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Evaluation of Tomato Transplant Production Methods for Improving Establishment Rates

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Abstract. **Eight different tomato (*Lycopersicon esculentum* Mill.) transplant production methods were tested during two growing seasons (1993–94) to determine their effectiveness in increasing both establishment rate and yield. Seven-week-old greenhouse grown transplants of 'Hypeel 696' were shipped from Florida to Pennsylvania and planted at the Pennsylvania State Univ. Horticulture Research Farm. Transplants were also grown at the Pennsylvania State University to compare their growth with that of southern-grown plants. In 1993, increased nutrient levels during the last 10 days of transplant production significantly increased transplant size, establishment rate, and early yields, while the addition of Hydretain®, an aid to water retention and uptake, significantly increased total yield. In 1994, plants from Florida that were chilled for 7 days before transplanting and the Pennsylvania-grown plants had faster establishment rates than did nonchilled plants from Florida, but differences in yield were nonsignificant. Chilled and Pennsylvania-grown plants had significantly higher soluble carbohydrate levels in leaves, stems, and roots than did nonchilled and Florida-grown plants, while nutrient-conditioned plants had higher levels in leaves and stems. Establishment rate was not correlated with carbohydrate level. Chemical name used: (2-chloroethyl) phosphonic acid (ethephon).**

Tomato transplants comprise about one-third of all vegetable transplants grown for field production in the United States, with more than 500 million plants produced annually in Florida alone (U.S. Dept. of Commerce, 1991; Vavrina and Summerhill, 1992). One of the most critical steps in producing tomatoes from transplants is the initiation of new growth after planting in the field. This plant establishment is important for producing uniform stands that can compete effectively against weed and insect pressure (Orzolek, 1991). However, a wide range of environmental factors, such as extreme temperatures and reduced water and nutrient availability, can reduce the establishment rate.

Several different treatments have been evaluated for hardening plants to unfavorable environmental conditions. Cold tolerance of tomato seedlings increased after exposure to low temperatures (Pardossi et al., 1988; Wheaton and Morris, 1968), and ethephon application to tomato transplants increased survival rates in the field following a frost (Liptay et al., 1982). Pretransplant nutritional conditioning (PNC), the application of additional nutrients during the production cycle, increased both shoot growth before transplanting and early and total yields (Melton and Dufault, 1991). Low water availability has been alleviated through the addition of Hydretain®, a humectant that improves water retention in the soil and water uptake by the plant. Watering potted plants with Hydretain® increased the number of days to wilting for several different crops (Barrett, 1991).

Although many methods for improving tomato transplant growth and yield have been developed, the plant characteristics responsible for these improvements still are not well understood. High levels of nutrients in the plant tissue at the time of transplanting may be one factor which determines establishment rate. For example, N levels in tomato shoots at the time of transplanting were correlated with the rate of root growth in the field (Liptay and Nicholls, 1993). These nutrients may serve as a reserve that the plant can draw on after transplanting if nutrient availability and uptake are reduced. Another factor that may affect establishment is the carbohydrate level in the tissue. Again, these carbohydrates could act as an energy reserve to fuel plant growth if carbon fixation is reduced after transplanting. Also, levels of soluble carbohydrates, such as glucose, fructose, and sucrose, have been correlated with increased cold tolerance in tomato (Keller and Steffen, 1995; King et al., 1988), which may in turn lead to a faster overall growth rate. The purposes of this study were to 1) identify tomato transplant production methods that increase establishment rates and yield, and 2) determine whether high soluble carbohydrate levels before transplanting hasten establishment.

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Materials and Methods

Plant materials. All transplants, except those grown in Pennsylvania, were grown in greenhouses at the Southwest Florida Research and Education Center in Immokalee, Fla. (1993) or at Speedling, Bushnell, Fla. (1994), then shipped to Pennsylvania for planting in the field. Seeds of 'Hypeel 696' (Petoseed Seed Co., Saticoy, Calif.), a processing tomato cultivar, were sown into a nonfortified plug mix in polystyrene Todd planter flats, size 080 (Speedling, Bushnell, Fla.). Cells in the tray were inverted pyramids with a width of 2.0 cm, a depth of 4.1 cm, and a volume of 5.6 cm^3. The transplants were grown by the Speedling II system, which includes an ebb and flow watering system with constant feeding of nutrients (Thomas, 1993). Further details on commercial cultural practices were proprietary. Seven weeks after seeding the plants were shipped in their trays to Pennsylvania and planted within 5 d.

