Growth and Yield of Tomato Plants in Response to Age of Transplants

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Abstract. Studies were conducted to evaluate growth of tomato (*Lycopersicon esculentum* Mill.) transplants in the field in response to age of transplants in Spring and Fall 1989. Transplants were 2 (2W), 3 (3W), 4 (4W), 5 (5W), or 6 (6W) weeks old. Drip and subseepage irrigation were used. In spring, older transplants produced more shoot and root growth up to 2 (T2) weeks after transplanting. At 3 (T3) and 4 (T4) weeks after transplanting, there were no differences between 4W, 5W, and 6W transplants. These trends were independent of irrigation systems. Total yield and early yield were similar for all transplant ages. In fall, shoot growth increased linearly with increasing transplant age at T0, but not thereafter. Chlorophyll a + b increased over time, but no treatment differences were found at T4. At planting, 2W transplants had a higher Chl a : b ratio than older transplants. This difference was reduced at T1 and T2 and became insignificant at T4. These results indicate that no improvement in yields was obtained using the traditional older transplants. Younger transplants might be used to achieve rapid seedling establishment with minimal transplant production costs.

In Florida, fresh-market tomatoes are established in the field by direct seeding or by using 5- or 6-week-old containerized transplants. Effects of age of containerized Transplants have been reported on several vegetable species. Lowest head weight variability was found in "lettuce using 13- and 19-day-old transplants compared to those 25 days old (Wurr and Fellows, 1986). Conversely, earlier yields were obtained from 7-week-old lettuce transplants than from those 6 to 3 weeks old (Wang and Kratky, 1976). Yields were similar for 3- to 6-week-old Chinese cabbage transplants (Kratky et al., 1982). Similarly, marketable curd yields did not differ among 5- to 8-week-old cauliflower transplants (Wurr et al., 1986). Asparagus transplants that were 8.5 weeks old produced more shoots than those 6 and 7 weeks old, and a similar number as 10-week-old transplants (Dufault and Waters, 1984). In pepper, 60-day-old seedlings had greater early yields than younger ones (Weston, 1988).

Plant growth improvement using relatively young bareroot tomato transplants has been reported (Nicklow and Minges, 1962). Weston and Zandstra (1989), using containerized transplants, reported that plant height, leaf area, and shoot weight increased linearly as transplant age increased from 3 to 6 weeks, but measurements were done only at transplanting. None of these studies considered the changes in shoot and root development after transplanting. Such information would be useful in understanding the relationship between the physiological state of transplants and their growth responses under various cultural systems and environments.

This study was conducted to determine the effects of transplant age on growth after re-establishment and on fruit size, count, and yield.

Materials and Methods

Transplant production, Spring 1989. Seedlings were grown at Speedling, Inc., in greenhouses at Bushnell, Fla. (lat. 28.4 N and long. 82.5 W). Speedling polystyrene trays with 128 inverted pyramid cells of 3.8 x 6.4 cm (side length x depth; 31 cm³) were used. Tomato seeds were sown in a 2 peat : 1 vermiculite : 1 perlite mix (by volume) on 19 and 26 Dec. 1988 and on 2 and 9 Jan. 1989 to obtain 3 (3W)-, 4 (4W)-, 5 (5W)-, and 6 (6W)-week-old transplants. Trays were held in germination chambers at 25C and 100% relative humidity for 3 days and then in greenhouses where they remained until transplanting. After seedling emergence, transplants were irrigated using a flotation system three times/week for 45 min until 21 days (Leskovar et al., 1990). In each irrigation, a soluble fertilizer (20N-10P-20K) was given at a concentration of 50 mg of N/liter. After 21 days, seedlings (4W, 5W, and 6W) were irrigated twice/week for 30 min. In the last irrigation, seedlings were watered with the same nutrient solution and rate used before. The greenhouse was held at a 28C maximum and 6C minimum.

Transplant production, Fall 1989. Seedlings were grown in Speedling polystyrene trays with 200 inverted pyramid cells of 2.5 x 7.0 cm (side length x depth; 18 cm³). Tomato seeds were sown on 15, 21, and 28 July and 4 Aug. 1989 for the 2-, 3-, 4-, and 5-week-old transplants, respectively. After 5 days, seedlings were irrigated daily with a 20N-10P-20K (50 mg of N/liter) nutrient solution for 30 min until 21 days and using the same irrigation system used in Spring 1989. After 21 days, transplants (4W and 5W) were irrigated three times/week for 30 min and 1 day before delivery to the field with the same nutrient solution and rate used before. The greenhouse was held at a 34C maximum and 18C minimum.

