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# SOIL BORON EXTRACTIONS AS INDICATORS OF BORON CONTENT OF FIELD-GROWN CROPS

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**Determining the relationship between soil B and crop B content can help predict when crops will respond to B fertilizer and when B toxicity may be expected. Such a relationship can then be used to make fertilizer recommendations or to flag conditions of potential B toxicity. Soil samples were obtained from 65 sites located in the Broadview Water District in the San Joaquin Valley of California. A diverse set of extractants was evaluated including: hot water-soluble, 1:1 soil:distilled water and 1:2 soil:distilled water, ammonium acetate, calcium chloride-mannitol, and DTPA-sorbitol extracts. Soil extract B values were correlated significantly with various B reactive soil constituents, including aluminum and iron oxide, clay, organic matter, and calcium carbonate content. The 1:1 water extract B was highly significantly correlated (99% level) with other measures of extractable B used in the study. Extractants were compared on soil samples collected from six depths at 65 field sites in the San Joaquin Valley of California that were cropped to alfalfa, melons, and cotton. Boron concentrations of whole plants and composites of 10 leaves were determined. Plant sampling occurred at the time of soil sampling for the alfalfa. Cotton and melons were sampled at flowering and prior to fruit set, the recommended growth stages, respectively, for tissue sampling, and 6 weeks thereafter. Five weeks later the cotton was sampled a third time. Significant correlations (95% level) between extractable soil B and plant B were found for melons and cotton but not for alfalfa. Correlation coefficients for the ammonium acetate, DTPA-sorbitol, and 1:1 water extract were not statistically significantly different (95% level). Although significant correlations (95% level) were obtained, the equations provided relatively poor predictive capability. These results illustrate the difficulty of predicting plant B content based on soil B analyses from a single soil sampling. (Soil Science 2002;167:720–728)**

**Key words: Ammonium acetate extract, saturation extract, DTPA-sorbitol extract, alfalfa, cotton, melon.**

**BORON** (B) is a micronutrient element that plants require in trace amounts. The concentration range in which plants exhibit neither deficiency nor toxicity symptoms is narrower for B than for any other nutrient element. Plants can experience both B deficiency and B toxicity in a single growing season (Reisenauer et al., 1973). In humid regions, rainfall can cause excessive leaching of B, and fertilization is often required to avoid deficiency symptoms. In arid regions, on the other hand, lack of drainage and additions of B via irrigation water often produce symptoms of toxicity (Nable et al., 1997).

Soil tests for plant-available B have been developed principally to diagnose deficiency, not to determine toxicity. Historically, the most common method for estimating available soil B has

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been the hot water-soluble soil test of Berger and Truog (1940). The hot water-soluble procedure measures B capacity in that it extracts B from the organic, adsorbed, and soluble pools of the soil (Offiah and Axley, 1993). To evaluate soil conditions conducive to B toxicity effects in plants, the B concentration of the saturation extract is commonly measured. The B concentration of this test has been considered comparable to that of B in the soil solution (Bingham, 1973). This is rarely true, however, because the mass of B extracted in a saturation extract does not include the B adsorbed, the quantity of which depends on soil B and soil specific adsorption characteristics (Offiah and Axley, 1993).

A diverse set of soil extractions was evaluated for use in diagnosing a wide range of B concentrations, from potentially deficient to potentially toxic, in Australian soils (Cartwright et al., 1983). A calcium chloride-mannitol extract was recommended as the best soil B extractant for wheat plants grown in a pot experiment. Based on comparable effectiveness and reduced price, Vaughan and Howe (1994) recommended the use of another chelator, sorbitol, rather than mannitol in extracting B from a group of soils having diverse chemical and physical characteristics. Both extracts were highly correlated with hot water-soluble B. Although sorbitol-extractable B has not yet been correlated with plant B uptake, a DTPA-sorbitol method is being recommended by the North American Proficiency Testing Program for estimating the potential soil bioavailability of Zn, Cu, Mn, Fe, and B (Miller et al., 2000). For alfalfa grown in a container experiment, the ammonium acetate B extraction was considered comparable to the hot water-soluble B extraction in assessing conditions of B deficiency based on correlations with plant B content (Gupta and Stewart, 1975). All of these soil tests determine various proportions of the organic, adsorbed, and soluble B pools in soils.

