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Transplant Production Systems Influence Growth and Yield of Fresh-market Tomatoes

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Abstract. **'Sunny' tomato (*Lycopersicon esculentum* Mill.) containerized transplants were grown with the standard or conventional systems (SS) and with recently developed flotation systems (FS). Standard system and FS transplants, and direct-seeding using coated seeds were evaluated in the field for root and shoot growth and yield at Parrish, Bradenton, and Naples during fall, winter, and spring plantings. Plant growth characteristics were measured weekly before, during, and after transplanting or sowing. In the Parrish and Bradenton Fall 1987 and Bradenton Spring 1988 experiments, SS transplants had greater leaf area, root volume, shoot dry weights, and shoot : root ratios than FS transplants. During early development, the FS transplants had more lateral root growth than SS transplants, but had similar total root growth and horizontal and vertical root distribution after transplanting in the field. Transplants and direct-seeded plants allocated 72% of the total root mass in the upper 0 to 10 cm of the soil. In Fall 1987, SS transplants had between 29% and 41% more fruit yield than FS transplants at Bradenton and Parrish, respectively. In the Naples Winter 1988 and Parrish and Bradenton Fall 1989 experiments, both transplant types had similar fruit yields, but more than direct-seeded plants. Transplants grown with the flotation system are recommended for use provided that seedlings are grown and maintained with minimum hardening before establishment in the field.**

Tomatoes are established in the field by direct-seeding using the plug-mix seeding method (Hayslip, 1974), transplanting containerized seedlings grown in multicellular trays in greenhouses, or transplanting bare-rooted seedlings (Hochmuth et al., 1988). Containerized tomato transplants have higher plant survival, faster establishment, improved plant uniformity, and earlier maturity than direct-seeded plants (McKee, 1981; Weston and Zandstra, 1989).

Root elongation, orientation, and branching patterns are affected by the physical and chemical properties of the soil or soilless growing media (Feldman, 1984). Stresses originating in the root zone are expressed in the shoots, affecting the dry-matter partitioning between roots and shoots, and hence the productivity of the plant (Brower and de Wit, 1969). Brower (1963) described the functional equilibrium between roots and shoots as interrelated growth, in which changes in the rate of shoot growth are expressed in the roots and vice versa.

Containerized transplants may be subjected to water, fertilizer, light, mechanical, and air temperature stresses, which may cause morphological and/or physiological changes during early root and shoot development in the greenhouse and/or field. Transplant condition or quality at time of planting were influenced by root-container size (Knavel, 1965; Weston and Zandstra, 1986), transplant nutrition (Jaworski and Webb, 1966; Melton and Dufault, 1991; Widders, 1989), transplant age (Chipman, 1961; Leskovar et al., 1991), and transplant storage (Dufault and Melton, 1990; Leskovar and Cantliffe, 1991). Transplant quality at time of planting also affects stand establishment, fruit size, and fruit yield (Chipman, 1961; Leskovar et al., 1991; Nicklow and Minges, 1962; Weston and Zandstra, 1989).

Between 1985 and 1989 a flotation or sub-irrigation (or commonly referred to as ebb and flow) system was constructed by Speedling, Inc. in Florida and California (Thomas, 1992). This system, which was originally designed to grow tobacco plants to increase field survival and reduce transplant shock, is now being used to grow many commercial vegetables. It utilizes recycled stored or collected water, saving water and reducing fertilizer and pesticide use as compared with the traditional overhead irrigated systems. Trays are suspended on metal wires 0.20 m above concrete floors, and every 2 to 3 days the irrigation water is raised to the level of the container, maintained for 15 to 45 min, and then decreased to its original level or returned to the main reservoir until the next irrigation.

During transplant production, cell moisture can be considered a major factor affecting transplant condition. Flotation systems are a viable alternative to improve uniformity and quality of pepper transplants, as compared to standard transplant systems using overhead irrigation (Leskovar and Cantliffe, 1993). However, transplant production system effects on tomato transplant growth before and after field transplanting under various field environments are not known.

The objectives of this study were to investigate the effects of transplant production system on post-planting root and shoot growth, to determine the relationships of early plant growth characteristics to fruit yield, and to compare growth and yield of plants established by direct-seeding or transplants.

Materials and Methods

Greenhouse transplant systems. 'Sunny' tomato seedlings were grown in two field locations, with different transplant production systems, in (1) standard plastic greenhouses at Sun City, Fla., lat. 27.4'N and long. 82.3'W (SS transplants), and in (2) fully auto-

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Table 1. Greenhouse temperature and cultural conditions for the standard and flotation tomato transplant systems.

