Management of Nitrogen and Irrigation in Lettuce Transplant Production affects Transplant Root and Shoot Development and Subsequent Crop Yields

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Abstract. Lettuce (*Lactuca sativa* L.) ‘South Bay’ transplant growth and development were evaluated at 0, 30, 60, 90, and 120 mg·L⁻¹ N fertigated at frequencies of every 1, 2, 3, or 4 days in a floatation production system to produce plants with optimum roots and shoots which easily pull from trays. Greenhouse experiments (four) were conducted to evaluate root and shoot weight, percent transplant pulling success, and leaf N content, 28 days after sowing (DAS). Field trials, using transplants produced in Greenhouse experiments 2 and 4, were conducted to evaluate subsequent yield, head quality characteristics, and leaf N content. Generally, as N concentrations increased, dry shoot weight and leaf N concentration increased, and root:shoot ratios decreased linearly or quadratically. Lettuce transplants grown in a floatation irrigation system fertigated every second to third day with 60 to 90 mg·L⁻¹ N resulted in transplants with optimum root systems to achieve the highest pulling success rate from flats. Subsequent yields and head quality were optimum for pretransplant production fertigation N concentration of 60 to 90 mg·L⁻¹, regardless of irrigation frequency.

Poor stand establishment of direct-seeded lettuce crops using both pelleted and raw seeds, particularly during conditions of environmental stress, has led to the use of transplants as a means of establishing economically viable plant stands (Cliffe, 1989). Guzman et al. (1989) reported that superior plant stand was the major contributing factor for increased marketable yields from transplanted crisp-head and romaine lettuce (*Lactuca sativa* L.). They concluded that growers in southern Florida, with harsh and unreliable weather, may minimize economic losses and become more consistent suppliers of lettuce if a portion of the crop were transplanted. According to Klassen (1986), other reasons growers were transplanting rather than direct-seeding included improved plant-to-plant uniformity

especially for an once-over harvested crop such as lettuce, early-season weed control, more uniform spacing of plants, and elimination of manual thinning densely seeded rows.

Containerized vegetable transplants grown in greenhouses can either be overhead irrigated, or subirrigated. Using subirrigation (floatation system), Leskovar and Cantliffe (1993) reported improved uniformity and quality of transplants, as compared with overhead irrigation. Drought stress and root pruning methods used to harden and prevent stem elongation in fresh-market tomato (*Lycopersicon esculentum* Mill.) transplants grown with a floatation system, resulted in an increase in lateral root elongation with a decrease in shoot:root ratio (Leskovar et al., 1994). A reduction in shoot:root ratio and an improvement in water-use efficiency of pepper (*Capsicum annuum* L.) transplants were also reported by Leskovar and Heineman (1994) when plants were produced via the floatation system of irrigation.

Growers have not been able to produce the highest quality lettuce transplants on a seasonal basis using the floatation system. A well-developed root system is essential so that transplants can be easily pulled from the transplant flat, or easily damaged plants with scorched leaves may result, especially when transplanted in the field onto polyethylene covered raised beds. If shoots are too short, they cannot be easily handled and can be trapped under the polyethylene mulch. When

using the floatation system of irrigation, management of fertilization is critical, since high rates of fertilizers, especially N, can increase lettuce transplant shoot growth at the expense of root growth (Masson et al., 1991; Tremblay et al., 1987; Tremblay and Senecal, 1988). Combination of N concentration with irrigation frequency can have a direct impact on minimizing N losses from the media due to leaching from excess irrigation. Nutrient requirements for lettuce transplant production using a floatation irrigation system have been reported for P (Soundy et al., 2001a) and K (Soundy et al., 2001b).

This study was conducted to a) determine the optimum fertigation frequency and N concentration for optimizing lettuce transplant root and shoot growth via a floatation irrigation system, and b) improved subsequent field crop yield and head quality.

Materials and Methods

Greenhouse experiments. ‘South Bay’ lettuce transplants were grown in a glass greenhouse located at the University of Florida, Gainesville. Speedling styrofoam planter flats (model F392A; Speedling, Sun City, Fla.) [392 cells of 1.9 × 1.9 × 6.3 cm; 10.9 cm³ (length × width × depth; volume)], were used for transplant production. A peat + vermiculite + styrofoam bead mix (1:2:1, by volume), with AquaGro wetting agent (Aquatrols, Cherry Hill, N.J.) at 0.2 kg·m⁻³, was used for the media. Experiments were conducted over several seasons (Table 1). Transplants were grown with natural photoperiod extended to 16 h by 1000-W, high-pressure sodium lamps (250 μmol·m⁻²·s⁻¹ photosynthetic photon flux). Flats were seeded, then covered with a thin layer of vermiculite, overhead irrigated sufficiently to moisten the vermiculite, and transferred to a cooler at 20 °C for germination. After 48 h, flats were returned to the greenhouse.

