

Boron Improves Growth, Yield, Quality, and Nutrient Content of Tomato

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ABSTRACT. Boron deficiency in fresh-market tomatoes (*Lycopersicon esculentum* Mill.) is a widespread problem that reduces yield and fruit quality but is often not recognized by growers. Tomatoes were grown in field and hydroponic culture to compare the effects of foliar and soil applied B on plant growth, fruit yield, fruit quality, and tissue nutrient levels. Regardless of application method, B was associated with increased tomato growth and the concentration of K, Ca, and B in plant tissue. Boron application was associated with increased N uptake by tomato in field culture, but not under hydroponic culture. In field culture, foliar and/or soil applied B similarly increased fresh-market tomato plant and root dry weight, uptake, and tissue concentrations of N, Ca, K, and B, and improved fruit set, total yields, marketable yields, fruit shelf life, and fruit firmness. The similar growth and yield responses of tomato to foliar and root B application suggests that B is translocated in the phloem in tomatoes. Fruit from plants receiving foliar or root applied B contained more B, and K than fruit from plants not receiving B, indicating that B was translocated from leaves to fruit and is an important factor in the management of K nutrition in tomato.

Boron deficiency in fresh-market tomatoes (*Lycopersicon esculentum* Mill.) is often not recognized by growers. Boron deficiency, however, is widespread (Gupta et al., 1985) and can cause serious yield reductions and uneven ripening of tomato fruit (Adams, 1978). Boron becomes less available to plants as soil pH increases (Bunt, 1956). Therefore the practice of applying lime to improve the uptake of other important nutrients can cause B deficiency (Fleming, 1980). Boron deficiency can also occur readily in tomatoes grown in areas with acid sandy soils and heavy rainfall (Adams, 1986) because it is easily leached under such conditions (Mengel and Kirkby, 1987). These conditions are common in the southeastern United States (Mortvedt and Woodruff, 1993; Offiah and Axley, 1993) and increase the difficulty of managing B nutrition in tomatoes in this region.

Maintenance of high foliage K levels during tomato fruit development is recommended but is often difficult to achieve (Adams, 1986; Bradley and Flemming, 1960). Fruit become large sinks for K as they develop, thereby diminishing K levels in leaves that are needed for continued plant growth and physiological processes (Ho and Hewitt, 1986). Adequate B levels help to maintain leaf K levels in tomato during fruit development (Sperry, 1995). Blevins et al. (1993) reported that B has a major influence on the plasma membrane of plant cells and ion transport and that B amendments increased K, Ca, and Mg levels in soybean [*Glycine max* (L.) Merr.] leaves.

Fresh-market tomato production commonly involves use of raised beds with black polyethylene mulch and drip-irrigation. Soluble fertilizers are often applied directly to the root zone through the drip-irrigation system. Although B can be supplied to tomatoes as dry fertilizer (Mortvedt and Woodruff, 1993), dry B formulations are difficult to manage because typically very small amounts are required, it is subject to loss by leaching, and the range of deficient to toxic levels of soil B is very narrow (Reisenauer et al., 1973).

Application of B to tomatoes via drip-irrigation or in a regular

foliar spray regime ensures a steady supply of B throughout the growing season without the management concerns of supplying B as a dry formulation. Application through the drip-irrigation system places B directly in the root zone and foliar B applications allow uptake directly through the leaves. The objective of this study was to determine if B, applied in a liquid formulation to the foliage and/or roots, would improve yields, fruit quality, and nutrient content of tomatoes.

Materials and Methods

HYDROPONIC STUDIES. Production of tomato seedlings for the hydroponic study was carried out by seeding fresh-market 'Celebrity' tomato in flats containing steam sterilized river bottom sand. Flats were placed in a deionized water intermittent mist bed under cycles of 23 °C day/18 °C night with an 18-h photoperiod provided by cool-white fluorescent lamps. Eighteen days following sowing, seedlings were transplanted to acid washed 3.75-L plastic containers containing continuously aerated nutrient solutions and placed in a greenhouse. To eliminate light, the plastic containers were sprayed with aluminum colored paint and polystyrene covers were made to fit tightly in the openings. Three small holes were bored in each cover to accommodate two plants (one plant per hole) and an air tube. A closed-circle air manifold was constructed with Tygon tubing and attached to an air pump (Rev-A, Thomas Industries, Inc., Pittsburgh, Pa.) and acid washed air stones were attached to the manifold, placed in the containers, and suspended 2.5 cm from the bottom of the container. Constant levels of a modified Hoagland solution minus the B (Maynard and Hochmuth, 1997) were maintained in the plastic containers by adding double-deionized water daily. Nutrient solutions were completely changed every 7 d.

