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Effect of Excess Boron on Broccoli, Cauliflower, and Radish

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Abstract. **The boron tolerance of broccoli (*Brassica oleracea* L. Italica Group), cauliflower (*Brassica oleracea* L. Botrytis Group), and radish (*Raphanus sativus* L.) was determined in large, outdoor sand cultures. Boron treatments were imposed by irrigation with culture solutions that contained 1.0, 4.0, 8.0, 12.0, 16.0, or 20.0 mg B·liter^{-1} for broccoli and cauliflower, and 1.0, 3.0, 6.0, 10.0, 13.0, or 16.0 mg B·liter^{-1} for radish. Relative yield was reduced 1.8%, 1.9%, and 1.4% with each unit (mg·liter^{-1}) increase in soil solution B (B_{sw}) above 1.0, 4.0, and 1.0 mg B·liter^{-1} for broccoli, cauliflower, and radish, respectively. Increasing B_{sw} significantly reduced plant size of all 3 vegetables. Over the B range tested, no leaf injury was apparent for these 3 vegetables.**

Although B is an essential constituent of the soil solution for normal plant growth, the difference between adequate and toxic concentrations may be only a few milligrams per liter (5). Consequently, excess applications of B-containing fertilizers (14) or the use of B-containing irrigation waters (5) can result in toxic levels of B in the soil. The absorption of this excess B by a crop will cause plant injury and yield decline.

Eaton (5) has reported that B is carried to the leaves in the transpirational stream, where it moves from the veins into the interveinal tissue and accumulates at the tip and margins, resulting in leaf necrosis. Data on the metabolic disruption within the plant tissues caused by excess B absorption is still lacking.

Boron tolerance classification for many vegetable crops has been based upon the incidence of B injury and not on the yield decline of the harvested product (5, 13). However, some studies have shown that unless the product is a leafy type vegetable, the occurrence of leaf injury is not a reliable indicator for B tolerance (7, 12). Consequently, reliable quantitative data based on yield for many vegetables are lacking. Therefore, this study was initiated to determine the B tolerance of broccoli, cauliflower, and radish as measured by the yield and quality of the fresh product.

Materials and Methods

Twenty-four sand tanks (2.08 × 0.86 × 0.84 m deep), which contained a coarse river sand, were used in these tests. The sand was washed to remove fine soil particles that could absorb B from the irrigation waters. Each sand tank was irrigated from a 1365-liter reservoir that contained nutrient solutions with different B concentrations. Irrigation waters were surface-applied 3 times each day, with the sand being completely saturated with each irrigation. The applied solutions were collected in corregated polyethylene tile lines located in the bottom of each tank, and returned to the reservoirs by gravity flow.

The irrigation waters contained 2.0 mM $Ca(NO_3)_2$, 1.5 mM KCl, 1.0 mM $MgSO_4$, 0.5 mM $NH_4H_2PO_4$, 0.5 mg·liter^{-1} Fe as chelated sodium ferric diethylenetriamine pentaacetate, 0.25

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mg·liter^{-1} Mn as $MnCl_2$, 0.025 mg·liter^{-1} Zn as $ZnSO_4$, 0.01 mg·liter^{-1} Cu as $CuSO_4$, and 0.005 mg·liter^{-1} Mo as MoO_3. The B treatments were imposed by adding different amounts of H_3BO_3 to the irrigation waters prior to planting. Before adding the H_3BO_3, a sample of the irrigation water was taken from each reservoir to determine B levels resulting from impurities in the nutrient salts and the tap water used to fill the reservoirs. The amount of H_3BO_3 added to each reservoir then was adjusted to obtain the 6 desired treatment levels. Treatments were replicated 4 times. Irrigation water samples were taken monthly to monitor and maintain desired B levels.

Since the washed sand used in this study possessed no exchange capacity, the B concentrations in the irrigation water (B_{iw}) and in the soil water (B_{sw}) were identical. Therefore, since plants respond to the B concentration in the soil water (7), all data presented in this paper are given in terms of that parameter. For comparison with soil conditions, the relationship that exists between B_{iw} and B_{sw} at various leaching fractions has been previously presented (7).