In an effort to control drainage volumes from agricultural lands in the Western San Joaquin Valley of California, a study is underway to maximize crop use of shallow groundwater during the growing season (Soppe and Ayars, 2001; Soppe et al., 2001). Shallow groundwater usage by crops improves irrigation efficiency because a portion of the applied water lost to deep percolation is recovered and, therefore, both the depth of water application and the drainage volume are reduced. However, such a management system has the potential to impact crop yield adversely due to increased salinity and increased B concentrations in the groundwater relative to the irrigation water. We will investigate the growth of cotton and alfalfa plants on fields where the drains are plugged to maximize shallow groundwater use.

The objectives of our study were: (i) to determine extractable soil B on a field scale with various extractants and to determine plant B uptake for several field-grown crops; (ii) to evaluate the soil B extractants for their ability to predict plant B content under conditions of potential B toxicity; and (iii) to determine the relationship between measures of extractable soil B and various B-reactive soil constituents.

## MATERIALS AND METHODS

Soil samples were collected from 19 sites on Section 4 of the Broadview Water District in the San Joaquin Valley of California on August 10, 1999. These samples will be referred to as the preliminary experiment. Soil samples were subsequently collected from 65 sites on Sections 4 and 13 of the Broadview Water District on April 6, 2000. These samples will be referred to as the full-scale experiment. Ten sites were sampled on quarter section 4–1, which was cropped to alfalfa. Quarter sections 4–2, 13–3, and 13–4 were cropped to melons and contained 28 sampling sites. The remaining 27 sites were located on quarter sections 4–3, 4–4, 13–1 and 13–2, which were cropped to cotton. Sample sites were chosen for their total apparent salinity using an EM 38 (Geonics Ltd., Ontario, Canada)[a] survey of the fields. Soil samples were taken in 30-cm increments up to a depth of 180 cm using a truck-mounted Giddings soil sampling rig (Giddings Manufacturing, Ft. Collins, CO). Soil sampling was one core per site. The soils belong to the Lillis soil series and are classified as very-fine, smectitic, thermic Halic Haploxererts. The drains in the cotton and alfalfa fields were plugged during the growing season to maximize shallow groundwater use by the crops. The average B concentration of the irrigation water was less than 0.75 mg $B \cdot L^{-1}$.

Cotton leaves were sampled midway through the growing season on August 10, 1999, on 15 sites of Section 4. These samples constitute the preliminary experiment. Alfalfa samples were obtained at the time of soil sampling on April 6, 2000. We sampled shoots of one entire plant located immediately adjacent to the soil sampling site. Cotton was initially sampled on June 28, 2000, at flowering, which is the sampling time recommended for plant testing (Jones and Steyn, 1973). Additional cotton sampling was conducted

on August 9 and on September 14, 2000. Melon shoots were sampled prior to fruit set on June 28, 2000, as recommended by Jones and Steyn (1973). Melon shoots were also sampled on August 9, 2000, when the crop was mature. Plant samples for cotton and melons were obtained as shoots of one entire plant as well as composites of 10 leaves of diverse plants at all sampling times. Plant samples sampled in 2000 constitute the full-scale experiment.

Plants were washed in deionized water, oven-dried at 70 °C for 72 h, and ground to pass a 40-mesh screen. For B analysis, 500 mg of 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 by inductively coupled plasma (ICP) spectrometry on an IRIS Thermo Jarrell Ash Spectrometer (Franklin, MA). The detection limit for this instrument is 10 $\mu g\ B \cdot L^{-1}$. To avoid B contamination, plastic and B-free glassware was used throughout the experiments.

