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Yield and Quality Responses of Garlic and Onion to Excess Boron

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Abstract. This **study, conducted in large, outdoor sand cultures, was initiated to determine the effects of excess B on garlic *(Allium sativum* L.) and onion *(Allium cepa* L.) and to establish their B tolerances as measured by yield and quality of the marketable product. Boron treatments were imposed by irrigation with culture solutions that contained 0.5, 1.0, 5.0, 10.0, 15.0, or 20.0 mg B/liter. Relative yields of garlic and onion were reduced 2.7% and 1.9% with each unit (mg·liter^{-1}) increase in soil solution B (B_{sw}) above 4.3 and 8.9 mg B/liter, respectively. Increasing B_{sw} reduced garlic bulb weight and diameter but did not significantly affect onion bulb weight or diameter. Boron concentration in leaves and bulbs was directly correlated to B_{sw}.**

As good-quality water for irrigation becomes less abundant, many waters previously rejected because of high B content will have to be used to meet future agricultural needs. These waters, as well as those currently used that contain elevated B levels, may cause severe yield reduction of many agricultural crops.

Boron, applied in irrigation water (B_{iw}), will concentrate in the soil profile as other solutes do. The rate at which B concentrates depends on soil properties, amount of irrigation water applied, leaching fraction, and the B concentration in the irrigation water (Rhoades, 1982). Some of the B is adsorbed by fine soil particles, and an equilibrium is established between the adsorbed B and the dissolved B in the soil solution (B_{sw}) (Eaton and Wilcox, 1939; Hatcher and Bower, 1958). Plants have been shown to respond to soil solution B (Hatcher et al., 1959).

Numerous crop species, including onion, were tested for B tolerance by Eaton (1944) in the early 1930s. However, his B tolerance classification for many crops was based on the incidence of leaf injury and not on the yield decline of the marketable product. Recent studies (Francois, 1984, 1986, 1988, 1989) have shown that the occurrence of leaf injury is not a reliable indicator of yield reduction. Consequently, reliable quantitative data to estimate yield reduction from excess B are lacking for many vegetables. Onion and garlic, which are grown for the fresh and processing (dehydration) markets, fall into this category. This study was initiated to determine the effects of excess B on garlic and onion and to establish their B tolerances as measured by yield and quality of the marketable product.

Twenty-four sand tanks (2.08 x 0.86 x 0.84 m deep) containing a course 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 various B concentrations. Irrigation waters were surface-applied three times each day, with the sand being saturated completely with each irrigation. The solutions were collected in corrugated polyethylene tile lines located in the bottom of each sand tank and returned to the reservoirs by gravity flow.

The irrigation solutions contained the following nutrient salts per liter: 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 Fe as chelated sodium ferric diethylenetriamine pentaacetate, 0.25 mg Mn as $MnCl_2$, 0.025 mg Zn as $ZnSO_4$, 0.01 mg Cu as $CuSO_4$, and 0.005 mg Mo as MoO_3. The B treatments, added as H_3BO_3 to the irrigation solutions before planting, were 0.5, 1.0,5.0, 10.0, 15.0, and 20.0 mg·liter^{-1}. Before adding the H_3BO_3, an irrigation water sample was taken from each reservoir to determine B levels from impurities in the nutrient salts and the tap water used to fill the reservoir. The amount of H_3BO_3 added to each reservoir then was adjusted to obtain the desired treatment levels. Irrigation solution samples were taken monthly to monitor and maintain desired B levels. Solution pH varied between 7.6 and 7.8. The experimental design consisted of six treatments replicated four times in a randomized complete block.

Since the washed sand possessed negligible exchange capacity, the B concentration in the irrigation water (B_{iw}) and soil water (B_{sw}) were identical. Because plants respond to the B concentration in the soil solution (B_{sw}) (Hatcher et al., 1959), data presented in this study are given in terms of B_{sw}. The relationship that exists between B_{iw} and B_{sw} at various leaching fractions in soils has been described (Francois, 1984).

