Increased Yield of Heat-tolerant Tomatoes with Deep Transplanting, Morning Irrigation, and White Mulch

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Abstract. Studies were conducted in Fall 1994 and Summer 1995 to determine growth and yield response of heat-tolerant tomatoes (*Lycopersicon esculentum* Mill.) to transplant depth, time of daily irrigation, and polyethylene mulch color. Five-week-old tomato transplants were planted to a depth of either 7.5 or 15.0 cm, drip irrigated every other day for 2.5 h starting at either 7:30 AM or 2:30 PM for 80 d following transplanting, and mulched with white-surface (white on black) or black polyethylene. Soil temperatures were recorded daily at 4:00 PM for 21 d from the beginning of fruit set (2 weeks following transplanting) until the tomato canopy shaded the mulch surface. Transplanting tomatoes to a depth of 15.0 cm significantly increased marketable yield in both years and the total yield in 1 year of this study. Mean fruit mass was not influenced by transplant depth, but plant dry mass was significantly increased by deeper transplanting in 1995. Morning irrigation increased the marketable and total yields and mean fruit mass in both years and plant dry mass in 1995. White-surface mulch had a similar effect on yield and fruit mass. Soil temperature was significantly lower at the 15.0-cm depth than at 7.5 cm in both years. Morning irrigation and white-surface polyethylene mulch also significantly reduced soil temperature in both years.

The desire to extend the normal tomato growing season into the hot summer months by breeding heat-tolerant tomatoes has received considerable attention in the past several years (Hanna and Hernandez, 1982; Hanna et al., 1982; Wessel-Beaver and Scott, 1992). As a result, several heat-tolerant cultivars and inbred lines were developed for producing tomatoes under these above-optimal temperature conditions (Hanna et al., 1992; Scott et al., 1995). Although these cultivars and inbred lines are genetically adapted to produce under high temperatures using normal cultural practices, little is known concerning whether or not alternative cultural practices such as planting depth, the time of day irrigation is applied, or polyethylene mulch color might enhance their environmental adaptation and yield.

Information on the effects of planting depth on growth and yield of vegetable crops is

limited. Lindgren (1990) found that asparagus (*Asparagus officinalis* L.) spear emergence and spring harvest date were delayed and susceptibility to frost injury was decreased with increasing plant depth. Recent studies by Vavrina et al. (1994) indicated that bell pepper (*Capsicum annuum* L.) transplants set to the depth of cotyledon leaves or to the first true leaf yielded more fruit than transplants set to the top of the root ball. Vavrina et al. (1996) also reported that deeper transplanting of tomatoes increased first harvest yield.

The use of drip irrigation in vegetable production has increased in popularity. Water quantity and frequency of application have been the focus of most drip-irrigation studies (Hartz, 1993; Locascio et al., 1989). However, effect of daily time of application has received no attention.

Although field studies have indicated that polyethylene mulch color can have an effect on soil temperature and tomato yield (Decoteau et al., 1989), the effect of mulch color on heat-tolerant tomato growth and yield is not fully documented. Our study was conducted to determine how transplanting depth, time of daily irrigation, and polyethylene mulch surface color affect growth and yield of heat-tolerant tomatoes.