Three treatments were applied in this study: no B; 1 mg·L⁻¹ B as H₃BO₃ supplied in the nutrient solution; and a foliar application of 1.87 mg·L⁻¹ B as N-Boron (4.5–0–0 with 3.3% B chelated with mannitol) (Claw El, Divison of Brandt Consolidated, Pleasant Plains, Ill.) Treatments were started when seedlings were placed in the 3.75-L containers. The B treatments were supplied continuously in the nutrient solution and the foliar applications were applied every seven days. The foliar treatments were applied with a hand held spray bottle and sprayed until just before run off. To

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prevent contamination of plant roots and growth solution with the foliar spray treatment, containers were taken to a separate room before treatment and the containers and plants up to the first leaves were protected by securing a 56.7-L plastic bag tightly around the stem. A new bag was used for each container and each time a treatment was applied. Plants were harvested 56 d after transplanting. To remove B treatment surface residues from roots and shoots, the tissues were rinsed under warm tap water for 15 s, washed for 30 s in 0.2 N HCl, rinsed under warm tap water for 15 s, and rinsed for 30 s in distilled water (Williams and Nelson, 1992). All samples were weighed, dried at 70 °C for 72 h, reweighed, ground in a stainless steel Wiley mill) to a particle size ≤ 1 mm (20-mesh screen), and dry-ashed at 500 °C. Samples were analyzed for total N by a semimicro-Kjeldahl procedure in which salicylic acid was added as a pretreatment to digestion to aid in the reduction of NO_3 (Eastin, 1978). Boron was determined by the curcumin procedure (Grinstead and Snider, 1967) and K, Ca, Mg, and S (sulfur) were analyzed by atomic absorption spectroscopy (Christian and Feldman, 1970). Phosphorus was analyzed colorometrically (Chapman and Pratt, 1961) using a UV/VIS spectrophotometer (Perkin-Elmer, Norwalk, Conn.). An estimate of total nutrient uptake was calculated by multiplying the concentration of nutrient (mg nutrient/g plant tissue) by the total dry weight of the specific plant tissue.

This study was repeated three times using a randomized complete block design with three treatments and five replications. A fourth study was conducted that included the three treatments described previously, plus an additional foliar + root B application treatment. The foliar+root B application treatment supplied 1 $\text{mg}\cdot\text{L}^{-1}$ B from H_3BO_3 in the nutrient solution and 1.87 $\text{mg}\cdot\text{L}^{-1}$ B as an N-Boron foliar spray. Except for the addition of the foliar+root B application treatment, the fourth study was conducted using the same materials and methods as described previously.

The results of all four experiments were subjected to ANOVA. No treatment by experiment interactions were found, so the data were grouped as one experiment with four treatments and unequal replication ($n = 5$ for the foliar + root treatment, $n = 20$ for all other treatments). The grouped data were subjected to analysis of variance and, where appropriate, to the F protected LSD mean separation test using SAS (SAS Institute, Cary, N.C.).

FIELD STUDY. This field study was conducted on a Norfolk loamy sand (fine loamy, siliceous, thermic Typic Paleudult) in Clayton, N.C. Soil had a pH of 6.6 and contained less than 0.1 $\text{mg}\cdot\text{kg}^{-1}$ B. This site was selected because B deficiency symptoms are likely to occur in tomato plants when soil B concentrations are below a critical level of 0.1–0.7 $\text{mg}\cdot\text{kg}^{-1}$ (Maynard and Hochmuth, 1997). Soil B levels were analyzed colorometrically using the hot-water-soluble B extraction method of McGeehan et al. (1989).