Season	Year	Flat[y] size	Seeded	Temperature (C) Max	Min	Fertilization (mg·liter^{-1}) N[x]	P	K	Irrigation[z] frequency (no./week)	Water withheld (days)
					Standard					
Fall	1987	175	29 June	40	26	75	30	99	7	2
Spring	1988	150	1 Jan.	32	13	40	16	53	4	4
Winter	1988	l00A	7 Nov.	34	15	45	18	60	4	4
Spring	1989	l00A	12 Dec.	34	14	50	20	66	4	4
Fall	1989	l00A	12 July	30	14	50	20	66	4	4
					Flotation					
Fall[w]	1987	175	29 June	40	25	75	30	99	4	6
Spring	1988	150	1 Jan.	32	9	40	16	53	4	4
Winter	1988	l00A	7 Nov.	34	12	50	20	66	3	4
Spring	1989	l00A	12 Dec.	28	12	50	20	66	4	4
Fall	1989	l00A	12 July	28	12	50	20	66	4	4

[z]Irrigations were done at midday. Standard system utilized overhead irrigation. For the flotation system, at each irrigation, water was pumped from a main reservoir into the greenhouse, raised to the level of the container, maintained for 30 min, and then lowered (Fall 1987) or returned back to the main reservoir.
[y]Speedling polystyrene flats were size 175 [96 cells of 2.5 × 6.4 cm; 39.5 cm^3 (side length × depth; volume)]; size 150 (128 cells of 3.8 × 6.4 cm; 31 cm^3); size l00A (200 cells of 2.5 × 7.2 cm; 18.8 cm^3).
[x]Total N was 12% $N0_3$–N and 8% NH_4–N.
[w]Roots that were grown outside of the base of the polystyrene flats were hand-pruned 25 days after seeding.

Table 2. Field cultural practices utilized for each experiment.[z]

Experiments Location	Season	Year	Treatments	Plant within row spacing (cm)	Fertilizer (kg·ha^{-1}) N	P	K	Transplant Planted	age (days)	Harvests[y] DAS	DAT
Parrish	Fall	1987	SS, FS	60	255	270	510	2 Aug.	35	---	72/87/103
Bradenton	Fall	1987	SS, FS	60	326	108	520	2 Aug.	35	---	72/87/103
Parrish	Spring	1988	SS, FS	60	242	80	590	25 Feb.	44	---	85/99/115
Naples	Winter	1988	SS, FS, DS	55	271	202	495	21 Dec.	44	96/112/125	85/96/112/125
Parrish	Spring	1989	SS, FS, DS	60	242	80	590	24 Jan.	43	89/104/124	76/89/104/124
Parrish	Fall	1989	SS, FS, DS	76	250	270	510	16 Aug.	43	90/113	75/90/113
Bradenton	Fall	1989	SS, FS, DS	50	255	100	373	17 Aug.	43	90/113	75/90/113

[z]Beds, with plants on single rows, were spaced 1.8 m. Beds were fumigated with 67 methyl bromide : 33 chloropicrin at 220 kg·ha^{-1}. Polyethylene mulch (0.038 mm thick) was white in fall and black in spring and winter, respectively. Seepage irrigation was applied in all locations, except that drip irrigation was applied in Bradenton, Fall 1989. Irrigation was provided to maintain a water table ≈40 cm (seepage) or ≈30 cm (drip) from the top of the bed. In all locations, 1.2-m-long stakes were driven into the mulched bed between alternating plants 14 DAS, followed by tying four times during the season. Treatments were: SS = standard system transplants, FS = flotation system transplants, DS = direct-seeding.
[y]DAT = days after transplanting; DAS = days after seeding.

mated plastic greenhouses with a flotation irrigation system in Bushnell, Fla., lat. 28.4'N and long. 82.5'W, (FS transplants), both at Speedling, Inc. The second production system is in an area isolated from commercial tomato production to minimize plant exposure to bacterial leaf spot (*Xanthomonas campestris* pv. *vesicatoria*). Transplants were grown in the standard and flotation systems in Fall 1987, Spring 1988, Winter 1988, and Spring and Fall 1989. Differences in each transplant system (standard or flotation) in relation to maximum/minimum greenhouse temperatures, fertilization, irrigation frequencies, and time of water being withheld as a hardening procedure before transplanting are described for each season/year (Table 1).

Field experiments. Seven different location-season-year experiments (Table 2) were conducted between 1987 and 1989 in commercial fields in Parrish, Fla. (sandy, siliceous, hyperthermic, Alfic Haplaquods), Bradenton, Fla. (sandy, siliceous, hyperthermic, Entic Haplaquods), and Naples, Fla. (sandy, siliceous, hyperthermic, Alfic Arenic). Black mulch was used in the spring and winter when soil-level temperatures were <18C at planting, and white mulch was used in the fall when soil temperatures were normally >27C. Cultural management practices (Table 2) were similar to those used commercially in the area (Hochmuth et al., 1988). Transplants produced in Sun City (SS transplants) and Bushnell, Fla. (FS transplants) were used in the Parrish Fall 1987, Bradenton Fall 1987, and Parrish Spring 1988 experiments.

