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Effect of high boron application on boron content and growth of melons

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Abstract

Management options for reducing drainage water volumes on the west side of the San Joaquin Valley of California, such as reuse of saline drainage water and water table control, have the potential to adversely impact crop yields due to a build up in soil solution boron concentration. An earlier experiment had shown that extrapolation of B soil tests to field conditions provided poor predictability of B content of melons despite statistically significant relationships. Consequently, three tests for extractable soil B were evaluated for their ability to predict conditions of potential B toxicity in melons grown under controlled conditions. Melons were grown for 95 days in two consecutive years in containers of Lillis soil (very-fine, smectitic, thermic Halic Haploxerert) that had been pretreated with solutions containing B concentrations as great as 5.3 mmol L^{-1}. Extractable soil B was determined using ammonium acetate, DTPA-sorbitol, and a 1:1 aqueous soil extract at the beginning and end of the experiment. The B treatments caused various deleterious effects on melon growth and development. Fresh and dry plant matter decreased significantly with increasing B concentrations, while B concentration of plant leaves, stems, and fruits increased significantly with increasing B. The number of days to first flowering was significantly delayed from 35 days at B treatments $<$ 2 mmol L^{-1} to 51 days at B treatments $>$ 3 mmol L^{-1}. Fruit set was completely inhibited at the highest B treatment of 5.3 mmol L^{-1}. Plant analysis revealed a highly significant relationship between soil extract B obtained with all three extractants and leaf, stem, and fruit B content. Correlation coefficients for plant stems and fruits were much higher than for plant leaves. Correlation coefficients for all soil tests were almost equivalent, although the highest values were obtained for the DTPA-sorbitol extract indicating the greatest predictive capability. The soil tests were well able to predict B damage to melons in a container experiment.

Introduction

Boron is a nutrient element required by plants in trace amounts. The concentration range that produces neither deficiency nor toxicity symptoms in plants is very narrow. Crop plants can experience both deficiency and toxicity of B in a single growing season (Reisenauer et al., 1973). In humid regions, excessive leaching of B can result from rainfall, requiring B fertilization to avoid deficiency symptoms. In arid regions, on the other hand, toxicity symptoms often occur because of additions of B via irrigation water and lack of drainage (Nable et al., 1997).

Boron deficiency in crop plants is widespread throughout the world. For this reason, a variety of soil tests for plant-available B have been developed to diagnose B deficiency conditions. The most common of these has been the hot-water-soluble test developed by Berger and Truog (1940). A calcium chloride-mannitol extract was recommended as the best extractant for wheat plants on 18 Australian soils ranging in B concentration from potentially deficient to potentially toxic (Cartwright et al., 1983). An ammonium acetate extract was considered appropriate for diagnosing B deficiency of alfalfa (Gupta and Stewart, 1975). A DTPA-sorbitol extract is currently recommended by the North American Proficiency Testing Program for

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estimating the potential soil bioavailability of Zn, Cu, Mn, and Fe, in addition to B (Miller et al., 2000).

Tests developed to predict B deficient soils have not generally been evaluated for their ability to predict soil conditions conducive to B toxicity effects in plants. Although the B concentration of the soil saturation extract has been used as an indicator of toxic soil B levels, soil analysis is considered to provide little more than a general risk assessment of B toxicity (Nable et al., 1997). None of the hot-water-soluble, saturation extract, ammonium bicarbonate-DTPA, and calcium chloride-mannitol extractable B procedures adequately assessed B toxicity to alfalfa in four Colorado soils (Gestring and Soltanpour, 1987). Aqueous and DTPA extracts may be appropriate for evaluating potential B toxicity in potting media containing composted waste material (Handreck, 1990). In the toxicity range, there was a linear relationship between relative dry matter yield of sunflower and soil solution B concentration obtained by centrifugation (Aitken and McCallum, 1988).

In a prior field study, we evaluated various soil extractions for their ability to predict B content of field-grown alfalfa (*Medicago sativa* L.), melons (*Cucumis sativus* L.), and cotton (*Gossypium hirsutum* L.) (Goldberg et al., 2002). Three extracts were evaluated in detail: (1) ammonium acetate; (2) DTPA-sorbitol; (3) 1:1 soil:water. Results of our study found statistically significant relationships between these three extracts and whole plant and leaf B concentration for melons and cotton but not for alfalfa. Correlation coefficients in this prior study were lower than those obtained previously in greenhouse evaluations of B soil tests, possibly because the field is a much less controlled environment where clay content, water content, and root distribution vary considerably. Although the melon leaves exhibited marginal chlorosis characteristic of B injury, leaf B concentrations in the field survey experiment did not reach levels generally considered to be toxic to melons (Eaton, 1944). This could be another reason for the scatter in the plant B concentration with soil B content in the prior study.