The experimental site was prepared for tomato production by the application of 11.2 $\text{kg}\cdot\text{ha}^{-1}$ P, 84 $\text{kg}\cdot\text{ha}^{-1}$ K, and 56 $\text{kg}\cdot\text{ha}^{-1}$ N broadcast applied and incorporated into the soil. Beds were formed and fumigated with a mixture of 67% methylbromide and 33% chloropicrin (CCl_3NO_2) at 224 $\text{kg}\cdot\text{ha}^{-1}$ 4 weeks before planting. At the same time, black polyethylene mulch (1.5 m wide \times 0.04 mm thick) and drip-tape (61 cm emitter spacing) (Typhoon: Netafim, Valley Stream, N.Y.) were applied. The drip-tape was placed 4 cm deep and 10 cm from the center of the bed. Plots consisted of four 4.6 m long rows spaced 1.5 m apart with the outer two rows serving as guard rows. Six-week-old greenhouse-grown 'Celebrity' transplants were mechanically set 46 cm apart in-row on 3 May 1994. Plants were staked and trained to the string weave system (Konsler and Gardner, 1990).

Lateral shoots, 5 to 10 cm long, were removed from the base of the plant up to, but not including, the shoot immediately below the first flower cluster. Recommended weed, disease, and insect management practices (North Carolina State Univ., 1993) were used throughout the course of the study.

Treatments were assigned to the experimental plots as a randomized complete block design with three treatments and five replications. The three treatments consisted of no B fertilization, a weekly foliar B application, and a weekly soil B application. Foliar B was applied at 0.56 $\text{kg}\cdot\text{ha}^{-1}$ B as N-Boron using a backpack sprayer. Weekly soil B was applied at 0.56 $\text{kg}\cdot\text{ha}^{-1}$ through a line of drip-tape separate from the irrigation drip-tape, placed directly under the polyethylene mulch and on top of the soil. The separate line could be attached or unattached to the irrigation drip-tape system when soil B treatments were applied. A polyvinyl chloride pipe injection manifold with a backflow prevention valve was constructed (Lancaster et al., 1998), connected to the soil B treatment drip system, and used to apply the soil B treatments. Application of the experimental treatments began at first anthesis and continued for 8 weeks for a total of 4.48 $\text{kg}\cdot\text{ha}^{-1}$ B. Leaflet samples were taken from the petiole of the fourth leaf from the growing tip to evaluate B effects on leaflet K and other nutrient changes from first anthesis through fruit development. Leaflets were sampled 7 d following the first B applications and weekly thereafter for 8 weeks. Percent fruit set was evaluated by tagging newly opened blossoms once a week and counting the number of tagged blossoms which set fruit 1 week later. Plant height was measured from mulch surface to the growing tip at time of last harvest. Fruit were harvested six times at the breaker stage (just showing pink at the blossom end), graded, and weighed weekly. Fruit were graded into U.S. Combination, U.S. no. 3, and culls (U.S. Dept. of Agriculture, 1961). Yields reported are marketable fruit (U.S. Combination and U.S. no. 3) or total yield (marketable plus culls). Fruit were culled for cracks, zippers, cat-facing, and other damage. All cracked fruit were weighed.

Forty randomly selected fruit per plot were placed on tables in a well ventilated laboratory at 22 °C and evaluated for shelf life. Fruit were placed on paper and arranged so they were not touching. Fruit were checked daily and removed at first sign of breakdown due to dehydration or disease and days to removal were recorded.

Another randomly selected group of fruit was used for nutrient analysis. Boron treatment surface residues were removed from this fruit using the method of Williams and Nelson (1992) described previously. Fruit were cut and separated into 600 g allotments per plot, then dried at 70 °C for 96 h, weighed for dry matter, ground, and analyzed for tissue nutrient content as described previously.

An additional group of randomly selected fruit was harvested from each plot at the breaker stage for crack-point testing. Forty fruit per plot were placed on paper, and arranged so they were not touching, on tables in a well-ventilated laboratory with day/night cycles of ≈ 12 h at 22 to 23 °C. The fruit were allowed to attain uniform ripeness of the light red stage and then subjected to crack point testing using an Instron Universal Tester (model TM; Instron Corp., Atlanta, Ga.). Pressure was exerted midway between the blossom and stem ends of the fruit with a 10.16 cm^2 plate moving at constant speed. The force needed to cause the skin to crack was recorded.