A diverse set of soil B extractants was used in the study. Hot water-soluble B was determined using a modification of the method of Berger and Truog (1940). We used a simplification of this method developed by Gupta (1967) that consists of boiling the soil slurry on a hot plate for 5 minutes. Aqueous extracts of 1:1 soil:distilled water and 1:2 soil:distilled water were utilized. Such extracts have the advantage of a constant soil:water ratio, unlike the saturation extract, and the disadvantage of greater dilution of the soil solution. Saturation extracts and 1:1.5 aqueous extracts were found to remove about the same amount of total B from potting media (Handreck, 1990). We also extracted the soils with 1 *M* ammonium acetate as well as with 0.01 *M* calcium chloride/0.05 *M* mannitol (Cartwright et al., 1983). 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 (DTPA-sorbitol) was also evaluated (Miller et al., 2000). Boron concentrations in the 1:1 extract were determined using a Lachat Quikchem AE Automated Ion Analyzer and the Azomethine-H method described by Bingham (1982). Boron concentrations in all remaining extracts were analyzed using ICP spectrometry. Standards were prepared with the appropriate extractant matrix.

Contents of iron and aluminum oxides, clay minerals, organic matter, and calcium carbonate were determined since these are all soil constituents that act as sinks regulating the soil solution B concentration (Goldberg, 1993). Free Fe and Al oxides were extracted using the method of Coffin (1963). Iron and Al concentrations in the extracts were determined using ICP spectrometry. Inorganic and organic carbon were determined using a UIC Full Carbon System 150 with a C coulometer. Total carbon was determined directly by furnace combustion at 950 °C; inorganic carbon was determined using an acidification module and heating. Organic carbon was determined by calculating the difference. Ranges in these soil properties are as follows: Al oxide content = 0.31–1.1 $g \cdot kg^{-1}$; Fe oxide content = 6.8–15.2 $g \cdot kg^{-1}$; organic carbon content = 0.7–16.6 $g \cdot kg^{-1}$; inorganic carbon content = 0.059–5.5 $g \cdot kg^{-1}$.

Clay content was obtained from a complete particle size distribution function for each soil sample. The basic hydrometer method outlined by Gee and Bauder (1986) was used 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 from the sedimentation cylinders 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). The sediment was washed through each sieve, and the sand fraction defined by each sieve was transferred, oven dried at 105 °C, and weighed.

Pearson correlation analyses were performed on the following variables: (i) between various soil B extractions; (ii) between soil B extractions and various soil properties; and (iii) between crop B levels and soil B extractions (on a crop by crop basis). An alpha = 0.05 level was used to indicate statistical significance, and correlation coefficients significant at the 0.01 level were judged to be highly statistically significant.

## RESULTS AND DISCUSSION

Soil samples from the preliminary sampling of August 1999 were treated with all six soil B extractants. There were highly significant positive correlations between the amounts of B extracted for each set of extractants (see Table 1). The relation between various measures of soil extractable B and increasing contents of various B reactive soil constituents is indicated in Table 2. Information is presented by depth inasmuch as an F-test on depth effects was found to be highly significant. Soil extract B values were significantly correlated with various B reactive soil constituents. The highest correlations found were for the hot

TABLE 1
Correlation coefficients (*r*) between soil B extractions

| | 1:1 water | $NH_4$ acetate | $CaCl_2$ mannitol | 1:2 water | DTPA-sorbitol | Hot water-soluble |
|---|---|---|---|---|---|---|
| 1:1 water | 1.00 | 0.78** | 0.88** | 0.89** | 0.88** | 0.73** |
| $NH_4$ acetate | | 1.00 | 0.82** | 0.76** | 0.81** | 0.88** |
| $CaCl_2$ mannitol | | | 1.00 | 0.91** | 0.96** | 0.89** |
| 1:2 water | | | | 1.00 | 0.93** | 0.88** |
| DTPA-sorbitol | | | | | 1.00 | 0.86** |
| Hot water-soluble | | | | | | 1.00 |

