

# Early Growth of Muskmelon in Mulched Minitunnels Containing a Thermal Water Tube. II. Air, Soil, and Water Tube Temperatures and Vegetative Growth

Fahrurrozi Aziz<sup>1</sup> and Katrine A. Stewart<sup>2</sup>

Department of Plant Science of McGill University, Macdonald Campus, 21,111 Lakeshore Road, Ste. Anne de Bellevue, Quebec, H9X 3V9 Canada

Sylvie Jenni<sup>3</sup>

Agriculture and Agri-Food Canada, Horticultural Research and Development Centre, Saint-Jean-sur-Richelieu, 430 Boul. Gouin, St. Jean-sur-Richelieu, Quebec, J3B 3E6 Canada

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**ABSTRACT.** Field experiments were conducted during 1997, 1998, and 1999 to determine effects of 10 combinations of mulched minitunnel and thermal water tube on air, soil, and water-tube temperatures and on vegetative growth of 'Earligold' netted muskmelon (*Cucumis melo* L. Reticulatus Group) within the tunnels. Use of mulched minitunnels significantly increased air, soil and water temperatures during the preanthesis phase in all years compared with control treatments. Inclusion of water tubes and venting the tunnels decreased air temperature fluctuations in the tunnels. During the first 10 to 15 days after transplanting, plants grown in nonperforated tunnels had higher relative growth rates (RGRs), net assimilation rates (NARs), and dry weights (DWs) than those grown under perforated tunnels and control plots. Plants in tunnels containing thermal water tubes generally had higher RGRs, NARs, and DWs than those without tubes. During the later part of the experiment, from 11 to 16 days after transplanting until anthesis, however, there were no consistent effects of mulched minitunnels on RGR, NAR, and plant DW. Tunneled muskmelons had significantly higher RGRs, but generally lower NARs than those grown without tunnel. Use of mulched minitunnels significantly increased plant DW at anthesis in 1997, but not in 1998 and 1999. Plants grown in the minitunnels containing a thermal water tube generally had higher RGRs, NARs, and DWs than those without water tubes. Ventilating nonperforated tunnels generally increased RGR, NAR, and plant DW. Plants grown in the tunnels reached anthesis 10 days earlier than those without tunnels.

Use of plastic mulch and minitunnel combinations to modify crop microclimate is becoming commonplace for early production of muskmelons (*Cucumis melo* Reticulatus Group) in cool climates. In Quebec, Canada Argall and Stewart (1989) and Jenni et al. (1998) found that high air and soil temperatures in the minitunnel were conducive to increased growth and yield. In other areas, excessively high air temperatures that occurred in nonperforated tunnels decreased final yields (Motsenbocker and Bonanno, 1989). To alleviate this harmful effect, inclusion of thermal water tubes in minitunnels has been recommended to optimize muskmelon growth and development (Jenni et al., 1996 1998).

Most studies examining effects of minitunnels on muskmelon growth have focused on flowering and final yields (Farias-Larios et al., 1998; Jenni et al., 1998; Loy and Wells, 1975; Motsenbocker and Bonanno, 1989). However, little work has been undertaken regarding the influence of minitunnels on early vegetative growth and, indeed, this is the period when the tunnels have the most influence as they are removed upon flowering to promote bee pollination (Robinson and Decker-Walters, 1997). Since growth responses of indeterminate species, including muskmelons, during vegetative

phase are determinate, biomass production of muskmelons during vegetative growth would be roughly exponential and primarily a function of environmental conditions. According to Geiger and Servaites (1991), dry matter produced during the preanthesis period is crucially important as it provides carbon reserves to counter environmental stresses. Crops that underwent stressful conditions during the vegetative phase of development had lower dry weights (DWs) during the reproductive phase (Chiariello and Gulmon, 1991). Clearly, there is a need to better understand the consequences of using minitunnels, during the preanthesis phase, on muskmelon production. Therefore, this study reports the effects of mulched minitunnel and thermal water tube combinations on air, soil and water-tube temperatures and growth and development of muskmelons during the vegetative phase.

## Materials and Methods

Field experiments were conducted during the Summers 1997, 1998, and 1999 at the Horticulture Research Centre, Macdonald Campus, McGill University, Sainte Anne de Bellevue, Quebec (lat. 45° 26 'N, long .73° 56 'W). The experimental site was a Gleyed Eluviated Eutric Brunisol which was fall-ploughed, spring-harrowed, and fertilized with N, P, and K according to local recommendations (Conseil des Production Vegetales du Quebec, 1994) based on soil tests. A green wavelength-selective mulch (Climagro, Plastitech, St-Remi, Quebec) and drip irrigation lines were mechanically installed over the 15-cm-high soil beds 1 week before transplanting.

In 1997, 1998, and 1999, three types of polyethylene tunnels, with and without thermal water tubes, were compared with control

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<sup>1</sup>Former PhD student. Present address: Fakultas Pertanian Universitas Bengkulu, Jalan Raya Kandang Limun Bengkulu, 38371A Indonesia.

<sup>2</sup>Associate professor and corresponding author.

<sup>3</sup>Researcher.

