

ROOT ENVIRONMENT WATER POTENTIAL AND TOMATO FRUIT GROWTH

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Abstract

Tomato plants were grown in a climate chamber in water culture at standard nutrient solution concentration with electrical conductivity of $2 \text{ mS}\cdot\text{cm}^{-1}$. At the start of the development of the fourth cluster the EC was increased to 6, 9 or $12 \text{ mS}\cdot\text{cm}^{-1}$, resulting in a water potential of the nutrient solution of -0.2 , -0.3 or -0.4 MPa , respectively. We measured the growth in volume of all fruits with an electronic calliper and at specific periods individual fruit growth using displacement transducers. Plant water potential was measured with a pressure chamber. Fruit water status was determined by measuring the osmotic potential of the pericarp. Above a threshold value the total fruit growth rate was linearly related to EC, with a sensitivity of about $10\%(\text{mS}\cdot\text{cm}^{-1})^{-1}$. The effect of EC on fruit growth was not only dependent on the level of EC, but also on the length of exposure to high EC during fruit development. Plant water potential changed concomitantly with EC. Fruit osmotic potential lagged behind and was also dependent on the length of exposure to high EC. We consider the water potential gradient between plant and fruit to be the driving force for import of water into the fruit and present a fruit growth simulation on the basis of the relationships between root environment water potential and plant-to-fruit water potential gradient.

Key words: *Lycopersicon esculentum*, electrical conductivity, osmotic potential, water relations

1. Introduction

In growing media, e.g. rockwool slabs, the level of water stress imposed on the roots by the concentration of nutrients is known to affect tomato plant and fruit growth and fruit quality (Adams, 1991; Ehret & Ho, 1986a; Sonneveld & Welles, 1988). The electrical conductivity (EC) of the nutrient solution added to the growing medium is used as a measure of its nutrient concentration (c). The nutrient concentration exerts its 'water stress effect', because it sets the osmotic potential of the solution ($\Psi_{\pi}^{\text{solution}}$) (Slatyer, 1967):

$$\Psi_{\pi}^{\text{solution}} = -cRT$$

with y in MPa, c in $\text{moles}\cdot\text{cm}^{-3}$, R as the universal gas constant ($8.31 \text{ J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}$), T as temperature in K. The relation between EC, $\Psi_{\pi}^{\text{solution}}$ and c is complicated, but from Richards (1954) the following approximations can be deduced:

$$\Psi_{\pi}^{\text{solution}} = -0.036\cdot\text{EC}^*$$

$$c_a = 12.4\cdot\text{EC}^*$$

$$\text{EC}^* = (1 - 0.02\cdot(T-298))\cdot\text{EC}$$

with EC in $\text{mS}\cdot\text{cm}^{-1}$, c_a as [anion] or [cation] in $\text{meq}\cdot\text{l}^{-1}$, EC^* as normalised EC at $T=298 \text{ K}$. The conversion from c to c_a (from meq to moles) depends on the composition of the nutrient solution. McNeal et al. (1970) present various statistical

methods for calculating EC from the individual ion concentration in a mixed-salt solution. According to Otten (1994) a value of $0.1 \text{ mS}\cdot\text{cm}^{-1}$ is valid as a rough estimate for a 10^{-3} normal mixed-salt solution. Together with the matric potential of the growing medium (Ψ_m^{medium}) $\Psi_\pi^{\text{solution}}$ constitutes the water potential of the root environment ($\Psi^{\text{root env}}$):

$$\Psi^{\text{root env}} = \Psi^{\text{solution}} + \Psi_m^{\text{medium}}$$

Although the relative contribution of $\Psi_\pi^{\text{solution}}$ depends on the nature and water content of the growing medium, in media other than soil it is a substantial component of the total water potential. The combined effects of $\Psi^{\text{root env}}$ and aerial climatic factors determine the water status of the plant, which in its turn affects several physiological processes and consequently plant growth and product quality (Bradford & Hsiao, 1982; McIntyre, 1987; Van de Sanden, 1995). To enable optimisation of EC with respect to productivity and quality we investigated the effects of $\Psi^{\text{root env}}$ on tomato plant and fruit water status and the relationship between plant and fruit water status and fruit growth.

