

Tomato Seedling Growth, Earliness, Yield, and Quality following Pretransplant Nutritional Conditioning and Low Temperatures

Regina R. Melton¹ and Robert J. Dufault²

Coastal Research and Education Center, Department of Horticulture, Clemson University, 2865 Savannah Highway, Charleston, SC 29414

Additional index words. *Lycopersicon esculentum*, Solanaceae, stress, transplant, hardening, chilling

Abstract. ‘Sunny’ tomato (*Lycopersicon esculentum* Mill.) seedlings were pretransplant nutritionally conditioned (PNC) in 1988 and 1989 with factorial combinations of N from 100 to 300 mg·liter⁻¹ and P from 10 to 70 mg·liter⁻¹. In 1988, all conditioned seedlings were exposed to 12 hours of 2C for eight consecutive nights before transplanting. In 1989, half of the conditioned plants were exposed to a low-temperature treatment of 8 days with 12-hour nights at 2C and 12-hour days in a warm greenhouse (19C/26C, night/day). In both years, as N PNC increased to 200 mg·liter⁻¹, seedling growth increased. Increasing P PNC from 10 to 40 mg·liter⁻¹ increased seedling growth, but only in 1988. In both years, P PNC did not affect yields. Low-temperature exposure in 1989 decreased seedling growth in comparison to those held in a warm greenhouse (19C/26C, day/night). In 1988, first harvest yields were not affected by N PNC; however, in 1989, as N increased to 200 mg·liter⁻¹, early yields increased. In 1988, total yields increased with N PNC from 100 to 200 mg·liter⁻¹ and in 1989 with N at 50 to 100 mg·liter⁻¹ with no further increases from 100 to 200 mg·liter⁻¹. Low-temperature exposure had no effect on earliness, yield, or quality. A PNC regime combining at least 200 mg N/liter and up to 10 mg P/liter should be used to nutritionally condition ‘Sunny’ tomato seedlings to enhance yield.

Most tomato fields in coastal South Carolina are established using greenhouse-grown transplants. Once planted, the seedlings may be exposed to near chilling temperatures for weeks before fields warm. Low-temperature stresses may delay flowering, fruiting, and possibly reduce total yields and quality. We hypothesized that earliness and overall yields would be improved using pretransplant nutritional conditioning (PNC), whereby seedlings are nutritionally conditioned during greenhouse transplant production to enable them to better tolerate transplant stresses and enhance earliness.

PNC has been shown to have long-term effects on muskmelon and tomato (Dufault, 1986; Weston and Zandstra, 1989). Although muskmelon transplant shock increased as PNC levels increased, recovery from shock was faster with higher PNC regimes (Dufault, 1986). Earliness was affected by high vs. low PNC for muskmelon (Dufault, 1986) and tomato (Weston and Zandstra, 1989), but total yields were not affected.

The influence of PNC on improving cold tolerance of tomatoes at near freezing temperatures is unknown. Low temperatures may reduce survival and possibly delay early tomato yields (Brasher and Westover, 1937). However, seedlings conditioned with a 48-h low-temperature exposure (12.5C) were more cold-tolerant than those conditioned for 3 h at the same temperature (Wheaton and Morris, 1968). Tomato productivity increased in greenhouse studies by exposing seedlings to chilling (10-13C) temperatures, especially in conjunction with high N nutrition (Wittwer and Teubner, 1957). The objectives of our study were

to determine the effects of N and P PNC and low temperature on tomato seedling growth, earliness, yield, and fruit quality.

Materials and Methods

Influence of NP and low temperatures on seedling growth. ‘Sunny’ tomato seeds were planted on 2 Mar. 1988 in quartered Todd flats (Speedling, Sun City, Fla.), (size 150, volume 30.5 cm³) filled with Sogemix #3 peatmoss/vermiculite medium (Sogevex, Apopka, Fla.). A soil test indicated (in mg·liter⁻¹) 8N-28P-103K and a 5.7 pH. The range of pretransplant nutritional regimes were based on a previous greenhouse study (Melton and Dufault, 1991). Solutions consisted of factorial combinations of N from calcium nitrate at 100, 200, and 300 mg·liter⁻¹ and P from calcium phosphate at 10, 40, and 70 mg·liter⁻¹. Additionally, the following were included in all nutrient solutions: K (potassium sulfate at 100 mg·liter⁻¹); magnesium sulfate (70 mg·liter⁻¹); and calcium carbonate (471 mg·liter⁻¹, included to prevent a calcium compounding effect). Micronutrients were supplied in all nutrient solutions with Soluble Trace Element Mix (Peter’s Fertilizer Products, W.P. Grace & Co., Allentown, Pa.) at the recommended rate of 313 mg·liter⁻¹. The pH of each solution was adjusted to 7.0 using H₂SO₄ or NaOH.

