VOL. 1, NO. 2, AUGUST 2006 ISSN 1990-6145
Journal of Agricultural and Biological Science

www.arpnjournals.com

EFFECT OF BORON SUPPLY ON THE UPTAKE OF MICRONUTRIENTS BY RADISH (*Raphanus sativus L.*)

M. Tariq[1] and C. J. B. Mott[2]
[1]Department of Soil and Environmental Sciences, NWFP Agricultural University, Peshawar, Pakistan
[2]Department of Soil Science, University of Reading, England, UK
E-mail: [1]drtariqssc@yahoo.com

ABSTRACT

The present study was based on the hypothesis that Boron (B) induces changes of other micronutrients in soil-plant systems. A preliminary study was carried out in sand culture growing radish (*cv. French breakfast*) as a test crop, 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 significant treatment effects were found on the growth response of radish plants, and maximum yield was recorded at 0.5 mg L^{-1} of added B. Toxic effects accompanied by considerable yield decreases was observed at higher levels of B supply. The concentrations of B, Zn and Cu in plants were increased and Fe, Mn and Mo were decreased. The total uptake of all micronutrients except B decreased with increasing levels of B in the nutrient solution, and showed close similarity to the growth response of radish plants. Generally, low and high levels of added B had interactive effects on the concentration and total uptake of micronutrients. Moreover, Zn/Cu ratio increased and Mn/Zn and Mn/Fe decreased, while Fe/Cu showed inconsistent trend with increasing B levels in the nutrient solution. Differences in the concentration and total uptake of micronutrients occurred because of (a) nutrient concentration or dilution in the radish plants, and (b) nutrient distribution among the root and top of plants. Differences arising purely from differential distribution could be eliminated if the composition of the entire plant is considered as a unit. It was however, evident that B supply had specific effects with respect to different micronutrients.

Keywords: radish yield, concentration, total uptake, ratios, interaction, sand culture.

INTRODUCTION

Boron is one of the important micronutrient among essential elements for plant growth, and play a significant role in the physiological and biochemical processes within plants. Several reports in the literature indicated that the supply of B in the substrate may affect the behavior of other micronutrients in plants, but the specific function of B on the behavior of other micronutrients is not well defined. Presumably, due to its complex chemistry in soil and little known physiological and biochemical functions in plants. Moreover, it is well understood that the B chemistry in soil and its role in plant is differs from other micronutrients, such as Zn, Cu Fe, Mn and Mo, but its deficiency or excess may affect the solubility of these micronutrients in soil (Santra *et al.*, 1989) and uptake by plants (Alvarez-Tinaut *et al.*, 1979; Gomez-Rodriguez *et al.*, 1981; Dave and Kannan, 1981). So, it is evident from the literature that B induced changes of other micronutrients in soil-plant system, but still it is not clear whether the effects of B on the behavior of other micronutrients are based on the physiology of plants or due to some chemical reactions in soils. It is also not known whether B has a direct effect on the micronutrients concentration and transport or is indirectly involved in the physiology of these micronutrients. However, information regarding the effect of B on the uptake and transport of micronutrients (Zn, Cu, Fe, Mn and Mo) is scant. A preliminary study was undertaken to determine whether changes in mineral nutrients composition were similar to those observed by various workers in solution/ sand culture studies for different crops, such as Parks *et al.* (1944) for tomato, McIlrath *et al.* (1960) for perennial fodder grass, Gomez-Rodriguez *et al.* (1981) for sunflower and Mozafar (1989) for maize, could be demonstrated in radish using sand culture technique. Because soil modifies the availability of applied nutrients due to fluctuations in pH, lime and organic matter content and several other factors. However, the most suitable approach for such experiment would seem to be by means of sand culture technique. Highly purified quartz sand will not react with any nutrient of culture solution. Moreover, the great porosity of sand (<250µm) assures the roots of well aerated medium (Hewitt, 1966). Therefore, to test the general hypothesis that Boron induces in the availability of other micronutrients, an experiment was carried out with the objective, to assess the influence of B on the concentration, total uptake and ratio of micronutrients 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 18^0C, 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 30cm of each other. The position of each pot was randomly changed once a week,

Journal of Agricultural and Biological Science

to minimize the spatial variations in the green house during the course of experiment.

