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Effect of Greenhouse Temperature on Tomato Yield and Ripening

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ABSTRACT

High fuel costs have encouraged producers of greenhouse tomato (*Solanum lycopersicum* L.) in the mid-Atlantic region to reduce air temperatures during the day. However, effects on fruit ripening and yield are not known, especially under the low light conditions found in off-season production. This 2-yr study compared fruit ripening and yield of tomato under two temperature regimes during the fall season. Two sets of 18 tomato plants, three rows of six, were grown in soilless culture under either a warm or cool temperature regime. Temperatures were similar during night hours but allowed to rise to at least 21-24 ºC in the cool greenhouse section and 23-26 ºC in the warm section, depending on daily solar heating. Mean 24 hour temperature difference between zones was less than 2 ºC. Ripe tomato fruit were harvested and weighed 3 times per week for 8 weeks and the remaining un-ripened green tomatoes were weighed at the termination of the experiment to obtain total fruit biomass. The warm zone produced significantly greater weight of ripe tomatoes (23%) than the cool zone. However, total fruit weight (ripe and green), was not significantly different. Thus, a relatively small increase in temperature (2 ºC) during the mid-day was associated with a significant increase in fruit ripening but not in total fruit weight. This study showed that greenhouse temperature could be used to better manage fruit production to match weekly market demand without affecting total fruit weight and that consistently maintaining a cool greenhouse would delay tomato ripening and likely increase the potential for plant stress due to high fruit loads remaining on the vines.

Keywords: *Solanum lycopersicum*, soilless culture, PAR, solar radiation

INTRODUCTION

Greenhouse tomato (*Solanum lycopersicum* L.) production is an important source of income for limited-resource producers in the mid-Atlantic region of the U.S.

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Tomato seeds are usually planted in the late fall and harvested in late winter through the early summer. These vine-ripened tomato fruits are often produced without the use of pesticides and marketed locally at a premium to restaurants, food retailers, and through farmer's markets. Higher energy costs during the last decade encouraged some producers to lower greenhouse day temperatures several degrees, but without knowledge of the effects of these changes on fruit ripening and yield. From work done in Quebec, Canada, Dalton (2003, 2005) recommended that day temperatures during seasons with low light intensity be set from 19 and 21 ºC, depending on the level of light intensity. Night temperatures were recommended to be 17 to 18 ºC. Cooler temperatures may affect flowering, fruit set, and fruit weight (Ercan and Vural 1994). Prior to these recommendations, many mid-Atlantic region growers had been using day temperatures several degrees higher. Both early production and high energy efficiency have been noted as important factors in greenhouse vegetable production (Zhang et al. 2010) and lowering greenhouse temperatures can save significant amounts of energy (Elings et al. 2005). Heating costs are often second only to labor costs and increases in fuel prices have created interest in maintaining the lowest possible temperature without harming fruit yields and early harvest.

Cooler greenhouse temperatures can also be used to reduce plant stress during periods of low light intensity; such as short day lengths in the winter and prolonged periods of overcast weather (Dalton 2003). However, warmer temperatures result in more rapid fruit ripening (Adams et al. 2001) and are recommended for greenhouse producers if plant vigor is good and light intensity is sufficient to support the existing fruit load (Dalton 2003). Optimal greenhouse temperature for tomato production in the mid-Atlantic region has not been established. Thus, producers rely on models developed for higher latitudes, the Netherlands and Canada.

The ability of greenhouse tomato cultivars to utilize available photosynthetically active radiation (*PAR*) has greatly increased in recent decades. Greenhouse tomato yields in the Netherlands have doubled since the 1950's due to increased photosynthesis rates and changes in plant architecture that decreased the light extinction coefficient (Higashide and Heuvelink 2009). A preliminary study of photosynthesis rates of tomato leaves (cultivar 'Trust') in a commercial Virginia greenhouse indicated lower temperatures (18 C vs. 23 C) would not greatly reduce CO_2 fixation rates at light intensities typically available in the greenhouse during fall and winter (400 *PAR*). There was no difference in CO_2 fixation rates at light intensities typically found during overcast winter days (50-100 *PAR*) (Kraemer, unpublished data). This indicated that lower greenhouse temperatures could potentially be used to reduce energy costs. The current study was initiated to compare fruit yield and ripening of tomato fruit grown in a greenhouse under two temperature regimes during the fall season. Night temperatures were the same in both treatments but maximum daytime temperatures differed by about 2 ºC. The experiment was conducted over two years, during the fall when natural light intensities were low. The results are most applicable to tomato growers in latitudes similar to the mid-Atlantic region of the U.S. and will allow these producers to better optimize their energy resources.