Since direct-seeding through plastic mulch is still used in some eastern coastal areas of Florida, a direct-seeded treatment (DS-plants) was added to the SS- and FS-transplant treatments in the following experiments: Naples Winter 1988; Parrish Spring 1989; Parrish Fall 1989, and Bradenton Fall 1989. Coated seeds were sown at a rate of four seeds/hill in 60 ml commercial mix (Terra-Lite Metro Mix 200; W.R. Grace & Co., Cambridge, Mass.) and then thinned to one plant/hill 21 days after seeding (DAS).

Plant samplings. At both greenhouse locations and field sites, two whole plants/plot were sampled before and at planting and 7, 14, 21, and 28 days after transplanting (DAT). Shoots were severed

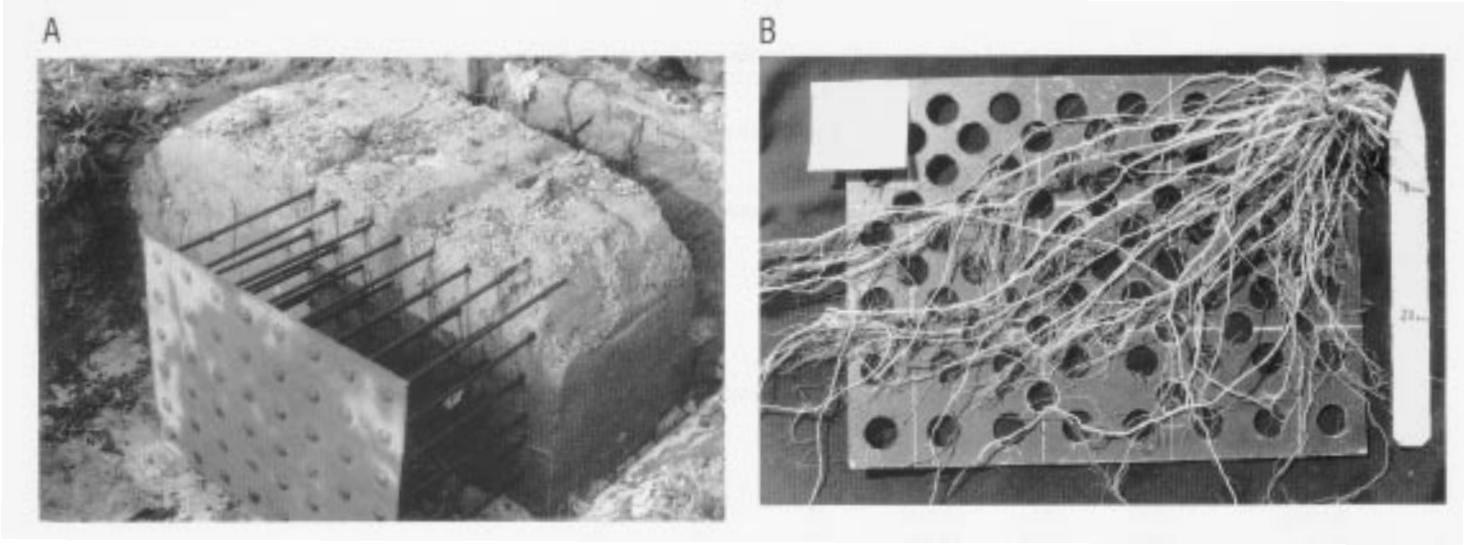

Fig. 1. Metallic monolith pinboard used for excavating the soil-root samples (**A**). Root distribution of tomato transplants after extraction and washing from the soil (**B**).

at the 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. The leaf number (>1 cm long) was counted and leaf area was measured with a leaf area meter (model LI-3100; LI-COR, Lincoln, Neb.). Root samples were excavated with a shovel in an 20 × 20-cm area previously marked by a metallic square frame with the plant in the center of the square, to a 30-cm depth. Plants were gently shaken to remove adhering soil, placed in polyethylene bags, and transported to 5C rooms, where they remained for 1 to 2 days. Root samples were soaked in water and roots were collected from the suspension by washing on a 1-mm mesh screen. The washed roots were blotted and root volume was estimated by water displacement (Bohm, 1979). Roots were partitioned into taproot, basal roots (arising from the lower region of the hypocotyl), and lateral roots (≥0.5 cm long). Plant material was oven-dried at 65C for 3 days, shoot (leaves + stems) and root dry weights were measured, and shoot : root ratios were calculated.

