Greenhouse Tomato Production with High Saline Nutrient Solution Simulating a Re-circulating Irrigation System without Environmental Discharge

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Abstract

Increased tomato fruit quality in response to increased salinity is well documented (Li, 2000). However, the increased fruit quality is achieved at the expenses of severe yield losses mostly due to reduced fruit size (fresh weight) and increased incidence of physiological disorders such as blossom end rot (BER). The ability to minimize the negative effects of high salinity at the root level, while increasing fruit quality, through manipulation of environmental factors, which affect potential transpiration, was demonstrated.

Two greenhouse canopy environments were selected for inducing transpiration [high vapor pressure deficit (VPD) (2 kPa), and suppressing transpiration [low VPD (0.8 kPa). Fruit quality parameters from the treatment environments were contrasted with those from a standard commercial greenhouse environment in which VPD was not controlled and day-night temperature were 24ºC / 19ºC. All environmental treatments were associated with two electrical conductivities (EC) of the nutrient solution: 2.5 dS m^{-1} ($EC_{standard}$) and 8 dS m^{-1} (EC_{high}). Maximum total fresh yield and marketable yield was obtained in the standard environment under $EC_{standard}$. The major factor in changing fresh weight and BER was EC, while canopy environment affected the magnitude of the change. High EC significantly increased % Brix, acidity, and firmness, while transpiration regime seems to have no effect. Compared with the standard canopy and root environment, an increase of 5.5 dS m^{-1} in salinity at the root level resulted in a marketable yield decreased of 59%, 61% and 87% on the standard, LET_0 and HET_0, respectively. This decrease was due to a decrease in average fruit weight associated with an increase in BER incidence. This study suggests that, the decrease in marketable yield observed under high salinity conditions (whether resulting from a closed irrigation system or simply increased EC in the nutrient solution), could be minimized once associated with a canopy environment, which reduces potential transpiration. This combination, significantly reduced BER incidence.

Introduction

Assimilate distribution between vegetative organs and fruits, is dependent on the environmental conditions that govern plant water status, nutrient uptake and fruit development. Plant transpiration, reduces leaf water potential, which in turn increases the gradient of water potential between roots and leaves, thus stimulating water and nutrient uptake. Therefore transpiration is a very important physiological process for plant growth. It serves as the driving force for water transport, as well as distribution of nutrients. In Hydroponic systems nutrients are supplied diluted in irrigation water at certain target concentration. However it is common practice to irrigate with 30% more nutrient solution [or *ca* 10 to 25% more salts] (van de Vooren *et al*., 1986) to meet water demand and prevent solute accumulation in the root zone. The excess nutrient solution drains to waste, potentially polluting soil and surface water. The Netherlands

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was the first country to solve this problem by adopting a re-circulation system (closed system) within their low solar radiation climate. A closed system ensures a total reuse of water and nutrients, linking water savings with the elimination of nutrient emissions.

However, the EC at the root level tends to increase because of the imbalance of nutrients supplied to those consumed. Currently in the U.S., states such as California are following the Dutch example through the *Federal Water Pollution Control Act*, under which Hydroponic growers must cease discharge of wastewaters to surface waters according to the National Pollutant Discharge Elimination System (NPDES). Under these legal requirements, the grower needs to adapt his growing system to catch all excess drainage water for reuse, and face the real potential of crop yield losses due to salt accumulation. Greenhouse tomato research reveals that crop yield decreases with increasing salinity due to physiological fruit disorders (*e.g.* blossom-end rot) (Maas and Hoffman, 1977; Hoffman, 1986). On the other hand, important tomato quality parameters such as total soluble solids, acidity, and fruit firmness are increased by high EC. Hence the challenge is to take advantage of the fruit quality-enhancing effect of high saline solution and simultaneously reduce its negative effect in yield. Sonneveld (1988) reported a lower salt sensitivity for several species growing in a greenhouse. O'Leary (1975) found that high humidity minimized lethal levels of salinity in red kidney beans. Therefore, the major goal of this study is to develop a production system, which minimizes yield losses while optimizing fruit quality under increased nutrient solution concentration (closely related to the electrical conductivity, EC) potentially associated with re-circulating of drainage water within a production systems without discharge. Specifically this study was undertaken to evaluate: i) whether manipulation of transpiration through environmental control can minimize the negative effects of high nutrient solution salinity upon yield and BER and ii) the potential of high salinity of the nutrient solution in improving fruit quality.

