

COMBINED EFFECT OF CLIMATE AND CONCENTRATION OF THE NUTRIENT SOLUTION ON A GREENHOUSE TOMATO CROP. I: VEGETATIVE GROWTH

C. Stanghellini, W.Th.M. van Meurs, L. Simonse and J. van Gaalen
Institute of Agricultural and Environmental Engineering (IMAG-DLO)
P.O.Box 43, 6700 AA Wageningen, The Netherlands

Keywords: waste water, EC-salinity, leaf development, water uptake, humidity, transpiration, blossom-end rot

Abstract

Growing systems that recirculate the nutrient solution are attractive, because they couple saving of water and fertilizers with decreased leaching. However, the longer irrigation water is collected and re-used, the higher the concentration of salts. Maintaining the EC of the nutrient solution within (conservative) boundaries requires flushing rates of 30% or more, in spite of the recirculating facilities. In order to determine the processes responsible for the reduction of fresh yield, that is often the consequence of growth under salinity stress, we investigated the effect on vegetative growth of a tomato crop, of high EC in combination with two water uptake rates. Associated yield and yield quality data are presented in the second paper of this series.

Climate in two identical glasshouses was controlled to maintain a constant ratio (65%) of potential evaporation, while preserving equal assimilation levels. Half of the rows in each house were given a 2 dS/m treatment in the root medium whereas the other half were given 10 dS/m. Leaf growth, canopy development and fresh and dry yield were traced during a whole spring growing season. No effect of the climate treatment could be detected in leaf area or leaf shape. High salinity, on the other hand, reduced total leaf area by ca. 15%, through a prompt reduction of leaf expansion. Reduction in light interception was smaller, so that there was no detectable cut back of dry matter accumulation in the fruits.

1. Introduction

Re-use of drained irrigation water in protected cultivation leads to accumulation of nutrients and other ions. A high solute content is known to reduce yield (e.g. Sonneveld, 1988) and is related to some fruit disorders (for instance, Adams and Ho, 1992; Ho *et al.*, 1993; Willumsen *et al.*, 1996). However, high salinity is also believed to improve quality of fruits (Matan and Golan, 1988; van Ieperen, 1996). Weather/climate conditions during growth are suspected to modulate all above mentioned effects (for instance, Bradfield and Guttridge, 1984 and Banuelos *et al.*, 1985). Hence, an appropriate use of available tools for manipulating indoor climate, could mitigate the effect of a high salinity of irrigation water and possibly offset a decrease in yield by an increment in quality of the product. Such a cost-benefit balance, requires some insight into the crop response to both salinity and selected factors of the climate within the house.

The interaction between climate (potential evaporation in particular) and salinity in determining amount and quality of production of a greenhouse tomato crop is the subject of

shown in *Fig. 2*. Leaf pruning was started on February 15th, and performed according to common practice. By March 15, the oldest leaves still remaining were fully grown in all treatments, and data thereafter were fitted by the decreasing sigmoid alone (*Fig. 3*).

Individual leaf area, A , was calculated from length and width, l and w (m), Eq.(1), by an adaptation of a formula empirically determined by Van Der Varst and Postel (1972):

$$A = \frac{0.25l.w}{1-1.48l.w} \quad \text{m}^2 \quad (2)$$

The product $l \cdot w$ was used, instead of l^2 of the original formula (l and w of tomato leaves are nearly equal), in order to account for possible morphological differences between treatments.

3. Results

No significant differences were detected in the aspect ratio (w_M/l_M , the best-fitted dimensions of fully expanded leaves), that was always and in all treatments very close to 1. On the other hand, measured w/l of not fully-expanded leaves was less than 0.9, which suggests that leaves expand in width after reaching full length. The trend of l_M during the season is shown in *Fig. 4* for all treatments. Obviously a figure with w_M instead of l_M would be quite similar. The effect of the salinity treatment is evident, whereas the climate treatment hardly has any effect, at both EC levels. The profile of the areas, calculated by means of Eq.(2) for the leaves after full expansion, is shown in *Fig. 5*. When the treatments were started, the 15th leaf was fully expanded and the 20th was present in all cases. Increased EC reduced leaf expansion without delay. Maximum dimensions had a decreasing trend also in the low EC treatments (*Figs. 4 and 5*) and the effect of the EC treatment tended to attenuate.

Obviously, there is no significant difference between the climate treatments, neither with respect to leaf expansion, nor to leaf area. *Fig. 6* shows the total leaf area (not accounting for leaf pruning) produced by plants in each treatment. Points are cumulated values calculated by means of Eq.(2), and the lines are fitted polynomials. The two low EC treatments accumulated almost exactly 4 m² and the other two 3.4 m². As leaves were pruned according to common practice, actual leaf area peaked in the first week of April, at 2 and 1.4 m²/plant, for the low and high EC treatments, LAI = 4.4 and 3.1, respectively.

Both high EC treatments had a daytime water uptake rate that was about 10% less than the uptake of the low EC section of the same compartment (only daytime readings were used, as nighttime values are affected by a relatively large error, due to the hours of recirculation, compared with the small uptake). This would imply that water uptake per unit leaf area was unaffected by EC, within the margin of the accuracy of estimate, both of leaf area and water uptake.