Spring 1989, Expt. 1, Parri.sh. Transplants were planted at a commercial farm located in Parrish, Fla., (sandy, siliceous, hyperthermic, Entic Haplaquods) on 2 Feb. 1989. The transplants were 3 (3 W), 4 (4W), 5 (5 W), or 6 (6W) weeks old. Plants were grown on single raised (15-cm-high) beds spaced 1.8 m between rows and 0.6 m within rows. Fertilizer (26N-107P-

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Table 1. Shoot and root characteristics of tomato transplants as affected by their age, Spring 1988. Experiment 1 at Parrish, Fla., and Expt. 2 at Bradenton, Fla.²

Transplant age (weeks)	Stem length (cm)			Stem diam (mm)			Leaf area (cm ²)		
	T0	T1	T2	T0	T1	T2	T0	T1	T2
<i>Expt. 1</i>									
3	3.9	6.1	8.3	1.6	3.3	4.8	9	38	106
4	6.0	7.3	9.4	2.5	4.4	5.0	21	63	110
5	7.5	9.4	12.9	2.6	4.1	5.3	26	62	204
6	8.3	11.3	14.9	2.6	3.8	5.6	28	81	211
Significance	Q*	L**	L**	Q**	Q*	L*	L**	L**	L**
<i>Expt. 2</i>									
3	3.9	5.8	7.3	1.6	3.2	4.3	9	33	64
4	6.0	7.5	8.8	2.5	4.3	5.0	21	55	98
5	7.5	9.2	10.9	2.6	3.8	4.5	26	61	125
6	8.3	11.7	13.9	2.6	4.1	5.1	28	83	172
Significance	Q*	L**	L**	Q**	Q*	L*	Q**	L**	L**

²T0 = at transplanting; T1 and T2 are 1 and 2 weeks after transplanting.

***Significant F test at $P = 0.05$ or 0.01 , respectively. Transplant age effect was linear (L) or quadratic (Q).

42K, kg·ha⁻¹) was broadcast and incorporated in the center of the bed. Topdress fertilizer (300N-480K, kg·ha⁻¹) was applied in two bands in shallow grooves on the bed surface 25 cm to each side of the bed center. Beds were fumigated with 67 methyl bromide :33 chloropicrin at 210 kg·ha⁻¹ and covered with black polyethylene mulch (0.038-mm thickness). Subseepage irrigation was applied to maintain a uniform level of moisture and a water table ≈40 cm deep. Subseepage irrigation ditches were located between every four beds. Standard pesticides and cultural practices were used (Hochmuth, 1988). The monthly means after transplanting were 18.5C for Feb. and 21.2C for March.

Plants for root samples were shovel-excavated at times noted below at 20 x 20 cm (side x side) from the center of the plant and at a 30-cm depth. Plants were first gently shaken with the shovel, grasped by the stem, placed in polyethylene bags, and transported to 5C rooms, where they remained for 1 to 2 days, until examined. Shoots were excised at soil surface. Stem diameter was measured with a digital caliper just below the cotyledonary node. Stem length was measured from the shoot apex to the cut end and leaf area (LA) with a LI-COR (Model LI-3100; LI-COR, Lincoln, Neb.) leaf area meter. Soil was washed from the roots, and roots collected from the medium from a 1-

mm² mesh screen. Each type of plant material was oven-dried separately at 65C for 3 days, and dry weight of leaves (LDW), stems, and roots were recorded. Shoot : root ratios (S: R), specific leaf area (SLA = LA/LDW), and relative growth rates (RGR) were calculated (Hunt, 1982). Fruits were harvested at the mature-green stage from 10 plants per replication at 89, 104, and 124 days after transplanting, respectively. Fruits were graded (U.S. Dept. of Agriculture, 1976) into large (65-70 mm in diameter) and extra large (> 70 mm in diameter) sizes, counted, and weighed. Since the field environment was considered near optimum for plant growth, medium (57-65 mm in diameter) fruits were left on the plants for further growth.

A randomized complete block design with four replications for each treatment was used. Plants were sampled (two per replication) destructively at 0, 7, 14, 21, and 28 days after planting. Effects of transplant age were partitioned into linear or quadratic orthogonal responses. Data for leaf, stem, and root growth (dry weight) were analyzed by polynomial regression (SAS Institute, Cary, N.C.). Fruit yield data were subjected to analysis of variance and orthogonal contrasts. Means were separated by LSD (0.05).

