

Root and Shoot Modification by Irrigation¹

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SUMMARY. Irrigation methods, rates, timing, and frequency may influence the physical and chemical properties of the growing media thereby affecting root initiation, elongation, branching, development and dry matter partitioning between roots and shoots.

Understanding irrigation management relative to transplant growth modification is of utmost importance to produce high-quality transplants with the ability to withstand transplanting shock in diverse field environments. Transplant root systems have important physical and physiological roles from early stages of seedling emergence through subsequent seedling growth and development. The size, distribution, or architecture of a transplant root system may control the relative size and growth rate of the developing shoot. The importance of root morphological components of vegetable seedling root systems has been reviewed by Leskovar and Stoffella (1995). The purpose of this paper is to review the influence of irrigation systems and the interaction with other production factors on root and shoot growth and development of vegetable transplants.

Irrigation systems

Overhead irrigation is the most commonly used irrigation system for containerized production of vegetable transplants. In the overhead system, flats are generally supported by a T-rail system, and at each irrigation water is delivered by a sprinkler system until leaching (Fig. 1). Subirrigation, commonly referred to as ebb-and-flow or flotation systems (Fig. 2), was developed by Speedling, Inc. in Florida in 1984, and in California in 1991 (Thomas, 1993). Overhead and ebb-and-flow systems are also used in Japan, but the former dominates because of its simplicity (Kozai and Ito, 1993). The ebb-and-flow system, which is a variation of the continuous flotation system originally designed to grow tobacco (*Nicotiana tabacum* L.) plants to increase field survival and reduce transplant shock, is now being used in Florida and California to grow a large number of commercial vegetables.



Fig. 1. Greenhouse with overhead irrigation system.

This system uses recycled stored- or collected- water, saving water and reducing fertilizer and pesticide use compared to overhead irrigated systems. Trays are suspended on metal wires ~0.20 m above concrete floors, and every 2 to 3 d the irrigation water is

raised to the level of the container, maintained for 15 to 45 min and then decreased to its original level or returned to the main reservoir until the next irrigation. In this system, water moves by capillary action generally until cells are saturated. Previous investigations found that flotation systems improved uniformity and quality of bell and jalapeno pepper

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(*Capsicum annuum* L.), and tomato (*Lycopersicon esculentum* Mill.) if grown with minimal nutrient and drought stress (Leskovar and Boales, 1995; Leskovar and Cantliffe, 1993; Leskovar et al., 1994). However, in Europe there is a concern that viruses including tomato spotted wilt virus, tomato mosaic virus and lettuce big vein virus are released from roots of diseased plants and spread by recirculating nutrient solution of the ebb-and-flow irrigation system with the potential to contaminate the irrigation water and to infect healthy plants (Buttner et al., 1995). Similarly, several plant pathogenic fungi such as *Pythium* sp. and *Phytophthora* sp. can cause persistent problems with recycled irrigation water (Pottorff and Panter, 1997; Sanogo and Moorman, 1993).

Root and shoot development

Bell pepper transplants grown with overhead irrigation had more basal but less lateral root elongation than transplants grown with the ebb-and-flow system (Table 1). In tomato, more early basal root dry matter allocation in overhead-irrigated transplants during

the first 2 weeks after transplanting was important for the subsequent shoot growth increase 3 to 4 weeks after transplanting (Leskovar et al., 1994). These investigations reported that tomato transplants grown with flotation had excessive root growth outside the bottom of the container, and consequently roots were severely pruned in

Fig. 2. Greenhouse with ebb-and-flow irrigation system.



the greenhouse for ease in transplant manipulation in production fields. However, root pruning before transplanting delayed reestablishment of tomato transplants (McKee, 1981). Cabbage (*Brassica oleracea* L. var. *capitata* L.) transplant production

using overhead, ebb-and-flow, and float bed systems was investigated relative to survival, transplant shock and growth (Frantz and Welbaum, 1995a). Constant availability of water in the floating systems or short drying cycles in the ebb-and-flow systems contributed to excess root growth through the bottom of the trays, producing plants with less ability to overcome transplant shock. Similar conclusions were reported for sweet corn (*Zea mays* var. *saccharata*) transplants in a floatbed system (Frantz and Welbaum, 1995b).