In the Naples Winter 1988 and Parrish Spring 1989 experiments, half of the plant root system was sampled from one plant per five replications from SS transplants, FS transplants, and DS-plants, using a modified monolith pinboard (Bohm, 1979). A root sampler was constructed, consisting of a one-sided steel plate 50 × 30 cm (width × depth), 0.5-cm thick, with six rows of 30-cm-long nails of 0.5 cm in diameter at 5-cm intervals (Fig. 1A). To improve the original root retention in the pinboard during washing, three additional rows of 30-cm-long nails were added to the upper, middle, and lower sections of the pinboard plate (not shown in Fig. 1A). A trench of 1.0 × 0.8 × 0.5 m (length × width × depth) was dug around the plant. Excavated soil-root samples were washed and roots were pushed to the base of the plate, excised, and separated at three horizontal levels, 0 to 10 cm, 10 to 20 cm, and 20 to 30 cm, and in three vertical positions, 0 to 15 cm, 15 to 30 cm, and 30 to 45 cm (Fig. 1B), resulting in nine root distribution sectors. This sampling technique was effective for collecting basal and lateral roots, but was ineffective in trapping very small higher-order laterals that may be lost during the washing procedure.

In all experiments a randomized complete-block design (RCBD) with treatments replicated six (Parrish and Bradenton, Fall 1987) or five times were used at each sampling date (0, 7, 14, 21, and 28 DAT). In the Fall 1987 experiments, each experimental unit of 162 m^2 consisted of three rows of 50 plants each. In the Spring and Winter 1988 and Spring and Fall 1989 experiments, a RCBD was used with treatments replicated five times and three rows of 25 plants each. Growth data for each experiment were subjected to analyses of variance (ANOVA), with sampling dates partitioned into linear or quadratic orthogonal responses. In those cases where shoot and/or root growth was linear, the test of homogeneity of the regression coefficients (b_i) ($P \leq 0.05$) between treatments was performed.

Yield. Fruits were harvested at the advance mature-green stage from the center 25 plants/plot on the days indicated (Table 2) for the Fall 1987 experiments and from the center 15 plants/plot for the remaining five experiments. The index used for harvesting was based on internal fruit appearance. A typical advance mature-green fruit has some internal red coloration. Fruits were counted, weighed, and graded by diameter (U.S. Dept. of Agriculture, 1976) into medium (57 to 65 mm), large (65 to 70 mm), and extra-large (>70 mm) sizes. Misshapen, diseased, or undersized (<57 mm) fruits were considered culls. Yield data for each experiment were subjected to ANOVA. In Fall 1989, yields were analyzed for locations (Parrish and Bradenton) and planting method (SS transplants, FS transplants, and direct-seeded) and significant interactions were partitioned for medium and extra-large fruit size.

Results and Discussion

Root and shoot growth. Two weeks after transplanting, transplants grown with the standard system (SS transplants) had larger leaf area and stem diameter (300 cm^2 and 6.7 mm) than transplants grown with the flotation system (FS transplants) at Parrish in Fall 1987, and more leaves and larger stem diameters than FS transplants (240 cm^2 and 6.0 mm) at Bradenton in Fall 1987 (data not shown). Transplant system interacted with time for shoot dry weight (SDW), root dry weight (RDW), and shoot : root ratio (S:R). At Parrish in Fall 1987, SS transplants had more SDW than FS transplants 1 week (T_1) after transplanting (WAT), with no differences at T_2 and T_3 (Table 3). Root growth was also greater for SS transplants during the first two WAT, with no differences thereafter. The greater early root dry-matter allocation in SS transplants at T_1 and T_2 may be important for the subsequent shoot growth increase at T_3 and T_4, indicating that the size of a root system may exert a control over the size of the shoots.

In these seasons, FS transplants had less frequency of irrigation and more days of water and nutrients withheld (hardening) before transplanting (Table 1). In addition, roots that grew outside of the base of polystyrene flats were hand-pruned, affecting subsequent dry-matter partitioning between roots and shoots, leaf enlarge-

Table 3. Effects of tomato transplant system on shoot and root growth dry weight at Parrish and Bradenton Fall 1987 experiments.

Transplant	Parrish					Bradenton				
System	T_0[z]	T_1	T_2	T_3	T_4	T_0	T_1	T_2	T_3	T_4
					Shoot dry wt (g)					
Standard	0.27	1.09	6.83	24.9	59.8	0.27	1.00	5.55	21.5	51.6
Flotation	0.24	0.82	5.55	16.4	43.0	0.24	0.87	4.82	17.7	42.6
Significance	**	**	NS	NS	*	**	*	*	**	*
					Root dry wt (g)					
Standard	0.07	0.14	0.55	1.9	3.7	0.07	0.10	0.39	1.3	2.6
Flotation	0.06	0.10	0.34	1.7	2.8	0.06	0.08	0.28	1.4	2.6
Significance	NS	**	**	NS	NS	NS	**	**	NS	NS
					Shoot : root ratio					
Standard	4.1	7.9	12.6	13.2	16.5	4.1	10.1	14.3	17.5	20.3
Flotation	3.8	8.3	16.5	9.4	15.3	3.8	11.6	17.9	12.7	16.1
Significance	*	NS	**	**	NS	*	NS	**	**	*

[z]T_0 = time at planting (35 days after seeding). T_1,T_2 T_3 and T_4 are times at 1, 2, 3, and 4 weeks after transplanting.
[NS,*,**]Nonsignificant or significant F test at $P = 0.05$ or 0.01, respectively.

