Nutrient Accumulation and Tipburn in NFT-grown Lettuce at Several Potassium and pH Levels

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Abstract. 'Buttercrunch', 'Grand Rapids', and 'Summer Bibb' lettuce (*Lactuca sativa* L.) seedlings were grown with the nutrient film technique (NFT). The influence of two K concentrations (150 and 225 mg-liter⁻¹) and four solution pH levels (5.0, 5.5, 6.0, and 6.5) on lettuce tipburn was investigated in four experiments. Additionally, the influence of pH on foliar nutrient concentration was examined. Even though tipburn was observed in 'Buttercrunch' and 'Summer Bibb' lettuce, neither K nor pH level consistently affected tipburn incidence. No tipburn was observed in 'Grand Rapids'. Solution pH generally did not affect concentration of total N and NO₃-N in lettuce tissue. Increasing the pH increased K concentration and resulted in increased proportions of K compared to Mg or Ca. Although the influence of solution pH on P, Ca, and Mg concentration was significant, nutrient accumulation differences were not reflected in lettuce fresh-weight differences. The influence of K solution concentration and pH on lettuce yield was not significant. Tipburn incidence in NFT-produced lettuce appears to be primarily affected by environmental conditions maintained during greenhouse growth.

Numerous investigations with field and greenhouse-grown lettuce have indicated the relationship between temperature, light intensity and duration, and relative humidity on tipburn, a Ca-related disorder that occurs under specific environmental conditions (Collier and Tibbitts, 1984; Schlaghauser et al., 1987; Tibbitts and Rao, 1966). Experiments conducted in the field sometimes suggest that factors involved in tipburn development are different from those determined to be critical in greenhouse production, particularly in NFT, where crop maintenance depends on nutrient solution properties. The solution properties that most affect hydroponically grown lettuce appear to be temperature, electrical conductance, ratio of nutrients, and pH. In addition, greenhouse lettuce cultivars differ in their incidence of

tipburn when grown under standard greenhouse production practices (Cox and McKee, 1976).

Although very little information is available regarding the influence of K concentration on incidence of tipburn in NFT-produced lettuce, Borkowski and Ostrzycka's (1973) findings suggest that increased K availability increases incidence of tipburn injury in greenhouse-grown potted lettuce. Additionally, to our knowledge, the influence of solution pH in soilless culture on lettuce tipburn has not been investigated. Information reported usually concerns the pH optimum for crop growth (Douglas, 1985; Graves, 1983). The objectives of this study were thus to determine the influence of K level and pH of nutrient solution on the incidence of tipburn and yield of lettuce grown in NFT. The effect of pH on nutrient accumulation in lettuce was also evaluated.

Four NFT experiments were conducted in a greenhouse in Lexington, Ky. (Table 1). 'Summer Bibb' lettuce was used in Expt. 1; 'Summer Bibb', 'Buttercrunch', and 'Grand Rapids' in Expt. 2; and in Expts. 3 and 4 'Summer Bibb' and 'Buttercrunch' were evaluated. Lettuce seed was sown in individual Jiffy-9 peat pellets (Jiffy Products of America, Chicago), which were placed in a bottom-heated (28°C) mist bench. At the first true-leaf stage, plants were moved to a bench with a capillary mat for subirrigation. Lettuce was irrigated once every 24 h with 0.2% Peter's Professional fertilizer solution (15N-7P-14.2K) (Peters Fertilizer Products, W.R. Grace and Co., Fogelsville, Pa.) until seedlings reached the three to four true-leaf stage. The plants were grown thereafter in 7.5-cm-diameter polyvinylchloride gutters that were

cut in half lengthwise. Within each gutter, up to nine transplants, spaced 20 cm apart, were set through holes in a polyethylene cover. Temperature and light conditions in the greenhouse varied with the season of production. Temperature generally ranged from 23 to 30°C during the day and 18 to 24°C at night.

