Comparison of Cabbage Seedling Growth in Four Transplant Production Systems

Jonathan M. Frantz¹, Gregory E. Welbaum², Zhengxing Shen, and Ron Morse

Department of Horticulture, Virginia Tech, Blacksburg, VA 24061-0327

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Abstract. “Float-bed” (FB) is a simple hydroponic system used by the tobacco industry for transplant production. “Ebb-and-flood” (EF) is a modified FB system with periodic draining of the bed to limit water availability and control plant growth. Field-bed cabbage (*Brassica oleracea* L. gp. *Capitata*) transplant production was compared with FB, EF, and overhead-irrigated plug-tray greenhouse systems. Plants were produced in May and June and transplanted in a field near Blacksburg, Va., in June and July of 1994 and 1995, respectively. Beds for FB and EF production consisted of galvanized metal troughs (3.3 × 0.8 × 0.3 m) lined with a double layer of 0.075-mm-thick black plastic film. In 1994, both EF and FB seedlings were not hardened before transplanting, were severely stressed after transplanting, and had higher seedling mortality compared with plants from other systems. Plug-tray transplants showed the greatest increase in leaf area following transplanting and matured earlier than seedlings produced in other systems. In 1995, EF- and FB-grown cabbage plants were hardened by withholding water before transplanting, and seedlings had greater fresh mass and leaf area than plug-tray or field-bed seedlings 3.5 weeks after transplanting. Less succulent cabbage transplants were grown in EF and FB systems containing 66 mg·L⁻¹ N (40% by nitrate) and 83 mg·L⁻¹ K. Compared with the FB system, the EF system allowed control of water availability, which slowed plant growth, and increased oxygen concentration in the root zone. Both EF and FB systems are suitable for cabbage transplant production.

Hydroponics, or “soilless culture,” is the practice of growing plants in solution or moist inert substrates containing essential mineral nutrients instead of soil (Resh, 1992). An inexpensive, non-recirculating, deep-batch hydroponic system is widely used for tobacco (*Nicotiana* sp.) transplant production in the southeastern United States (Thomas, 1993). Tobacco transplants are grown in vermiculite-based, soilless media in polystyrene plug-trays floating on a shallow bed of nutrient

solution. Some tobacco farmers grow transplants during the early spring using outdoor or greenhouse “float-beds” (FB), and these facilities are not used the remainder of the year. Finding alternative uses for these facilities would provide additional income and increase profitability for tobacco farmers.

Research in North Carolina has demonstrated that tobacco FB technology can be adapted to produce pepper transplants (Galloway, 1997). In the mountains of Southwest Virginia and North Carolina, cabbage is an important crop that is established from transplants. Currently, seedlings for early-season plantings are produced in Georgia or Florida and shipped north to cabbage growers, while transplants for midseason production are grown locally in densely seeded field beds. We investigated whether tobacco FB could produce transplants for cabbage growers, or cabbage growers could adapt FB technology for both early and midseason production.

There are several advantages to growing cabbage transplants using the FB system: 1) soil fumigation is not required; 2) the application of mineral nutrients can be easily monitored and precisely controlled using low-cost, ion-specific meters (Hartz et al., 1994); 3) since all water is applied directly to the roots and the foliage is never wetted, the likelihood of foliar diseases is reduced; 4) labor costs for watering plants can be eliminated; and 5) plants grow rapidly because roots are constantly in nutrient solution (Kratky et al., 1989).

However, there are several disadvantages to the FB system as well: 1) plants may be too succulent and overly susceptible to transplant shock; 2) little is known about the optimal nutrient concentration required to grow transplants of many horticultural crops; 3) diseases may spread rapidly through the nutrient solution; and 4) polystyrene trays used for FB are not biodegradable, and disposing of used trays is a problem.

The “ebb-and-flood” (EF) system is similar to the FB system, except that beds are periodically drained to control water availability (Fischer, 1990). In the EF system, water availability is limited during the ebb cycle to control plant growth and to increase oxygen concentration in the root zone, both of which are classic problems in noncirculating hydroponic systems (Chun and Takakura, 1993).