2. Materials and methods

Tomato, cv. Counter, was grown in a controlled environment at $22 \text{ }^\circ\text{C}$ day/night temperature, 0.7 kPa vapour pressure deficit, $400 \text{ mmol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ photosynthetic active radiation (12 h daylength, HPS + HPI lamps) and ambient $[\text{CO}_2]$. To eliminate effects of Ψ_m^{medium} we have used aerated water culture ($\Psi^{\text{root env}} = \Psi_\pi^{\text{solution}}$) with a standard nutrient solution of $2 \text{ mS}\cdot\text{cm}^{-1}$ EC and a $\Psi_\pi^{\text{solution}}$ of -0.075 MPa (Steiner, 1961). We studied the effects of EC increase on:

plant water status by measuring the xylem water potential with a pressure chamber (Ritchie & Hinckley, 1975);

fruit water status by measuring the osmotic potential of sap expressed from the pericarp, after freezing and thawing, with a Wescor 5000 vapour pressure osmometer. We assumed that the error due to mixing apoplast and symplast fractions was negligible and considered fruit osmotic potential to be a reasonable approximation of fruit water potential, since the turgor of the pericarp is probably small (data not shown) (Johnson et al., 1992; Shackel et al., 1991; Verkerke et al., 1994);

long term fruit volume increase by measuring the diameter of all individual fruits three times a week with an electronic calliper. Fruit volume (V^{fruit}) was estimated from the formula $V^{\text{fruit}} = 0.87^4/3 \cdot \pi \cdot r^3$;

short term fruit volume increase by continuous measurement of fruit diameter using displacement transducers (LVDT).

EC was increased at the start of growth of the fourth cluster.

3. Results and discussion

A sudden change of the water potential of the root environment affects the water status of the plant. In Figure 1 the xylem water potential (Ψ^{xy}) is shown before and after a change of $\Psi^{\text{root env}}$ from -0.07 to -0.43 MPa (from 2 to $12 \text{ mS}\cdot\text{cm}^{-1}$, resp.). The change in Ψ^{xy} is roughly equivalent to the change of $\Psi^{\text{root env}}$. In seedlings of

cucumber we have found a comparable sensitivity of Ψ^{xyl} to $\Psi^{root\ env}$ (Van de Sanden & Veen, 1991). Figure 2 shows the diurnal growth of one individual tomato fruit before and after exposure to low $\Psi^{root\ env}$ (-0.43 MPa). Before exposure, the normal growth rate (under these circumstances) is between 50 and 100 mm³·h⁻¹, but after the change in $\Psi^{root\ env}$ it hardly exceeds 50 mm³·h⁻¹, with an attenuated diurnal amplitude, as was also found by Ehret & Ho (1986b). Pearce et al. (1993) attributed this decreased daytime fruit expansion rate at high salinity in mid-season to a concomitant negative effect of $\Psi^{root\ env}$ and irradiance on plant water status.

Below a threshold value of around -0.2 MPa (6 mS·cm⁻¹) we found the total fruit volume to decrease linearly with a decrease of $\Psi^{root\ env}$ (Figure 3). The sensitivity was 260 cm³·d⁻¹·MPa⁻¹. In terms of EC this corresponds to a loss of total fruit growth rate of around 10%·(mS·cm⁻¹)⁻¹. The same type and magnitude of response have been found by Ehret & Ho (1986a) and Sonneveld & Welles (1988).

Not only the level of $\Psi^{root\ env}$, but also the length of exposure to a certain level during fruit development determines its effect at harvest. Fruit size (Figure 4), fruit pericarp dry matter content (DMC) (Figure 5) and fruit pericarp osmotic potential (Ψ_{π}^{fruit}) (Figure 6) were all found to be affected in proportion to the duration of low $\Psi^{root\ env}$, relative to total duration of fruit development. Effects on fruit development rate were negligible. As can be seen from Figures 4 and 5 the decrease in fruit size coincides with an increase in fruit DMC. This suggests, that the influence of $\Psi^{root\ env}$ on water import predominates and that the dry matter import into the fruit is hardly affected, as was also concluded by Ehret & Ho (1986a).