(nontunnel) plots. The tunnels used were a) clear perforated (500 holes/m<sup>2</sup>, Plastitech), b) clear nonperforated (Plastitech), and c) infrared-blocking nonperforated (Polyon-Barkai, Polywest, Encinatas, Calif.). Combinations of tunnels and thermal tubes in 1997, 1998, and 1999 were as follows: 1) no tunnel/no thermal tube (OO), 2) no tunnel/a thermal tube (OT), 3) clear perforated polyethylene/no thermal tube (PO), 4) clear perforated polyethylene/thermal tube (PT), 5) clear nonperforated polyethylene/no thermal tube (CO), 6) clear nonperforated polyethylene/thermal tube (CT), 7) infrared-blocking nonperforated polyethylene/no thermal tube (IO),

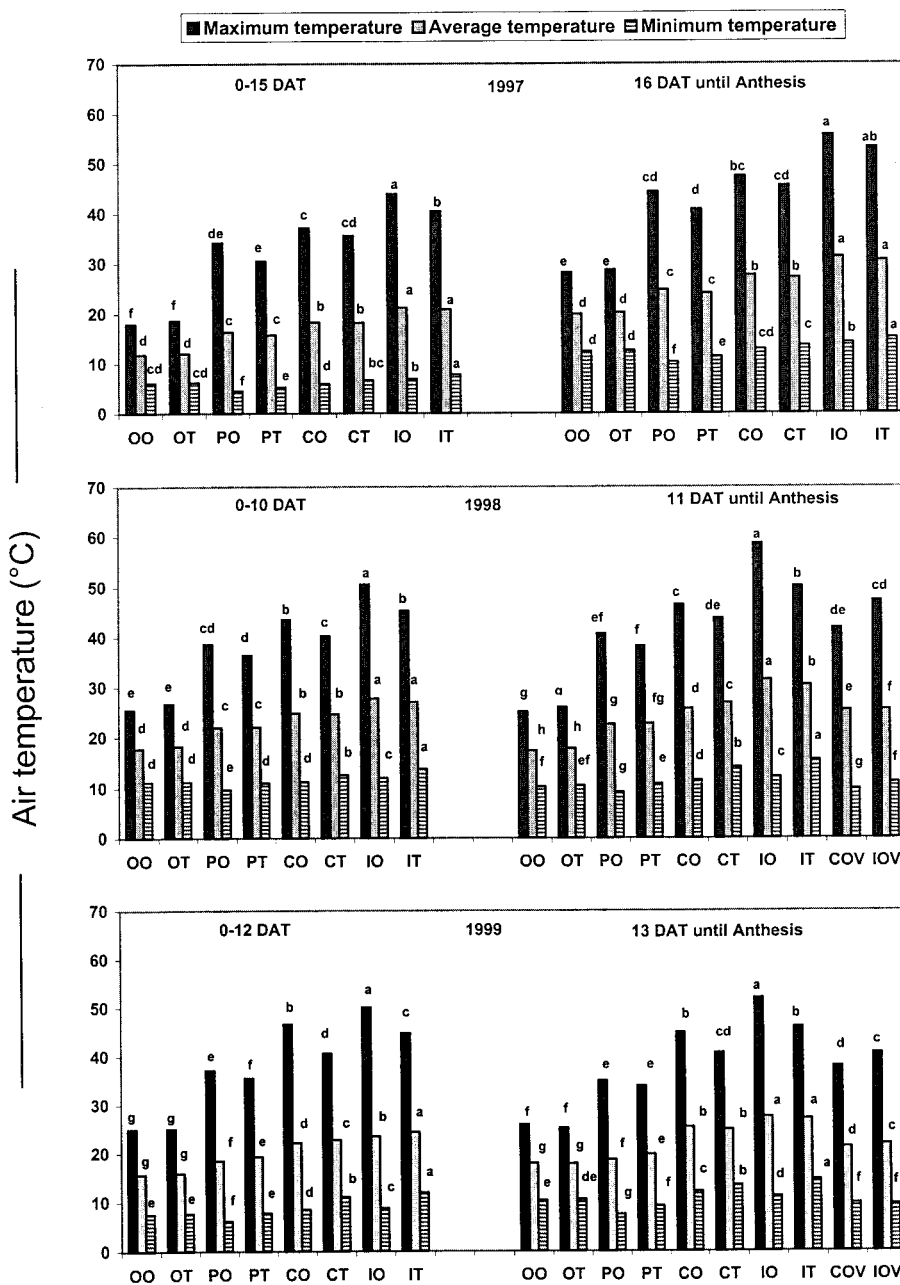
8) infrared-blocking nonperforated polyethylene/thermal tube (IT); and in 1998 and 1999, two treatments were added: 9) clear nonperforated polyethylene/no thermal tube/ventilated (COV) and 10) infrared-blocking nonperforated polyethylene/no thermal tube/ventilated (IOV). The experimental design was a randomized complete block with four blocks. Polyethylene was stretched over 10-gauge wire hoops and soil-secured along the mulched bed to create minitunnels 0.375 m high × 0.8 m wide × 8 m long. In treatments with thermal tubes, a clear polyethylene tube, 8.0 m long and 0.32 m wide was filled with water and placed along the inside edge of each tunnel, as described by Jenni et al. (1998). In 1997, the tubes were staked on the mulch surface. However, in 1998 and 1999, the tubes were trenched (5 cm deep and 10 cm wide) into the mulched soil bed to simplify tube placement. For the ventilated treatments (COV and IOV), ventilation consisted of cutting 15-cm slits 1 m apart on the leeward (south) side of the tunnel surfaces. The tunnels were ventilated when the ratio of variable to maximum

fluorescence (Fv/Fm) dropped below 0.5 for 3 consecutive d, indicative of plants under severe or extreme stress (Bjorkman and Demmig, 1987). Tunnels were ventilated 13 d and 10 d after transplanting in 1998 and 1999, respectively.

