Nutrient Requirements for Lettuce Transplants Using a Floatation Irrigation System II. Potassium

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Abstract. Although floatation irrigation has numerous advantages for vegetable transplant production, including improved seedling health, lettuce (*Lactuca sativa* L.) transplants grown with floatation (ebb and flow) irrigation can have poor root systems. Floatation fertigation of 'South Bay' transplants with K at 15, 30, 45, or 60 mg·L⁻¹ K applied every 2 to 4 days, increased fresh and dry root weight at 28 days. Higher K (24 mg·kg⁻¹) in the medium did not affect root weight. Fresh and dry shoot weight, leaf area, relative shoot ratio (RSR), relative growth rate (RGR), leaf weight ratio (LMR), and root weight ratio (RMR) were unaffected by applied K, regardless of the initial K concentration in the medium. Available K in a vermiculite-containing medium may have supplied all the K required. When 60 was compared with 100 mg·L⁻¹ N at various levels of K, the applied K again did not influence dry root weight; however, at 100 mg·L⁻¹ N, root weight was reduced as compared with 60 mg·L⁻¹ N, regardless of the level of applied K. In a field experiment, pretransplant K had no effect on growth. Transplants grown with no added K in a peat + vermiculite mix with at least 24 mg·L⁻¹ water-extractable K produced yields equivalent to transplants supplied with 15, 30, 45, or 60 mg·L⁻¹ K via floatation irrigation.

Nutritional practices affect vegetable transplant size, quality, and growth in the field (Dufault and Schultheis, 1994; Garton and Widders, 1990; Jaworski and Webb, 1966; Jaworski et al., 1967; Kratky and Mishima, 1981; Masson et al., 1991a, 1991b; Melton and Dufault, 1991; Weston and Zandstra, 1989). The need of transplants for fertilizer K is not well established. Dufault (1985) reported that K had no effect on growth of celery [*Apium graveoleus* L. var. *duke* (Mill.) Pers.] transplants, but the medium contained 40 mg·kg⁻¹ HCl-extractable K and may have supplied all the K required. Melton and Dufault (1991) grew tomato (*Lycopersicon esculentum* Mill.) transplants with either 25,

75, or 225 mg·kg⁻¹ K applied three times per week; K did not influence transplant height, stem diameter, leaf number, leaf area, total chlorophyll, fresh shoot weight, or dry shoot and root weight. Again, the transplants may not have responded because the medium contained 103 mg·kg⁻¹ K.

Tremblay and Senécal (1988) grew lettuce, broccoli (*Brassica oleracea* L. var. *italica* Plenck.), pepper (*Capsicum annuum* L.), and celery transplants in Metromix with varying N and K applied daily and reported that 50 to 350 mg·L⁻¹ K increased celery and broccoli leaf area. Leaf area of lettuce was increased by K with 350 mg·L⁻¹ N, but not with 150 mg·L⁻¹ N. Increasing the K concentration reduced pepper leaf area in a nutrient solution containing 150 mg·L⁻¹ N, but increased it in one containing 350 mg·L⁻¹ N. Neither root growth characteristics nor root : shoot ratio of broccoli, celery, and lettuce were affected by K fertilization.

Information is lacking on the growth response of lettuce roots and shoots to frequent K applications, as practiced in the floatation system of irrigation. In this system, nutrients can be supplied with every irrigation by floating flats directly in nutrient solution. We have reported on the effects of P fertilization in a previous paper (Soundy et al., 2001). The present investigation was conducted to determine the K requirement, supplied via floatation irrigation, that would produce lettuce transplants with well-developed root systems that would become established rapidly in the field and grow uniformly.

Greenhouse experiments. 'South Bay' lettuce transplants were grown in a glass greenhouse at the Univ. of Florida, Gainesville, in Speedling styrofoam planter flats (Speedling, Sun City, Fla.), as previously reported (Soundy et al., 2001) (Table 1).