This information will become increasingly important for growers in Arizona when environmental regulatory measures impose the re-use of all wastewater to reduce nutrients emission into the environment, as is already the case in the state of California. In the near future there will be increasingly high costs of compliance with federal, state, and water quality regulations imposed by local governments concerned with the environmental impact of greenhouse crop production systems. Thus, the economic vitality of the horticulture greenhouse industry in Arizona will depend on the development of practices that minimize environmental impact.

Methodology

The experiments were conducted in three, 58 m^2 compartments in a free standing A-frame greenhouse at the University of Arizona in the Controlled Environment Agriculture Program (CEAC) Tucson, Arizona. 'Rapsodie' (Rogers Seeds) tomato plants were seeded in rockwool cubes on July 17, 2003, and transferred into rockwool blocks July 28, 2003. On August 14, 2003, 288 of the most vigorous seedlings (with 5 to 6 true leaves) were transplanted into the greenhouse on rockwool slabs placed in eight 2.44 m × 0.31 m experimental blocks. Each experimental block had 2 slabs each with a total of 6 plants/slab (12 plants/experimental block). Crop density was 2.58 plants m^{-2} in North-South oriented rows. The extreme East and West blocks were guard rows and not included in the data. Plants were grown in the high wire system (Van de Vooren et al., 1986). Fruits trusses were pruned to 4 fruits per truss and all axillary shoots were removed weekly in order to maintain a single growing tip. Canopy and root environmental treatments were initiated on October 7, 2003, when plants were fully developed and already had approximately seven developed and developing fruit trusses. First ripe fruits totally developed under treatments were harvest December 4, 2004. Harvest was done once a week until January 29, 2004.

Tomato plants (cv. Rapsodie), were grown in rockwool slabs in a greenhouse with 3 separate compartments each with an individual environmental control (heating, cooling /humidification). Two different daytime potential transpiration regimes (ET_0) were selected: i) to induce transpiration (HET_0), (high VPD, 2 kPa) and ii) to suppress transpiration (LET_0), (low VPD, 0.6 kPa). Day-night air temperature was 27 ºC/18 ºC and 24 ºC /22 ºC in the HET_0 and LET_0, respectively. A third compartment served as the standard environment with day-night air temperature regime representative of the traditional environmental conditions in commercial greenhouses in the southwest USA (24 ºC /19 ºC) and VPD was not controlled. All canopy treatments were associated with two electrical conductivities (EC) of the nutrient solution: 2.5 dS m^{-1} ($EC_{standard}$) and 8 dS m^{-1} (EC_{high}). EC_{high} was achieved by addition of NaCl to the nutrient solution. Vapor pressure deficit (VPD) conditions were obtained by using a high-pressure fog system (Mee Industries Inc.) in each treatment compartment that would be actuated each time VPD fell below the set point value for each compartment. Environmental control was automated through a computer interface equipped with a Paragon system with the desired environmental strategy for cooling, humidifying, heating. To improve air temperature uniformity, a plenum was installed in all compartments along each row of plants, adjacent to their root zone. Blowers forced incoming evaporative cooling air into plenum continuously as part of the 'ventilation' mode in all compartments. In order to eliminate the effect of different temperature regimes associated with different VPD conditions, it was important to maintain a fairly constant 24-hour average air temperature among all compartments. The relatively constant 24-hour air temperature in the two treatment compartments was accomplished by incorporating a heat exchange unit after the blowers, which allowed for a net gain in absolute humidity at approximately constant air temperature. The average 24-hour air temperature was maintained nearly constant at 23 ^{o}C in the treatment compartments and at approximately 22 ^{o}C in the standard environment.