'Earligold' netted muskmelon were seeded into 7.5-cm<sup>2</sup> cell packs containing Pro-mix 'BX', peat-based growing medium (Premier Horticulture, Riviere de Loup, Quebec, Canada) and placed in a greenhouse with days/night temperatures of 25 to 28/18 to 20 °C and natural daylight. Seedlings were watered until runoff with foliar fertilizer (75 mg·L<sup>-1</sup> of a 20N-8.8P-16.6K water soluble fertilizer, Plant Products Inc., Brampton, Ontario, Canada) at 2 weeks of age, and were watered as necessary. Three-week-old seedlings were transplanted on 13, 6, and 5 May 1997, 1998, and 1999, respectively. Row spacing was 0.7 m between plants and 2.0 m between rows. There were 11 plants per plot with the end plants serving as guards. Plants received 300 mL of a starter solution [300 mg·L<sup>-1</sup> of a 10N-22P-16.6K water soluble fertilizer (Plant Products Inc.)] immediately after transplanting. Throughout the experiment, drip irrigation was applied for 5 h after 3 to 4 d without precipitation.

At transplanting the shoots (leaves and stems) of 27 plants were harvested and dried at 70 °C for 48 h and the DW recorded. Fifteen (1997), 10 (1998), and 12 (1999) d after transplanting, one replicate (nine plants) of the experiment was harvested and shoot DWs were recorded. At anthesis, 90% of the muskmelons had at least one fully open perfect flower, and 18 plants per treatment (six plants per replicate) were harvested. Leaf area was measured with a portable leaf area meter (Delta T Devices, Cambridge, United Kingdom), and relative growth rates (RGRs) and net assimilation rates (NARs) were calculated on shoots (leaf and stem tissue) following methods proposed by Gardner et al. (1985).

Fig. 1. Effects of mulched minitunnels on maximum, average, and minimum air temperatures from transplanting (DAT) until anthesis of 'Earligold' netted muskmelons in 1997, 1998, and 1999. The first letter of a treatment indicates the type of tunnel with O = none, P = perforated clear polyethylene, C = nonperforated clear polyethylene, and I = infrared-blocked polyethylene. The second letter indicates the presence (T), or absence (O) of water tubes. The third letter (V) indicates the ventilating treatment. Lower case letters denote mean separations for maximum, average, and minimum air temperatures by Duncan's multiple



range test,  $P = 0.05$ .

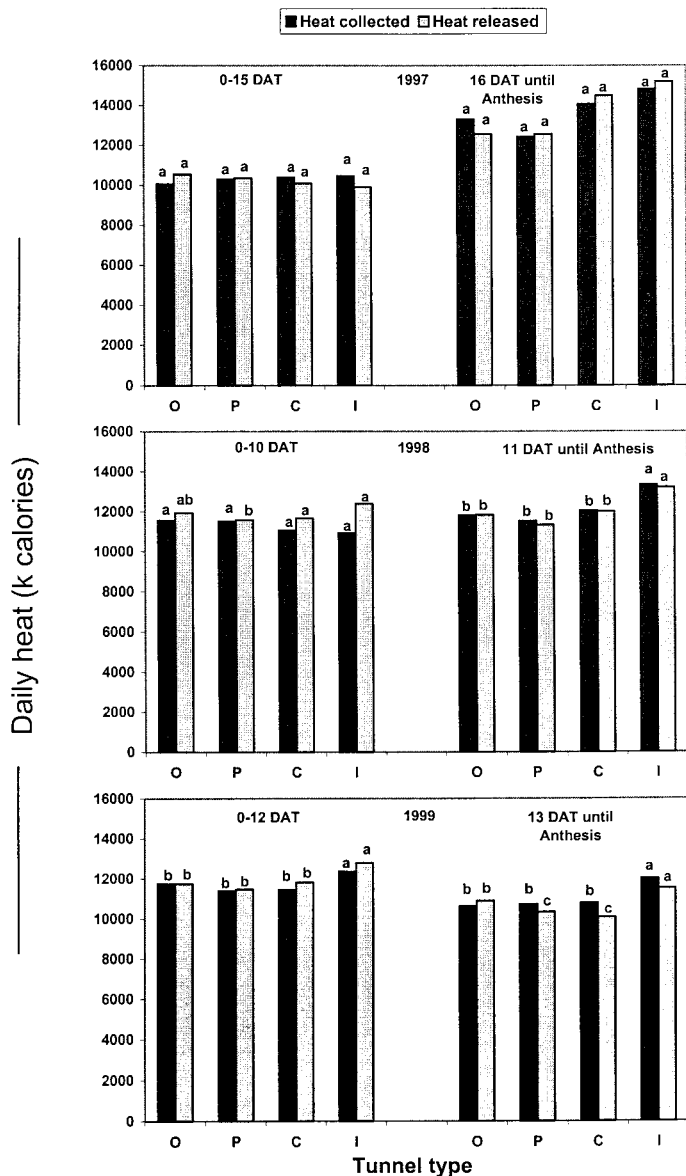


Fig. 2. Effect of minitunnel type on daily heat collected and released by thermal water tubes from transplanting (DAT) until anthesis of 'Earligold' netted muskmelons in 1997, 1998, and 1999. Letters indicate the type of tunnel with O = none, P = perforated clear polyethylene, C = nonperforated clear polyethylene and I = infrared-blocked polyethylene. Lower case letters denote mean separation among types of tunnels by LSD,  $P = 0.05$ .