Plants in Expt. 1 were irrigated every 2 to 4 d by floating flats until field capacity was reached, in nutrient solution containing K at 0, 15, 30, 45, or 60 mg·L⁻¹ as KCl. Other nutrients were supplied at equivalent rates to all plants in the ebb and flow system and consisted (in mg·L⁻¹) of 100 N, 30 P, 100 Ca, and half-strength Hoagland's solution with micronutrients (Hoagland and Arnon, 1950). Expt. 1 was conducted during the summer and had average daily maximum media temperatures of 32 °C and minimum of 23 °C. A randomized complete-block design was used with treatments replicated four times.

Plants in Expt. 2 were irrigated once every 2 to 4 d by floating flats, until field capacity was reached, in nutrient solution containing K at 0 or 60 mg·L⁻¹ as KCl. Other nutrients were applied as described for Expt. 1. Media treatments used for the experiment were 1 peat : 2 vermiculite (v/v) and 1 peat : 1 rockwool (v/v) (Table 1). Average daily maximum media temperatures was 25 °C, while the minimum temperature was 14 °C with both light treatments. The factorial experiment was in a split-block design with light treatment as the main block and K and media as subplots. Each treatment was replicated three times.

Plants in Expt. 3 were irrigated every other day by floating flats, until field capacity was reached, in nutrient solution containing K at 0, 15, 30, 45, or 60 mg·L⁻¹ in combination with N at 60 or 100 mg·L⁻¹. Potassium was supplied from KCl, while N was supplied from NH₄NO₃. Other nutrients were applied as described for Expt. 1. Expt. 3 was conducted during the winter season, had average daily maximum media temperature of 29 °C, while the minimum was 21 °C. The experiment was a randomized complete-block design with treatments replicated four times.

Plant samples (five per plot) for growth measurements were taken at 28 d after sowing (DAS). Measurements are listed in the Tables and are described in Soundy et al. (2001).

Leaf petioles for sap testing were collected at 30 DAS in Expt. 2, and 28 DAS in Expts. 1 and 3. The sap was squeezed from collected petiole pieces using a hydraulic sap press onto sampling sheets according to Hochmuth (1992). A CARDY meter (Spectrum Technologies, Plainfield, Ill.) was used to measure K⁺ concentrations in the petiole sap.

Dry shoot samples from the last sampling dates were ground to pass a 20-mesh screen and dry-ashed for K or acid-digested for total Kjeldahl N according to Wolf (1982). The samples were analyzed with model 61-E Inductively Coupled Plasma Spectrometry (Thermo Jarrell Ash Corporation, Franklin, Mass.). A 300 Series Rapid Flow Analyzer (ALPKEM Corp., Wilsonville, Ore.) was used to determine N.

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Table 1. Sowing schedule and initial media test.

Sowing date	Media test ^a						
	pH	EC (dS·m ⁻¹)	NO ₃ -N -----	P -----	K (mg·kg ⁻¹)	Ca -----	Mg -----
14 Jul	4.7	0.9	1.3	12.4	14.6	14.2	11.6
28 Jan							
Peat + vermiculite	4.9	0.1	0	0.7	10.9	0.9	1.8
Peat + rockwool ^b	5.3	0.1	0	0.3	2.5	0.8	0.8
Peat						0.8	1.2
31 Jan	5.2	0.2	0.3	0.4	24.4	0.6	5.8

^aConcentrations in the saturated paste extract (Hanlon et al., 1994).^b40% hydrofile and 10% hydrorepellent rockwool.

Data were subjected to analysis of variance (ANOVA) using PROC GLM and/or PROC MIXED (SAS Institute, Cary, N.C.). Treatment sums of squares were partitioned into linear or quadratic polynomial contrasts.

Field experiment. Plants from Expt. 3 were transplanted at the Univ. of Florida Horticulture Unit, Gainesville, on 29 Feb. 1996. All soil conditions, planting methodology, and harvest procedures are previously described in Soundy et al. (2001).

Results and Discussion

Expt. 1. Applied K did not influence lettuce fresh and dry shoot weight (Table 2) for plants sampled 28 d after sowing (DAS). There was a positive linear response of fresh and dry root weight to applied K. Applied K did not influence leaf area. There was a positive linear increase in tissue K in response to applied K.

At 28 DAS, RSR, RGR, NAR, LAR, SLA, LMR, and RMR values were not influenced by applied K, since shoots were unaffected while there was minimal increase in root growth due to added K (data not shown).