The objectives of the present study were: (1) to determine extractable soil B with various extractants: ammonium acetate, DTPA-sorbitol, and 1:1 soil:water; (2) to determine uptake of B into melon leaves, stems, and fruits from soil amended with various B levels in a container experiment; (3) to evaluate the ability of the soil B extractants to predict B content of melon leaves, stems, and fruits under conditions of potential B toxicity.

Table 1. Initial physical and chemical properties of Lillis clay

Property	Value	Observations
Organic carbon content (%)	0.80 ± 0.026	3
Inorganic carbon content (%)	0.23 ± 0.010	3
Aluminum oxide content (%)	0.0923 ± 0.0031	3
Iron oxide content (%)	1.187 ± 0.0097	3
Surface area ($m^2\ g^{-1}$)	177.64 ± 21.15	8
Clay content (%)	54.34	1
Silt content (%)	40.10	1
Sand content (%)	5.56	1

Materials and methods

Approximately 2000 kg of soil were collected from Section 4 of the Broadview Water District in the San Joaquin Valley of California on 15 May 2001. Soil samples were taken from the 0–25-cm depth using a shovel. The soil is a silty clay belonging to the Lillis soil series classified as a very-fine, smectitic, thermic Halic Haploxerert. The soil was homogenized and crushed to pass a 0.635-cm screen. Initial physical and chemical characteristics of the soil were determined (see Table 1). Organic and inorganic carbon were measured using a UIC Full Carbon System 150 with a C coulometer.[1] Inorganic carbon was determined using an acidification module and heating to 70 °C. Organic carbon was obtained by subtracting inorganic carbon from total carbon determined directly by furnace combustion at 950 °C. Free Fe and Al oxides were extracted using the method described by Coffin (1963). Iron and Al concentrations in these extracts were determined using inductively coupled plasma optical emission spectrometry (ICP-OES). A complete particle size distribution function for the soil was obtained using the basic hydrometer method (Gee and Bauder, 1986) to determine the silt and clay fractions from approximately 50 to 1.4 μm. The same sample was used for determining the sand fractions between 2 mm and 50 μm using a wet sieve method. The sediment and suspension were quantitatively transferred and collected after passing through a nest of 11 sieves (2, 1.4, 1, 0.7, 0.5, 0.355, 0.25, 0.18, 0.147, 0.105 mm and 90 μm), oven dried at 105 °C, and weighed.

[1] Trade names and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product listed by the U.S. Department of Agriculture.

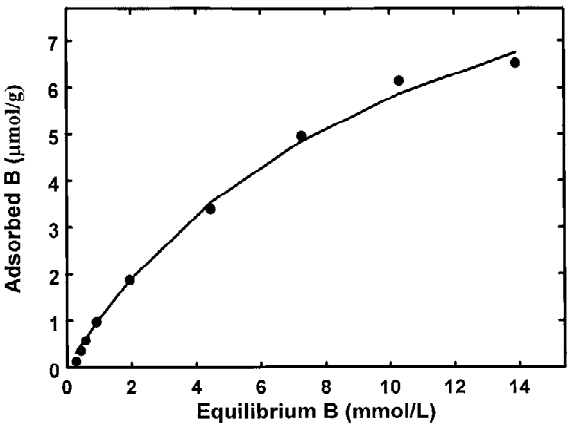

Figure 1. Boron adsorption on Lillis soil. Circles represent experimental data points. Solid line represents Langmuir adsorption isotherm equation fit: M = 11.75 μmol B g^{-1}, K = 0.0967 L mmol^{-1}, $R^2 = 0.996^{**}$.

