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Effect of applied boron on the accumulation of cations and their ratios to boron in radish (*Raphanus sativus* L.)

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Abstract

The present study was based on the hypothesis that B has close relationships with cations in soil-plant systems. A study was carried out to assess the influence of B on the concentration of cations and their ratios to boron in radish (cv. French breakfast) crop, using sand culture technique, under green house conditions. The experiment was laid out in a randomized complete block design and replicated three times. Boron was applied at the rate of 0, 0.25, 0.50, 1.0, 2.0, 3.0 and 5.0 mg B L^{-1} as H_3BO_3 along with a basal dose of modified complete nutrient solution based on the Long Ashton Formula. Results revealed that the concentrations of B and K in plants were increased and Ca, Mg and Na were significantly decreased. Generally, low and high levels of added B had interactive effects on the concentration of cations in radish plants. The K/Ca, K/Na and K/Mg ratios were increased and Ca/Mg decreased in plants with increasing B levels in the nutrient solution. Moreover, the cation ratios to boron such as K/B, Ca/B, Mg/B and Na/B significantly decreased in both plant tops and roots with increasing B levels in the nutrient solution. These ratios provided some indication for the interrelationships of boron with cations in plants. The present study suggests that the deficiency or excess of B not only affects the relative values of individual element, but it also affects the balance among cations or cations ratio to boron in radish plants.

Key words: cations, concentration, ratios, interaction, sand culture

Introduction

Boron is considered one of the important micronutrients for plant nutrition. A great deal of attention has been given to studying the effects of B supply in relation to growth and production of various crops, but information on the resulting concentration and uptake of other nutrients is limited. Indeed, the specific effects of B on the behaviour of nutrients is still an unresolved matter among plant nutritionists, presumably due to a lack of knowledge of its biochemical function in plants and complex chemistry in soil. It is well documented in the literature that the range between deficiency and toxicity for B is narrow in soil-pant systems (Bergmann 1984). Because B deficiency and toxicity not only affect the crop yield but also affect the other nutrient-elements as well, specifically K, Ca, Mg and Na (Mozafar, 1989). Many investigators reported that B levels in the growth media affect the availability of K (Kumar *et al*., 1981), Ca (Ramon *et al*., 1990), Mg (Alvarez-Tinuat et al 1979) and Na (Singh and Singh, 1983) to plants. Similarly a number of reports in the literature indicate that B has close relations with these cations and these relationships exist both in soils as well as in plants and some times indicated by the cations ratio to boron such as K/B (Singh and Sinha, 1976), Ca/B (Lal *et al*., 1979), Mg/B (Carpena-Artes and Carpena-Ruiz, 1987) and Na/B (Mehrotra *et al*., 1989). Moreover, it is evident from the literature that the deficiency or excess of B may affect the cations ratio in plants. As Singh and Sinha (1976) reported that with increasing B in soils K/Ca ratio in plants significantly decreased, because of decrease in K and increase in Ca content of plants. Similarly, Woodruff *et al*., (1960) found that the K/Ca and K/Mg ratios were equalized with added B, but the (Ca+Mg)/K ratios were decreased both with and without added B. So for, the evidence suggests that the deficiency or excess of B not only affects the relative values of individual cations, but it also affects the balance among certain cations within plants, causing either an increase or decrease of dry matter production. However, information regarding the effect of B on the availability of cations (K, Ca, Mg and Na) is limited and the nature of these complex interactions are still obscure. Therefore, the present study was undertaken to test the general hypothesis, that B has close relationships with cations in plants, could be demonstrated in radish, using sand culture technique with the main objective, to assess the influence of B on the accumulation of cations and their ratios to boron in radish plants.

Materials and methods

Experimental conditions and design

The experiment was carried out in the green house. The day/night temperature varied with in the range 22 to 18 ^{0}C, respectively. Artificial illumination was used to give 16 hrs day^{-1} and the relative humidity was around 65% during the experiment. The experiment was laid out in a randomized complete block design and replicated three times. The three blocks together therefore, gave a total of 21 pots. Each block was situated within a distance of 30 cm of each other. The position of each pot was randomly changed once a week, to minimize the spatial variations in the green house during the course of experiment.

