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Growth, Yield, and Nutrient Uptake of Transplanted Fresh-market Tomatoes as Affected by Plastic Mulch and Initial Nitrogen Rate

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Abstract. **Two field experiments were conducted with two cultivars of transplanted tomatoes (*Lycopersicon esculentum* Mill.) with and without plastic mulch, varying the initial rate of N fertilizer, but maintaining the total N rate at 168 kg·ha^{-1} by sidedressing. In 1982, 0 and 112 kg·ha^{-1} initial N rates, and bare ground, black mulch, and clear plastic mulch were compared on a gravelly loam soil. In 1983, initial N rates used were 34, 67, 101, or 134 kg·ha^{-1}, with bare ground and clear mulch on a silt loam soil. Effects of the plastic mulch dominated both experiments. Mulching increased rate of basal branch appearance and led to early flowering on branches. Total plant growth, as measured by vine weights at final harvest, was increased by mulch in both years. Mulching increased early yield only in 1983, but increased total yields by 13% and 79% in 1982 and 1983, respectively. Initial N fertilizer rates did not influence total yields significantly in either experiment, although high initial N rate, combined with clear plastic mulch, led to a significant decrease in percent marketable fruit in 1982. In 1983, mulching increased shoot concentrations of N, NO_3-N, P, K, Ca, Mg, Cu, and B ($P = < 0.01$) in spite of the fact that mulched plants were larger than unmulched plants at sampling time, 24 days after transplanting. Nitrogen fertilizer increased only the N and P concentrations and to a lesser extent than did the mulch.**

The most common response of tomatoes to plastic mulch is an increase in total yield, but no decrease in days to first ripe fruit (1, 4, 13, 18), although there are exceptions (3). Relative to unmulched plants, shallower root distribution, higher soil moisture and carbon dioxide levels, higher soil temperatures, and better nutrient availability by reduction of leaching have been most frequently given as reasons for the yield responses obtained under mulch (1, 4, 5, 12, 13, 17–19, 21). Few detailed studies on plant growth and flowering as influenced by soil mulching have been made, however (20).

Nitrogen fertilizer management of tomato has been investigated for many years (2, 14). Research in California indicates that tomatoes forage efficiently for soil nitrogen, obtaining only 30% to 40% from fertilizer sources (9, 16). Under the low soil temperatures occurring in spring in the northeastern U.S., tomatoes may well be more dependent on fertilizer N than in areas of high soil temperature. Under the low light intensities of greenhouses in the winter, excessive N fertilizer, applied in the vegetative stage, has been blamed for decreased fruit setting and excessive vegetative growth (14). Garrison et al. (6) demonstrated, however, that high N rates did not adversely affect the flower formation or fruit set of field-grown tomatoes. Tomato growers in New York often complain of excessive vegetative growth and delayed yield production when using plastic mulch. They normally apply all the N at planting, for fear that sidedressed N will not be available due to the presence of the mulch. The present experiments were conducted to determine if initial N rates would need to be reduced to avoid excess leafiness and to produce maximum early and total yields of fresh market tomatoes when using plastic mulch.

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Materials and Methods

Expt. 1, in 1982, compared the effect of bare ground or black or clear plastic mulch on 'Springset' and 'Pik-Red' tomatoes grown with 0 or 112 kg·ha^{-1} N applied at planting. Experimental design was a split-plot with initial N rates as main plots and cultivars and mulch factorially arranged in the subplots, with four replications.

The experiment was conducted on a Howard gravelly loam soil of good drainage (loamy-skeletal, mixed mesic, Glossoboric Hapludalf) and high fertility status as indicated by a pH of 6.6, organic matter content of 2.6%, and P and K soil test values of 47 and 355 $kg \cdot ha^{-1}$, respectively, based on extraction with Morgan's sodium acetate–acetic acid solution buffered at pH 4.8 (8). After broadcast application of 49 $kg \cdot ha^{-1}$ P and 77 $kg \cdot ha^{-1}$ K, and N application to the main plots, the fertilizer was incorporated by a cultivator, followed by application of 0.84 $kg \cdot ha^{-1}$ α,α,α-trifluoro-2-6,-dinitro-*N*-*N*-dipropyl-p-toluidine (trifluralin) herbicide. To prevent weed growth under the clear plastic mulch, a 39-cm strip of soil was sprayed with 1.7 $kg \cdot h^{-1}$ 2-sec-butyl-4,6-dinitrophenol (dinoseb) immediately before mulch application. Two weeks later, on 27 May, 6-week-old transplants of 'Pik-Red' and 'Springset' tomatoes were set into the single-row subplots and spaced 61 and 183 cm within and between rows, respectively. Subplot length was 6.1 m. Total N fertilizer was adjusted to 168 $kg \cdot ha^{-1}$ N by one or three sidedressings of 56 $kg \cdot ha^{-1}$ N as ammonium nitrate for the 112 and 0 initial N rate treatments, respectively. These sidedressings were applied at 27, 48, and 69 days after transplanting (DAT). To ensure that the first sidedressing reached the roots of mulched transplants in the zero N plots, the equivalent of 28 $kg \cdot ha^{-1}$ was applied by hand as an aqueous solution (1 liter/plant) at the base of each plant, with the remainder banded at the edge of the plastic. All other plots received an equivalent amount of water at the same time.

