Table 1. Adjustment guide for hole burner on a Model 900 Mechanical Mulch Planter.

Cups	Plant spacing	Crank radius	Drive ratio
2	32 in (81 cm)	5.1 in (12.9 cm)	1:2
3	21 in (54 cm)	3.4 in (8.6 cm)	1:3
4	16 in (41 cm)	2.6 in (6.5 cm)	1:4
5	13 in (33 cm)	2.0 in (5.2 cm)	1:5

for each turn of the cup wheel. The position of the chain on the roller chain sprockets can be adjusted for precise timing adjustment of the hole burner and the transplanter wheel so that each cup accurately enters each preformed hole.

The in-row plant spacing on this transplanting machine can be changed by adding or removing seedling cups from the wheel. If the number of cups is changed from four, the burner crank radii and drive ratio must be adjusted accordingly. Table 1 gives the crank radii and drive ratios for each available plant spacing from 32.5 cm (12.8 in) to 81.3 cm (32 in.).

The speed of the hole burner mechanism is, of course, a function of the transplanting rate. A typical plant setting rate for a transplanter with one worker feeding the plants is about 1 to 1.5 plants per second. At this rate, the hole burner mechanism must turn at 60 to 90 rpm, an appropriate rotational speed for this mechanism without having to be dynamically balanced.

Field Performance

This mechanism has been field evaluated with a 7.6 cm (3 in.) cup dibble hole burner heated with a LPG burner. It has given satisfactory service while planting experimental plots. A modified mechanism with a 10 cm (4 in.) cup dibble burner has been installed on an automatic vegetable transplanter and has performed satisfactorily at a transplanting rate of over two seedlings per second.

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REDUCING ROOT-ZONE TEMPERATURE TO ENHANCE HEAT-TOLERANT TOMATO YIELD

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Abstract. **Studies were conducted for two years to determine the influence of deep transplanting, time of daily irrigation, and polyethylene mulch color on root-zone temperature and yield of two heat-tolerant tomato (*Lycopersicon esculentum* Mill.) cultivars. Five-week-old tomato transplants were planted to a depth of either 7.5 or 15.0 cm, irrigated every other day for 2.5 hours starting at either 7:30 AM or 2:30 PM for 80 days following transplanting, and mulched with white-surface (white on black) or black polyethylene. Soil temperatures were recorded daily at 4:00 PM for 21 days from the beginning of fruit set (two weeks following transplanting) until the tomato canopy shaded the mulch surface. Transplanting tomatoes to a depth of 15.0 cm significantly lowered soil temperature than at the 7.5 depth and increased the marketable yield in both years and the total yield in one year of this study. Fruit weight was not influenced by transplant depth, but plant dry weight was significantly increased by transplanting deeper in 1995. Morning irrigation and white-surface polyethylene mulch also significantly reduced soil temperature and increased the marketable and total yields and average fruit weight in both years and plant dry weight in 1995.**

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 ambient temperatures using standard 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 improve their root-zone environment and yield.

Information on the effects of planting depth on root-zone temperature and growth and yield of vegetable crops is limited. Lindgren (1990) found that asparagus (*Asparagus officinales* L.) spear emergence and spring harvest date were delayed

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and susceptibility to frost injury was decreased with increasing plant depth, but no information on soil temperature at planting depth was provided. 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. They speculated that larger yield from deeper transplanting may have resulted from improved temperature for root growth. In 1996, Vavrina et al. reported that deeper transplanting of tomatoes increased their first harvest yield.

The use of drip irrigation in vegetable production has increased in popularity. The primary reasons growers have switched from traditional methods of irrigation to drip irrigation are improved water application efficiency and precision nutrient and water placement offered by this system. 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 on soil temperature and yield has received little 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 root-zone temperature of heat-tolerant tomatoes and their growth and yield is not fully documented. This study was conducted to determine how transplanting depth, time of daily irrigation, and polyethylene mulch surface color affect root-zone temperature and growth and yield of heat-tolerant tomatoes.