Mature, fully expanded leaves were sampled from all 3 crops for elemental analysis. Since B accumulates in leaf margins (6, 7), entire leaves were used for the sample. Leaves were washed, dried at 70°C, and finely ground in a blender. Boron was determined colorimetrically by the azomethine-H method (8) after the leaf material was digested by dry-ashing with CaO. Nitric-perchloric acid digests of the dried ground leaves were analyzed for P by molybdovanadate-yellow colorimetry (9), and Ca, Mg, and K by atomic absorption spectrophotometry.

Broccoli and cauliflower. Broccoli (cv. Waltham 29) and cauliflower (cv. Snowball 'Y') seed were planted 6 Oct. 1982. Two rows of each cultivar were planted in each sand tank. The seeds were placed about 4 cm apart within the row. One month after planting, the stand was thinned to 5 plants of each cultivar per row.

The B concentrations in the irrigation water were 1.0, 4.0, 8.0, 12.0, 16.0, and 20.0 mg B·liter^{-1}. These B concentrations were selected as the result of a preliminary test made during Winter 1981–82.

Broccoli and cauliflower were first harvested on 14 Jan. and 1 Feb. 1983, respectively. Broccoli was harvested when heads were at least 6.4 cm in diameter and stalk lengths were between 15.3 and 21.5 cm long (1). Cauliflower was harvested when curds were at least 10.2 cm in diameter (2). The only deviation from these standards occurred when the broccoli head or cauliflower curd began to lose compactness. At harvest, the plants were cut at the sand surface and weighed. For broccoli, all extraneous stems and leaves were removed and the plants were weighed again. For cauliflower, all jacket leaves, except the inner 4, were removed and the butt was then closely trimmed before re-weighing.

Leaf samples for chemical analysis were taken for each cultivar the same day the first harvest occurred.

Radish. 'Crimson Giant' seed were planted 17 Oct. 1983. Four rows were planted in each tank. After emergence, the plants were thinned to 2.5 cm apart within the row.

The B concentrations in the irrigation water were 1.0, 3.0, 6.0, 10.0, 13.0, and 16.0 mg B·liter^{-1}. These concentrations were selected on the basis of a previous study reported by Eaton (5).

The first harvest occurred on 23 Nov. 1983—37 days after planting. Subsequent harvests were made at about weekly intervals with the final harvest on 15 Dec. 1983. At harvest, the plants were counted, the tops and roots weighed separately, and the roots sized according to the U.S. grading standards for radishes (3).

Leaf samples for chemical analysis were taken on 23 Nov. 1983, the first harvest day.

Results and Discussion

Broccoli and cauliflower. The effect of increasing B_{sw} concentration on broccoli and cauliflower yields is presented in Table 1. Both species showed a significant yield reduction for both total and trimmed weight with B_{sw} >4.0 mg B·liter^{-1}. However, total weight was reduced considerably more than trimmed weight with increasing levels of B_{sw}. Over the B_{sw} range tested, total weight of broccoli and cauliflower decreased 46% and 34%, while trimmed weight decreased only 30% and 27%, respectively.

Trimmed weight to total weight ratios significantly increased as B_{sw} increased. At 1.0 mg B·liter^{-1}, the trimmed weight for broccoli and cauliflower was only 16.3% and 29.6% of the total plant weight. However, at 20.0 mg B·liter^{-1}, the trimmed weights increased to 21.0% and 32.8% of the total plant weights, respectively.

Linear regression analyses for relative yield of trimmed broccoli and cauliflower are presented in Figs. 1 and 2, respectively.

Table 1. Broccoli and cauliflower yield parameters at 6 different B concentrations in the soil solution.

	Broccoli				Cauliflower			
Soil water boron (mg·liter^{-1})	Total wt (g)	Trimmed wt (g)	Head diam (cm)	Trimmed wt to total wt (%)	Total wt (g)	Trimmed wt (g)	Head diam (cm)	Trimmed wt to total wt (%)
1.0	283	46	7.3	16.3	505	150	12.6	29.6
4.0	269	45	7.2	16.9	530	157	12.4	29.6
8.0	189	36	7.0	19.4	463	144	12.3	30.9
12.0	207	39	6.8	18.7	499	140	12.1	28.2
16.0	164	33	6.4	20.0	414	134	11.6	32.9
20.0	153	32	6.4	21.0	332	109	10.5	32.8
Significance								
Treatment	***	*	*	*	***	*	*	*
Linear[z]	***	***	***	***	***	***	***	*

[z]Single degree of freedom comparison

*,***Significant at 5% or 0.5% level, respectively.