**Significant at the 0.01 level.

water-soluble and the DTPA-sorbitol extracts; these were significant for organic carbon content (30–60 cm) and Al oxide content (60–90 cm), and highly significant for Fe oxide content and clay content (60–90 cm). The soil property showing the strongest correlation with extractable soil B was clay content. It is reasonable that significant correlations are obtained with B reactive soil constituents since all B soil tests measure B adsorption capacity to some extent. A multivariable regression of soil B with Al oxide content, Fe oxide content, organic carbon content, and clay content was also found to be significant for the 0–30-cm depth for DTPA-sorbitol and hot water-soluble extracts and highly statistically significant for the 60–90-cm depth for all soil tests. Overall, the highest correlation coefficients with the most variables were found for the 60–90-cm depth.

For the preliminary experiment, the ammonium acetate extract was the only measure of extractable soil B that was significantly correlated with leaf B content, and only for the surface soil horizon (see Table 3). The degree to which soil B extracts and content of B reactive soil constituents relate to B content of cotton leaves midway through the growing season was evaluated and is presented in Table 3. There was a highly significant correlation between inorganic carbon content of the surface horizon and cotton leaf B concentration. A comparably significant correlation was obtained for Fe oxide content. Organic carbon content in both the 0–30-cm and the 30–60-cm horizons was significantly negatively correlated with leaf B concentration. For the middle horizon, a multivariable regression of Al oxide content, Fe oxide content, inorganic carbon content, and organic carbon content was found to be significant.

For the full-scale experiment on 65 sites, extractable B was measured using three extractants.

TABLE 2
Correlation coefficients (*r*) for soil extractable B and several soil constituents

| Depth (cm) | Soil content | $NH_4$ acetate | $CaCl_2$ mannitol | 1:1 water extract | 1:2 water | DTPA-sorbitol | Hot water-soluble |
|---|---|---|---|---|---|---|---|
| 0–30 | Al | ns | 0.59* | 0.55* | 0.53* | 0.60* | ns |
| | Fe | 0.63* | ns | ns | ns | ns | ns |
| | OC | ns | ns | ns | ns | ns | ns |
| | clay | ns | 0.66** | 0.52* | 0.62** | 0.80** | ns |
| | All variables | ns | ns | ns | ns | 0.81* | 0.87* |
| 30–60 | Al | 0.51* | ns | ns | ns | ns | ns |
| | Fe | ns | ns | ns | ns | ns | ns |
| | OC | 0.62* | ns | 0.60* | 0.59* | 0.66** | 0.55* |
| | clay | 0.72** | ns | 0.57* | 0.58* | 0.69** | ns |
| | All variables | ns | ns | ns | ns | ns | ns |
| 60–90 | Al | 0.59* | ns | 0.63* | 0.58* | 0.62* | 0.62* |
| | Fe | 0.64* | ns | 0.63* | 0.58* | 0.63* | 0.64* |
| | OC | ns | ns | ns | ns | ns | ns |
| | clay | 0.68** | 0.53* | 0.73** | 0.66** | 0.72** | 0.68** |
| | All variables | 0.85** | 0.83* | 0.86* | 0.85* | 0.86* | 0.86* |

ns: not significant.
*Significant at the 0.05 level.
**Significant at the 0.01 level.

TABLE 3
Correlation coefficients (r) for cotton leaf B as a function of soil extractable B and soil constituents in the preliminary experiment

| Soil content | Depth (cm) | Leaf B ($mg \cdot kg^{-1}$) |
|---|---|---|
| $NH_4$ acetate | 0–30 | 0.53* |
| (mg/kg) | 30–60 | ns |
| | 60–90 | ns |
| IOC | 0–30 | 0.66** |
| | 30–60 | ns |
| | 60–90 | ns |
| Fe | 0–30 | 0.60* |
| | 30–60 | ns |
| | 60–90 | ns |
| OC | 0–30 | −0.61* |
| | 30–60 | −0.64* |
| | 60–90 | ns |
| All soil variables | 0–30 | ns |
| | 30–60 | 0.64* |
| | 60–90 | ns |

ns not significant.
*Significant at the 0.05 level.
**Significant at the 0.01 level.

