Conclusions

In summary, using conventional constant liquid fertilization practices, NZ/N-P-K would successfully lower leachate concentrations of NH_4 , PO_4 , and K during crop production, and thus decrease environmental contamination from these nutrients while still producing quality plants. EZ1 supplemented with a 50% reduced water-soluble fertilizer rate ($105 \text{ mg} \cdot \text{L}^{-1} \text{ N}$ from 18N-4P-15K) produced plants similar to control plants based on all growth measurements except fresh mass. EZ2, which received N alone in water-soluble fertilizer, decreased leaching of PO_4 and K while providing adequate levels of these nutrients for growth of commercial quality, although some growth measurements and tissue nutrient concentrations were less than control plants. With further refinements, these zeolite-based products show promise for decreasing nutrient leaching during crop production and for resulting in crop quality comparable to current commercial standards while substantially reducing grower inputs of nutrients and labor required to fertilize.

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Varying Fertigation Volume Modifies Growth of Processing Tomato Transplants Produced in the Greenhouse and Affects Leaching from Plug Trays

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ADDITIONAL INDEX WORDS. mineral, leaching, growing medium, *Lycopersicon esculentum*

SUMMARY. Tomato (*Lycopersicon esculentum* Mill) seedlings given 0.3 to 0.4 L/tray per day of a mineral solution containing (in $\text{mg} \cdot \text{L}^{-1}$) 150N-47P-216K-64Ca-40Mg maintained optimal height at 10 to 13 cm for Ontario processing tomato transplants. Seedlings given greater fertigation volumes were too tall and spindly to use as transplants. Transplants given 0.2 L of water per tray per day were very short (6 cm) compared to those receiving 0.3 to 0.4 L. As fertigation volume was increased from 0.2 to 0.7 L, shoot N remained constant while root N increased. Shoots had about a 3-fold higher level of N, P, and K than the roots. Calcium and magnesium were similar in roots and shoots. Mineral leaching from the trays was 1% of the total volume applied for the 0.4-L and 4% for the 0.7-L treatment.

Controlling seedling height in the greenhouse is an important aspect of processing tomato transplant production for ease of plant handling in the transplanting

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process and also for stress tolerance acquisition to overcome potential inclement weather when transplanted outdoors in the field. Cultural practices that can restrain seedling growth, each with advantages and disadvantages, include drought stress (Latimer, 1990), air movement (Liptay, 1985; 1992), restricted root volumes (Liptay and Hoffmann, 1988), mechanical perturbation (Latimer, 1990), negative DIF, i.e., difference between day and night temperatures (Erwin et al., 1991; Moe et al., 1992), and restricted nutrient feeding (Dufault, 1986; Liptay and Nicholls, 1993; Melton and Dufault, 1991a, 1991b; Weston and Zandstra, 1989; Widders, 1989). In commercial transplant production, a constant concentration of nutrient solution is often used, but at different volumes, depending on the evaporative demand in the greenhouse. Thus, this study was undertaken to identify fertigation volumes at a fixed mineral concentration for optimal transplant growth and to assess mineral loss through leaching at various volumes of nutrient solution given to the seedlings.

Materials and methods

'Ohio 8245' tomato (*Lycopersicon esculentum*) seeds were sown into Metro Mix 220 growing medium (W.R. Grace, Mississauga, Ontario) in multicelled 26 × 52-cm, trays (TLC Polyform Inc. Plymouth, N.Y.), 288 cells/tray with 6-cm³ cells. The tray capacity was 288 cells × 6 cm³/cell, 1.7 L. Seeds were covered with a thin layer of medium horticultural grade vermiculite (particles ≤4 mm), moistened, and germinated for 72 h in a growth chamber set at 23 °C. The seedlings were then placed in a greenhouse set at 24 °C day and 16 °C night

for a 16-h photoperiod, supplemented with high-pressure sodium lights providing 200 μmol·m⁻²·s⁻¹. Nutrient solution was applied carefully with a watering can every morning beginning 14 d after seeding at 0.2, 0.3, 0.4, 0.5, 0.6, or 0.7 L/tray per day. Before day 14, the trays were watered with 300 mL of water per tray per day. The nutrient volumes applied could be represented as percentages of the tray capacity. These values were 12% for 0.2 L, 18% for 0.3, 24% for 0.4, 29% for 0.5, 35% for 0.6, and 41% for 0.7 L. Soluble 5N-4.8P-21.6K (5-11-26) was supplemented with magnesium nitrate and calcium nitrate to make a solution containing (in mg·L⁻¹) 150N-47P-216K-64Ca-40Mg. This formulation was chosen because of performance of the seedlings in the greenhouse and as transplants outdoors (Liptay and Nicholls, 1993). The experiment was a randomized complete-block design with four replications. The experiment had been repeated three times; results are reported for the last experiment. Height and shoot fresh weight and dry weight were determined 42 d after seeding. Shoot and root mineral analyses were done on day 28. Leachate from the trays was collected in rectangular pans, of the same dimensions as the tray, placed under each tray. The leachates were collected weekly from day 14 to 42. They were then combined in bottles and stored until analysis. Shoot, root, and leachate N and P concentrations were analyzed (Auto Analyzer II; Technicon, Wilmington, N.C.) using the Industrial Method No. 329-74W/A, colorimetric method. The shoots and roots were dried, ground, wetashed, and analyzed for K, Ca, and Mg (Warncke, 1988).