MATERIALS AND METHODS

The glass A-frame greenhouse (Rough Brothers, Cincinnati, OH) used in this study was located at the Randolph Farm of Virginia State University near Ettrick, VA at 37º

14' north latitude. The greenhouse had side vents, an evaporative cooling system at the intake vents, and hot-water radiator heating along the walls at roof and floor. The greenhouse contained 4 sections (6 x 15 m) that were separated by glass walls and had individual environmental controls (Growmaster Procom, Micro Grow Greenhouse Systems, Inc., Temecula, CA). The sections were aligned on an east-west axis, with the two outer sections (east and west) used in this study. Because there was a potential difference between sections in direct exposure to morning and afternoon solar radiation, the experiment was repeated a second year with the locations of the warm & cool sections reversed. In 2009, the east greenhouse section was selected as the cool zone; whereas in 2010, it was the warm zone.

Each greenhouse zone had a HOBO® Micro Station equipped with an 8-bit Temperature Smart Sensor and a Photosynthetically Active Radiation Smart Sensor (Onset Computer, Pocasset, MA). Photosynthetically Active Radiation (*PAR*) was measured in units of photons ($\mu mol \cdot m^{-2} \cdot sec^{-1}$). The temperature probes were shielded from direct sunlight and placed 4 feet off the concrete floor whereas the light sensors were horizontally leveled and placed 8 feet above the floor.

Three time intervals for temperature were used to allow for slower temperature increases from cool nights. Minimum and maximum night temperatures (sunset to sunrise) were set at 17 and 19 ºC, respectively, in both the warm and cool greenhouse zones. Morning temperatures (sunrise to 11 AM) were set at 18 and 20 ºC in the cool zone and 19 and 22 ºC in the warm zone. Mid-day temperatures (11 AM to sunset) were set at 21 and 24 ºC in the cool zone and 23 and 26 ºC in the warm zone. Actual temperatures in the greenhouse were dependent upon solar intensity and outside air temperature, with temperatures at the lower end of the range during cooler and overcast weather.

Seeds of tomato cultivar 'Trust' were sown on July 15th in both years and maintained in a climate controlled greenhouse with temperature set to 24 ºC. Tomato transplants were set into 6-inch-diameter (15 cm) plastic pots with coconut fiber media (Fiber Dust, LLC, Glastonbury, CT) and maintained until late August. They were then moved to the experimental greenhouse, divided into two equal groups of 18, and each transplanted into 5 gal (19 L) black plastic bags containing coconut fiber (EZ Gro Bags, Hydro-Gardens, Colorado Springs, CO). The plants were arranged in three rows of six plants in each of the two greenhouse temperature zones. Bags were spaced 0.7 m apart within the row and rows were spaced 1.5 m apart.

Drip irrigation of individual bags was controlled by an Orbit 4-Station Programmable Timer, model 57114 (Orbit Irrigation Products, Inc., Bountiful, UT) connected to a dual injector drip irrigation system. The injectors (DI 16; Dosatron International, Inc., Clearwater, FL) were each set to 1:100 injection ratios of two nutrient solutions: 1) 368 g of 5N-11P-26K fertilizer (Peters Professional soluble, Peters Chemical Company, Hawthorne, NJ) with micronutrients and 36.8 g magnesium sulfate per gallon, and 2) 244 g calcium nitrate and 42 g potassium nitrate per gallon. Plants were drip irrigated four times daily until leaching from the bags was observed. Tomato plants were grown as vines, attached by clips to polyester twine hanging down from an upper support beam. Side shoots were removed weekly to maintain a single vine and the twine was lowered as the plants grew. Leaves below the last truss were also removed and flowers were pollinated three times per week with an electric pollinator. Trusses were pruned to a maximum of five fruit. Ripe tomato fruit were

TABLE 1. Mean light intensity (*PAR*) in west and east greenhouse sections in years 2009 and 2010 (1 Sept. - 5 Dec.).