The 1:1 soil:water extract was chosen because it had already been used for several years in the shallow groundwater usage studies of Soppe and Ayars (2001). The ammonium acetate extract was used because it was the only soil B extract that gave a significant correlation with cotton leaf B concentration in the preliminary experiment. The DTPA-sorbitol extract was chosen because it gave significant correlations with the largest number of B reactive soil constituents. The hot water-soluble B extract was not used in the full-scale experiment because of reproducibility problems resulting from differential evaporation during the boiling step.

There were statistically significant positive relationships between extractable soil B concentrations and B content of melon leaves (see Table 4). The correlation coefficients are listed in Table 4 for whole plant B and composite leaf B as a function of extractable soil B. The correlation between soil B and plant B was higher for the plant sampling prior to fruit set than for the later sampling. This is not surprising since sampling of melon leaves before fruit set is recommended (Jones and Steyn, 1973). Correlation with extractable soil B was higher for whole plant B than for composite leaf B. The highest correlation coefficient ($r = 0.74^{**}$) was obtained with the 1:1 soil:water extract at the 60–90-cm depth.

Figure 1 shows the relationship between soil B and whole plant melon B for various extracts for rootzone-averaged depth (0–90 cm). Plant water and solute uptake represents an integration of the water and solute composition of the rootzone. Water uptake is related to root distribution. The first assumption is that water and solute uptake occur equally from all depths in the root-

TABLE 4
Correlation coefficients (*r*) for melon B as a function of soil extractable B

| Extractant | Soil depth (cm) | Plant B | | Leaf B | |
|---|---|---|---|---|---|
| | | 6/28/00 prior to fruit set | 8/9/00 | 6/28/00 prior to fruit set | 8/9/00 |
| $NH_4$ acetate B | 0–30 | 0.62** | 0.40* | 0.58** | 0.42* |
| | 30–60 | 0.68** | 0.47* | 0.58** | 0.41* |
| | 60–90 | 0.68** | 0.51** | 0.52** | 0.43* |
| | 0–90 depth averaged | 0.64** | 0.46** | 0.54** | 0.41** |
| DTPA-sorbitol B | 0–30 | 0.65** | ns | 0.48** | ns |
| | 30–60 | 0.65** | 0.38* | 0.52** | ns |
| | 60–90 | 0.67** | 0.47* | 0.50** | 0.42* |
| | 0–90 depth averaged | 0.62** | 0.38** | 0.48** | 0.35** |
| 1:1 water B | 0–30 | 0.58** | ns | 0.42* | ns |
| | 30–60 | 0.59** | ns | 0.47* | ns |
| | 60–90 | 0.74** | 0.44* | 0.55** | 0.42* |
| | 0–90 depth averaged | 0.60** | 0.34** | 0.46** | 0.33** |

ns: not significant.
*Significant at the 0.05 level.
**Significant at the 0.01 level.