About 80% of the lettuce transplant dry matter was allocated to shoots and 20% allocated to roots after 28 DAS. Thus in this experiment, K applied to a peat + vermiculite media with 15 mg·L⁻¹ water extractable K, increased transplant root growth, but not shoot growth. Sufficient K for shoot growth may have been available from the media during the growing cycle.

Expt. 2. The peat and rockwool (molten, spun basalt rock fibers medium) had lower initial K concentrations than vermiculite (Table 1).

At 30 DAS, both K and media influenced fresh and dry shoot weights (Table 3). When

produced with 60 mg·L⁻¹ K, plants grown in peat + rockwool mix had more fresh shoot weight than plants grown in the peat + vermiculite mix. There was no response of dry shoot weight to applied K in the peat + vermiculite mix. In peat + rockwool mix, applied K resulted in an increase in dry shoot weight.

Plants grown in peat + vermiculite mix had greater fresh and dry root weight as compared to those in peat+rockwool mix under both light treatments (Table 3). For both media types, fresh and dry root weight were greater with 60 mg·L⁻¹ K as compared to no K.

Regardless of sampling date, applied K did not influence leaf area when plants were grown in peat+vermiculite mix, indicating sufficient K in the media (Table 3). Plants had greater leaf area at 60 mg·L⁻¹ K as compared to when no K was added to peat rockwool mix. With no added K, plants in peat + vermiculite mix had greater leaf area than plants in peat + rockwool mix. The opposite result occurred with 60 mg·L⁻¹ K. By applying 60 mg·L⁻¹ K, petiole sap K was more than that found in plants grown with no K (Table 3). Plants grown in peat + vermiculite mix had greater concentrations of petiole sap K than those grown in peat + rockwool mix. Plants grown in peat + vermiculite media had greater total leaf tissue K concentration than plants grown in peat + rockwool media (Table 3) probably due to inherently higher levels of K in vermiculite. Plants grown with 60 mg·L⁻¹ K had greater K concentration in the leaves than plants grown with no K, especially those plants grown in peat + rockwool mix.

Plants grown with 60 mg·L⁻¹ K in peat+vermiculite media had greater RSR values than those grown with no K, since added K increased dry root weight but not dry shoot weight (Table 4). Added K did not

influence RSRs for plants grown in peat + rockwool mix. RGR values were lower in peat + rockwool mix with no K than with 60 mg·L⁻¹ K, while in the peat+vermiculite mix, RGR was not affected by K. Neither media influenced NAR. Similar to Expt. 1, RGR and NAR were not influenced by added K in a peat + vermiculite media.

Also, at 30 DAS, plants grown with 60 mg·L⁻¹ K had smaller LMR values compared with plants grown without K. Similarly, plants grown in peat + vermiculite mix had smaller LMR values than plants grown in peat + rockwool mix. The opposite response to applied K and to media type occurred for RMR. Once again, added K increased root growth more than shoot growth.

In Expt. 2, plants grown in peat+rockwool mix (3 mg·kg⁻¹ water extractable K) responded more to applied K than plants grown in peat + vermiculite mix (11 mg·kg⁻¹ water extractable K). Unlike vermiculite, rockwool is inherently low in K. In the peat + rockwool mix, 60 mg·L⁻¹ K as compared to no K led to increases in shoot, root, and leaf growth. Potassium fertilization also led to increased K concentrations in plant leaves.

In general, RSR, RGR, NAR, SLA, and LAR were not affected by K. Even though these transplant growth characteristics were not affected by K, transplants grown with no K in the peat + rockwool mix were of inferior quality since they could not be easily removed from the transplant flat (data not provided).

Table 3. Root and shoot characteristics of lettuce transplants 30 d after sowing as affected by potassium and media for Expt. 2, February.