The flats were placed in a greenhouse and maintained at a mean of 19C/26C (night/day). Each replication (a quartered flat) consisted of 32 seedlings. The nine NP PNC treatments were replicated four times and arranged in a randomized complete block design. The first nutrient application was made on 16 Mar. 1988 at the second true-leaf stage, 14 days after seeding. The flats were floated in nutrient solutions in 38 × 25 × 9-cm plastic storage boxes (Max Klein Co., Baraboo, Wis.) for 1 h, then drained for 1 h, and returned to their respective bench locations. Nutrient solutions were applied three times/week until 25 Mar., when at least one treatment across all replications had reached minimal transplanting stage (≈ 15 to 20 cm height with five true leaves). A total of five PNC treatments were made.

Received for publication 14 Aug. 1990. Technical contribution no. 3154 of the South Carolina Experiment Station, Clemson Univ. This study was funded from the USDA grant (CSRS-85-CSRS-2-2541) “Agricultural Adjustment in the Southeast through Alternative Cropping Systems”. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

¹Graduate Student.

²Associate Professor.

On 27 Mar., the seedlings in all the PNC treatments were placed for eight consecutive nights in darkness at ≈ 2 C in a cooler from 1900 to 0700 HR and returned to the greenhouse (26 ± 6 C) from 0700 to 1900 HR to simulate low-temperature extremes possible in the field. The seedlings (including those held in the greenhouse) were not nutritionally conditioned during low-temperature exposure but were irrigated with tap water only. Although we attempted to illuminate the seedlings in the coolers during low-temperature stress treatments, heat from the lights within the coolers increased unit temperatures significantly. Hence, low-temperature imposition was scheduled to occur in darkness to reduce the number of hours of light deprivation. The effect of the increased periods of darkness imposed during low-temperature stress on seedling growth is unknown.

Nine plants were randomly chosen from each flat for seedling growth analysis on 4 Apr. 1988. Variables measured included: shoot fresh weight; stem diameter (at cotyledonary node); expanded true leaf number (leaves with clearly visible petioles); leaf area per seedling, including petiole (LI-COR LI-3100 leaf area meter; LI-COR, Lincoln, Neb.); and shoot and root dry weights per treatment plot (dried for 24 h at 65 C). One leaf disk (0.31 cm^2) from the second true-leaf tip of five plants each per treatment was removed with a hole punch, composite, and total chlorophyll was determined (Moran, 1982). Chlorophyll content was used to quantify the visible differences in greenness among the PNC treatments.

Growth data were subjected to a factorial analysis of variance (ANOVA). The relative importance of N and P on tomato seedling growth was determined by partitioning the total sum of squares for treatments into main and interaction effects and by expressing their individual contribution to variation as a percentage of the total sum of squares for the model (composed of only those sources of variation in the ANOVA).

Refinements of the experimental treatments used in 1988 were necessary in 1989 to clarify the meaning and precision of the experiments. Ineffectual treatments, such as the 70 mg P and 300 mg N/liter were abandoned. Generally, similar experimental procedures were followed in 1989 as in 1988, with the following modifications. The seeds were planted on 17 Mar. 1989. Nutrient concentrations included N rates at 50, 100, and 200 mg-liter⁻¹ and P rates at 10 and 40 mg-liter⁻¹. The Ca level was adjusted to 309 mg-liter⁻¹. In addition, two flats per PNC treatment were used; one flat was exposed to low temperatures at the end of the PNC applications, while the other flat remained in the greenhouse. This procedure allowed for separation of the effect of PNC on seedling response to high- and low-temperature environments near the time of field planting. The first nutrient application was made on 29 Mar. 1989 at the first true-leaf stage. A total of five PNC treatments were used. On 7 Apr. 1989, four replications (flats) of each nutrient treatment were placed in darkness in a cooler at ≈ 2 C from 1900 until 0700 HR for 8 consecutive days. Low-temperature-stressed plants were returned to a greenhouse at a daytime mean of 26 ± 6 C from 0700 until 1900 HR daily. Another complete set of PNC treatment flats remained in the same greenhouse until field planting and were not exposed to low-temperature treatments. Seedling growth data was taken on 14 Apr., 28 days from seeding on nine randomly chosen plants from each flat.