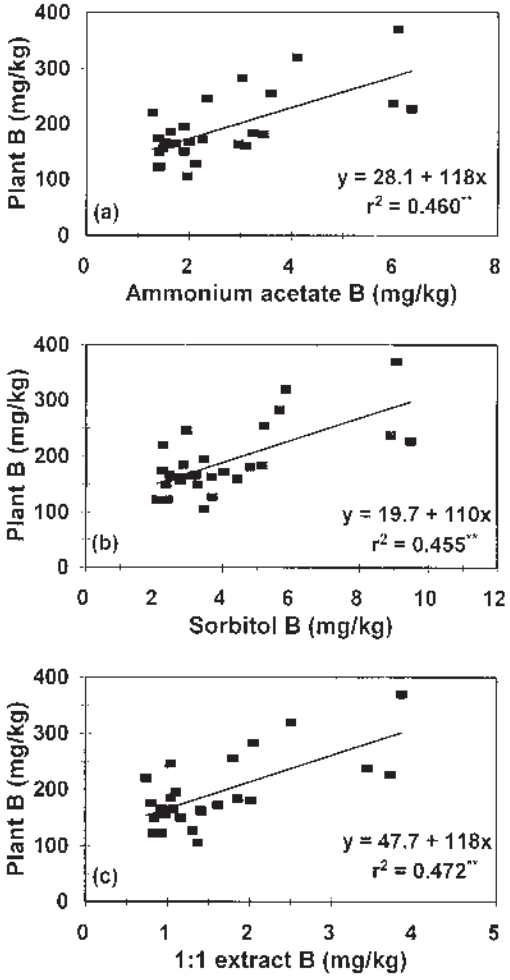


Fig. 1. Boron content (mg·kg$^{-1}$) of melon plants prior to fruit set as a function of extractable soil B content (mg·kg$^{-1}$) depth averaged over the root zone (0–90 cm): a) ammonium acetate extract; b) DTPA-sorbitol extract; c) 1:1 soil:water extract.

zone. Depth-averaged values gave slightly lower, but not statistically significantly different, correlation coefficient values than did selected depths. We did not utilize individual depths since there was no rationale for selecting arbitrary and different depths for different sampling times and different crops.

Correlation coefficients indicated for the three extracts were not statistically significantly different at the 95% level of confidence. Linear relationships are evident, although the data exhibit considerable scatter. At the time of the second plant sampling, which was close to harvest, the melon leaves exhibited marginal chlorosis characteristic of B injury. Although yield was not a measured variable in our study, there was no apparent yield decrement observed upon harvest by the farmers. Melon B concentrations ranged from 100 to 400 mg·kg$^{-1}$. In an earlier sand culture study, melons showed toxicity symptoms when B in the dry matter exceeded 900 mg·kg$^{-1}$, although effects on plant yield were also not measured in this study (Eaton, 1944).

The relationships between extractable soil B contents and B content of cotton leaves and whole plants were positive and statistically significant. Table 5 provides the correlation coefficients for whole plant B and composite leaf B as a function of extractable soil B. The correlations between soil B and plant B or leaf B were highest for the latest plant sampling and for the deepest horizons. The correlation for plant B at flowering was generally not significant except for a very weak correlation with the 1:1 soil:water extract ($r = 0.18^*$, see Table 5). This is surprising since the recommended time for sampling cotton for B and other elements is at flowering (Jones and Steyn, 1973). Extraction of water by the cotton lowered the water table from 100 cm to 180 cm over the course of the growing season. The result of this was that most of the water uptake at the end of the season came from the deepest depth where the soil B content is higher.

Table 6 provides B concentration ranges for all three extracts at all six depths. The DTPA-sorbitol extract removed the most B from the soils. Correlation with soil B was generally higher for composite leaf B than for whole plant B for cotton, especially at the end of the growing season. Extractable soil B more than doubled from the 0 to 30-cm to the 150 to 180-cm depth. Relationships between two extractable soil B measures and composite leaf B near the end of the growing season over rootzone-averaged depth (0–180 cm) are indicated in Fig. 2. Correlation coefficients for the three extracts were not statistically significantly different at the 95% level of confidence. Positive linear relationships are clearly evident despite the variation in the data. Cotton B concentrations ranged from 100 to 300 mg·kg$^{-1}$. Leaf burn toxicity symptoms have been reported on cotton in sand culture in the range of 500 to 1600 mg B·kg$^{-1}$ in the dry matter (Eaton, 1944). However, B tolerance is also pH-dependent; Fox (1968) reported increased B tolerance of cotton at high soil pH.