In Expt. 1, the influence of irrigation frequency with N concentration of 100 mg·L⁻¹ on lettuce transplant growth was evaluated. Previous investigations reported that 100 mg·L⁻¹ was used for optimizing P (Soundy et al., 2001a) and K (Soundy et al., 2001b) concentrations for lettuce transplant production under a floatation irrigation system. Treatments consisted of 0%, 20%, 40%, and 60 % moisture deficit from field capacity (FC). Flats were weighed twice daily, and irrigation was applied when the flats had lost a predetermined amount of moisture. The 0%, 20%, 40%, and 60 % moisture deficits were equivalent to irrigation applied every 1, 2, 2 to 3, and 3 to 4 d. Irrigations were conducted by floating flats directly in water or nutrient solution. Transplants were fertigated seven times during the experiment. Fertilizers (mg·L⁻¹) consisted of 100N–30P–30K–100Ca, and half-strength Hoagland’s solution for micronutrients only (Hoagland and Arnon, 1950). A flat was considered a replication in all greenhouse studies. A randomized complete block experimental design was used with treatments replicated four times.

Since irrigation frequency influenced subsequent lettuce transplant growth, the effects

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Table 1. Sowing schedule and initial media test (Hanlon et al., 1994) for greenhouse Expts. 1 to 4.

Greenhouse experiment	Sowing date	Media test ^z						
		pH	EC (dS·m ⁻¹)	NO ³ -N	P	K	Ca	Mg
1	18 June	5.1	0.1	0	1.0	16.6	1.3	4.0
2	23 Feb.	5.1	0.1	0	0.6	12.6	1.1	4.5
3	27 June	4.8	0.1	0	0.5	13.1	1.2	4.3
4	18 Sept.	4.4	0.3	0	0.3	20.9	1.6	3.9

^z Concentrations in the saturated paste extract.

of N concentration in the nutrient solution in combination with several irrigation frequencies were evaluated (Expts. 2, 3, and 4.). Transplants in Expts. 2, 3, and 4 were grown with N application concentrations of 0, 30, 60, 90, or 120 mg·L⁻¹. Other nutrients were applied at equivalent concentrations to all transplants and consisted of (mg·L⁻¹) 30P–30K–30Ca, and half-strength Hoagland's solution for micronutrients only (Hoagland and Arnon, 1950). Fertigation frequency treatments were subirrigated daily, or every second, third, or fourth day. The experiments were arranged in a randomized complete block design with 20 treatments replicated four times and arranged in a factorial combination of five concentrations of N and four levels of fertigation frequency.

Plant samples (five per replication) were taken 28 d after sowing (DAS) for growth measurements. Shoots and roots were dried for 3 d at 70 °C, weighed, and root to shoot ratios calculated.

Individual lettuce transplants were pulled from a flat (five plants per replication) using a model DPP Dial Push-Pull (John Chatillon and Sons, Kew Gardens, N.Y.) attached to a binder clip fastened to the base of the stem. Pulling success (%) was calculated as the percentage of plants that could be pulled from the transplant flat without any breakage.

Dry shoot samples from each plot were ground to pass a 20-mesh screen and acid-digested for total Kjeldahl N in all experiments according to Wolf (1982). Subsamples (0.25 g) were weighed into 50 mL digestion tubes. Sulfuric acid and 30% hydrogen peroxide were added to the tubes, which were then heated on a digestion block at 375 °C. After the digestion process was completed (a total of 2.5 h), the samples were allowed to cool, and deionized water was used to bring the volume to 25 mL. The solutions were filtered through P8 filter papers (Fisher), with a particle retention of >25 µm, into 25-mL scintillation vials. The solution samples were then sent to the Analytical Research Laboratory, University of Florida, and N was determined on a rapid-flow analyzer (300 Series; ALPKEM Corp., Wilsonville, Ore.).