A B adsorption isotherm (amount of B adsorbed as a function of equilibrium B concentration) was determined on the bulk soil collected for the experiment. Two hundred g of soil were mixed with 150 mL of solution containing 0, 0.0925, 0.185, 0.463, 0.925, 1.39, 2.31, 4.63, 9.25, 13.9, 18.5, or 23.1 mmol B L^{-1} in 420-mL plastic containers. The containers were covered with snaptight lids and equilibrated at room temperature (24.2 °C) for 22 h. The soil pastes were transferred to filter funnels fitted with no. 50 Whatman[1] filter paper. The filtrates were collected under vacuum and analyzed for B using ICP-OES. Boron adsorption was determined as the difference between initial B added (also analyzed by ICP-OES) and equilibrium B concentration. The Langmuir adsorption isotherm:

$$B_{\text{ads}} = \frac{K B_{\text{eq}} M}{1 + K B_{\text{eq}}},$$

where B_{ads} is the B adsorption, B_{eq} is the equilibrium B concentration, M is the maximum B adsorption, and K is a parameter, was fitted to the B adsorption data. An excellent fit was obtained as seen in Figure 1. In order to obtain an accurate determination of maximum B adsorption, it was necessary to include B additions that were higher than those commonly found in natural soils.

Using the adsorption isotherm, seven solution B concentrations were chosen to provide a maximum equilibrium B concentration of 2.31 mmol L^{-1}. This concentration had been found previously to result in a 50% reduction in dry weight of melons grown in sand culture (El-Sheikh et al., 1971). The soil was

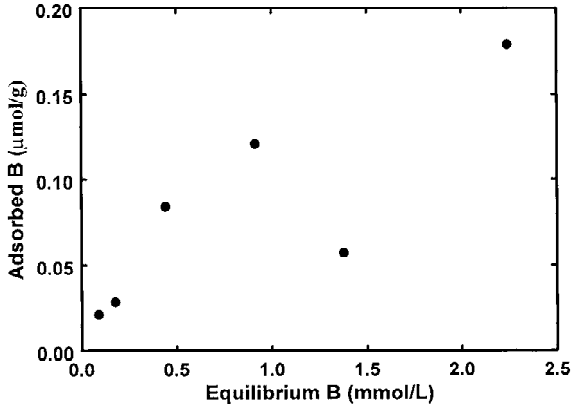

Figure 2. Boron adsorption on blasting sand.

subdivided into seven 0.191-m^3 cement mixing tubs. Each subsample was pretreated by mixing with 72 L of a solution containing 0, 0.463, 0.981, 1.61, 2.22, 3.33, or 5.27 mmol B L^{-1}. The soils were dried, crushed, and 24 kg were packed into 20-L containers (height 36 cm, diameter 28.5 cm) to a constant bulk density of 1.35 Mg m^{-3} above an 8-cm deep sand layer. The sand was blasting sand, feldspar #90 obtained from P.W. Gillibrand Co., Simi Valley, CA. An active drainage system using a porous ceramic solution sampler (constructed as described by Suarez, 1986) at 33.3 kPa suction was installed in the sand layer. The experiment consisted of four replicates of each of the seven treatments. The 28 containers were placed outdoors on pallets in a randomized block design.

A B adsorption isotherm was determined on the sand using 5 g of sand mixed with 25 mL of solution containing 0, 0.0925, 0.463, 0.925, 1.39, 2.31, or 4.63 mmol B L^{-1} in 50-mL centrifuge tubes. The suspensions were shaken on a reciprocating shaker for 22 h, then centrifuged. The decantates were analyzed for pH, filtered through a 0.45-μm membrane filter, and analyzed for B using ICP-OES. Scatter is observed in the B adsorption data due to the very low amount adsorbed by the sand material (see Figure 2). A particle size analysis of the sand found that 95% of the particles were sand size (0.05–2 mm) and 80% were in the size range of 0.1–0.2 mm.

The irrigation system was composed of one 0.009 m^3 h^{-1} drip emitter in each bucket. A 2-L plastic bottle was added to the system at a similar elevation to simulate an experimental unit collecting the volume of a representative drip emitter. The bottle was weighed and emptied periodically to estimate the amount of irrigation water being delivered via the

automated drip system. Timing of irrigation was set to slightly exceed evapotranspiration requirements. Tensiometers were placed 20 cm deep into the soil (22 cm below the top of the container) in several treatments to monitor soil matric potential and to help evaluate evaporative demand and changes in water storage.

On 12 July 2001 four seeds of muskmelon (*Cucumis melo* L.) variety *Top Mark* (Heirloom Seeds, Elizabeth, PA) were planted in each container. Fertilizer was applied pre-plant at the rate of 67.2 kg N ha^{-1}, 84 kg P_2O_5 ha^{-1}, and 84 kg K_2O ha^{-1}. A side-dressing of KNO_3 was applied at 50.4 kg N ha^{-1} during rapid vine growth.

