Salinity and Boron Effects on Growth and Yield of Tepary and Kidney Beans

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Abstract. Crops tolerant to salt and boron have an advantage when grown in soils, near power plants, that are contaminated by saline cooling tower water or by waste products such as coal fly ash containing high levels of B. In addition, tolerant crops may have higher yields in arid and semi arid regions where salt and B problems coexist. This greenhouse study was conducted in order to compare the response of tepary bean (*Phaseolus acutifolius* A. Gray) and kidney bean (*Phaseolus vulgaris* L.) to combinations of high levels of solution B and chloride salts. The plants of both species were grown in 10-L plastic buckets containing silica sand and were irrigated with half-strength Hoagland's No. 1 nutrient solution to which boric acid and a mixture of NaCl and $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ on a 1:1 equivalent ratio were added. Boron treatments consisted of 5, 20, and 25 $\text{mg} \cdot \text{L}^{-1}$ and the target electrical conductivity (EC) levels were 1, 4, 8, 12, and 15 $\text{dS} \cdot \text{m}^{-1}$. The maximum growth and yield for tepary bean occurred at 5 $\text{mg} \cdot \text{L}^{-1}$ B and 4 $\text{dS} \cdot \text{m}^{-1}$. These values of B and salinity were 6.5 and 4 times higher than those threshold values reported for kidney bean. Furthermore, tepary bean produced profitable yield (80% of control) in the 5 $\text{mg} \cdot \text{L}^{-1}$ B, 8 $\text{dS} \cdot \text{m}^{-1}$ treatment and it even produced beans at B concentration as high as 20 $\text{mg} \cdot \text{L}^{-1}$ B, four times higher than that observed for kidney bean.

Waste products from coal-burning power generating stations represent a serious problem of environment contamination. Coal burning results in the formation of large amounts of ash at power generating stations. For example, the Mohave Generating Station, a 1580 megawatt coal-fired plant in Nevada, produces an average of 20.6 tons/h of fly ash (Southern California Edison, 1984). The fly ash contains various percentages of B depending on the original coal source. Boron concentrations from 48 to 618 $\text{mg} \cdot \text{kg}^{-1}$ in the ash have been reported from 17 power plants (Mulford and Martens, 1971; Plank and Martens, 1974). Saline water, which varies considerably in concentration and composition over time, results from the circulation and subsequent evaporation of water through turbine cooling cycles in power generating stations.

Agriculture could make productive use of both waste materials—mixing the fly ash into sandy soils increases water holding capacity and nutrient content, while moderately saline water can be used for irrigation. Thus, the search for salt- and B-tolerant crops is important for utilizing waste materials from coal-burning power plants. Furthermore, similar crops could be grown in salt-affected soils irrigated with B-rich water often found in

arid and semi-arid regions (Keren and Bingham, 1985; Dudley, 1994), where efficient utilization of all available water resources is of utmost importance.

Plant tolerance to salinity and B differs widely among plant species, and to some extent, among cultivars within a species (Marschner, 1998). Kidney bean or common bean is sensitive to both B and salt with threshold values of 0.75 $\text{mg} \cdot \text{L}^{-1}$ B and 1.0 $\text{dS} \cdot \text{m}^{-1}$ electrical conductivity (EC) (Mass, 1984, cited by Ayers and Westcott, 1989; and Maas, 1986). Oertli and Khol (1961) found that common beans growing in a solution containing 10 $\text{mg} \cdot \text{L}^{-1}$ B showed toxicity symptoms after 8 d. Tepary bean is a leguminous plant that thrives in some hostile environments including warm deserts and alkaline soils (Thomas, et al., 1983; Teiwes and Nabhan, 1983), and has produced good yields even in highly saline soils (Zaiter and Mahfouz, 1993).

Little information is available concerning the combined effects of salinity and B on survival, growth, and yield of tepary bean. Therefore, the goal of this study was to compare the response of tepary and kidney bean to combinations of high levels of B and chloride salts and to define the upper limits of tolerance for tepary bean to these compounds.