The influence of irrigation timing and system on root elongation, root morphology, shoot growth and water status of 'TAM-Mild Jalapeno-1' pepper seedlings was reported by Leskovar and Heineman (1994). Irrigation systems used were a) ebb-and-flow (EF), b) 4 weeks EF plus 2 weeks overhead (EF+OI); c) six weekly cycles of alternating ebb-and-flow and overhead (EF/OI), and d) overhead (OI). Total root elongation was similar for all irrigation treatments. However, basal root length was greater for OI than for EF transplants, and lateral root length

Table 1. Effect of irrigation system on root growth components of bell pepper transplants (original data in Leskovar and Cantliffe, 1993).

System	Length (cm)		Count		Dry wt (mg)
	Basal	Lateral	Basal	Lateral	
Overhead	362	254	32	15	34
Ebb-and-flow	296	491	28	15	46
Significance	*	**	*	NS	**

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

was greater for EF than for OI transplants (Fig. 3). Providing uniform moisture levels around the hypocotyl region during the last 2 weeks before field establishment of pepper seedlings is thought to enhance basal root primordia development (Leskovar and Heineman, 1994). OI transplants had higher shoot/root ratio ($S:R = 5$) and maintained a higher shoot water potential ($I_{stem} = -0.58$ MPa) than EF transplants ($S:R = 3$; $\psi_{stem} = -0.69$ MPa), respectively. The latter had lower stomatal conductance and photosynthesis compared to OI and EF+OI-transplants (not shown).

Leskovar and Heineman (1994) concluded that flotation irrigation may be used to reduce shoot to root ratio and promote hardiness in single stem jalapeno transplants. Conversely, Galloway et al. (1996) reported that banana 'Banana Supreme', bell 'Camelot' and jalapeno 'Mitla' pepper transplants grown with ebb-and-flow systems were taller than with overhead irrigation. In the field, spatial and temporal root growth distribution of bell pepper transplants grown with ebb-and-flow and overhead irrigation systems were similar when described between 30 and 86 DAT (Leskovar et al., 1990). Currently, we are investigating the in-

teraction of irrigation systems (ebb-and-flow) and overhead, and N levels (50, 100, and 200 mg·L⁻¹ N) on root and shoot growth of five vegetable species including a jalapeno pepper hybrid 'Mitla'. Based on preliminary unpublished data we were not able to measure growth responses obtained previously in 'TAM-Mild Jalapeno-1' pepper. In addition to seasonal differences in greenhouse conditions and frequency of fertilization affecting plant N utilization, the influence of irrigation method and the interaction with N on root and shoot development appear to

be both species- and cultivar-dependent.

Root development is a dynamic process responding to several stress stimuli, probably as an adaptive mechanism (Fig. 4). Roots sensing drought stress synthesize chemicals and transport a signal to the shoots influencing stomatal behavior, gas exchange characteristics and ultimately growth (Davies et al., 1990). When drought stress and root pruning were used to harden and prevent stem elongation in fresh market tomato transplants grown with flotation irrigation, there was an increase in lateral root elongation, and a decrease in shoot to root ratio, but leaf enlargement and total plant size were negatively affected (Leskovar et al., 1994). Reduced root dry weight, basal root number, basal root diameter, and shoot growth were measured on pepper transplants exposed to mild drought stress and compared to wellwatered seedlings (Table 2) (Leskovar and Cantliffe, 1992). Induced drought or application of abscisic acid (ABA) to control shoot growth in bell pepper plants in the greenhouse altered dry matter partitioning and stomatal behavior (Watts et al., 1981, Berkowitz and Rabin, 1988; Leskovar and Cantliffe, 1992). This response was suggested to be mediated by endogenous changes of ABA concentration acting as a signal for control of growth processes (Davis et al., 1986). A reduction of shoot to root ratio either by shoot growth reduction or by larger root growth relative to shoot growth was correlated with ABA synthesis induced by drought (Creelman et al., 1990). When ABA at 10^{-4} M was applied to pepper seedlings 3 weeks after seeding, there was a transient inhibition of leaf weight increase, but root mass was unaffected (Leskovar and Cantliffe, 1992). ABA at 10^{-3} M reduced relative growth rates of eggplant (*Solanum melongena* L.) seedlings (Latimer and

Mitchell, 1988). Exogenous application of ABA increased leaf resistance, leaf water potential and seedling survival in peppers (Berkowitz and Rabin, 1988).