For comparison plants were grown for 6 weeks in greenhouses at the Horticulture Research Farm, Russell E. Larson Research Center, Rock Springs, Pa. Cultivar, cell size, and plug mix were identical with those used in Florida, but the plants were watered about once daily by overhead irrigation instead of the ebb-and-flow system. The plants were placed in a cold-frame for 1 week before transplanting. No additional treatments were applied.

Treatments applied to Florida-grown plants. The following six treatments were applied: 1) Roots were drenched one day before shipping with Hydretain® (Ecologel USA, Tampa, Fla.), which contained 35.2% hydrogenated simple sugars, 1.5% calcium lignosulfonate, and 63.3% inert ingredients applied at a concentration of 6.7% Hydretain®; 2) Ethephon (Ethrel®; Amchem Corp., Ambler, Pa.) was sprayed onto the foliage to the drip stage at 75 or 150 $mg \cdot L^{-1}$ a.i.; 3) GLK 8903, an experimental liquid product (proprietary) designed to reduce chilling damage (Great Lakes Chemical Co., West Lafayette, Ind.) was sprayed onto the foliage to the drip stage at 5 $mL \cdot L^{-1}$; 4) Roots were soaked in a 1% P solution for 1 h; 5) Transplants were treated every 3 d starting 10 d before shipping (four applications total) by soaking the trays in a nutrient solution of N (200 $mg \cdot kg^{-1}$), P (40 $mg \cdot kg^{-1}$), and K (100 $mg \cdot kg^{-1}$) for 1 h. In 1994, the N concentration was reduced to 100 $mg \cdot kg^{-1}$; 6) Transplants were chilled in a growth

chamber at 12 °C for 2 d (1993) or 7 d (1994).

Culture of plants. All transplants were planted in the field on 18 May 1993 and 20 May 1994 in a randomized complete-block design with four replications per treatment and 50 plants per replication The plants were spaced 0.3 m apart in rows 1.5 m apart and watered after transplanting with a 12.0N–20.9P–6.7K starter fertilizer at a concentration of 600 mg·kg^{-1} N. The plants were drip irrigated through the season and side-dressed once during the first week of July with 20.0N–8.7P–16.7K through the irrigation system at a rate of 11.12 kg N per ha. The fields were sprayed with esfenvalerate [(S)-cyano (3-phenoxyphenyl) methyl-(S)-4-chloro-alpha (1-methylethyl) benzene acetate] and oxamyl {methyl *N′N′*-dimethyl-*N*-[(methylcarbamoy)oxy]-1-thiooxamimidate} for control of Colorado potato beetle (*Leptinotarsa decemlineata* Say) and later in the season with a mixture of metalaxyl [*N*-(2,6-dimethylphenyl)-*N*-(methoxyacetyl)-alanine methyl ester] and chlorothalonil [tetrachloroisophthalonitrile] for control of early blight (*Alternaria solani* Ellis and Martin).

Data recorded. Shoot and root dry mass, leaf number, and height of five plants per replication were measured before transplanting, and all parameters except root dry mass were measured again 2 weeks after transplanting, then weekly for 4 weeks. Both red and green fruit were harvested from 10 plants in each replication during the first week of September. An estimate of the yield in tonnes·ha^{-1} was calculated based on a plant population of 20,000 plants/ha. The relative growth rate (RGR) during the first 2 weeks after transplanting was calculated from shoot dry mass using the following formula:

$$RGR = \frac{\ln(\text{final mass}) - \ln(\text{initial mass})}{\Delta t}$$

where final mass is the shoot dry mass 2 weeks after transplanting, initial mass is the shoot dry mass at the time of transplanting, and Δt is 14 d.

Soluble carbohydrate levels in the roots, stems, and leaves were also measured for six of the treatments before transplanting to determine the relationship between carbohydrate level and growth rate. Plants treated the day before shipping (Hydretain, P soak, and GLK) were not measured, since these treatments were not expected to have as great an effect on carbohydrate levels. Dried plant tissue was ground through a 40-mesh sieve and 10 mg of tissue was then shaken in 10 mL distilled water for 1 h to extract soluble carbohydrates. This solution was then centrifuged to separate the insoluble plant tissue from the remaining solution. The concentration of carbohydrates in the supernatant was determined by the phenol-sulfuric acid method described by Dubois (1956).