Materials and Methods

A sand culture experiment was conducted in a greenhouse at the Univ. of California, Riverside. Temperatures in the greenhouse

ranged between a minimum of 21 °C and a maximum of 32 °C. Plants were grown in 10-L plastic buckets containing ≈ 11.5 kg of no. 16-mesh silica sand. Four buckets were placed atop each of 32 concrete tanks containing 100 L of the test solutions which were circulated through the buckets four times a day and allowed to drain back into the tank. Seeds were sown directly into the buckets and thinned to the single best plant after two weeks. Each tank supported two 'Latifolius' tepary bean and two 'Linden Red' kidney bean plants. Solutions were mixed and run through the sand buckets before seeds were planted. Samples of the circulating solutions were taken periodically and analyzed to monitor B, EC, and nutrients.

Nutrients were added in amounts to form 0.5 strength Hoagland's No. 1 solution, minus B, to 100 L of deionized water in each tank (Hoagland and Arnon, 1938). Boron was added as boric acid to achieve 5, 20, and 25 $\text{mg} \cdot \text{L}^{-1}$. Salinity was increased to 1, 4, 8, 12, and 15 $\text{dS} \cdot \text{m}^{-1}$ by using a mixture of NaCl and $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ on a 1:1 equivalent ratio. Quantities of each added salt were determined from graphs in the U.S. Dept. of Agriculture (USDA) Agricultural Handbook 60 (U.S.S.L. Staff, 1954). The pH of the solutions tended to be slightly acidic and were adjusted toward 6.5 with KOH every week. During the growing season, deionized water was added weekly to maintain the nutrient solution volume near 100 L.

Harvest was spread over a wide span of time as some plants died after only a couple of weeks, while others showed no sign of going into senescence nearly three months after sowing. Those plants were finally harvested green. Plants were removed by hand and all pods were collected, counted and weighed to obtain the bean yield. Pods were shelled by hand, seeds counted and weighed, and the dry matter excluding bean seeds but including pods was weighed. All yield data were combined from the two plants, one in each bucket, then divided by two for a per plant value. All dead leaves were saved from each plant throughout the season to add to the final vegetative yield.

Dried leaves were analyzed for B and sodium content after grinding in a Wiley mill. Depending on the predicted B concentration, 0.01 to 0.3 g of ground material was placed in a fused quartz crucible, then heated in a muffle furnace to 500 °C over 3 h. A blank (empty) crucible, and occasionally a National Bureau of Standards B leaf tissue sample (NBS #1573) were processed and analyzed along with the leaf samples. To the cooled sample in the crucible, exactly 10 mL of 1 N HCl was added and allowed to equilibrate for 15 min. The mixture was centrifuged for 10 min at 2000 rpm in plastic vials and the samples were refrigerated. Boron was analyzed colorimetrically using the azomethine-H method, modified from Matt et al. (1975). The significant difference in the procedure used here compared to Matt et al. (1975) is that the samples were not filtered through activated charcoal, since they were not colored. Samples

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were analyzed on a Bausch & Lomb Spectronic 100 spectrophotometer. Tissues to be analyzed for Na were digested using the method of Ganje and Page (1974) and analyzed on a Beckman DU-2 flame spectrophotometer. The EC was measured on a direct-reading digital meter (Aquatronics model 390).

The experiment was a $2 \times 3 \times 5$ factorial, with two levels for species, three for B rates and five for salinity levels. There were a total of 32 tanks containing 16 different combinations of B and salinity with two replications. The tanks were completely randomized. Each experimental unit consisted of two plants, which were combined in order to determine yield, total dry matter, and leaf B and sodium concentrations. Instead of adding more replicates, we decided to test a larger number of B/salinity treatments. The control treatment, $0.2 \text{ mg}\cdot\text{L}^{-1}$ B and $1 \text{ dS}\cdot\text{m}^{-1}$ EC, was also replicated. Analysis of variance and Duncan tests were made at $P = 0.05$ by using proc GLM from SAS software.

Results and Discussion

Yield and total dry matter. Statistical analysis of the yield and total dry matter indicated that all main effects and interactions among cultivar and B; cultivar and salinity; B and salinity; and cultivar, B, and salinity were significant at $P = 0.05$ for both variables (Tables 1 and 2). Boron and salinity in the nutrient solution explained 70% and 50% of the yield variation obtained from tepary bean and kidney bean respectively. Other factors including temperature, radiation, water and nutrient uptake could have also affected yield.