Environmental (VPD and day-night air temperature difference) and electrical conductivity (EC) treatments started 7 weeks after transplant when plants were well developed, and were maintained for a period of 15 weeks (total experimental period of 7 weeks). EC was increased from 2.5 dS m^{-1} to 8 dS m^{-1} by addition of NaCl to the nutrient solution upon start of the experiment. Fruit quality parameters were monitored weekly upon each harvest and included number, fresh and dry weight, number of blossom end rot (BER), total soluble solids (% Brix), acidity and fruit firmness. The last three parameters were measured in three fruits per experimental block (six fruits per canopy-EC treatment combination).

Results and Discussion

A summary of the environmental conditions achieved in each compartment is presented in Table 1. The mean VPD achieved for the day period with a light level above 300 µmol m^{-2} s^{-1} [corresponding to 95% of cumulative PAR (mol m^{-2} per day)], was 2.1 kPa and 0.60 kPa, for the HET_0 and LET_0 treatments, respectively. The mean VPD for the same day period in the standard environment was 1.2 kPa (table 1). During the entire experimental period the mean air temperature never exceeded 0.5 ºC and 2 ºC from the target day and nighttime temperatures, respectively.

Even though day and night temperatures differences were associated with VPD treatments, this report will focus on the effect of VPD in the results observed, since the selected combinations of the two parameters reinforce each other with respect to their effect on potential transpiration (within the range of temperatures used).

Table 1 - Average day, night and 24 hour vapor pressure deficits (VPD), and air temperature achieved for each environment during the experimental period.

	VPD ± SD (kPa)			T ± SD (º C)		
Environme	Day[1]	Night	24 hr	Day[1]	Night	24 hr
HET_0	2.1±0.36	1.34±0.32	1.67±0.42	27.5±2.3	20.0±0.5	23.7±4.2
LET_0	0.60±0.29	0.73±0.19	0.67±0.33	24.5±1.6	21.1±0.6	22.8±2.1
Standard	1.16±0.42	0.81±0.25	0.96±0.37	24.2±1.7	19.3±0.8	21.8±2.1

SD = Standard Deviation
[1] corresponding to the daytime period with light levels (PAR) > 300 µmol m^{-2} s^{-1}

The mean effects of transpiration regimes and nutrient salinity (EC) levels on fruit yield and quality parameters are presented in table 2. An increase in EC resulted in a decrease in total and marketable (fruits > 150 g) fresh weight, regardless of the transpiration regime provided. This decrease in weight under high salinity was mainly due to reduction of fruit size (table 2) in all transpirations regimes. However, under the standard and HET_0 regimes (highest VPD treatments) marketable yield loss was further enhanced by an increase in BER incidence (table 3). Specifically, a 5.5 dS m_{-}^{1} increase in nutrient solution salinity resulted in a decrease of cumulative marketable yield of 59%, 61% and 87% in the standard, LET_0, and HET_0 transpiration regimes, respectively. The percentage decrease in marketable yield per unit increase in EC above 2.5 dS m^{-1} ($EC_{standard}$), was 11% for the standard and LET_0 canopy environments and 16% for the HET_0.
Dry weight was not significantly different in all canopy and salinity treatments, which suggest that the decreased in fresh weight observed for EC_{high} is due to a reduced water flow into these fruits during development. This is accordance with the higher total soluble solutes observed for plants growing under high salinity (5.4 in EC_{high} versus 4 % Brix in $EC_{standard}$), in all transpiration regimes.

Table 2 – Mean main effects of transpiration regimes and root salinity on fruit quality parameters.