Statistical analysis. Analysis of variance, means separation with Fisher's LSD values, and correlation analysis were performed with SAS version 6.06 (SAS Inst., Cary, N.C.).

Table 1. Effect of preplanting treatments and place of production on tomato plant size at the time of transplanting and relative growth rate of shoots for the first 14 d after transplanting. Seven-week-old transplants were planted in the field at the Horticulture Research Farm, Rock Springs, Pa., on 18 May 1993 and 20 May 1994. Preplanting treatments were applied to plants grown in Florida.

Treatment	Height (cm)	Leaf no.	Root dry mass (g)	Shoot dry mass (g)	RGR[z]
			1993		
No treatment, Fla.	12.6	4.7	0.07	0.17	0.019
No treatment, Pa.	19.7*	4.9	0.07	0.26*	0.026
Ethephon (mg·L^{-1}): 75	15.0	4.6	0.07	0.19	0.023
150	14.3	4.7	0.07	0.22	0.015
GLK 8903	13.8	4.9	0.07	0.20	0.017
NPK soak	25.6*	5.9*	0.07	0.23*	0.040*
P soak	13.1	4.7	0.06	0.19	0.015
Chilled	13.7	4.7	0.07	0.19	0.021
Hydretain	14.2	4.6	0.08	0.20	0.016
Fisher's $LSD_{0.05}$	4.3	0.4	NS	0.05	0.009
			1994		
No treatment, Fla.	18.5	4.0	0.07	0.23	0.033
No treatment, Pa.	19.1	5.0*	0.08	0.31*	0.048*
Ethephon (mg·L^{-1}): 75	18.6	4.0	0.07	0.20	0.036
150	19.1	3.9	0.08	0.21	0.025
GLK 8903	18.4	4.0	0.07	0.21	0.035
NPK soak	17.0	3.9	0.05*	0.20	0.040
P soak	17.6	4.0	0.07	0.23	0.016*
Chilled	14.7*	3.8	0.07	0.17	0.048*
Hydretain	17.1	4.0	0.07	0.21	0.030
Fisher's $LSD_{0.05}$	1.5	0.3	0.05	0.01	0.012

[z]RGR = {ln(final dry mass) – ln(initial dry mass)}/14 days.
NS, *Nonsignificant or significantly different from control at $P \leq 0.05$ by LSD.