4. Discussion

To our present knowledge, there have been no previous experiments where potential evaporation (and not a particular climate factor or a particular water supply) was a treatment. Accordingly, it is not obvious how the present results may be placed within the framework of existing knowledge. In fact, given the constraints on both radiation (unchanged) and temperature (affected as little as possible), the present climate treatment was essentially a humidity treatment, albeit not a *constant* humidity (nor vapour pressure deficit, VPD)

treatment. Mean values of VPD for the two treatments were 0.5 and 0.3 kPa. Within this range, no effect of "humidity" on leaf growth or yield (the latter only in the low EC treatment, Stanghellini *et al.*, 1997) was detected. Holder and Cockshull (1990) had a significant reduction in the area of leaves expanding at the time VPD was decreased from 0.8 to 0.1 kPa. Interpolation of their data for our VPD range, points to a reduction of 20% in the area of the most affected leaves, that is not to be found in our data. Bakker (1991) observed that transpiration (or humidity) does not affect growth, provided it is kept above a calcium deficit "threshold", that might be interesting to quantify in future research.

Actually, it is common practice among Dutch growers to invest quite a fraction of the energy they save by insulating glasshouses into climate manipulations that strive to lower ambient humidity, in the conviction that a humid environment will harm crop development. Bakker *et al.* (1994), investigated the effect (both on growth and production of tomato) of a number of such practices. On average, treatments resulting in higher humidity resulted in slightly smaller leaf area per plant, although the differences, just as in *Fig. 6*, were not statistically significant. Even then, there was no effect at all on production, a result similar to ours.

On the other hand, there is little doubt that high salinity reduces leaf area, ca. 15% in our case. Also Willumsen *et al.* (1996) observed a significant decrease in leaf length of tomatoes in high EC treatments, although fresh weight of mature leaves did not appear to be reduced. From the model presented in *Fig. 1* of Stanghellini and De Jong (1995) it can be estimated that decreasing LAI by 30% from 4.5 would lessen shortwave absorption of a canopy, with a row-crop configuration similar to the present one, by only 10%. Accordingly, any reduction in assimilation due to the reduced leaf area in the high salinity treatment must have been small. Indeed, yield dry matter accumulation in our experiment, *Fig. 7*, was not affected by any treatment (except for the incidence of blossom-end rot in the high EC-high transpiration treatment). This is consistent with the findings of Adams and Holder (1992) that both high humidity and high salinity decreased dry weight of leaves but did not reduce dry matter accumulation in the fruit. In fact, Ehret and Ho (1986) speculated that the allocation of assimilates to fruits is less sensitive to a reduction in supply than allocation to leaves.

5. Conclusion

Apparently, there is no direct effect of potential evaporation on leaf growth, in the range explored by this research, that is, transpiration levels above those that cause visual symptoms of calcium deficiency or the onset of botrytis, and below those that cause water stress. On the other hand, a high salinity immediately reduced leaf expansion and resulted in 15% less leaf area per plant. Water uptake was reduced by a similar amount, suggesting that plants were transpiring at the "potential" rate. Fresh yield, but not dry matter yield, was reduced by high EC (Stanghellini *et al.*, 1997).

6. Acknowledgments

The present research was funded by: European Union shared costs research contract (AIR-CT93-1603) "Management and control for quality of greenhouses (MACQU)"; Dutch-Israeli Agricultural Research Program (DIARP 95/11) "Optimization of fruit quality of greenhouse pepper and tomato by manipulating transpiration and solute content". Matching funds from

Dutch Agricultural Research Department (DLO programme 217) "Plant physiology, produce formation and quality of protected horticultural crops". The contribution of Ferry Corver and Henk Scholten to the daily running of the experiment has made it possible. The help of Rein Bijkerk with the data management is gratefully acknowledged.

7. References

- Adams, P. & L.C. Ho, 1992. The susceptibility of modern tomato cultivars to blossom-end rot, in relation to salinity. *J. Hort. Science*, 67: 827-839.
- Adams, P. & R. Holder, 1992. Effects of humidity, Ca and salinity on the accumulation of dry matter and Ca by the leaves and fruit of tomato (*Lycopersicon esculentum*). *J. Hort. Science*, 67: 137-142.
- Bakker, J.C., 1991. Analysis of humidity effects on growth and production of glasshouse fruits vegetables. PhD dissertation, Agricultural University, Wageningen, 155 pp.
- Bakker, J.C., R. De Graaf & J. Janse, 1994. Onderzoek minimale transpiratie in relatie tot energieverbruik, produktie en kwaliteit van glastuinbouwgewassen. Internal report, Glasshouse crops Research Station, Naaldwijk: 34 pp.
- Banuelos, G.S., G.P. Offerman & E.C. Seim, 1985. High relative humidity promotes blossom-end rot on growing tomato. *HortScience*, 20(5): 894-895.
- Bradfield, E.G. & C.G. Guttridge, 1984. Effects of night-time humidity and nutrient solution concentration on the calcium content of tomato fruit. *Scientia Horticulturae*, 22: 207-217.
- Ehret, D.L., & L.C. Ho, 1986. The effects of salinity on dry matter partitioning and fruit growth in tomatoes grown in nutrient film culture. *J. Hort. Science*, 61: 361-367.
- Ho, L.C., R. Belda, M. Brown, J. Andrews & P. Adams, 1993. Uptake and transport of calcium and the possible causes of blossom-end rot in tomato. *J. Exptl. Botany*, 44: 509-518.
- Holder, R. & K.E. Cockshull, 1990. Effects of humidity on the growth and yield of glasshouse tomatoes. *J. Hort. Science*, 65: 31-39.
- Matan, E. & R. Golan, 1988. A saline irrigation regime for improving fruit quality without reducing yield. *J. Am. Soc. Hort. Science*, 113: 202-205.
- Sonneveld, C., 1988. The salt tolerance of greenhouse crops. *Neth. J. Agric. Science*, 36:63-73.
- Stanghellini, C., 1987. Transpiration of greenhouse crops: an aid to climate management. PhD dissertation, Agricultural University, Wageningen, 150 pp.
- Stanghellini, C & W.T.M. Van Meurs, 1992. Environmental control of greenhouse crops transpiration. *J. Agric. Engng. Res.*, 51: 297-311.
- Stanghellini, C. & T. De Jong, 1995. A model of humidity and its applications in a greenhouse. *Agric. For. Meteorol.*, 76: 129-148.
- Stanghellini C., W.T.M. Van Meurs, F.J.M. Corver, E. Van Dulleme & L. Simonse, 1997. Combined effect of climate and concentration of the nutrient solution on a greenhouse tomato crop. II: Yield quantity and quality. *Acta Horticulturae*, present issue.
- Van Der Varst, P.G.I. & J.D.G. Postel, 1972. Bepaling bladoppervlak van tomatenplanten. ITT, Wageningen, report 46: 36 pp.
- Van Ieperen, W., 1996. Effects of different day and night salinity levels on vegetative growth, yield and quality of tomato. *J. Hort. Science*, 71: 99-111.
- Willumsen, J., K.K. Petersen & K. Kaack, 1996. Yield and blossom-end rot of tomato as affected by salinity and cation activity ratios in the root zone. *J. Hort. Science*, 81-98.