Basal nutrient and boron solutions

All the nutrient solutions were prepared from Analar Grade chemicals and deionised water of a conductivity 0.20 µmhos cm^{-1}. Boron was applied at the rate of 0, 0.25,0.50, 1.0, 2.0, 3.0 and 5.0 mg B L^{-1}as H_3BO_3 along with a basal dose of modified complete nutrient solution based on the Long Ashton Formula as recommended by Hewitt (1966). The detail of the various salts concentration used as shown in Table 1. Complete nutrient solution with different B concentrations were started a week after germination. The nutrient solutions were freshly prepared whenever added, and the pH of each solution was maintained to 5.5± 0.1 either with 0.1 M HCl or 0.1 M NaOH. Each pot was kept at a constant moisture content by means of alternate day additions of culture solution following weighing of the pot. A total quantity of 200 mL was supplied to each pot during the course of the experiment. During the final week of the experiment the plants only received deionised water. Stock solutions for each nutrient element were prepared separately in the plastic volumetric flasks and stored in a refrigerator. At each B level the nutrient solution was prepared by mixing the appropriate volume of concentrated nutrient stock solutions.

Table 1. Chemical composition and concentration of basal nutrient solution, based on (modified) Long Ashton Formula

Compound	g L^{-1}	mM	Element	mg L^{-1}
KNO_3	0.505	5.0	K	195
			N	70
$Ca(NO_3)_2$	0.656	4.0	Ca	160
			N	112
$NaH_2PO_4.2H_2O$	0.208	1.33	P	41
			Na	31
$MgSO_4.7H_2O$	0.369	3.0	Mg	24
$Fe.citrate.5H_2O$	0.0245	0.1	Fe	5.6
$MnSO_4$	0.00223	0.01	Mn	0.55
$CuSO_4.5H_2O$	0.00024	0.001	Cu	0.064
$ZnSO_4.7H_2O$	0.000296	0.001	Zn	0.065
$(NH_4)_6.Mo_7O_{24}.4H_2O$	0.000035	0.0002	Mo	0.019
NaCl	0.00585	0.1	Cl	3.55

Sowing

Six radish seeds *(cv. French breakfast)* was sown uniformly 1cm deep and 2.5 cm apart from one another, in each 15 cm plastic pot containing 1 kg of acid-leached fine sand, and the surface of sand covered with black alkathene granules, to prevent rapid loss of moisture and algal growth. A glass wool filter paper was placed at the bottom of each pot to cover holes and the pot placed on a plastic saucer. The moisture content of the sand was kept at approximately 60% of its water holding capacity. The seeds germinated within a week and upon establishment the seedlings were thinned out so that finally each pot contained four equal size radish plants.

Water loss evaluation

Water losses by evapotranspiration was monitored by weighing daily the control pots (with out seedlings) as well as the varying B treatment pots. It is evident that the moisture content of the sand depended on the intensity of evapotranspiration of pots i.e. growth rate, temperature and relative humidity in the green house.

Harvest

The radish plants were harvested upon attaining marketable maturity. The plants were dug out with their root system and washed thoroughly with deionised water, then placed on tissue paper to remove excess water. After removing the water, the tops and roots were separated for each treatment pot. The separated parts were dried in aluminium dishes at 80 C^0 for 48 hrs in a large oven.

Plant analysis

After oven drying, the plant samples were ground using a Tema mill which was cleaned thoroughly with a brush and acetone for each treatment and analyzed for K, Ca, Mg, Na and B content by dry ashing technique as suggested by Mozafar (1989), and using ICP-OES for elemental analysis. Multi-element standard solutions were prepared of low, moderate and high concentrations in the same matrix as the samples for each element to calibrate the ICP-OES before introducing the samples, and the results printed on Dec-writer II input/output terminal.

Statistical analysis

Statistical analysis of all the data collected during investigations were performed by MSTAT-C computer package and the means were compared by the LSD-test of significance (Steel and Torrie, 1980).

Results and discussion

Nutrients concentration in radish plants

Boron concentration in plants showed a significantly linear and positive relationship between B in tops (r = 0.99) and roots (r = 0.96) and B in nutrient solution (Table 2). This indicated that the accumulation of B in the leaves of plants depends only on the B levels in the root media (Salinas *et al*., 1986). Results revealed that the plant tops contain a higher concentration of B than roots, suggesting translocation through the xylem stream