'California Early' garlic cloves and 'Southport White Globe' onion (dehydrator type) seed were planted 8 Oct. 1987. Three rows (280 mm apart) of each species were planted in each sand tank. One month after planting, the stand of each species was thinned to ≈50 mm apart within the row.

Mature, most recently fully expanded

Table 1. Vegetative growth and yield components of garlic and onion grown at six B concentrations in the soil solution.

Soil water B (mg·liter^{-1})	Vegetative dry wt (g/plant)	Bulb: Solids (%)	Bulb: Avg wt (g/bulb)	Bulb: Avg diam (mm/bulb)
Garlic				
0.5	11.0	34.8	41.4	49.5
1.0	11.4	34.4	45.3	51.3
5.0	10.6	34.4	43.4	50.5
10.0	10.2	34.5	35.8	46.9
15.0	8.3	33.9	29.7	42.9
20.0	6.9	34.0	25.7	41.1
Significance				
Treatment	***	NS	***	***
Linear[z]	***	NS	***	***
Quadratic[z]	NS	NS	NS	NS
Onion				
0.5	13.8	21.3	117.4	64.4
1.0	13.6	21.1	117.8	64.8
5.0	12.5	20.8	114.3	62.5
10.0	13.9	21.0	109.0	62.7
15.0	13.2	20.7	113.6	64.0
20.0	9.7	20.3	87.4	56.6
Significance				
Treatment	NS	*	NS	NS
Linear[z]	NS	***	*	*
Quadratic[z]	NS	NS	NS	NS

[z]Single-degree-of-freedom comparison.
[NS],*,***Nonsignificant or significant at P = 0.05 or 0.005, respectively.

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Table 2. Boron concentrations in garlic and onion leaves and bulbs at six B concentrations in the soil water.

Soil water B ($mg \cdot liter^{-1}$)	B concn in garlic ($mg \cdot kg^{-1}$ dry wt)		B concn in onion ($mg \cdot kg^{-1}$ dry wt)	
	Leaves	Bulbs	Leaves	Bulbs
0.5	59	10	38	21
1.0	71	12	45	20
5.0	182	15	94	23
10.0	558	22	213	24
15.0	573	29	333	29
20.0	1173	37	394	32
Significance				
Treatment	***	***	***	***
Linear[z]	***	***	***	***
Quadratic[z]	NS	NS	NS	NS

[z]Single-degree-of-freedom comparison.
[NS], *** Nonsignificant or significant at $P = 0.005$, respectively.

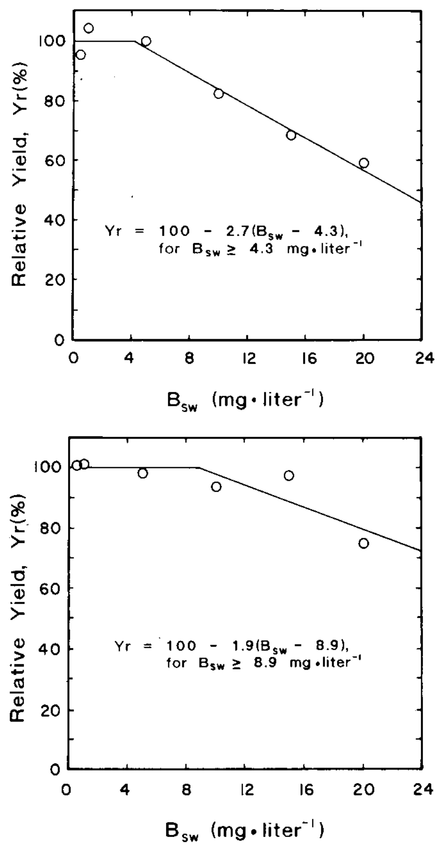

Fig. 1. Relative yield (Yr) of garlic **(top)** and onion **(bottom)** bulbs as influenced by B concentration in the soil solution.

leaves were sampled from both species on 14 Apr. 1988. Leaves were washed with distilled water, dried at 70C, and finely ground in a blender. Boron was determined calorimetrically by the azomethine-H method (John et al., 1975) 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 calorimetry (Kitson and Mellon, 1944), and Ca, Mg, Na, and K were determined by atomic absorption spectrophotometry.