Duplicated air, soil, and water-tube temperature data were obtained using copper-constantan thermocouples connected to AM-32 multiplexers and a datalogger (CR-10; Campbell Scientific, Inc., Edmonton, Alberta Canada), installed in Stevenson screens. Thermocouples measuring air temperatures were located 7.5 cm above the mulch surface and were set inside white painted plastic tubes 15 cm in length and 3.3 cm in diameter to protect the sensors from direct solar radiation. Soil and water temperatures were measured at 7.5 cm below the mulch surface and 2.0 m from the end of the thermal water tubes, respectively. Temperatures were recorded at 10-min intervals and averaged on an hourly basis from transplanting until anthesis. Vaissala sensors (Campbell Scientific) were installed in nonperforated clear polyethylene, perforated clear polyethylene tunnels, and in control plots to record relative humidity. These sensors were connected to the datalogger. Optical properties of the polyethylene

tunnels were determined using a spectroradiometer (LI-1800; LI-COR, Lincoln, Nebr.).

Heat collected and released by the water tubes was calculated following the formula of Pavlou (1990). Energy collected =  $(T_{max} - T_{1min}) \times M_w \times C$ , and energy released =  $(T_{max} - T_{2min}) \times M_w \times C$  where  $T_{max}$  and  $T_{1min}$  are maximum and minimum water temperatures, respectively, for the calculation day,  $T_{2min}$  is the minimum water temperature of the following day and  $M_w$  is water mass (assumed to be 643 kg), and  $C$  is the specific heat of water (assumed to be 1).

Data were subjected to analysis of variance using SAS procedures (Version 6.12; SAS Institute, Inc., Cary, N.C.). Orthogonal contrasts ( $P = 0.05$ ) were used to compare groups of treatments and means were separated by least significant difference (LSD) and Duncan's multiple range test at ( $P = 0.05$ ).

## Results and Discussion

**AIR TEMPERATURES.** Mulched minitunnels alone or in combination with thermal water tubes had significantly higher average and maximum air temperatures than did control treatments immediately after transplanting in all experimental years (Fig. 1). Mulched minitunnels without thermal water tubes have been investigated previously for use with muskmelons (Bonanno and Lamont, 1987; Loy and Wells, 1982; Motsenbocker and Bonanno, 1989). Solar radiation trapped in the tunnels is primarily responsible for increases in air temperatures. Average air temperatures in the nonperforated tunnels were significantly higher than those in the perforated tunnels (Fig. 1). Perforations decreased heating effects by allowing air movement into the tunnel (Savage, 1980), and were comparable to tunnel venting. Tunnel ventilation significantly decreased the maximum, and minimum air temperatures (Fig. 1). Similar results were reported by Champagne and Stewart (1990).

Average air temperatures in the nonperforated infrared-blocked tunnels were significantly higher than those under clear nonperforated tunnels. Radiation in the near infrared spectrum (770 to 1100 nm) were 90% and 87%, for the infrared-blocked and clear nonperforated tunnels, respectively (data not presented). Formation of water films on the inner side of nonperforated tunnels could further reduce loss of thermal radiation from the mulch surface thus increasing temperatures in the tunnel. Similarly, elevated  $CO_2$  levels in the nonperforated tunnels (Aziz, 2000) might warm the tunnel environment by trapping heat.

Inclusion of thermal water tubes in the minitunnels significantly decreased maximum air temperatures in the tunnels throughout the experiment (Fig. 1). Similar results were demonstrated by Mawardi and Stewart (1993) and Jenni et al. (1998). This reduction was due to heat being collected by the water tubes during the day (Fig. 2).

The nonperforated tunnels increased air minimum temperatures, although the numerical increases were not always statistically significant, compared with controls. Minimum air temperature in the perforated tunnels without water tubes was lower than all other treatments. Jenni et al. (1991) reported similar results and suggested this was due to radiative cooling that occurred in the tunnel. Inclusion of water tubes in the minitunnels significantly increased minimum temperatures throughout the experiment (Fig. 1). Similar results have been demonstrated by Mawardi and Stewart (1993). This increase was due to the tubes releasing absorbed heat at night (Fig. 2). Grafiadellies (1986) made use of this principle to heat greenhouses passively.