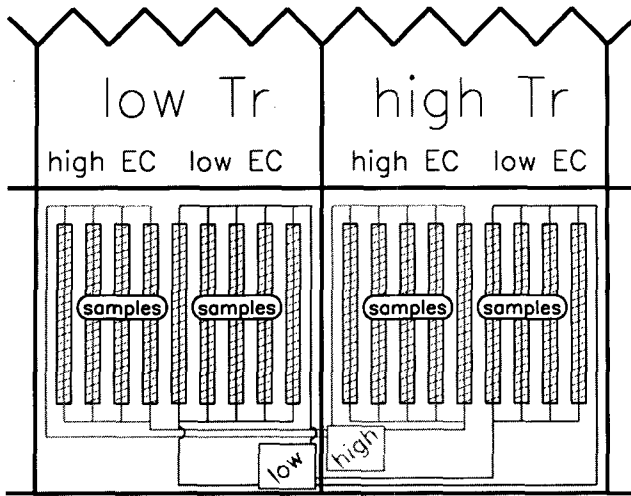


Figure 1. Schematic representation of the experimental set-up. "low Tr" and "high Tr" stand respectively for low and high [potential] transpiration. Low and high EC solutions were recirculated as schematically shown. For 7 plant per treatment, randomly selected within the rows marked with "samples", leaf development was monitored.

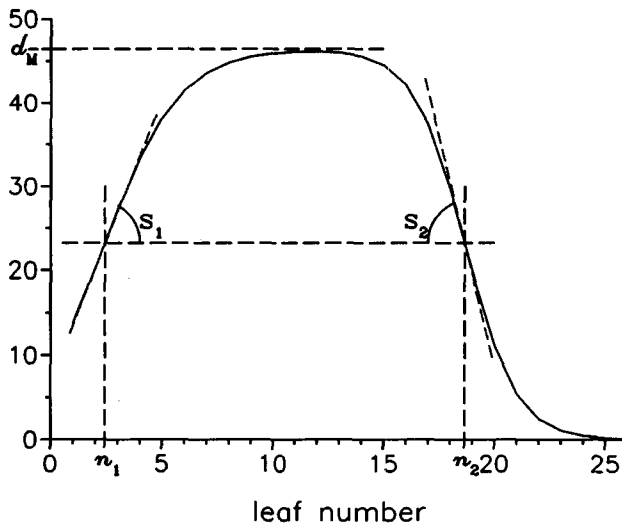


Figure 2. Illustration of the parameters of the curve, Eq.(1), used for best-fitting the measured leaf dimensions. Six weeks after starting the measurements and four weeks after starting leaf pruning, the oldest leaves present were fully grown in all treatments, and only the decreasing sigmoid (d_M , n_2 and s_2) was fitted.

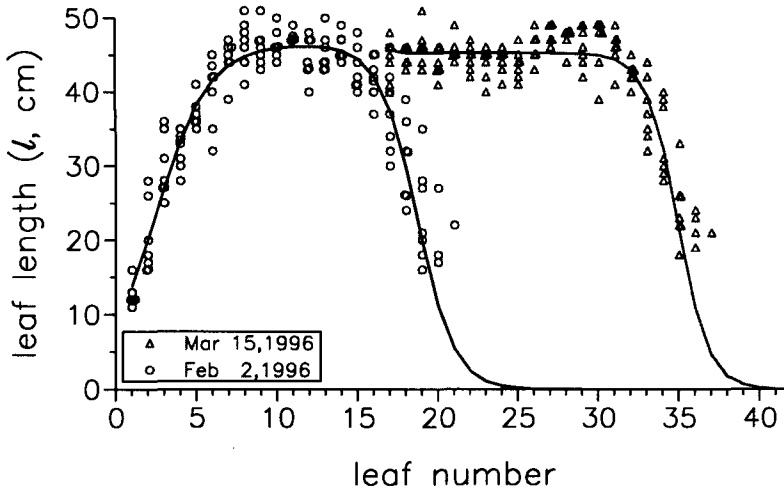


Figure 3. Measured leaf length vs leaf number, on two days, of the 7 sample plants in the low transpiration, low EC treatment. The corresponding fit-lines, Eq.(1), are also shown.