In this study, FB and EF cabbage transplant production methods were compared with the traditional field-bed and overhead-irrigated plug-tray systems. Seed germination percentages, transplant survival rates, and changes in seedling leaf area were compared to determine whether EF and FB systems could be adapted for cabbage transplant production.

Materials and Methods

Galvanized metal troughs (3.3 × 0.8 × 0.3 m) for EF and FB systems were lined with a double layer of 0.075 mm-thick, black plastic film (Southern States Cooperative, Richmond, Va.). Each trough was filled to a depth of 28 cm with nutrient solution by dissolving 326 or 189 g of water-soluble fertilizer (20N–5P–30K or 20N–2.2P–25K, with Mg, B, Cu, Fe, Mn, Mo, and Zn; Peters Professional, The Scotts Co., Marysville, Ohio) in 570 L of tap water in 1994 or 1995, respectively. The sources of nitrogen were 10% ammoniacal, 40% nitrate, and 50% urea. The calculated nutrient concentrations (in mg·L⁻¹) were 114 N, 13 P, and 143 K in 1994 and 66 N, 7 P, and 83 K in 1995. Actual concentrations of NO₃⁻, K⁺, and total dissolved salts were measured daily using calibrated hand-held meters (Spectrum Technologies, Plainfield, Ill.). Nutrient concentrations were adjusted to near initial values at 2-week intervals by adding tap water or fertilizer. The EF bed was flooded with nutrient solution at a rate of 114 L·min⁻¹ from a holding tank for 6 h every 12 h or 1 h every 6 h in 1994 and 1995, respectively, by submersible pumps (Rule Industries, Gloucester, Mass.) activated by programmable, digital plug-timers (DT1; Intermatic Inc., Spring Grove, Ill.). Two-hundred-cell polystyrene trays (individual cell dimensions: 2.8 × 2.8 × 7.5 cm; Southern States) containing soilless media (tobacco mix; Carolina Soil Co., Kinston, N.C.) were floated in each system in late May after planting cabbage seed in both years. Areas of each bed without trays were covered with black plastic film or sheets of polystyrene to prevent the proliferation of algae. During each dry cycle, trays in the EF system rested on a polyvinyl-chloride pipe support placed 23 cm above the bottom of each bed.

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¹Current address: Dept. of Horticulture, 1165 Horticulture Bldg., Purdue Univ., West Lafayette, IN 47907-1165. E-mail: frantz@hort.purdue.edu

²To whom reprint requests should be addressed. E-mail: welbaum@vt.edu

Cabbage seeds (cv. Hermes; Royal Sluis, Salinas, Calif.) were hand-seeded 2 cm deep during the final week of May for all treatments. For the plug-tray system, 200-cell polystyrene trays, identical to those used for the EF and FB systems, were filled with Sunshine Mix I (Fissons, Vancouver, B.C.). Trays were supported on top of wide-mesh galvanized screen that allowed sufficient air circulation for air pruning of roots. Trays were hand-watered twice daily and fertigated weekly using the same nutrient solution from the FB tank beginning 2 weeks after planting.

Ten rows of 20 cabbage seeds each were also hand-seeded 1 cm deep in a field near Blacksburg, Va., in late May 1994 and 1995. Fertilizer (10N-4.3P-8.3K) was incorporated before planting at a rate of 125 kg·ha⁻¹ in accordance with soil test results. Sprinkler irrigation provided up to 2.5 cm of water per week to field transplant beds. The percent seedling emergence was determined at transplanting based on the total number of seeds sown in each treatment. Field-bed plants were pulled out by hand, grouped in bundles of ~50 plants each, periodically moistened with water, and replanted in 1 or 2 d.