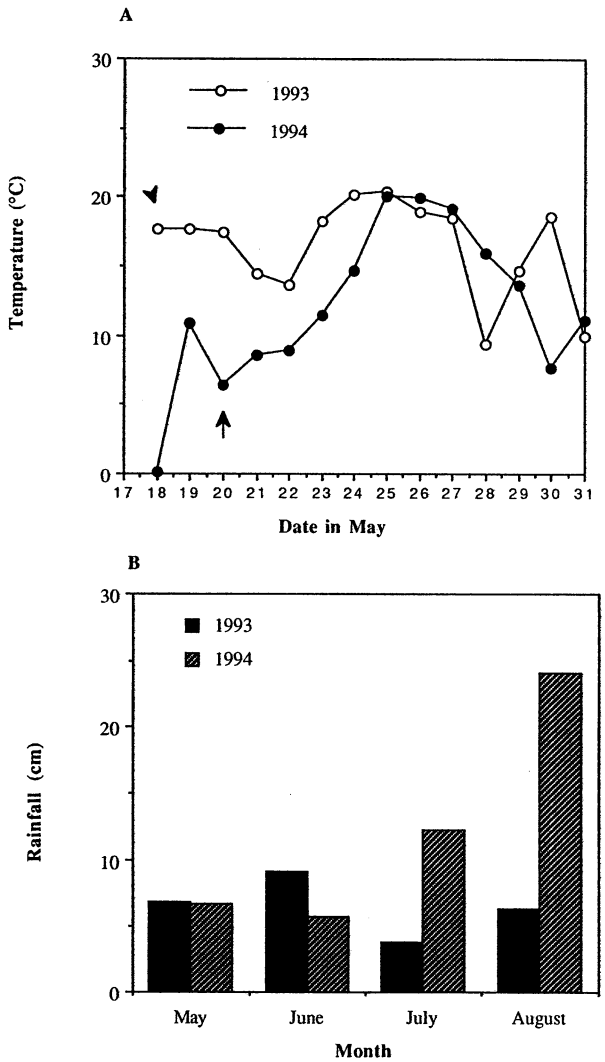

Fig. 1. (**A**) Average daily temperature during the last 2 weeks of May 1993 and 1994 at the Horticulture Research Farm, Rock Springs, Pa. Values were computed by averaging the daily high and low temperatures. Arrows indicate planting dates. (**B**) Total monthly rainfall during the growing seasons of 1993 and 1994 at the Horticulture Research Farm, Rock Springs, Pa.

Results and Discussion

Only soaking in nutrient solutions and chill treatments significantly influenced shoot growth before transplanting. In 1993, soaking in NPK during the last 10 d of the production period (PNC) doubled plant height and increased dry mass and leaf number 26% to 29% (Table 1). However, these plants had long thin stems which tangled easily with other plants in the tray, making them poorly suited for mechanical transplanting. When the N level was reduced in 1994 from 200 to 100 mg·kg^{-1}, shoot growth did not differ significantly from the control. Melton and Dufault (1991) also observed increased height and shoot dry mass in nutritionally conditioned tomato transplants, but did not report any difficulty with transplanting. The Pennsylvania-grown (PA) plants were also larger than the Florida controls, with a significantly higher shoot dry mass in both years. Chilling reduced shoot dry mass and plant height in 1994, but not in 1993. Reduced growth in 1994 was probably due to the longer chilling period (7 d in 1994 vs. 2 d in 1993).

The PNC, PA, and chill treatments significantly increased establishment rates as reflected by RGR in both years. The PNC transplants had a significantly higher RGR than the nontreated plants in 1993, but not in 1994, possibly due to the reduced root growth observed in 1994 (Table 1). The chilled and PA grown plants had higher relative growth rates than the control in 1994, but not in 1993. The difference in response for these two years may be due to the lower temperatures during May of 1994. The average temperature during the first week after transplanting was 17.0 °C in 1993, vs. 8.7 °C in 1994 (Fig. 1A). Cold hardening of the PA and chilled plants may have contributed to the increased growth under the low temperatures of 1994, but did not affect growth during the relatively warm days of 1993.

In both years the Pennsylvania plants were significantly taller and had a higher shoot dry mass and leaf number than the Florida plants 2, 3, 4, 5, and 6 weeks after transplanting (data not shown). The PNC plants were also larger than the controls 2, 3, and 4 weeks after transplanting in 1993, but there were no significant differences at 5 and 6 weeks. There were no other significant differences among treatments.

In 1994 the PNC treatment reduced root growth before transplanting by 29%, while the P soak treatment decreased relative growth rate after transplanting by 52% (Table 1). Since these treatments did not reduce growth in 1993, the damage was probably indirect. The reason why both treatments reduced growth compared to the control in 1994 is not clear.

The Hydretain®, P soak, PA, and Ehi treatments increased total yield, but the results were not consistent in both years (Fig. 2A). The plants treated with Hydretain® yielded 54% more than the control in 1993; whereas the other three treatments increased yield 17% compared to the control. None of the yields was significantly different from that of the control in 1994. The different yield response