To guard against poor germination, additional melon seeds were planted in vermiculite in the greenhouse on 18 July 2001 and irrigated with tap water. On 31 July and 1 August 2001 melon seedlings were transplanted from the greenhouse into the outdoor containers to provide two plants per pot. On 31 July 2001 benylate fungicide[1] (Benlate TM, DuPont, Wilmington, DE) and deltamethrin[1] (Deltaguard TM, AgrEvo Environmental Health, Inc., Montvale, NJ) were applied at manufacturer recommended rates to control powdery mildew and ant infestations, respectively. Lady beetles were also utilized to control aphids as a bio-control when appropriate. Soapy suds were also used to control whitefly and aphids on 20 August 2001. On 21 August 2001 Diazinon 25[1] (TM, Proguard, Inc., Suisan, CA) was applied at manufacturer recommended rates for whitefly and black aphid control. Average outdoor conditions were: 14 h day length, 20 °C minimum temperature, and 40 °C maximum temperature.

An estimate of evaporative demand was determined from the water evaporated from four buckets. Black 20-L buckets, similar to those used for the plants, were filled with water to marked 20-L volumes and periodically replenished to this mark with a measured amount of water. The buckets were located on the periphery of the experiment. Total evaporation from the black buckets was 116 ± 0.1 cm over 35 measurements. Local evaporative demand estimated from weather station number 44 (California Irrigation Management Information System, CIMIS, Riverside, CA) was 51.5 cm total for the growing period. Applied water estimated from the bottle was 100 cm accounting for additional water applied as drainage water to maintain conservation of B mass. Drainage amount was variable as a result of treatment effects on plant growth and variation in hydraulic properties from pot to pot and ranged from 0.55 to 12.3 cm. Drainage amount tended to be higher for high B treatments and lowest for low B treatments. The increase in drainage was likely due to a decrease in transpiration resulting from a reduction in biomass and leaf area due to high B treatment. Applied amounts of water exceeded local estimates of reference evapotranspiration and were similar to the evaporative demand measured with the buckets reflecting the hotter microclimate of the pot experiment. Based on tensiometer readings taken at least every third day, the melons never experienced matric stress with no tensiometers exceeding −0.04 MPa tension immediately before each irrigation event. Care was taken to avoid overwatering in those units where plant growth and water use were dramatically reduced by B treatment.

On 4 September 2001 a preliminary plant sampling was carried out by removing the first three to six leaves of each plant from the oldest to the youngest. In this sampling, leaves from all four replicates of each treatment were combined. This sampling occurred prior to fruit set as recommended for determination of nutrient status of melons (Jones and Steyn, 1973). A final plant sampling was carried out on 15 October 2001. Leaves were separated from stems and fruits. Each replicate of each treatment was analyzed individually. Leaves, stems, and fruits were also analyzed separately. Plant samples were washed in deionized water, oven dried at 70 °C for 72 h for plants and 2 weeks for fruit, and ground to pass a 40-mesh screen. Ground plant samples were ashed at 550 °C for 4 h and dissolved in 2.5 mL of 7% nitric acid in non-borosilicate glassware (Hatcher and Wilcox, 1950). The solution volume was brought to 25 mL and analyzed for B concentration using ICP-OES.

Soil B content of each treatment at the start of the experiment was determined with various extractions. These included aqueous extracts of 1:1 soil:distilled water and saturation extracts. The advantage of saturation extracts is the small dilution of the soil solution; while 1:1 extracts have the advantage of constant soil:water ratio. We also extracted the soils with 1 *M* ammonium acetate (Cartwright et al., 1983) and DTPA-sorbitol: an extractant containing 0.005 *M* diethylenetriaminepentaacetic acid, 0.01 *M* $CaCl_2$, 0.1 *M* triethanolamine (TEA) adjusted to pH 7.3, and 0.2 *M* sorbitol (Miller et al., 2000).

Soils were sampled after harvest using a 3.81-cm diameter sampling tube. Subsamples were taken at the 0–13- and 13–26-cm depths. The sand layer was also sampled. Extractable soil B was determined in ammonium acetate, DTPA-sorbitol, and 1:1 extracts

using ICP-OES. Extractable B from the sand fraction was determined only in the 1:1 extract.