**SOIL TEMPERATURES.** Soil temperatures were higher, although differences were not always significant, in all nonperforated tunnel

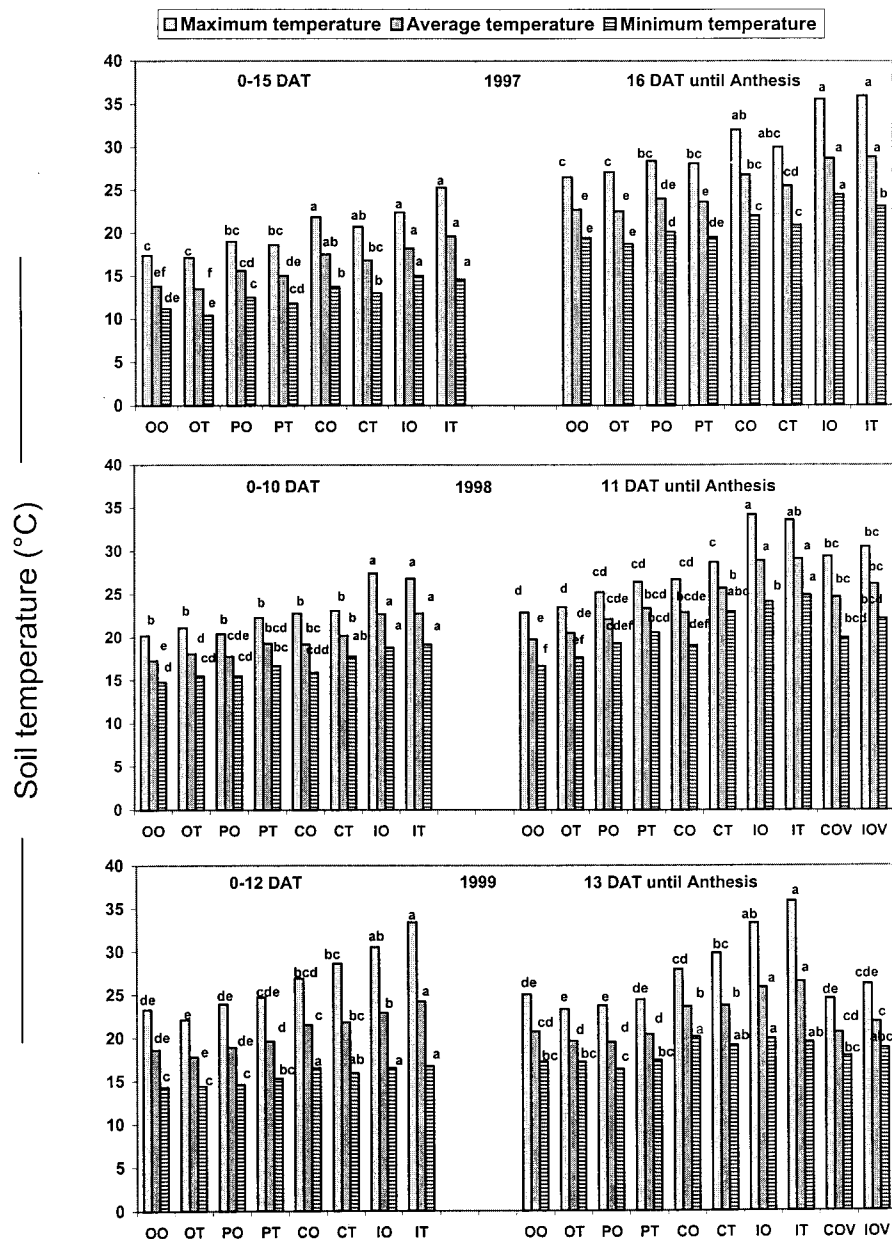


Fig. 3. Effects of mulched minitunnels on maximum, average, and minimum soil temperatures from transplanting (DAT) until anthesis of 'Earligold' netted muskmelons in 1997, 1998, and 1999. The first letter of a treatment indicates the type of tunnel with O=none, P=perforated clear polyethylene, C=nonperforated clear polyethylene, and I=infrared-blocked polyethylene. The second letter indicates the presence (T) or absence (O) of water tubes. The third letter (V) indicates the ventilating treatment. Lower case letters denote mean separations for maximum, average, and minimum soil temperatures by Duncan's multiple range test,  $P = 0.05$ .

treatments than under perforated tunnels and control treatments (Fig. 3). Plastic mulches have been reported to increase soil temperatures significantly compared with bare soil (Brandenberger and Wiedenfeld, 1997; Zermeno et al., 1998). Placing a minitunnel on the mulch also increased soil temperature, although not always significantly, compared with mulch alone. Motsenbocker and Bonanno (1989) and Farias-Larios et al. (1998) reported similar results. High air temperatures in the tunnel increase soil temperatures, since the heat is transferred through the mulch by conduction (Perry, 1998). Good contact between the plastic mulch and soil

surface is necessary for conduction to occur (Ham and Kluitenberg, 1994). According to Tanner (1974), there is a greenhouse effect under the mulch surface that warms the soil.

The presence of thermal water tubes in the tunnel generally decreased, but not significantly, soil temperatures. The thermal water tube may have reduced heat conduction to the plastic mulches since the tube covered approximately 40% of the mulch surface.

**WATER TEMPERATURES AND HEAT COLLECTED AND RELEASED.** At the start of the growing season, use of minitunnels significantly increased maximum, and minimum water temperature in all years (Fig. 4). Water tubes in the infrared tunnels had the highest temperatures, followed by clear nonperforated, clear perforated tunnels, and controls. Later in the season, results were more variable reflecting the different seasons. In 1997 and 1998 maximum water temperatures were significantly higher for all the minitunnels compared with the control treatments. However, in 1999, there was no difference in maximum water temperature between the control and perforated tunnel treatments but these were significantly lower than those in the nonperforated tunnels. For all years, minimum temperatures in the infrared-blocked tunnels were significant warmer than the controls.