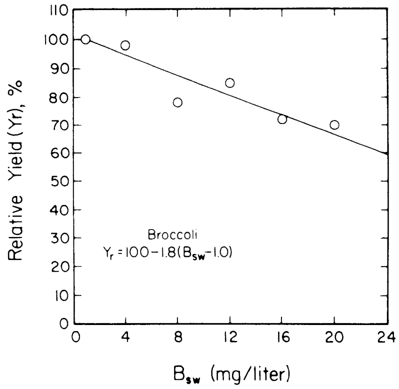

Fig. 1. Relative yield of broccoli as influenced by B concentration in the soil solution.

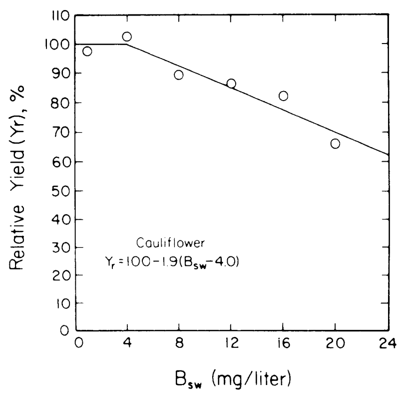

Fig. 2. Relative yield of cauliflower as influenced by B concentration in the soil solution.

Table 2. Boron concentration in broccoli and cauliflower leaves sampled from plants grown at 6 soil solution B concentrations.

Soil water boron ($mg \cdot liter^{-1}$)	Leaf B concentration ($mg \cdot kg^{-1}$ dry wt)	
	Broccoli	Cauliflower
1.0	55	54
4.0	134	52
8.0	343	73
12.0	471	90
16.0	695	114
20.0	943	160
Significance		
Treatment	***	***
Linear[z]	***	***

[z]Single degree of freedom comparisons.
***Significant at 0.5% level.

The analysis for broccoli shows that each unit increase in B_{sw} above 1.0 $mg \cdot liter^{-1}$ reduced yield 1.8%, while that for cauliflower indicates a 1.9% yield reduction for each unit increase in B_{sw} above 4.0 $mg \cdot liter^{-1}$. Applying the Maas–Hoffman equation (4, 11) to these data indicates that a 50% yield decline would occur at a B_{sw} concentration of about 30 $mg \cdot liter^{-1}$ for both broccoli and cauliflower, respectively. Relative yield for any B_{sw} concentration exceeding the threshold of 1.0 $mg \cdot liter^{-1}$ for broccoli and 4.0 $mg \cdot liter^{-1}$ for cauliflower can be calculated with the formula presented in the respective figures.

Although broccoli and cauliflower are both reported to have a high B requirement (10), B accumulation was considerably greater in broccoli leaves than in cauliflower leaves (Table 2). Each unit increase in B_{sw} increased leaf B about 8 and 47 $mg \cdot kg^{-1}$ dry weight for cauliflower and broccoli, respectively. Apparently the accumulated B in the leaf tissue was still below the injurious level, since neither species developed the marginal necrosis that is usually associated with high leaf B (5–7).

Table 3. Radish root and top weights at 6 different B concentrations in the soil solution.

Soil water boron ($mg \cdot liter^{-1}$)	Root wt (g)	Top wt (g)	Root wt to top wt ratio
1.0	10.2	16.2	1.59
3.0	9.8	16.0	1.63
6.0	9.3	14.3	1.54
10.0	8.8	13.0	1.48
13.0	8.5	12.0	1.41
16.0	8.0	11.5	1.44
Significance			
Treatment	***	***	NS
Linear[z]	***	***	*

[z]Single degree of freedom comparisons.
NS, *, ***Nonsignificant or significant at 5% or 0.5% levels, respectively.

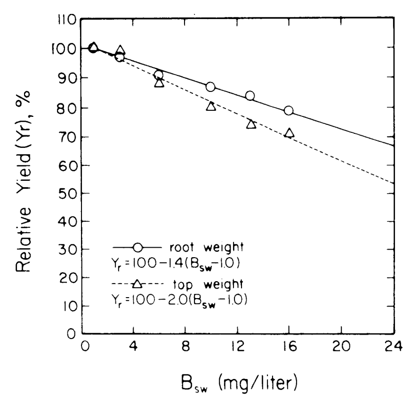

Fig. 3. Relative root and top weight of radish as influenced by B concentration in the soil solution.