Float-bed and EF plants were transplanted without a hardening treatment in 1994. Starting 12 d before transplanting in 1995, FB and EF trays were placed outside the greenhouse for a short time each day until wilting commenced. Seven- to 8-cm-tall transplants were set in a field of Hayter loam soil (fine-loamy, mixed, mesic Ultic Hapludalf) near Blacksburg, Va., in beds covered with black plastic mulch (1.2 m × 0.05 mm) or rye (*Secale cereale* L.) straw in 1994 and 1995, respectively. To compensate for faster development of FB, EF, and plug-tray plants compared with field-grown plants in 1994, FB and EF plants were transplanted 2 weeks earlier, and plug-tray plants were transplanted 1 week earlier than field-grown plants. In 1995, the hardening treatment slowed the growth of EF and FB plants, and all treatments were transplanted at the same approximate size on the same day. In late June 1994, all seedlings were hand-transplanted in double-rows 0.5 m apart with an in-row spacing of 0.6 m in a complete-block design with two replications of 30 plants each. In early July 1995, eight double rows of eight plants each were mechanically transplanted (B & B Notill, Laurel Fork, Va.) in a randomized complete-block design replicated four times. After transplanting, rainfall was supplemented with drip (1994) or sprinkler (1995) irrigation to provide at least 2.5 cm of water per week.

Four randomly selected plants from each replication of each treatment were harvested to determine leaf area (LI-3000; LI-COR, Lincoln, Nebr.) at weekly intervals beginning 2 weeks after emergence in 1994 and at transplanting in 1995. The percentage of plants surviving transplanting was determined 3 weeks after transplanting and did not include plants harvested for leaf area determination. Mature cabbage heads without wrapper leaves were harvested at weekly intervals for 4 weeks in late Aug. and early Sept. 1994. The log

Table 1. Cabbage seedling emergence and survival percentages 3 weeks after transplanting.

System	Seedling emergence (%)		Surviving transplants (%)	
	1994	1995	1994	1995
Ebb-and-flood	97.0 a ^c	84.7 a	68 c	94 b
Float bed	97.5 a	91.6 a	53 d	96 b
Plug-tray	89.0 b	88.2 a	90 b	100 a
Field bed	87.2 b	64.4 b	96 a	97 ab
Significance	*	***	***	*

^cNumbers followed by a common letter in the same column do not differ significantly by LSD, $P \leq 0.05$.

*, ***, Significant at $P \leq 0.05$ or 0.001 by F test, respectively.

Fig. 1. Mean cabbage seedling fresh and dry mass measured 2, 3, and 4 weeks after seeding in 1994. The LSD bar was determined from the pooled variance of all treatments. Filled and open symbols indicate fresh and dry mass, respectively.

Fig. 2. Mean cabbage seedling leaf area measured before and after transplanting in 1994. The vertical dotted line indicates field planting. The LSD bars on the left and right side of the figure were determined from the pooled variance of all treatments before and after transplanting, respectively.

mean time to harvest was determined from transplanting using the equation

$$\log t = \sum n_i \log t_i (\sum n_i)^{-1}$$

where n_i is the number of harvested heads at time t_i . The percentage of plants producing heads was determined at the final harvest and was based on the number of plants that survived transplanting. At transplanting in 1995, the nutrient content of four to six dried, fully expanded, true leaves from five, 4-week-old transplants from each treatment was analyzed using a wet-ash extraction procedure of 70% nitric : 60% perchloric acid (2:1). Tissue samples were filtered, diluted, and analyzed using an inductively coupled plasma spectrometer (Thermo Jarrel Ash Cooperative, Franklin, Mass.). Samples for nitrogen analysis were digested (Kjeltec System 20; Tecator, Herndon, Va.) in concentrated H_2SO_4 , and the solutions were distilled, and analyzed (Kjeltec Auto 1030 Analyzer) by the Protein Nutrition Laboratory at Virginia Tech.

Insect pests were controlled using local commercial recommendations (Baldwin et al., 1994). Germination and harvest data were compared by analysis of variance (ANOVA) (CoHort Software, Minneapolis) on arcsin-transformed percentage data and log-transformed time values. Nontransformed values are shown in the tables.