Materials and Methods

Studies were conducted in the Fall (July to Nov., 1994) and Summer (May to Aug., 1995) on a Norwood sandy loam soil (Typic Udifluvent; fine-silty, mixed, calcareous, thermic) at the Red River Research Station, Louisiana State University Agricultural Center in Bossier City, LA. Planting dates, harvest period, air temperature during fruit set, and rainfall during the test period in each year were recorded (Table 1). Soil temperature at 7.5-and 15-cm depth were recorded daily for 21 days at 4:00 PM beginning two weeks after transplanting and continued 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, Inc., Logan, Utah). Also, maximum and minimum air temperatures during the same period were recorded. 'Sunmaster' cultivar was used in 1994 studies and was replaced with 'Solar Set' in 1995 because of the unavailability of seeds of the former. The experimental 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. 'Sunmaster' and 'Solar Set' heat-tolerant tomato seeds were sown in No. 38 growing trays (Growing Systems, Inc., Milwaukee, Wisconsin) in 1994 and 1995, respectively. Transplants were raised in soilless mix (Pro-Mix BX; Premier Brands, Yonkers, N.Y.) for five 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 Kennco's plant setter (Kennco Mfg., Inc., Ruskin, Florida.) to eliminate possible variation in planting depth if transplants were set to the top of the root ball or to the first true leaf in holes made by any other means. These depths were selected based on the average height of the root ball (7.5 cm) and the first true leaf (15.0 cm) in 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 treatments using Hardie irrigation tape (Eht101250-600) with 30-cm emitter spacing and 1.14 liter/hr flow per emitter (Hardie Irrigation, Sanford, FL).

Samples of the tops of five plants, without fruit, were collected before the first harvest, oven-dried at 71C for 5 days, then weighed. Tomatoes were harvested at the pink stage three times a week for the periods indicated in Table 1. Fruit with blossom-end rot and other visible defects were removed and the rest were size-graded by a machine according to U.S. Dept. Of Agriculture standards (U.S. Dept. of Agriculture, 1991) for U.S. small, medium, large, and extra large. Marketable yield was determined by combining the weight of fruit graded medium, large, and extra large. Total yield was the sum of fruit graded small, medium, large, and extra large. Average fruit weight was determined by dividing the total marketable yield by the number of marketable fruit. Data were analyzed by ANOVA and GLM (SAS Institute, Cary, N.C., 1990).

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

Planting dates[z]	Harvesting periods	Temp (C)[y] Max	Temp (C)[y] Min	Rainfall (mm)
17 Aug. 1994	24 Oct.-7 Nov.	33.3	21.7	404.4
16 May 1995	12 Jul.-2 Aug.	32.3	19.3	186.4

[z]Tomatoes were sown in the greenhouse 5 weeks earlier to produce transplants.
[y]Air temperatures were recorded during the same period as root temperature.

Results and Discussion

Root-zone temperature was lower at the 15.0-cm than at the 7.5-cm depth in both years of this study (Table 2). The

Table 2. Main effects of transplant depth, time of irrigation, and mulch surface color on soil temperature at 4:00 PM.

Treatment	Temperature (C) 1994	Temperature (C) 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 $P \leq 0.01$.

Table 3. Main effects of transplant depth, irrigation time, and mulch surface color on tomato growth and yield for two years.

	Fruit yield (t·ha⁻¹)				Fruit wt. (gm)		Plant dry wt. (gm)	
	Marketable		Total					
Treatment	1994	1995	1994	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 $P \le 0.05$, 0.01, or 0.001, respectively.