Calcium, Mg, K, and P concentrations in the leaves were not as significantly affected as B concentrations in the soil water increased (data not shown).

Radish. Radish root and top weights were significantly reduced as B_{sw} increased (Table 3). At the high B_{sw} concentration of 16.0 $mg \cdot liter^{-1}$, the root and top weights were reduced 22% and 29%, respectively. The root to top ratio, however, was not significantly affected over the B_{sw} range tested.

Linear regression analyses for both root and top weights expressed on a relative basis are presented in Fig. 3. The analyses show that each unit increase in B_{sw} above 1.0 $mg \cdot liter^{-1}$ reduced root weight 1.4% and top weight 2.0%. The formula presented in Fig. 3 indicates that a 50% reduction in radish root weight would occur at a B_{sw} of 37 $mg \cdot liter^{-1}$ (4, 11).

Root size was reduced significantly by increased B_{sw} concentration (Table 4). Fifty-four percent of the roots harvested from the 1.0 mg $B \cdot liter^{-1}$ treatment were designated large or very large, while 45% were medium or small. At 16 mg $B \cdot liter^{-1}$ only 35% were sized large or very large, whereas 64% were medium or small. Although the roots were decreased in size

Table 4. Distribution of radish root sizes at 6 different B concentrations in the soil solution.

Soil water boron ($mg \cdot liter^{-1}$)	Root size diam[z]				
	Very small (<15.9 mm)	Small (15.9–19.1 mm)	Medium (19.1–25.4 mm)	Large (25.4–31.8 mm)	Very large (>31.8 mm)
			Harvested roots (%)		
1.0	1	8	37	40	14
3.0	2	8	43	39	8
6.0	2	10	47	36	5
10.0	1	10	47	35	7
13.0	1	11	53	30	5
16.0	1	11	53	30	5
Significance					
Treatment	NS	NS	***	*	***
Linear[y]	NS	***	***	***	***

[z]Diameter is the greatest dimension of the root measured at right angles to a line running from the crown to the base of the root.
[y]Single degree of freedom comparisons.
NS, *, ***Nonsignificant and significant at 5% or 0.5% levels, respectively.

Table 5. Boron, Ca, and P concentrations in radish leaves and roots at 6 B concentrations in the soil water.

Soil water boron ($mg \cdot liter^{-1}$)	Leaves			Roots		
	B ($mg \cdot kg^{-1}$ dry wt)	Ca ($mmol \cdot kg^{-1}$ dry wt)	P ($mmol \cdot kg^{-1}$ dry wt)	B ($mg \cdot kg^{-1}$ dry wt)	Ca ($mmol \cdot kg^{-1}$ dry wt)	P ($mmol \cdot kg^{-1}$ dry wt)
1.0	43.0	764	83.2	34.6	190	88.8
3.0	74.2	730	83.0	45.2	180	91.2
6.0	131.8	725	73.0	76.5	179	84.4
10.0	210.2	630	69.2	102.6	178	76.5
13.0	278.8	608	56.8	147.8	178	75.9
16.0	348.2	611	47.0	172.8	180	78.9
Significance						
Treatment	***	***	*	***	NS	NS
Linear[z]	***	***	***	***	NS	**

[z]Single degree of freedom comparisons.
NS, *, **, ***Nonsignificant or significant at 5%, 1%, or 0.5% levels, respectively.

with increased B_{sw}, only 1% to 2% of the total number of roots harvested were too small to meet the minimum size designation of 15.9 mm for U.S. grade No. 1 radishes.

The significant increases in B concentration found in both leaves and roots were directly related to the B_{sw} concentration (Table 5). Leaves contained nearly twice the B concentration found in the roots. Although Eaton (5) reported marginal leaf necrosis on radish leaves at a B_{sw} concentration of 10 $mg \cdot liter^{-1}$, no leaf injury symptoms were observed in this study with B_{sw} concentration as high as 16 $mg \cdot liter^{-1}$.

Calcium and P concentration in the leaves decreased significantly with increasing B_{sw} while all other ions remained unchanged (Table 5). This is in contrast to the results for broccoli and cauliflower and those obtained in a previous study with tomatoes (7), where Mg, K, and P concentration in the leaves increased and Ca remained unchanged with increasing levels of B_{sw}.

