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Spacing, Root Cell Volume, and Age Affect Production and Economics of Compact-growth-habit Tomatoes

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Abstract. **Compact-growth-habit (CGH) tomatoes (*Lycopersicon esculentum* Mill.) do not require the pruning, staking, and tying required for many fresh-market tomato cultivars. In 1990, 5-week-old transplants of the CGH tomato breeding line NC 13G-1 were grown in single rows with in-row spacings of 31, 46, 61, and 76 cm and in double rows with in-row spacings of 31 and 46 cm. NC 13G-1 produced high early and total season marketable yields when grown in either double-row treatment compared to any single-row treatment. In 1991 and 1992, 4- and 5-week-old NC 13G-1 transplants were produced in five root cell volumes (8.6, 13.6, 27.0, 37.1, and 80.0 cm^3), transplanted into double rows with an in-row spacing of 46 cm, and evaluated for yield. Five-week-old transplants produced in 37.1- and 80-cm^3 cells flowered sooner after transplanting and produced higher early season yields than 4-week-old transplants produced in the three smaller cells. Midseason yields increased quadratically and late-season yields decreased quadratically as root cell volume increased. Total season marketable yields did not differ among treatments. In 1991, production costs were influenced by root cell volume, but not in 1992. In 1992, net returns for the four smallest cell volumes were similar, and lower than for transplants grown in the largest cell volume. In both years, highest net returns were achieved with transplants produced in 37.1-cm^3 cells. Considering the estimated 1992 net returns of $17,000/ha, production of CGH tomatoes may provide an alternative for staked-tomato growers concerned with labor availability and production costs, even though marketable yield from NC 13G-1 was lower than with a conventional cultivar under the standard system.**

Production costs for staked, fresh-market tomatoes are among the highest for any vegetable crop. Labor costs associated with transplanting, pruning, staking, and tying plants to stakes (Konsler and Gardner, 1990) can account for up to 55% of total production costs (Davis and Estes, 1993). Elimination or reduction of some of these costs could increase returns to growers.

Compact-growth-habit (CGH) tomatoes possess a unique plant architecture resulting from the combination of two traits that alter their vegetative growth habit compared to normal-growth-habit tomatoes, now used in staked, fresh-market tomato production (Kemble et al., 1994). The combination of these two traits, brachytic gene (*br*) (Burton et al., 1955) and prostrate growth habit (Ozminkowski et al., 1990), produces a low-growing (≈46-cm canopy height), spreading (≈60 cm in diameter) plant that holds most of its fruit aboveground. As a result, CGH tomato plants do not require pruning, staking, tying, or any of the labor or material costs associated with these practices. Because of the unique architecture of the CGH tomato, a new cultural system had to be developed before the plant could be recommended for commercial use.

As in-row spacing was decreased in normal-growth-habit tomatoes, early season yields increased, but overall fruit size was reduced (Austin and Dunton, 1970; Davis and Estes, 1993; Frost and Kretchman, 1988). In contrast, wide in-row spacings produced larger fruit and more fruit per plant than narrow in-row spacings (Austin and Dunton, 1970; Frost and Kretchman, 1988; Stoffella et al., 1988). In addition, tomatoes grown in double-row configurations generally produced higher yields per unit area than those grown in single rows (Austin and Dunton, 1970; Wilcox, 1970).

Transplant size and age must also be considered. Transplant height, leaf area, plant dry weight (Weston and Zandstra, 1986), and yield (Weston and Zandstra, 1986, 1989) increased with increasing root cell volume. Transplants produced in large cells matured earlier and produced higher early season yields as compared to smaller transplants produced in smaller cells (Weston and Zandstra, 1986). Several studies have shown that, for normal-growth-habit tomatoes, 5-week-old transplants produced larger fruit than older transplants (Cooper and Morelock, 1983; Leskovar et al., 1991; Weston and Zandstra, 1989).

The objectives of this research were to 1) determine an optimum in-row spacing and spatial arrangement for CGH tomatoes, 2) examine how earliness and yield of CGH tomatoes were affected by root cell volume and transplant age, and 3) estimate the economic returns generated by the various treatments.