marketable yield of tomatoes transplanted to a depth of 15.0-cm was also greater in 1994 and 1995 as compared with yield of tomatoes transplanted to a depth of 7.5-cm (Table 3). Deeper planting also significantly increased the total yield in 1995, but not in 1994. Average fruit weight was not influenced by planting depth in either year, but plant dry weight was significantly increased by deeper transplanting in 1995. The larger yield from deeper transplanting may be the result of lower temperature in the root zone, and possibly less variation in soil moisture resulting in improved root growth of the tomato plant. Deeper transplanting may also have caused a greater root mass to form on the extra buried portion of the stem, resulting in a healthier and stronger plant and increased yield. Lamont (1996) concluded from his review of vegetable production systems using plasticulture that a slight reduction in soil temperature when soil is hot can be beneficial to establish and produce a crop. Our previous observational trials indicated that shallow transplanting of heat tolerant tomatoes in July resulted in a high mortality rate of these transplants because of the heat and drought conditions in the shallow root zone. Vavrina et al. (1994) speculated that deeper transplanting of bell pepper may have placed roots in a cooler environment and reduced the fluctuation of soil temperature resulting in improved temperature conditions for root growth and higher yields. In their recent study on tomatoes, Vavrina et al. (1996) indicated that the same reasons hypothesized for yield increase of pepper may apply to tomatoes.

Morning irrigation provided some small but significant reduction in soil temperature (Table 2), and increased the marketable and total yields and the average fruit weight of tomatoes in both years of this study (Table 3). Dry weight of tomato plants irrigated in the morning was significantly greater in 1995 but not in 1994. These small reductions in soil tem-

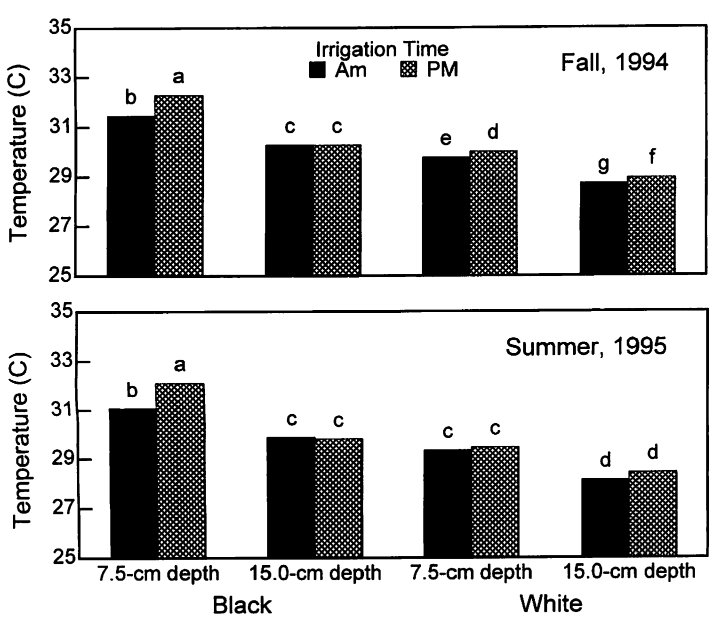

Figure 1. Combined effect of irrigation time, transplanting depth, and polyethylene mulch surface color on soil temperature during the fall of 1994 and summer of 1995. Mean separation at $P \le 0.05$ by LSD test.