Expt. 2 explored further the response of fresh-market tomatoes to different levels of starting N fertilizer, with and without clear plastic mulch. 'Springset' and 'Pik-Red' cultivars again were used, and 34, 67, 101, and 134 $kg \cdot ha^{-1}$ N applied at transplanting (on 3 June). Plots given low initial rates of N were sidedressed twice, at 26 and 74 DAT, to bring total N applied to 168 $kg \cdot ha^{-1}$. Plots receiving 101 and 134 kg received only one sidedressing of 67 and 34 $kg \cdot ha^{-1}$, respectively, at 26 DAT.

The experiment was conducted on an Eel silt loam (fine-loamy, mixed, non-acid, mesic Aquic Udifluvent) of good fertility status with a pH of 6.4, organic matter content of 3.3%, and soil test values of 27 and 270 $kg \cdot ha^{-1}$ for P and K, respectively, based on Morgan's extracting solution (8). The experiment was designed as a randomized complete block with four replications and factorial treatment design. The soil was prepared as in 1982, except that 0.84 $kg \cdot ha^{-1}$ trifluralin and 0.28 $kg \cdot ha^{-1}$ 4-amino-6-tert-butyl-3-(methylthio)-as-triazin-5(4*H*-one) (metribuzin) were sprayed on and lightly incorporated prior to application of clear polyethylene mulch of 122-cm width. The single-row plots were spaced 183 cm apart, with in-row spacings of 61 cm. Since total N applied was the same in all plots, and the experimental area was level, it was felt that there would be minimal border effects with regard to fertilizer between plots. There were eight plants per treatment per replication.

In 1983, 'Pik-Red' was sampled for nutrient analysis the afternoon of 27 June, 24 DAT. The fifth leaf from the top was taken from each of the eight plants in a replication and combined into one sample for that replication. Conditions at sampling time were clear and bright, with air temperature at 31°C and good soil moisture. The dried ground sample for analysis consisted of both petioles and leaflets from the sampled leaves. Total N was determined by Kjeldahl, whereas NO_3-N was determined electrochemically using an Orion Specific ion electrode coupled with a double-junction reference electrode. All other nutrient analyses were performed on an inductively coupled argon plasma (ICAP) multi-element emission spectrometer.

Soil temperatures were measured at 5-, 10-, and 15-cm depths in one replication of the bare and mulched plots during early July in 1983 only, using a thermistor sensor recording thermometer (Model CR21, Campbell Scientific, Logan, Utah).

In both experiments, fruit were harvested when ripe at weekly intervals, beginning in early August, for 54 and 49 days in Expts. 1 and 2, respectively. Fruit were graded into US no. 1, no. 2, and culls. At the last harvest, plants were pulled and their fresh weight without fruit determined.

Rainfall was supplemented by sprinkler irrigation in both seasons, and weekly fungicide sprays were applied to control *Alternaria solani* (Jones and Grout).

Results and Discussion

In both experiments, plastic mulch significantly increased the number of branches that developed within a month after transplanting (Table 1). In 1983, clear mulch also slightly accelerated main stem node development, which also may have increased flower cluster number slightly by 28 DAT (Table 2). In these experiments, the plants started flowering on the main stem, and flowering on branches only began after three main stem clusters had reached anthesis. The early branching resulted in early flowering on the branches, and was the main contributor to an increase in flower cluster numbers on mulched plants by 38 DAT. At both 28 and 38 DAT, 'Springset' had more flower clusters per plant than 'Pik-Red'. 'Springset' also had more branches and bore a larger percentage of flower clusters on branches than 'Pik-Red' (Table 2). 'Pik-Red' showed a greater increase in flower cluster number with mulching than 'Springset', leading to a significant cultivar × mulch interaction. Nitrogen fertilizer treatments had no significant effect on branching in either experiment.

