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Producing Horticultural Crops Using Hydroponic Tobacco Transplant Systems

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SUMMARY. Intensive, deep-batch, hydroponic systems that use float beds (FBs) are used extensively by the tobacco industry to produce transplants. FBs and a modified FB system with separate drying and flooding stages called ebb-and-flood (EF) beds were used to grow 12 diverse horticultural crops to maturity. Beds were filled with 570 L of water with 114

mg·L⁻¹ N and 143 mg·L⁻¹ K or 66 mg·L⁻¹ N and 83 mg·L⁻¹ K in 1994 and 1995, respectively. The EF beds were flooded for 6 hours, then drained for a 6-hour dry stage each 12 hours in 1994, and flooded for 1 hour and dried for 5 hours each 6-hour period in 1995 from May through August. Although both systems were suitable for producing Chinese water spinach (*Ipomoea aquatica* Forssk.—see footnote in Table 1), vegetable amaranth (*Amaranthus tricolor* L.), zinnia (*Zinnia elegans* Jacq.), and sweet basil (*Ocimum basilicum* L.), the EF system provided greater control over water availability and higher oxygen concentration in the root zone.

An inexpensive, deep-batch hydroponic system in which roots are grown in a volume of water or dilute nutrient solution is widely used to produce tobacco (*Nicotiana* spp.) transplants in the south-

eastern United States (Fig. 1). Tobacco transplants are commonly grown in a vermiculite-based, soilless medium in polystyrene plug trays floating on shallow beds of nutrient solution. These outdoor or greenhouse float beds (FBs) are used by tobacco farmers to grow transplants during the early spring and are unused the rest of the year (Fig. 1). There are ≈400 plastic-covered greenhouses in Virginia used solely for seasonal FB tobacco transplant production (S. Flora, personal communication). Existing tobacco FB systems and systems modified to be ebb-and-flood (EF) systems could potentially produce high-value horticultural crops to supplement farm incomes when tobacco transplants are not being produced.

Herbs (Wees and Stewart, 1986), ornamentals (Buwalda et al., 1994), and specialty vegetables (Schon et al., 1992) have been successfully grown to maturity hydroponically. We evaluated FB and EF systems, similar to those used by the tobacco industry, for their suitability to produce high-value edible and ornamental horticultural crops. A secondary objective was to evaluate

Fig. 1. Float beds, like the ones pictured here, are used by tobacco growers in the southeastern United States to produce transplants. Float beds are typically constructed using a rectangular wooden frame lined with plastic and filled with nutrient solution or water. Some outdoor beds are covered with hoop tents (left) and heated (black box suspended over the bed).

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Table 1. Summary of crops grown in 1994. Yield comparisons of the most promising crops grown again in 1995 are shown in Table 2.

Crop	Scientific name	Cultivar and source ^a	Trays ^b	Years	Comments
Amaranth, vegetable	<i>Amaranthus tricolor</i> L.	Red Leaf, JSS	72-Cell	1-2	Two harvests, flowered under long days, which reduced vegetative growth
Basil	<i>Ocimum basilicum</i> L.	Sweet Basil, B	72-Cell	1-2	>80% Germination, four harvests
Carrot	<i>Daucus carota</i> L.	Thumbelina, SS	72-Cell	1	>75% Germination, root cracking, poor color
Chive	<i>Allium tuberosum</i> Rottler ex Sprengel	Chinese, YLS	72-Cell	1	<10% Germination
Cucumber	<i>Cucumis sativus</i> L.	Futura, SS	3.8-L	1	Plants unstable, average yield four fruit/plant
Eucalyptus	<i>Eucalyptus macrocarpa</i> Hook.	Blue Bush, T&M	72-Cell	1	<25% Germination, maximum plant height 15 cm
Lettuce	<i>Lactuca sativa</i> L.	Buttercrunch, SS	72-Cell	1	Too hot for summer greenhouse production
Radish	<i>Raphanus sativus</i> L.	Red Globe, SS	72-Cell	1	>80% Germination, root cracking, poor color
Statice	<i>Limonium sinuatum</i> (L.) Mill.	Midnight Blue, SS	72-Cell	1	Flowering inhibited
Tomato	<i>Lycopersicon esculentum</i> L.	Vendor, SS	3.8-L	1	Plants unstable, fruit cracking
Water spinach ^c	<i>Ipomoea aquatica</i> Forssk.	Chinese, YLS	72-Cell	1-2	>70% Germination, three harvests in 120 d
Zinnia	<i>Zinnia elegans</i> Jacq.	Ice Cream Coral, B	72-Cell	1-2	>75% Germination, three harvest in 120 d

^aB = Burpee, Warminster, Pa.; JSS = Johnny's Selected Seeds, Albion, Maine; SS = Stokes Seeds Inc., Buffalo, N.Y.; T&M = Thompson & Morgan, Jackson, N.J.; YLS = Yi Lin Seed Co Ltd., Tainan, Taiwan.