Table 2. Effect of added boron on the nutrients concentration of radish plants

Boron added mg L^{-1}	B µg g^{-1}	K %	Ca %	Mg %	Na %
		Tops			
0.0	34.84	1.54	3.24	0.62	2.65
0.25	74.03	1.64	3.05	0.71	2.38
0.5	110.7	1.72	3.03	0.72	1.85
1.0	159.0	1.85	2.93	0.63	1.47
2.0	255.9	1.97	2.92	0.58	1.40
3.0	455.9	2.04	2.75	0.55	1.00
5.0	586.7	2.05	2.55	0.52	0.94
LSD(P<0.01)	156.1	NS	0.45	0.16	0.69
LSD(P<0.05)	126.8	NS	0.26	0.09	0.56
		Roots			
0.0	13.25	3.38	0.41	0.19	2.22
0.25	17.03	3.97	0.39	0.18	1.74
0.5	23.16	4.06	0.38	0.19	1.72
1.0	23.93	4.18	0.38	0.17	1.30
2.0	30.36	4.21	0.36	0.16	1.26
3.0	48.17	4.26	0.34	0.14	0.96
5.0	51.34	4.53	0.29	0.10	0.80
LSD(P<0.01)	20.62	NS	0.06	0.07	0.69
LSD(P<0.05)	16.76	NS	0.05	0.04	0.56

*, ** = indicate significance at P<0.05 and P<0.01 levels, respectively
NS= non significant

and transpiration involved in the accumulation of B in leaves. Shelp *et al*., (1987) and Oertli and Richardson (1970) have also emphasized that leaf venation, xylem stream, and transpiration as factors primarily involved in the accumulation of B in leaves. According to latter authors and the present study suggest as well that B translocates readily in the xylem, but arriving in the leaves it becomes one of the least mobile micronutrients. Therefore, leaves are the main organ for B accumulation, and the amount of B accumulated in the leaves could not be redistributed to other organs under these conditions. Similar observations were made by Gomez-Rodriguez *et al*. (1981).

Results show that with increasing levels of added B the concentration of K in plant tops and roots increases (Table 2), but the differences in the treatments were statistically non significant. Results also showed that the concentration of K in the roots were two times greater than that in tops, indicating either that K can be retranslocated from tops to roots or that some K did not reach the leaves during plant growth. The mechanisms involved under the K-B synergism with regard to present results could be explained by suggesting that the addition of B in the nutrient solution enhanced the K concentration of plants, because B depressed the concentration of Ca due to antagonism. These results are in line with the previous work of Kumar *et al*. (1981). So, B is indirectly involved in the increased accumulation of K by plants. Similar observations were reported by Woodruff *et al.* (1960).

Results show the Ca concentration significantly decrease as the plants received higher quantities of B (Table 2), which resulted negative relationship. Results also indicate that the increased K concentration was the indirect effect of added B, while the decreased concentration of Ca at higher B levels seems to be the direct effect of B which also resulted in a reduction in yields. These results are in line with an early work of Reeve and Shive (1944). They reported that B has a direct and intimate relationship with Ca, and indirect with K in the absorption and accumulation processes of these two cations by plants. It is well understood that B deficiency induces abnormal changes in the Ca metabolism of the cell wall. Similarly in the present study, B deficiency increased the Ca concentration and reduced the translocation of this element from roots to tops. Similar observations were made by Chauhan and Powar (1978) and Singh and Singh (1984). They reported that the tissues of plants inadequately supplied with B contained higher percentages of Ca than in the presence of sufficient and toxic B.

Results showed that the trend in Mg concentration in plant tops and roots is different from Ca (Table 2), and the maximum Mg concentration occurred at 0.5 mg B L^{-1}, beyond this level the concentration tended to decrease as the B levels increases in the nutrient solution. Moreover, it was evident from the results that the response of Mg is dependent on the substrate B and the data trend closely similar to growth response, indicating both Mg and yield were similarly affected by B. Oyewole and Aduayi (1992) and Alvarez-Tinaut *et al*. (1979) also reported that the Mg content and distribution were closely related to growth demands.

Results show the Na concentration in plant tops and roots significantly decreases with increasing B levels in the nutrient solution (Table 2). It is evident from the data that at highest B level of 5 mg B L^{-1} the concentration of Na in tops and roots become equal, indicating that an equal distribution of Na in both plant parts occurred, and perhaps this is related to B toxicity. Results regarding the Na concentration in plants was also found similar to that of Ca and Mg. However, the antagonism observed between K and Na at higher levels of added B than with Ca and Mg. This explains the high uptake of K at low levels of Na. Similar antagonism between Na and K at higher levels of B was also observed by El-Kholi (1961). The complicated interaction between Na and B at higher levels seems to be due to the increased ratio of K/Na in plants.