Sand and pots:

Before use the sand was washed with tap water, rinsed in deionised water and then soaked in 3% HCl + 1% oxalic acid mixture for one week. After that period the sand was leached several times with deionised water until the pH of the leachate was the same as water. The sand was air dried in plastic trays under growth chamber conditions (Hewitt, 1966). The plastic pots and saucers were also washed thoroughly in 3% HCl and then with deionised water and dried in an oven at 40° C.

Sowing:

Six radish seeds *(cv. French breakfast)* was sown uniformly 1cm deep and 2.5cm apart from one another, in each 15cm 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.

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 5.0mg 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 is 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 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

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 and measurements:

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 the fresh weight of tops and roots were recorded for each treatment pot. The separated parts were dried in aluminum dishes at 80°C for 48 hours in a large oven. After drying the plants were weighed and the dry weight of tops and roots were recorded for each treatment pot.

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 Zn, Cu, Fe, Mn, Mo 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

Fresh matter yield:

Fresh matter yield is an important component of radish crop and vegetable growers are always interested in its quantity as well as quality. The results showed that maximum yield of both tops and roots were obtained from the treatment receiving 0.5mg B L^{-1} followed by 0.25mg B L^{-1} (Table-2), but no significant difference was found between the yields of these two treatments, indicating a narrow range (as expected) for B sufficiency.

Table-2. Effect of added Boron on the yield of radish plants.

Boron Added mg L^{-1}	Fresh Matter Yield g pot^{-1}		Dry Matter Yield g pot^{-1}	
	Tops	**Roots**	**Tops**	**Roots**
0.0	24.45	39.27	2.36	2.39
0.25	38.60	61.69	4.18	3.86
0.5	38.70	65.03	4.46	3.97
1.0	32.41	47.35	3.85	2.99
2.0	26.96	38.87	3.36	2.43
3.0	22.15	37.52	2.76	2.37
5.0	18.04	25.26	1.94	1.65
LSD(P<0.01)**	11.13	30.66	2.02	2.77
LSD(P<0.05)*	9.05	17.55	1.18	1.05

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

A similar non-significant difference was found by Scripture and McHargue (1945) between 0.25 and 0.5mg B L^{-1} in sand culture study. The treatment received 0.5mg B L^{-1} seems to be an optimum level of soluble B for radish, which showed the best growth response. These findings are supported by the previous work of Coetzer *et al*. (1990) and Buzetti *et al.* (1990). Such treatment showed 58.28% increase for tops and 65.6% increase for roots over control, however, beyond the 0.5mg B L^{-1} the yield is significantly decreased due to toxic levels of added B. This is good evidence for demonstrating that the radish crop responds to added B in a limited range, above which toxic levels are reached causing a subsequent decline in yields. The conclusion can be drawn from the overall results that almost similar trends exist both in tops and roots with regard to fresh yield. However, the roots fresh weight was considerably more than tops, which in fact the storage organ of radishes contains high watery juice and are succulent in the fresh state. The analysis show that each unit increase in B supply above 0.5mg B L^{-1} reduced the fresh matter yield of radish, suggesting excess B supply reduced the size of bulbs and damaged the leaves of plants.

Dry matter yield:

Dry matter yield is an important criterion for the estimation of nutrient content and total uptake by plants. Dry matter yield of tops and roots were recorded separately, when fresh plant materials were oven dried until a constant weight was established. Results showed that again, the maximum dry matter yield of tops and roots were obtained from the treatment receiving 0.5mg B L^{-1}, but the yield of this treatment was found statistically at par with 0.25mg B L^{-1} as in the case of with fresh matter yield. This treatment also showed 88.89% increase for tops and 66.11% increase for roots over control. This indicates that the radish crop responds well within the normal range of added B. Similar results were reported by Agarwala *et al*. (1978) and Orlova *et al*. (1980). Results also revealed that further increase in B supply causes a subsequent decline in the yields. The decrease in yields are mainly due to the toxic effects of B, resulting in reduced size and weight of plants. These results also indicate that radishes are more sensitive to B toxicity than deficiency under the conditions of the experiment. Dry matter yield of tops and roots decreases in a similar way as in the case of fresh matter yield, but there is difference found in the weight of roots. In fresh matter yield the weight of roots were considerably more than tops, while in dry matter yield the roots are lower than tops, and this is due to a difference in the moisture content of roots and leaves.

