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Effect of Clay Content in Soil on Boron Uptake and Yield of Wheat[1]

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ABSTRACT

The effect of total B content in soil on B uptake by wheat (*Triticum aestivum* L.) and its effects on yield were studied for three soil-sand mixtures at soil-to-soil + sand ratios of 1:3, 2:3, and 1. The results indicate that the higher the clay content of a soil, the lower is the B activity in solution for any given amount of B added. It was suggested that the soil adsorption sites act as a pool to which B can be stored or removed depending on the change in solution B concentration in soil. The B uptake by the plants is higher as the sand content increases, for any total amount of B added. However, the experimental results from all three soil-sand mixtures lie on the same line when the B content in the shoot is plotted against B activity in soil solution (r^2 = 0.9695). The dry matter of the plants was decreased with both an increase in total amount of B added and an increase in the sand content for any given amount of total B. As found for B uptake, the relative dry matter weight and the relative yield values lie on the same linear line when they are plotted against B activity in soil solution from all three soil systems. This indicates that the yield responds to B activity in soil solution only.

Additional Index Words: **B adsorption, B availability to plants, B toxicity, *Triticum aestivum* L.**

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BORON, if present in too low or high amounts in the soil, can markedly reduce plant growth. There is a relatively narrow concentration range between levels of soil B causing deficiency and toxicity symptoms in plants.

Substantial work on B uptake by plants has been carried out in sand culture (Eaton, 1935; 1944) and criteria for acceptable levels of B in irrigation waters were established from these experiments. For example, water containing B at levels above 0.37 mmol L^{-1}, was generally toxic for most crops (U.S. Salinity Laboratory Staff, 1954). However, those experiments were made in sand culture and B-soil interactions were not considered.

Boron is adsorbed by various soil components. Important factors influencing adsorption and removal of B from solution include the initial B content of the soil, the pH of the soil, the type of exchangeable ions present in ionic composition of the soil solution, the amounts and types of minerals in the soil, the wetting and drying cycles, and the water-to-soil ratio (Biggar and Fireman, 1960; Hingston, 1964; Keren and Gast, 1981; Keren and Mezuman, 1981; Keren and O'Connor, 1982; Mezuman and Keren, 1981; Sims and Bingham, 1967).

It has been shown that B adsorption by clay minerals can be described by a competitive adsorption model (Keren et al., 1981; Keren and Gast, 1983; Keren and Mezuman, 1981). Using this model, the concentration of B in the soil solution was predicted to increase only very slightly as the water-to-soil ratio is changed (at a fixed amount of B in the soil). They suggested that soil adsorption sites act as a buffer in this regard, from either increasing B to the solution or removing B from it, depending on the change in B concentration of the solution and on the soil adsorption properties.

In assessing the suitability of the B concentration of the irrigation water, the physicochemical characteristics of the soil may play an important role, because of the interaction between B and soil. The existing criteria, however, do not allow for such effects.

The effect of adsorbed and soluble B in soil on B availability to plants was studied recently by Keren et al. (1985). They found that B uptake by bell pepper (*Copsicum frutescens* L.) plants (semitolerant with respect to B toxicity) grown in a soil of low clay content was significantly greater than that of plants grown in a soil of high clay content at any level of added B. However, when B contents of the plants were related to B activities in the soil solutions, the experimental results for both soils lay on the same straight line, indicating that B uptake by bell pepper plants is essentially related to soluble B with adsorbed B having little or no effect.

Although wheat (*Triticum aestivum* L.) is a crop tolerant of salinity (Maas, 1984), it was found (sand culture study) to be relatively sensitive with respect to B toxicity (Bingham et al., 1985). In many semiarid and arid regions in the world, irrigation of wheat is a common practice. The water used may have a B concentration above the threshold value for wheat. Since it has not been established that plants other than bell peppers respond mainly to the activity of B in soil solution, the present study was undertaken to determine whether B uptake by wheat and the wheat yield are affected by adsorbed B or only by soluble B. Such studies are necessary to establish the general validity of the bell pepper finding.

MATERIALS AND METHODS

A montmorillonitic soil (Typic Chromoxererts) developed on basaltic alluvium was used in this study. Soil from the surface horizon (0–20 cm) was collected, air-dried, passed through a 2-mm screen and mixed thoroughly. The characteristics of the soil, which were obtained by routine procedures (Black, 1965), are as follows: The clay, silt, and sand percentages are 62.0, 23.4, and 14.6, respectively; the $CaCO_3$ percentage is 22.3; and the soil pH is 7.6. The B adsorption coefficients for these soils were obtained by the method of Keren et al. (1985).