The composition of the nutrient solution used for NFT production was (mg-liter⁻¹): N, 140; P, 60; Ca, 150; Mg, 40; Fe, 2; Mn, 0.5; Cu, 0.05; Zn, 0.1; B, 0.3; Mo, 0.04; and K, 150 or 225 (Willumsen, 1984). In Expts. 1 and 2, the factorial design consisted of two concentrations of K (150 and 225 mg-liter⁻¹) and four pH levels (5.0, 5.5, 6.0, and 6.5). Treatments were replicated three times and arranged in a randomized complete-block design with nine plants per experimental unit in Expt. 1 and four plants per unit in Expt. 2. Based on the results of Expts. 1 and 2, one level of K (150 mg-liter⁻¹) and four levels of pH were investigated in Expts. 3 and 4. Experiments 3 and 4 were also replicated as a randomized complete-block design with cultivar and pH level as factors; each experimental unit consisted of eight plants. Based on ambient temperature and plant size, solutions were recirculated with pumping from six to 14 times each 24 h for 20 min for each recirculation at the rate of 1 liter of solution/minute per trough. A standard solution volume of 1.8 liters was available for each plant in each experiment.

Table 1. Dates for sowing, treatment initiation, and termination for studies conducted with lettuce grown with the nutrient film technique in greenhouses.

Action	Expts.			
	1	2	3	4
Sowing date	3 Apr.	11 May	20 Aug.	4 Oct.
Treatment initiation	25 Apr.	30 May	11 Sept.	26 Oct.
Experiment termination	16 May	15 June	5 Oct.	3 Dec.

Table 2. Incidence of tipburn injury* in lettuce at 150 mg K/liter and four pH levels.

Cultivar	pH	Expt.	
		3	4
Summer Bibb	5.0	12.5	16.7
	5.5	20.8	8.3
	6.0	20.8	4.2
	6.5	25.0	4.2
Significance			
Linear		*	*
Quadratic		*	NS
Buttercrunch	5.0	45.8	37.5
	5.5	75.0	41.2
	6.0	100.0	33.3
	6.5	75.0	16.7
Significance			
Linear		NS	NS
Quadratic		*	NS

*Tipburn injury was rated visually at the end of the experiment by estimating the percentage of plants exhibiting tipburn injury at 32 and 30 days after the start of the experiment for Expts. 3 and 4, respectively.

NS, *Nonsignificant or significant at $P = 0.05$.

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Table 3. Foliar content (percent) of NO₃-N and total N, P, K Ca, Mg, and Na in lettuce produced by the nutrient film technique in Expt. 3.

Variable	Nutrients (%)						
	NO ₃ -N	N	P	K	Ca	Mg	Na
Cultivar							
Buttercrunch	0.81	5.32	0.87	7.26	1.16	0.30	0.032
Summer Bibb	1.20	5.69	1.03	7.67	1.58	0.42	0.037
LSD (0.05)	0.06	0.14	0.03	0.13	0.03	0.01	0.003
pH							
5.0	0.95	5.53	0.98	7.34	1.42	0.39	0.009
5.5	0.97	5.45	0.93	7.37	1.36	0.37	0.014
6.0	1.05	5.50	0.97	7.50	1.36	0.35	0.036
6.5	1.04	5.53	0.92	7.64	1.33	0.34	0.078
LSD (0.05)	0.08	0.19	0.04	0.19	0.05	0.02	0.004
Significance							
Cultivar	***	***	***	***	***	***	***
pH							
Linear	*	NS	*	**	**	***	***
Quadratic	NS	NS	NS	NS	NS	NS	***
Cultivar × pH	NS	NS	NS	NS	NS	NS	**

NS,*,**,*Nonsignificant or significant at $P = 0.05, 0.01, \text{ or } 0.001$, respectively.

Table 4. Foliar content (percent) of NO₃-N and total N, P, K, Ca, Mg, and Na in lettuce produced by the nutrient film technique in Expt. 4.

Variable	Nutrients (%)						
	NO ₃ -N	N	P	K	Ca	Mg	Na
Cultivar							
Buttercrunch	1.37	5.72	1.00	8.10	1.47	0.41	0.136
Summer Bibb	1.65	6.14	1.41	7.93	1.89	0.53	0.119
LSD (0.05)	0.07	0.09	0.04	0.16	0.05	0.01	0.005
pH							
5.0	1.43	5.88	1.18	7.49	1.62	0.46	0.49
5.5	1.50	5.95	1.24	8.04	1.72	0.49	0.90
6.0	1.55	6.03	1.26	8.24	1.70	0.47	0.142
6.5	1.55	5.88	1.15	8.29	1.67	0.46	0.228
LSD (0.05)	0.09	0.12	0.05	0.22	0.07	0.02	0.007
Significance							
Cultivar	***	***	***	*	***	***	***
pH							
Linear	**	NS	NS	***	NS	NS	***
Quadratic	NS	*	***	**	*	**	***
Cultivar × pH	NS	NS	*	NS	NS	NS	NS

NS,*,**,*Nonsignificant or significant at $P = 0.05, 0.01, \text{ or } 0.001$, respectively.