Cations ratio in radish plants

K/Ca Ratio

Results show that K/Ca ratio in plants increases with increasing B levels in the nutrient solution (Table 3). It is interesting to note that an antagonistic effect observed from the K/Ca ratio in plant tops and roots between K and Ca with regard to B levels in the nutrient solution. This would seem to suggest that some factors other than the concentration of K and Ca are involved in the uptake mechanisms of these ions. These results confirmed the findings of El-Kholi (1961) who concluded that at higher B levels the uptake of K increased and Ca decreased.

Ca/Mg Ratio

Results regarding the Ca/Mg ratio in tops and roots show an inconsistent trend (Table 3) and the differences existed among the treatments were not very large with regard to B application. Data revealed that all the treatments show a fairly constant Ca/Mg ratio in plants, though there was a slight depression observed in the treatment receiving 0.5 mg B L^{-1}, and this may be due to the higher concentration of Mg in both tops and roots of radish plants. Generally, it can be concluded that as the concentrations of B increases the Ca/Mg ratio tended to be decreased (only in tops not in roots) because of the reduction in plant Ca.

K/Mg Ratio

The balance between K and Mg is demonstrated in Table 3. In addition to the K/Ca ratio there exists a K/Mg effect at all levels of added boron. Results show as the K/Ca ratio in plant tops and roots increases the K/Mg ratio also increases, despite the fact that the Ca/Mg ratio showed an irregular, though fairly constant trend. Results suggest that the reduction in Mg concentration at higher levels of added B correlated with the enhanced K concentration in plants. These results are in line with previous work of Patel and Mehta (1966) and Salinas *et al*. (1986). It can be concluded from the results that the effect of B on the Mg concentration in plants is similar to Ca. There is an antagonism between Mg and B at higher levels, presumably due to the imbalance or increased ratios of K/Mg or K/Ca in plants.

Table 3. Effect of added boron on the cation ratios in radish plants

Boron added mg L^{-1}	K/Ca	Ca/Mg	K/Mg	K/Na
		Tops		
0.0	0.47	5.22	2.48	0.58
0.25	0.54	4.29	2.31	0.69
0.5	0.57	4.21	2.39	0.93
1.0	0.63	5.05	2.94	1.26
2.0	0.67	5.03	3.40	1.40
3.0	0.75	5.00	3.71	2.04
5.0	0.80	4.90	3.94	2.18
LSD($P<0.01$)	NS	NS	1.41	NS
LSD($P<0.05$)	NS	NS	1.00	NS
		Roots		
0.0	9.46	2.15	20.42	1.75
0.25	10.18	2.17	22.06	2.28
0.5	10.68	2.00	21.37	2.36
1.0	11.00	2.23	24.59	3.21
2.0	11.69	2.25	26.31	3.34
3.0	12.53	2.42	30.43	4.43
5.0	15.62	2.90	45.30	5.66
LSD($P<0.01$)	5.06	NS	12.34	5.00
LSD($P<0.05$)	3.60	NS	8.80	3.56

Data of each ratio calculated from Table 2
*, ** = indicate significance at $P<0.05$ and $P<0.01$ levels, respectively
NS= non significant

K/Na Ratio

Results also show the antagonistic effects as were observed for K/Ca and K/Mg could also be observed for K/Na ratio in plants (Table 3). It is clear from the results that the K/Na ratio increases as the B levels increases in the substrate, suggesting high concentration of K and low concentration of Na in plants at higher B levels might be due to an antagonistic effect of K on Na. A general conclusion can be drawn from the results of K/Na ratio that B has indirect effect on the K behaviour in plants. The increased absorption of K may be due to the reduced Ca or Na absorption, which causes increased K/Ca and K/Na ratios in plants. Furthermore, significant reduction in Ca, Mg and Na absorption with increasing levels of B was caused not only by lower dry matter yield, but also by the increased K absorption by plants. Francois (1988) also reported that in sand culture, plants well supplied with B took up more K but less Ca, Mg

It is evident from the overall results that the increase or decrease of cations in plants was due to the possible imbalances in the ratio of the cations themselves, which seems to be due to low or excess B supply in the substrate.

Cation ratios to boron in radish plants

K/B Ratio

Results show that with increasing B levels in the nutrient solution the K/B ratio in tops and roots significantly decreases (Table 4). Results indicate that the magnitude of K/B ratio were significantly higher than tops, which is mainly due to the low K concentration found in tops and high in roots. It is clear from the results that K/B ratio was highest in B deficient and lowest in B toxic plants. Similar results were reported by Singh and Sinha (1976) for cauliflower and Carpena-Artes and Carpena-Ruiz (1987) for tomato.