The soil was divided into three parts, and three mixtures of pure sand (0.6–0.8 mm diam) and soil were prepared at soil-to-soil + sand ratios of 1:3, 2:3, and 1. The sand was added in order to obtain "soils" having different clay contents (and hence different B adsorption capacities) but the same B adsorption affinity coefficients.

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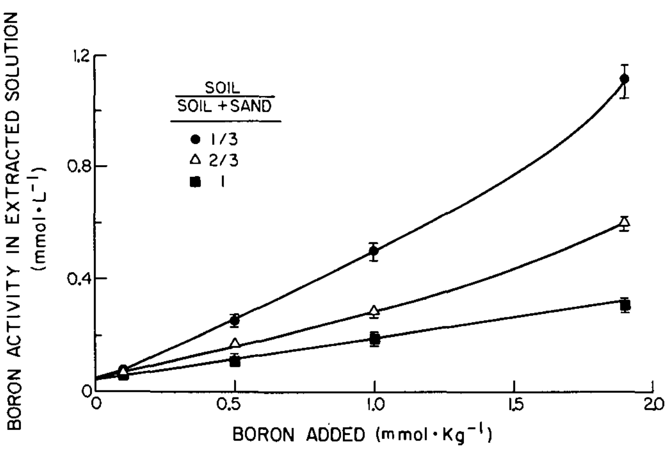

Fig. 1. Boron activity in extracted solution of saturated paste as a function of total amount of B added to soil, for three ratios of soil-sand mixtures.

Boron was added to the soil-sand mixtures to produce five levels of total B (adsorbed + dissolved) (control; 0.1, 0.5, 1.0, and 1.9 mmol kg^{-1} soil-sand mixtures) in the following manner, in order to minimize the variability in B distribution in the soil. The ~3 kg of soil-sand mixture added to each pot was divided into 10 equal parts, each of which was wetted to "field capacity" using 5 mmol $CaCl_2$ L^{-1} solution containing B (as boric acid) at the appropriate concentration needed to obtain the desired B level in the soil. Then the soil was covered to prevent evaporation, and equilibrated for 7 d. Following this, the soils were placed in the pots and leached with 5 mmol $CaCl_2$ L^{-1} solution containing B at a concentration that would be in equilibrium with the desired amount of adsorbed B. When the concentration of the leachate was that of the leaching solution, soils were allowed to drain to field capacity.

In the fall of 1983, the soils were sown with wheat seeds and covered with small polystyrene balls in order to minimize evaporation during the growing season. During the first few weeks of the experiment, the seedlings were thinned to two plants per pot. At the first tillering stage the plants were thinned to one plant per pot. The plants were irrigated at a frequency appropriate to maintain the water content in the soils within a range corresponding to a water potential range of 0.01 to 0.03 MPa.

During the first few weeks of the experiment deionized water was used for irrigation. Later in the growing season Hoagland's nutrient solution (B-free) was used for irrigation, with the concentration increased (up to one) according to the development of the plants. Twice, during the growth period, the soils were leached to reduce the salinity buildup. It was assumed that this leaching did not considerably modify plant uptake. For example, the depletion of B by leaching was <5% and 0.5% of the total B in the soil-to-soil + sand ratios of 1:3 and 1, respectively.

The plants were harvested at the mature-grain stage, separated into shoot and grain components, dried at 65°C after rinsing with deionized water, and then weighed for yield data. After weighing, the leaf samples were ground in a Wiley mill and the ground material was stored in a desiccator. Subsamples of 0.2 g were then placed in a crucible and heated at 550°C for 2 h in a muffle furnace. After cooling, 10 cm^3 of 1 mol HCl L^{-1} solution was added to the ash in the crucible and allowed to stand for 15 min. An aliquot of this solution was analyzed colorimetrically for B using the Azomethine-H method (Gupta and Stewart, 1975).

After harvesting, the moist soil of each pot was mixed thoroughly, and 500 g was used to obtain a saturation extract (U.S. Salinity Laboratory Staff, 1954). The soil samples were never dried during the analysis. The solution extracts were analyzed for pH, electrical conductance, and B.