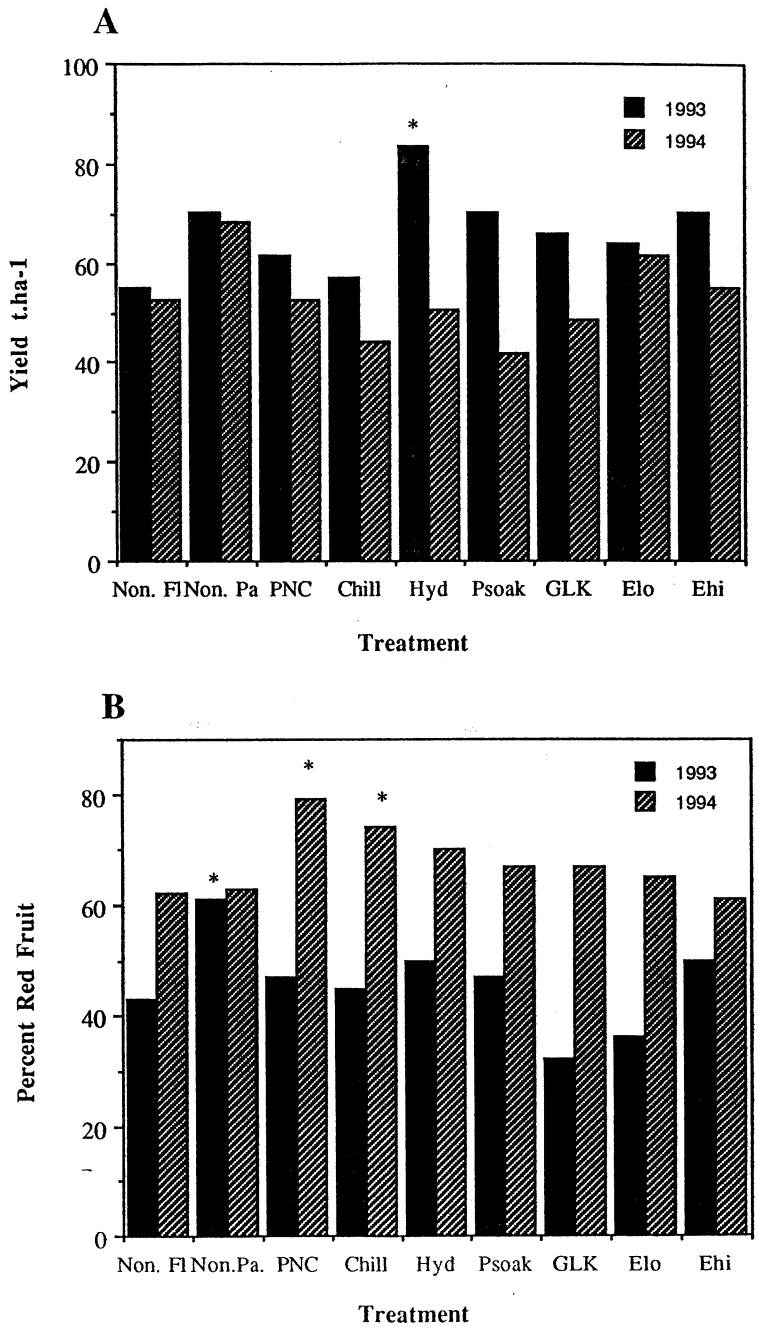

Fig. 2. (**A**) Effect of preplanting treatments and place of production on total marketable yield of tomato. Both red and mature green fruit were harvested during the first week of September. Bars with asterisks are significantly different from the control at $P \leq 0.05$. Fisher's LSD = 22.7. There were no significant differences in yield in 1994. Hyd = Hydretain; E = ethephon; PA = Pennsylvania-grown; NPK soak = pretransplant nutritional conditioning. (**B**) Effect of preplanting treatments and place of production on percent red fruit. Fruit were harvested during the first week of September. Bars with asterisks above are significantly different from the control at $P \leq 0.05$. Fisher's LSD = 12.1 for 1993 and 11.2 for 1994.

observed in the two years may have resulted from a difference in weather conditions. The total rainfall for Aug. 1993 was 6.4 cm, compared with 24.1 cm in 1994 (Fig. 1B). The Hydretain®, PNC, PA, and chill treatments increased early fruit yield, but the results were not consistent in both years (Fig. 2B). Hydretain® aids water uptake, and therefore improved fruit development during the dry conditions of Aug. 1993, but did not have an effect in the extremely wet August of 1994. In 1993 the plants grown in Pennsylvania produced a higher percentage of red fruit than did plants grown in Florida (Fig. 2B), indicating faster ripening, but total yield was not greater (Fig. 2A). Similar results were observed in Michigan, where locally grown transplants produced higher early yields than those grown in Florida, but total yield was not affected (Weston and Zandstra, 1986). In 1994 the PNC and chill treatments also induced earlier fruit ripening, but again the total yields were not affected. Melton and Dufault (1991) also observed that pretransplant nutritional conditioning increased early yields in tomato.