Table 4. Effect of added boron on the cations ratio to boron in radish plants

Boron added mg L^{-1}	K/B	Ca/B	Mg/B	Na/B
		Tops		
0.0	444.0	930.0	177.9	760.6
0.25	221.5	412.0	95.90	321.5
0.5	155.4	273.7	65.04	167.1
1.0	116.3	184.3	39.62	92.45
2.0	76.98	114.1	22.66	54.71
3.0	44.74	60.31	12.06	21.93
5.0	34.94	43.46	8.86	16.02
LSD(P<0.01)	34.14	145.10	39.19	113.3
LSD(P<0.05)	24.36	103.50	27.95	80.83
		Roots		
0.0	2928.3	309.4	143.4	1675.5
0.25	2331.2	229.0	105.7	1021.7
0.5	1753.0	164.1	82.04	742.66
1.0	1746.8	158.8	71.04	543.25
2.0	1386.7	118.6	52.70	415.02
3.0	884.37	70.58	29.06	199.29
5.0	822.35	56.48	19.48	155.82
LSD(P<0.01)	837.10	133.9	51.27	268.10
LSD(P<0.05)	597.10	95.52	36.57	191.20

Data of each ratio calculated from Table 2
*, ** = indicate significance at P<0.05 and P<0.01 levels, respectively
NS= non significant

and Na.

Ca/B Ratio

The Ca/B ratio has often been used as a measure of the status of B nutrition of plants. Results showed that increasing B levels in the nutrient solution resulted in a decrease Ca/B ratio of plants (Table 4). Results also indicate that the reduction in radish yield at higher levels (2 to 5 mg B L^{-1}) was due to B toxic effects, and this may have disturbed the Ca/B ratio in plants, which caused a reduction in growth. Similar results were reported by Lal *et al*. (1979) and Singh and Singh (1984). However, if the Ca/B ratio is considered as an indication of B status of radish plants then the ratios from 274 to 412 for tops and 164 to 229 for roots appeared to be associated with the normal range of B in plants, which results in maximum radish yields.

Mg/B Ratio

Results show the application of B in nutrient solution led to a significant decrease in the Mg/B ratio (Table 4). Results also show that the highest Mg/B ratio in tops and roots were found at 0 mg B L^{-1} and lowest ratio at 5 mg B L^{-1}, indicating that as the B levels in the substrate increases the Mg/B ratio in plants decreases. Again these results are in line with work of Singh and Sinha (1976) and Carpena-Artes and Carpena-Ruiz (1987). Moreover, results revealed that the magnitude of the Mg/B ratio in roots was more than in the tops. This may be due to the fact that the concentration of Mg found in the roots was very low as compared to tops of the plants.

Na/B Ratio

Results show that the Na/B ratio in plant tops and roots decreases with each increment of added B (Table 4). But the magnitude of the ratio in roots were approximately three times greater than tops, it may be due to the fact that almost equal distribution of Na was occurred in both parts of the plant. On the other hand, the concentration of B in both plant parts were different which ultimately resulted higher and lower Na/B ratio in roots and tops of plants. However, the results indicate that the B deficiency and toxicity in plants are associated with high and low Na/B ratio, respectively. Mehrotra (1989) also reported that B phytotoxicity was associated with a low Na/B ratio of sugar beet.

It is obvious from the overall results that the decreasing trends existed for each cation ratio to B. It is interesting to note that each ratio show almost similar trend and a linear decrease occurred in ratios for both tops and roots of radish, when B added from 2 to 5 mg B L^{-1} in nutrient solution. Which suggest that B toxicity and deficiency in radish plants was associated with the low and high K/B, Ca/B, Mg/B and Na/B ratios, respectively. So, the evidence is that plants growing in B deficient or toxic conditions may result in abnormal ratios depending on the crop species, soil type or other environmental conditions.

Conclusions

The following conclusions were drawn from the present sand culture study.

- The concentrations of B and K in plants were increased and Ca, Mg and Na were decreased. The relative amount of K was higher in roots compared to tops and rest of the elements showed higher amounts in tops than roots. Generally, low and high levels of added B had interactive effects on the concentration of cations in plants.
- The K/Ca, K/Na and K/Mg ratios were increased and Ca/Mg decreased in radish plants with increasing B levels in the nutrient solution.
- The cation ratios to boron such as K/B, Ca/B, Mg/B and Na/B significantly decreased in both plant tops and roots with increasing B levels in the nutrient solution. These ratios provided some indication for the interrelationships of boron with cations in radish plants.
- The present study suggests that the deficiency or excess of B not only affects the relative values of individual element, but it also affects the balance among cations or cations ratio to boron in plants.

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