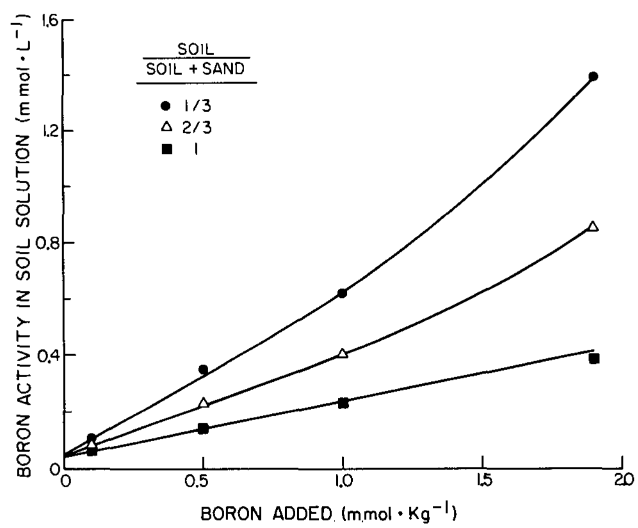

Fig. 2. Boron activity in soil solution as a function of total amount of B added to soil, for three ratios of soil-sand mixtures at field capacity water content.

Computations

Adsorbed B was calculated as the difference between the amount added and that found in solution at equilibrium. It was assumed that negative adsorption of borate ions, $B(OH)_4^-$, by the soil was negligible. The adsorption coefficients of the soil were obtained using the adsorption equation derived by Keren et al. (1981).

The ionic strength, I, was calculated using the equation derived by Griffin and Jurinak (1973): $I = 0.013$ EC, where EC is the electrolytic conductivity, in dS m^{-1}. The ionic strength corrections for determining B activity in solution were made using single-ion and single-molecule activity coefficients (Keren and O'Connor, 1982). The B distribution coefficient between the solid and the liquid phases at field capacity was calculated from these data using the adsorption model of Keren et al. (1981).

RESULTS AND DISCUSSION

The resulting B activities in the saturation paste of the soils as a function of amounts of B added are presented in Fig. 1. The B concentration that was initially present in the soil is given by the intercept of the lines. It is evident that this amount is relatively low for all three systems and can be ignored, except for the lowest B treatments. The results indicated that the higher the clay content of the soil, the lower is the B activity of the soil solution for any given amount of B added. Thus, the amount of adsorbed B is dependent on soil texture, as is the concentration of soluble B prior to the attainment of steady state.

The soils of lower clay content have fewer adsorption sites. Since the affinity coefficients for the adsorbent species ($B(OH)_3$, $B(OH)_4^-$, OH^- are the same for all of the soil-sand mixtures, adsorbed B increases as the number of adsorption sites increases and for any total B content, and as the B activity in soil solution increases. This indicates that the soil adsorption sites will buffer against fluctuations in solution B concentration when the B adsorption content is less than the maximum adsorption sites available for B. This buff-

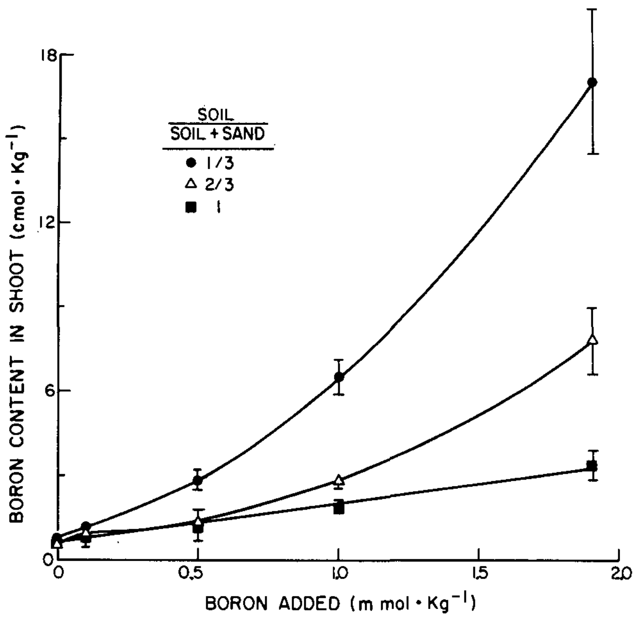

Fig. 3 Relationship between B content in wheat shoot and the amount of B added to soil, for three ratios of soil-sand mixtures.

