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Tomato Flowering and Early Yield Response to Heat Buildup under Rowcovers

Roy H. Peterson[1] **and Henry G. Taber**
Department of Horticulture, Iowa State University, Ames, IA 50011

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Abstract. **Five polyethylene rowcover treatments (none, slitted white, slitted clear, chimney, and perforated) were combined factorially with four tomato *[Lycopersicon esculentum* (Mill)] cultivars ('PikRed', 'Jetstar', 'Supersonic B', and 'Heinz 1810') in a 2-year experiment. Clear or white rowcovers more than doubled early yield in 1986, from 1.2 to 2.9 t·ha^{-1}. This early yield advantage resulted from an advancement of flowering rather than an increase in fruit number or size. In Spring 1987, high temperature caused increased fruit abortion with all rowcovers, resulting in early yield reduction. Flower production on the first two clusters for either year was not reduced by high temperatures and was increased for 'Heinz 1810'. Tomatoes under slitted, white covers, the best-yielding treatment in 1987, yielded only 72% of those without rowcovers. Sustained high temperature, ≈ 40C for 3 consecutive hours or more, occurred with all rowcovers and correlated with early yield loss.**

The value of rowcovers for warm-season vegetable crops comes from enhanced early yield (Wells and Loy, 1985; Wolfe et al., 1989). Rowcovers were first used commercially in the late 1950s in California (Hall, 1977). Several different rowcover systems with various light transmission and ventilation characteristics are in use. The self-ventilating, slitted, hooped polyethylene rowcovers developed in the early 1980s reduce the labor requirements of hand-ventilating, but high temperatures detrimental to early tomato yield may still occur. A recent review of the literature by Wolfe and Bell (1987) indicated that rowcovers over tomato usually had no effect or reduced yield because of inadequate ventilation and excessively high temperatures. A review of tomato flowering and fruit set by Picken (1984) indicated that fruit set reduction was associated with temperatures > 30C. However, we have observed that early tomato yield was enhanced by use of slitted, hooped rowcovers in most years even when maximum air temperature under the cover exceeded 30C (Taber, 1983).

Tomato flower buds are highly susceptible to high temperatures 5 to 9 days before anthesis, and flowers are highly susceptible 1 to 3 days thereafter (Sugiyama et al., 1966). Blossoms may drop when exposed for 3 h or more to temperatures > 40C (Bar-Tsur, 1977; Sugiyama et al., 1966), but this response to temperature is cultivar-dependent (El Ahmadi and Stevens, 1979; Rudich et al., 1977; Shelby et al., 1978; Weaver and Timm, 1989).

The time elapsing between anthesis and noticeable fruit development, as well as ripe fruit development, is much shorter at high than moderate temperatures (Abdalla and Verkerk, 1968). Plants with a rowcover can be subjected to temperatures several degrees warmer than ambient (Taber, 1983; Wells and Loy, 1985; Wolfe et al., 1989). The objective of this experiment was to evaluate the effects of elevated tunnel temperatures caused by rowcovers on the flowering, fruit set, and early yield of four tomato cultivars.

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[1]Current address: 5339 Robert Ave., St. Louis, MO 63109.

Materials and Methods

The experiment was conducted in 1986 and 1987 at the Horticulture Research Station in central Iowa on a Clarion loam soil (fine-loamy, mixed, mesic typic Hapludoll). A spring broadcast application of N, P, and K was applied according to soil test recommendations. To suppress weed growth, α,α,α– trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine (trifluralin) was incorporated preplant at 1.2 kg a.i./ha before laying a 1.2-m-wide black plastic mulch on 1.8-m row centers. Trickle irrigation tubing was buried 5 cm just off row center at the same time the mulch was laid. Soil moisture was maintained at 30 to 40 kPa with the use of tensiometers placed at 20-cm depths. A conventional spray program for insect and disease management was followed throughout the growing season.