Influence of NP and low temperatures in the field. Seedlings from each treatment flat were hand-transplanted on 5 Apr. 1988 and 14 Apr. 1989 at the Clemson Univ. Coastal Research and Education Center, Charleston, S.C. Soil type was a Yauhannah loamy fine sand, an Aquic Hapudults. The field was fertilized

with (in kg-ha⁻¹) 165N-76P-179K before planting. Dolomitic limestone was added as indicated by soil tests. Beds on 1.8-m centers were fumigated with methyl bromide at 220 kg-ha⁻¹ and mulched with 0.3-mm (1.25 mil) black plastic. Plants were spaced 0.5 m apart within rows, and each 4.6-m-long test plot contained 10 plants. Each treatment was replicated four times in a randomized complete block design. Plots were drip-irrigated as necessary when tensiometers (30 cm deep) were at 0.2 Pa in 1988 and at 0.1 Pa in 1989. Tomatoes were staked, tied, suckered, and sprayed with pesticides using standard commercial recommendations (Cook, 1980).

The fruits from the first flower cluster were harvested from a plant in the center of each treatment plot the day before the first harvest to determine if PNC and/or low-temperature exposure affected the weight and quality in the first cluster. All of the remaining fruit were harvested at the breaker stage (Ware and McCollum, 1980). The fruit was graded using USDA standards of small (<5.5 cm), medium (5.5-7.0 cm), large (>7.0 cm), and cull fruit. The cull fruit was categorized separately by major blemish factors as follows: cracking, blossom-end rot (BER), green shoulders, and seams. There were three weekly harvests in 1988 and four in 1989. Data were analyzed by harvest date and also pooled over the entire harvest season each year. Data analysis was the same as outlined in the greenhouse study.

Results

Influence of PNC on seedling growth. The effect of N and P nutritional conditioning on seedling growth differed between 1988 and 1989. Plant height, stem diameter, leaf number, leaf area, and fresh and dry shoot weights were higher at 200 than at 100 mg N/liter in 1988, with no further increases above 200 mg-liter⁻¹ (Table 1). Root dry weight increased with N from 100 to 300 mg-liter⁻¹. Total chlorophyll content was higher at 300 than at 100 or 200 mg N/liter, substantiating an apparent visual enhancement of greenness with high N.

Plant height, stem diameter, leaf number, leaf area, and fresh and dry shoot weights responded similarly in 1989 as in 1988, but with N in the range of 50 to 200 mg-liter⁻¹ (Table 1). Total chlorophyll was higher with 200 mg N/liter than at the lower concentrations. Root dry weight increased only with N from 50 to 100 mg-liter⁻¹. Nitrogen interacted with low-temperature exposure to affect all of the variables; however, only 5% to 8% of the variation was attributable to this effect, which we considered to be negligible.

Phosphorus PNC affected all of the growth variables measured in 1988 (Table 1). Stem diameter, leaf number, leaf area, fresh shoot weight, and dry shoot and root weights were higher with 40 than with 10 mg P/liter, with no further effect above 40 mg-liter⁻¹. Plant height increased with P concentration from 10 to 70 mg-liter⁻¹. Total chlorophyll was lower with 40 than with 10 mg P/liter, with no further decrease at 70 mg-liter⁻¹. Phosphorus had less effect in 1989 than in 1988; at 40 mg-liter⁻¹, it increased stem diameter, leaf area, and fresh and dry shoot weights relative to 10 mg-liter⁻¹. The higher P concentration caused a decrease in total chlorophyll. Phosphorus did not interact with N or low-temperature exposure to affect any growth variable.

Low temperatures in 1989 significantly reduced all growth variables in comparison to those not exposed to chilling (Table 1).

Influence of PNC and low temperature in the field. Yield and quality of fruit harvested from the first flower cluster were not

Table 1. Effects of N and P PNC and low temperature on tomato seedling growth.