Mulch did not affect the number of fruit that developed on the first two main stem clusters in either year. 'Springset' had more fruit per cluster than 'Pik-Red'. Initial N fertilizer rate had no significant effect on fruit numbers on the first two clusters

Table 1. Effect of plastic mulch and cultivars on branches > 5 cm in length and main stem node number.

	Branch no./plant			Main stem node no.
	Year and DAT[z]			Year and DAT
	1982	1983	1983	1983
Treatment	27	20	28	20
		Mulch		
None	3.8	1.3	5.8	10.7
Black	4.5	---[y]	---[y]	---[y]
Clear	6.0	7.6	9.6	13.0
Significance	**	**	**	**
		Cultivar		
Pik-Red	3.8	4.1	6.9	11.0
Springset	5.8	4.9	8.6	12.8
Significance	**	**	**	**

[z]DAT = days after transplanting.
[y]Treatment not used in 1983.
**Significant at the 1% level.

Table 2. Influence of plastic mulch on flower cluster numbers and their distribution and fruit numbers on the first two clusters for 'Springset' and 'Pik-Red' tomatoes.

Treatment	Flower clusters (no./plant) Year and DAT[z] 1983 28	1983 38	Main stem clusters (%) Year and DAT 1983 38	Fruit no., cluster 1 + 2 Year and DAT 1982 50	1983 62
		Mulch			
None	2.6	8.6	52	7.8	10.2
Black	---[y]	---[y]	---[y]	8.6	---[y]
Clear	3.1	21.9	22	8.6	10.0
Significance	**	**	**	NS	NS
		Cultivar			
Pik-Red	2.7	12.6	41	6.8	8.8
Springset	3.0	17.9	33	9.9	11.5
Significance	**	**	**	**	**
		Mulch × cultivar interaction			
Pik-Red					
None	2.3	6.8	58	6.2	8.8
Black	---[y]	---[y]	---[y]	7.3	---[y]
Clear	3.1	18.4	24	6.8	8.6
Springset					
None	2.9	10.4	46	9.5	11.5
Black	---[y]	---[y]	---[y]	9.9	---[y]
Clear	3.1	25.3	20	10.4	11.4
Significance	**	**	**	NS	NS

[z]DAT = days after transplanting.
[y]Treatment not used in 1983.
NS,**Nonsignificant or significant at the 1% level, respectively.

Table 3. Early (to 25 Aug.) and total marketable yield (to 22 Sept. and 30 Sept. for 1982 and 1983, respectively) for two cultivars of tomato with or without plastic mulch.

Treatment	Marketable yield (t·ha^{-1}) Early 1982	Early 1983	Total 1982	Total 1983	Vine wt/plant (kg) 1982	Vine wt/plant (kg) 1983
			Mulch			
None	7.2	7.8	64.5	51.1	1.42	0.96
Black	8.1	---[z]	72.8	---[z]	1.75	---[z]
Clear	8.1	10.8	72.8	91.6	1.78	1.78
Significance	NS	**	**	**	**	**
			Cultivar			
Pik-Red	8.3	8.8	68.3	62.0	1.58	1.25
Springset	7.2	9.8	71.7	80.4	1.72	1.49
Significance	*	*	NS	**	NS	**
			Cultivar × mulch interaction			
Pik-Red						
None	7.4	6.6	62.9	45.5	1.36	0.87
Black	9.2	---[z]	72.2	---[z]	1.74	---[z]
Clear	8.3	11.0	69.9	78.8	1.65	1.63
Springset						
None	6.7	9.0	66.3	56.4	1.46	1.05
Black	7.2	---[z]	73.2	---[z]	1.77	---[z]
Clear	7.8	10.6	75.7	104.4	1.91	1.92
Significance	NS	**	NS	**	NS	NS

[z]Treatment not used in 1983.
NS,*,**Nonsignificant or significant at the 5% or 1% levels, respectively.

Table 4. Influence of initial N fertilizer rate and plastic mulch on total marketable yield and its components in 1982.

Treatment	Marketable yield (t·ha^{-1})	Fruit size (g)	Fruit no. (× 1000/ ha)	Marketable fruit (%)
		N fertilizer		
0	70.0	188	813	78
112	70.1	196	755	76
Significance	NS	NS	NS	NS
		Fertilizer × mulch interaction		
0 bare	61.4	189	708	76
0 black	71.7	187	830	79
0 clear	76.8	189	903	80
112 bare	67.9	198	736	77
112 black	73.7	189	810	77
112 clear	68.8	201	720	74
Significance	*	NS	**	*

NS,*,**Nonsignificant or significant at the 5% or 1% levels, respectively.

and there was no significant mulch × fertilizer interaction (data not shown). This is indirect evidence for a lack of adverse effect on first cluster fruitset by high initial N rates, even when combined with plastic mulch.