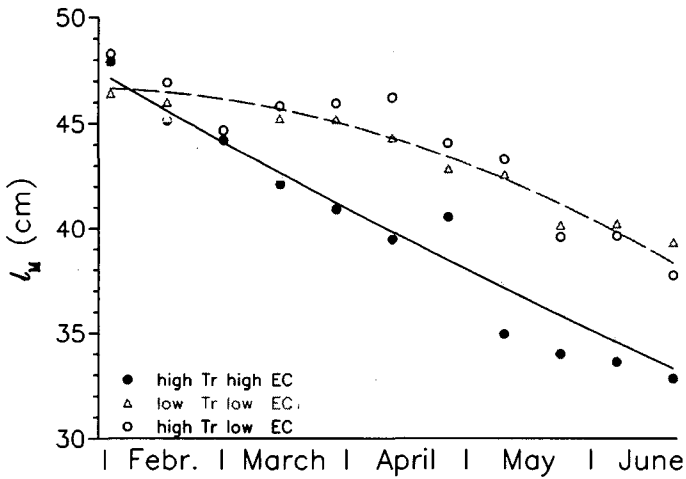


Figure 4. Best-fitted maximum length of the leaves (l_M of Eq.(1)), for each day that measurements were taken. The curves are quadratic polynomials drawn for the low and high EC treatments, respectively, taken together.

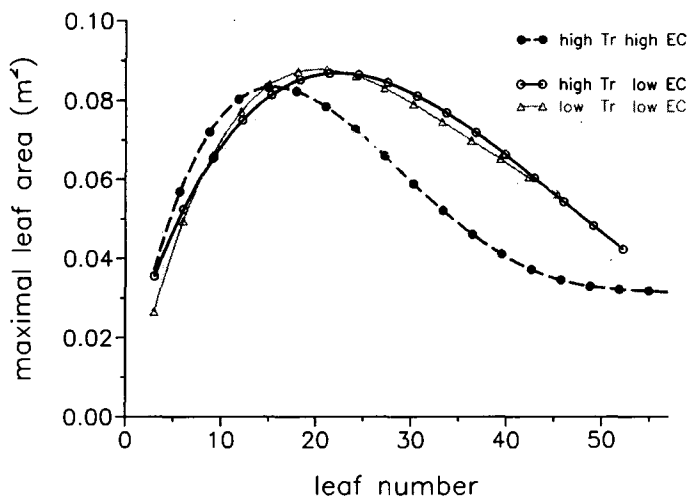


Figure 5. Maximum area extension reached by each leaf, for all treatments. Leaf 15 was fully expanded, and leaf 20 was present in all cases, when the treatments were started. The curves for each treatment are drawn up to the leaf that was expanded to within 2% of l_M at the end of the experiment, as can be calculated by the fitted coefficients of Eq(1). For clarity, not the data but the 4th degree best-fit polynomials are shown.

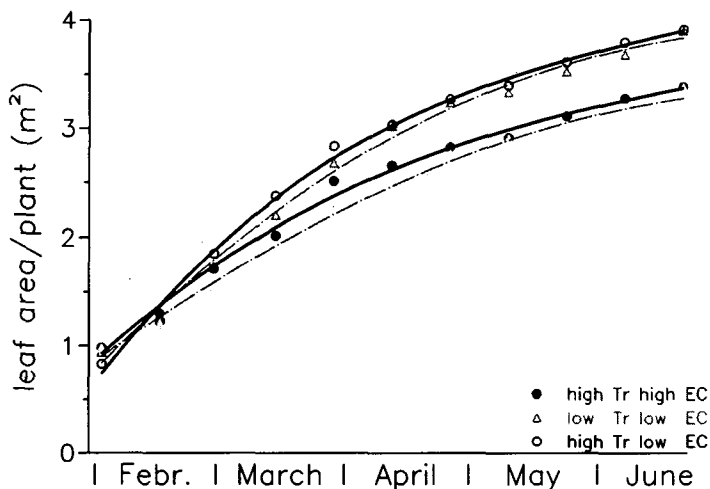


Figure 6. Total leaf area per plant. Points are means of areas calculated from the measured dimensions, and lines are best-fit polynomials

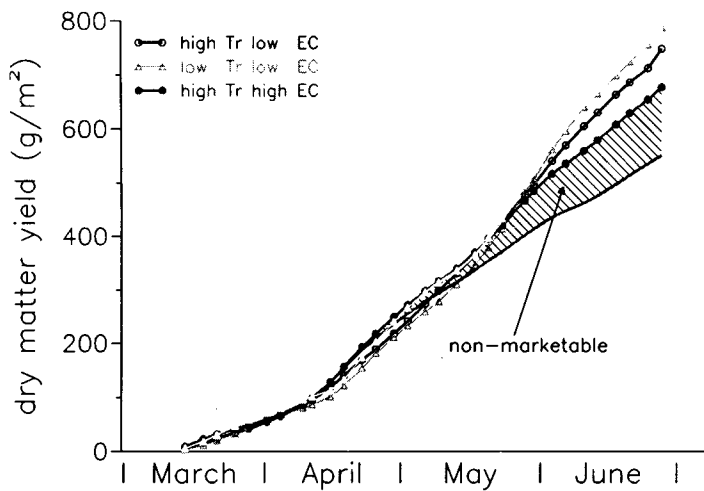


Figure 7. Total dry matter production (dry matter fraction of fresh yield) of the four treatments. The shaded parts represent yield that was unmarketable, due to blossom-end rot.