Four-week-old tomato seedlings raised in a 50-cell pack in the greenhouse were transplanted to the field on 1 May 1986 and 29 Apr. 1987 in a factorial, split-plot, randomized complete-block design. Treatments consisted of single-row plots, 6.1 m long, with in-row plant spacing of 61 cm. The five rowcover (whole plot) treatments evaluated were: 1) no cover (control); 2) slitted white (Insolar, Ken-Bar, Reading, Mass.); 3) slitted clear (Ken-Bar); 4) perforated = clear with 5-mm-diameter perforations spaced equidistantly at 10 cm; and 5) chimney = same as perforated but with a 10-cm-diameter hole above each plant. All plastics were linear, low-density materials, 0.02 to 0.03 mm thick. Transmittance of photosynthetically active radiation (Quantum Sensor; LI-COR, Lincoln, Neb.) on a bright, sunny day was 78% for the white, 86% for the clear, and 90% for the perforated and chimney plastics. At the time of planting, rowcovers were placed over wire hoops spaced every 1.5 m down the row. The height of the rowcovers over the black plastic mulch was 36 cm, and the rowcover was pulled tight to prevent sagging between hoops.

Four tomato cultivars (subplot) with different growth characteristics were selected: 'PikRed', early season maturity, determinate growth habit; 'Jetstar', second early season with indeterminate growth habit; 'Supersonic B', main season with indeterminate growth habit; and 'Heinz 1810', an early determinate processing tomato that tolerates heat stress.

Air temperatures were measured in every plot with shielded copper-constantan thermocouples placed next to the plant at a height of 20 cm. Three thermocouples were wired in parallel according to the procedure of Culick et al. (1982) to give one average output reading for each plot. In 1986, the temperatures were recorded with a Honeywell chart recorder once on the hour. In 1987, temperatures were monitored with a CR-10 data logger (Campbell Scientific, Logan, Utah) with a scan rate of 5 min and averaged hourly.

The rowcovers were removed on 29 May 1986 and 22 May 1987 when the plants began to touch the tops of the covers. Open flowers were visible on the first cluster for rowcovers in both years. Data were collected for number of flowers per cluster for the first two clusters, percent fruit set, date of first harvest, fruit size, and weight of marketable and cull fruits, Culls included small fruit and fruits with rots, radial and concentric cracks, and blotchy ripening. There was almost no catfacing or abnormally shaped fruit in either year. Early yield occurred from 14 to 21 July 1986 and from 7 to 13 July 1987. Harvests for total yield ended 20 Aug. 1986 and 19 Aug. 1987 for 5 and 6 weeks of harvest, respectively.

Results and Discussion

Temperature. The five rowcover treatments provided a significant separation in maximum temperatures (Fig. 1, Table 1), with consistent trends in both years. Rowcovers affected air temperature increases relative to no cover in the sequence: white, clear, chimney, and perforated—results similar to those of others (Wells and Loy, 1985; Wolfe et al., 1989). The maximum daily temperature ranged from a low of 15C for no cover and white to a high of 50C for chimney and perforated in 1986. In 1986, 4 cool, cloudy days did not raise temperatures under any of the rowcovers. In 1987, the maximum daily temperature ranged from a low of 18C with the no cover and white to 48C with the chimney rowcover. Ambient air temperatures for May were average in 1986 and 3 .0C above the average of 16.0C for 1987. Thus, average maximum temperatures were very high for all rowcovers in 1987; the average maximum temperature for slitted clear in 1987 was as high as that for perforated in 1986.

From 19 to 21 May 1986, there was a 17C difference between no cover and the perforated rowcover at 1300 HR, the time of maximum difference in temperatures (Fig. 2). The greatest difference between treatments in 1987 was 10C. Little or no temperature differences occurred between rowcovers for minima at 0600 HR, just before sunrise for both seasons, agreeing with a previous report (Wolfe et al., 1989). Air temperatures under the rowcovers, as compared with no cover, rose quicker in the morning and peaked later in the day. This warmer environment provides for quicker plant growth and development (Wells and Loy, 1985).