Following final harvest, two plants per plot were harvested and prepared for tissue analysis as described previously. Samples were analyzed for total N, P, K, B, Ca, Mg, and S as described

previously. An estimate of total nutrient uptake was calculated by multiplying the concentration of nutrient (mg nutrient per g plant tissue) by the total dry weight of the specific plant tissue or organ.

Data were subjected to analysis of variance and, where appropriate, to the F protected LSD mean separation test using SAS (SAS Institute, Cary, N.C.).

Results and Discussion

Hydroponic studies. Plants not treated with B had lower shoot and root dry weights than plants treated with a B application (Table 1). Stunted growth in B deficient conditions has been observed in tomato and several other crops (Gupta and Cutcliffe, 1985; Nelson et al., 1977). Shoot N, Mg, and S concentrations were not affected by B treatments (data not shown); however, plants treated with root and root+foliar applied B had higher shoot P, K, and Ca levels than plants not treated with B (Table 1). Boron applied to foliage and/or roots improved uptake of N, K, Ca, and B into shoots, roots, and fruit (Table 2). Boron concentration was lowest in shoots of plants receiving no B (Table 1). Potassium concentrations in tomato shoots responded positively to B supplied to the roots or as a foliar amendment, which agrees with the work of Cerda and Roorda van Eysinga (1981) on tomato and Schon and Blevins (1990) on soybean.

Roots from plants not treated with B had the lowest Ca and B concentration (Table 1) and were stunted with blackened tips. These are classic symptoms of B deficiency (Maynard and Hochmuth, 1997). Roots from plants receiving B had none of these symptoms. Lack of B deficiency symptoms and high tissue B concentration (Table 1) and uptake (Table 2) in roots from plants that received only foliar applied B suggests that B was

translocated from foliage to roots. Roots from the control plants, although clearly B deficient, still contained small amounts of B (Table 1). We analyzed seed from 'Celebrity' tomato and 20-d-old 'Celebrity' seedlings and found an average of 27 mg·kg⁻¹ B in seed and 10 mg·kg⁻¹ B in seedlings.

Historically, B has been considered to be a phloem immobile element (Oertli and Richardson, 1970). One of the exceptions appears to be some plants that translocate sugar alcohols such as mannitol and sorbitol. Sugar alcohols, however, are not present in tomatoes (Brown et al., 1999). The apparent phloem transport of B that was observed in this study has been reported by other researchers working with tomatoes (Cerda and Roorda van Eysinga, 1981) as well as a variety of other crops: in B deficient broccoli (*Brassica oleracea* L.) (Benson et al., 1961; Shelp, 1987) and grape (*Vitis vinifera*) (Scott and Schrader, 1947), or following foliar applications of B on apple [*Malus ×sylvestris* (L.) Mill. var. *domestica* (Borkh.) Mansf.], pear (*Pyrus communis* L.), prune (*Prunus domestica* L.), and cherry (*P. avium* L.), (Picchioni et al., 1995). In a study of the mobility of foliar-applied labelled ¹⁰B in peach (*Prunus persica*), Shu, et al. (1993) showed that B is swiftly (within 72 h of foliar application) re-translocated in the phloem in priority to sinks throughout the plant, regardless of the distance from the source application. These workers conclude that the commonly held view of B as a phloem immobile element may be partly due to the difficulty of using conventional non-tracer methods to observe the movement of the small amounts of B typically involved in plant growth and development.

Field study. PLANT GROWTH AND YIELD. Tomato response to B application under field culture supported the results observed in the hydroponic experiments. Tomatoes receiving soil or foliar-applied B had better growth and were more productive compared to plants that did not receive B (Table 3). Fruit set occurred more

Table 1. Shoot and root tissue nutrient concentration and dry matter of 56-d-old 'Celebrity' tomato grown in hydroponic culture and treated with foliar, root, foliar+root, or no applied boron.