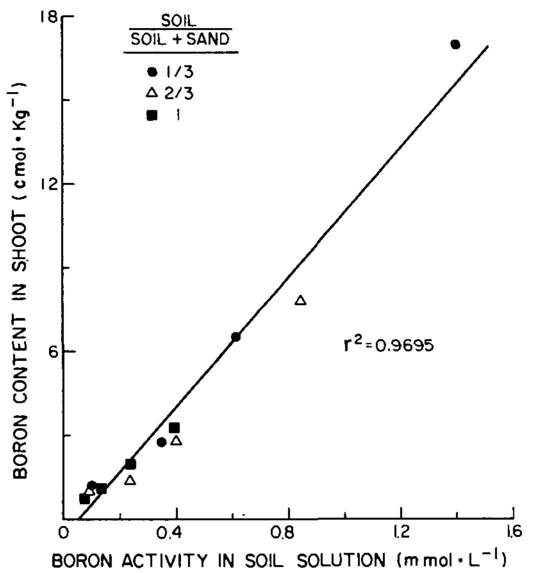

Fig. 4 Relationship between B content in shoot and the B activity in soil solution, for three ratios of soil-sand mixtures at field capacity water content.

ering capacity of a soil is dependent on the affinity coefficients for the various B species and the maximum adsorption sites available for B (Keren and Bingham, 1985).

The results presented in Fig. 1 also show that a linear relation exists between the B activity of the saturation extract and the amount of B added for the undiluted soil, but not for the soil-sand mixture systems. Moreover, the deviation from linearity increases as both the sand percentage and the amount of B added increase. This deviation can be explained by considering the differences in the total number of adsorption sites in the different soil systems. The B adsorption capacities for the soil and for the 2:3 and 1:3 soil-sand mixtures are 8.8, 5.9, and 2.9 mmol kg^{-1} soil, respectively. Assuming that all of the added B was adsorbed by these soil systems, 21, 32, and 65%, respectively, of the adsorption sites of the soil systems would be occupied by B. Because the total B adsorption capacities of the soil-sand mixtures are much lower than that of the undiluted soil, the saturation level of adsorbed B in the soil-sand mixtures will be obtained at lower activities of soluble B than for the soil alone and, therefore, deviation from linearity will begin at lower levels of B added.

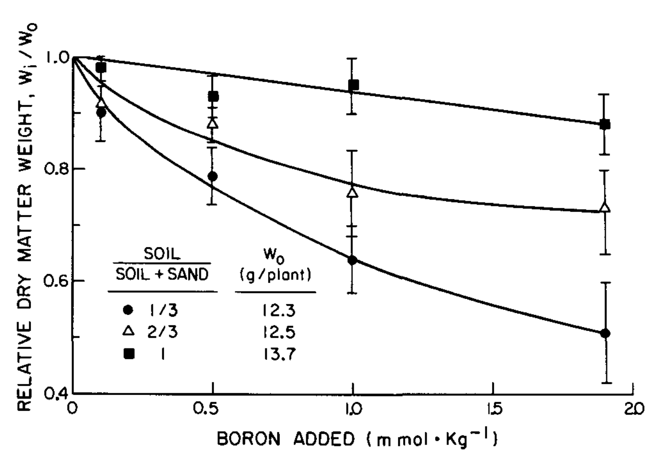

Fig. 5. Relative dry matter weight as affected by the amount of B added to soil, for three ratios of soil-sand mixtures.

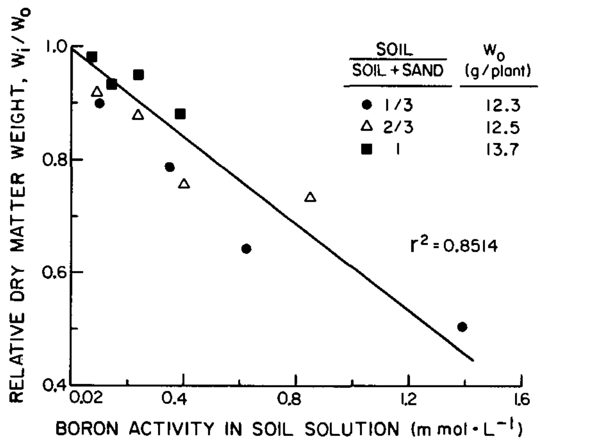

Fig. 6. Relative dry matter weight as affected by B activity in soil solution, for three ratios of soil-sand mixtures at field capacity water content.