Picken et al. (1985) stated that the optimum temperature for vegetative growth of tomatoes is 18 to 25C. While rowcovers elevated average daily temperatures into this range, they also caused temperature peaks that could cause blossom drop. Air temperature for all rowcovers, except slitted white, exceeded 40C at least 1 day in both years. Exposure to sustained temperatures of 40C will result in increased fruit loss for most cultivars (Bar-Tsur, 1977; Picken, 1984; Rudich et al., 1977; Sugiyama et al., 1966; Weaver and Timm, 1989). Days with consecutive hours ≈ 40C occurred with chimney and perforated rowcovers in 1986 and with all rowcovers in 1987 (Table 2). This sustained high air temperature occurred near the end of the rowcover period (Fig. 1) when plants were larger and more susceptible to fruit abortion (Sugiyama et al., 1966).

Flower production. As expected, cultivars differed significantly (P = 0.01) in flower production for the first two clusters. 'Jetstar' and 'Heinz 1810' produced the most flowers (15) in both years, and 'PikRed' produced the fewest (11 in 1986, 12 in 1987). However, for both years, there was an interaction between rowcover and cultivar for flower production in the second cluster only. In both 1986 and 1987, 'Heinz 1810' produced 4.6 and 2.3, respectively, more flowers on the second cluster

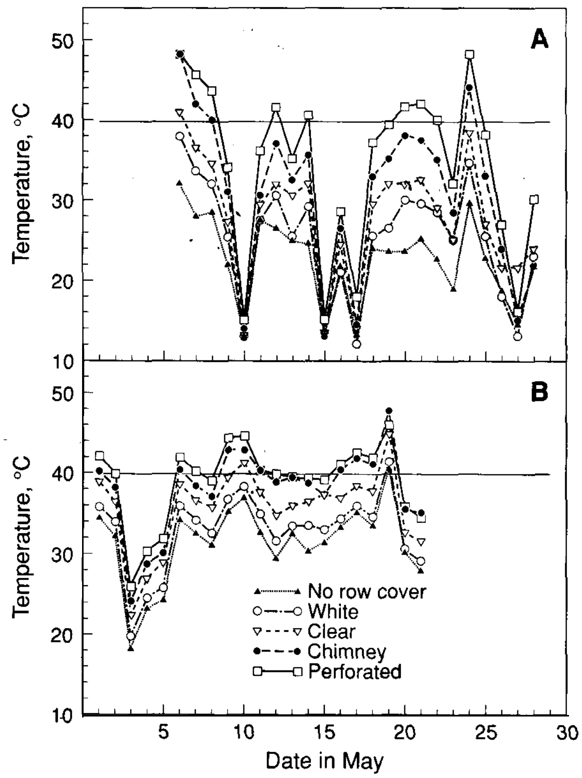

Fig. 1. Maximum daily temperatures (between 1200 and 1500 HR) under various rowcovers for **(A)** 1986 and **(B)** 1987.

Table 1. Average maximum and minimum temperatures for rowcover treatments, 6-28 May 1986 and 1-21 May 1987.[z]

Rowcover	Maximum (°C) 1986	Maximum (°C) 1987	Minimum (°C) 1986	Minimum (°C) 1987
None	24.5 e	31.4 e	15.1	16.0
White, slitted	27.2 d	32.9 d	14.8	15.8
Clear, slitted	29.9 c	35.7 c	14.9	15.9
Chimney	31.8 b	38.1 b	14.8	15.9
Perforated	36.4 a	39.0 a	14.8	16.1

[z]Memr separation within columns by Duncan's multiple range test, P = 0.05.

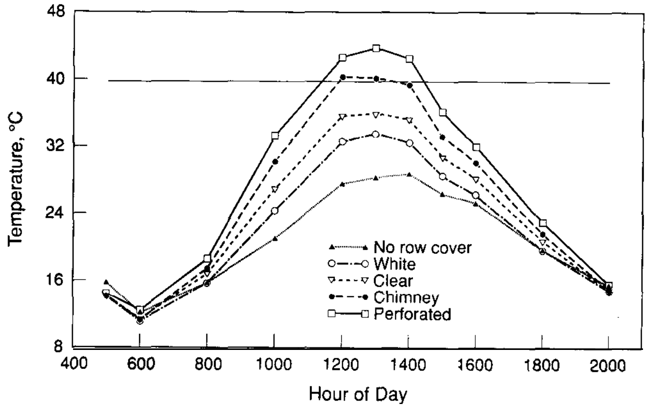

Fig. 2. Hourly temperatures under rowcovers averaged for the 3-day high temperature period of 19-21 May 1986.