Boron treatment	Nutrient concn ^z				Dry matter (g)
	P	K	Ca	B	
	mg·g ⁻¹				
Shoot					
None	7.0 b ^y	47.4 c	16.4 c	16.6 c	2.35 b
Foliar applied	6.7 c	53.0 b	17.9 b	95.6 a	3.11 a
Root applied	7.2 a	62.1 a	18.8 a	73.7 b	3.35 a
Root+foliar	7.2 a	62.8 a	18.9 a	94.0 a	3.16 a
Root					
None	8.3a	46.1 a	6.3 b	20.4 b	0.64 b
Foliar applied	8.5 a	45.4 a	8.1 a	68.0 a	1.06 a
Root applied	8.8 a	45.4 a	8.0 a	71.7 a	1.16a
Root+foliar	8.5 a	45.6 a	8.0 a	69.4 a	1.05 a

^zReported tissue concentration and dry matter means are the combined treatment means of all experiments.

^yMean separation within columns by F protected LSD at $P \geq 0.05$.

Table 2. Nutrient uptake response to foliar, root, or no applied B in tomatoes under hydroponic culture.

Boron treatment ^z	Total uptake (shoot + root)				Shoot content				Fruit content			
	N	K	Ca	B	N	K	Ca	B	N	K	Ca	B
	g/plant				g/plant				g/plant			
	mg/plant				mg/plant				mg/plant			
None	0.17 b ^y	0.11 b	0.030 b	0.03 b	0.14 b	0.09 b	0.030 b	0.02 c	0.03 b	0.02 b	0.003 b	0.006 b
Foliar applied	0.30 a	0.23 a	0.070 a	0.40 a	0.23 a	0.18 a	0.060 a	0.29 a	0.07 a	0.05 a	0.010 a	0.100 a
Soil applied	0.29 a	0.25 a	0.070 a	0.36 a	0.22 a	0.20 a	0.060 a	0.26 b	0.07 a	0.05 a	0.008 a	0.090 a
Soil+foliar	0.29 a	0.25 a	0.070 a	0.40 a	0.23 a	0.20 a	0.060 a	0.30 a	0.06 a	0.05 a	0.008 a	0.100 a

^zReported nutrient uptake means are the combined treatment means of all experiments.

^yMean separation within columns by F protected LSD at $P \geq 0.05$.

Table 3. Influence of foliar and soil applied boron on field-grown tomato quality and yield parameters.

Boron treatment	Plant growth and fruit yield								Fruit quality			
	Plant dry wt (g)	Plant ht (cm)	Fruit set (%)	Total yield (Mg·ha ⁻¹)	Marketable yield (%)	Fruit yield (Mg·ha ⁻¹)			Shelf life (d)	Crack point (N)	Concentric crack (Mg·ha ⁻¹)	Radial crack
						Jumbo	Extra large	Large				
None	405 b	122 b	56.1 b	37.0 b	82.5 b	2.66 b	4.75 b	10.8 b	8.0 b	47.0 b	1.29 a	0.43 a
Foliar	457 a ^z	135a	80.4 a	49.6 a	87.5 a	4.69 a	8.96 a	14.4 a	13.0 a	53.2 a	0.78 b	0.15 b
Soil	454 a	137 a	73.2 a	48.1 a	87.7 a	4.46 a	8.67 a	14.0 a	14.2 a	55.4 a	0.79 b	0.26 ab

^zMean separation within columns by F protected LSD at $P \geq 0.05$.

Table 4. Shoot and fruit tissue nutrient concentration of fresh-market field-grown tomato treated with foliar and root applied boron.

Boron treatment	Nutrient concn ^z		
	K (g·kg ⁻¹)	Ca (g·kg ⁻¹)	B (mg·kg ⁻¹)
Shoot			
None	29.8 b	22.9 b	29.7 b
Foliar applied	48.7 a	24.8 ab	80.3 a
Root applied	54.8 a	25.1 a	78.2 a
Fruit			
None	35.2 b	2.4 a	17.1 b
Foliar applied	46.9 a	2.6 a	27.3 a
Root applied	44.0 a	2.6 a	28.8 a

^zMean separation within columns by F protected LSD at $P \geq 0.05$.

than 70% of the time on plants receiving foliar or soil applied B compared to only 56% of the time on plants that did not receive B (Table 3). Plants receiving foliar or soil B had higher total and marketable yields than plants receiving no B (Table 3).