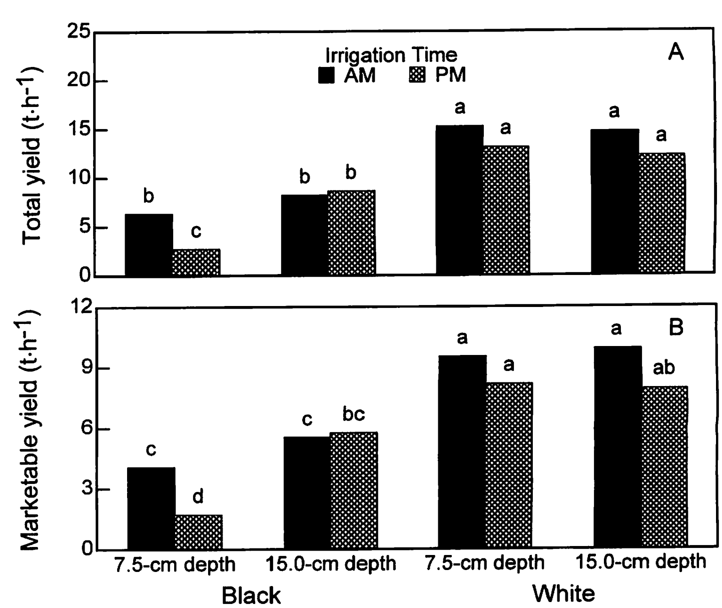

Figure 2. Combined effect of irrigation time, transplanting depth, and polyethylene mulch surface color on (A) total tomato yield and (B) marketable tomato yield of the heat tolerant tomato 'Sunmaster' grown during the fall of 1994. Mean separation at $P \le 0.05$ by LSD test.

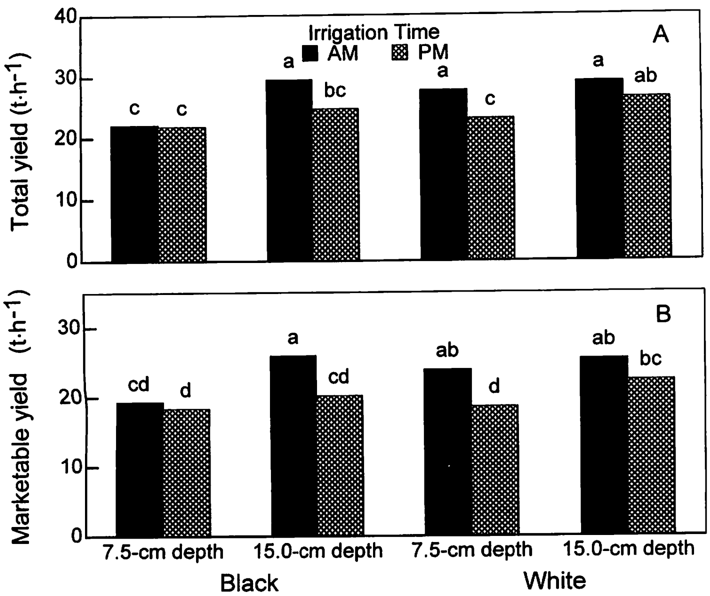

Figure 3. Combined effect of irrigation time, transplanting depth, and polyethylene mulch surface color on (A) total tomato yield and (B) marketable tomato yield of the heat tolerant tomato 'Solar Set' grown during the summer of 1995. Mean separation at P ≤ 0.05 by LSD test.

peratures combined with morning irrigation may have resulted in improved transpiration and consequently reduced leaf and canopy temperatures and improved the photosynthetic activity. It is also possible that the early-morning irrigation may have lessened the daily temperature stress plants encounter as temperature starts to climb.

White-surface mulch significantly reduced root-zone temperature (Table 2) and increased the marketable and total yields of the heat-tolerant cultivars tested in this study (Table 3). Fruit weight was also greater in both years and plant dry weight was greater in 1995. There is little agreement among researchers concerning the optimum root zone temperature for active tomato growth. However, Gosselin and Trudel (1993) indicated that maximum yields were obtained at 24 C root temperature combined with 18 C air temperature. Decoteau et al.(1989) indicated that soil temperatures were warmer under black or red mulch than under white or silver-colored mulch. They also indicated that tomato plants grown with white mulch produced more foliage.

Mulch color, planting depth, and time of irrigation interacted with soil temperature 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 15.0-cm depth with 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 factors which reduce the temperature of the root-zone may be beneficial in increasing the yield of heat-tolerant tomatoes. This reduction in root-zone temperature can be accomplished by deeper transplanting, using white-surface polyethylene mulch, morning irrigation, or a combination of all three. It is also possible that deeper transplanting may have resulted in the development of adventitious roots from the buried stem surface providing increased root mass and, therefore, increased uptake of water and nutrition. Morning irrigation may have facilitated transpiration, thereby cooling the canopy and relieving some of the stress of diurnal increases in ambient temperature.

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