Table 4. Effects of tomato transplant system on shoot and root growth at Parrish, Spring 1988.

Transplant	Time[z]						
system	T_{-2}	T_{-1}	T_0	T_1	Significance	R^2	b_i
			Leaf area (cm^2)				
Standard	24	33	41	51	L**	0.73	—
Flotation	20	30	30	33	C**	0.41	—
Significance	*	*	**	**			
			Root volume (cm^3)				
Standard	0.33	0.37	0.61	0.71	L**	0.70	0.019
Flotation	0.32	0.43	0.52	0.62	L**	0.57	0.014
Significance	NS	*	*	NS			**
			Shoot dry wt (mg)				
Standard	99	176	248	297	L**	0.84	9.60
Flotation	84	153	191	250	L**	0.72	7.67
Significance	*	**	**	NS			*

[z]T_{-2} and T_{-1} are 2 and 1 weeks before transplanting. T_0 = time at initial transplanting (44 days after seeding). T_1 = 1 week after transplanting.
[NS,*,**]Nonsignificant or significant F test at $P = 0.05$ or 0.01, respectively. Significant time effects were linear (L) or cubic (C). Slope (b_i) coefficients are significantly different at $P = 0.05$ or 0.01 if paired t values are >1.960 or 2.576, respectively. Paired t values were 2.632 for root volume (RV) and 2.545 for shoot weight (SDW).

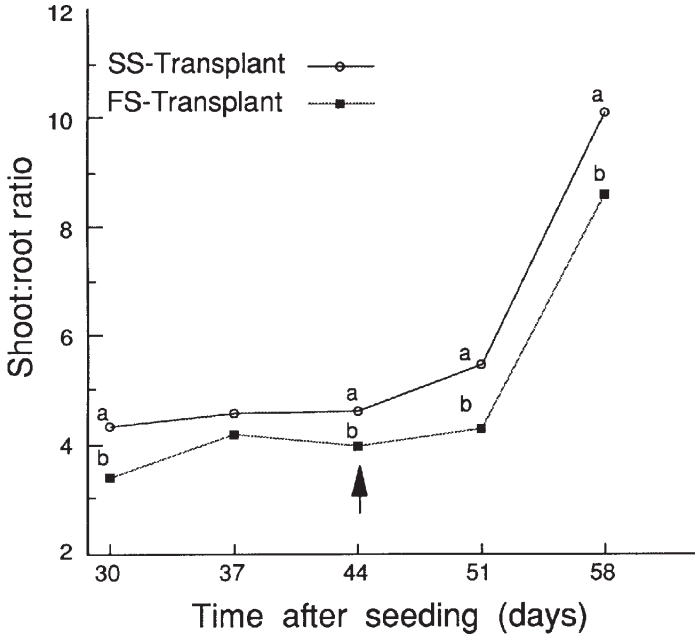

Fig. 2. Shoot : root ratio increase of tomato transplants before and after transplanting, Spring 1988. Mean separation within a growth stage at $P = 0.05$.

ment, and plant size. During 'hardening', availability for nutrients such as N and P can be critical for the subsequent growth after transplanting (Widders, 1989). In grasses, lateral roots grown under water stress conditions can be subjected to suberization and aging of root apicals, affecting the absorption and transport of nutrients such as Ca (Troughton, 1981). In tomatoes, individual tap, basal, and lateral root types appeared to have different K and NO_3-N uptake in space and time (Toulemonde, 1992).

Transplant system also interacted with time for leaf area (LA), root volume (RV), and SDW in the Parrish Spring 1988 experiment. Leaf area for SS transplants increased linearly compared to FS transplants between 2 weeks before (T_{-2}) and 1 week after (T_1) transplanting (Table 4). Root volume (RV) and SDW increased linearly in both type transplants; however, SS transplants had higher RV-slopes ($b_{RV} = 0.019$, $P < 0.01$) and SDW-slopes ($b_{SDW} = 9.60$, $P = 0.05$) than FS transplants ($b_{RV} = 0.014$, $b_{SDW} = 7.67$), respectively. Both transplant systems had similar exponential trends during 30 to 58 DAS, but SS transplants had a greater (4.6) shoot : root ratio (S:R) than FS transplants (4.0) at time of transplanting until 58 DAS (Fig. 2), at which time each transplant system had the same S:R ratio (data not shown). Slight shoot-growth restriction was considered to be an advantage to avoid the excess growth that could decrease fruit set in tomato (Van Vooren et al., 1986). A reduction in the growth potential of young shoots and roots was reported to decrease flower bud abortion and to increase fruit set (Russell and Morris, 1983). Restriction of root and shoot growth may reduce the assimilate used for these organs, increasing availability for development of the first inflorescence.