Table 2. Influence of transplant age on the mean relative growth rate (RGR) following transplanting, Spring 1988. Experiment 1 at Parrish, Fla., and Expt. 2 at Bradenton, Fla.²

Transplant age (weeks)	RGR (g·g ⁻¹ ·day ⁻¹)			
	T0-T1	T1-T2	T2-T3	T3-T4
<i>Expt. 1</i>				
3	0.112	0.069	0.089	0.034
4	0.103	0.040	0.125	0.042
5	0.067	0.067	0.094	0.040
6	0.061	0.063	0.084	0.036
LSD (0.05)	0.026	---	0.032	---
<i>Expt. 2</i>				
3	0.105	0.054	0.098	---
4	0.086	0.040	0.099	---
5	0.044	0.051	0.100	---
6	0.066	0.049	0.081	---
LSD (0.05)	0.020	---	---	---

²T0-T1, T1-T2, T2-T3, and T3-T4 are weekly time intervals after

Fig. 1. Root dry weight as affected by transplant age. Spring 1989, Expt. 1, Parrish, Fla. Transplant age effects were linear (L) or quadratic (Q) at time of planting (T0) and 1 (T1), 2 (T2), 3 (T3), and 4 (T4) weeks after transplanting. Vertical bars represent $\pm$ SE. T0 (Q, $r^2 = 82$), T1 (L, $r^2 = 75$), T2 (L, $r^2 = 78$), T3 (Q, $r^2 = 70$), and T4 (Q, $r^2 = 70$).

Table 3. Effects of transplant age on yield and fruit count for the early and all harvests (Expt. 1, Parrish, Fla., Spring 1989).

Transplant age (weeks)	Early harvest			All harvests		
	Large	Extra large	Total	Large	Extra large	Total
	<i>Yield (t·ha⁻¹)</i>					
3	14.3	14.0	28.2	60.7	32.0	92.7
4	18.4	17.2	35.6	71.2	32.7	103.9
5	20.4	21.2	41.5	63.7	39.2	102.9
6	13.8	16.4	30.2	56.8	31.5	88.3
Significance	Q*	NS	Q*	Q*	NS	Q*
LSD (0.05)	4.8	---	---	12.2	---	---
	<i>Fruit/plant (no.)</i>					
3	13.3	9.1	22.4	52.3	20.5	72.7
4	17.3	10.9	28.2	62.1	20.5	82.7
5	19.3	13.6	32.9	56.6	25.1	81.7
6	13.0	10.6	23.6	48.7	20.1	68.8
Significance	Q*	NS	Q*	Q*	NS	Q*

NS,*,**Nonsignificant or significant F test at $P = 0.05$ or 0.01 , respectively. Transplant age effect was linear (L) or quadratic (Q).

Spring 1989, Expt. 2, Bradenton. Transplants were set at a commercial farm in Bradenton, Fla., (sandy, siliceous, hyperthermic, Alfic Haplaquods) on 2 Feb. 1989. The transplants were 3 (3 W), 4 (4W), 5 (5 W), or 6 (6W) weeks old. Plants were grown on single raised (20 cm) beds covered with black polyethylene mulch. The plants were spaced 1.8 m between rows and 0.5 m within rows. Preplant (39N-100P-62K, kg·ha⁻¹) and topdress fertilizer (216-311K, kg·ha⁻¹) were applied as for Expt. 1. Drip tubing (Netafim, Altamonte Springs, Fla.) was positioned 15 cm deep and 25 cm to the sides of the plants. Drippers were spaced 60 cm apart with a drip discharge of 2.25 liters·h⁻¹. Irrigation kept the water table at 50 cm from the top of the bed. Fumigation was done as in Expt. 1. Plant sampling was initiated at transplanting until 21 days thereafter (DAT). A late freeze in Feb. killed these plants; thus, no yields were obtained. Growth measurements and data analysis were as in Expt. 1.

Fall 1989, Expt. 3, Parrish. Transplants were set on 17 Aug. 1989 in Parrish, Fla., in the same field as of Expt. 1. The transplant ages were 2 (2W), 3 (3 W), 4 (4W), or 5 (5W) weeks.

Cultural practices were the same as described for Expt. 1, except that within-row plant spacing was 0.75 m and beds were mulched with white polyethylene mulch. Plant sampling was done at 0, 7, 14, and 21 days after planting. The monthly means after transplanting were 28.6C for August and 27.9C for September. Medium, large, and extra-large fruits were harvested at 75, 90, and 109 days after transplanting. Growth measurements and data analysis were the same as described above.