Nutrient rate	Plant ht (cm)		Stem diam (mm)		Leaf no.		Leaf area (cm ²)		Total chlorophyll (µg·cm ⁻²)		Shoot wt (g)				Root dry wt (mg)	
											Fresh		Dry			
	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989
N (mg·liter⁻¹)																
50	---	8.2 c	---	2.4 c	---	3.4 c	---	30.17 c	---	102.3 b	---	1.41 c	---	0.20 c	---	46 b
100	7.4 b*	11.5 b	3.1 b	2.8 b	3.6 b	3.9 b	42.41 b	48.93 b	100.3 b	115.2 b	1.85 b	2.23 b	0.28 b	0.28 b	44 b	52 a
200	8.4 a	12.4 a	3.3 a	3.1 a	3.9 a	4.1 a	60.43 a	65.87 a	112.3 b	134.2 a	2.44 a	2.79 a	0.34 a	0.32 a	49 ab	52 a
300	8.3 a	---	3.3 a	---	4.0 a	---	60.41 a	---	114.5 a	---	2.44 a	---	0.33 a	---	50 a	---
P (mg·liter⁻¹)																
10	7.1 b	10.9 a	3.0 b	2.7 b	3.6 b	3.8 a	43.84 b	47.02 b	125.3 a	122.0 a	1.86 b	2.09 b	0.27 b	0.26 b	44 b	49 a
40	8.3 ab	10.9 a	3.3 a	2.8 a	4.9 a	3.8 a	58.96 a	49.92 a	101.8 b	112.6 b	2.43 a	2.20 a	0.34 a	0.27 a	51 a	51 a
70	8.7 a	---	3.4 a	---	3.9 ab	---	60.46 a	---	100.0 b	---	2.43 a	---	0.33 a	---	48 a	---
Cold stress (C)																
No	---	12.9 a	---	3.0 a	---	4.1 a	---	56.98 a	---	125.2 a	---	2.48 a	---	0.30 a	---	59 a
Yes	---	8.9 b	---	2.6 b	---	3.6 b	---	39.67 b	---	109.3 b	---	1.81 b	---	0.23 b	---	41 b
Source of variation^y																
Rep	9.1	2.7**	3.8	3.1**	13.3*	14.8**	1.9	1.0	9.2*	3.1	2.1	1.8	4.5	3.8**	25.0**	6.3**
N	19.8**	30.3**	19.7**	52.1**	23.2**	46.6**	42.6**	64.8**	15.1**	46.4**	36.7**	63.9**	32.0**	61.2**	8.3*	8.3**
P	39.8**	0.0	49.3**	1.4**	28.4**	0.0	33.3**	0.5*	51.7**	6.0**	34.4**	0.6*	35.2**	0.7*	16.7**	0.0
NP	0.4	0.2	7.0	0.1	5.9	0.3	2.7	0.1	5.5	1.7	3.2	0.0	5.1	0.1	8.3	0.0
C	---	52.6**	---	32.24**	---	26.3**	---	22.8**	---	17.0**	---	22.3**	---	24.0**	---	66.7**
NC	---	6.9**	---	3.8**	---	3.0**	---	6.6**	---	7.6**	---	6.9**	---	4.8**	---	8.3**
PC	---	0.1	---	0.3	---	0.0	---	0.0	---	0.3	---	0.0	---	0.0	---	0.0
NPC	---	0.0	---	0.4	---	0.0	---	0.0	---	0.8	---	0.0	---	0.5	---	0.0
Error	30.9	7.2	20.2	6.4	29.3	9.0	19.5	4.1	18.6	17.1	23.6	4.5	23.2	5.0	41.7	10.4

^aMean separation within main effect by LSD at $P = 0.05$.

^yComposed of all sources of variation.

*,**F value significant at $P = 0.05$ or 0.01 , respectively. Values not followed by asterisks are not significant at $P = 0.05$.

affected in 1988 or 1989 by nutrient treatment or low-temperature exposure (data not shown).

In 1988, early yield in the first harvest was unaffected by N and P regime (data not shown). However, by the last harvest, N accounted for a major portion of variation and also a significant amount was assigned to the main effect of P, indicating that PNC has long-term effects on productivity (Table 2). In 1988, yields from the third harvest increased by 17% for N PNC rates at 200 and 300 mg·liter⁻¹ relative to those conditioned with 100 mg N/liter. Increased P, like N, produced higher yields in the third harvest with 40 mg N/liter than with 10; however, increasing P to 70 mg·liter⁻¹ did not increase yield further.