Studies were conducted in the fall (July to Nov., 1994) and summer (May to Aug., 1995) on a Norwood sandy loam soil (Typic Udifluent; fine-silty, mixed, calcareous, thermic) at our laboratory. Planting dates, harvest period, air temperature during fruit set, and rainfall during the test period in each year were recorded (Table 1). The cultivar Sunmaster was used in the 1994 study and was replaced with 'Solar Set' in 1995 due to the unavailability of 'Sunmaster' seed. The two cultivars are genetically adapted to set fruit under heat stress and are mostly used by commercial growers and home gardeners for tomato production under hot summer and fall conditions of the southern United States. The design was a 2 × 2 × 2 factorial, arranged in a randomized complete block with four replications. Treatments were: 1) transplants planted 7.5 vs. 15.0 cm deep, 2) morning (7:30 to 10:00 AM) vs. afternoon (2:00 to 4:30 PM) irrigation, and 3) white-surface (white on black) vs. black-surface (black on black) polyethylene mulch. Tomato seeds were sown in No. 38 growing trays (Growing Systems, Milwaukee, Wis.) in both years. Transplants were raised in soilless mix (Pro-Mix BX; Premier Brands, Yonkers, N.Y.) for 5 weeks in the greenhouse before being planted in the field in 1.5 × 30-m plots. White- and black-surface polyethylene mulch (1.5 m wide), and drip irrigation tubing were applied to the test plots by machine. Transplants were set to the indicated depth using a plant setter (Kennco Mfg., Ruskin, Fla.). The depths were selected based on the average height of the root ball (7.5 cm) and the first true leaf (15.0 cm) in a 100-plant sample of our transplants. Equal amounts of water (Hanna et al., 1984) were applied every other day (except when unnecessary due to rain) to morning and afternoon irrigation plots using Hardie irrigation tape with 30-cm emitter spacing and 1.14 L·h⁻¹ flow per emitter (Hardie Irrigation, Sanford, Fla.). Soil temperature at 7.5- and 15-cm depth were recorded daily for 21 d at 4:00 PM beginning 2 weeks after transplanting and continuing until the plant canopy shaded the mulch surface. Soil temperatures were measured using 107B soil temperature probes connected to a CR-10 data logger (Campbell Scientific, Logan, Utah).

Samples of the tops of five plants, without fruit, were collected before the first harvest, oven-dried at 71 °C for 5 d, then weighed. Tomatoes were harvested at the pink stage three times a week for 2 to 3 weeks (Table 1). Fruit with blossom-end rot and other visible defects were removed and the rest were size-graded according to U.S. Dept. of Agriculture

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Table 1. Planting date, harvest periods, average air temperatures, and total rainfall during the growing season of tomatoes in 1994 and 1995.

Planting date ²	Harvesting period	Temp (°C) ³		Rainfall (mm)
		Max	Min	
17 Aug. 1994	24 Oct.–7 Nov.	33.3	21.7	404
16 May 1995	12 July–2 Aug.	32.3	19.3	186

²Tomatoes were sown in the greenhouse 5 weeks earlier to produce transplants.

³Air temperatures were recorded during the same period as root temperature.

Table 2. Main effects of transplant depth, irrigation time, and mulch surface color on tomato growth and yield for 2 years.

Variable	Fruit yield (t·ha ⁻¹)				Fruit mass (g)		Plant dry mass (g)	
	Marketable		Total		(g)		(g)	
	1994 ^a	1995	1994 ^a	1995	1994	1995	1994	1995
Depth (cm)								
7.5	5.9	20.0	9.3	23.7	173	187	128	207
15.0	7.3	23.4	10.9	27.5	175	190	132	224
Significance	**	***	NS	***	NS	NS	NS	**
Irrigation time								
AM	7.3	23.6	11.1	27.1	179	193	132	222
PM	5.9	19.8	9.2	24.0	169	183	128	209
Significance	*	***	*	***	**	***	NS	*
Mulch color								
White/Black	8.9	22.5	13.8	26.6	178	192	130	230
Black	4.3	20.9	6.5	24.5	170	184	130	200
Significance	**	*	***	**	*	***	NS	***

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 3. Main effects of transplant depth, time of irrigation, and mulch surface color on soil temperature at 4:00 PM.