^bThe 3.8-L trays are round polystyrene pots.

^cWater spinach has been classified as a federal noxious weed in the United States.

the effectiveness of hand-held nitrate, K, and conductivity meters as tools for monitoring the concentrations of nutrients in solution.

Materials and methods

Beds for EF and FB systems were constructed inside greenhouses using galvanized metal troughs (3.3 × 0.8 × 0.3 m) lined with a double layer of 0.075-mm-thick, black plastic film (Southern States Cooperative, Richmond, Va.). Each bed was filled to a depth of 28 cm (11 inches) with nutrient solution by dissolving 326 g (1994)

or 189 g (1995) of water-soluble fertilizer (20N-2.2P-25K, with 0.05% Mg, 0.007% B, 0.004% Cu, 0.05% Fe, 0.003% Mn, 0.0009% Mo, and 0.003% Zn, Peters Professional, Scotts Co., Marysville, Ohio) in 570 L of tap water. Nitrogen sources were 10% ammoniacal, 40% nitrate, and 50% urea. The calculated nutrient concentrations were 114 mg·L⁻¹ N, 13 mg·L⁻¹ P, and 143 mg·L⁻¹ K in 1994 and 66 mg·L⁻¹ N, 7 mg·L⁻¹ P, and 83 mg·L⁻¹ K in 1995. Actual concentrations of NO₃⁻, K⁺, and total dissolved salts were measured daily using hand-held meters calibrated with standard solutions

(Spectrum Technologies, Plainfield, Ill.). Tap water or fertilizer was added periodically to adjust nutrient concentrations and pH. Dissolved oxygen concentrations in the root zone [15 cm (6 inches) deep] were measured weekly from 16 May until 11 July using a hand-held oxygen meter (YSI Inc., Yellow Springs, Ohio). FBs remained filled throughout, while EF beds alternated 6 h flood/6 h dry and 1 h flood/5 h dry in 1994 and 1995, respectively. In EF beds, nutrient solution was pumped to and from a holding tank using submersible pumps (Rule Industries, Inc. Gloucester,

Table 2. Comparison of crops successfully grown in ebb-and-flood (EF) or float-bed (FB) hydroponic systems in a greenhouse during Summer 1995.

Crop	Germination				Harvest					
	Hours ^a		Percent		Harvest (no.)		MTH ^b (d)		Yield ^c	
	EF	FB	EF	FB	EF	FB	EF	FB	EF	FB
Zinnia	56*	26*	97**	78**	3	5	43**	57**	150**	295**
Basil	100 ^{NS}	50 ^{NS}	88 ^{NS}	88 ^{NS}	4	4	73**	67**	9.4 ^{NS}	9.8 ^{NS}
Amaranth	167 ^{NS}	111 ^{NS}	50**	89**	2	2	48 ^{NS}	46 ^{NS}	1.4 ^{NS}	1.3 ^{NS}
Water spinach ^w	0.8 ^{NS}	0.9 ^{NS}	75 ^{NS}	70 ^{NS}	2	3	42**	46**	3.1***	12.4***

^aWeighted mean time to germination = $(\sum n_i t_i) / \sum n_i$, where n_i is the number of newly germinated seeds at time t_i .

^bWeighted mean time to harvest = $(\sum n_i t_i) / \sum n_i$, where n_i is the number of flowers or the stem and upper five leaves of each plant harvested at time t_i .

^cYield for zinnia is in flowers/m² and all other is kg·m⁻² fresh weight.

^wSee footnote, Table 1.

^{NS}, **, *** Nonsignificant or significant using *t* test at *P* ≤ 0.05, 0.01, or 0.001, respectively, for comparing EF and FB systems within each category.