There were no differences among treatments in the amount of heat collected and released by the thermal water tubes in 1997 (Fig. 2). There was no difference in the heat absorbed by the water tubes at the start of the 1998 growing season. Water tubes in the perforated tunnels released less heat than the other tunnels although the difference was only significant for the infrared-blocked tunnel. Later in the season, water tubes in the infrared-blocked tunnel collected and released significantly more heat than the other treatments.

Through 1999, the water tubes in the infrared-blocked minitunnels collected and released significantly more heat than all other treatments. The increased heat collected in these tunnels was due to the higher air temperature in these tunnels (Fig. 1).

**MUSKMELON GROWTH DURING THE FIRST 10 TO 15 D AFTER TRANSPLANTING.** Use of a perforated tunnel increased shoot DW by 2.4 times in 1997 and 1999 and 1.2 times in 1998 compared with the controls 10 to 15 d after transplanting (Table 1). When nonperforated tunnels were used, the shoot DWs increased by 10.0, 3.2, and 5.2 times that of the controls for 1997, 1998, and 1999, respectively (Table 1). High air and soil temperatures in the minitunnels likely contributed to increased DW (Figs. 1 and 2). RGR and NAR of muskmelons grown in nonperforated tunnels were consistently greater than RGR and NAR values of plants grown in perforated tunnels and in control plots during the 0 to 15 d after transplanting (Table 2). Differences in RGR and NAR among the treatments were largest in 1997. RGR and NAR values of muskmelons were generally higher in 1998 and 1999 than in 1997. This might reflect the warmer air temperatures of 1998 and 1999. Elevated air and soil

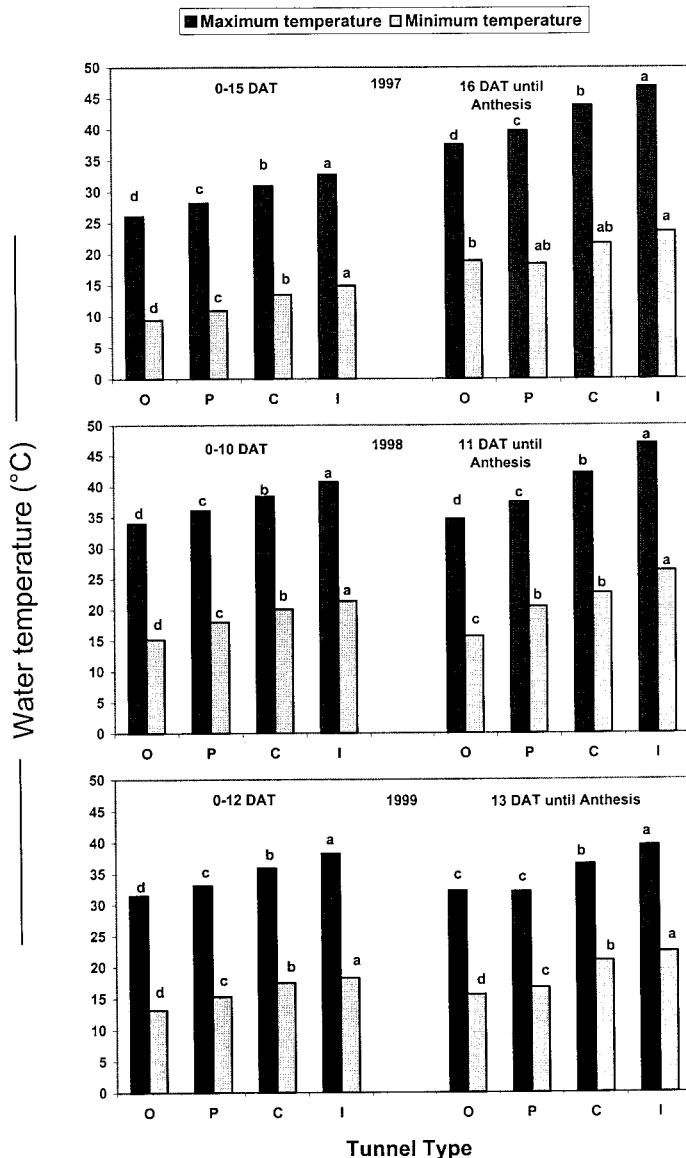


Fig. 4. Effect of minitunnel type on maximum and minimum water temperature of thermal water tubes from transplanting (DAT) until anthesis of 'Earligold' netted muskmelons in 1997, 1998, and 1999. Letters indicates the type of tunnel with O = none, P = perforated clear polyethylene, C = nonperforated clear polyethylene and I = infrared-blocked polyethylene. Lower case letters denote mean separation among types of tunnels by LSD,  $P = 0.05$ .

temperatures in the tunnels (Figs. 1 and 2) might be responsible for increased RGR and NAR. Negative RGR and NAR values for the controls in 1997 (Table 2) were due to low air temperatures and transplanting shock. Increased CO<sub>2</sub> concentrations in the nonperforated tunnels (Aziz, 2000) might have also contributed to improved growth. Elevated CO<sub>2</sub> has been reported to increase crop growth (Nederhoff et al., 1992), including muskmelons (Acock et al., 1990; Mavrogianopoulos et al., 1999). Over the 3 years of these experiments, relative humidity (RH) in the nonperforated tunnels was consistently higher than ambient (i.e., 77% versus 63%, respectively—data not presented). High RH has been shown to improve plant growth by stimulating photosynthetic rates (Bunce, 1984).