For alfalfa, a statistically significant linear relationship with plant B was found only for ammo-

TABLE 5
Correlation coefficients (r) for cotton B as a function of soil extractable B

| Extractant | Soil Depth (cm) | Plant B | | | Leaf B | | |
|---|---|---|---|---|---|---|---|
| | | 6/28/00 at flowering | 8/9/00 | 9/14/00 | 6/28/00 at flowering | 8/9/00 | 9/14/00 |
| $NH_4$ acetate B | 0–30 | ns | ns | 0.43* | ns | 0.56* | 0.57** |
| | 30–60 | ns | 0.58* | 0.52** | ns | 0.64* | 0.56** |
| | 60–90 | ns | 0.62* | 0.47** | ns | 0.73** | 0.61** |
| | 90–120 | ns | 0.72** | ns | ns | 0.70** | 0.68** |
| | 120–150 | ns | 0.75** | ns | ns | 0.60* | 0.71** |
| | 150–180 | ns | 0.78** | 0.56** | 0.45* | ns | 0.82** |
| | 0–180 depth averaged | ns | 0.48** | 0.34** | 0.27** | 0.50** | 0.55** |
| DTPA-sorbitol B | 0–30 | ns | ns | 0.56** | ns | 0.54* | 0.65** |
| | 30–60 | ns | 0.64* | 0.63** | ns | 0.56* | 0.64** |
| | 60–90 | ns | 0.64** | 0.50** | ns | 0.69** | 0.66** |
| | 90–120 | ns | 0.71** | 0.40* | ns | 0.72** | 0.67** |
| | 120–150 | ns | 0.72** | ns | ns | 0.61** | 0.61** |
| | 150–180 | ns | 0.69** | 0.52** | ns | ns | 0.76** |
| | 0–180 depth averaged | ns | 0.54** | 0.35** | 0.25** | 0.49** | 0.55** |
| 1:1 extract B | 0–30 | ns | ns | 0.45* | ns | 0.57* | 0.58** |
| | 30–60 | ns | ns | 0.57** | ns | ns | 0.49** |
| | 60–90 | ns | ns | 0.50** | ns | 0.57* | 0.53** |
| | 90–120 | ns | 0.75** | 0.47* | ns | 0.73** | 0.68** |
| | 120–150 | ns | 0.75** | 0.42* | ns | 0.57* | 0.68** |
| | 150–180 | ns | 0.69** | 0.58** | 0.44* | ns | 0.81** |
| | 0–180 depth averaged | 0.18* | 0.52** | 0.42** | 0.28** | 0.50** | 0.56** |

ns: not significant.
*Significant at the 0.05 level.
**Significant at the 0.01 level.

nium acetate extractable B in the surface horizon ($r = -0.64$*). This relation was negative, suggesting the unreasonable result that plant B concentration decreases with increasing soil B concentration. It is surprising that a better relation was not obtained inasmuch as the alfalfa samples were obtained at the exact time of soil sampling and adjacent to the sampling hole. Alfalfa is a perennial crop and is exposed to diverse conditions that include low soil B during the rainy winter months, which could explain the weak relationship observed between soil B and plant B. Indeed, B concentrations in the alfalfa were less than 100 $mg \cdot kg^{-1}$. This concentration is far below the 500–1000 mg $B \cdot kg^{-1}$ in the dry matter found to cause toxicity symptoms in sand culture (Eaton, 1944) and 850 mg $B \cdot kg^{-1}$ found for alfalfa grown in three Colorado soils (Gestring and Soltanpour, 1987). The lack of significant correlation could also be caused by the large variability inherent in field conditions or indicative of baseline scatter associated with relatively low B concentrations for most of the alfalfa sites evaluated. Since alfalfa is a deep-rooted crop, the lack of correlation at the lower depths is especially surprising.