		Mean Fruit Quality Parameters ± SE						
		[1] Total FW cumulative (Kg)	[1] FW m. y. Cumulative (kg)	[1] % m. y.	[1] Total DW cumulative (Kg)	[2] % Brix	[2] pH	[2] Firmness (Kg m^{-2})
EC (dS m^{-1})	Standard	161.29±0.90^a	16.99±1.63^a	56.36±4.71^a	19.46±0.90^a	4.10±0.077^b	4.42±0.017^a	2.03±0.05^b
	High	116.32±0.68^b	6.28±0.88 ^{b}	21.55±3.89^b	17.34±0.68^a	5.38±0.068^a	4.31±0.020^b	2.26±0.06^a
Significance		***	***	***	NS	***	***	**
Canopy environment	HET_0	138.54±9.38^a	8.18±1.89^b	26.66±5.39^b	18.34±1.03^a	4.81±0.205^a	4.39±0.023^a	2.17±0.07^a
	LET_0	134.89±9.27^a	11.52±2.14^a	49.25±6.54^a	17.85±1.02^a	4.61±0.170^a	4.35±0.034^a	2.078±0.08^a
	Standard	142.98±9.36^a	15.22±2.12^a	40.96±6.09^{ab}	19.00±1.03^a	4.81±0.248^a	4.35±0.023^a	2.19±0.07^a
Significance		NS	**	**	NS	NS	NS	NS

[1] Means are weekly averages of two experimental blocks per treatment (N=12)
[2] Means are weekly averages of three fruits per experimental block per treatment (N=6)
Significant differences were determined by ANOVA followed by Tukey HSD test (α = 0.05), N = 6 for % Brix, pH and firmness
SE, Standard Error; FW, fresh weight; m. y., marketable yield.*** $p < 0.001$, ** $p < 0.01$,* $p < 0.05$, ^{NS} $p > 0.05$

Even though not statistically significant, the weekly percent average of marketable fruits grown at high salinity was the highest for LET_0 (data not shown).
This demonstrates that a reduction in air VPD, and consequent reduction of potential transpiration, is effective in alleviating the negative affect of increased salinity at the root level Furthermore, with the exception of fruit size, all other fruit quality parameters studied, were significantly improved by increased salinity [% Brix, acidity and firmness] (table 2).

BER incidence was low for all canopy treatments at $EC_{satandard}$. High salinity resulted in a significantly increased BER in all canopy treatments with a VPD > 1 KPa (standard and HET_0 regimes). However, this tendency was eliminated when high nutrient solution salinity was associated with low VPD (LET_0). This is presented in table 3.

Table 3 – Mean interactions between the effect of potential transpiration regimes and salinity at root level on the number of fruits with BER (as a percentage of total number of fruits harvested).

	EC (dS m$^{-1)}$	**Mean % Number BER Fruits** ± SE
HET_0	Standard	3.15 ± 1.39 ^{b}
	High	11.63 ± 2.54 ^{a}
LET_0	Standard	2.28 ± 1.12 ^{b}
	High	3.00 ± 1.13 ^{b}
Standard	Standard	0.64 ± 0.29 ^{b}
	High	10.25 ± 1.86 ^{a}

Means are weekly averages of two experimental blocks per treatment (N=12)
Significant differences were determined by ANOVA followed by Tukey HSD test (α = 0.05)
SE, Standard Error
^{x} Mean plant responses within a column followed by different letter are significantly different at α = 0.05

Conclusions

In semi-arid climates, vapor pressure deficit (VPD) inside the greenhouse can reach high levels, with detrimental effect on yield. The high VPD levels seem to have a negative affect on marketable yield even with standard nutrient solution salinity. This negative effect is aggravated by increased salinity at the root level.
In this study we demonstrated that the magnitude of yield loss due to reduced fruit size and BER incidence, which occur under high salinity conditions, can be significantly reduced by reducing VPD inside the greenhouse.
These results suggest that when salinity becomes an issue, as it is frequently the case in re-circulating irrigation systems, environmental control of parameters that affect transpiration is an effective tool to control yield losses, while increasing fruit quality.

This study provides potential environmental control guide lines for greenhouse closed irrigation systems with increased salinity at the root level (due to nutrient solution re-circulation without discharge). These guide lines link reduced yield loss and increased fruit quality to water and nutrient savings.