Micronutrients concentration and total uptake:

As expected, B concentration in plants showed a significantly linear and positive relationship between B in tops ($r = 0.98$) and roots ($r = 0.92$) and B in nutrient solution (Table-3). 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

Journal of Agricultural and Biological Science

stream 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. Results also showed the B uptake by plants increases with each increment of added B except the treatment received 5mg B L^{-1} (Table-4). Results indicated that the reduction in B uptake at highest B level is due to either a growth response or due to the lower or higher concentrations of other elements in the respective treatment, created unbalanced nutrient ratios. These results are however, in line with the early work of McIlrath *et al*. (1960). It is also evident from the results that more uptake was obtained in the tops than roots as in the case with B concentration in plants. These results agreed with the previous findings of Kluge (1990) who reported that total uptake was concentrated more in the aerial part, whereas in the root less accumulated, suggesting passive acropetal transport of B with the transpiration stream. It is well understood that the range between deficiency and toxicity of B is very small which is also observed in the present study for radish plants. In the present study good growth was found at B concentration 74 to 159 µg B g^{-1} DM in the tops and 23 to 24 µg B g^{-1} in the roots. Toxic concentrations were possibly attained, when leaves and roots contained 256 to 586 and 48 to 51 µg B g^{-1} DM, respectively. Gupta (1983) also listed deficient, sufficient and toxic levels for radish (*cv. Cherry belle*) tops when the roots began to swell as < 9, 96-217 and > 217 µg B g^{-1} DM. However, comparing the present results with Gupta's results, the differences found are likely due to the different cultivar of radish used.

Table-3. Effect of added Boron on the micronutrients concentration of radish plants.

Boron Added mg L^{-1}	**B** ----------	**Zn** ----------	**Cu** -µg g^{-1}-	**Fe** ----------	**Mn** ------------	**Mo** ------------
			Tops			
0.0	34.84	17.89	3.59	52.48	104.6	3.81
0.25	74.03	16.18	2.94	52.89	84.15	5.67
0.5	110.7	15.24	2.83	56.19	80.50	4.58
1.0	159.0	18.38	3.33	57.77	75.16	3.71
2.0	255.9	19.72	4.03	59.59	74.03	3.06
3.0	455.9	19.09	3.53	52.79	71.50	2.89
5.0	586.7	21.20	2.94	47.92	67.88	1.52
LSD(P<0.01)**	156.1	NS	NS	NS	11.46	1.82
LSD(P<0.05)*	126.8	NS	NS	NS	8.18	1.48
			Roots			
0.0	13.25	20.06	1.35	31.87	14.88	0.26
0.25	17.03	14.20	2.05	59.93	12.65	0.24
0.5	23.16	16.60	1.74	30.14	12.23	0.40
1.0	23.93	22.53	1.70	26.96	11.32	0.62
2.0	30.36	18.84	1.51	26.65	10.58	0.43
3.0	48.17	21.29	1.23	25.67	9.90	0.32
5.0	51.34	14.76	0.94	19.47	9.29	0.07
LSD(P<0.01)**	20.62	NS	NS	NS	4.51	0.44
LSD(P<0.05)*	16.76	NS	NS	NS	2.63	0.25

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

Results showed an inconsistent trend in the Zn concentration of plants. This resulted non-significant effect of added B on Zn concentration (Table-3). Results further revealed that almost equal Zn concentrations were found in the tops and roots of radish plants, suggesting that Zn was equally distributed or not translocated from roots to tops, and this may be due to B effects on Zn mobility in plants. Shelp *et al*. (1987) also observed small changes due to B in the Zn translocation of radish plants. Results show that Zn uptake increases with increasing levels of added B up to 1mg B L^{-1} (Table- 4), but further increase in B levels decreases the Zn uptake. Moreover, the effect of B in depressing Zn uptake was more marked at 5mg B L^{-1}. This may be due to the interaction between B and Zn at higher levels of added B. Singh *et al*. (1990) found B-Zn interaction in plants due to boron toxicity.

The Cu concentration in plant tops tended to increase, while in roots decreases with increasing B levels in the nutrient solution (Table-3). This opposite trend may be due to changes occurring in the translocation of Cu from root to top within the plants. On

Journal of Agricultural and Biological Science

the other hand Cu uptake show an increasing trend up to 2mg B L^{-1} and onwards gradually decreases due to higher levels of added B (Table-4), suggesting normal levels caused more uptake over control as compared to higher B levels. The decrease in Cu uptake by tops and roots could be due to toxic effect of B on root cells, resulted in an impaired absorption process. Alvarez-Tinaut *et al.* (1979) and Singh *et al*. (1990) also reported that the low Cu uptake by plants was due to excess B.