Results and Discussion

In 1994, the percent emergence of cabbage seedlings in field beds and plug-trays was lower than in EF and FB systems (Table 1). Fresh mass of field-bed and plug-tray plants was similar during the first 4 weeks after planting in 1994, while both EF and FB plants grew more rapidly and had the greatest fresh mass at transplanting (Fig. 1). Dry mass, however, showed no difference among the four treatments, indicating that EF and FB plants had a higher water content (Fig. 1). Both EF and FB plants experienced severe transplant shock in 1994 because leaf area decreased after transplanting, and seedling mortality was greater compared to the other systems (Fig. 2, Table 1). The transplant shock occurred because FB plants were overly succulent due to the constant supply of water, and ebb cycles were not sufficiently long to harden EF plants. One week after transplanting, the initial leaf area advantage EF and FB seedlings enjoyed at transplanting was lost, and field-bed plants, which showed the least transplant shock, had the largest leaf area (Fig. 2). Cabbage heads from plug-tray transplants matured earlier than seedlings produced in other systems, while the EF plants took the longest to mature (Table 2). The mean head mass at harvest was greatest for plug-tray plants (Table 2). The number of plants producing heads was greatest for plug-tray transplants and least for field-bed transplants (Table 2). Seedlings grown in polystyrene trays and field beds produced similar total yields of mature cabbage heads in a previous study (Smith, 1986).

In 1995, the length of the flood cycle for the EF system was decreased to 1 h every 6 h to

Table 2. Harvest data for cabbage transplants in 1994.

System	Transplanting to harvest ^a (d)	Head fresh mass (g)	Plants producing heads (%)
Ebb-and-flood	78.6 a ^b	653 ± 29	81 c
Float bed	74.4 b	565 ± 22	88 b
Plug-tray	61.7 d	659 ± 33	93 a
Field bed	65.3 c	614 ± 24	73 d
Significance	**	---	***

^aMean time to harvest from transplanting based on $\log t = \sum n_i \log t_i (\sum n_i)^{-1}$, where n_i is the number of harvested heads at time t_i . Antilog values are shown.

^bNumbers followed by a common letter in the same column do not differ significantly by LSD, $P \leq 0.05$.

*, **, *** Significant at $P \leq 0.01$ or 0.001 by F test, respectively.

Fig. 3. Mean cabbage plant leaf area measured before and after transplanting in 1995. The vertical dotted line indicates field planting. The LSD values were determined from the pooled variance of all treatments.

Table 3. Nutrient content of fully expanded leaves harvested from five, 4-week-old transplants in 1995.

System	Nutrient (%)						Na (mg·kg ⁻¹)
	Ca	P	Mg	N	K	S	
Ebb-and-flood	1.84 a ^c	0.38	0.78 c	3.0 a	5.5 b	1.87 a	2097 ab
Float bed	1.47 b	0.40	0.67 b	3.2 a	5.6 b	1.62 ab	2489 a
Plug-tray	1.71 a	0.44	0.96 a	1.2 b	2.8 a	1.01 b	1096 bc
Field bed	1.83 a	0.35	0.75 bc	2.0 ab	3.2 a	1.57 ab	684 c
Significance	*	NS	**	*	*	*	*
Sufficient ^b	3.0–4.5	0.4–0.8	0.5–2.0	3.0–5.0	3.5–6.0	---	---

^aNumbers followed by a common letter in the same column do not differ significantly by LSD, $P \leq 0.05$.

^bSufficiency range for 2- to 6-week-old cabbage plants according to Jones et al., 1991.

NS, *, ** Nonsignificant or significant at $P \leq 0.05$ or 0.01 by F test, respectively.

further reduce water availability and create differences between the EF and FB treatments. The percent emergence of cabbage seedlings in field beds was lower than in any of the greenhouse production systems in 1995 (Table 1). Also for 1995, EF and FB seedlings were hardened outside the greenhouse before transplanting. The hardening treatment reduced transplant shock and increased EF and FB seedling survival percentages compared with those obtained the previous year (Table 1). The survival percentages among all treatments were similar. Leaf area in FB and EF were not significantly different from those in other treatments at transplanting (Fig. 3). Changes in seedling fresh mass among treatments mirrored changes in leaf area (data not shown). Float-bed plants grew more rapidly during the

first 3 weeks after transplanting than those in other treatments in 1995 (Fig. 3). Float-bed and EF plants were the largest 3.5 weeks after transplanting, indicating that they were sufficiently hardened at transplanting to minimize shock so that rapid growth could resume in the field (Fig. 3). Harvest data were not collected in 1995.