Table 2. Number of hours and number of days with 3 consecutive hours above 40C while the rowcovers were in place, 1986 and 1987.

Rowcover	1986 Hours ≥40C	1986 Days with 3 consecutive hours ≥40C	1987 Hours ≥40C	1987 Days with 3 consecutive hours ≥40C
None	0	0	2	0
White	1	0	5	1
Clear	1	0	11	2
Chimney	6	1	35	5
Perforated	28	7	43	9

Table 3. Effect of rowcovers on fruit abortion from the first two flower clusters and on the number of fruit and fruit size for the early harvest, 1986 and 1987.[z]

	Fruit aborted (%)		Early harvest Fruit/plant (no.)		Early harvest Fruit wt (g)	
Rowcover	1986	1987	1986	1987	1986	1987
None	27 b	31 b	1.2 bc	2.9 a	176	176
White	19 a	33 b	2.4 a	1.8 b	181	197
Clear	18 a	33 b	2.6 a	1.9 b	198	194
Chimney	24 b	40 a	1.7 b	0.9 c	166	192
Perforated	25 b	41 a	1.0 c	1.0 c	204	190

[z]Mean separation in columns by Duncan's multiple range test, P = 0.05.

when under rowcovers that generated the highest temperatures (chimney and perforated). With the exception of 'Jetstar' in 1987 (a 12% reduction), no rowcover treatment reduced flower production. Field and growth chamber experiments by other researchers showed that high temperatures did not reduce flower production (Aballa and Verkerk, 1968; El Ahmadi and Stevens, 1979).

Flower set and fruit abortion. There was no interaction between rowcover and cultivar, so only the main effects of rowcover are presented (Table 3). Fruit set across cultivars was similar for all rowcover treatments and ranged from 95% to 97%. The difference in fruit numbers (early harvest) was related to the number of aborted fruit on the first two clusters rather than the number of flowers fertilized. In 1986, the white or clear rowcovers reduced fruit abortion by 5% to 9% compared with no, chimney, or perforated covers; this reduction contributed to the greater number of early fruit harvested from white and clear treatments. Also, the clear and white rowcovers increased earliness by advancing the appearance of flowers, including some early harvest from the third cluster. Although high temperatures occurred for short periods, there were several days where maximum did not equal 20C (Fig. 1).

For 1987, chimney and perforated rowcovers increased fruit abortion by 9% compared with the other treatments, but the number of early fruit was reduced by all covers when compared with no cover, with chimney and perforated having the greatest reduction. Data on fruit abortion do not account for the 65% reduction in early fruits. White and clear rowcovers did not increase fruit abortion, but the number of early fruit was significantly reduced. Unlike in 1986, maximum daily temperatures were rarely below 30C. Day-to-day fruit setting is highly erratic (Rick and Dempsey, 1969), and data on fruit abortion were taken only once, when fruit was ≈2.5 cm in diameter. Fruit continued to abort up to the first harvest.

When there are three consecutive hours above 40C, advancement of early fruit ripening is lost because of flower blossom loss (Picken, 1984; Sugiyama et al., 1966). Temperatures >40C can cause loss of pollen viability and lack of fruit set (Picken et al., 1985; Shelby et al., 1978). Fertilized fruit may also abort if the temperature is above 40C for too long (El Ahmadi and Stevens, 1979; Rudich et al., 1977). Although high night temperatures can reduce fruit set (Shelby et al., 1978), minimum temperatures during May were consistently below 20C in both years. As temperature increased above 40C under various rowcovers, early yield advantage was lost. In 1986, only the chimney and perforated rowcovers generated temperatures > 40C for 3 consecutive hours (Table 2). In 1987, temperatures of at least 40C were reached under all the rowcovers for at least one 3-h period and 30C was reached for most of the covered period. These results indicate that high temperatures under the rowcovers do not reduce flower production but do increase fruit abortion. In contrast, Rudich et al. (1977) found a greater reduction in percent fruit set as a result of high temperature.