Results showed that the Fe concentration in tops increases up to 2mg B L^{-1} then decreases with increasing B levels (Table-3), while maximum Fe concentration in roots was recorded at 0.25mg B L^{-1} in the nutrient solution. Similarly the highest Fe uptake occurred in tops at 0.5 mg B L^{-1}, and in roots at 0.25mg B L^{-1} (Table-4) then gradually decreased with each increment of added B, because of reduced plant growth and smaller root size, as affected by B toxic conditions. It is evident from the results of Fe concentration and uptake that higher levels of B antagonized Fe absorption, which seems to be related to a reduced ratio of Mn/Fe in plant tops and roots. However, it can be concluded and agreed with the literature (Singh *et al*., 1990 and Alvarez-Tinaut *et al*., 1979) that B is involved in the interaction of Mn-Fe in plants.

The Mn concentration in plant tops and roots significantly affected with the added B (Table-3). Results clearly shows that each B treatment reduces the concentration of Mn and this may be a contributory reason for the apparent toxicity of B to plants. Because of its absence the concentration of Mn in the tops was significantly increased, but the magnitude in the increase was not reached to the critical toxicity level of Mn in plants. Shorrocks (1995) reported that Mn toxicity and B deficiencies have close association in the visible symptoms of various crops, such as cotton, potato and muskmelon. The present findings with regard to the trend of Mn concentration in plants agreed with the findings of Gomez-Rodriguez *et al*. (1981), Alvarez-Tinuat *et al*. (1980) and Garate *et al*. (1984) , but they did not report clear physiological or chemical mechanism involved in the B-Mn antagonism. In general, it would seem perhaps that such antagonism in our investigation was the indirect effect of B on the absorption of Mn. This is suggested by the decreased Mn/Fe and Mn/Zn ratios in plants. Similarly, excess B application significantly reduced the uptake of Mn in plants (Table- 4). It is obvious from the results that an almost similar decreasing trend was found in Mn concentration and uptake by plants. Results also indicate that the uptake data is somewhat similar to growth response, indicating both were affected in the same manner. However, results suggested the hypothesis that the low Mn uptake with increasing levels of B could be due to B-Mn antagonism, and may caused decrease of the Mn/Zn or Mn/Fe ratios in plants.

The concentration of Mo was affected more strikingly by changes in B supply than that of any other micronutrient (Table-3). Results showed that the concentration of Mo significantly decreased both in tops and roots of radish with increasing levels of added B. The negative relationship of Mo and B are in contrast with the previous findings of Sillanpaa (1982). This contrasting relationship might be due to the difference in the metabolism of B in monocotyledon and dicotyledon crops, such as wheat-maize and radish. Results also showed that the growth response of radish, and Mo concentration or uptake has a similar trend, indicating similarity in B toxicity and Mo deficiency. The data revealed that at 5mg B L^{-1} the Mo concentration in roots was significantly reduced, and resulted in a value of 0.07 µg g^{-1} DM, which seems to be below critical deficiency level of 0.1 µg g^{-1} for various crops (Jones, 1972). However, it can be postulated that there is a probable antagonism between B and Mo at higher levels of added B, due to anion competition of molybdate and borate on root surface. These findings are in line with the early work of McIlrath *et al*. (1960). On the other hand, Bonilla *et al.* (1980) found that the visual symptoms in plants with Mo deficiency and B toxicity are very similar. They concluded that the drop in Mo due to B toxicity was due to reduced nitrate reductase activity and resulted in accumulation of NO_3. In the present study nitrate reductase activity was not determined, so it can only be assumed that at toxic B level Mo concentration in roots dropped below some critical level, which may be due to reduced nitrate reductase activity. Results further show that the Mo uptake was increased at 0.25 and 0.5mg B L^{-1} (Table-4), while further increased in B levels caused significant decrease in the uptake with each increment of added boron; this antagonism could be due to excess B in the substrate. It could be concluded from the overall results that higher levels of B causes possible antagonism between B and Mo in plants, presumably due to the competition between borate and molybdate anions on root cells, resulting in low Mo absorption.