The effect of the thermal water tube was inconsistent over the years in terms of RGR and NAR. The tubes improved growth of muskmelons indirectly through decreased air temperature fluctuations in the tunnels (Fig. 1).

**MUSKMELON GROWTH FROM 11 TO 16 D AFTER TRANSPLANTING TO ANTHESIS.** Use of mulched minitunnels reduced time to flowering compared with nontunneled muskmelons by 11 d in 1997 and 1998 and 9 d in 1999 (Table 1). The shortest time to anthesis occurred in the nonperforated tunnels containing a thermal tube which flowered 12, 15, and 11 d earlier than the controls. Jenni et al. (1996, 1998) and Loy and Wells (1975) reported similar results. Reduction in time to flowering was probably due to increases in both air and soil temperatures in the tunnels (Figs. 1 and 2). Although the use of mulched minitunnels reduced time to anthesis, excessively high air temperatures in the tunnels negatively affected growth between 15 d after transplanting and anthesis. Indeed, all of the muskmelons grown in infrared tunnels without thermal water tubes died 17 d and 19 d after transplanting in 1998 and 1999, respectively.

At anthesis, the shoot DW of muskmelons grown in mulched minitunnels was significantly higher than the control plots in 1997 and 1999 but not in 1998 (Table 1). The presence of thermal water tubes had no effect on shoot DW. Muskmelons grown in tunnels had significantly higher RGRs than those grown without tunnels in all years (Table 2). Plants grown in nonperforated tunnels without thermal tubes had lower RGRs than those grown in either perforated tunnels or in nonperforated tunnels with thermal tubes. These values were significant in 1998. The lower RGRs for the nonperforated tunnels without thermal tubes reflect the excessively high air temperatures recorded in this treatment. Farias-Larios et al. (1998) and Jenni et al. (1996) recommended maintaining temperatures below 35 °C and 40 °C, respectively, to optimize muskmelon growth. The higher RGR of the nonperforated tunnels with thermal tubes can be attributed to a combination of high air temperatures and enriched CO<sub>2</sub> levels (Aziz, 2000). Similar results have been reported by Acock et al. (1990).

There was no significant difference in the NAR among treatments in 1997 and 1998. In 1999, plants grown in nonperforated tunnels had significantly lower NARs than those of all other treatments (Table 2). High air temperatures in these treatments might have reduced leaf growth (Friend et al., 1965) and eventually reduced NARs. The highest NARs were recorded in the control treatments.

**EFFECT OF VENTILATION ON MUSKMELON GROWTH.** Ventilating by crosscutting the surface of the tunnels on the leeward (south) side did not significantly increase shoot DW in 1998 but did in 1999 (Table 1). Lack of response of muskmelons to ventilation in 1998 might have reflected their inability to resume growth fully after being exposed to stressful conditions, i.e., high air temperatures, before minitunnel venting. Ventilating, however, significantly increased muskmelon RGR (Table 2) due to decreased maximum air temperatures (Fig. 1).

## Conclusions

Use of mulched minitunnels increased air, soil, and water temperatures throughout the experiment. Use of thermal water tubes and ventilating the tunnels decreased air temperature fluctuations in the tunnels. Mulched minitunnels generally increased shoot DW, RGR, and NAR of muskmelons during the first 10 to 15 d after transplanting. At anthesis, however, it did not always increase DW, RGR, and NAR of muskmelons. Including a thermal water tube or venting the tunnel generally increased DW, RGR, and NAR of muskmelons. Use of nonperforated tunnels (particularly infrared blocking) with a thermal tube consistently optimized early growth and development of muskmelon during the coldest part of our growing season. The thermal tube is a requirement for nonperforated

Table 1. Effect of minitunnel and thermal water tube combinations on days to anthesis (DA) and shoot dry weight (DW) (in grams) of 'Earligold' netted muskmelons after transplanting (DAT) and at anthesis in 1997, 1998, and 1999.

