CALCIUM-BORON INTERACTION IN RADISH PLANTS GROWN IN SAND CULTURE

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A sand culture experiment was carried out to study the Ca-B interaction growing radish (*cv. French breakfast*) as a test crop under green house conditions. Calcium was applied at the rate of 80, 200, and 500 mg Ca L^{-1} as $CaCl_2$. $2H_2O$ and boron was applied at the rate of 0.05, 0.25, 1.0 and 5.0 mg B L^{-1}as H_3BO_3 in different combinations along with a basal dose of modified complete nutrient solution based on the Long Ashton Formula. The experiment was laid out in a randomized complete block design with 4^3 factorial arrangement and replicated three times. Results revealed that maximum fresh and dry matter yields were recorded at 500 mg Ca and 1 mg B L^{-1}, corresponding to Ca/B ratio of 500:1in the nutrient solution. The concentration of Ca and B in radish plants increased with increasing the respective levels of these elements in the nutrient solution, but the total uptake of these two elements showed a close similarity to growth response of radish plants, indicated total uptake was a useful but alternative way in determining the effect of Ca-B on the response of plant's content of these two elements. Moreover, with decreasing the Ca/B ratio in nutrient solution the ratio in tops and roots linearly decreases and showed significantly positive correlations, while, an optimum Ca/B ratio in plant tops and roots were found to be 241 and 188, respectively. The values for both plant parts found to be normal in predicting the maximum yield of radish plants.
Keywords: Radish, yield, concentration, total uptake, ratio and sand culture

INTRODUCTION

The interrelationships of Ca and B is outstanding in soil-plant systems. In this regard Brenchley and Warington (1927) were the first researchers who suggested this relationship. In subsequent decades, this relationship was expressed in terms of a ratio between these two elements in plants, which has resulted in many publications by a number of investigators, Jones and Scarseth (1944), Brennan and Shive (1948), Lal *et al.* (1979), Golakiya and Patel (1988) and some other researchers. The results of these investigators showed that crops grow normally if a certain balance exists both in the intake and tissue concentration of Ca and B. However, a large number of reports in the literature emphasize that Ca/B ratio in plants could be effectively utilized for detecting B deficiency, sufficiency and toxicity in different plant species as Ca/B ratios are inversely related to the concentration of B in the substrate. Moreover, it is well understood that the toxic effects of B may be reduced or prevented by adding Ca to soils. These phenomena have been ascribed both to reactions with in soil and to metabolic processes in plants (Kabata-Pendias and Pendias, 1992). The general conclusion is that Ca/B ratio indicates the status or balance between these nutrients in plant or in soil and are virtually indispensable to one another, because quite small variations in the ratio can affect plant growth. Therefore, to confirm the relationships between Ca and B, an experiment was carried out with a test hypothesis, to see whether the concentration or ratio of these two elements in nutrient solution are important; because some investigators reported that the ratio not be given the same importance as the level of the individual elements (Gupta, 1979). To test this straightforward hypothesis the present experiment was proceeded with the main objectives, to determine the effect of Ca-B levels/ratios on the growth, concentration, total uptake and ratio of these nutrient-elements by 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 C^0, 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 with 4^3 factorial arrangement and replicated three times. The three blocks together therefore, gave a total of 36 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.

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.

Ca-B levels and basal nutrient 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 0.05, 0.25, 1.0 and 5.0 mg B L^{-1}as H_3BO_3 and calcium was applied at the rate of 80, 200, and 500 mg Ca L^{-1} as $CaCl_2$. $2H_2O$ along with a basal dose of modified complete nutrient solution based on the Long Ashton Formula as recommended by Hewitt (1966). Supplements of nitrate and calcium to the medium, given in Table 1, were made with $NaNO_3$ and $CaCl_2$. $2H_2O$. Complete nutrient solution with different B and Ca concentrations were started a week after germination. Plants were flushed on alternate day with ½ strength of the basal nutrient solution for a week and later on full strength, including the appropriate Ca-B levels. 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 and Ca level, the nutrient solution was prepared by mixing the appropriate volume of concentrated nutrient stock solutions.