A second melon crop was planted in the same soil containers in early May 2002, grown in the same manner as in 2001, and harvested on 11 September 2002. Leaf, stem, and fruits were sampled at harvest. Plant samples were treated and analyzed with the same procedures as in 2001. Soils were sampled at harvest at the 0–13- and 13–26-cm depths and the sand layer as in 2001. Boron was determined in 1:1 soil:distilled water extracts using ICP-OES.

Pearson correlation coefficients and simple linear regression models were used to determine the statistical significance of the various soil/plant boron concentrations (Myers, 1986). A Langmuir equation was also used to describe the leaf B versus soil extract B concentration relationships.

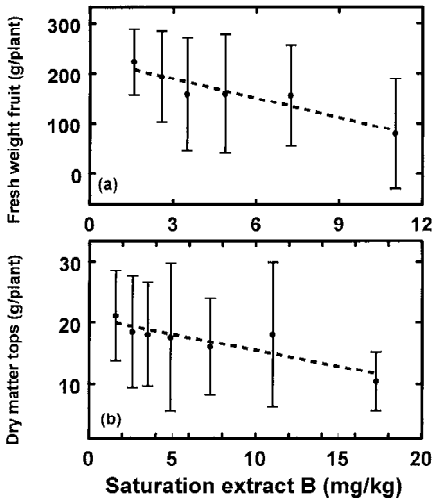

Figure 3. Plant yield of melons as a function of soil saturation B content: (a) fresh weight of fruit; (b) dry matter of tops. Error bars represent one standard deviation from the mean of eight plants per treatment.

Results and discussion

Transpiration efficiency of the melons was estimated by dividing the total dry weight of all biomass (g dry weight of leaves, stems, and fruit) by the total transpired water (mL of cumulative estimated transpiration). We assumed that the evaporation rate was 10% of the cumulative evapotranspiration observed in the study, a value consistent with that expected for surface evaporation corrections (Allen et al., 1998). Transpiration efficiencies were $\leq$0.8 mmol CO_2 mol H_2O^{-1} for all treatments in both trials and agreed reasonably well (assuming 44% carbon) with reported values for melon (0.5 mmol CO_2 mol H_2O^{-1}, Leskovar et al., 2001). The average transpiration efficiency for the first trial ranged from 0.37 $\pm$ 0.02 to 0.44 $\pm$ 0.08 mmol CO_2 mol H_2O^{-1} (mean $\pm$ SE) and was unaffected by increasing B concentrations. For the second trial where applied water was measured exactly not estimated, assuming similar soil surface evaporation, transpiration efficiencies ranged from 0.58 $\pm$ 0.09 to 0.78 $\pm$ 0.11 mmol CO_2 mol H_2O^{-1} and were also unaffected by toxic levels of soil boron.

Initial soil extractable B concentration correlated well with predicted melon yield (e.g., Figure 3a, $r = 0.94^{**}$ for saturation extract B). This represents an evaluation of the predictive capability of this particular soil test. Similar behavior had been observed for melon tops as a function of B treatment in sand culture (El-Sheikh et al., 1971). Dry matter of plant tops and fruit at harvest exhibited a generally decreasing trend with increasing amount of extractable B (see Table 2 and Figure 3b). This effect was more pronounced for the fruit dry matter ($r = 0.98^{**}$) than for plant tops ($r = 0.88^{**}$). Similar effects were observed in the second year (data not shown).

Boron concentration of various plant parts (leaves, stems, and fruits) increased with increasing extractable B. The highest correlation was found for fruit dry weight which was inversely related to fruit B concentration ($r = 0.98^{**}$) (see Figure 4). A similar trend was observed the second year (data not shown) and had previously been observed for melons in sand culture (El-Sheikh et al., 1971). Leaf B concentrations for all treatments exceeded the concentration of 500 mg kg^{-1} found to cause moderate to severe necrosis of melon leaves in a prior greenhouse study (Bohn and Davis, 1968). Indeed marginal chlorosis was found on all B treatments. Melons are classified as moderately B tolerant (Maas and Grattan, 1999).

Additional deleterious effects of B on melon growth and development were found. The number of days to first flowering was significantly delayed at the two highest B treatments (see Figure 5). Additionally, fruit set was completely inhibited at the highest B treatment. Since fruit is the marketable plant part of melons, these effects would be a much better indicator of B damage than reductions in dry matter production. Similar effects of high B on flowering and fruit set were observed in pear trees (Crandall et al., 1981). It is likely that these deleterious effects may also decrease yield of other crops.