Journal of Agricultural and Biological Science

www.arpnjournals.com

Table-4. Effect of added Boron on the total uptake of micronutrients by radish plants.

Boron Added mg L^{-1}	**B** ----------	**Zn** ----------	**Cu** ---µg pot^{-1}---	**Fe** ----------	**Mn** ------------	**Mo** ------------
Tops						
0.0	82.22	42.22	8.47	123.85	246.88	8.99
0.25	309.45	67.63	12.29	221.08	351.75	23.70
0.5	493.72	67.97	12.62	250.61	359.03	20.43
1.0	612.15	70.76	12.82	222.41	289.37	14.28
2.0	859.82	66.26	13.54	200.22	248.74	10.28
3.0	1258.5	52.69	9.74	145.70	197.34	7.98
5.0	1128.1	41.13	5.70	92.96	131.69	2.95
LSD(P<0.01)**	682.32	NS	NS	136.90	175.60	11.59
LSD(P<0.05)*	554.50	NS	NS	97.67	125.20	9.42
Roots						
0.0	31.67	47.94	3.23	76.17	35.56	0.62
0.25	65.74	54.81	7.91	231.33	48.83	0.93
0.5	91.95	65.90	6.91	119.66	48.55	1.59
1.0	71.55	67.36	5.08	80.61	33.85	1.85
2.0	73.77	45.78	3.67	64.76	25.71	1.04
3.0	114.2	50.46	2.92	60.84	23.46	0.76
5.0	84.71	24.35	1.55	32.13	15.33	0.12
LSD(P<0.01)**	NS	NS	3.38	64.97	28.92	NS
LSD(P<0.05)*	NS	NS	2.75	46.34	20.63	NS

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

Micronutrients ratio in radish plants:

Zn/Cu Ratio:

Results show that Zn/Cu ratio in tops increases, but an inconsistent trend in the roots was found with increasing levels of added B (Table-5). It is evident from the results that the increasing trend in the Zn concentration of tops is linked to the increase Zn/Cu ratio in plants, suggesting that perhaps B is indirectly involved in the Zn-Cu interactions. These results agreed with the previous findings of Leece (1978), he reported that due to higher B levels the Zn/Cu ratio tended to increase in plants.

Fe/Cu Ratio:

Results regarding the Fe/Cu ratio show an inconsistent trend indicating B has no consistent effect inducing the changes in Fe/Cu ratio both in tops and roots of plants (Table-5). In the literature information regarding the Fe/Cu ratio in plants with regard to B supply is very scarce, so, no satisfactory explanation can be offered, other than that the inconsistent trend in the ratio might be due to rather small changes which occurred in the concentration of these two elements, which is clear from the concentration and uptake results (Tables 3 and 4).

Mn/Zn Ratio:

Results showed that Mn/Zn ratio in plants decreased with increasing levels of added B (Table-5). The decreasing trend in the ratio was seems to be due to the reduction of Mn concentration in plants as affected by B supply. Warnock (1970) reported a Zn/Mn ratio associated to maximum yield was 4.4. In the present study the Mn/Zn ratio beyond 1mg B L^{-1} reduces below the reported critical limit, which suggests that the higher B levels caused a reduced ratio of Mn to Zn.

Mn/Fe Ratio:

Results show that Mn/Fe ratio significantly decreases with increasing levels of added B (Table-5). Results also revealed that low Mn/Fe ratio in tops and roots were found to be 1.24 and 0.21, respectively, indicating Fe concentration considerably increased and Mn decreased in the corresponding treatments. Alvarez-Tinaut *et al.* (1980) reported Mn/Fe ratio associated to maximum yield was 2.29. However, in the present study all the treatments showed low Mn/Fe ratios as compared to reported limit. The present results also suggest that the mechanisms involved under the B-Mn antagonism, perhaps due to the reduced ratio between Mn and Fe in plants.

Table-5. Effect of added Boron on the micronutrients ratios in radish plants.