Mass.) with a flow rate of 114 L·min⁻¹. Pumps were turned on and off by programmable, digital plug timers (DTI, Intermatic Inc., Spring Grove, Ill.).

The crops grown during 1994 are summarized in Table 1. The most promising crops from 1994—zinnia for cut flowers, water spinach (see footnote, Table 1), vegetable amaranth, and sweet basil—were also evaluated in 1995. Seeds were planted 2 cm deep on 16 May in every cell (1994) or every other cell (1995) of 72-cell (single-cell dimensions, 5 × 5 × 7.6 cm) polystyrene trays (Southern States) to give an approximate plant population density of 400 and 200 plants/m² for 1994 and 1995, respectively. Trays were filled with a vermiculite-based, soilless medium (Tobacco Mix, Carolina Soil Co., Kinston, N.C.) and floated in each system. A small drain hole in the bottom of each tray cell allowed capillary movement of nutrient solution into the medium. Trays rested on a polyvinyl-chloride pipe support placed 23 cm above the bottom of each EF bed during dry cycles. Areas in each bed not covered by trays were shielded with plastic film or sheets of polystyrene to inhibit the growth of algae. Crops were grown to maturity from May through August in a glasshouse cooled with a pad-and-fan system to provide a night/day temperature range of 19/32 °C. Insect pests were controlled using local extension recommendations (Baldwin et al., 1994). Two trays of each crop were arranged in a randomized, complete-block design in both systems. Total germination percentage was determined 3 weeks after planting. Germination and harvest data were compared by analysis of variance (ANOVA) (CoStat; CoHort Software, Minneapolis, Minn.) on arcsin-transformed percentage data and log-transformed time values. Nontransformed values are shown in the tables.

Results and discussion

The growth and development of 12 vegetable and ornamental crops were evaluated in EF and FB systems during 1994 (Table 1). Many of these crops were not well suited to either system and were dropped from the second year of the study. The crops best suited for floating culture in 1994 were zinnia, basil, vegetable amaranth, and water spinach because they had

high germination percentages, could be harvested repeatedly during the season, and produced plants <2 ft tall that were not top-heavy at maturity (Table 1). These four crops were selected for more extensive evaluation in 1995. Plant growth was similar in both systems in 1994 because excess nutrient solution remained in the EF trays during dry cycles. In 1995, the flood portion of the wetting and drying cycle was decreased from 6 h to a total of 2 h every 12 h to reduce water and nutrient availability. Early germinating plants shaded and stunted later emerging ones within the same tray in 1994, so plant spacing was doubled in 1995 to reduce competition.

In 1995, germination percentages for water spinach and basil were the same in both systems (Table 2). However, a high percentage of amaranth germinated under continuously flooded conditions in the FB system, while zinnias germinated better in the EF system. Zinnias and water spinach matured more rapidly in the EF system, while basil matured faster in the FB system (Table 2). The mean time to harvest for amaranth was the same in both systems. The total marketable yield of water spinach and zinnias was higher in the FB system, whereas for basil and amaranth there was no difference between systems (Table 2). FB zinnia flowers were very succulent and wilted within 2 h after harvest compared to 4 h for those from the EF system. Basil and water spinach had increased shelf life and amaranth leaves were more attractive with greater red

coloration in the EF system. Overall, EF plants were less succulent than FB plants, probably because the drying cycles hardened the plants during development. Regrowth of zinnia and water spinach plants was faster following harvest in the FB system, possibly because the roots were constantly in nutrient solution. Leaves of basil, amaranth, and water spinach were visibly larger and tasted more tender when grown in the FB system. Subjective taste comparisons revealed that FB and EF water spinach and basil plants had a milder flavor than plants purchased commercially. FB and EF basil, in particular, had a strong aroma but lacked full flavor.

Insufficient Ca²⁺ and excessive water may have decreased the flavor of hydroponically grown basil and water spinach. Calcium concentrations have been linked to essential oil content and composition of oil in basil (Takano, 1993). The fertilizer selected for this study is widely used by the horticulture industry because it is nonacidifying, relatively low in salts, and water soluble; however, it does not include Ca²⁺. Basil and water spinach may require greater quantities of Ca²⁺ than was provided by the soilless mix and nutrient solution used in this study to develop full flavor.