Materials and Methods

From 1990 through 1992, field studies were conducted at the Mountain Horticultural Crops Research Station in Fletcher, N.C., on a Hayesville loam (clayey, oxidic, mesic Typic Hapludults). Dolomitic limestone, P, and K, based on soil test results (North Carolina Dept. of Agriculture, 1987), and 101 kg N/ha were broadcast-applied and incorporated. Beds (1.5 m apart center to center) were shaped, and black polyethylene mulch (1.5 m wide × 0.04 mm thick) and drip-irrigation tape [Ro-Drip with 46-cm emitter spacing (Roberts Irrigation Products, San Marcos, Calif.) was used in 1990; Typhoon with 61-cm emitter spacing (Netafim, Valley Stream, N.Y.) was used in 1991 and 1992], centered in the bed at a depth of 4 cm, were installed in a single operation. In 1992, beds were fumigated with a mixture of 67% methyl bromide and 33% chloropicrin

Table 1. Characteristics of Todd planter flats used for growing tomato transplants.

Todd planter flat[z]	Cell vol (cm^3)[y]	Cell depth (cm)	Cell area (cm^2)	Seedling density (plants/m^2)
080A	8.6	4.5	4.3	1448
080M	13.6	6.4	3.6	1679
100A	27.0	7.6	6.5	862
150	37.1	6.4	14.5	547
200	80.0	7.6	25.8	308

[z]Todd planter flats are made from expanded polystyrene. Cell shape is a square, inverted pyramid. Area (length × width) of each tray is similar.
[y]Water volume of cells.

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(CCl_3NO_2) at a rate of 224 kg•ha^{-1} 2 weeks before transplanting. Beginning at fruit set, an additional 22.7 kg N/ha was applied weekly through the drip-irrigation system alternately with 20N–4.4P–16.6K and 13N–0P–36.5K.

Transplants were grown in a medium containing 1 fine peat : 1 horticultural vermiculite (v/v) amended with 7.1 kg dolomitic limestone, 1.0 kg 13N–0P–36.5K, 0.3 kg $MgSO_4$, 3.5 kg Esmigran (micronutrient fertilizer; Sierra Chemical Co., Milpitas, Calif.), 35.6 g chelated Fe, 2.8 g B (US Borax and Chemical Corp., Los Angeles), and 1.3 kg 0N–8.8P–0K/m^3. After emergence, seedlings were fertilized twice weekly with 100 mg N/liter from 20N–4.4P–16.6K (W.R. Grace and Co., Cambridge, Mass.). The greenhouse was maintained at 29/17C (day/night).

Plots were 6.1 m long. To harvest from the same number of plants per plot, a 4.6-m (in 1990, 1991, and 1992) or 4.9-m (in 1990; due to various in-row spacings) section was harvested from the center of each plot. Fruit were harvested at the breaker stage or riper and then graded into U.S. Combination (highest quality), U.S. #3 (some cosmetic defects), and culls (unmarketable) (North Carolina Dept. of Agriculture, 1986). U.S. Combination grade fruit were size-separated according to diameter: jumbo (>88 mm), extra large (73 to 88 mm), large (64 to 72 mm), and medium (58 to 63 mm). All yields are reported as marketable yields (U.S. Combination and U.S. #3 grades) per hectare. In each year, early season yields consisted of the first three harvests, midseason yields consisted of the next two harvests, and late-season yields consisted of the last two harvests. Data were subjected to analysis of variance procedures using SAS (SAS Inst., Cary, N.C.).

In-row spacing and spatial arrangement. In 1990, 5-week-old transplants of NC 13G-1, a CGH fresh-market tomato breeding line, and ‘Mountain Spring’, a normal-growth-habit tomato, were set in the field on 8 June. NC 13G-1 plants were transplanted by hand into single rows with in-row spacings of 31, 46, 61, and 76 cm and into staggered, double rows with in-row spacings of 31 and 46 cm (each in-row spacing had 46 cm between rows within the bed). ‘Mountain Spring’ was grown as a control in single rows with an in-row spacing of 61 cm. Fruit were harvested weekly for 6 weeks beginning 13 Aug. The design was a randomized complete block with four replications.

Root cell volume × transplant age. In 1991 and 1992, NC 13G-1 was sown two seeds per cell into five sizes of Todd planter flats (Speedling, Sun City, Fla.) (Table 1). Flats were sown 4 and 5 weeks before transplanting. Seedlings were thinned to one per cell following emergence.