Average yield was greater for tepary bean than for kidney bean for every B and salinity treatment except the control (Table 1). At $5 \text{ mg}\cdot\text{L}^{-1}$ B, tepary bean yield increased 16% and 25% with respect to control treatment in solu-

tions with EC of 1 and $4 \text{ dS}\cdot\text{m}^{-1}$, respectively, but was 20% less than control at $8 \text{ dS}\cdot\text{m}^{-1}$. In contrast, kidney bean yield decreased 52%, 63%, and 93% with respect to the control treatment when grown at $5 \text{ mg}\cdot\text{L}^{-1}$ B and salinities of 1, 4, and $8 \text{ dS}\cdot\text{m}^{-1}$ respectively. Both species failed to set seed at 12 and $15 \text{ dS}\cdot\text{m}^{-1}$ regardless of the B concentration (Table 1).

In treatments of $20 \text{ mg}\cdot\text{L}^{-1}$ B and low salinity, tepary bean yield was severely decreased to only 28% (at $1 \text{ dS}\cdot\text{m}^{-1}$) or 11% (at $4 \text{ dS}\cdot\text{m}^{-1}$) of the control treatment yield. At the same treatment levels, kidney bean failed to produce any seed at all. Neither species produced seed at $20 \text{ mg}\cdot\text{L}^{-1}$ B and $8 \text{ dS}\cdot\text{m}^{-1}$. Similarly, there was no yield at $25 \text{ mg}\cdot\text{L}^{-1}$ B and any salinity (Table 1).

In the same way, total dry matter production by tepary bean was less influenced by B and salinity than in kidney bean (Table 2). Salinity actually had a positive effect on total tepary bean dry matter yield at $4 \text{ dS}\cdot\text{m}^{-1}$ and B concentrations of 5 and $20 \text{ mg}\cdot\text{L}^{-1}$. At $5 \text{ mg}\cdot\text{L}^{-1}$ B combined with $8 \text{ dS}\cdot\text{m}^{-1}$, tepary bean total dry matter was reduced by 20% with respect to the control treatment, while at $5 \text{ mg}\cdot\text{L}^{-1}$ B and either 12 or $15 \text{ dS}\cdot\text{m}^{-1}$, tepary bean did not survive. In contrast, kidney bean dry matter was drastically decreased at $5 \text{ mg}\cdot\text{L}^{-1}$ B and 1, 4, and $8 \text{ dS}\cdot\text{m}^{-1}$ and was unable to survive at 20 and $25 \text{ mg}\cdot\text{L}^{-1}$ B (Table 2).

Total dry matter was not always a good indicator for potential yields. For example, even though an increase of EC from 1 to $4 \text{ dS}\cdot\text{m}^{-1}$ had a positive effect on total dry matter of tepary bean when grown at 5, 20, and $25 \text{ mg}\cdot\text{L}^{-1}$ B, seed yield was only increased at $5 \text{ mg}\cdot\text{L}^{-1}$ B. Treatments of 20 and $25 \text{ mg}\cdot\text{L}^{-1}$ B severely limited bean yield (Table 1). Thus, it seems that B concentration affected specific factors and yield components

such as sterility, size and number of pods, and seed weight, which may explain the large reduction in yield of that species grown at high concentrations of B.

The means for each species, taken over all treatments, indicate that tepary bean was more tolerant to both B and salinity than was kidney bean (Tables 1 and 2). Tepary bean exhibited its maximum growth and yield in this study at $5 \text{ mg}\cdot\text{L}^{-1}$ B and $4 \text{ dS}\cdot\text{m}^{-1}$. These levels of B and salinity were 6.5 and four times higher than those threshold values reported for kidney bean (Maas, 1986). Furthermore, tepary bean produced a profitable yield (80% with respect to control treatment) even when grown in $5 \text{ mg}\cdot\text{L}^{-1}$ B and $8 \text{ dS}\cdot\text{m}^{-1}$. This salinity is close to the $9 \text{ dS}\cdot\text{m}^{-1}$ reported as a threshold for good tepary bean yield (Goertz and Kobriger, 1986). In addition, tepary bean can produce seed at B concentrations as high as $20 \text{ mg}\cdot\text{L}^{-1}$ B, four times higher than that observed for kidney bean.