These results agree with other studies in which soil applied B (Gulati et al., 1980) or foliar applied B (Gascho, 1993; Oplinger et al., 1993; Schon and Blevins, 1990; Weaver et al., 1985) improved yields in tomato, soybean, and snap bean (*Phaseolus vulgaris* L. var. *vulgaris*). De Magalhaes et al. (1981) reported increased tomato fruit yields and quality with soil applied boron but had no response to foliar applied boron. Oplinger et al., (1993) observed that B applied to soybean foliage at initial flowering increased yields by 3% and Gascho (1993) reported yield increases when B and N were applied to soybean foliage during reproductive development. Yields of jumbo, extra large, and large fruit were greater when plants were treated with foliar or soil applied B than if plants received no B (Table 3). Yields of medium and small fruit were not affected by B (data not shown).

FRUIT QUALITY. Foliar and soil applied B increased shelf life and fruit crack point compared to nontreated plants (Table 3). In this study, plants treated with soil applied B had a higher concentration of Ca than plants not treated with B, but fruit Ca concentrations were not significantly different (Table 4). Similar results were obtained in a controlled environment study (Sperry, 1995).

Concentric and radial fruit crack are two common types of cracks which occur on tomatoes (Peet, 1992; Sperry, 1995). Plants treated with foliar B had less fruit with concentric and radial

cracks than plants not treated with B (Table 3). These results suggest that B may be important in reducing the incidence of fruit cracking. Dixon et al. (1973) reported that cracking in apple was entirely eliminated by sprays containing B. This may be due to the effects of B on membranes and cell walls. Many studies have shown that B helps maintain membrane stability (Ginzburg, 1961; Pilbeam and Kirkby, 1983; Yamouchi et al., 1986). Yamouchi et al. (1986) reported that B deficiency in tomato actually induced a reduction in the amount of Ca associated with the pectin fraction of tomato leaf cell walls. They found 67% of the total B in the cell wall fraction of tomato leaf tissues and suggested that B may function in cell wall metabolism by maintaining the Ca-pectin association.

TISSUE NUTRIENT CONTENT. As in the hydroponic study, K concentration (Table 4) and uptake (Table 5) were highest in shoot tissues when plants were treated with foliar or soil B. Calcium and B concentration (Table 4) and uptake (Table 5) were lowest in plant tissues when plants were not treated with B, while Ca was highest in plants treated with soil B. This agrees with studies by Hill and Grant (1935), and Minarik and Shive (1939) who demonstrated that adding B to the growing medium increased the amount of Ca in plants. It is interesting that although total plant uptake of N, K, and Ca increased with B application (Table 5), the concentration of N did not (data not shown) indicating that N uptake keeps pace with growth while increased K and Ca uptake exceeded the increased growth resulting from B applications. Shoot N, P, Mg, and S concentrations were not altered by B treatment (data not shown).

Widders and Lorenz (1982) demonstrated that redistribution of K from vegetative tissues contributed up to 12% of the total K content of tomato fruit with subsequent foliar K levels decreasing during fruiting by 20% to 40%. We wanted to observe whether soil or foliar B amendments would aid in maintenance of foliar K concentrations during fruit development. There was a significant B × week interaction (Fig. 1). As fruit development progressed, leaflet K levels declined from >4% to <2% during weeks 3 through 8 in plants not treated with B. Potassium levels in plants treated with soil or foliar B declined from ≈4.5% at week 2 to just over 3% at week 6 and maintained these levels through week 8. Based on these results, applied B appears to be important in maintaining high leaflet K concentrations in field grown tomato, especially after 5 to 6 weeks of fruit development. Similar results were found in a 2-year field study by Sperry (1995). No significant

Table 5. Total nutrient uptake response to foliar or root applied B in field-grown tomatoes.