	2009		2010	
Time Period	West	East	West	East
12:00 AM - 4:00 AM	1	1	1	1
4:00 AM - 8:00 AM	21	22	29	36
8:00 AM - 12:00 PM	362	358	394	409
12:00 PM - 4:00 PM	359	346	446	408
4:00 PM - 8:00 PM	49	32	21	23
8:00 PM - 12:00 AM	1	1	1	1
24-h Mean	132	127	149	146

harvested three times weekly for eight weeks, from October until early December.

Tomato fruit were weighed in the greenhouse at the time of harvest. The number and weight of ripe tomato fruit, weight of green tomato fruit, and total fruit weight were compared between temperature treatments. Each of the three rows of tomato plants within a greenhouse temperature zone was treated as a replicate. Individual year and combined two-year data were analyzed using one-way analysis of variance (ANOVA) with means separated at $P \leq 0.05$ by t test, (PROC ANOVA, SAS Institute, 2009). Simple linear regression analysis was used to evaluate relationships between environmental parameters and yields over the 8 weeks of fruit harvest (PROC REG, SAS Institute, 2009).

RESULTS

Mean light intensity was similar in the two temperature zones in both years although zone 1 (west side) had slightly greater (3%) mean Photosynthetically Active Radiation (*PAR*) than zone 4 (east side) (Table 1). This difference was largely due to the western zone receiving more direct sunlight than the eastern zone in the late afternoon. Conversely, early morning sunlight was often more diffused because of higher humidity and fog. The temporal difference in light intensity between the zones created a small asymmetry, because morning mean temperatures in both zones were lower than afternoon temperatures. Thus, the zones assigned to temperature treatments were alternated the second year. Weekly mean light intensity (24-h) is provided in Tables 2 and 3 for the 8 weeks during which fruit were harvested in 2009 and 2010, respectively. Mean weekly *PAR* values ranged from 83 to 173 and were affected by both overcast weather and shortening day length. Daily mean values during this 8-week period ranged from 33 to 244 *PAR*.

Air temperature was greatest during the afternoon hours in both zones, as were the temperature differences between zones, about 2 ºC (Fig. 1). Zone temperatures were similar during the night hours, 8:00 PM to 8:00 AM. In the first year, zone 1 (warm) had a slightly warmer (0.5 ºC) night temperature due to initial differences in the calibration of the temperature sensors. Mean night temperatures during the second year were within 0.05 ºC. Mean overall temperatures were slightly cooler (1 ºC) during the second year due to generally cooler weather conditions. Overhead shade cloth was not used and inside temperatures sometimes increased beyond the cooling set points on sunny warm days, to a maximum of 29 ºC. Mean 24-h temperature was 1.5 ºC and 1.2 C higher in the warm zone than the cool zone in 2009 and 2010, respectively (Tables 2 and 3).