COMBINED EFFECT OF CLIMATE AND CONCENTRATION OF THE NUTRIENT SOLUTION ON A GREENHOUSE TOMATO CROP. I: VEGETATIVE GROWTH

C. Stanghellini, W.Th.M. van Meurs, L. Simonse and J. van Gaalen
Institute of Agricultural and Environmental Engineering (IMAG-DLO)
P.O.Box 43, 6700 AA Wageningen, The Netherlands

Keywords: waste water, EC-salinity, leaf development, water uptake, humidity, transpiration, blossom-end rot

Abstract

Growing systems that recirculate the nutrient solution are attractive, because they couple saving of water and fertilizers with decreased leaching. However, the longer irrigation water is collected and re-used, the higher the concentration of salts. Maintaining the EC of the nutrient solution within (conservative) boundaries requires flushing rates of 30% or more, in spite of the recirculating facilities. In order to determine the processes responsible for the reduction of fresh yield, that is often the consequence of growth under salinity stress, we investigated the effect on vegetative growth of a tomato crop, of high EC in combination with two water uptake rates. Associated yield and yield quality data are presented in the second paper of this series.

Climate in two identical glasshouses was controlled to maintain a constant ratio (65%) of potential evaporation, while preserving equal assimilation levels. Half of the rows in each house were given a 2 dS/m treatment in the root medium whereas the other half were given 10 dS/m. Leaf growth, canopy development and fresh and dry yield were traced during a whole spring growing season. No effect of the climate treatment could be detected in leaf area or leaf shape. High salinity, on the other hand, reduced total leaf area by ca. 15%, through a prompt reduction of leaf expansion. Reduction in light interception was smaller, so that there was no detectable cut back of dry matter accumulation in the fruits.

1. Introduction

Re-use of drained irrigation water in protected cultivation leads to accumulation of nutrients and other ions. A high solute content is known to reduce yield (e.g. Sonneveld, 1988) and is related to some fruit disorders (for instance, Adams and Ho, 1992; Ho *et al.*, 1993; Willumsen *et al.*, 1996). However, high salinity is also believed to improve quality of fruits (Matan and Golan, 1988; van Ieperen, 1996). Weather/climate conditions during growth are suspected to modulate all above mentioned effects (for instance, Bradfield and Guttridge, 1984 and Banuelos *et al.*, 1985). Hence, an appropriate use of available tools for manipulating indoor climate, could mitigate the effect of a high salinity of irrigation water and possibly offset a decrease in yield by an increment in quality of the product. Such a cost-benefit balance, requires some insight into the crop response to both salinity and selected factors of the climate within the house.

The interaction between climate (potential evaporation in particular) and salinity in determining amount and quality of production of a greenhouse tomato crop is the subject of

shown in *Fig. 2*. Leaf pruning was started on February 15th, and performed according to common practice. By March 15, the oldest leaves still remaining were fully grown in all treatments, and data thereafter were fitted by the decreasing sigmoid alone (*Fig. 3*).

Individual leaf area, A , was calculated from length and width, l and w (m), Eq.(1), by an adaptation of a formula empirically determined by Van Der Varst and Postel (1972):

$$A = \frac{0.25l.w}{1-1.48l.w} \quad \text{m}^2 \quad (2)$$

The product $l \cdot w$ was used, instead of l^2 of the original formula (l and w of tomato leaves are nearly equal), in order to account for possible morphological differences between treatments.

3. Results

No significant differences were detected in the aspect ratio (w_M/l_M , the best-fitted dimensions of fully expanded leaves), that was always and in all treatments very close to 1. On the other hand, measured w/l of not fully-expanded leaves was less than 0.9, which suggests that leaves expand in width after reaching full length. The trend of l_M during the season is shown in *Fig. 4* for all treatments. Obviously a figure with w_M instead of l_M would be quite similar. The effect of the salinity treatment is evident, whereas the climate treatment hardly has any effect, at both EC levels. The profile of the areas, calculated by means of Eq.(2) for the leaves after full expansion, is shown in *Fig. 5*. When the treatments were started, the 15th leaf was fully expanded and the 20th was present in all cases. Increased EC reduced leaf expansion without delay. Maximum dimensions had a decreasing trend also in the low EC treatments (*Figs. 4 and 5*) and the effect of the EC treatment tended to attenuate.

Obviously, there is no significant difference between the climate treatments, neither with respect to leaf expansion, nor to leaf area. *Fig. 6* shows the total leaf area (not accounting for leaf pruning) produced by plants in each treatment. Points are cumulated values calculated by means of Eq.(2), and the lines are fitted polynomials. The two low EC treatments accumulated almost exactly 4 m² and the other two 3.4 m². As leaves were pruned according to common practice, actual leaf area peaked in the first week of April, at 2 and 1.4 m²/plant, for the low and high EC treatments, LAI = 4.4 and 3.1, respectively.

Both high EC treatments had a daytime water uptake rate that was about 10% less than the uptake of the low EC section of the same compartment (only daytime readings were used, as nighttime values are affected by a relatively large error, due to the hours of recirculation, compared with the small uptake). This would imply that water uptake per unit leaf area was unaffected by EC, within the margin of the accuracy of estimate, both of leaf area and water uptake.