Nitrogen PNC in 1989 accounted for a significant portion of variation in early yields in comparison to the other main effects and interactions; however, the effect of N PNC diminished by the last harvest (Table 2). Seedlings conditioned with N at 200 mg·liter⁻¹ yielded more fruit in the first harvest than those conditioned with the 50- or 100-mg·liter⁻¹ rates. In the second and third harvests, seedlings conditioned with N at 100 mg·liter⁻¹ yielded more fruit than those conditioned with 50 mg·liter⁻¹; N at 200 mg·liter⁻¹ did not increase yield further. Pretransplant conditioning with N, P, or cold stress had no significant effect by the last harvest.

Analysis of the pooled yields over all harvests in 1988 indicated that total marketable yield was significantly higher at 200 than at 100 mg N/liter (Table 2); however, N at 300 mg·liter⁻¹ did not increase yield further. In 1989, total marketable yield from plants conditioned with N at 100 or 200 mg·liter⁻¹ was significantly greater than N at 50 mg·liter⁻¹.

In 1989, neither P nor low-temperature exposure affected any yield variables (data not shown).

Quality blemishes were significantly affected by PNC in 1989 (Table 3), but not in 1988 (data not shown). BER was a severe problem in 1989, affecting 30% to 40% of all cull fruit produced in this growing season. BER was most severe at a PNC rate of 50 mg N/liter. At 100 mg N/liter, the incidence of concentric cracking increased in comparison to the other N rates. The percentage of seamed fruit increased from 2% to 6% at 50 and 200 mg N/liter. Green shoulders were more common at 200 mg N/liter than at lower levels. Neither low-temperature exposure nor P had any effect on incidence of fruit blemishes in 1989 (data not shown).

Discussion

A traditional practice to harden seedlings has included withholding nutrients before transplanting. These practices are thought to be detrimental to the production potential of tomatoes. Our results indicated that high N and P PNC enhanced seedling shoot and root growth.

Weston and Zandstra (1989) recommended that 400 mg N/liter should be considered optimal for the production of large seedlings that produce increased early and total yields. In 1988, 300 mg N/liter did not yield more fruit than the 200-mg·liter⁻¹ PNC rate. We suggested that N at 50 mg·liter⁻¹ is deficient and may permanently reduce yield potential. Courter et al. (1977) stated that plants overly hardened with water withdrawal, temperature stress, and/or nutrient withdrawal, resume growth slowly and may never fully recover, mature later, and may have reduced yields.

Table 2. Effects of N and P PNC and low temperature on total tomato marketable yield for each harvest.^z

Nutrient rate	Harvest no.						
	1988		1989				
	3	Total	1	2	3	4	Total
	(t·ha ⁻¹)						
N (mg·liter ⁻¹)							
50	---	---	1.4 b	3.2 b	8.4 b	3.6 a	16.6 b
100	9.2 b ^y	21.3 b	2.4 b	7.2 a	15.2 a	4.8 a	29.6 a
200	14.1 a	29.7 a	4.6 a	7.6 a	14.4 a	5.8 a	32.4 a
300	14.5 a	32.7 a	---	---	---	---	---
P (mg·liter ⁻¹)							
10	10.6 b	23.2 b	2.4 a	6.2 a	12.8 a	5.2 a	26.6 a
40	14.1 a	32.4 a	3.2 a	5.8 a	12.4 a	4.4 a	25.8 a
70	13.1 ab	28.2 ab	---	---	---	---	---
Cold stress (C)							
No	---	---	2.6 a	6.6 a	12.4 a	4.6 a	26.2 a
Yes	---	---	3.0 a	5.6 a	13.0 a	5.0 a	26.6 a
Source of variation ^x							
Rep	5.5	19.4	10.5	4.8	5.6	5.9	8.8
N	31.6**	25.9**	30.0**	18.4*	15.5*	8.2	26.6**
P	12.3*	16.4**	2.7	0.2	0.1	1.9	0.1
NP	12.7	1.9	2.8	5.4	11.4*	4.2	8.9
C	---	---	0.6	1.3	0.1	0.3	0.0
NC	---	---	0.9	3.7	0.5	1.8	0.4
PC	---	---	5.7*	0.8	1.7	0.3	0.0
NPC	---	---	1.6	0.0	5.8	1.5	1.9
Error	37.9	36.4	45.3	65.4	59.5	76.1	53.2

^z1988—First harvest lost to blossom-end rot.

^yMean separation within main effect by LSD at $P = 0.05$.

^xComposed of all sources of variation.

***F value significant at $P = 0.05$ or 0.01 , respectively. Values not followed by asterisks are not significant at $P = 0.05$ or 0.01 .

Table 3. Effects of N and P PNC and low temperature on percentage of cull production due to fruit quality blemishes in 1989.