Table 2. Dry matter yield and boron concentrations of melons at harvest

Treatment B (mmol L^{-1})	Leaf dry weight (g $plant^{-1}$)	Stem dry weight (g $plant^{-1}$)	Fruit dry weight (g $plant^{-1}$)	Whole plant dry weight (g $plant^{-1}$)	Leaf B (mgkg^{-1})	Stem B (mgkg^{-1})	Fruit B (mgkg^{-1})
0	7.41 ± 2.23	2.64 ± 0.68	11.1 ± 3.29	19.8 ± 7.30	817 ± 137	69.9 ± 20.5	78.5 ± 10.5
0.463	5.87 ± 2.83	2.10 ± 0.95	10.5 ± 5.54	18.5 ± 9.09	1240 ± 333	93.8 ± 24.7	101 ± 20.5
0.981	6.93 ± 3.01	2.55 ± 1.20	8.62 ± 4.54	18.1 ± 8.45	1520 ± 230	102 ± 12.9	149 ± 32.0
1.61	6.32 ± 3.60	2.30 ± 1.38	9.01 ± 7.17	17.6 ± 12.1	2000 ± 393	142 ± 38.3	194 ± 42.1
2.22	6.39 ± 2.86	2.54 ± 1.14	7.09 ± 4.22	16.0 ± 7.88	2450 ± 458	157 ± 19.7	244 ± 35.2
3.33	8.69 ± 6.14	6.18 ± 4.61	3.18 ± 4.42	18.1 ± 11.8	2950 ± 439	226 ± 44.0	381 ± 118
5.27	6.21 ± 2.77	4.21 ± 2.06	0[†]	10.4 ± 4.77	2880 ± 267	279 ± 61.9	0[†]

[†]No fruit set.

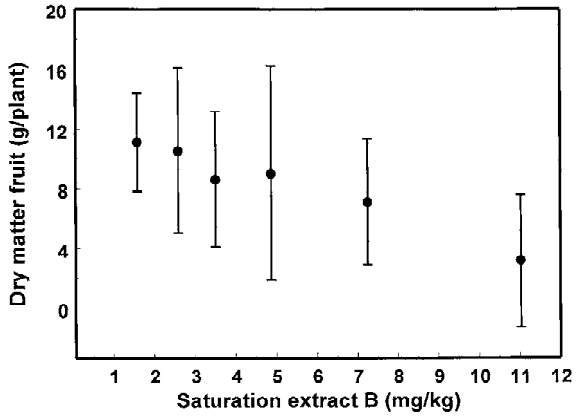

Figure 4. Melon fruit dry matter as a function of fruit B content. Error bars represent one standard deviation from the mean of eight plants per treatment.

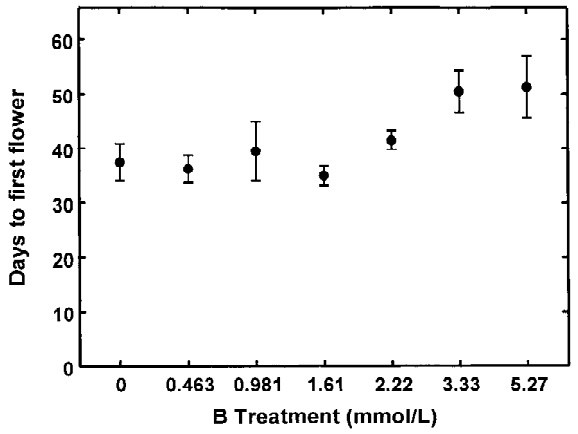

Figure 5. Delay in flowering of melons as a function of B treatment. Error bars represent one standard deviation from the mean of four replicates per treatment.

The amounts of B extracted at the start of the experiment with each of the three extractants were very highly correlated. Correlation coefficients for all combinations were > 0.99. Based on these results all extractants were judged suitable for evaluation of plant B uptake and toxicity. The much lower, albeit statistically significant, correlation between extractable B and plant B observed in an earlier field study (Goldberg et al., 2002) is attributed to sampling uncertainties and spatial and temporal fluctuations in soil B in the field.

Extractable B at the end of the experiment was determined at two depths: 0–13 cm and 13–26 cm. The statistical analysis for the end of the experiment was carried out on measurements for each individual pot. While the correlations between depths were highly statistically significant they were lower than those between the different types of extracts. Correlation coefficients are provided in Table 3.