Four- and 5-week-old plants were transplanted by hand into staggered, double rows (1 June 1991 and 8 June 1992) on raised beds with 46 cm between double rows within a bed and 46 cm between plants within the row. In both years, fruit were harvested weekly for 7 weeks beginning on 5 Aug. 1991 and 6 Aug. 1992. The design was a randomized complete block with five replications.

Because of the unique plant architecture resulting from the compact growth habit, lower foliage of newly transplanted seedlings was heat-injured where leaves contacted the black polyethylene mulch in 1991. In 1992, mulch-covered beds were sprayed with 3 water : 2 flat white exterior latex paint (v/v) from a backpack sprayer (Solo, Newport News, Va.) to increase light reflectance and reduce heat from the black polyethylene mulch. As a result, use of the white paint prevented all leaf injury.

To compare the performance of the treatments in this study to that of staked-tomato production in western North Carolina, benefits–cost index values (BCIV) were generated for each of the 10 treatments using the method described by Estes et al. (1985). BCIV reflect changes in returns and costs associated with each treatment. All treatments were adjusted by a control that represented a baseline and had a BCIV of zero. This process yielded net positive effects and net negative effects associated with costs and returns for each treatment compared to the control. BCIV were calculated as [(net positive effects/net negative effects) – 1]. The control was based on 1991 and 1992 costs and returns for staked, fresh-market production of ‘Mountain Spring’ tomato. These control data were based on weekly yield data collected from replicated variety trials that included ‘Mountain Spring’ at Fletcher (R.G. Gardner, unpublished data).

A partial budget for 1991 and 1992 was developed to assess production costs incurred by the 10 treatment combinations. The partial budget was based on a 1988 partial budget for staked, vine-ripe, fresh-market tomato production in the mountains of western North Carolina (Estes et al., 1988) and adjusted to reflect current market and area prices for various materials and present labor rate (E.A. Estes, written communication). Additionally, labor and material costs associated with pruning, staking, and tying were removed, as these costs were not required with CGH tomatoes. Labor costs were based on a $4.75 per hour (average rate of pay for field labor in North Carolina) rate and average time required for each operation. Transplant costs were based on information provided by a national supplier and several local suppliers of transplants. In these calculations, we assumed that as the density of a flat increased, price per plant decreased (Marr and Jirak, 1990). We also assumed that it would require 1.5× longer to transplant the required number of CGH tomato transplants into double rows than into single rows. In addition, the difference in the cost for producing a 4-week-old vs. 5-week-old transplant was negligible (data not shown) and, therefore, was not included in transplant cost estimates. Preharvest costs included transplants, fertilizer, and pesticides as well as fixed costs associated with land, equipment, overhead (bulk bins, harvesting buckets), and irrigation (pump, filter) (Table 2). Postharvest costs included those costs associated with harvesting and marketing fruit through a western North Carolina packinghouse. Production costs were calculated as the sum of the preharvest and postharvest costs. Gross returns were estimated from total season marketable yields and appropriate prices (loaded on truck, but not shipped) for each fruit grade for a particular week at a western North Carolina shipping point. Net returns represent the difference between gross returns and total production costs.

Table 2. Partial budget for preharvest costs ($/ha) for each root cell volume used in 1991/1992 root cell volume × transplant age study for the compact-growth-habit tomato line NC 13G-1. Transplant costs are not included.

Preharvest costs	$/ha
Polyethylene mulch, drip tape, fumigant[z]	$1728
Main irrigation lines, lay-flat[y]	432
Lime, preplant fertilizer, postplant fertilizer	511
Herbicides	59
Insecticides	156
Fungicides	336
Transplant cost[x]	(see Table 4)
Set transplants (labor)	70
Filling-in skips (replace missing/dead plants)	170
Labor for cultural operations (95 h at $4.75/h)[w]	1114
Scouting for insect, disease, nutritional problems	123
Fixed costs	
Land (rent)	220
Equipment[y]	330
Overhead cost, bulk bins, harvesting buckets[y]	441
Irrigation (equipment, pump, machinery)[y]	220
Preharvest subtotal	$5910

[z]Contract costs for fumigation, mulch, and drip-tape application.
[y]Prorated over 3 years.
[x]Does not include cost of transplants.
[w]Cultural operations such as pesticide application and field preparation, but does not include costs for pruning, staking, or tying.