4. Discussion

To our present knowledge, there have been no previous experiments where potential evaporation (and not a particular climate factor or a particular water supply) was a treatment. Accordingly, it is not obvious how the present results may be placed within the framework of existing knowledge. In fact, given the constraints on both radiation (unchanged) and temperature (affected as little as possible), the present climate treatment was essentially a humidity treatment, albeit not a *constant* humidity (nor vapour pressure deficit, VPD)

treatment. Mean values of VPD for the two treatments were 0.5 and 0.3 kPa. Within this range, no effect of "humidity" on leaf growth or yield (the latter only in the low EC treatment, Stanghellini *et al.*, 1997) was detected. Holder and Cockshull (1990) had a significant reduction in the area of leaves expanding at the time VPD was decreased from 0.8 to 0.1 kPa. Interpolation of their data for our VPD range, points to a reduction of 20% in the area of the most affected leaves, that is not to be found in our data. Bakker (1991) observed that transpiration (or humidity) does not affect growth, provided it is kept above a calcium deficit "threshold", that might be interesting to quantify in future research.

Actually, it is common practice among Dutch growers to invest quite a fraction of the energy they save by insulating glasshouses into climate manipulations that strive to lower ambient humidity, in the conviction that a humid environment will harm crop development. Bakker *et al.* (1994), investigated the effect (both on growth and production of tomato) of a number of such practices. On average, treatments resulting in higher humidity resulted in slightly smaller leaf area per plant, although the differences, just as in *Fig. 6*, were not statistically significant. Even then, there was no effect at all on production, a result similar to ours.

On the other hand, there is little doubt that high salinity reduces leaf area, ca. 15% in our case. Also Willumsen *et al.* (1996) observed a significant decrease in leaf length of tomatoes in high EC treatments, although fresh weight of mature leaves did not appear to be reduced. From the model presented in *Fig. 1* of Stanghellini and De Jong (1995) it can be estimated that decreasing LAI by 30% from 4.5 would lessen shortwave absorption of a canopy, with a row-crop configuration similar to the present one, by only 10%. Accordingly, any reduction in assimilation due to the reduced leaf area in the high salinity treatment must have been small. Indeed, yield dry matter accumulation in our experiment, *Fig. 7*, was not affected by any treatment (except for the incidence of blossom-end rot in the high EC-high transpiration treatment). This is consistent with the findings of Adams and Holder (1992) that both high humidity and high salinity decreased dry weight of leaves but did not reduce dry matter accumulation in the fruit. In fact, Ehret and Ho (1986) speculated that the allocation of assimilates to fruits is less sensitive to a reduction in supply than allocation to leaves.

5. Conclusion

Apparently, there is no direct effect of potential evaporation on leaf growth, in the range explored by this research, that is, transpiration levels above those that cause visual symptoms of calcium deficiency or the onset of botrytis, and below those that cause water stress. On the other hand, a high salinity immediately reduced leaf expansion and resulted in 15% less leaf area per plant. Water uptake was reduced by a similar amount, suggesting that plants were transpiring at the "potential" rate. Fresh yield, but not dry matter yield, was reduced by high EC (Stanghellini *et al.*, 1997).

6. Acknowledgments

The present research was funded by: European Union shared costs research contract (AIR-CT93-1603) "Management and control for quality of greenhouses (MACQU)"; Dutch-Israeli Agricultural Research Program (DIARP 95/11) "Optimization of fruit quality of greenhouse pepper and tomato by manipulating transpiration and solute content". Matching funds from

Dutch Agricultural Research Department (DLO programme 217) "Plant physiology, produce formation and quality of protected horticultural crops". The contribution of Ferry Corver and Henk Scholten to the daily running of the experiment has made it possible. The help of Rein Bijkerk with the data management is gratefully acknowledged.

7. References

- Adams, P. & L.C. Ho, 1992. The susceptibility of modern tomato cultivars to blossom-end rot, in relation to salinity. *J. Hort. Science*, 67: 827-839.
- Adams, P. & R. Holder, 1992. Effects of humidity, Ca and salinity on the accumulation of dry matter and Ca by the leaves and fruit of tomato (*Lycopersicon esculentum*). *J. Hort. Science*, 67: 137-142.
- Bakker, J.C., 1991. Analysis of humidity effects on growth and production of glasshouse fruits vegetables. PhD dissertation, Agricultural University, Wageningen, 155 pp.
- Bakker, J.C., R. De Graaf & J. Janse, 1994. Onderzoek minimale transpiratie in relatie tot energieverbruik, produktie en kwaliteit van glastuinbouwgewassen. Internal report, Glasshouse crops Research Station, Naaldwijk: 34 pp.
- Banuelos, G.S., G.P. Offerman & E.C. Seim, 1985. High relative humidity promotes blossom-end rot on growing tomato. *HortScience*, 20(5): 894-895.
- Bradfield, E.G. & C.G. Guttridge, 1984. Effects of night-time humidity and nutrient solution concentration on the calcium content of tomato fruit. *Scientia Horticulturae*, 22: 207-217.
- Ehret, D.L., & L.C. Ho, 1986. The effects of salinity on dry matter partitioning and fruit growth in tomatoes grown in nutrient film culture. *J. Hort. Science*, 61: 361-367.
- Ho, L.C., R. Belda, M. Brown, J. Andrews & P. Adams, 1993. Uptake and transport of calcium and the possible causes of blossom-end rot in tomato. *J. Exptl. Botany*, 44: 509-518.
- Holder, R. & K.E. Cockshull, 1990. Effects of humidity on the growth and yield of glasshouse tomatoes. *J. Hort. Science*, 65: 31-39.
- Matan, E. & R. Golan, 1988. A saline irrigation regime for improving fruit quality without reducing yield. *J. Am. Soc. Hort. Science*, 113: 202-205.
- Sonneveld, C., 1988. The salt tolerance of greenhouse crops. *Neth. J. Agric. Science*, 36:63-73.
- Stanghellini, C., 1987. Transpiration of greenhouse crops: an aid to climate management. PhD dissertation, Agricultural University, Wageningen, 150 pp.
- Stanghellini, C & W.T.M. Van Meurs, 1992. Environmental control of greenhouse crops transpiration. *J. Agric. Engng. Res.*, 51: 297-311.
- Stanghellini, C. & T. De Jong, 1995. A model of humidity and its applications in a greenhouse. *Agric. For. Meteorol.*, 76: 129-148.
- Stanghellini C., W.T.M. Van Meurs, F.J.M. Corver, E. Van Dullemeijer & L. Simonse, 1997. Combined effect of climate and concentration of the nutrient solution on a greenhouse tomato crop. II: Yield quantity and quality. *Acta Horticulturae*, present issue.
- Van Der Varst, P.G.I. & J.D.G. Postel, 1972. Bepaling bladoppervlak van tomatenplanten. ITT, Wageningen, report 46: 36 pp.
- Van Ieperen, W., 1996. Effects of different day and night salinity levels on vegetative growth, yield and quality of tomato. *J. Hort. Science*, 71: 99-111.
- Willumsen, J., K.K. Petersen & K. Kaack, 1996. Yield and blossom-end rot of tomato as affected by salinity and cation activity ratios in the root zone. *J. Hort. Science*, 81-98.