Plant leaves were sampled prior to fruit set as recommended for plant testing of melons (Jones and Steyn, 1973). In order to minimize the effect of plant sampling on plant growth, we analyzed samples of the first three to six oldest leaves composited from all four replicates of each treatment. Leaf B content was highly linearly correlated with extract B content for the lower six B concentrations (see Figure 6). For the highest B treatment, the incremental increase in leaf B concentration was much less. In order to accurately describe leaf B content as a function of soil extract B for all treatments, a nonlinear function was required. We chose the Langmuir equation also known as the Michaelis–Menten equation. Correlation coefficients for linear and nonlinear fits are highly statistically significant and are indicated in Table 4. As an example, Figure 6 indicates the relationship between B concen-

Table 3. Correlation coefficients (r) between soil B extractions by depth at the end of the experiment

	NH_4 acetate 0–13 cm	DTPA-sorbitol 0–13 cm	1:1 Water extract 0–13 cm	NH_4 acetate 13–26 cm	DTPA-sorbitol 13–26 cm	1:1 Water extract 13–26 cm	1:1 Water extract sand
NH_4 acetate 0–13 cm	1.000	0.902**	0.808**	0.761**			
DTPA-sorbitol 0–13 cm		1.000	0.886**		0.883**		
1:1 Water extract 0–13 cm			1.000			0.871**	0.915**
NH_4 acetate 13–26 cm				1.000	0.976**	0.906**	
DTPA-sorbitol 13–26 cm					1.000	0.929**	
1:1 Water extract 13–26 cm						1.000	0.862**
1:1 Water extract sand							1.000

**Significant at the 0.01 level.

Table 4. Leaf B concentration (mg/kg) at flowering as a function of soil extract B concentration (mg/kg)

Extract	Linear fit ($n = 6$)†			Langmuir fit ($n = 7$)		
	Intercept	Slope	Correlation coefficient (r)	Maximum adsorption (M)	K	Correlation coefficient (r)
NH_4 acetate	385	218	0.986**	4713	0.02341	0.978**
DTPA-sorbitol	−42.5	83.5	0.987**	10827	0.005682	0.957**
1:1 Water	404	179	0.985**	4766	0.08286	0.985**
Saturation	414	202	0.986**	4567	0.02341	0.985**

**Significant at the 0.01 level.
†To obtain an improved linear fit the highest data point was not considered.

tration in the 1:1 soil:water extract at the beginning of the experiment and leaf B content prior to fruit set. The ability of leaf B concentration prior to fruit set to predict melon fruit dry matter was highly significant ($r = 0.94^{**}$). A similar relationship also existed between leaf B concentration prior to fruit set and fruit fresh weight ($r = 0.92^{**}$, see Figure 7) indicating the ability of the recommended plant analysis to predict marketable yield of melons. The correlation between melon fruit yield was comparable in quality for leaf B content and soil extractable B content.

Correlations between leaf B, stem B, and fruit B content at harvest and soil extractable B were highly significant (see Table 5). Similar results were obtained for the second year (data not shown). Correlation coefficients were almost equivalent for the 0–13-cm depth, the 13–26-cm depth, and the 0–26-cm averaged depth. The highest correlation coefficients were obtained for the DTPA-sorbitol extraction indicating the greatest predictive capability. Correlation coefficients for the sand layer were lower than those for the soil depths. This result was not surprising given the lower B adsorption capacity of the sand.

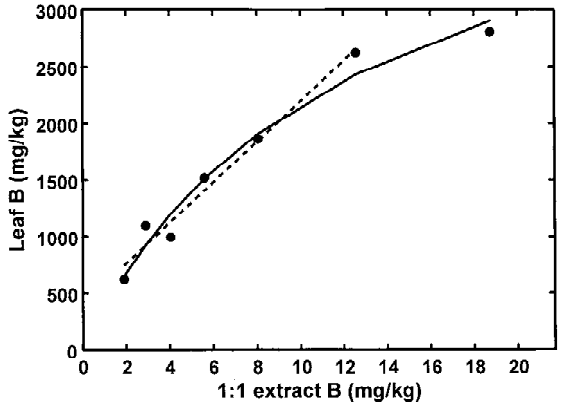

Figure 6. Leaf B content of melons prior to fruit set versus initial 1:1 soil:water extract B. Circles represent experimental data points. Dashed line represents linear fit: b = 404 mg B kg^{-1}, m = 179, R^2 = 0.970**. Solid line represents Langmuir–Michaelis–Menten equation fit: M = 4766 mg B kg^{-1}, K = 0.0967 kg mg^{-1}, R^2 = 0.971**.