Irrigations were discontinued on 20 May 1988 when both species were considered mature. At maturity, onions exhibited a weakness in the plant tops and tended to fall over, while garlic showed distinct knobbiness and there were three to four leaf sheaths per clove. Both plant species were left to dry for 10 days in the sand after the last irrigation. All plants were then removed from the sand tanks and placed on plastic sheets to finish drying. After drying, the tops for both species were removed by cutting them » 4 cm above the bulb. To determine vegetative growth, the tops from all plants were dried in a forced-air drier at 70C until completely dry and then weighed. Before weighing, the roots were closely trimmed to the base of each bulb and all extraneous sand removed. The bulbs were then sized according to the U.S. grading standards for fresh-market garlic (Agricultural Marketing Service, 1981) and onion (Agricultural Marketing Service, 1971). Before sizing the garlic, all loose side cloves were removed from the primary bulb.

After the bulbs of both species were weighed and sized, two random samples of 10 bulbs each were taken from each treatment for percent solids determination. The samples were finely chopped with a food chopper, weighed, and dried in a forced-air drier at 105C until completely dry. The percent solids was then determined gravimetrically.

An additional sample of bulbs was used for elemental analysis. For these analyses, the analytical methods were the same as those used to determine leaf elemental content.

Calculated coefficients for unequally spaced treatments were used to determine single-degree-of-freedom comparisons for treatments.

Garlic response. A significant reduction in bulb weight and diameter occurred when B_{sw} exceeded 5.0 $mg \cdot liter^{-1}$ (Table 1). Although not directly measured, a calculation of density using average bulb weight and diameter showed a tendency toward higher weights per unit volume when B_{sw} was > 5.0 $mg \cdot liter^{-1}$. Although the diameter was significantly reduced over the B_{sw} range tested, the bulbs harvested from all treatments exceeded the 39-mm diameter required for U.S. No. 1 grade garlic (Agricultural Marketing Service, 1981).

Percent solids in the garlic, a measure of quality for processing, was unaffected by increased B_{sw}. However, the percent solids obtained in this study was ≈ 6% below the average expected in garlic grown in the San Joaquin Valley of California (E.A. Kurtz, personal communication).

To determine the B tolerance, bulb weight was statistically analyzed with a piecewise linear response model (Francois, 1984; Maas and Hoffman, 1977; van Genuchten and Hoffman, 1984). The data indicate that each unit increase in B_{sw} > 4.3 mg B/liter (threshold) resulted in a 2.7% decrease in relative yield (Fig. 1, top). A 50% yield decline will occur at a B_{sw} concentration of ≈23 $mg \cdot liter^{-1}$. Relative yield for any given B_{sw} concentration exceeding the threshold can be calculated for yield reduction with the equation presented in Fig. 1, top. According to the categories established by Maas (1986), garlic would be classified as moderately tolerant to B_{sw}.

Leaf injury symptoms were noted for the first time ≈1 month after planting. Tip chlorosis developed on the leaves of all plants when B_{sw} exceeded 10 $mg \cdot liter^{-1}$. At harvest, all plants growing on the 1.0 mg B/liter or higher treatments had developed tip necrosis, with chlorosis extending 10 to 30 mm down the leaf margins immediately below the necrotic tips. This marginal chlorosis from B accumulation differs from the type of leaf injury seen on most other crops with parallel venation (Francois and Clark, 1979; Oertli and Kohl, 1961). Leaves with parallel veins usually develop tip chlorosis and/or necrosis that progresses uniformly down the entire leaf as B accumulates. The severity of the leaf damage in this study was correlated directly to the B_{sw} concentration. The necrosis on plants treated with 10 mg B/liter encompassed ≈30 mm of the leaf tip, whereas it encompassed 100 and 150 mm of the tip with 15 and 20 mg B/liter, respectively.