	K (mg·L ⁻¹)		
Mix	0	60	Response
<i>Fresh shoot weight (mg)</i>			
Peat + vermiculite	1456	1422	NS
Peat + rockwool	1329	1844	**
Response	NS	**	
<i>Dry shoot weight (mg)</i>			
Peat + vermiculite	123.9	121.0	NS
Peat + rockwool	93.1	142.0	**
Response	**	**	
<i>Fresh root weight (mg)</i>			
Peat+vermiculite	378	420	*
Peat+rockwool	238	377	**
Response	**	*	
<i>Dry root weight (mg)</i>			
Peat + vermiculite	29.8	33.6	**
Peat + rockwool	17.7	28.9	**
Response	**	**	
<i>Leaf area (cm²)</i>			
Peat + vermiculite	52.0	50.4	NS
Peat + rockwool	38.5	64.8	**
Response	**	**	
<i>Leaf petiole sap K (mg·L⁻¹)</i>			
Peat + vermiculite	1917	2633	**
Peat + rockwool	78	1100	**
Response	**	**	
<i>Leaf tissue K (g·kg⁻¹)</i>			
Peat + vermiculite	30.3	37.7	**
Peat + rockwool	2.7	17.3	**
Response	**	**	

NS, *, ** Nonsignificant or significant *t* test at 5% or 1% levels, respectively.

Table 2. Root and shoot characteristics of lettuce transplants as affected by K nutrition for Expt. 1, July/August, 28 d after sowing.

Potassium applied (mg·L ⁻¹)	Fresh shoot wt (mg)	Dry shoot wt (mg)	Fresh root wt (mg)	Dry root wt (mg)	Root : shoot ratio	Leaf area (cm ²)	Leaf petiole sap K (mg·L ⁻¹)	Leaf tissue K (g·kg ⁻¹)
0	1366	80.0	298	19.9	0.25	46.3	2300	41.9
15	1347	82.4	296	20.8	0.25	46.5	2125	42.8
30	1395	80.7	302	20.8	0.26	47.6	2325	47.6
45	1454	88.3	324	22.4	0.25	49.6	2825	48.0
60	1474	85.6	333	22.8	0.27	50.2	2450	48.7
Response	NS	NS	L*	L**	NS	NS	L**	L**

^aLinear (L) effects significant at *P* = 0.05 (*), 0.01 (**), or nonsignificant (NS).

Table 4. Influence of potassium and media on growth characteristics of lettuce transplants 30 d after sowing for Expt. 2, February.

Mix	K (mg·L ⁻¹)		Response
	0	60	
<i>Root : shoot ratio</i>			
Peat + vermiculite	0.24	0.28	**
Peat + rockwool	0.19	0.20	NS
Response	**	**	
<i>Relative growth rate (mg·mg⁻¹/wk)</i>			
Peat + vermiculite	0.58	0.60	NS
Peat + rockwool	0.50	0.68	**
Response	NS	NS	
<i>Leaf area ratio (cm²·mg⁻¹)</i>			
Peat + vermiculite	0.34	0.33	NS
Peat + rockwool	0.36	0.39	NS
Response	NS	*	
<i>Leaf weight ratio</i>			
Peat + vermiculite	0.81	0.78	*
Peat + rockwool	0.84	0.83	NS
Response	**	**	
<i>Root weight ratio</i>			
Peat + vermiculite	0.19	0.22	*
Peat + rockwool	0.16	0.17	NS
Response	**	**	

NS, *, **Nonsignificant or significant *t* test at 5% or 1% levels, respectively.

Expt. 3. Nitrogen was included as a variable during a winter production period because N adversely affects leaf growth of lettuce transplants under low light and temperature. There were no K × N interactions for dry shoot or root weight at 28 DAS (Table 5). Dry shoot weight was unaffected by K. Potassium did not influence dry root weight. Plants grown with 60 mg·L⁻¹ N had greater root weight than plants grown with 100 mg·L⁻¹ N.

Nitrogen at 60 mg·L⁻¹ led to a decrease in leaf area when K was applied, while at the 100 mg·L⁻¹ level, applied K did not influence leaf area. Tremblay and Sénécal (1988) reported that leaf area of lettuce transplants increased in response to applied K from 50 to 350 mg·L⁻¹ with 350 mg·L⁻¹ N, but not with 150 mg·L⁻¹ N using an overhead irrigation system.