Tomato fruit were harvested for 8 weeks, from October 11 to Dec 05 in 2009 and from October 17 until December 10 in 2010 (Tables 2 & 3). The first harvest of ripe fruit was about a week later in 2010 than in 2009, accounting for the slightly later termination date in 2010. Ripe tomato yield increased to a maximum in the 3rd or 4th week, corresponding to the first week of November in both years. The tomato plants were fully developed by this time with each vine having 7 trusses. From this time onwards the weekly ripe fruit weight harvested was significantly correlated with mean weekly *PAR* ($r^2 = 0.25$, df = 17, F = 5.3, $P < 0.035$). The mean weekly *PAR* varied with atmospheric conditions but tended to decrease throughout the 8-wk harvest at a rate of 6.6 *PAR* per week (F = 26, df = 31, $r^2 = 0.46$, $P < 0.001$) as was expected from shortening days. Total ripe tomato fruit weight was significantly greater in the warmer than the cooler zone in both 2009 (F = 17.3; df = 1,5; $P < 0.009$) and in 2010 (F = 10.5; df = 1,5; $P < 0.032$),(Tables 4 & 5). Combined analysis of both 2009 and 2010 showed no significant interactions or year effects. Total ripe fruit weight was significantly greater (23%) in the warmer zone (F = 19.0; df = 2,8; $P < 0.049$) (Table 6). The mean weight of ripe tomato fruits was slightly greater (4%) in the warm zone (Table 6) although this difference was not significant in either year. Thus, the difference in total harvest weight of ripe tomato fruits was largely due to the 19% greater number of tomato harvested in the warm zone rather than a difference in individual fruit weight.

In contrast to the yield of ripe tomato fruit, the total weight of green tomato fruit remaining on the vine at the conclusion of the experiment was significantly greater (17 %) in the cool zone in the first year (F = 21.6; df = 1,5; $P < 0.01$) (Table 4) and greater (8 %), though not significantly so, in the second year (Table 5). The combined weight of ripe and green fruit was not significantly different between zones in either year. Total fruit weight (ripe and green) over two years was only slightly greater (1 %) in the warm zone than the cool zone (Table 6). Small differences in light intensity between the two greenhouse sections may have been responsible for a slight difference in total tomato fruit weight between the two sections. Over the two-year period, the greenhouse section with the more direct afternoon sun (zone 1) had a slightly higher mean total fruit weight, 39.3 kg vs. 38.9 kg (Table 6). However, there were no significant year effects on yield or other parameters.

DISCUSSION

Tomato requires a minimum amount of solar radiation to maintain plant vigor. Dalton (2003) estimated that it takes about 100-125 joules per cm^{-2} of energy per day for each truss of tomatoes on a vine, and an additional 100-125 joules cm^{-2} per day for general plant maintenance. He estimated that it requires an average of more than 5600