We propose, that the effect of $\Psi^{root\ env}$ on tomato fruit growth rate can be described by the water potential gradient between the plant and the fruit ($\Delta\Psi^{plant-fruit}$), which is the driving force for water import into the fruit. If we assume Ψ_{π}^{fruit} to be indicative for Ψ^{fruit} , the relations as presented in Figures 1 and 6 describe the effect of a change in $\Psi^{root\ env}$ on $\Delta\Psi^{plant-fruit}$ at the moment of change and during subsequent development. Combined with knowledge of the 'standard' growth curve we simulated the response of fruit growth (rate) on a sudden change in $\Psi^{root\ env}$ from -0.07 to -0.43 MPa (Figure 7). The synthesis of the effects of root environment with those of the aerial environment will provide a description of the dynamics of plant water relations (Marcelis, 1989). Quantitative knowledge of these effects and of the relationship between water relations and fruit growth and quality parameters (like size, DMC and Ψ_{π}^{fruit}) will make it feasible not only to predict effects of root environment, but also to optimise root (and aerial) climate in terms of fruit growth and quality.

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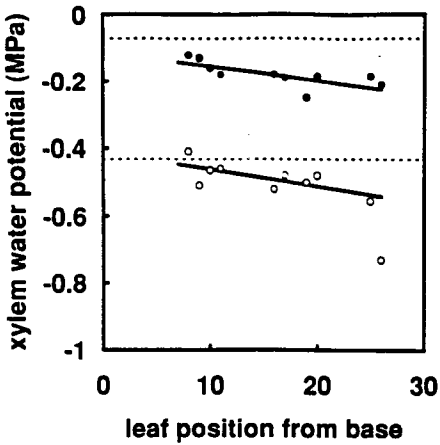


Figure 1 - Xylem water potential of leaves at various positions of the stem at -0.07 MPa (upper line) and at -0.43 MPa (lower line) root environment water potential. Dashed lines represent the applied levels of root environment water potential

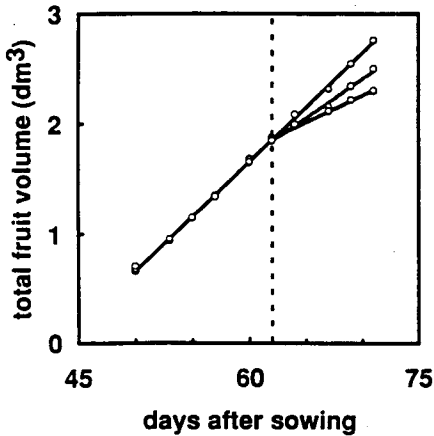


Figure 3 - Time course of total fruit volume for a single plant. At 62 days after sowing the root environment water potential was changed from -0.07 MPa to -0.22 (upper), to -0.32 (middle) and to -0.43 MPa (lower line)

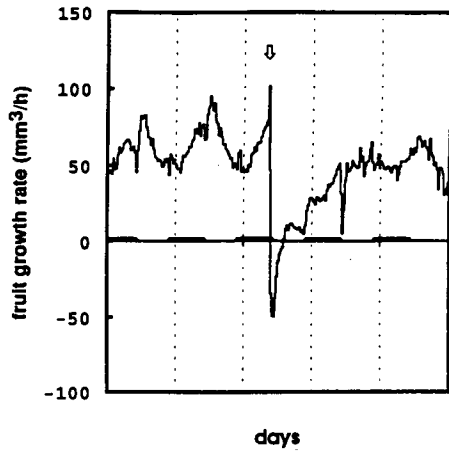


Figure 2 - Diurnal courses of individual fruit growth rate on five successive days (— is dark period). The ↓ indicates the change of root environment water potential from -0.07 to -0.43 MPa