Leaf B and sodium concentration. Boron concentration and salinity had a significant ($P = 0.05$) interactive effect on leaf B concentration for both plant species. Leaf B concentration in kidney bean ranged from $220 \text{ mg}\cdot\text{kg}^{-1}$ B in the control treatment to $4200 \text{ mg}\cdot\text{kg}^{-1}$ B in the $20 \text{ mg}\cdot\text{L}^{-1}$ B, nonsaline treatment (Fig. 1). Values of tepary leaf B concentration ranged from $110 \text{ mg}\cdot\text{kg}^{-1}$ B in the control treatment to $4700 \text{ mg}\cdot\text{kg}^{-1}$ B in the high B, low salinity treatment (Fig. 1, alternate groups of bars).

Leaf B concentration generally increased with increasing solution B concentration at each salinity level (Fig. 1). However, leaf B concentrations were lower for both bean species grown at the highest salinity levels (Fig. 1). There was no significant difference in leaf B concentration in the 20 and $25 \text{ mg}\cdot\text{L}^{-1}$ B treatments at any of the salinity levels for both bean plants. In a study of

Table 1. Effect of boron and salinity on seed yield of tepary and kidney beans. Values are the mean (g/plant) $\pm$ standard error (SE).

Species	EC ($\text{dS}\cdot\text{m}^{-1}$)	Boron ($\text{mg}\cdot\text{L}^{-1}$)				Mean ^c	N ^b	SE
		0.2	5	20	25			
<i>Phaseolus acutifolius</i> (Tepary bean)	1	66.4 ^a (10.20)	77.1 (8.35)	18.6 (2.30)	0.0	21.8	12	0.92
	4		83.2 (3.50)	7.4 (5.87)	0.0	19.6	12	0.92
	8		53.8 (4.13)	0.0	0.0	9.8	12	0.92
	12		0.0	0.0	0.0	0.0	12	0.92
	15		0.0	0.0	0.0	0.0	12	0.92
Mean ^w	16.0							
N	30							
SE	0.58							
<i>P. vulgaris</i> (Kidney bean)	1	73.0 (7.88)	34.83 (2.77)	0.0	0.0			
	4		27.1 (2.21)	0.0	0.0			
	8		4.8 (1.04)	0.0	0.0			
	12		0.0	0.0	0.0			
	15		0.0	0.0	0.0			
Mean ^v	4.5							
N	30							
SE	0.58							
Mean ^u		28.1	2.6	0.0				
N		20	20	20				
SE		0.71	0.71	0.71				

^aMeans for salinity levels taken over all boron levels combining tepary and kidney species.

^bNumber of observations.

^cMeans of two replications or four plants ($\pm$ SE).

^wMean for tepary species over all salinity and boron treatments.

^vMean for kidney species over all salinity and boron treatments.

^uMeans for boron treatments taken over all salinity levels combining tepary and kidney species.

Table 2. Effect of boron and salinity on total dry matter of tepary and kidney beans. Values are the mean (g/plant) $\pm$ SE.

Species	EC (dS·m ⁻¹)	Boron (mg·L ⁻¹)				Mean ^z	N ^y	SE
		0.2	5	20	25			
<i>P. acutifolius</i> (Tepary bean)	1	138.1 ^a (21.81)	176.5 (11.94)	119.0 (15.7)	4.2 (3.03)	63.8	12	2.82
	4		182.6 (4.50)	147.0 (3.35)	29.5 (29.3)	71.2	12	2.82
	8		109.1 (9.45)	0.4 (0.11)	0.2 (0.02)	21.8	12	2.82
	12		0.0	0.0	0.0	0.1	12	2.82
	15		0.0	0.0	0.0	0.0	12	2.82
Mean ^w	51.2							
N	30							
SE	1.79							
<i>P. vulgaris</i> (Kidney bean)	1	169.1 (14.16)	82.6 (3.89)	0.2 (0.07)	0.1 (0.01)			
	4		67.6 (6.08)	0.0	0.0			
	8		20.5 (2.19)	0.0	0.0			
	12		0.0	0.0	0.0			
	15		0.0	0.0	0.0			
Mean ^v	11.5							
N	30							
SE	1.79							
	Mean ^u		63.9	26.7	3.4			
	N		20	20	20			
	SE		2.19	2.19	2.19			