The partitioning of the root system into their components for the Naples Winter 1988 experiment indicated that FS transplants developed more tap and lateral roots than SS transplants, but developed similar basal roots (Table 5). Bell pepper transplants grown with overhead irrigation had more basal but less laterals than transplants grown with the flotation system (Leskovar and

Cantliffe, 1993). In the greenhouse, shoot : root ratios decreased from 4.7 at 24 DAS to 4.0 at 45 DAS, then increased immediately after field transplanting. Total root growth and root horizontal (within a depth of 0 to 10, 10 to 20, and 20 to 30 cm) and vertical (0 to 15, 15 to 30, and 30 to 45 cm from the center to the side of the plant) distribution were not significantly different between transplant types and direct-seeded plants (Table 6). Therefore, root growth compensation occurred, minimizing the initial differences in root dry weights. Seventy two percent (Naples Winter 1988) and 68% (Parrish Spring 1989) of the total root mass was located in the upper 0 to 10 cm of the soil probably by a greater contribution of basal roots (Fig. 1B). Total basal root growth from bell pepper containerized transplants grown with white mulch in the spring accounted for 81% of the total root mass when sampled 109 DAT (Leskovar and Cantliffe, 1993).

Table 5. Effects of tomato transplant system on root growth at Naples, Winter 1988.

Source of variation	Root components (mg)			Shoot : root ratio
	Tap	Basal	Lateral	
Transplant system (TS)				
Standard	5	41	15	5.7
Flotation	8	34	25	5.6
Significance	*	NS	*	NS
Time[z]				
T_{-3}	---	---	---	4.7
T_{-2}	---	---	---	4.9
T_{-1}	---	---	---	4.3
T_0	4	14	10	4.0
T_1	5	25	16	7.6
T_2	10	74	33	11.0
Significance	L**	Q**	L**	C**
TS × time	NS	NS	NS	NS

[z]T_{-3}, T_{-2}, and T_{-1} are 3, 2, and 1 week(s) before transplanting, respectively. T_o = time at initial transplanting (45 days after seeding). T_1 and T_2 are 1 and 2 weeks after transplanting, respectively.
NS,*,**Nonsignificant or significant F test at $P = 0.05$ or 0.01, respectively. Significant time effects were linear (L), quadratic (Q), or cubic (C).

In the Bradenton Fall 1989 experiment, transplant system interacted with time for most of the growth variables. Before transplanting, SS transplants had greater LA, stem length (SL), stem dry weight (STDW), leaf dry weight (LDW), and S : R ratio than FS transplants; however, after transplanting, FS transplants had better shoot growth than SS transplants (Table 7). In the Parrish Fall 1989 experiment, FS transplants had greater LA (139 vs. 124 cm^2) and lower S : R than SS transplants (data not shown). However, transplants grew similarly between T_0 and T_1, and RGR were 0.011, 0.043, and 0.068 $g \cdot g^{-1} \cdot d^{-1}$, for root, stem, and leaf dry weights, respectively. During week 2, RGR increased to 0.075, 0.097, and 0.126 $g \cdot g^{-1} d^{-1}$, for root, stem, and leaf dry weights, respectively.

Transplant condition, which is directly related to the cultural practices and environment of transplant production, significantly influenced subsequent plant growth and development in the field. However, direct extrapolation of early root and shoot growth by individual transplants to final growth in the field is confounded by differences in greenhouse management, such as irrigation and nutrition, and field environments. Further studies are needed to evaluate individual components and their interactions in the transplant production systems.

Fruit yield. SS transplants had 33% and 24% more extra-large fruits during the early harvest (Fig. 3 A and B) and 27% and 46% more total fruit yield at the second harvests at Parrish and Bradenton, respectively, in Fall 1987. A pooled yield of all harvests indicated that SS transplants produced 35.3 $t \cdot ha^{-1}$ and 40.7 $t \cdot ha^{-1}$ at Parrish and Bradenton, respectively, which represents 29% and 41% more total marketable fruit yield than FS transplants. In tomato, plant growth and yield can decrease in proportion to the severity of the hardening treatment imposed on transplants in the greenhouse before transplanting (Rubatzky, 1986) as it was evident in this experiment for FS transplants.

In the Parrish Spring 1988 experiment, fruit yields and fruit number/plant were not significantly different between transplant treatments (not shown). For the early harvest at Naples, Winter 1988, transplants had higher medium and large fruit yield than direct-seeded plants (data not shown) and total fruit yields ($t \cdot ha^{-1}$) were 14.1 ± 1.0 , 17.0 ± 2.2, and 10.2 ± 1.3 for the SS transplants, FS transplants, and direct-seeded plants, respectively. At mid-

Table 6. Means of horizontal and vertical root dry weight distribution of tomato plants established by transplants or direct-seeding, Naples Winter 1988 and Parrish Spring 1989 experiments.