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 depend on the intensity of evapotranspiration of pots i.e. growth rate, temperature and relative humidity in the green house.

Harvest and measurement

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 and fresh weight was recorded 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

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 N	195 70
$Ca(NO_3)_2$	0.656	4.0	Ca N	160 112
$NaH_2PO_4.2H_2O$	0.208	1.33	P Na	41 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

and acetone for each treatment and the ground plant materials were dry ashed, the technique as suggested by Isaac and Kerber (1971), using Atomic Absorption Spectrophotometer for elemental determination of Ca. While B was determined by Azomethine-H method (Porter *et al.*, 1981), using Technicon Auto Analyzer. Standard solutions of low, moderate and high concentrations were also prepared in the same matrix as the samples for each element to calibrate the instruments before introducing the samples.

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

Fresh matter yield

Fresh matter yield is an important parameter of radish crop and vegetable growers are always interested in its quantity as well as quality. Results showed that a maximum fresh matter yield of tops and roots were obtained from the treatments receiving 500 mg Ca and 1 mg B L^{-1} and 80 mg Ca and 0.25 mg B L^{-1} in nutrient solution, respectively (Table 2). These results suggest that this is a range of Ca-B levels in nutrient solution, where the radish crop responded well. Furthermore, a significant reduction is obvious in the fresh matter yield at highest B level (5 mg L^{-1}) with each Ca level, suggesting that the fresh weight of the radish crop was significantly affected due to a toxic concentration of B. Results also show that the fresh weight values for roots were considerably higher than tops because of course the roots of radishes contain more water and remain more succulent in the fresh state than leaves. The present result suggests that the toxic level of B has a pronounced effect in the reduction of yield (Francois 1984, 1986 and 1989), and this reduction in yield was not only the result of the toxic effect of B on plants, or this may be due to the improper balance between Ca-B in solution as well as in plants (Patel and Mehta, 1966). Because the reverse levels of both elements in nutrient solution created high and low Ca/B ratios. The important point brought out by this is that the Ca/B ratio is not the only factor which is responsible for the appearance of either B deficiency or toxicity on plants; the absolute concentration of Ca and B in the substrate is also very important for a normal plant growth and production. Similar conclusions were also drawn by Patel and Mehta, (1966). It is interesting to note that the treatments receiving a highest and lowest Ca level produced almost equally low fresh weights, which suggest that fresh weight was depressed in the former case by Ca excess and B deficiency, and in the latter by B toxicity and Ca deficiency in nutrient solution. The same situation in the case of apple seedlings was found by Woodbridge *et al.* (1974) from a solution culture studies.

Table 2. Effect of added Ca-B levels on the yield of radish

Added Ca (mg L^{-1})	Added B (mg L^{-1})	Fresh matter yield g pot^{-1}		Dry matter yield g pot^{-1}	
		Tops	Roots	Tops	Roots
500	0.05	18.40	29.44	1.84	0.92
	0.25	22.98	61.71	2.56	3.74
	1.0	42.30	62.12	5.64	4.97
	5.0	14.91	27.54	1.66	1.78
200	0.05	21.86	29.23	2.19	0.92
	0.25	37.44	62.15	4.16	3.76
	1.0	31.50	48.42	3.50	3.87
	5.0	17.70	21.39	1.97	1.38
80	0.05	26.20	43.73	2.62	1.37
	0.25	25.23	67.76	2.80	4.10
	1.0	27.03	48.12	3.01	3.85
	5.0	17.58	18.19	1.95	1.17
LSD ($P<0.05$)					
Ca		NS	NS	NS	NS
B		15.02	23.75	1.63	1.49
Ca x B		11.55	NS	1.25	NS