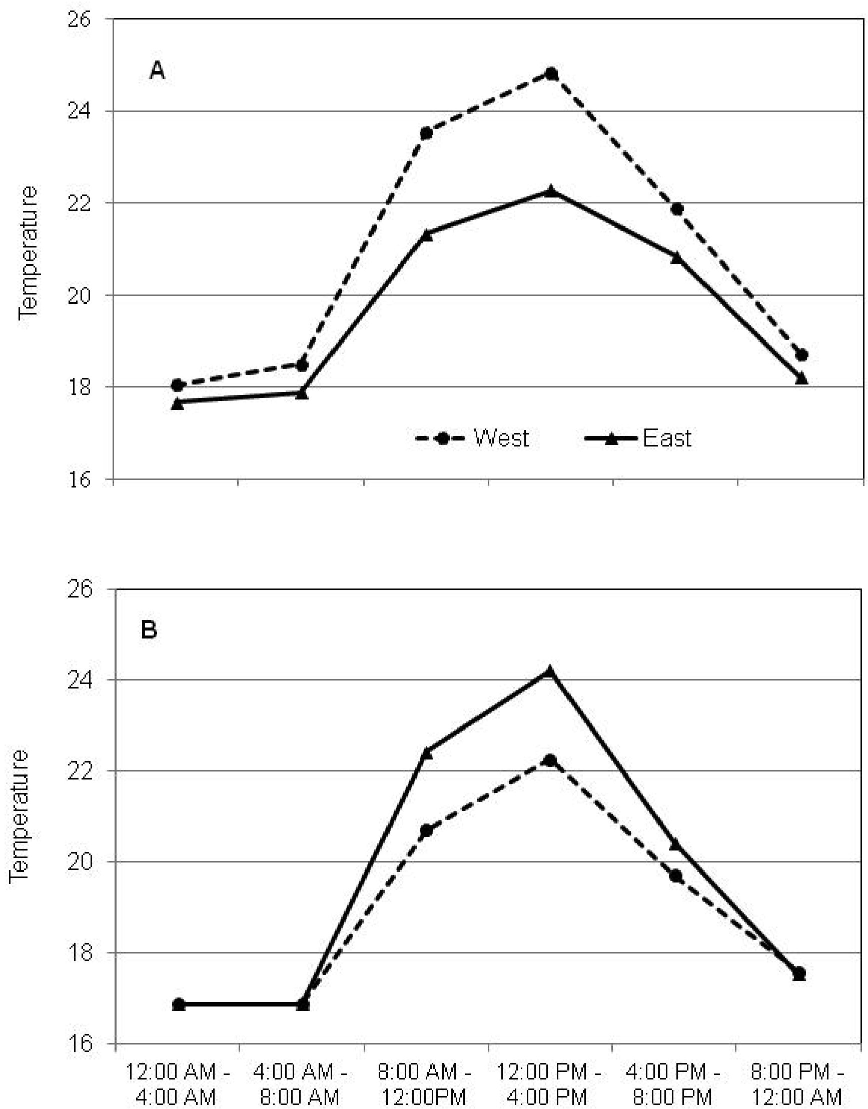

FIGURE 1. Mean temperatures (C) in west and east greenhouse sections during 4 h periods in year 2009 (A) and in year 2010 (B).

to 7000 joules per cm^2 solar energy per week to maintain a tomato plant with 7 trusses and that in Quebec this could be expected from the middle of March on. More southern latitudes could be expected to have greater amounts of solar energy during the fall and

TABLE 2. Weekly yield of ripe tomato and mean 24-h light intensity (*PAR*) and temperature for warm and cool greenhouse sections in year 2009 (11 Oct. - 5 Dec.).

Week	Warm (west section)					Cool (east section)				
	Fruit No.	Total wt (kg)	Mean wt (g)	Light (*PAR*)	Temp (°C)	Fruit No.	Total wt (kg)	Mean wt (g)	Light (*PAR*)	Temp (°C)
1	11	1.48	134	108	20.7	7	0.99	141	118	19.7
2	34	5.25	154	156	21.7	33	4.59	139	145	20.2
3	26	4.26	164	116	21.7	17	3.53	208	102	19.4
4	63	12.31	195	113	20.8	48	9.31	194	98	18.1
5	23	4.59	199	93	18.9	20	3.60	180	93	17.8
6	19	4.36	229	88	19.3	31	6.34	205	89	18.1
7	29	6.43	222	102	18.7	20	5.83	291	102	17.2
8	38	9.56	252	104	19.0	18	4.52	251	93	18.3
Mean	30	6.03	194	110	20.1	24	4.71	193	105	18.6

TABLE 3. Weekly yield of ripe tomato and mean 24-h light intensity (*PAR*) and temperature for warm and cool greenhouse sections in year 2010 (17 Oct. - 10 Dec.).

	Cool (west section)					Warm (east section)				
Week No.	Fruit No.	Total wt (kg)	Mean wt (g)	Light (*PAR*)	Temp (°C)	Fruit No.	Total wt (kg)	Mean wt (g)	Light (*PAR*)	Temp (°C)
1	4	0.87	217	163	17.0	8	1.61	201	161	19.4
2	9	1.72	191	132	19.4	20	4.18	209	134	20.8
3	54	10.92	202	123	18.1	52	10.64	205	120	18.4
4	38	7.62	201	173	17.8	46	9.61	209	151	18.7
5	31	6.72	217	124	18.2	20	4.82	241	114	19.8
6	19	3.41	179	107	18.3	37	6.85	185	104	19.6
7	21	4.37	208	96	17.8	28	6.25	223	89	18.8
8	28	6.14	219	91	17.9	24	6.24	260	83	18.9
Mean	26	5.22	204	126	18.1	29	6.28	217	120	19.3

TABLE 4. Tomato fruit yield under warm (east section) and cool (west section) greenhouse temperature regimes in 2009.