After 4 weeks, most basil, amaranth, and zinnia plants in the FBs were epinastic due to reduced oxygen concentration in the root zone (Fig. 2). EF beds maintained >6 mg·L⁻¹ dissolved oxygen in the root zone throughout the experiment because the nutrient solution was aerated when

Fig. 2. Comparison of dissolved oxygen concentrations in nutrient solution of float-bed and ebb-and-flow systems producing basil, vegetable amaranth, zinnias, and water spinach (see footnote, Table 1) in a greenhouse from 16 May to 11 July 1994. Values are means of four measurements taken from the root zone of two beds. Values of SE are not shown because they are smaller than data symbols.

Fig. 3. Comparison of total salts, NO_3^- , and K^+ in float beds and ebb-and-flood beds producing basil, vegetable amaranth, zinnias, and water spinach (see footnote, Table 1) in a greenhouse from 16 May to 11 July 1994. Values are means of four measurements taken from two beds. Values of SE are not shown because they are smaller than data symbols.

pumped to the holding tank. Oxygen limitation of root growth is a classic problem in non-circulating hydroponic systems (Chun and Takakura, 1993). Low oxygen can reduce plant growth by decreasing nutrient availability (Baas, 1991). Even in well-aerated systems, root respiration may rapidly decrease dissolved oxygen levels (Chun and Takakura, 1993). The nutrient solution volume in both systems was sufficiently large compared to the number of plants, so the dissolved oxygen content was reduced only after ≈ 4 weeks of stagnation in the FBs, while oxygen levels in the EF beds were unaffected by rapid root respiration. Our beds were about twice as deep as those typically used by the tobacco industry. The rate of oxygen depletion from FBs varies depending on bed depth and shape. Oxygen concentrations in FBs could be increased by bubbling air through the nutrient solution. FBs are not commonly aerated for producing tobacco transplants, so this practice was not investigated because our primary objective was to evaluate existing FB technology.

In both years, NO_3^- and K^+ contents in solution were periodically monitored using ion-specific meters. These meters allowed ion concentrations to be monitored and readjusted to near initial levels throughout the season (Fig. 3). Assuming that no nitrification occurred in solution, N contributed by NO_3^- in the fertilizer was $46 \text{ mg} \cdot \text{L}^{-1}$ (total N was $114 \text{ mg} \cdot \text{L}^{-1}$), while the initial K^+ was $143 \text{ mg} \cdot \text{L}^{-1}$ in 1994. Nitrogen concentration calculated from initial meter readings of NO_3^- in 1994 were 50 and $64 \text{ mg} \cdot \text{L}^{-1}$ from EF beds and FBs, respectively.

Initial meter readings of K^+ were 106 and $144 \text{ mg} \cdot \text{L}^{-1}$ for FBs and EF beds, respectively. Soluble salt concentrations in 1994 ranged from 315 to $405 \text{ mg} \cdot \text{L}^{-1}$ for EF beds, while measurements for FBs were more variable, fluctuating from 265 to $591 \text{ mg} \cdot \text{L}^{-1}$. Ion-specific meter readings of NO_3^- and K^+ were less than total salt reading of electrical conductivity as expected (Fig. 3). Ion-specific meters provide a better assessment of the nutrient solution because, unlike conductivity measurements of total salts, concentrations of nutrients essential for plant development are measured (Hochmuth, 1994).

The rapid, succulent growth of seedlings and the short storage life of zinnia cut flowers in 1994 suggested that N levels were excessive for basil and zinnia production, so N and K levels were reduced the following year. In 1995, concentrations of $66 \text{ mg} \cdot \text{L}^{-1}$ N and $83 \text{ mg} \cdot \text{L}^{-1}$ K were maintained throughout the season. In 1995, salt concentrations were also lower, ranging from 200 to $300 \text{ mg} \cdot \text{L}^{-1}$ during the season (data not shown). Plants grew rapidly, and no deficiency symptoms were observed.

While both systems were suitable for growing zinnias, basil, vegetable amaranth, and water spinach to maturity, the EF system offered more control over growth because plant access to the nutrient solution could be controlled and higher oxygen concentrations were maintained in the root zone. The timing of wet and dry cycles is critical to the success of the EF system. The optimum duration of the flood

cycle varies with tray and bed characteristics, environmental conditions, plant age, and the species (Fischer, 1990). The FB system widely used by the tobacco industry for transplant production can be easily modified for producing high-value horticulture crops.

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