The solution drained from the trough between pumpings. The solution pH was adjusted daily, using 1 M NaOH or 1 M HCl, and solutions were replaced weekly. Solution pH was generally quite stable for all treatments, with pH variations of less than 5% above or below selected values. Potassium concentrations did not vary more than 10% from selected values during experimentation.

During experiments, the general appearance and incidence of tipburn was observed for each individual head of lettuce. Fresh weight and the percentage of plants showing tipburn were determined at the conclusion of each experiment. Based on results for Expts. 1 and 2, more detailed investigations were performed in Expts. 3 and 4. In Expts. 3 and 4, six leaf samples were randomly selected from the plants within each treatment for chemical analysis. The samples were washed, oven-dried at 50C, and pulverized. Total N (micro-Kjeldahl); total P (colorimetry); total K, Ca, Mg, and Na (atomic absorption spectrometry); and water-soluble nitrate (photo-colorimetric method) were analyzed. The

content of elements was expressed as a percentage of dried matter.

Data were subjected to analysis of variance and regression, or trend analysis was used where appropriate. A slope comparison test was used to compare cultivar yield response over pH levels. Means were separated by Fisher's protected LSD (0.05).

Between 70% and 100% of 'Summer Bibb' and 'Buttercrunch' plants in Expts. 1 and 2 developed tipburn in all pH solutions and K treatments. Tipburn was observed as early as 5 to 6 days after plants were placed in NFT solutions in these experiments, with increasing tipburn incidence occurring until harvest at 21 or 16 days. Tipburn incidence in 'Summer Bibb' or 'Buttercrunch' lettuce was not significantly influenced by solution pH level or K concentration (data not shown). No tipburn was observed in 'Grand Rapids' lettuce in any solution for the duration of the experiment. 'Grand Rapids' was previously reported to be resistant to tipburn (Schlagenhauer et al., 1987) and was included in our experimentation for comparative purposes.

In Expts. 3 and 4, 'Summer Bibb' lettuce

generally exhibited from 30% to 50% lower incidence of tipburn than did 'Buttercrunch' (Table 2). The initial symptoms of tipburn injury were observed at about the same time in each treatment (between 20 and 30 days). Solution pH did have a significant influence on tipburn injury observed, particularly in 'Summer Bibb' lettuce, but this pH trend effect was not consistent among experiments. In Expt. 3, the percentage of plants exhibiting tipburn increased slightly with increasing pH, while the percentage decreased in Expt. 4. When analyzed over cultivar, cultivar × pH interactions were not significant in Expts. 3 or 4 (data not presented). The results obtained in all experiments suggest that tipburn injury is primarily controlled by genetic factors and is influenced by environmental conditions maintained during growth, with greater incidence of tipburn observed in greenhouse experiments conducted during the long, warm days of spring and summer.

Differences in K concentrations generally did not have a major influence on 'Summer Bibb' and 'Buttercrunch' lettuce fresh weight after 21 or 16 days of growth in NFT solutions in Expts. 1 and 2, respectively (data not presented). Significant differences were observed only in Expt. 2, when the fresh weight of 'Grand Rapids' plants produced at 150 mg K/liter was higher than that produced at 225 mg K/liter. The effect of pH on lettuce fresh weight was also minimal. With 'Buttercrunch', the highest fresh weight (75 g/plant) was observed at pH 6.5 and 150 mg K/liter, as compared to 65 g/plant at 225 mg K/liter. There were no significant interactions between K level and pH for lettuce fresh weight in Expts. 1 and 2.