Fall 1989, Expt. 4, Bradenton. Transplants were set on 17 Aug. 1989 in Bradenton, Fla., in the same field as Expt. 2. The transplant ages were 2 (2W), 3 (3W), 4 (4W), or 5 (5W) weeks. All experimental and cultural practices were the same as for Expt. 2. The monthly means after transplanting were 28.3C for August and 27.7C for September. Chlorophyll (Chl) content on the newest fully expanded leaflet (> 2 cm long) was determined (Arnon, 1949). Measurements were performed in a UV/VIS spectrophotometer (Lambda 3A; Perkin-Elmer, Norwalk, Conn.) at 663, 652, and 645 nm; Chl a, b, and a + b in milligrams per gram fresh weight (FW) was determined, and Chl a : b ratio calculated. Samplings, growth measurements, and data analysis were conducted as before.

Results and Discussion

Spring 1989. Stem length and leaf area increased linearly with increasing transplant age at 1 (T1) and 2 (T2) weeks after transplanting (Table 1). At T1 and T2, 5W and 6W transplants had greater root dry weights than 3W and 4W transplants; however, at T3 and T4, dry weights were not significantly different among 4W, 5W, and 6W transplants (Fig. 1). Similar responses were observed for leaf and stem dry weight increase. Initially, after transplanting, 3W and 4W transplants had higher RGR and thus greater capacity to resume growth than older transplants (Table 2). The low RGR values during the 2nd week of growth were probably due to low mean temperatures (maximum/minimum, 23/9C). Between 2 and 3 weeks, 4W transplants had a higher plant RGR (Table 2) and root RGR (0.124 g·g⁻¹·day⁻¹) than 6W (0.078) transplants.

During seedling culture, older transplants may be exposed to more water and fertilizer stress than younger transplants. Widlers (1989) emphasized the importance of increasing the seedling nutrient content to enhance growth after field planting.

Table 4. Shoot characteristics of tomato transplants as affected by age, Fall 1989. Experiment 3 at Parrish, Fla., and Expt. 4 at Bradenton, Fla.²

Transplant age (weeks)	Stem length (cm)			Stem diam (mm)			Leaf area (cm ²)		
	T0	T1	T2	T0	T1	T2	T0	T1	T2
<i>Expt. 3</i>									
2	4.2	7.8	11.0	1.6	3.5	8.4	6	27	200
3	5.5	8.1	11.2	2.1	3.2	8.5	10	40	203
4	8.3	9.6	15.7	2.6	3.8	8.6	21	41	390
5	13.1	11.5	15.6	2.9	3.7	7.4	30	30	195
Significance	Q**	L**	L**	L**	NS	NS	L**	Q*	NS
LSD (0.05)	0.8	1.8	3.0	0.2	---	---	4	---	---
<i>Expt. 4</i>									
2	4.2	6.9	11.3	1.6	2.8	4.3	6	20	122
3	5.5	7.3	9.2	2.1	3.2	3.8	10	26	73
4	8.3	9.5	12.9	2.6	3.7	4.6	21	38	114
5	13.1	13.3	16.7	2.9	3.5	4.5	30	52	174
Significance	Q**	Q*	Q*	L**	L*	NS	L**	L**	NS

²T0 = at transplanting; T1 and T2 are 1 and 2 weeks after transplanting.

NS,*,**Nonsignificant or significant F test at $P = 0.05$ or 0.01 , respectively. Transplant age effect was linear (L) or quadratic (Q).

Table 5. Effects of transplant age on yield and fruit number for the early and all harvests (Expt. 3, Parrish, Fla., Fall 1989).

Transplant age (weeks)	Early harvest			Total harvests			
	Large	Extra large	Total	Medium	Large	Extra large	Total
<i>Yield (t·ha⁻¹)</i>							
2	5.1	5.8	10.9	5.1	26.7	12.5	44.3
3	7.7	5.3	13.0	7.9	30.4	10.5	48.9
4	5.7	7.7	13.4	5.8	27.2	14.4	47.5
5	6.1	2.9	8.9	6.1	28.1	8.8	42.4
Significance	NS	NS	NS	NS	NS	NS	NS
<i>Fruit/plant (no.)</i>							
2	5.8	4.4	10.2	7.4	29.3	9.6	46.2
3	8.6	4.2	12.9	11.3	33.8	8.7	53.8
4	6.0	6.7	12.7	8.3	29.5	12.2	50.0
5	7.0	2.3	9.4	8.6	31.2	6.5	46.3
Significance	NS	NS	NS	NS	NS	NS	NS

^{NS}Nonsignificant F test.