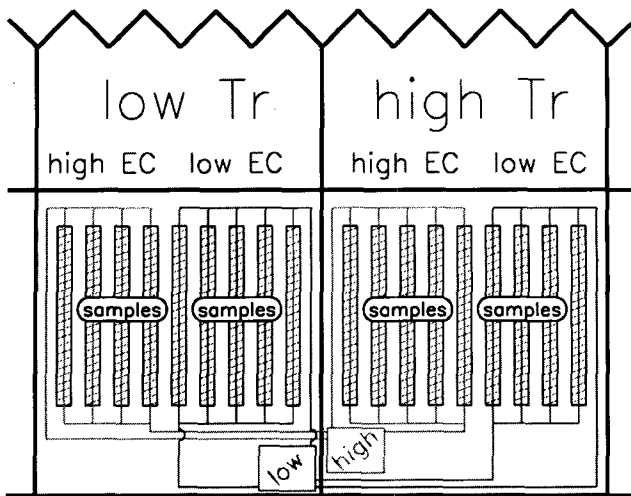


Figure 1. Schematic representation of the experimental set-up. "low Tr" and "high Tr" stand respectively for low and high [potential] transpiration. Low and high EC solutions were recirculated as schematically shown. For 7 plant per treatment, randomly selected within the rows marked with "samples", leaf development was monitored.

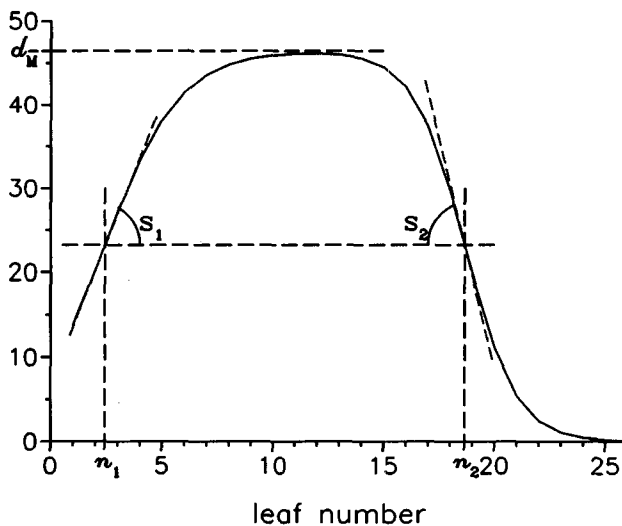


Figure 2. Illustration of the parameters of the curve, Eq.(1), used for best-fitting the measured leaf dimensions. Six weeks after starting the measurements and four weeks after starting leaf pruning, the oldest leaves present were fully grown in all treatments, and only the decreasing sigmoid (d_M , n_2 and s_2) was fitted.

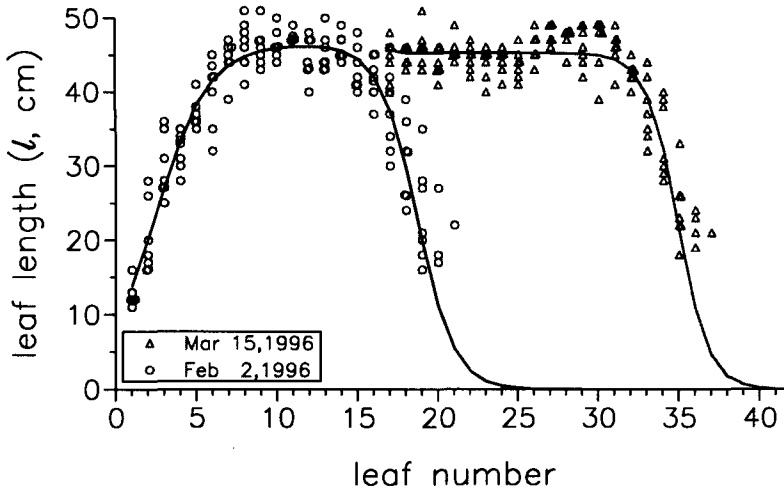


Figure 3. Measured leaf length vs leaf number, on two days, of the 7 sample plants in the low transpiration, low EC treatment. The corresponding fit-lines, Eq.(1), are also shown.