There were no K × N interactions for leaf tissue N or leaf tissue K (Table 5). There was a negative linear response of leaf tissue N to applied K, but the magnitude of this decrease was very small. Leaf tissue K increased in a linear fashion to applied K, but this increase did not influence shoot or root growth. Plants had similar K concentrations in the leaves, regardless of applied N, while N concentrations were greater in leaves of plants grown with 100 than with 60 mg·L⁻¹ N.

There were no K × N interactions for RSR and applied K did not influence RSR values (Table 5). Root : shoot ratios were greater in plants grown with 60 than 100 mg·L⁻¹ N.

There were no K × N interactions for RGR or NAR, (Table 6). Applied K did not influence RGR values, however, RGR values were greater with 100 than 60 mg·L⁻¹ N by both sampling dates. Potassium did not influence NAR. Net assimilation rate was greater for plants grown with 60 mg·L⁻¹ N, than plants receiving 100 mg·L⁻¹ N.

Applied K did not influence SLA with 60 mg·L⁻¹ N, while with 100 mg·L⁻¹ N, SLA

Table 5. Root and shoot characteristics of lettuce transplants as affected by K and N nutrition for Expt. 3, February, 28 d after sowing.

Nutrient applied (mg·L ⁻¹)	Dry shoot wt (mg)	Dry root wt (mg)	Root : shoot ratio	Leaf area (cm ²)		Leaf tissue N (g·kg ⁻¹)	Leaf tissue K (g·kg ⁻¹)
				N ₁ ^z	N ₂ ^z		
K							
0	93.9	25.1	0.27	51.4	67.2	23.5	36.5
15	91.5	24.9	0.28	47.8	71.6	23.6	38.8
30	95.7	25.4	0.27	51.5	73.5	23.3	45.1
45	91.2	23.9	0.27	45.8	74.4	22.5	49.6
60	88.6	24.8	0.29	45.6	72.1	22.4	53.2
Response	NS	NS	NS	L ^{**y}	NS	L ^{**}	L ^{**}
N							
60	80.1	26.7	0.33			18.8	45.5
100	104.3	23.0	0.22			27.4	43.8
Response	**	**	**			**	NS
K × N	NS	NS	NS	*		NS	NS

^zN₁ = 60 mg·L⁻¹; N₂ = 100 mg·L⁻¹.

^yLinear (L).

NS, *, **Nonsignificant or significant *t* test at 5% or 1% levels, respectively.

Table 6. Influence of K and N nutrition on growth characteristics of lettuce transplants for Expt. 3, February, 28 d after sowing.

Nutrient applied (mg·L ⁻¹)	Relative growth rate (mg·mg ⁻¹ /wk)	Net assimilation rate (mg·cm ⁻² /wk)	Specific leaf area (cm ² ·mg ⁻¹)		Leaf area ratio (cm ² ·mg ⁻¹)		Leaf wt ratio	Root wt ratio
			N ₁	N ₂	N ₁	N ₂		
K								
0	0.74	1.43	0.61	0.65	0.47	0.53	0.79	0.21
15	0.71	1.36	0.62	0.68	0.46	0.55	0.78	0.22
30	0.73	1.43	0.61	0.69	0.46	0.57	0.79	0.21
45	0.75	1.42	0.60	0.71	0.45	0.58	0.79	0.21
60	0.73	1.37	0.59	0.72	0.44	0.59	0.78	0.22
Response N	NS	NS	NS	L ^{**y}	NS	L ^{**}	NS	NS
60	0.70	1.48					0.75	0.25
100	0.76	1.32					0.82	0.18
Response	*	**					**	**
K × N	NS	NS	*		**		NS	NS

^zN₁ = 60 mg·L⁻¹; N₂ = 100 mg·L⁻¹.

^yLinear (L).

NS, *, **Nonsignificant or significant at 5% or 1% levels, respectively.

increased linearly with applied K (Table 6). Applied K did not influence LAR at the 60 mg·L⁻¹ N level, but with 100 mg·L⁻¹ N, LAR increased in linear fashion to applied K. Leaf area ratio was greater when plants were grown with 100 than with 60 mg·L⁻¹ N.