Fig. 2. Total chlorophyll (Chl) a + b (A) and chlorophyll a : b ratio (B) as affected by transplant age at time of planting (T0) and 1 (T1), 2 (T2), 4 (T4), and 6 (T6) weeks after transplanting.

Nutrient deficiency and dehydration have been reported to decrease the permeability of roots, possibly due to suberization of the cell walls (Passioura, 1988).

Early total and total (pooled harvests) fruit yields were similar for all transplant ages (Table 3). Five-week-old transplants had 47% more early large fruit, and 4W transplants 25% more total large fruit yield than 6W transplants (Table 3). Therefore, the growth advantages of younger (3W and 4W) transplants were eventually translated into similar or higher yields of large fruit. However, Weston and Zandstra (1989) reported that total marketable yield for 3W, 4W, 5W, and 6W transplants grown under sprinkler irrigation increased linearly with increasing transplant age.

Spring 1989. Most of the root and shoot characteristics followed the same trend as in the first experiment (Table 1), but

higher growth rate values for younger transplants (3W and 4W) were found only during the first week of growth (Table 2).

Fall 1989. Transplants that were 4 or 5 weeks old had significantly longer stems than 2W and 3W plants (Table 4). At T0, leaf area increased linearly with increasing transplant age from 2W to 5W; however, these differences were minimal at T1. Similarly, at T0, leaf, stem, and root dry weights increased linearly with increasing transplant age, but these differences were not observed thereafter (data not presented).

Early total and total marketable fruit yields were similar among treatments (Table 5) and trends did not depend on transplant age. Larger early fruit yields were found for 5-week-old bare-root transplants than for 7- or 9-week-old transplants (Nicklow and Minges, 1962).

Fall 1989. Chl a + b (mg·g⁻¹ FW) of the transplants increased through 4 weeks after transplanting (Fig. 2A). At T0, Chl a + b for 2W seedlings was 1.736 (SE ± 0.082), 44% and 17% higher than that of the 5W and 4W seedlings, respectively. Lower values for older transplants at T0 may have been due to reduced light interception resulting from plant competition in the container. At T0, the leaf area index was 4.8 for 5W compared to 1.0 for 2W plants. At T1 and T2, older transplants had more Chl a + b than younger transplants. Later, this difference became nonsignificant. At T0, the Chl a : b ratio for the 2W seedling was significantly higher (2.8) than that for older transplants (2.4), a difference that was less evident at T1 and T2, and insignificant at T4. In many plant species, Chl a : b values of 2.5 to 2.9 have been reported for shade leaves, and values of 3 to 3.5 are characteristic for sun-exposed leaves (Czeczuga, 1987). Therefore, the ratio of Chl a to b was modified by growth conditions and environmental factors, such as light (Lichtenhaler, 1987).

SLA at transplanting was 0.436 (SE ± 0.021), 0.331 (±0.011), 0.274 (±0.007), and 0.255 (±0.007) cm²·mg⁻¹ for 2W, 3W, 4W, and SW transplants, respectively. The high SLA in young transplants indicated that their leaves, still in the process of extension, were thinner than the thicker, smaller leaves of older transplants. SLA decreased at T1, and at T2, values were not significantly different and ranged from 0.173 to 0.187 cm²·mg⁻¹ for 5W and 2W, respectively. We suggest that younger transplants, with initially higher Chl a + b, Chl a : b ratios, SLA values, and RGR, had a more efficient photosynthetic system than older transplants.

The increase in stem diameter and leaf area with increase in transplant age stopped after T1 (Table 4). Fruit yield, fruit size, and fruit count were not significantly different among treatments for early or all harvests. Total yields (t-ha⁻¹) were 43.6 for 2W, 44.5 for 3W, 45.5 for 4W, and 46.8 for 5W transplants. The lack of fruit yield differences between 2W to 5W transplants indicates that there were no advantages to using 5 W transplants.

In conclusion, the initial favorable transplant growth characteristics acquired while growing in the greenhouse, most evident for older transplants, were modified in the field under subseepage or drip irrigation. Transplants that were 4 weeks old in fall and 5 weeks old in spring had similar or higher yields than older transplants. These results suggest that no improvement in fruit yield is to be expected using the traditional 5W and 6W transplant compared to younger transplants. Use of younger transplants offers the advantage of rapid seedling establishment with minimal transplant production costs.

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