Root distribution (cm)	Root dry wt (g)[z]				Root dry wt (g)			
	Transplants		Direct-seeding	F test	Transplants		Direct-seeding	F test
	Standard	Flotation			Standard	Flotation		
	Naples Winter 1988				Parrish Spring 1989			
Horizontal								
0–10	3.42	3.81	3.71	NS	5.13	4.71	4.62	NS
10–20	1.27	1.47	1.05	NS	1.20	1.15	0.94	NS
20–30	0.05	0.04	0.14	NS	1.21	0.56	0.50	NS
LSD (0.05)	2.01	2.49	2.07		3.04	2.74	2.77	
Vertical								
0–15	3.43	3.71	3.49	NS	4.90	4.31	4.28	NS
15–30	0.87	0.84	1.00	NS	1.49	14.4	1.11	NS
30–45	0.44	0.76	0.41	NS	1.15	0.71	0.68	NS
LSD (0.05)	2.04	2.57	2.17		3.10	2.87	2.88	

[z]Based on 1/2 of total root system. The main shoot was located in the 0 to 10 cm horizontal and 0 to 15 cm vertical compartment (Fig. 1B). Root samples were taken 125 days after planting.
NSNonsignificant.

Table 7. Effects of tomato transplant system on shoot and root growth, Bradenton Fall 1989.

Transplant system	Time[z] T_{-1}	T_0	T_1	T_2	Significance	R^2
			Leaf area (cm^2)			
Standard	20	25	51	265	C**	0.97
Flotation	17	25	62	409	C**	0.98
Significance	**	NS	NS	**		
			Stem length (cm)			
Standard	8.4	11.6	12.2	17.6	C**	0.93
Flotation	6.2	8.6	12.2	18.0	Q**	0.97
Significance	**	**	NS	NS		
			Root dry wt (mg)			
Standard	27	46	54	127	Q**	0.81
Flotation	27	53	62	184	C**	0.96
Significance	NS	NS	NS	*		
			Stem dry wt (g)			
Standard	0.05	0.11	0.15	0.48	C**	0.96
Flotation	0.04	0.08	0.l9	0.70	C**	0.97
Significance	**	**	NS	*		
			Leaf dry wt (g)			
Standard	0.12	0.17	0.31	1.57	C**	0.98
Flotation	0.08	0.13	0.38	2.51	C**	0.98
Significance	**	**	NS	**		
			Shoot : root ratio			
Standard	6.2	6.1	12.6	16.4	L*	0.38
Flotation	4.4	4.0	9.2	17.5	Q**	0.96
Significance	**	**	NS	NS		

[z]T_{-1} = 1 week before transplanting. T_o = time at initial transplanting (35 days after seeding). T_1 and T_2 are 1 and 2 week(s) after transplanting.
NS,*,**Nonsignificant or significant F test at $P = 0.05$ or 0.01, respectively. Significant time effects were linear (L), quadratic (Q), or cubic (C).