The chilled and PA plants had significantly

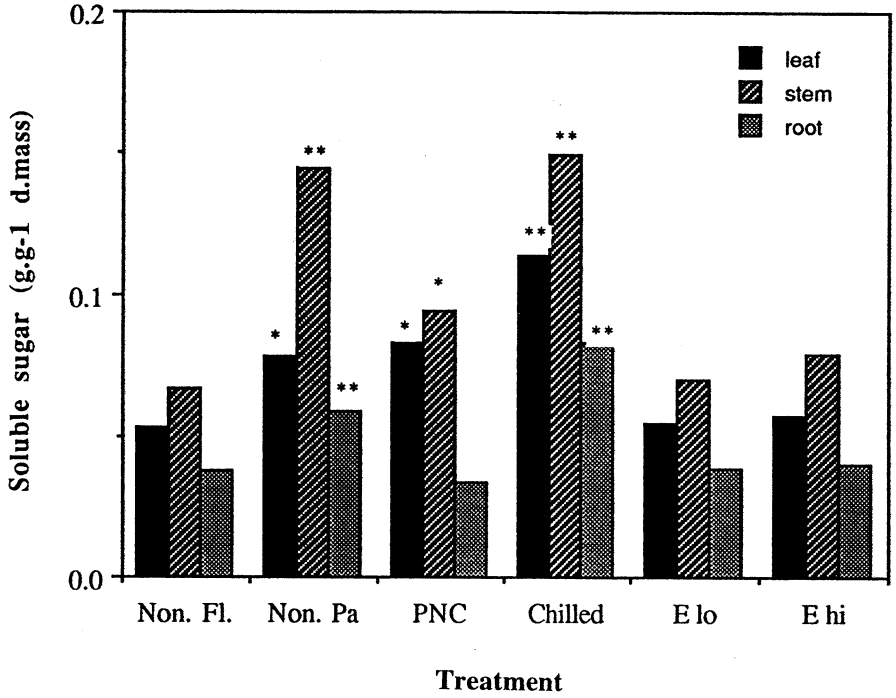

Fig. 3. Effect of preplanting treatments and place of production on soluble carbohydrate concentrations of tomato plants at the time of transplanting, 19 May 1993. Bars with asterisks are significantly different from the control at $P \leq 0.05$ (*) or $P \leq 0.01$ (**). Fisher's LSD at $P = 0.05$ for leaf, shoot and root 0.02 and 0.01, respectively. E = ethephon; NPK soak = pretransplant nutritional conditioning; PA = Pennsylvania-grown.

higher soluble carbohydrate levels than did the Florida-grown controls in the roots; stems, and leaves, while the PNC plants had higher levels of carbohydrates only in the leaves and stems (Fig. 3). Increased soluble carbohydrate levels in response to chilling have been reported for a wide range of species (Purvis, 1991) including tomato (King et al., 1988). Cold hardening of the PA plants before transplanting probably was responsible for this effect. Higher levels of net photosynthesis caused by higher nutrient levels may have increased carbohydrate levels in the leaves and stems of the PNC plants. In 1993 soluble carbohydrate levels were not correlated with relative growth rates after transplanting (r = 0.14, n = 6), primarily because the chilled plants had the highest carbohydrate levels but the third lowest growth rate (RGR). Although increased soluble carbohydrate levels have been associated with greater chilling tolerance in tomato (Keller and Steffen, 1995; King et al., 1982, 1988), other factors, including tissue nutrient levels before transplanting and tolerance to other environmental conditions, such as drought and high light intensity, may have a stronger influence on the establishment of tomato plants in the field.

The effectiveness of the treatments chosen for this study depended strongly on the weather conditions in the field. Chill hardening (both in Pennsylvania and Florida) increased establishment rates under low temperatures, while Hydretain® increased total fruit yields in a season with below-average rainfall. Nutritional conditioning at 200 mg·kg^{-1} N also increased establishment rates , but N levels must be adjusted carefully to prevent excessive growth before transplanting. Although some of the treatments were effective under more extreme environmental conditions, none increased establishment and yield in both years. This lack of consistency in response probably reflects the initial high quality of the Florida-grown control plants. Evaluation of these production methods over several growing seasons would be necessary to determine whether improvements in establishment rate and yield were consistent enough to justify the additional inputs.

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