NS = Non Significant

Dry matter yield

Dry matter yield of tops and roots were recorded separately, after drying the fresh plant material at 80°C for 48 hrs. Results regarding the analysis of variance for dry tops and roots (Table 2) showed significant treatments effect, due to varying Ca and B levels in the nutrient solution. The data show that maximum dry matter yield was obtained from the treatment receiving 500 mg Ca and 1 mg B L^{-1} in solution and below or above this level a significant decrease in dry matter yield occurred, presumably due to imbalance of Ca and B levels in the nutrient solution. Results regarding reduced dry matter yield at lower and higher Ca and B levels seems to be due to influence of Ca/B ratio on plant growth, which caused reduction in dry matter yield. Similar findings were reported by Golakiya and Patel (1988). On the basis of average effects of Ca/B ratios the conclusion can be drawn that the 500:1 ratio would be desirable for good yield of radish in the nutrient solution. However, the data could not easily show a range of minimum and maximum for Ca/B ratio in solution for obtaining a good yield, because the differences among the treatments were not very large. This indicates that besides a favorable ratio, a minimum of absolute concentration of both nutrients in the growth medium is essential (Lal *et al.*, 1979).

Ca concentration and uptake

Results showed that with increasing the Ca in solution the concentration of Ca in tops as well as in roots non significantly increases (Table 3), and considerably decreases with each increment of added B in the nutrient solution. However, the decreasing trend is more marked in tops than roots. Results revealed that the Ca concentration in plants largely depended to solution B as expected, and this indicated that the absorption of Ca was controlled by the B levels in the solution, because of antagonism. This indicates that the Ca absorption and utilization by radish is dependent to B in the growth medium. These results accord with those reported by Patel and Mehta (1966) and Yamauchi *et al.* (1986). Another important point which was obvious from the present results is that at 500 mg Ca and 1 mg B L^{-1} the concentration of Ca was slightly reduced in both tops and roots of plant, but the total uptake was increased. Perhaps this may be due to a dilution effect, because such treatment produced maximum dry matter. Similar conditions for dilution effect in plant nutrition studies were also reported by Jarrell and Beverly (1981). Regarding the data of the total uptake of Ca by tops and roots showed an inconsistent trend (Table 3), but it is obvious from the results that significant differences existed in the treatments due to large variations in the solution levels. A maximum uptake of Ca in the tops was recorded at 500 mg Ca and 1 mg B L^{-1}, and this treatment produced maximum dry matter yield as well. In roots a maximum uptake was obtained at 500 mg Ca and 0.25 mg B L^{-1}, followed by 500 mg Ca and 1 mg B L^{-1} in the

Table 3. Effect of added Ca-B levels on the concentration and total uptake of Ca and B by radish

Added Ca (mg L^{-1})	Added B (mg L^{-1})	Ca concentration %		Ca uptake mg pot^{-1}		B concentration µg g^{-1}		B uptake µg pot^{-1}	
		Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots
500	0.05	3.06	0.86	56.3	7.9	59.3	17.4	109.2	16.0
	0.25	2.81	0.78	71.9	29.2	76.0	18.1	194.6	67.5
	1.0	2.68	0.56	151.1	27.8	111.3	29.8	627.9	148.3
	5.0	2.80	0.62	46.5	11.0	266.0	40.3	441.6	71.7
200	0.05	2.15	0.80	47.1	7.4	59.3	19.4	129.9	17.9
	0.25	2.00	0.65	83.2	24.4	84.7	22.9	352.2	86.2
	1.0	1.93	0.54	67.5	20.9	112.0	22.9	392.0	134.4
	5.0	1.66	0.50	32.7	6.9	291.3	34.7	573.9	57.5
80	0.05	1.28	0.63	33.5	8.6	60.7	41.7	158.9	28.5
	0.25	1.26	0.50	35.3	20.5	85.3	20.8	238.9	111.0
	1.0	1.09	0.48	32.8	18.5	114.0	27.1	343.1	155.1
	5.0	1.11	0.39	21.6	4.6	302.7	40.3	590.2	54.4
LSD (P<0.05)									
Ca		NS	NS	412.7	NS	0.63	0.59	40.73	NS
B		61.79	25.51	305.3	84.47	0.46	0.43	30.13	18.54
CaxB		NS	NS	234.7	NS	NS	NS	23.16	NS