Boron treatment	Total uptake (shoot + root) (kg·ha ⁻¹)				Shoot uptake (kg·ha ⁻¹)				Root uptake (kg·ha ⁻¹)			
	N	K	Ca	B	N	K	Ca	B	N	K	Ca	B
None	397 b ^z	233 b	137 b	0.22 b	329 b	174 b	133 b	0.17 c	67 b	60 b	4.0 b	0.05 b
Foliar applied	475 a	427a	169 a	0.71 a	386 a	319 a	163 a	0.53 a	89 a	108 a	6.0 a	0.18 a
Soil applied	466 a	456 a	169 a	0.68 a	382 a	358 a	163 a	0.51 b	84 a	98 a	6.0 a	0.17 a

^zMean separation within columns by F protected LSD at $P \geq 0.05$.

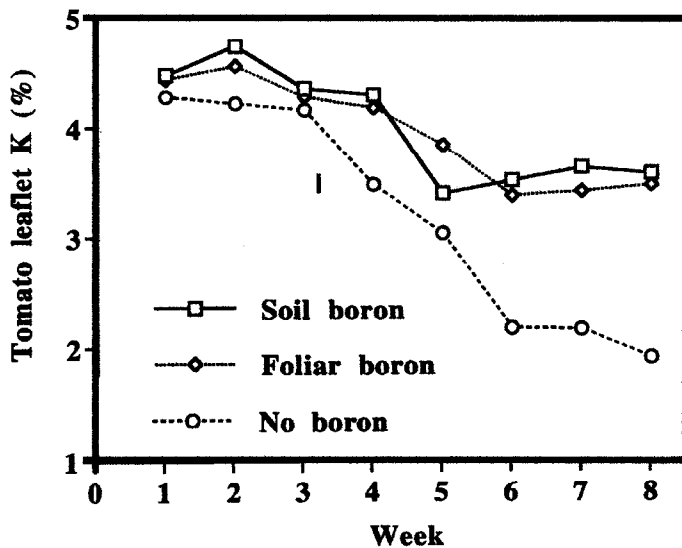


Fig. 1. Influences of foliar or soil applied B and weeks on tomato leaflet K content from field grown tomatoes. Vertical line represents LSD at $P < 0.05$.

changes occurred in leaflet N, P, Ca, Mg, S, or B levels during fruit development (data not shown).

Potassium concentration was greater in fruit from plants receiving applied B than in fruit from plants not treated with B (Table 4). This suggests that B is important in the maintenance of K levels in plant tissues including fruit and that B was transported from both roots and leaves to the developing fruit. It was shown by Sperry (1995) that foliar B sprays did not penetrate mature green tomato fruit skin. Similarly, Campbell et al. (1975) demonstrated that B moves from leaves to developing peanut (*Arachis hypogaea* L.) fruit and burrs of subterranean clover (*Trifolium subterraneum* L.). Picchioni et al. (1995) and Hanson et al. (1985) observed that B moved out of leaves via phloem in apple, pear, plum, prune, and cherry. Boron did not influence fruit N, P, Ca, Mg, or S levels (data not shown).

Conclusion

These studies illustrate the importance of proper B nutrition to the improved production of fresh-market tomatoes. Regardless of application method, addition of B increased tomato growth; uptake of N, K, Ca, and B; and plant tissue concentrations of K, Ca, and B. In field culture, foliar and/or root applied B similarly increased fresh-market tomato plant and root dry weight, plant tissue concentrations and plant uptake of N, Ca, K and B, and improved fruit set, total yields, marketable yields, fruit shelf life, and fruit firmness. The similar growth and yield responses of tomato to foliar and root B application suggests that B is translocated in the phloem in tomatoes. Fruit from plants receiving foliar or root applied B contained more B and K than fruit from plants not receiving B, indicating that B was translocated from leaves to fruit and is an important factor in the management of K nutrition in tomato.

It should be noted that in the field study over $4 \text{ kg} \cdot \text{ha}^{-1}$ of B was applied per season. In the southeastern United States, B usually leaches readily from the plant root zone and B levels do not accumulate in the soil. In some soils and environments in other regions, however, high rates of B applied in one season to a tomato crop may leave enough residual B in the soil to cause B toxicity if a B sensitive crop is planted in that field the following year.

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