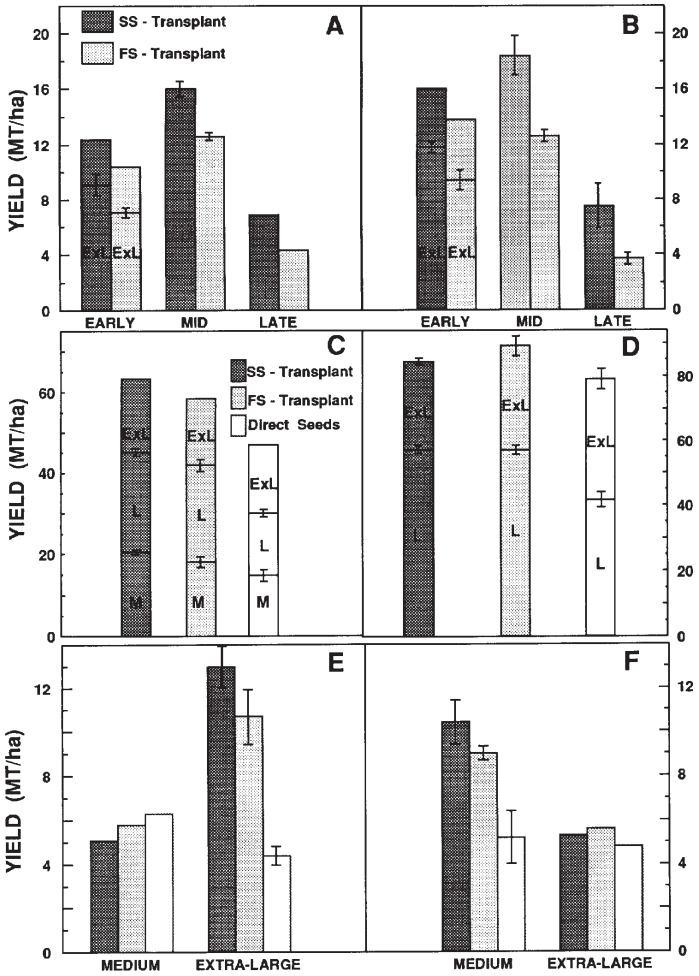

Fig. 3. Effect of plant establishment, transplant produced with the standard system (SS), flotation system (FS), and direct-seeding, on tomato fruit yield. Early, mid and late harvest fruit yield at Parrish, Fall 1987 (**A**) and Bradenton, Fall 1987 (**B**). Total fruit yield at Naples, Winter 1988 (**C**) and Parrish, Spring 1989 (**D**). Total yield for medium and extra-large fruits at Parrish, Fall 1989 (**E**) and Bradenton, fall 1989 (**F**). M = medium size fruits (57 to 65 mm in diameter); L=large fruits (65 to 70 mm in diameter) and EXL = extra-large fruits (>70 mm in diameter). Vertical bars ±SE were placed when plant establishment was significant at $P = 0.05$.

harvest, direct-seeded plants had greater extra-large fruit yield than SS and FS transplants. Total yields were not different between transplant types; however, they had more medium, large, and total yields (62.9 ± 1.6 for SS transplants and 58.6 ± 2.4 for FS transplants) than direct-seeded plants (46.7 ± 2.9) (Fig. 2C). SS transplants, FS transplants, and direct-seeded plants produced 51, 49, and 38 total fruits/plant, respectively. In the Parrish Spring 1989 experiment, FS transplants had 54% higher total (7.9 $t \cdot ha^{-1}$) fruit yields and more (6.6) fruit number/plant than SS transplants at the first harvest. At the second harvest, both transplants had an average of 23 $t \cdot ha^{-1}$, 46% more than fruit yields of direct-seeded plants. The lack of earliness for seeded plants was compensated with larger fruit yields in late harvests, so that fruit yields were not significantly different among planting methods (Fig. 3D). This response has been previously reported for tomatoes grown in the spring (Liptay et al., 1982; Long and Cantliffe, 1975). However, bell pepper established by direct-seeding with primed or raw seeds had lower total yields than containerized transplants produced with overhead or flotation systems in the spring (Leskovar and Cantliffe, 1993).

In Fall 1989, transplants yielded more larger fruits and total fruit yield, with greater number of large and total fruit, than direct-seeded plants (Table 8). In this season, low temperatures during late development may have limited the yield potential of direct-seeded plants. Transplant production system interacted with location for medium and extra-large fruits. At Parrish, where plants were grown under seepage irrigation and water was maintained constantly in the field, transplants had more extra-large fruit yield (Fig. 3E) and extra-large fruit number (6.9 fruits/plant) than direct-seeded plants (2.2 fruits/plant). At Bradenton, where plants were grown under drip irrigation, transplants yielded more medium-sized fruit (Fig. 3F) and higher fruit number (10.3 and 5.3 fruits/plant for transplants and direct-seeded plants, respectively). Although drip irrigation is considered more efficient than seepage irrigation (Hochmuth et al., 1988), short periods with emitter-clogging may have hindered the beneficial effects in this experiment, thus affecting fruit size.

In conclusion, transplant production systems influenced transplant condition at planting, affecting the subsequent growth and development in the field. Early in ontogeny, basal roots were more prominent for SS transplants, and lateral roots for FS transplants. Transplants had earlier and higher yields than direct-seeded plants in fall and winter. The use of FS transplants is suggested if plants are subjected to minimal hardening before transplanting.

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Table 8. Effects of location and planting method on total fruit yields and fruit number/plant for tomato, Fall 1989.

Source of variation	Fruit yield ($t \cdot ha^{-1}$)				Fruit number/plant			
	Medium	Large	Extra large	Total	Medium	Large	Extra large	Total
Location (L)								
Parrish	6.3	29.7	9.8	45.8	7.0	24.2	5.5	36.8
Bradenton	8.2	29.3	5.2	42.8	8.3	22.6	2.7	33.7
Significance	NS	NS	**	NS	NS	NS	**	NS
Planting method (PM)								
Standard	7.8	32.7	9.2	49.7	8.1	26.4	5.4	39.9
Flotation	7.4	32.2	8.1	47.7	7.7	25.8	4.6	38.0
Direct-seeding	6.6	23.5	5.3	35.3	7.1	18.2	2.5	27.8
LSD (0.05)	---	4.9	2.5	6.0	---	3.8	1.2	4.9
L × PM	**	NS	*	NS	**	NS	*	NS

[z]Fruit diameters were 57 to 65 mm (medium), 65 to 70 mm (large), and >70 mm (extra large).
[NS,*,**]Nonsignificant or significant F test at $P = 0.05$ or 0.01, respectively.

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