Yield. Early yield of tomatoes showed no rowcover x cultivar interaction; thus, only the main effects of rowcovers are presented. There were significant cultivar yield differences, such as time of yield, percentage of marketable yield, fruit number, and fruit size, which is to be expected based on individual cultivar traits (data not presented).

For 1986, the enhancement of growth under the clear and white rowcovers resulted in a significant increase in early and total marketable yields (Table 4). Clear enhanced early yield by 177% and white by 109%, compared with no rowcover. These two rowcovers produced significantly more fruit than the other rowcovers (Table 3). There was no difference in fruit size. The chimney and perforated covers did not enhance early yield even though the plants under these covers were vegetatively larger (observation) than plants with no rowcovers. There was no increase in early fruit harvest for those rowcovers with temperatures > 40C (chimney and perforated). Early yield and number of fruit for chimney and perforated covers were similar to those for no rowcover (Tables 3 and 4). Second-cluster flower production and fruit set were not decreased and was significantly increased (by 30%) for 'Heinz 1810'. Rowcovers may have advanced flowering (not measured) of some clusters, but this effect appears to have been offset by a higher percentage of abortion with the chimney and perforated covers. There was no significant difference in the percentage (range 13% to 44%) of early cull fruit for either 1986 or 1987.

Table 4. Effect of rowcovers on early and total marketable tomato yield, 1986 and 1987.

	Marketable yield[z,y] Early		Total	
Rowcover	1986	1987	1986	1987
	$t \cdot ha^{-1}$			
None	1.2 b	3.6 a	31 b	63
White	2.5 a	2.6 b	36 ab	61
Clear	3.3 a	2.5 b	40 a	64
Chimney	1.4 b	1.4 c	39 a	62
Perforated	0.9 b	1.4 c	40 a	64

[z]Mean separation in columns by Duncan's multiple range test, P = *0.05.*

[y]Early yields of tomatoes harvested during first 7 days; total yield for 37 days in 1986 and 43 days in 1987.

Early yield was the highest for the no cover treatment and most depressed for chimney and perforated covers in 1987. Both of these generated an early yield only 39% of that for no rowcover; whereas plants under the white and clear covers produced only 72% of the early yield without cover. Correlation analysis showed a significant (P =0.05) negative relationship (r = – 0.61) between early yield and the number of days with temperature in excess of 40C for 3 h (Tables 2 and 4). Because of the risk of sustained high temperatures on warm, sunny days, rowcovers for tomatoes should be well ventilated.

Total yield was not affected by rowcover treatment in 1987. Thus, early fruit loss appears to have increased vegetative growth, especially with the perforated and chimney covers, resulting in more fruit in later harvests. For 1986, rowcovers increased yield 8.7 $t \cdot ha^{-1}$ compared with no rowcover (Table 4), except for the white rowcover. The white-pigmented plastic reduced light transmission, keeping the temperature under the rowcover lower; thus, the plants were not as large as those under perforated and chimney covers. This difference slightly reduced the total yield from plants under the white covers as compared with the others. There was no difference in the total percentage of culls (range 28% to 37%) produced for any of the rowcover treatments in either year.

A rowcover's main advantage is in early yield enhancement. This goal was achieved in 1986, but not in 1987 when early yields were significantly reduced under all rowcovers compared with no rowcover. Rowcovers should be removed when temperature remains high for more than 1 h during flowering and fruit set. Any heat-unit or degree-day model for predicting early yield would have to include a high-temperature factor, as suggested by Wolfe et al. (1989). Perhaps materials could be developed that would regulate transmittance of solar radiation based on tunnel temperature.

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