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Effect of Root Container Size and Location of Production on Growth and Yield of Tomato Transplants

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Additional index words. *Lycopersicon esculentum*, transplant container, early yield, total yield, Speedling

Abstract. **'Pik-Red' tomato (*Lycopersicon esculentum* Mill.) transplants produced in 2 locations (Florida and Michigan), in 6 root cell sizes were compared for fruit productivity in Michigan. Transplants grown in large cells produced more early yields than those from small cells, but generally did not produce more total yields. Large root cell size had a greater effect on transplant size than did wide spacing in the flat. Speedling root cell size 175 (39.5 cm^3) produced the largest transplants, the largest early fruit yields, and the greatest weight of marketable fruit. Transplants grown in Speedling trays in Michigan produced larger early yields than Speedling transplants grown in Florida.**

Tomatoes are a major fresh market crop in Michigan. They are grown from transplants because of the relatively short growing season. Good-quality transplants are essential for successful tomato production in this system, since plant condition at transplanting affects stand, early yield, total yield, and fruit size (3, 6, 7, 9).

A number of cultural practices are known to affect tomato transplant quality and subsequent fruit yield in the field. Fruit yield increased as space per plant during seedling growth in the greenhouse increased (2, 6, 9, 12). Plants grown in large containers or root cells had more leaves, faster growth rate after transplanting (9, 12), and produced more early yield than plants from small containers (6, 11, 15). Seedlings adequately fertilized with N, P, and K produced greater early and total yields than seedlings fertilized with minimal amounts of these nutrients (4, 5, 10). Overhardening and poor or prolonged shipping and storage of transplants also reduced tomato yields (5, 14).

Michigan growers obtain a majority of their plants from the southern United States. Most of the plants are field-grown and often suffer severe transplant shock on field setting (5, 13, 14); therefore, farmers are looking for other sources of plants. Speedling (Sun City, Fla.), has become a major supplier of greenhouse-grown plants for Michigan farmers. The Speedling system uses trays of the same outer dimensions but with several available cell sizes. Plants grown in the small-size cells are less expensive to produce than those in large cells because they require less greenhouse space. The Speedling plants are normally of good quality, but often suffer a lag in growth after setting in the field. The size of the root cells and the conditions under which the transplants are produced may affect their growth and productivity in the field.

Since root cell size and environment of production are known to affect transplant quality, these studies were initiated to compare Michigan- and Florida-grown tomato plants for quality and productivity.

Materials and Methods

Transplant production and growing conditions. At Michigan State Univ., 'Pik-Red' tomato seeds were germinated for 48 hr at 25°C and suspended in Viterra II hydrogel (1% by weight) before planting in a modified Cornell Mix A (8) in 5 sizes of flats (080, 100A, 125, 150, and 175) on 13 May 1980 and 4 May 1981 (Table 1). The plants were grown in a greenhouse with temperatures of 26° (day) and 20° (night), 13- to 14-hr photoperiod, and luminance of 500 $\mu mol \cdot s^{-1} \cdot m^{-2}$. No supplemental lighting was used. Plants were watered overhead twice daily. When true leaves appeared, the plants were fertilized weekly with a soluble 20N–8.6P–16.6K fertilizer at a rate of 2.7 g per liter of water (540 ppm N).

'Pik-Red' tomato seeds of the same lot were sown at Speedling facilities on 13 May 1980 in 080-, 100A-, and 125-size flats and on 4 May 1981 in 080-, 100A-, 125-, 150-, and 175-size flats. Plants were grown in a modified Cornell Mix A (8) in a plastic house with maximum 29°C (day) and minimum 16°

Table 1. Depth, area, and volume of root cells of Speedling planter flats.[z]

Flat size	Cell side length (cm)	Cell surface area (cm^2)	Cell depth (cm)	Cell volume (cm^3)
080	2.03	4.1	3.2	4.4
080A	2.03	4.1	4.1	5.6
100A	2.54	7.8	7.2	18.8
125	3.18	10.1	4.6	15.4
150	3.81	14.5	6.4	30.7
175	4.45	18.7	6.4	39.5

[z]Speedling (Todd) planter flats are made of expandable polystyrene and are produced in a number of sizes, with a descriptive number indicating the cell size, (e.g., a 100-size flat has cells 2.5 cm long on a side). The size numbers indicate this length in hundredths of an inch. The cells are shaped as square, inverted pyramids.

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