Table 3. Early and total season marketable yields for several in-row spacings and row arrangements within a bed for NC 13G-1 and ‘Mountain Spring’ tomatoes in 1990.

Cultivar or line	In-row spacing (cm)	No. rows in bed[y]	Marketable yield[z] Early (Mg•ha^{-1})	Marketable yield[z] Total (Mg•ha^{-1})
NC 13G-1	31	1	45.5 b	72.0 b
	46	1	43.4 b	70.6 b
	61	1	36.8 bc	63.5 b
	76	1	34.2 bc	63.1 b
NC 13G-1	31	2	71.5 a	91.3 a
	46	2	68.3 a	89.8 a
Mountain Spring	61	1	25.7 c	60.3 b

[z]Means separation within a column by protected LSD ($P \le 0.05$).
[y]Number of rows of plants within the same bed.

Results and Discussion

In-row spacing and spatial arrangement. NC 13G-1 grown in double rows with close in-row spacings (31 and 46 cm) produced higher early and total season marketable yields than any single-row treatment with NC 13G-1 or 'Mountain Spring' (Table 3) ($P \leq 0.05$). Early and total season marketable yields did not differ among the NC 13G-1 single-row treatments, but there was a consistent trend toward higher yields as in-row spacing decreased. Ground scar and rot, attributed to contact with the polyethylene mulch, on early harvested fruit of 'Mountain Spring' reached 36% compared with 5% to 14% for fruit of NC 13G-1. For early season and total season yields, mean fruit weight of NC 13G-1 (191 g early; 183 g total) was not influenced by treatments, but was significantly less than that of 'Mountain Spring' (230 g early; 229 g total) ($P \leq 0.05$). Since there were no differences in the early season or total season marketable yields of NC 13G-1 grown in double rows with 31- or 46-cm in-row spacings, 46-cm in-row spacing would be a more economical choice because fewer plants would be required per hectare.

Cell volume × transplant age: Days to anthesis. Number of days from sowing to anthesis decreased as root cell volume increased in 1991 and 1992 ($P \leq 0.05$) (Fig. 1 A and B), as reported previously (Kemble et al., 1994). In 1991, a root cell volume × transplant age interaction showed that days from sowing to anthesis were shorter for 4-week-old transplants produced in 8.6- and 13.6-cm^3 cells and longer in those produced in 80-cm^3 cells than for 5-week-old transplants produced in the same cell volumes ($P \leq 0.05$) (Fig. 1A). Regardless of root cell volume in 1992, days from sowing to anthesis were shorter for 4-week-old transplants than for 5-week-old transplants ($P \leq 0.05$) (Fig. 1B). In 1991, there was a difference of 9 and 18 days for number of days to anthesis between the largest (80 cm^3) and smallest (8.6 cm^3) cells for 4- and 5-week-old transplants, respectively. In 1992, this difference was 11 and 12 days between the 80- and 8.6-cm^3 cells for 4- and 5-week-old transplants, respectively. These findings are similar to previous ones for NC 13G-1, in which Kemble et al. (1994) reported a difference of 16 days from sowing to anthesis with increasing cell volumes. In the present study, although 5-week-old transplants generally required more time to reach anthesis, they flowered an average of 6 and 3 days earlier after transplanting than 4-week-old transplants in 1991 and 1992, respectively (data not shown).

Yield and quality. In both years, within a transplant age, early season marketable yields (ESMY) increased as root cell volume increased from 8.6 to 37.1 cm^3 in 1991 and from 8.6 to 80 cm^3 in 1992 ($P \leq 0.05$) (Fig. 2). This increase probably is the result of larger transplants flowering sooner (Fig. 1) than smaller ones. In general, plants that were 5 weeks old at transplanting produced significantly higher ESMY than plants that were 4 weeks old at transplanting, except for plants produced in 8.6- and 13.6-cm^3 cells in 1991 (Fig. 2).