Although branching and flowering on branches were stimulated by plastic mulch, early yield (first 3 weeks' accumulated harvests) was increased by mulching only in 1983, and only for 'Pik-Red' (Table 3). There was, however, a more sizeable and consistent increase in total marketable yield in both years due to plastic mulch, substantiating the findings of others (1, 4, 13, 18). Varietal differences in early and total yields were not consistent from year to year. Total marketable yields were roughly proportional to vine fresh weights at final harvest, indicating that mulching stimulated plant growth, which then improved fruit production. Vandenberg and Tiessen (20) and Hurd et al. (10) showed similarly that vine weights and fruit yields tend to be positively related.

Initial N fertilizer rates did not influence early or total yields significantly in either year. In 1982, however, the high initial N rate, combined with clear plastic mulch, decreased total marketable yield, leading to a significant fertilizer × mulch interaction (Table 4). This decrease resulted from a decline in percent marketable fruit with fruit number rather than fruit size being most affected. No such interaction was apparent in 1983.

The mulch-induced total yield increases in 13% and 79% in 1982 and 1983, respectively, were apparently caused by an early start of branch growth (Table 1). Vine weights at final harvest indicate that this increased branch growth was maintained through the growing season (Table 3). Mulched plants produced more flower clusters than those not mulched (Table 2) and, since fruit setting apparently was not adversely affected by mulching (Table 2), they therefore produced higher yields.

The reason for increased branch growth of mulched plants only can be speculated at present. Root growth may have been stimulated by increased soil temperatures and improved soil moisture status under the mulch (1, 4, 5, 12, 13, 21), leading to early top growth (11). Moreover, a greater proportion of the root system may be exploiting soil near the surface where the fertilizer was shallowly incorporated, since the mulch prevented this surface from drying out. The root growth hypothesis is supported by the increased concentrations of N, NO_3-N, P, K, Ca, Mg, Cu, and B in the shoots of mulched plants (Table 5).

Table 5. The effect of clear plastic mulch and initial N rate on the nutrient concentration of 'Pik-Red' tomato leaves 24 days after transplanting, 1983.

	Nutrient concn									
	(%)						(ppm)			
Treatment	N	NO_3-N	P	K	Ca	Mg	Na	Cu	B	Zn
Mulch										
None	4.12	0.15	0.29	2.84	3.41	0.37	529	7.6	19	17
Clear	4.57	0.34	0.45	3.52	3.61	0.43	225	11.4	26	15
Significance	***	***	***	***	***	***	***	***	**	*
Initial N										
34	4.10	0.23	0.34	3.10	3.58	0.40	395	9.9	22	14
67	4.35	0.24	0.37	3.16	3.47	0.40	357	9.3	23	17
101	4.46	0.24	0.39	3.23	3.58	0.41	382	9.5	23	17
135	4.48	0.26	0.39	3.23	3.41	0.40	374	9.4	21	17
Significance	**	NS	*	NS	NS	NS	NS	NS	NS	NS

NS,*,**,***Nonsignificant or significant at the 5%, 1%, or 0.1% levels, respectively.

These concentrations occurred in spite of the fact that mulched plants were markedly larger and growing faster than unmulched plants at the time of sampling. Thus, differences in early uptake are even larger than indicated by concentration differences, since uptake is the product of mass × concentration. Particularly noteworthy was the magnitude of the increase in P and Cu concentration, 55% and 50%, respectively. Martin and Wilcox (15) and Gosselin and Trudel (7) showed that P content increases with increasing soil temperature. Rudich (17) also found that mulched tomato plants contained higher levels of P than unmulched plants. There were no differences in concentrations of Fe, Al, Mn, and Mo caused by mulching or initial N rate (data not shown). The slight but significant decrease in Zn concentration caused by mulch might well be dilution due to growth. The decreased Na concentration may relate to the increased K uptake. Significant mulch × fertilizer interactions did not occur for shoot nutrient concentrations.

The relatively poor growth and yield of the unmulched plants in 1983 probably was due to the relatively cold, heavy silt loam soil on which this experiment was conducted. Soil temperatures taken on July at a 10-cm depth were 3° to 4°C higher in mulched plots than unmulched and temperature differences were probably greater in June when the transplants began their early growth. No temperature data are available for the gravelly loam soil in 1982.

