78	172
T-8	EC_6-EC_6	3118	70	44.8	80	180
T-9	EC_6-EC_{10}	2740	74	37.2	71	201
T-10	EC_{10}-EC_{10}	2574	73	36.1	95	159
Analysis of variance[b]						
Treatments		**	NS	**	NS	NS
v.c. %		16.9	14.4	9.3	17.9	10.0

[a] EC_2-EC_2 indicates that the EC value was the same (2 mS/cm) in each 4 rock-wool pieces in a box. EC_2-EC_4 indicates that in two pieces the EC value is 2 mS/cm and in the other two 4 mS/cm, etc.

[b] ** Significant differences between means at $P < 0.01$. NS indicates non-significance at $P < 0.05$.

by treatments, of shoot dry weight only 25 %.

Fruit yield and weight per fruit decreased significantly with increasing EC in those treatments where all parts of the root system had the same EC value (compare T-1, T-5, T-8 and T-10). On the other hand, yield was not, or only slightly, reduced when EC levels in one part of the root system were increased, while

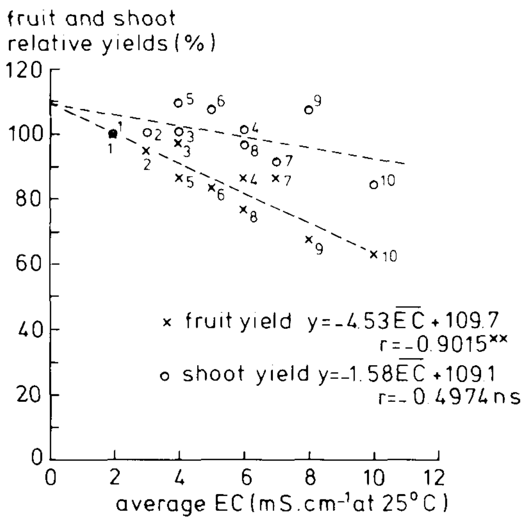

Fig. 2. Relation between relative figures of yields of fruit and dry weight of shoots, and average EC in the rock-wool substrate.

maintaining the other unchanged (compare T-2, T-3 and T-4 with T-1, etc.). The yield reduction in treatment T-4 compared with T-1 and of treatment T-9 compared with T-8 may be due not only to restricted root activity in the high-EC part but also to an increase in the EC value in the low-EC part.

Shalhevet & Bernstein (1968) showed that water uptake by alfalfa decreased as the salinity of that half of the root system increased and that yields were linearly reduced by increasing mean salinity of the root zone. This is in agreement with our findings. Bingham & Garber (1970) found a clear yield reduction in sweet corn when the whole root zone was salinized, but no or a small one with 2/3 of this zone under saline conditions.

The number of fruits per plant, the percentage of fruits with even colour, and the shoot dry weight were not significantly affected by the treatments. The effect on number of fruits affected by BER was very low, the highest number (3.6 %) being associated with treatment T-10 (EC_{10}-EC_{10}).

Root development

The root weight of each part of the root system in relation to the EC levels applied is given in Table 4. From these data it is evident that the treatments did not have a consistent effect on total root weight per plant, since root weight in some treatments with a high EC was higher than in those with a low EC (compare T-8 and T-9 with T-1 to T-6). However, in those treatments with different EC values, root development was, with one exception, always greater in the low than in the high-EC part. These results are in agreement with those reported by Eaton (1941).

Table 4. Root weight (air dried) in relation to the EC levels in a split-root system.[a]

Treatment		Root weight (g)				
code	EC levels (target)	EC_2	EC_4	EC_6	EC_{10}	total/plant
T-1	EC_2-EC_2	10.5	–	–	–	10.5
T-2	EC_2-EC_4	3.5	4.3	–	–	7.8
T-3	EC_2-EC_6	4.4	–	3.5	–	7.9
T-4	EC_2-EC_{10}	6.5	–	–	2.4	8.9
T-5	EC_4-EC_4	–	8.1	–	–	8.1
T-6	EC_4-EC_6	–	4.9	3.6	–	8.5
T-7	EC_4EC_{10}	–	5.8	–	4.4	10.2
T-8	EC_6-EC_6	–	–	12.0	–	12.0
T-9	EC_6-EC_{10}	–	–	7.3	4.7	12.0
T-10	EC_{10}-EC_{10}	–	–	–	8.5	8.5

[a] A single value for a treatment gives total root weight in the four rock-wool pieces; when two values are given each one is the sum of the root weights in two pieces.

Table 5. Mineral composition of tomato leaves.[a]

Treatment code	EC levels (target)	K	Ca	Mg	P	Total-N	NO_3-N	SO_4-S	Fe	Mn	Zn
T-1	EC_2-EC_2	1.25	0.91	0.26	0.19	2.21	0.34	0.54	2.52	2.75	1.08
T-2	EC_2-EC_4	1.31	0.78	0.26	0.19	2.35	0.37	0.46	2.81	4.08	0.94
T-3	EC_2-EC_6	1.34	0.74	0.26	0.19	2.25	0.32	0.42	2.59	2.24	0.83
T-4	EC_2-EC_{10}	1.49	0.59	0.25	0.19	2.41	0.40	0.39	2.40	2.56	1.33
T-5	EC_4-EC_4	1.38	0.72	0.27	0.23	2.36	0.50	0.39	2.83	2.50	1.12
T-6	EC_4-EC_6	1.35	0.65	0.25	0.20	2.42	0.36	0.42	2.71	2.22	0.82
T-7	EC_4-EC_{10}	1.53	0.60	0.24	0.20	2.22	0.45	0.35	2.62	2.57	1.14
T-8	EC_6-EC_6	1.43	0.64	0.25	0.19	2.42	0.37	0.39	3.01	2.38	1.22
T-9	EC_6-EC_{10}	1.46	0.55	0.25	0.19	2.47	0.34	0.32	2.67	2.49	1.16
T-10	EC_{10}-EC_{10}	1.60	0.59	0.22	0.20	2.57	0.42	0.36	3.92	3.02	1.01

[a] Fe, Mn and Zn are expressed in μmol/g dry weight, the other minerals in mmol/g dry weight.

Leaf mineral composition

The mineral composition of the tomato leaves is presented in Table 5. The concentration of most nutrients did not vary with the treatments, although the concentrations in the rock-wool solution varied widely. Contents of calcium and sulphate-S in the leaf decreased, and potassium increased with higher EC values in the rock-wool solution. These variations occurred when the EC in both parts of the root system was increased, but also when this was only so in one part. The variations observed in this experiment, however, do not seem high enough to ascribe the fruit yield reduction and the necrosis symptoms observed to nutrient deficiency or toxicity; the nutrient values remained within the range associated with normal tomato growth, according to Roorda van Eysinga & Smilde (1981).

The results also show that the tomato plant has a strong capacity to absorb ions selectively. Despite great differences in nutrition concentrations in the root zone, the plant succeeds in keeping its leaf concentration within rather narrow limits.

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