Field experiments. Transplants from each treatment in greenhouse Expts. 2 and 4 were transplanted on 23 Mar. and 17 Oct., respectively into an Arredondo fine sandy soil (loamy, siliceous, hyperthermic Grosarenic Paleudults) on raised beds covered with white-on-black polyethylene-mulch (0.038 mm thick) at the University of Florida Horticultural Research Unit, Gainesville.

The experiments were arranged in a randomized complete block experimental design

with 20 treatments replicated four times and arranged in a factorial combination of five concentrations of N and four levels of fertigation frequency. Preplant fertilizer (13N–0P–10.8K) was applied broadcast and incorporated in the bed at 230 kg·ha⁻¹. Raised beds spaced 1.2 m center to center, were fumigated with methyl bromide/chloropicrin (98:2) and then covered with polyethylene mulch. Each plot consisted of 30 transplants planted on double offset rows on the raised bed with a spacing of 30 cm between plants and between rows on the bed (equivalent to 54,000 plants/ha). After transplanting, 100 mL of nutrient solution (150 mg·L⁻¹ N from 20N–8.6P–16.7K) were applied to each transplant hole as a starter fertilizer. Water was applied twice daily for 20 min each, using drip irrigation lines placed on the center of the bed with emitters spaced 30 cm apart. Tensiometers (Irrometer Co., Riverside, Calif.) were used to monitor soil moisture tension in the beds. The root zone area soil tension was maintained at about –10 kPa according to Hochmuth and Smajstila (1998). Beginning one week after transplanting, fertilizer at 15 kg·ha⁻¹ N and 16 kg·ha⁻¹ K, supplied from NH₄NO₃ and KNO₃, was injected weekly using a venture-type injector (Netafim Irrigation, Altamonte Springs, Fla.), with the last application one week before harvest totaling 150 kg·ha⁻¹ N and 180 kg·ha⁻¹ K. Cultural management practices were similar to those used commercially in Florida (Maynard, 2003).

At crop maturity, the center 20 plants in a plot were weighed individually, and then 10 heads were assessed for firmness, cut longitudinally for height, diameter, stem, width, and core length. Wrapper leaves were sampled at harvest for analysis of tissue N according to Wolf (1982) as described previously for greenhouse experiments.

Statistical analyses. Data from each experiment were subjected to analysis of variance (ANOVA) using the Statistical Analysis System (SAS Institute, Inc., Cary, N.C.). In each experiment, (main effects of moisture deficit

treatment for greenhouse experiment one) (main effects of N concentration or irrigation frequency treatments for greenhouse Expts. 2 to 4 and field Expts. 1 and 2) were partitioned into linear or quadratic polynomial contrasts. Variables that had significant N concentration × fertigation frequency interactions were subjected to individual linear or quadratic regression analysis (SAS Institute) for each fertigation frequency treatment.

Results and Discussion

Greenhouse experiment 1. A greenhouse study was conducted to access the effects of water deficit on lettuce transplant growth. Shoot dry weight and leaf N content increased and shoot to root ratio decreased quadratically with increasing moisture deficit in the media (Table 2). Root dry weights were unaffected by moisture deficit in the media (Table 2). However, greater media moisture deficits resulted in transplants with lower root:shoot ratio indicating that a higher portion of dry weight accumulation occurred in the developing shoot system rather than the root system. Leaf N concentration increased quadratically as moisture deficit in media increased, suggesting that N uptake may have been reduced with greater irrigation frequencies. Although root weights were similar among treatments, transplants grown in media near field capacity (FC) (daily irrigation) or 60% FC (irrigated every 3 to 4 d) were considered inferior since they were difficult to pull (based on subjective observations) from the transplant tray, as compared to 20% and 40% moisture deficits. Therefore, subsequent greenhouse experiments were designed to evaluate the interactions of irrigation frequencies and N concentrations on subsequent transplant growth and pulling success from flats.

Greenhouse experiments 2, 3, and 4. Greenhouse studies were design to evaluate combinations of irrigation frequency and N concentrations through a floatation irrigation production system (Expts. 2, 3, and 4). Soundy and Cantliffe (2001) have reported that lettuce transplant root and shoot growth increased 15, 21, and 28 DAS as N concentration increased from 0 to 60 mg·L⁻¹ in a floatation irrigation system. However, since transplants (grown in Expt. 1.) could not be easily pulled from the trays and total potential growth was not achieved with 100 mg·L⁻¹ N 28 d after transplanting (DAT), N concentration range was expanded to include 120 mg·L⁻¹ N in subsequent

Table 2. Root and shoot characteristics of lettuce transplants (28 d after sowing) as affected by irrigation frequency (greenhouse Expt. 1).