Treatment	No. ripe Fruit	Mean ripe wt (g)	Total ripe wt (kg)	Total green wt (kg)	Total fruit wt (kg)
Warm	81	198	16.1	23.3	39.4
Cool	65	194	12.7	27.2	39.8
Significance[a]	NS	NS	**	*	NS

[a] NS, *, or ** indicates nonsignificant, significant at $P \leq 0.05$, or significant at $P \leq 0.01$, respectively, by F test.

TABLE 5. Tomato fruit yield under warm (west section) and cool (east section) greenhouse temperature regimes in 2010.

Treatment	No. ripe Fruit	Mean ripe wt (g)	Total ripe wt (kg)	Total green wt (kg)	Total fruit wt (kg)
Warm	79	213	16.9	22.3	39.2
Cool	68	205	13.9	24.1	38.0
Significance[a]	NS	NS	*	NS	NS

[a] NS or * indicates nonsignificant or significant at $P \leq 0.05$, respectively, by F test.

TABLE 6. Mean tomato yield under warm and cool greenhouse temperature regimes over two years (2009 & 2010).

Treatment	No. ripe Fruit	Mean ripe wt (g)	Total ripe wt (kg)	Total green wt (kg)	Total fruit wt (kg)
Warm	80	205	16.4	22.8	39.3
Cool	66	200	13.3	25.6	38.9
Significance[a]	NS	NS	*	NS	NS

[a] NS or * indicates nonsignificant or significant at $P \leq 0.05$, respectively, by F test.

winter months. However, periods of overcast weather can greatly reduce the amount of solar energy available to plants as shown in the degree of variation in weekly mean *PAR* (Tables 2 & 3) and range of 24-h mean *PAR* (33 to 244).

There is no direct conversion of radiometric light energy units (joules) to quantum *PAR* units because not all wavelengths are used for photosynthesis and the spectrum of solar radiation varies with the time of day (sun angle) and atmospheric conditions. However, a general conversion factor for solar radiation was developed for atmospheric measurements by Ting and Giacomelli (1987). Using this conversion (2.07 $\mu mol \cdot s^{-1} \cdot m^{-2}$ per joule$\cdot m^{-2}$), none of the weekly mean *PAR* levels in the current study (Tables 2 & 3) reached the minimum light requirements of Dalton (2003) for full tomato production, 5600 to 7000 joules per cm^2, although some days exceeded the minimum. Weekly solar energy during fruit production ranged from a low of 2425 joules (83 *PAR*) to a high of 5055 joules (173 *PAR*) per cm^2 per week. However, the tomato plants did not appear to be under stress and continued to produce a new set of flowers each week. Blossom drop was not a problem. This could be because plant density (0.8 plants/m^2) was much less than that used in most commercial greenhouses (2 plants/m^2) and thus plants were more exposed to the available light in this study. The wider spacing was used to eliminate possible stress effects from overcrowding and ensure equal sunexposure for all plants within a treatment.

There was a significantly greater total weight of harvested ripe fruit in the warm than the cool greenhouse zone. This agrees with Adams et al., 2001, who showed that the rate of tomato fruit ripening was positively related to higher temperatures, up to at least 26 ºC. The nearly equal weight of total fruit production (ripe and green) between temperature treatments indicates that the tomato cultivar 'Trust' can be grown at slightly lower daytime temperatures without a significant loss of fruit production, although ripening may be delayed. Dalton (2003) recommended that growers reduce daytime greenhouse temperatures by a few ºC during periods of low light intensity to reduce stress on plants, prevent loss of vigor, and maintain a balance between the vegetative and generative conditions. However, the present study showed that extended use of cooler temperatures would result in delayed ripening and increased stress on plants from increased fruit load. Dalton (2003) recommended setting greenhouse temperatures according to the amount of solar radiation available and the degree of plant vigor, i.e., higher temperatures during sunny days and when plants were too vigorous.. He stated that plants that were too vigorous had greater vegetative than generative growth and that warmer temperatures and higher light levels decreased vegetative growth and increased generative growth. The objective was to obtain a balance between vegetative and generative growth. De Koning (1989) also found that tomato plants shift assimilate partitioning from vegetative towards fruit growth with higher temperatures. That the results of the present study did not show a significant difference in total fruit weight (generative growth) between treatments may be related to the relatively small differences in temperatures in our study. Temperature treatments in the De Koning study differed by 6 ºC (17 to 23 ºC) whereas the difference in mean 24-h temperature between our treatments was only about 1 C over 24-h, and at most 2 ºC during mid-day. In addition, De Koning used constant temperatures whereas temperatures varied in the current study, as is commonly found in commercial greenhouses.