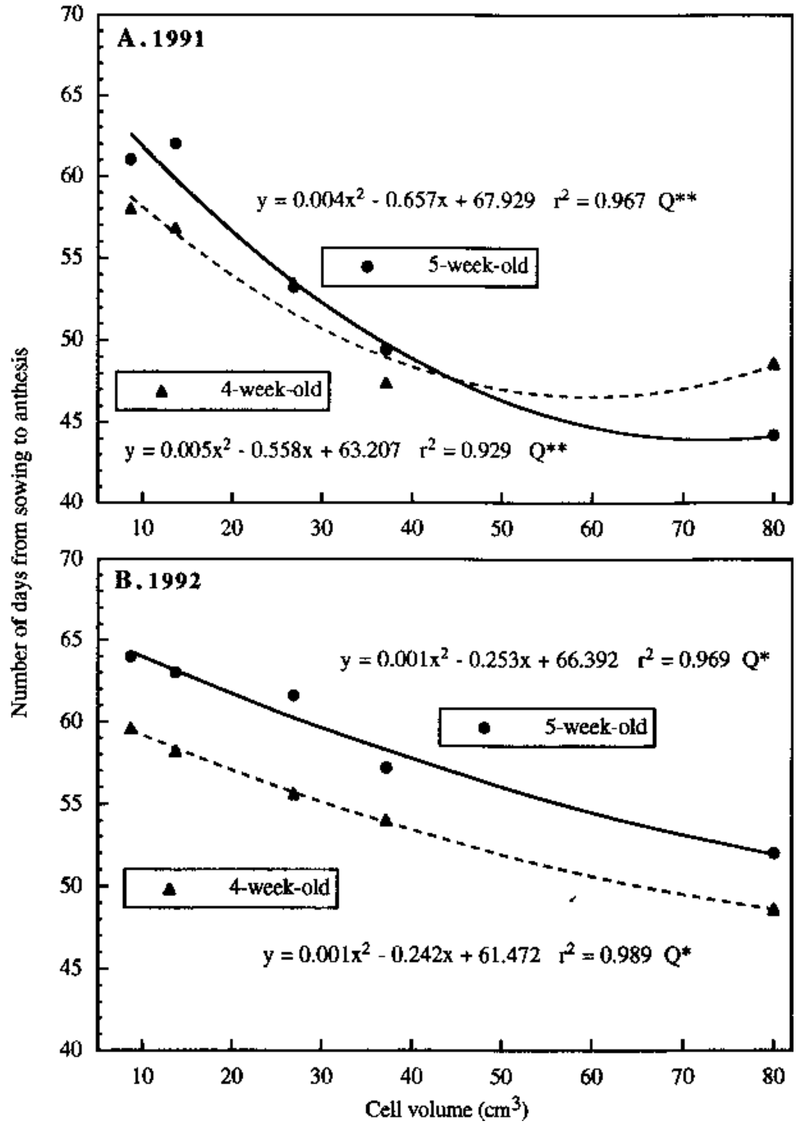

Fig. 1. Relationship between number of days from sowing to anthesis of 4- and 5-week-old NC 13G-1 tomato transplants in (**A**) 1991 and (**B**) 1992 in response to root cell volume. Cell volumes used in study were 8.6, 13.6, 27.0, 37.1, and 80 cm^3. *, **Significant at $P \leq 0.05$ or 0.01, respectively.

Almost continuous rains in 1991 resulted in much lower midseason marketable yields (MSMY) in 1991 than in 1992 ($P \leq 0.05$) (Fig. 3A). In both years, however, as root cell volume increased, MSMY increased up to 37.1 cm^3. Transplant age did not affect MSMY. Late-season marketable yields (LSMY) were also lower in 1991 than in 1992 ($P \leq 0.05$) (Fig. 3B). Transplant age also did not affect LSMY, but as root cell volume increased, LSMY decreased.

Within each year, total season marketable yields and fruit weight did not differ for any combination of root cell volume and transplant age. Average total season marketable yield was 48.6 $Mg \cdot ha^{-1}$ in 1991 and 79.6 $Mg \cdot ha^{-1}$ in 1992, respectively, a reflection of the difference in growing seasons. Fruit weight averaged 193 g in both years of the study, similar to that of the 1990 study. Although not significantly higher than the total season marketable yields produced by the other cell volumes, the 37.1-cm^3 cells produced the highest total season marketable yields with 60% and 80% of the total season yield being marketable in 1991 and 1992, respectively.