There were no K × N interactions for LMR or RMR. Potassium did not influence either LMR or RMR, since neither dry shoot weight nor dry root weight were influenced by added K. Plants grown with 60 mg·L⁻¹ N had greater RMRs than those grown with 100 mg·L⁻¹ N. About 25% of lettuce transplant dry matter was allocated to roots when plants were grown with 60 mg·L⁻¹ N as compared to 18% when grown with 100 mg·L⁻¹ N. This suggests that lower N concentration in the nutrient solution may help optimize root growth of lettuce transplants grown by floatation.

Root and shoot growth of lettuce transplants were not increased by fertilizer K in Expt. 3. When vermiculite was used in the media, 24 mg·kg⁻¹ water-extractable K was available before fertilizer applications were initiated. Therefore, sufficient K was apparently available or released during the growing cycle for good lettuce transplant growth.

In general, root and shoot growth of lettuce transplants were not improved by fertilizer K applied via floatation irrigation system to a peat + vermiculite mix. In Expt. 1, leaf tissue K at the end of the experiment ranged from 42 g·kg⁻¹ at 0 K to 49 g·kg⁻¹ at 60 mg·L⁻¹ K. In Expt. 3, leaf tissue analysis at the end of the experiment ranged from 37 g·kg⁻¹ at 0 K to 53 g·kg⁻¹ at 60 mg·L⁻¹ K. Leaf tissue K concentrations were similar in the two experiments, perhaps leading to the similar lack of response in root and shoot growth to applied K. Leaf K concentration of ≈40 g·kg⁻¹ appears to be adequate for production of high quality lettuce transplants, with enough roots in 28 d to fill the tray cell volume.

Root : shoot ratios were not affected by K, regardless of sampling date or season. Root : shoot ratios ranged from 0.25 to 0.27. In Expt. 3, N led to reduced RSRs possibly because the plants produced more shoots and less roots with 100 mg·L⁻¹ N than with 60 mg·L⁻¹ N. In general, fertilizer K influenced RGR and NAR of plants grown to 21 DAS, but not of plants grown to 28 DAS, perhaps indicating that K was more important earlier in transplant shoot growth.

Regardless of season, $\approx 79\%$ dry matter was partitioned to shoots and 21% partitioned to roots, implying that temperature differences did not influence dry matter partitioning in lettuce transplants. Fertilizer K did not influence LMR or RMR because neither dry shoot weight nor dry root weight responded to K.

In Expt. 2, plants grown in peat + rockwool mix ($2.5 \text{ mg}\cdot\text{kg}^{-1}$ water extractable K) responded more to applied K compared with plants grown in peat + vermiculite mix ($10.9 \text{ mg}\cdot\text{kg}^{-1}$ water extractable K) because, unlike vermiculite, rockwool is inherently low in K. In the peat + rockwool mix, applied K led to increases in shoot, root, and leaf growth.

In the present work, fertilizer K was not necessary when a peat + vermiculite media was used, since vermiculite supplied all the K needs for a 28-d growing period when floatation irrigation was used. For a media low in K, applying $60 \text{ mg}\cdot\text{L}^{-1}$ K resulted in improved root growth, leading to improved plant pulling success. During periods of low light intensity increasing light intensity during a 16-h photoperiod also improved root growth, resulting in high quality transplants.

Field experiment. Field-planted transplants from Expt. 3 were harvested in May, 64 d after transplanting. There were no $K \times N$ interactions for any parameter measured in this study. Pretransplant K and N did not influence lettuce head weight, firmness, head height, head diameter, stem width, or core length (data not presented).

Leaf tissue N decreased in linear fashion in response to pretransplant K (data not presented). Pretransplant N did not affect N concentration in plant leaves at harvest. Leaf tissue K was least with $60 \text{ mg}\cdot\text{L}^{-1}$ K for unknown reasons. Pretransplant N did not

influence K concentration in plant leaves at harvest.

Pretransplant K had no effect on post-transplant growth. Therefore, transplants grown with no K in a peat+vermiculite mix with at least $24 \text{ mg}\cdot\text{L}^{-1}$ water extractable K, produced yields equivalent to transplants grown with 15, 30, 45, or $60 \text{ mg}\cdot\text{L}^{-1}$ K, when K was applied via floatation irrigation.

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