^aMeans for salinity levels taken over all boron levels combining tepary and kidney species.^yNumber of observations.^zMeans of two replications or four plants ($\pm$ SE).^wMean for tepary species over all salinity and boron treatments.^vMean for kidney species over all salinity and boron treatments.^uMeans for boron treatments taken over all salinity levels combining tepary and kidney species.

prunus rootstocks, Elmotaïum et al. (1994) also found that salinity significantly depressed tissue B concentrations in five of the six rootstocks studied.

Leaf B concentrations were high in all of the treatments compared with literature values. This may be because the analyses were done on leaves of varying ages. In fact, leaves that fell naturally from the plants showed necrotic symptoms and were probably rich in B. These leaves were collected throughout the course of the experiment and were added to the leaves collected at harvest. Mengel and Kirkby (1987) reported that B accumulates in older tissue, particularly the edges of lower leaves.

Solution salinity had a significant effect ($P = 0.05$) on leaf sodium concentration in both species (Fig. 2). While highly variable, sodium concentrations reached nearly 1% of the dry weight of the tepary leaves in the 8 dS·m⁻¹ and 25 mg·L⁻¹ B treatment. The leaf sodium concentration was not affected by salinity in the 5 mg·L⁻¹ B treatments and had mean values of 927 and 1172 mg·kg⁻¹ Na for tepary bean and kidney bean, respectively. Tepary and kidney bean exhibited similar trends in leaf Na concentration with the highest accumulation of plant tissue sodium occurring for the most part in the 25 mg·L⁻¹ B treatments (Fig. 2). Both bean species had increasing sodium leaf concentrations in the same treatments as the decreasing B leaf concentrations, but uptake mechanisms were not investigated in this study. Kopsell et al. (2000) also found decreased leaf B content as other solutes were added to nutrient solutions used to grow *Brassica oleracea* plants.

Conclusions

Growth and yield of tepary and kidney bean were evaluated in response to high levels

Fig. 1. Leaf boron concentration response of kidney and tepary bean to varying boron and salinity levels. Each point represents the mean of four plants (two plants per tank, two replications per treatment). Vertical bars represent SE of the mean. Note that plants did not survive the 12 and 15 dS·m⁻¹ salinity treatments and thus are not included in this figure.

of chloride salts and B concentration. Tepary bean grew and produced seed better than did kidney bean at all combinations of B and salinity except the control treatment. A significant increase in total dry matter and seed yield was obtained for tepary bean when 5 mg·L⁻¹ B was added to the nutrient solution. On the contrary, a drastic decrease in both response variables was observed in kidney bean grown at 5 mg·L⁻¹ B. Salinity had a positive effect on total dry matter and yield of tepary bean when EC was increased from 1 to 4 dS·m⁻¹, and moderate yields were obtained even at 8 dS·m⁻¹. In contrast, salinity above 1

dS·m⁻¹ suppressed both total dry matter and seed yield of kidney bean.

It was not possible to determine accurate threshold values of B and salinity for tepary bean because the treatments were too widely spaced in this experiment, however the upper limits of tolerance were determined to be between 20 and 25 mg·L⁻¹ B and between 8 and 12 dS·m⁻¹. The results obtained from this study may be useful for developing management practices on soils high in salt and B. In addition, tepary bean may be a source of germplasm to improve salt tolerance, B tolerance, or both in other beans.

Fig. 2. Leaf sodium concentration response of kidney and tepary bean to varying boron and salinity levels. Each bar is the mean of the four plants (two plants for each of two replicates). Vertical bars represent the SE of the mean. Note that plants did not survive the 12 and 15 dS·m⁻¹ salinity treatments and thus are not included in this figure.

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