Results

SEEDLING GROWTH. As fertigation volume increased (Table 1), an increase in shoot fresh weight, dry weight, and stem diameter was noted. Optimal seedling heights for transplanting of processing tomatoes in Ontario were achieved with fertigation volumes of ≈0.3 to 0.4 L/tray per day. At 0.2 L/tray, the seedlings were too short, while at volumes >0.4 L, the transplants were too spindly.

MINERAL COMPOSITION. Phosphorus and potassium content in the shoots increased with increasing volume of fertigation, while N, Ca, and Mg were similar at all volumes (Table 2). Root N, P, and K increased with increasing volume. There was about a 3-fold higher content of N, P, and K in the shoots than in the roots.

LEACHING. The leachate for the whole duration of fertigation was <0.2 L/tray with fertigation volumes ≤0.4 L (Table 1). The leachate with the 0.3 to 0.4 L/tray per day feeding over the transplant production duration was ≈1% of the applied fertigation while it was just over 4% for the 0.7-L volume. The amount of leachate was highest when the seedlings were small and decreased as growth increased. In all cases, the mineral content of the leachate was about two-thirds of the concentration of the original fertigation solution.

Discussion

Optimal water deficit stress (Liptay et al., 1998), in addition to nutrient regulation (Dufault, 1986; Liptay and Nicholls, 1993; Melton and Dufault, 1991a, 1991b; Weston and Zandstra, 1989; Widders, 1989), are probably two of the most often used tools used in regulating seedling height during trans-

Table 1. Effect of mineral solution volume on tomato transplant growth.

Mineral solution vol (L/tray/d)	Stem diam (mm)	Shoot fresh wt (g/plant)	Shoot dry wt (g/plant)	Plant ht (cm)	Total leachate day 14 to 42 (mL/tray)
0.2	1.9	0.5	0.05	6.1	127
0.3	2.5	1.0	0.09	10.2	88
0.4	2.6	1.4	0.13	13.2	189
0.5	2.5	2.0	0.17	16.5	303
0.6	2.9	2.4	0.20	18.0	463
0.7	2.9	2.7	0.22	20.1	810
F test significance					
Linear	**	**	**	**	*
Quadratic	**	NS	**	**	**
Residual	NS	NS	NS	NS	NS

NS, **Nonsignificant or significant at $P = 0.01$, respectively.

Table 2. Mineral concentrations of transplant shoots and roots 28 d after seeding.

Mineral solution vol (L/tray/d)	Mineral (% of dry wt)				
	N	P	K	Mg	Ca
Shoot					
0.2	3.3	0.65	4.3	2.00	1.62
0.3	3.3	0.79	5.4	1.46	1.70
0.4	3.4	0.74	5.7	1.54	1.73
0.5	3.3	0.81	5.9	1.54	1.59
0.6	3.3	0.85	6.4	1.64	1.68
0.7	3.3	0.87	6.6	1.58	1.59
F test significance					
Linear	NS	**	**	NS	NS
Quadratic	NS	NS	NS	NS	NS
Residual	NS	NS	NS	NS	NS
Root					
0.2	0.7	0.1	0.9	2.16	1.16
0.3	1.0	0.1	1.3	1.75	1.27
0.4	1.2	0.2	1.7	1.88	1.44
0.5	1.3	0.2	1.9	1.85	1.38
0.6	1.4	0.3	2.2	1.77	1.23
0.7	1.3	0.3	2.2	1.86	1.24
F test significance					
Linear	**	**	**	*	NS
Quadratic	**	*	*	*	NS
Residual	NS	*	NS	NS	NS

NS,*,** Nonsignificant or significant at $P = 0.05$ or 0.01 , respectively.

plant production. Optimal water stress is an interesting technique for regulating height because extension growth of the stem and leaves can be achieved without reducing photosynthesis (Liptay et al., 1998). In these experiments, the treatments were a combination of water deficit stress and mineral level since mineral concentration was kept constant. At low feeding volumes of 0.3 to 0.4 L/tray per day, overall growth was limited (Table 1), thus restraining seedling height and producing a stockier transplant.

Additionally, the leaching of nutrient solution from trays at these feeding volumes represents <1% of that applied. Moreover the low-volume fertigation stress does not appear to have a negative effect on the mineral composition of the transplants (Table 2). It is, however, interesting that the roots have a quadratic response to mineral accumulation with increasing fertigation volume while shoots have only a linear. This would suggest that the potential for mineral accumulation in roots is somewhat greater than the potential for mineral transport to the shoots.

It is concluded that optimal fertigation volume produces transplants of height acceptable for the processing tomato in-

dustry in Ontario and allows <1% of the minerals to be applied to seedlings being lost by leaching from the tray.

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