The B activity of the equilibrium soil solutions at field capacity as a function of added B is presented in Fig. 2. The data were calculated from the saturation extract composition using the adsorption equations of Keren et al. (1981). Comparing these data with those of Fig. 1, it is evident that although the soluble B activity is higher in the soil water than in the saturation extract, the difference is relatively small in spite of the relatively large differences in the water contents between field capacity and saturation. This indicates that the adsorbed B does indeed act as a pool from which B is supplied to the solution, or as a reservoir in which B is stored, depending on the direction of change in solution B concentration in the soil.

The B contents of the wheat shoots as a function of the total amount of B added to the soil systems are

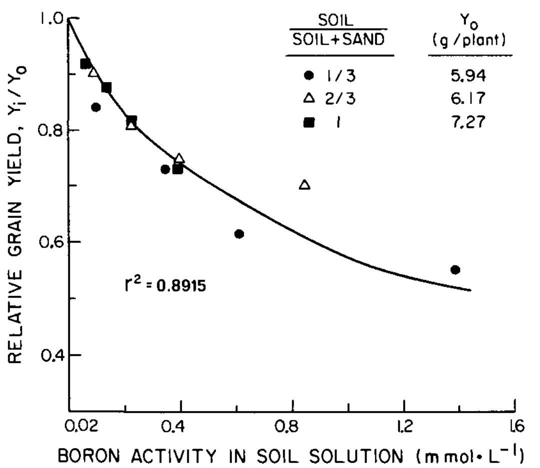

Fig. 7. Relative grain yield as affected by B activity in soil solution, for three ratios of soil-sand mixtures at field capacity water content.

given in Fig.3. The B uptake by the plants was higher as the sand content increased for any total amount of B added. The results indicate that shoot B content is linearly related to the total amount of B added to undiluted soil, but not to the soil-sand mixtures. This observation suggests that B uptake is dependent solely upon the activity of soil solution B.

The B contents in the wheat shoots were higher in the soil-sand mixtures relative to the undilutated soil for any given amount of added B (Fig. 3). However, when the B contents of the shoot were plotted against soluble B activities in the field capacity soil-water solutions (Fig. 4), the experimental points of all three soil systems are seen to lie on essentially the same line. The regression coefficient was 0.9846, indicating that B uptake by wheat and B activity in soil solution were highly correlated. This linear curve (Fig. 4) indicates that wheat plants obtain their B solely from B present in the soil solution. This conclusion is supported by results obtained in the B uptake study of Bingham et al. (1985), in which wheat was grown to maturity in sand cultures containing low to excessive concentrations of B. They found that the leaf B content was 130 mmol kg^{-1} when the plants were irrigated with a solution containing B at a concentration of 1.4 mmol L^{-1}. A similar B shoot content was found in the present study when the wheat was grown in soil-sand mixtures having a similar B activity in the soil solution (Fig. 4).

The relative dry matter weights of wheat shoots as a function of amount of B added are given in Fig. 5. The results indicate that the dry matter of the wheat plant is decreased when total amount of B added or the sand content increased, for any given amount of total B. The decrease in dry matter weight of the plants is concluded to be due to the accumulation of B in the plants (Fig. 3). For example, the greatest decrease in dry matter (50%) was obtained at the highest B content in the plant (170 mmol kg^{-1} dry matter).

When the relative dry-matter weight was plotted against the activities of B in the soil solution at field capacity (Fig. 6), the results of all three soil systems were found to lie on essentially the same linear line. The regression coefficient was -0.9227, indicating that the dry matter weight of wheat is affected by the B activity of the soil solution and not by adsorbed B.

The relative grain yield of wheat as a function of activities of B in the soil solutions at field capacity is presented in Fig. 7. Although wheat is moderately salt tolerant (Maas, 1984), it is moderately sensitive with respect to B. For example, when wheat was irrigated with a solution containing B at a concentration of 0.3 mmol L^{-1}, a 20% reduction in yield is observed. These results are in good agreement with those obtained in sand culture experiments by Bingham et al. (1985), who found that wheat yield was decreased by 45% when the B concentration in solution was 1.4 mmol L^{-1}. A similar reduction was obtained in the present study (see Fig. 7).

CONCLUSIONS

The results presented herein indicate that wheat responds to soil solution B activities and that soil adsorption sites act as a buffer with respect to B activity in soil solution (when the adsorption sites are under saturation with respect to B). Therefore, in assessing the B in irrigation water, the physicochemical characteristics of the soil must be taken into consideration, because of the interaction between B and soil, and since the B uptake by wheat plants is dependent only on B activity in soil solution.

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