Since K level generally had no significant effect on incidence of tipburn and plant growth in NFT lettuce, only the lower K concentration (150 mg-liter⁻¹) was used in Expts. 3 and 4. In Expt. 3, lettuce fresh weight accumulation was not influenced by either solution pH or cultivar ('Summer Bibb' and 'Buttercrunch') during the 25 days in NFT culture. Lettuce fresh weight ranged from 41.8 to 44.9 g among cultivars and solution pH treatments. In Expt. 4, pH had a minimally significant influence on yield, with lettuce fresh weight increasing as pH increased (Fig. 1). Both cultivars exhibited nearly equivalent increases in yield with increasing pH levels as measured by a slope comparison test, indicating no cultivar differences in response.

According to Willumsen (1984), different ratios of K, Ca, and Mg maintained in NFT solution had no influence on lettuce tipburn development and did not result in any significant yield differences. In field experiments, Collier and Huntington (1980) showed that lettuce grown on acidified plots (pH 5.5) did not consistently develop more tipburn than plants grown at pH 6.6. A high ratio of K fertilizer also did not enhance tipburn occurrence. Similarly, our studies indicate that, in NFT culture, neither K level nor pH level strongly affect the incidence of tipburn in several lettuce cultivars. Conversely, Bor-

Fig. 1. Influence of pH level on fresh weight of 'Summer Bibb' and 'Buttercrunch' lettuce at 150 mg K/liter in Expt. 4. The regression equation for 'Summer Bibb' yield response over pH level is $Y = 37.30 + 6.6x$. The regression equation for 'Buttercrunch' yield response over pH level is $Y = 48.00 + 7.00x$.

kowski and Ostrzycka (1973) reported that the addition of K increased the susceptibility of lettuce to tipburn injury in greenhouse pot investigations. It may be that higher concentrations of K in the growth medium reduced root pressure and the ability of potted lettuce to take up water, inducing greater tipburn incidence (Van den Ende et al., 1975).

Accumulation of $\text{NO}_3\text{-N}$ and total N, P, Ca, Mg, and Na was significantly higher ($P = 0.001$) in 'Summer Bibb' than in 'Buttercrunch' lettuce (Tables 3 and 4), indicating cultivar differences in nutrient accumulation. The reduced levels of Ca accumulation in 'Buttercrunch' lettuce may contribute to the increased incidence of tipburn observed in this cultivar over time, possibly due to enhanced sensitivity of this cultivar to unfavorable environmental conditions that resulted in reduced Ca levels in young lettuce leaves (Collier and Tibbitts, 1982, 1984). The pH level did not affect concentration of total N or $\text{NO}_3\text{-N}$, although a slight increase in NQ-N was observed with increasing pH in both experiments. Similar conclusions were obtained by Vassey et al. (1990) in soybean [*Glycine max* (L.) Merr.]. Increasing pH levels resulted in a linear or

quadratic increase in K accumulation in lettuce in Expts. 3 and 4. Islam et al. (1980) also obtained the same trend in hydroponically grown tomatoes (*Lycopersicon esculentum* Mill.). Although the influence of solution pH on P, Ca, and Mg concentration was significant, differences in nutrient accumulation were generally not great and were not reflected in lettuce fresh weight differences. Significant influence of pH on Na accumulation was related to the amount of NaOH used to maintain constant pH of nutrient solutions, with greater NaOH addition with increasing pH level. The suggestion that increased Na availability can increase the incidence of tipburn in lettuce (Sonneveld and Ende, 1975) was not confirmed in these experiments, particularly since the Na levels used were considerably lower than those investigated by Sonneveld and Ende. There were no significant interactions between cultivars and pH levels for $\text{NO}_3\text{-N}$ and total N, K, Ca, and Mg.

In conclusion, K provided at 150 mg-liter⁻¹ in solution was found to be sufficient for NFT lettuce production in these experiments. Potassium concentration did not significantly influence tipburn incidence in the three lettuce cultivars examined. 'Summer Bibb' and 'Buttercrunch' lettuce were tolerant of solution pH in the range of 5.0 to 6.5. The influence of pH on tipburn incidence and nutrient accumulation in lettuce was also limited. To significantly reduce tipburn damage in lettuce, a tolerant cultivar, such as 'Grand Rapids', should be used rather than adjustment of pH or K levels in NFT culture. In addition, environmental control of greenhouse temperatures, light intensity and duration, and relative humidity should also be practiced (Collier and Tibbitts, 1982, 1984).

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