TABLE 6
Extractable soil B content ranges for cotton with depth

| Depth (cm) | $NH_4$ acetate B ($mg \cdot kg^{-1}$) | DTPA-sorbitol B ($mg \cdot kg^{-1}$) | 1:1 water B ($mg \cdot kg^{-1}$) |
|---|---|---|---|
| 0–30 | 0.8–3.3 | 2.8–7.9 | 0.8–4.0 |
| 30–60 | 0.7–3.4 | 2.1–7.8 | 0.7–6.1 |
| 60–90 | 0.6–5.4 | 1.8–13.2 | 0.7–7.3 |
| 90–120 | 0.6–8.1 | 1.5–19.8 | 0.7–6.1 |
| 120–150 | 0.6–8.3 | 1.1–20.4 | 0.5–6.8 |
| 150–180 | 0.7–7.6 | 1.4–17.9 | 0.6–6.6 |

Whereas statistically significant relationships between extractable soil B and plant B concentration were found for melons and cotton, there was considerable variation in the data. Previous literature analyses have yielded improved linear relationships with higher correlation coefficients.

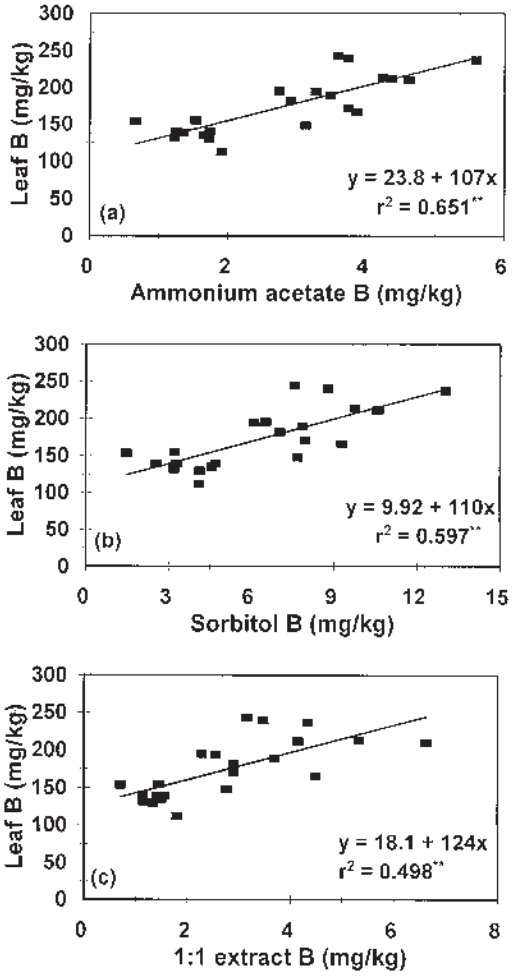


Fig. 2. Boron content (mg·kg$^{-1}$) of cotton leaves at the end of the growing season as a function of extractable soil B content (mg·kg$^{-1}$) depth averaged over the root zone (0–180 cm): a) ammonium acetate extract; b) DTPA-sorbitol extract; c) 1:1 soil:water extract.

An example is the study of Aitken et al. (1987) relating sunflower B concentration to hot water soluble and hot calcium chloride-mannitol extractable soil B in Australian soils treated with 0.5 and 1.0 kg B·ha$^{-1}$ ($r = 0.93^{**}$ for both extractants). Historically, evaluations of the ability of B soil tests to predict plant B content have been conducted in greenhouse environments. These conditions provide a much more controlled environment than the field, where clay content and water content vary considerably. In our study, clay content varied from 7 to 60% within the two sections investigated. In addition, B concentration in the irrigation water in our field study was essentially constant. Greater variability in soil solution B content might have produced a better correlation with plant B content. It is expected that a more controlled container experiment will yield improved correlations between the various measures of extractable soil B and plant B content. Such an experiment is underway at our laboratory and will be used to evaluate the ability of various soil B tests to predict plant B content, especially under conditions of potential B toxicity.

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