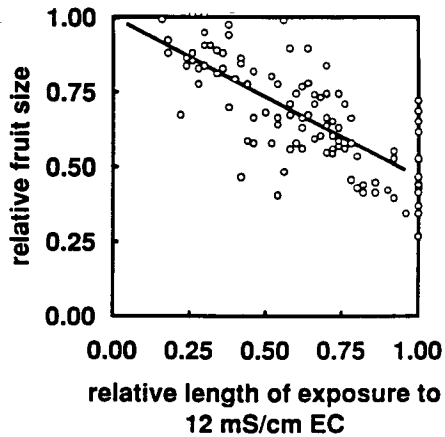


Figure 4 - Relative fruit size at harvest as affected by relative length of growth period (relative to total duration of development) at -0.43 MPa root environment water potential ($r=0.76$)

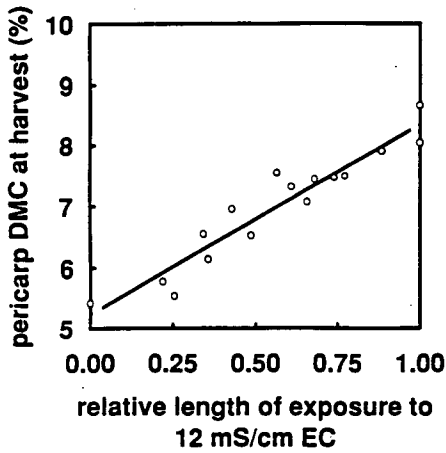


Figure 5 - Pericarp dry matter content (DMC) as affected by the relative length of growth period at -0.43 MPa root environment water potential ($r=0.95$)

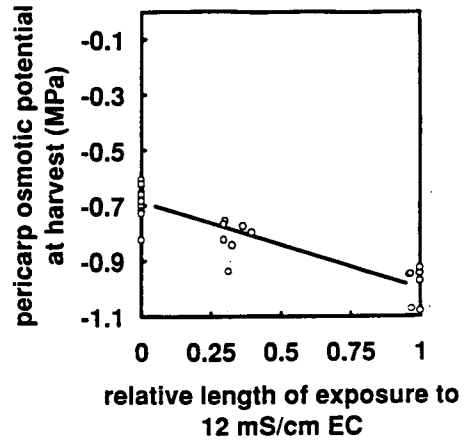


Figure 6 - Pericarp osmotic potential as affected by the relative length of growth period at -0.43 MPa root environment water potential ($r=0.91$)

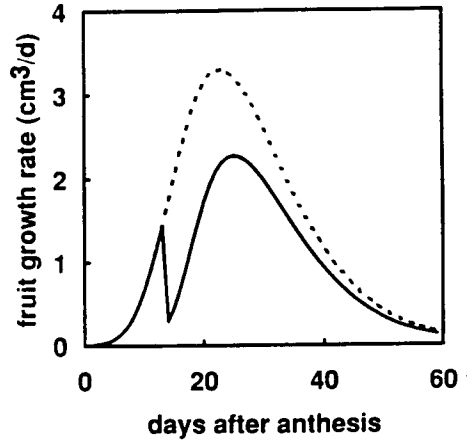
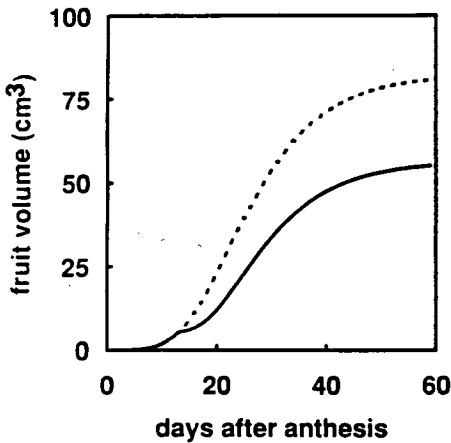


Figure 7 - Simulated single fruit volume and fruit growth rate from anthesis to harvest as affected by a change in root environment water potential from -0.07 to -0.43 MPa at 14 days after anthesis (—), compared to the control at -0.07 MPa (---)