Although the low NO_3 concentrations of unmulched plants in 1983 are indicative of low soil NO_3, mulched plants receiving identical amounts of N contained twice as much NO_3 (Table 5), suggesting that the reduced temperatures in unmulched plots indeed may have limited root growth and the uptake per unit of root. Alternatively, more NO_3 may have leached from the root zone of unmulched relative to mulched plants, and/or nitrification may have been greater under the mulch. These factors do not seem to be most important, because NO_3 concentrations remained low in unmulched plants receiving 134 $kg \cdot ha^{-1}$ of N 24 days earlier. The NO_3 concentration of young plants often is used as a guide in determining adequacy of soil N early in the season. This is of particular interest because, in the case of unmulched plants, where uptake was apparently inhibited by low temperature, one could have erroneously concluded that soil NO_3 was inadequate based on tissue testing only.

Initial N rate had very little influence on growth and yield in these experiments. No attempt was made to deplete the N level in the soil before these experiments were conducted, and it is likely that residual N remaining after the previous year's cropping was sufficient to carry the plants to the point where sidedressed N became available. Moreover, in 1983, even the lowest N treatment received 34 $kg \cdot ha^{-1}$ of N initially. Initial N rate did, however, increase concentrations of total N and P in the leaves sampled prior to sidedressing.

There was no indication of "excessive" vegetative growth at high initial N rates, even when combined with plastic mulch and when grown on a silt loam soil. It may be that 'Pik-Red' and 'Springset' have an inherently high fruit to leaf ratio. Although early use of N was markedly increased by the plastic mulch on the silt loam soil, the experiments indicate that N fertilizer management of these cultivars need not differ for mulched and unmulched plants. For the levels of N and the cultivars used here, the timing of the N application did not appear to be critical, as long as there was residual soil N.

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Restricted Root Zone Volume: Influence on Growth and Development of Tomato

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Abstract. **'Better Bush' tomato (*Lycopersicon esculentum* Mill.) plants were grown in small- (450-cm^3) or large- (13,500-cm^3) volume plastic containers and harvested every 2 weeks from time of planting until 12 weeks, at which time ripe fruits had developed. Plants were fertilized three to six times daily to prevent drought and nutrient stress. After only 2 weeks, there were significant reductions in total height, node number, leaf area, and dry weight of leaves. By 4 weeks, dry weights of stems and roots were also significantly less in small pots than in large pots. These differences were maintained for the next 10 weeks. Root restriction also generally caused an increase in root : shoot ratio. Roots in small-volume containers formed a highly branched mat, whereas those in large-volume containers had long taproots and showed little branching. Root restriction also significantly reduced the total number and fresh and dry weight of mature fruits. Despite these differences, both groups of plants had nearly 41% of the total photosynthate in the reproductive portion of the plant after 12 weeks of treatment. During weeks 6–8, the mean relative growth rate of plants in small pots was twice that in large pots but thereafter was only half as much. Restricting root volume had little or no effect on net assimilation rate. These data suggest that, for a given growing area, a culture system using small containers would be more efficient in producing fruit for a given weight and size of plant than one using large containers. These findings have important implications for growers and researchers involved in growing plants in confined spaces such as in a phytotron or controlled ecological life support system (CELSS).**

The importance of container volume often is ignored in many greenhouse and growth chamber studies, despite the fact that root restriction has been shown to affect the growth and development of many species of plants (B. Aloni and A. Carmi, personal communication; refs. 1, 6, 10, 11, 14, 17). This study was undertaken to observe the influence of root restriction on growth and yield in "Better Bush" tomato and to determine, on the basis of yield, the feasibility of using small-volume containers to grow tomato plants in a confined space such as a controlled ecological life support system (CELSS) (13, 15, 16).

Reducing soil volume often leads to dwarf plants (3, 7, 14, 17), but there may be no alteration of relative dry weight distribution, which would indicate a reduction in total plant growth (1, 10, 14); however, root growth may be impaired in a restricted volume, creating a relative decrease in root dry weight (5, 18). Plants grown in small containers characteristically develop a shorter, more densely branched root system than those grown in large containers; this, in turn, may affect total plant growth, since the roots are an important source of growth substances in the plant (14).

Reduced transport of gibberellins and cytokinins from the roots may be partly responsible for the retarded shoot growth observed in root-restricted plants, since exogenous application of these growth substances partially overcomes suppression of shoot growth (3). Root restriction has been shown to cause a reduction in shoot dry weight (2, 5), length (1, 2, 5, 10), internode elongation (1, 3, 4), and size and number of laterals (10, 14, 17). Other major vegetative effects of root restriction include reduction in leaf area (2, 4, 10, 12, 14), leaf number (11, 14), and leaf dry weight (2).

Aloni and Carmi (personal communication) and Carmi et al.

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