Minitunnel and thermal water tube combinations	1997			1998			1999		
	Shoot DW (g)			Shoot DW (g)			Shoot DW (g)		
	DA	15 DAT <sup>z</sup>	Anthesis	DA	10 DAT	Anthesis	DAT	12 DAT	Anthesis
No tunnel, no tube	42	0.12	14.8	37	0.51	28.0	33	1.21	37.3
No tunnel, tube	42	0.13	15.7	37	0.54	27.5	33	1.40	39.3
Clear perforated tunnel, no tube	33	0.37	22.1	28	0.69	32.3	23	2.97	18.8
Clear perforated tunnel, tube	33	0.23	18.8	26	0.63	37.3	22	3.43	25.8
Clear nonperforated tunnel, no tube	30	1.14	32.9	30	1.56	30.2	31	4.95	25.1
Clear nonperforated tunnel, tube	29	1.50	26.4	21	1.56	32.6	21	7.67	23.3
Infrared-blocked tunnel, no tube	31	1.10	20.2	NA <sup>y</sup>	1.05	NA	NA	5.09	NA
Infrared-blocked tunnel, tube	30	1.26	28.0	23	2.63	30.1	22	9.18	27.6
Clear nonperforated tunnel, no tube, vented (1998, 1999)	---	---	---	27	---	26.6	25	---	50.7
Infrared-blocked tunnel, no tube, vented (1998, 1999)	---	---	---	33	---	35.0	25	---	47.3
Analysis of variance									
Model		---	*		---	NS		---	***
Treatments		---	*		---	NS		---	***
Contrasts									
Tunnels vs. no tunnels		---	**		---	NS		---	***
Perforated vs. nonperforated		---	NS		---	NS		---	NS
Tubes vs. no tubes		---	NS		---	NS		---	NS
Vented vs. non vented		---	-		---	NS		---	***
Vented vs. perforated		---	-		---	NS		---	***

<sup>z</sup>No statistical analysis. Values are based on the means of nine plants.

<sup>y</sup>NA = data not available as all plants in this treatment died before anthesis.

NS, \*, \*\*, \*\*\* Nonsignificant or significant at  $P = 0.05, 0.01, \text{ or } 0.001$ , respectively.

minitunnels to avoid temperatures extremes and injury to the plants. Under our growing conditions, venting a nonperforated minitunnel was not a viable alternative to the use of a thermal tube under our growing conditions.

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Table 2. Effect of minitunnel and thermal water tube combinations on relative growth rate per plant and net assimilation rate of 'Earligold' netted muskmelons in 1997, 1998, and 1999.

	1997				1998				1999			
	Growth period in days from transplanting until anthesis (A)											
	0-15 <sup>z</sup>	16-A	0-15 <sup>z</sup>	16-A	0-10 <sup>z</sup>	11-A	0-10 <sup>z</sup>	11-A	0-12 <sup>z</sup>	13-A	0-12 <sup>z</sup>	13-A
Minitunnel and thermal water tube combinations	RGR (g·d <sup>-1</sup> ) <sup>y</sup>		NAR (mg·cm <sup>-2</sup> ·d <sup>-1</sup> ) <sup>x</sup>		RGR (g·d <sup>-1</sup> )		NAR (mg·cm <sup>-2</sup> ·d <sup>-1</sup> )		RGR (g·d <sup>-1</sup> )		NAR (mg·cm <sup>-2</sup> ·d <sup>-1</sup> )	
No tunnel, no tube	-0.02	0.17	-0.11	2.10	0.05	0.15	0.44	1.45	0.12	0.16	1.42	1.48
No tunnel, tube	-0.02	0.17	-0.63	2.10	0.06	0.14	0.51	1.28	0.13	0.16	1.48	1.30
Clear perforated tunnel, no tube	0.06	0.24	0.43	1.30	0.08	0.21	0.66	1.73	0.19	0.15	1.98	1.26
Clear perforated tunnel, tube	0.03	0.25	0.17	2.14	0.07	0.25	0.58	1.98	0.21	0.18	2.02	1.44
Clear nonperforated tunnel, no tube	0.13	0.19	0.95	1.77	0.17	0.15	1.56	1.11	0.24	0.08	2.92	0.85
Clear nonperforated tunnel, tube	0.15	0.18	1.09	1.21	0.17	0.28	1.57	2.00	0.27	0.12	2.47	0.79
Infrared-blocked tunnel, no tube	0.13	0.18	0.97	2.26	0.13	NA <sup>w</sup>	1.23	NA	0.24	NA	3.01	NA
Infrared-blocked tunnel, tube	0.14	0.20	1.06	1.62	0.12	0.19	1.97	1.48	0.29	0.11	2.97	0.79
Clear nonperforated tunnel, no tube, vented (1998, 1999)	---	---	---	---	---	0.16	---	1.35	---	0.15	---	1.32
Infrared-blocked tunnel, no tube, vented (1998, 1999)	---	---	---	---	---	0.18	---	2.25	---	0.16	---	1.54
Analysis of variance												
Model	---	***	---	NS	---	***	NS	NS	---	***	---	***
Treatments	---	***	---	NS	---	***	NS	NS	---	***	---	***
Contrasts												
Tunnels vs. no tunnels	---	***	---	NS	---	***	NS	NS	---	***	---	***
Perforated vs. nonperforated	---	***	---	NS	---	**	NS	NS	---	***	---	**
Tubes vs. no tubes	---	NS	---	NS	---	***	NS	NS	---	*	---	NS
Vented vs. non vented	---	---	---	---	---	**	NS	NS	---	NS	---	NS
Vented vs. perforated	---	---	---	---	---	NS	NS	NS	---	***	---	***

<sup>z</sup>No statistical analysis. Values are based on the means of nine plants.

<sup>y</sup>Data not available as all plants in this treatment died before anthesis.

<sup>x,w</sup>Data transformed before analysis of variance using log<sub>10</sub>( $\bar{y}$ ) and square root of ( $X = 1/2$ ) transformations, respectively.

NS,\*,\*\*,\*\* Nonsignificant or significant at  $P = 0.05, 0.01, \text{ or } 0.001$ , respectively.

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