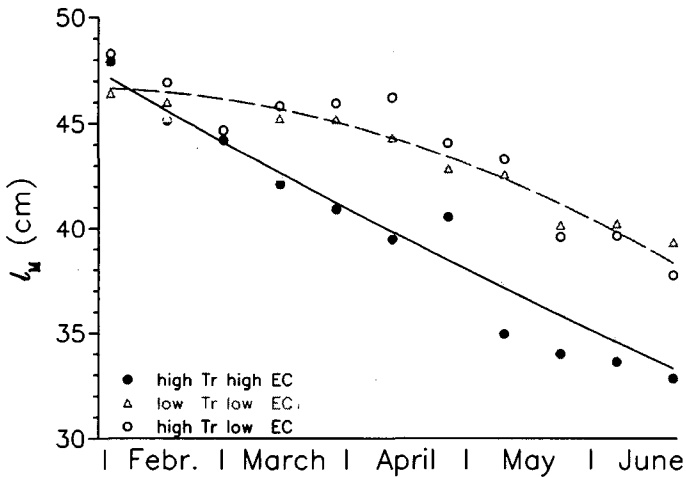


Figure 4. Best-fitted maximum length of the leaves (l_M of Eq.(1)), for each day that measurements were taken. The curves are quadratic polynomials drawn for the low and high EC treatments, respectively, taken together.

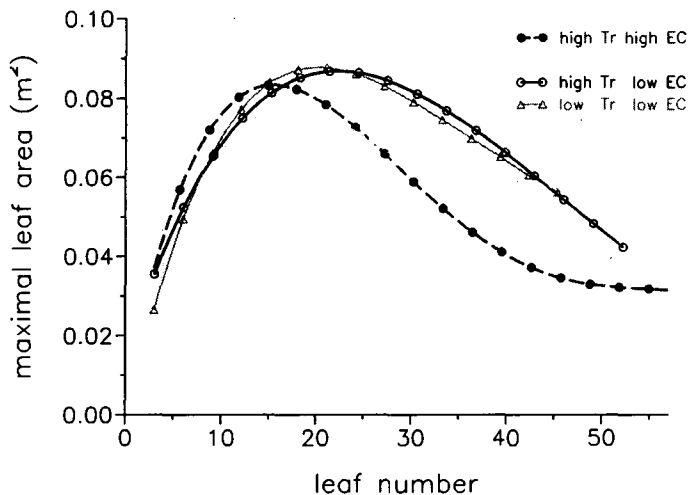


Figure 5. Maximum area extension reached by each leaf, for all treatments. Leaf 15 was fully expanded, and leaf 20 was present in all cases, when the treatments were started. The curves for each treatment are drawn up to the leaf that was expanded to within 2% of l_M at the end of the experiment, as can be calculated by the fitted coefficients of Eq(1). For clarity, not the data but the 4th degree best-fit polynomials are shown.

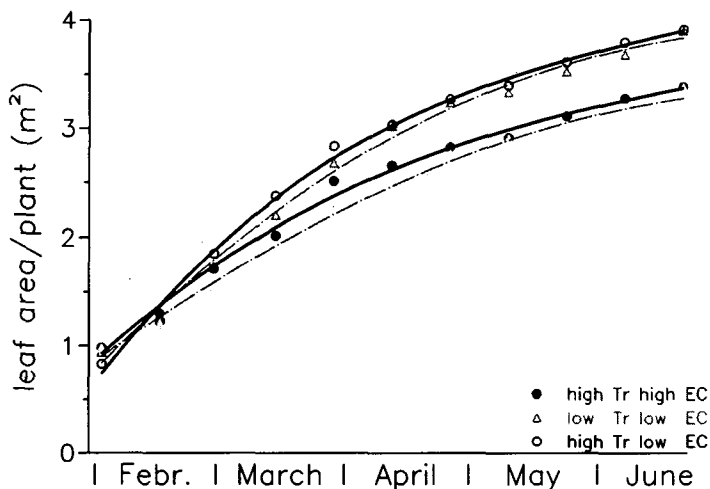


Figure 6. Total leaf area per plant. Points are means of areas calculated from the measured dimensions, and lines are best-fit polynomials

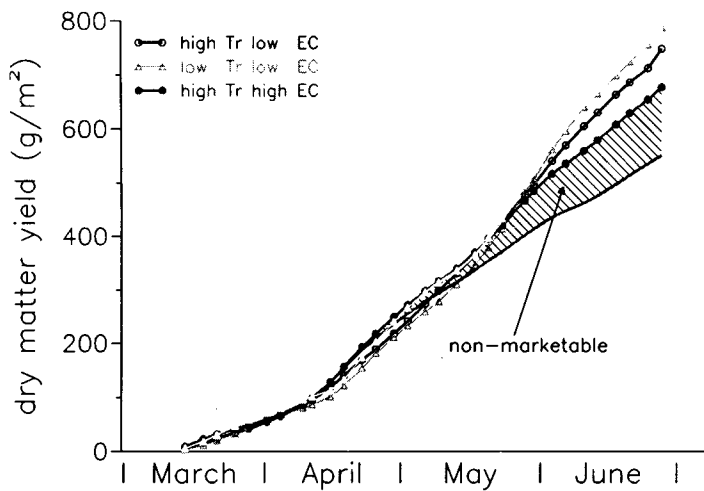


Figure 7. Total dry matter production (dry matter fraction of fresh yield) of the four treatments. The shaded parts represent yield that was unmarketable, due to blossom-end rot.