NS = Non Significant

solution, but the differences found in these two treatments were statistically non significant. Furthermore, the reduced uptake of Ca by roots was observed in the highest and lowest B levels, indicating the interference of very low and excessive B may cause the reduced uptake of Ca by plants. These results are in line with the previous study of Woodbridge *et al.* (1974). It can be concluded from the overall results of Ca that a close association found between the Ca and B with respect to its absorption and utilization by radish plants.

B concentration and uptake

Results show that with increasing B in the nutrient solution, the concentration of B both in tops and roots were significantly increased (Table 3), but the magnitude of increased B was independent to the supply of Ca as observed in the different Ca levels of the solution. Similar results were also reported by Yamauchi *et al.* (1986) for tomato in sand culture study. Results further revealed that the concentration of B found in tops is 3 to 7 times higher than roots, suggesting leaves are the main organ for B accumulation and the amount of B accumulated in the leaves was not retranslocated to the roots during plant growth. Francois (1986) also found nearly similar differences of B in both plant parts of the radish using sand culture technique. Moreover, in the present study reduced B concentration in the roots of the radish plants is perhaps caused by high Ca in the solution, the rate of transpiration greatly affected the B transport and its distribution from roots to leaves of plants (Oertli, 1994).

Results regarding the total uptake of B by tops showed a similar trend as for B concentration in plants (Table 3), but the roots data showed reduced B uptake at high B rate at each Ca level. This reduced B uptake by roots in the treatments 500/5, 200/5 and 80/5 were mainly due to growth response, because such treatments also yielded low dry matter for roots as compared to rest of the treatments. These results are in line with the findings of Dwivedi *et al.* (1992) who concluded that the reduced total uptake of B by pea and corn was merely due to sharp depression in dry matter yield at highest rate of B fertilization. However, the maximum B uptake by tops and roots were recorded from a treatment receiving 500 mg Ca and 1 mg B L^{-1} in the nutrient solution, indicating the increased B uptake existed with a maximum dry matter yield of radish.

Ca/B Ratio

The results of Ca/B ratio in plants are presented graphically in Figure 1 for both plant parts, and the graphs were drawn using log scale for the X-axis in terms of Ca/B ratio in the nutrient solution. Results