Moisture deficit from field capacity ^z (%)	Dry shoot wt (mg)	Dry root wt (mg)	Root to shoot ratio	Leaf tissue N (g·kg ⁻¹)
0	49.9	21.0	0.42	17.6
20	69.9	23.9	0.34	18.2
40	73.8	20.0	0.27	22.6
60	84.8	22.8	0.27	26.9
Significance	Q*	NS	Q*	Q*

^zMoisture deficits from field capacity for 0%, 20%, 40%, and 60% is equivalent to fertigation frequency every 1, 2, 2 to 3, and 3 to 4 d, respectively.NS,**Nonsignificant or significant at $P = 0.01$; L = linear, Q = quadratic.

Table 3. Root and shoot characteristics of lettuce transplants (28 d after sowing) as affected by fertilization N concentration and irrigation frequency (greenhouse Expts. 2, 3, and 4).

Treatment ^a	Expt. 2		Expt. 3			Expt. 4		
	Root to shoot ratio	Pulling success (%)	Dry root wt (mg)	Root to shoot ratio	Pulling success (%)	Dry root wt (mg)	Root to shoot ratio	Pulling success (%)
N concentration (mg·L ⁻¹)								
0	1.01	16	4.8	1.01	3	3.7	0.86	0
30	0.47	86	28.5	0.50	73	19.2	0.48	88
60	0.38	95	26.4	0.30	65	23.3	0.32	96
90	0.29	94	25.7	0.18	69	21.8	0.22	98
120	0.21	85	19.2	0.13	43	18.9	0.16	79
Significance	Q**	Q**	Q**	Q**	Q**	Q**	Q**	Q**
Frequency (F)								
1	0.41	74	25.1	0.41	45	18.2	0.37	73
2	0.46	83	23.2	0.43	50	18.9	0.39	68
3	0.47	79	17.6	0.49	55	16.6	0.42	76
4	0.55	65	14.2	0.53	49	15.7	0.44	69
Significance	L**	Q**	L**	NS	NS	NS	L*	NS
N × F	NS	NS	NS	NS	NS	NS	NS	NS

^aN = nitrogen; F = fertigation frequency.

NS,*,**Nonsignificant or significant at $P = 0.05$ or 0.01 ; L = linear, Q = quadratic.

Fig. 1. Lettuce transplant dry root weight response to fertigation N concentration and frequency 28 d after sowing. Expt. 2. **Significant quadratic (Q) regressions at 1% level.

greenhouse experiments. Irrigation frequency × N concentration interactions were significant for dry shoot weight in each experiment. Shoot weights increased as N concentrations increased, but the rate of increase and shape of the response curve (linear or quadratic) varied with irrigation frequency (data not shown). Root weights increased quadratically as N concentration increased in greenhouse Expts. 3 and 4 (Table 3).

Irrigation frequency had no effect on root weight in Expt. 4, but a linear decrease occurred as irrigation frequency increased in Expt. 3 (Table 3). Irrigation frequency × N concentration interaction was significant for root weight in Expt. 2. Root weights increased quadratically as N concentrations increased (up to 60 mg·L⁻¹), but the rate of increase was

greater with irrigation frequencies of every 1 or 2 d (Fig. 1). Root to shoot ratio decreased quadratically as N concentrations increased in each experiment (Table 3), suggesting that increasing N fertilization resulted in reduced root growth relative to shoot growth. As irrigation frequency decreased, root to shoot ratio linearly increased in Expts. 2 and 4 but had no effect in Expt. 3.

A significant irrigation frequency × N concentration interaction occurred for leaf tissue N concentration in each experiment. Leaf tissue N concentration linearly or quadratically increased (depending on irrigation frequency) as N fertilization concentrations increased (data not shown). Higher N fertilization concentrations increased leaf N concentration and subsequently increased shoot weights.

It is critical that transplants be completely pulled intact (no stem breakage with complete root system) from the trays to reduce subsequent field transplant loss. Pulling success (%) improved quadratically as N concentrations (up to 90 mg·L⁻¹) increased in each experiment (Table 3). Therefore, transplants fertilized with N concentrations at 60 to 90 mg·L⁻¹ and irrigated every 2 to 3 d resulted in transplants with optimum root growth and subsequent optimum pulling success.