Analysis of leaf composition showed that the concentration of B in the garlic leaves increased ≈20– fold over the B_{sw} range tested (Table 2). As observed with other plant species (Francois, 1984, 1986, 1988, 1989), the B concentration in leaves and subsequent leaf injury is not a reliable indicator for yield reduction. Whereas leaf injury occurred at a B_{sw} of 1.0 $mg \cdot liter^{-1}$, yield was not reduced until the B_{sw} exceeded 4.3 $mg \cdot liter^{-1}$.

Increased B concentrations in leaves were associated with a smaller, but statistically significant, increase in the bulbs (Table 2). However, when the B_{sw} exceeded 5.0 $mg \cdot liter^{-1}$ B concentrations in leaves were 20 to 30 times higher than those found in bulbs.

Increased B in the soil solution and subsequent B accumulation in the leaves and bulbs did not significantly affect the concentrations of Ca, Mg, P, or Na within the plant. Over the B_{sw} range tested, Ca, Mg, P, and Na averaged 288, 164, 119, and 11 $mmol \cdot kg^{-1}$ dry weight in leaves and 31, 41, 140, and 9 $mmol \cdot kg^{-1}$ dry weight in bulbs, respectively. Potassium concentration, which remained relatively unchanged in the leaves, increased significantly in the bulbs, from 381 to 453 $mmol \cdot kg^{-1}$ dry weight, as B concentration increased.

Onion response. In contrast to garlic, onion did not show a consistent reduction in bulb weight, bulb diameter, or vegetative growth with increasing levels of B_{sw} (Table 1). Although not affected significantly, the weight and diameter of bulbs grown with 20 mg B/liter were reduced relative to the lowest B_{sw} levels. Vegetative growth showed a similiar pattern.

Percent solids in the onions showed a significant linear reduction as the B_{sw} increased. However, percent solids in bulbs harvested from all treatments in this study fell within the range reported for ‘Southport White Globe’ (dehydrator type) (E.A. Kurtz, personal communication).

Piecewise linear regression analysis (Francois, 1984; Maas and Hoffman, 1977; van Genuchten and Hoffman, 1984) for bulb weight shows that each unit increase in B_{sw} above 8.9 mg B/liter decreased yield 1.9% (Fig. 1, bottom). The equation presented in the figure indicates that a 25% reduction in weight would occur at a B_{sw} of 22 mg B/liter. Onion, therefore, would be classified as very tolerant to B_{sw} (Maas, 1986).

The tolerance threshold of 8.9 mg B/liter is more than twice that previously reported for onion by Wilcox (1960). Eaton’s data (1944), when analyzed with the Maas-Hoffman model (1977), would indicate a B_{sw} threshold as low as 0.5 to 0.8 mg B/liter.

All plants grown with 10 mg B/liter or higher in the soil water developed leaf tip chlorosis and/or necrosis within 4 weeks of planting. As the plants matured, the extent of leaf injury became more severe with 10, 15, and 20 mg B/liter. Injury on plants grown with 5 mg B/liter was barely discernible throughout the study. In contrast to garlic, onion leaf injury was restricted to the distal tip of the leaves, with no marginal chlorosis.

The statistically significant increases in B concentration found in both leaves and bulbs were directly related to the B_{sw} concentration (Table 2). When the B_{sw} exceeded 10 mg B/liter, leaves contained ≈10 times the B concentration found in bulbs. The B concentrations found in the leaves and bulbs in this study are significantly lower than those reported by Eaton (1944).

The concentrations of K, Ca, Mg, P, and Na in the leaves and bulbs were unaffected by increased B_{sw} (data not presented).

This study shows that garlic and onion yield can be maintained with B_{sw} levels considerably higher than reported previously (Eaton, 1944; Wilcox, 1960). However, the B tolerance levels may vary somewhat, depending on climate, soil conditions, irrigation practices, and crop cultivar.

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