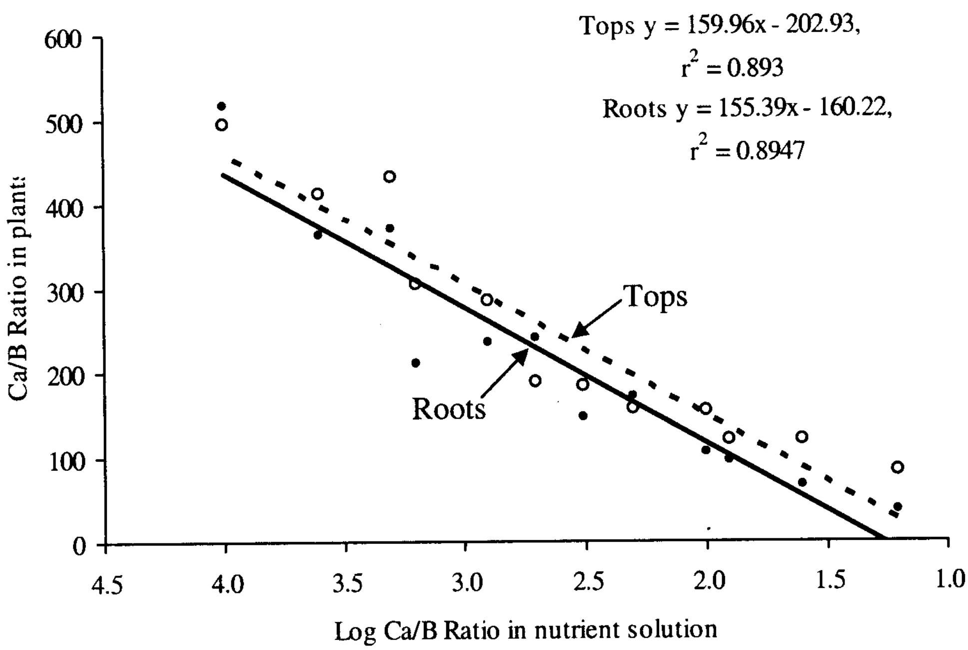

Fig 1. Relationship between Ca/B Ratio in nutrient solution and in radish plants

show that the Ca/B ratio in plant tops and roots significantly decreases as the solution ratio decreased and resulted a positive correlation. But the magnitude of decrease/increase in the plant ratio is depended on the levels of both elements in the substrate. Similar results were reported by various investigators who conducted sand culture studies, testing different crop species such as tomato (Brennan and Shive, 1948), siberian millet (McIlrath and Debryn, 1956), tobacco (Patel and Mehta, 1966), and sunflower (Tanaka, 1967). It is well documented that the Ca/B ratio in solution and plants generally increased with increasing Ca supply, and decreases with increasing supply of B. In the present study, as might be expected, the plants receiving the lowest level of B in each Ca level had highest Ca/B ratios and those on the highest level of B exhibited the lowest Ca/B ratios. However, if the Ca/B ratio is used as a measure of B deficiency, sufficiency and toxicity status, then the present results indicated that an increase in Ca/B ratio of the growth medium has also increased the Ca/B ratio in plant, and bring the plant closer to a condition which approaches B deficiency. Furthermore, a maximum yield is associated with a solution ratio of 500:1, corresponding to plant ratio 241 and 188 in tops and roots, respectively. Results also show that the Ca/B ratios found in roots are considerably higher than tops, which in fact may be due to the low Ca concentration occurred in the roots, or high concentration of B found in the tops. However, throughout the experiment the values of the Ca/B ratios varied over a wider range in the tops than in the roots of plants. In general, the overall results of Ca/B ratio in plants suggested that B toxicity was the main cause of reducing the ratio in tops and roots of radish plant. It is good evidence that the deficiency/toxicity of B in the substrate (soils) can also be characterized by high and low Ca/B ratios in radish plants. Similar conclusions were drawn by Singh and Sinha (1976) in the case of cauliflower grown on B deficient and rich soils. In the present study, it was also observed that plant parts and some experimental conditions, however, caused a difference in these ratios. The conclusion can be drawn from the present results and agreed with the literature that the possibility of using Ca/B ratio in plants as a guide in determining the need of B fertilization, which can be used as an index of the B status in soil-plant system.

CONCLUSIONS

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

- Maximum fresh and dry matter yields were recorded at 500 mg Ca and 1 mg B L^{-1}, corresponding to Ca/B ratio of 500:1 in the nutrient solution. An optimum Ca/B ratio in plant tops and roots were found to be 241 and 188, respectively. The values for both plant parts found to be normal in predicting the maximum yield of radish plant.
- The concentration and total uptake of Ca and B in radish plants increased with increasing the respective levels of these elements in the nutrient solution, and showed a close similarity to growth response of radish plants, indicated total uptake was a useful but alternative way in determining the effect of Ca-B on the response of plant's content of these two elements.
- With decreasing the Ca/B ratio in nutrient solution the ratio in tops and roots of radish plants linearly decreases and showed significantly positive correlations with one another, indicated plant's Ca/B ratio is dependent to ambient ratio.

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