Nutrient rate	Percentage of total cull fruit			
	Blossom-end rot	Concentric cracking	Seams	Green shoulders
N (mg·liter ⁻¹)				
50	40.0 a ^z	16.0 b	2.0 a	8.0 b
100	34.0 b	21.0 a	4.0 b	9.0 b
200	30.0 b	18.0 ab	6.0 c	12.0 a
Source of variation ^y				
Rep	3.33	7.14	0.00	0.00
N	26.67**	14.29*	50.00**	14.29**
P	0.00	7.14	0.00	0.00
NP	3.33	0.00	0.00	14.29*
C	3.33	0.00	0.00	0.00
NC	6.67	0.00	0.00	0.00
PC	0.00	0.00	0.00	0.00
NPC	0.00	0.00	0.00	0.00
Error	56.67	71.43	50.00	71.43

^zMean separation within main effect by LSD at $P = 0.05$.

^yComposed of all sources of variation.

***F value significant at $P = 0.05$ or 0.01 , respectively. Values not followed by asterisks are not significant at $P = 0.05$.

Our research suggested that concern over the effects of low temperature experienced in the field following transplanting may be unwarranted with the 'Sunny' tomato. Hurd and Cooper (1970) found that flower initiation in many tomato cultivars started

within 3 weeks of cotyledon expansion, coincident with the third oldest leaf being just in excess of 10 mm long. Apparently, in our study, first fruit initials were not affected during the time of low-temperature exposure since temperatures at 2C would have arrested their development. Low-temperature exposure decreased seedling growth and likely was stressful. Low temperatures are known to slow plant growth and reduce metabolic rates (Salisbury and Ross, 1985). The plants remaining in the greenhouse during this time were apparently able to continue more active growth in response to moderate night temperatures. However, there were no long-term effects of low-temperature exposure on earliness of fruit set, total yields, and fruit quality.

Nitrogen applied at 50 or 100 mg·liter⁻¹ in contrast to 200 mg·liter⁻¹ reduced yields. Although cultivar differences probably exist in response to PNC, nutritionally conditioning seedlings with at least 200 mg N/liter may enhance marketable yields relative to lower N rates. In tomato transplant production, the nutritional regimes used to produce seedlings have long-lasting effects on earliness and total yields. Therefore, a PNC regime combining at least 200 mg N and 10 mg P/liter should be used to nutritionally condition seedlings during the transplant production phase to promote earlier and higher yields.

Literature Cited

- Brasher, E.P. and K.C. Westover. 1937. The effect on yield of hardening the tomato plant. Proc. Amer. Soc. Hort. Sci. 35:686-689.
 Cook, W.C. 1980. Commercial tomato production in South Carolina. Clemson Coop. Ext. Circ. 625.
 Courter, J. W., J.S. Vandermark, and B.J. Jacobson. 1977. Growing vegetable transplants. Illinois Coop. Ext. Serv. Circ. 884.

- Dufault, R.J. 1986. Influence of nutritional conditioning on muskmelon transplant quality and early yield. *J. Amer. Soc. Hort. Sci.* 111:698-703.
- Hurd, R. and A. Cooper. 1970. The effect of early low temperature treatment on the yield of single inflorescence tomatoes. *J. Hort. Sci.* 45:19-27.
- Melton, R. and R.J. Dufault. 1991. Nitrogen, phosphorus and potassium fertility regimes affect tomato transplant growth. *HortScience* 26:141-142.
- Moran, R. 1982. Formula for determination of chlorophyll pigments extracted with N,N dimethylformamide. *Plant Physiol.* 69:1376-1381.
- Salisbury, F. and B. Ross. 1985. *Plant physiology*. 3rd ed. Wadsworth Publishing CO., Belmont, Calif.
- Ware, G.W. and J.P. McCollum. 1980. *Producing vegetable crops*. The Interstate Printers and Publishers, Danville, Ill.
- Weston, L.A. and B.H. Zandstra. 1989. Transplant age and N and P nutrition effects on growth and yield of tomatoes. *HortScience* 24:88-90.
- Wheaton, T. and L.L. Morris. 1968. Modifications of chilling sensitivity by temperature conditioning. *Proc. Amer. Soc. Hort. Sci.* 91:529-533.
- Wittwer, S.H. and F.G. Teubner. 1957. The effects of temperature and nitrogen nutrition on flower formation in the tomato. *Amer. J. Bot.* 44:125-129.