Field experiments. Field experiments were conducted to evaluate effects of lettuce transplant production practices (greenhouse Expts. 2 and 4) on subsequent yields and head quality characteristics (field Expts. 1 and 2, respectively). Irrigation frequency × N concentration interactions were not significant for any measured yield or head quality characteristic in either field experiment, therefore only main effects were presented (Tables 4 and 5).

As pretransplant N concentration (up to 90 mg·L⁻¹) increased, lettuce head weight, height, diameter, stem diameter, and core length increased quadratically in both field experiments. Head firmness rating increased and leaf tissue N concentration decreased quadratically as pretransplant N concentrations increased in field Expt. 2 (Table 5) but were similar with increased pretransplant N concentrations in field Expt. 1 (Table 4). Leaf N concentrations ranged from 24 to 25 and 34 to 36 g·kg⁻¹ in field Expts. 1 and 2, respectively. Hochmuth and Clark (1991) reported that leaf N concentrations of 20 to 30 g·kg⁻¹ were an adequate range for crisphead lettuce production. Transplant fertigation frequency had no effect on subsequent lettuce yields, head quality characteristics, or leaf tissue N concentration in either field experiment (Tables 4 and 5).

Lettuce transplants grown in a floatation irrigation system with 60 and 90 mg·L⁻¹ N concentrations applied every second to third day resulted in transplants with optimum root systems to achieve the highest pull success from flats. Subsequent lettuce yields and head quality were optimum for lettuce transplants produced with 60 to 90 mg·L⁻¹ N, regardless of irrigation frequency.

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Table 4. Effects of N concentration and fertigation frequency during transplant production (greenhouse Expt. 2) on subsequent lettuce yield and head quality, harvested 11 or 16 May (field Expt. 1).

Treatment ^z	Head wt (g)	Firm rating ^y (1–5)	Head ht (mm)	Head diam (mm)	Stem diam (mm)	Core length (mm)	Leaf tissue N conn (g·kg ⁻¹)
N concentration (mg·L ⁻¹)							
0	635	4.8	129	123	27	71	24.7
30	765	5.0	135	137	31	96	24.6
60	801	4.8	140	134	29	57	24.7
90	798	4.8	142	133	28	57	24.6
120	772	4.7	140	132	29	56	24.2
Significance	Q**	NS	Q**	Q**	Q**	Q**	NS
Frequency (F)							
1	731	4.8	137	132	29	66	25.1
2	759	4.8	138	133	29	67	24.6
3	764	4.8	137	131	29	67	24.0
4	762	4.9	138	131	28	69	24.6
Significance	NS	NS	NS	NS	NS	NS	NS
N × F	NS	NS	NS	NS	NS	NS	NS

^zN = nitrogen; F = fertigation frequency.

^yLettuce head firmness on a scale of 1 = loose, 5 = compact.

NS,**Nonsignificant or significant at $P = 0.01$; Q = quadratic.

Table 5. Effects of N concentration and fertigation frequency during transplant production on lettuce yield and head quality characteristics for greenhouse Expt. 4 harvested 20 Dec. (field Expt. 2).

Treatment ^z	Head wt (g)	Firm rating ^y (1–5)	Head ht (mm)	Head diam (mm)	Stem diam (mm)	Core length (mm)	Leaf tissue N conn (g·kg ⁻¹)
N concentration (mg·L ⁻¹)							
0	400	3.3	106	112	21	27	36.4
30	618	4.8	116	118	27	39	34.2
60	663	4.8	120	120	28	47	34.4
90	688	4.7	120	120	29	55	34.2
120	650	4.8	119	118	30	53	34.1
Significance	Q**	Q**	Q**	Q**	Q**	Q**	Q*
Frequency (F)							
1	599	4.4	117	118	27	46	35.2
2	598	4.4	115	116	27	45	34.4
3	605	4.6	118	120	27	45	34.7
4	613	4.5	115	117	26	41	34.2
Significance	NS	NS	NS	NS	NS	NS	NS
N × F	NS	NS	NS	NS	NS	NS	NS

^zN = nitrogen; F = fertigation frequency.

^yLettuce head firmness on a scale of 1 = loose, 5 = compact.

NS,**Nonsignificant or significant at $P = 0.01$; Q = quadratic.

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