Variable	Temp (°C)	
	1994	1995
Depth (cm)		
7.5	30.9	30.5
15.0	29.5	29.1
Significance	**	**
Irrigation time		
AM	30.0	29.6
PM	30.4	30.0
Significance	**	**
Mulch color		
White/Black	29.3	29.8
Black	31.1	30.7
Significance	**	**

**Significant at $P \leq 0.01$.

standards (U.S. Dept. of Agriculture, 1991) for U.S. small, medium, large, and extra large. Marketable yield was determined by combining the mass of fruit graded medium or larger; total yield was the sum of all four sizes. Mean fruit mass was determined by dividing the total marketable yield by the number of marketable fruit. Data were analyzed by analysis of variance and GLM (SAS Institute, Cary, N.C., 1990).

Results and Discussion

Yield was lower in 1994 than in 1995 due to increased disease and insect pressure. Setting tomato transplants to a depth of 15.0 cm significantly increased the marketable yield in both years compared to 7.5-cm depth (Table 2). The deeper planting also significantly increased the total yield in 1995, but not in 1994. Mean fruit mass was not influenced by planting depth in either year but plant dry mass was significantly increased by deeper transplanting in 1995. Root zone temperature was lower at the 15-cm than at the 7.5-cm depth (Table 3). Deeper transplanting may have caused a larger root mass to form on the extra buried portion of the stem and may also have improved root growth due to less fluctuation in moisture and temperature, resulting in a healthier and stronger plant and increased yield.

Morning irrigation increased the marketable and total yields and the mean fruit mass of tomatoes in both years of this study. Dry mass of tomato plants irrigated in the morning was

significantly higher in 1995 but not in 1994 (Table 2). Morning irrigation provided only a minor reduction in soil temperature (Table 3). However, the early-morning irrigation may have lessened the daily temperature stress plants encounter as air temperature start to climb.

Marketable and total yields of the heat-tolerant tomato cultivars tested in this study were significantly higher when tomatoes were grown with white than with black-surface polyethylene mulch. Fruit also was heavier in both years and plant dry mass was higher in 1995 with white mulch (Table 2). White-surfaced mulch significantly reduced root-zone temperature (Table 3). There is little agreement among researchers concerning the optimum root zone temperature for active tomato growth. However, Gosselin and Trudel (1983) indicated that maximum tomato yields in a green-

house were obtained with roots at 24 °C combined with air at 18 °C.

Mulch color, planting depth, and time of irrigation interacted with soil temperature and yield in respect to marketable and total yield in both years. The highest root-zone temperature in 1994 resulted from using black-surface mulch, transplanting at 7.5-cm depth, and irrigating in the afternoon (Fig. 1). This combination also resulted in the lowest marketable and total tomato yields (Fig. 2). The lowest root-zone temperature resulted from using white-surface mulch, transplanting at 15.0-cm depth, and irrigating in the morning (Fig. 1), but the highest yield resulted from using white-surface mulch regardless of planting depth or time of irrigation (Fig. 2). In 1995, root-zone temperature followed the 1994 trend (Fig. 1), and morning irrigation tended to increase tomato yields if planted at 15-cm depth with

Fig. 1. Combined effect of irrigation time, transplanting depth, and polyethylene mulch surface color on soil temperature during Fall 1994 and Summer 1995. Mean separation at $P \leq 0.05$ by LSD test.

Fig. 2. Combined effect of irrigation time, transplanting depth, and polyethylene mulch surface color on (A) total tomato yield and (B) marketable tomato yield of the heat tolerant tomato 'Sunmaster' grown during Fall 1994. Mean separation at $P \leq 0.05$ by LSD test.

Fig. 3. Combined effect of irrigation time, transplanting depth, and polyethylene mulch surface color on (A) total tomato yield and (B) marketable tomato yield of the heat-tolerant tomato 'Solar Set' grown during Summer 1995. Mean separation at $P \leq 0.05$ by LSD test.

black-surface mulch or at 7.5-cm depth with white-surface mulch as compared with afternoon irrigation (Fig. 3).

In conclusion, results from this study indicate that yield increase of heat-tolerant tomatoes can be accomplished by deeper transplanting, morning irrigation, using white-surface polyethylene mulch, or a combination of all three.

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