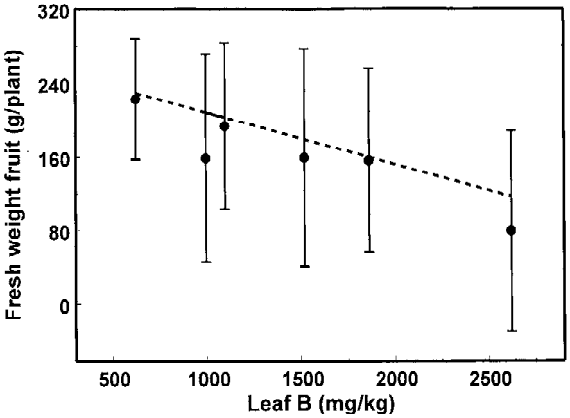

Figure 7. Yield of melon fruit as a function of leaf B content prior to fruit set. Error bars represent one standard deviation from the mean of eight plants per treatment.

When evaluating the ability of a soil test to predict plant B content, it may be more appropriate to determine the relationship between initial soil B and plant B at harvest. Correlations between different initial soil B extractions and B content of various plant parts at harvest are indicated in Table 6. Correlation coefficients for plant stems and fruits were much higher than for plant leaves. This was surprising since leaves are the plant parts recommended for plant testing analysis. It is encouraging that the correlation of soil extractable B was so high ($r > 0.99$**) with fruit B since this is the marketable plant part for melons. Figure 8 indicates the ability of one of the B soil tests to predict B content of melon leaves, stems, and fruits. We chose to present the DTPA-sorbitol results since this was the extract with the highest correlation coefficient for leaves and stems.

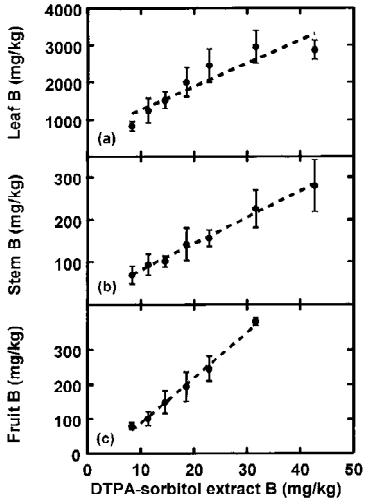

Figure 8. Ability of DTPA-sorbitol extractable B to predict B content of melons: (a) leaf B; (b) stem B; (c) fruit B. Error bars represent one standard deviation from the mean of eight plants per treatment.

Table 5. Correlation coefficients (r) between soil B extractions and plant B content at harvest

Extraction	Depth (cm)	Leaf B	Stem B	Fruit B
NH_4 acetate	0–13	0.760**	0.859**	0.793**
	13–26	0.859**	0.851**	0.808**
	0–26	0.848**	0.898**	0.881**
DTPA-sorbitol	0–13	0.844**	0.882**	0.813**
	13–26	0.903**	0.901**	0.913**
	0–26	0.900**	0.919**	0.909**
1:1 Water extract	0–13	0.760**	0.810**	0.755**
	13–26	0.917**	0.923**	0.915**
	0–26	0.885**	0.913**	0.896**
	sand	0.688**	0.820**	0.668*

*Significant at the 0.05 level.
**Significant at the 0.01 level.

Table 6. Correlation coefficients (r) between initial soil B extractions and plant B content at harvest

Extraction	Leaf B	Stem B	Fruit B
NH_4 acetate	0.884**	0.989**	0.998**
DTPA-sorbitol	0.921**	0.996**	0.996**
1:1 Water extract	0.892**	0.990**	0.998**
Saturation extract	0.882**	0.987**	0.996**

**Significant at the 0.01 level.

Ammonium acetate, DTPA-sorbitol, and 1:1 soil:water aqueous extracts are well able to predict B content of container grown melons. However, these extracts provided only poor predictability of B content of field grown melons despite statistically significant relationships (Goldberg et al., 2002). These results would draw into question the ability of one set of soil B extracts to represent spatial and temporal integration of soil solution B experienced by the plant under field conditions. Nonetheless, under uniform B conditions, soil tests of available B provide melon yield predictions under toxic conditions comparable in quality to those obtained from plant B analyses. For such conditions B soil tests are preferable because they can provide predictions of yield reductions at the beginning of the growing season. At the time of plant analysis yield reductions from B damage would already have occurred.

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