Production costs and returns. In 1991 and 1992, preharvest costs increased as root cell volume increased because cost per transplant increased (Table 4). Production costs in 1991 were higher for 37.1- and 80-cm^3 cells than for 8.6- and 27-cm^3 cells (Table 4), while in 1992, production costs did not differ among root cell volumes ($P \leq 0.05$). In 1991, gross returns (Table 4) were highest for the two largest root cell volumes ($P \leq 0.05$). In contrast in 1992, gross returns were reduced when transplants were grown in 80-cm^3 cells because transplants grown with this cell volume produced poorer fruit quality than those from the other cell volumes ($P \leq 0.05$). Of total marketable yields produced with the other root cell volumes, 47% to 54% was U.S. Combination grade, while only 36% of the yield produced with the 80-cm^3 cells was U.S. Combination grade. The remaining 64% was U.S. #3, receiving a much lower price than U.S. Combination grade fruit and, thus, resulting in reduced gross returns.

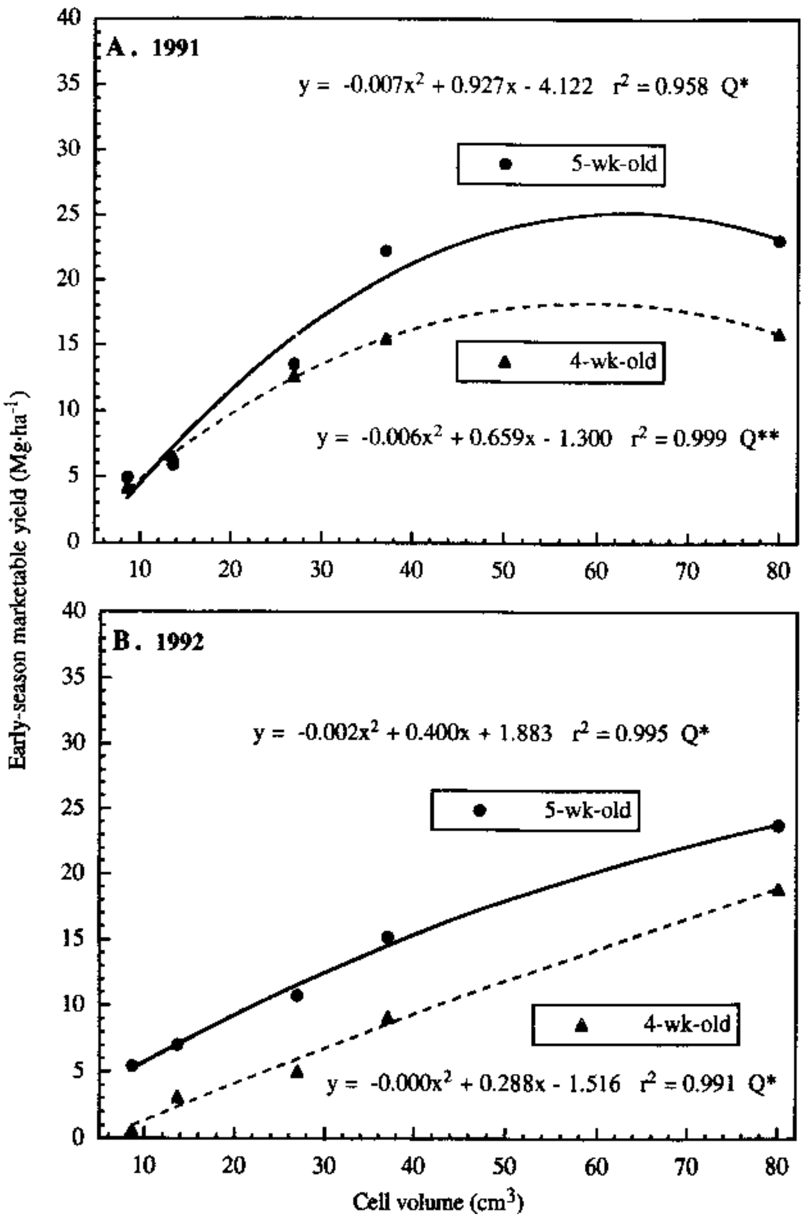

Fig. 2. Relationship between early season marketable yields of NC 13G-1 tomatoes in (**A**) 1991 and (**B**) 1992 in response to root cell volume and transplant age. Cell volumes used in study were 8.6, 13.6, 27.0, 37.1, and 80 cm^3. *,**Significant at $P \leq 0.05$ or 0.01, respectively.