The rapid succulent growth of seedlings in 1994 suggested that nutrient concentrations (in mg·L⁻¹) of 114 N, 13P, and 143 K may have been excessive. In 1995, concentrations (mg·L⁻¹) were reduced to 66 mg·L⁻¹ N (with initial 40% NO_3^-), 7 P, and 88 K, and plants grew rapidly with no deficiency symptoms. Studies in North Carolina concluded that 50 mg·L⁻¹ N, containing >50% NO_3^- , applied during the 2nd or 3rd week after seed emergence

was optimal for hydroponic production of crucifer transplants (Jester, 1996). Reduced nutrient levels and pretransplant hardening were responsible for the improved performance of EF and FB transplants in 1995 (Table 1).

In both years, NO_3^- and K^+ content in solution was monitored daily using ion-specific meters, so water or nutrients could be added periodically to maintain initial concentrations (Frantz and Welbaum, 1998). Although electrical conductivity is widely used to monitor the salinity of nutrient solution in tobacco FB, ion-specific meters directly measure the concentration of NO_3^- and K^+ and were useful tools for monitoring nutrient status in EF and FB systems in this study (Frantz and Welbaum, 1998; Hochmuth, 1994).

Both EF and FB cabbage transplants contained sufficient levels of N, P, K, and Mg in 1995, whereas field-bed and plug-tray transplants were low in N and K (Table 3). All transplants, and FB in particular, were deficient in Ca (Table 3). The Ca concentrations of 4-week-old cabbage seedlings ranged from 1.5% to 1.8%, while 1.5% to 3.0% Ca is considered low (Jones et al., 1991). The synthetic potting mix used in the EF and FB trays contained insufficient Ca to offset the lack of Ca in the water-soluble fertilizer used in the hydroponic systems. Water-soluble fertilizers containing Ca are best suited for EF and FB cabbage transplant production.

Low oxygen concentration in solution may have reduced Ca uptake by FB plants. Oxygen concentration in the FB decreased from 70 to 10 $\text{mg}\cdot\text{L}^{-1}$ between weeks 2 and 4, while the oxygen concentration in the EF system remained $>70\text{ mg}\cdot\text{L}^{-1}$ (Frantz and Welbaum, 1998). "Ebb-and-flood" beds maintained higher dissolved oxygen concentrations in the root zone because the nutrient solution was aerated when pumped to the holding tank. Oxygen limitation of root growth is a classic problem in noncirculating hydroponic systems (Chun and Takakura, 1993). Low oxygen is known to have a specific negative interaction with Ca uptake in some horticultural crops (Baas, 1991; Wagenvoort et al., 1985).

We did not observe disease symptoms on seedlings before transplanting regardless of the production system. However, pathogens

may spread rapidly among plants through the nutrient solution in large-scale commercial operations if phytosanitary measures aren't taken to control disease. For example, care must be taken to prevent contamination of float beds with field soil from shoes or other sources (W.R. Jester, unpublished observation). Plant pathogens may survive sterilization in cracks in polystyrene trays to transmit disease in float-bed systems (M.A. Hansen, Virginia Tech Plant Disease Clinic, unpublished results).

In this study, it was necessary to withhold water to harden FB plants and reduce transplant shock. The EF system limits water availability to avoid the overly succulent growth associated with FB systems. Limiting water availability to 6 h every 12 h produced EF transplants that were very similar to FB. Reducing the flood cycle to 1 h every 6 h slowed growth but did not sufficiently harden plants. An even longer dry cycle may be optimal for quality cabbage transplant production and could eliminate the need for additional hardening. Other techniques may also be successfully employed to prevent excessively rapid growth in the FB system. In North Carolina, transplant height in FB has been successfully controlled by growing newly germinated seedlings in water instead of nutrient solution for the first 2 weeks after germination, lightly clipping plants that are 9 cm tall, and growing plants under 17–23 °C day/8–17 °C night temperatures (Jester, 1996). Effective control of plant height of FB-grown pepper transplants was obtained by mechanical conditioning (Galloway, 1997). Float beds, like those used by the tobacco industry, as well as FB modified to be EF, can be successfully adapted for cabbage transplant production if steps are taken to prevent rapid succulent growth. Although EF system lacks the simplicity of the FB system, the EF system may be preferable for cabbage transplant production because it offers greater control over water availability and provides higher oxygen concentrations in the root zone.

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