The longer day and more direct solar radiation during fall and winter in the mid-Atlantic region of the U.S. may allow for a longer growing season and/or the use of higher temperatures than those recommended for use in greenhouses at higher latitudes, such as those in Quebec and the Netherlands. However, periods of overcast weather during fall and winter in the Mid-Atlantic region often reduce light intensity to below that recommended for full production. Greater spacing of plants within the greenhouse would likely allow plants to better utilize the available light during these periods and reduce stress. The mean rate of ripe fruit production (g/plant/day) in this study was greater in both the warm (142 g) and cool (118 g) greenhouse treatments than that of a local commercial greenhouse (102 g) using the same cultivar during a similar period of time (March-April) but at a higher mean plant density of 2 plants/m^2 (unpublished data, 2008-2010). Thus, the very low plant density used in this study (1 plant/m^2) would likely reduce greenhouse tomato yield and is not recommended.

Avoiding plant stress can be as important as increasing yields. To do this, growers often reduce daytime temperatures by several degrees during periods of prolonged overcast weather, similar to the cool temperatures used in this study. However, the results of this study indicate that keeping greenhouses at cooler temperatures to save on heating costs would significantly delay fruit ripening and increase fruit load on vines. Daytime greenhouse temperatures should be set according to the amount of solar radiation available. Fruit ripening would be enhanced by allowing greenhouses to warm on days with high light intensity, to 24 ºC or more, by reducing venting, and/or adding supplemental heating. Reduced venting would also allow greater use of CO_2 generators. This study shows that relatively small changes in daytime greenhouse temperature will allow growers to significantly modify fruit ripening and thus better match weekly tomato production with market demand.

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LITERATURE CITED

Adams,, S.R., K.E. Cockshull and C.R.J. Cave, 2001. Effect of Temperature on the Growth and Development of Tomato Fruits. *Annals of Botany*, 88:869-877.

Dalton, C. 2003. Practical Measurements to help greenhouse tomato growers read the productivity of their plants. *Tom Pousse*, week 15, April 17th. Quebec Department of Agriculture, Canada.

Dalton, C. 2005. Reading the Plants. 33rd Annual Conference of the North Carolina Greenhouse Vegetable Growers Association, October 25, North Carolina Cooperative Extension, Wake County Agricultural Services Center, Raleigh, NC.

Elings A, F.L.K. Kempkes, R.C. Kaarsemaker, M.N.A. Ruijs, N.J. van de Braak, and T.A. Dueck, 2005. The energy balance and energy-saving measures in greenhouse tomato cultivation. *Acta Horticulturae*, 691:67–74.

Ercan, N. and H. Vural 1994. The Effects of Low Temperatures on Fruit Set of Tomatoes. *Acta Horticulturae* 366: 65-72.

Higashide, T, and E. Heuvelink, 2009. Physiological and Morphological Changes over the Past 50 Years in Yield Components in Tomato. *Journal of the American Society for Horticultural Science*, 134(4):460–465. 2009.

De Koning, A.N.M. 1989. The Effect of Temperature on Fruit Growth and Fruit Load of Tomato. *Acta Horticulturae*, 248: 329-336.

SAS Institute, 2009. SAS user's guide, Version 9.2. SAS Institute, Cary, NC.

Ting, K.C., G.A. Giacomelli, 1987. Availability of Solar Photosynthetically Active Radiation. *Transactions of the ASAE*, 39: 1453-1457.

Zhang, L., X. Hao, Y. Li and G. Jiang, 2010. Response of Greenhouse Tomato to Varied Low Pre-night Temperatures at the Same Daily Integrated Temperature. *HortScience*, 45(11):1654–1661. 2010.