To compare the relative performance of the treatments in this study to the production system currently used in the southeastern United States, BCIV were calculated. Both years, all treatment BCIV were negative, i.e., below the BCIV of the control (data not shown), indicating that production of CGH tomato NC 13G-1 would have resulted in less income than the normal-growth-habit tomato 'Mountain Spring' grown in the conventional staked system. Although NC 13G-1 produced high total yields compared to staked 'Mountain Spring', the marketable yields of NC 13G-1 were lower because the fruit tended to be smaller than that of 'Mountain Spring' and there was a high percentage of off-shape fruit (data not shown). As a result, in 1991 and 1992, only 51% to 60% and 62% to 80%, respectively, of the total season yields of NC 13G-1 were marketable. Now, more advanced CGH tomato lines have larger, smoother fruit. In contrast, 88% and 83% of the total season yields produced by 'Mountain Spring' in 1991 and 1992, respectively, were marketable. Furthermore, the marketable yields of NC 13G-1 were comprised of a high percentage of U.S. #3 grade fruit that further reduced gross returns as compared to staked 'Mountain Spring' (data not shown) because U.S. Combination grade fruit returned an average of $2.00 to $3.00 per 9.1-kg box of graded fruit more than U.S. #3 grade fruit in 1991 and 1992, respectively (E.A. Estes, written communication).

In both years, net returns from each treatment with NC 13G-1 were lower than for staked 'Mountain Spring', which had net returns of $17,500 and $25,220/ha in 1991 and 1992, respectively (Table 4). Preharvest costs for staked-tomato production in western North Carolina were $7200/ha in 1991 and 1992, which was $814 (80-$cm^3$ cell) to $1120 (8.6-$cm^3$ cell)/ha higher than for the preharvest costs of the CGH tomato grown in double rows (Table 4). Thus, in the event of a crop failure, the financial risk with the CGH tomato would be lower than with staked-tomato production because a grower's initial outlays would be reduced.

Overall, NC 13G-1 responded to changes in root cell volume and transplant age similarly to normal-growth-habit tomatoes in terms of transplant size, number of days from sowing to anthesis, and yields (Adelana, 1983; Cooper and Morelock, 1983; Kemble et al., 1994; Weston and Zandstra, 1989). Economics of production, however, varied greatly from year to year, probably as a result of climatic and market differences. In 1991, the highest net returns were obtained with 37.1- and 80-cm^3 cells (Table 4), whereas in 1992, net returns were highest for transplants produced in the four smallest cells (8.6 to 37.1 cm^3) compared to the 80-cm^3 cells. Thus, choosing a root cell volume for CGH tomato transplant production is primarily a question of transplant production economics and space since more transplants are produced per square meter in flats with small cells than in flats with larger cells (1448 plants/m^2 in 8.6 cm^3 vs. 308 plants/m^2 in 80.0 cm^3). As a result, transplant production costs could be lower because more transplants could be produced in a given area (Marr and Jirak, 1990; Weston and Zandstra, 1986).

CGH tomatoes may provide an alternative to staked tomatoes for growers concerned with labor availability, management, and production costs. CGH tomatoes require fewer inputs than staked tomatoes, especially in terms of labor. Although the potential profit for CGH tomatoes is presently lower than for staked tomatoes, there is a reduced financial risk with the CGH tomato for the grower in case of a crop failure or weak market situation. In addition, newer CGH lines have improved quality and size, which will increase their market value.

Based on these studies, we recommend that 5-week-old CGH tomato transplants be produced in 37.1-cm^3 cells. If greenhouse space is limiting, however, smaller cells can be used. Plants should be grown on raised beds with black polyethylene mulch sprayed with white paint, and set in staggered, double rows with 46-cm in-row and between-row spacing.