Implications for stand establishment

The ultimate goal of the nursery is to produce a quality transplant with the ability to withstand transplanting

Fig. 3. Root systems of 6-week-old jalapeno, pepper seedlings as affected by transplant irrigation systems: 1) ebb-and-flow (EF), 2) 4 weeks ebb-and-flow plus 2 weeks overhead (EF+OI), 3) six weekly cycles of alternating ebb-and-flow and overhead (EF/OI), and 4) overhead (OI). Note less basals and more lateral root development in EF [ψ] compared with OI seedlings (4).



Fig. 4. Lateral root branching, an adaptive response of a stressed tomato root tip that reached the bottom of a transplant flat irrigated by ebb-and-flow system.



shock. Seedling establishment in any field environment depends on adequate development of a taproot, associated

laterals, and basal roots for dicot species, or adventitious roots and associated lateral roots for most monocot species (Leskovar and Stoffella, 1995). The capacity of a containerized transplant to overcome transplant shock and become established in a field environment following transplanting depends on the capacity of seedlings to withstand root disturbance (McKee, 1981), the water and nutrient uptake capacity of the roots, and the capacity of the preexisting roots to rapidly regenerate new lateral, basal, or adventitious roots. Transplant shock generally, occurs when transpiration exceeds water uptake, resulting in a sudden or severe plant water deficit (Nitzsche et al., 1991). Other manifestations of transplant shock includes leaf abscission, burning, and detopping. When 'TAM-Mild Jalapeno-1' pepper transplants grown with overhead irrigation in Texas and ebb-and-flow irrigation in Florida were evaluated 20 d after transplanting, transplant shock [dead, detopped (absence of shoot apex), or burned (> 1 cm long hypocotyl)] was 23% for overhead and 13% for ebb-and-flow irrigated transplants (Leskovar and Boales, 1995). This difference was due to an increase in the number of burned seedlings associated with taller and thinner stem plants obtained from the overhead system.

Irrigation methods and irrigation timing affect temporal and spatial nutrient concentrations, pH, and root medium electrical conductivity. Evidence for these changes has been reported in flowering plants including geraniums (*Pelargonium hortorum* Bailey), Easter lilies (*Lilium longiflorum* Thunb.), and poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) (Argo and Biernbaum, 1994; Argo and Biernbaum, 1995; Morvant et al., 1997), but is lacking on vegetable species. Nutrition often has a strong

Table 2. Effect of mild drought stress on root count and diameter of bell pepper transplants (data adapted from Leskovar and Cantliffe, 1992).

Treatment	Root count		Root diam (mm)	
	Basal	Laterals	Basal	Basal, 1 st order
Well watered	34	18	0.47	0.31
Mild drought stress	16	17	0.38	0.24
Significance	**	NS	*	**

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

influence on seedling growth and carbohydrate status, affecting post-transplant recovery to shock (Aloni et al., 1991; Dufault, 1994). For example, differential water condition at the root tip may affect root responsiveness to calcium (Takahashi et al., 1992).

Conclusions

The differential provision of water to root systems influences the morphology, dry-matter partitioning, and physiology of transplants. Irrigation systems, drought, and nutrient stress are critical techniques the nursery manager uses to sustain shoot growth and to harden seedlings prior to transplanting. With increasing use of small -volume cells (>200 cells/tray) and a wider array of vegetable species used, there is need for further research on the effects of irrigation methods, drought stress timing, and their interactive effect with nutrition. This research will enhance our understanding of root and shoot growth dynamics in the greenhouse, post-planting transplant shock, and shoot recovery in the field. This new information will provide vegetable nurseries integrated concepts aimed to assist them in their management decisions.

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