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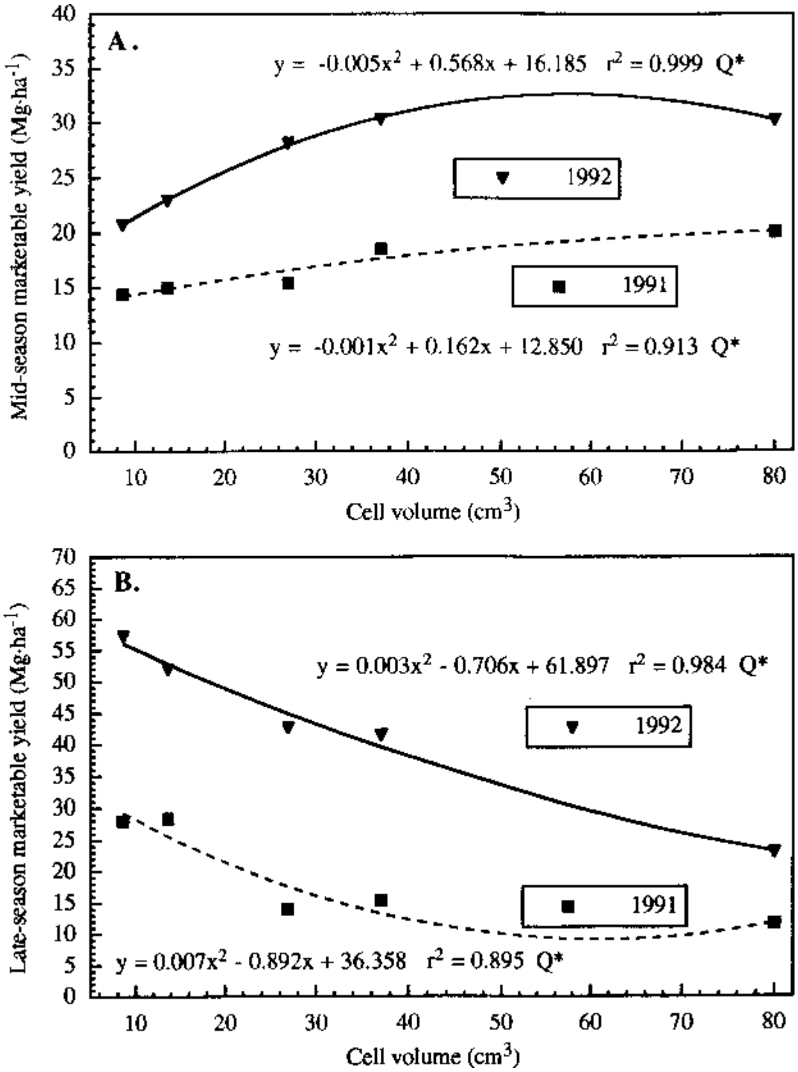

Fig. 3. Relationship between (**A**) midseason and (**B**) late-season marketable yields of NC 13G-1 tomatoes in 1991 and 1992 in response to root cell volume. Transplant age had no effect in either year so data were combined. Cell volumes used in study were 8.6, 13.6 , 27.0, 37.1, and 80 cm³. *,**Significant at $P \leq 0.05$ or 0.01, respectively.

Table 4. Transplant costs, gross returns, production costs, and net returns ($/ha) for each root cell volume used in 1991/1992 root cell volume × transplant age study for the compact-growth-habit tomato line NC 13G-1.

	Cell vol				
Criterion	8.6 cm³	13.6 cm³	27.0 cm³	37.1 cm³	80.0 cm³
			($/ha)		
1991/1992					
Preharvest cost					
Preharvest subtotal	$5,910	$5,910	$5,910	$5,910	$5,910
+ transplant costs	165	182	217	309	475
Total preharvest	$6,075	$6,092	$6,127	$6,219	$6,385
1991					
Postharvest costs/returns[z]					
Gross returns[y]	$19,890 b	$21,700 b	$18,840 b	$24,350 a	$23,180 a
Production costs[x]	20,800 b	21,560 ab	19,350 bc	22,600 a	21,740 a
Net returns[y]	$(–)910 c	$140 b	$(–)510 c	$1,750 a	$1440 a
1992					
Gross returns[y]	$45,790 a	$44,650 a	$43,760 a	$46,610 a	$40,040 b
Production costs[x]	29,500 a	29,170 a	29,020 a	29,600 a	28,500 a
Net returns[y]	$16,290 a	$15,480 a	$14,740 a	$17,010 a	$11,540 b

[z]Transplant age did not influence gross returns, production costs, or net returns.
[y]Mean separation within rows by protected LSD ($P \leq 0.05$).
[x]Production costs are the sum of preharvest and postharvest costs. Postharvest costs include harvesting and hauling charges ($0.48 per 9.1 kg of harvested fruit), grading and packing ($1.32 per 9.1 kg of harvested fruit), container costs ($0.48 per 9.1 kg of harvested fruit), and selling ($0.48 per 9.1 kg of harvested fruit) fees.

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