Boron Added mg L^{-1}	Zn/Cu	Fe/Cu	Mn/Zn	Mn/Fe
Tops				
0.0	4.98	14.67	5.84	1.99
0.25	5.50	17.99	5.20	1.59
0.5	5.38	19.85	5.28	1.43
1.0	5.52	17.35	4.09	1.30
2.0	4.89	14.78	3.75	1.24
3.0	5.40	14.95	3.74	1.35
5.0	7.21	16.30	3.20	1.41
LSD(P<0.01)**	NS	NS	2.13	0.54
LSD(P<0.05)*	NS	NS	1.51	0.38
Roots				
0.0	14.86	23.60	0.74	0.47
0.25	6.93	29.21	0.89	0.21
0.5	9.54	17.32	0.73	0.40
1.0	13.25	15.86	0.50	0.42
2.0	12.47	17.65	0.56	0.39
3.0	17.30	20.87	0.46	0.38
5.0	15.70	20.71	0.63	0.47
LSD(P<0.01)**	NS	16.12	NS	0.14
LSD(P<0.05)*	NS	11.50	NS	0.10

Data of each ratio calculated from Table-3
*, ** = indicate significance at P<0.05 and P<0.01 levels, respectively
NS = non-significant

CONCLUSION

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

- Significant treatment effects were found on the growth response of radish plants, and maximum yields were recorded at 0.5mg L^{-1} of added B. Toxic effects accompanied by considerable yields decreases were observed at higher levels of B supply.
- The concentrations of B, Zn Cu in plants were increased and Fe, Mn and Mo were decreased. Generally, low and high levels of added B had interactive effects on the concentration and total uptake of micronutrients.
- The total uptake of all micronutrients except B decreased with increasing levels of B in the nutrient solution, and showed close similarity to the growth response of radish plants.
- Zn/Cu ratio increased and Mn/Zn and Mn/Fe decreased, while Fe/Cu showed inconsistent trend with increasing B levels in the nutrient solution.
- Differences in the concentration and total uptake of micronutrients occurred because of (a) nutrient concentration or dilution in the radish plants, and (b) nutrient distribution among the root and top of plants. Differences arising purely from differential distribution could be eliminated if the composition of the entire plant is considered as a unit.

REFERENCES

Agarwala, S. C., S. Farooq and C. P. Sharma. 1978. Interaction of boron supply and nitrogen source on growth, boron uptake, nitrogen fractions and sugars in radish. N assimilation and crop productivity, Proceedings National Symposium Hissar, India. October, 1976. New Delhi India, Associated Publishing Company. 185-194.

Alvarez-Tinaut, M. C., A. Leal, I. Agui and L. Recalde-Martinez. 1979. Physiological effects of B-Mn interaction in tomato plants. III. The uptake and translocation of microelements. Analse de Edafologia y Agrobiologia. 38 (5/6): 1013-1029.

Alvarez-Tinaut, M. C., A. Leal and L. Recalde-Martinez. 1980. Iron-Manganese interaction and its relation to boron levels in tomato plants. Plant and Soil. 55:377-388.

Bonilla, I., O. Cadhia, O. Carpena and V. Hernando. 1980. Effects of boron on the nitrogen metabolism and sugar levels of sugar beet. Plant and Soil. 57:3-9.

Buzetti, S., T. Murooka and M. E. DE. Sa. 1990. Boron rate for soybeans under different soil acidity conditions. 1: Dry matter, grain yield and critical level in the soil. Revista Brasileria de Ciencia do solo. 14(2):157-161.

Coetzer, I. A., P. J. Robbertse, E. Stoffberg, C. S. Holtzhausen and R. O. Barnard. 1990. The effect of boron on reproduction in tomato and bean. South Afric. J. of Plant and Soil. 7:212-217.

Dave, I. C. and S. Kannan. 1981. Influence of boron deficiency on micronutrients absorption by *Phaseoulus vulgaris* and protein contents in cotyledons. Acta Physiologiae plantarum. 3: 27-32.

Garate, A. R. O. Carpena-Ruiz and A. M. Ramon. 1984. Effect of boron and manganese and other nutrients in fluids of vascular tissues. An Edafology Agrobiologia. 43: 146-177.

Gomez-Rodriguez, M. V., M. Gomez-Ortega and M. C. Alvarez-Tinaut. 1981. Boron, copper, iron, manganese and zinc contents in leaves of flowering sunflower plants (*Helianthus annuus L.*) grown with different boron supplies. Plant and Soil. 62:461-464.

Gupta, U. C. 1983. Boron deficiency and toxicity symptoms for several crops as related to tissue boron levels. J. of Plant Nutri. 6:387-395.

Hewitt, E. J. 1966. Sand and water culture methods used in the study of plant nutrition. CAB. Tech. Commun. No. 22 (2nd ed.). pp: 431-432.

Jones, J. B. JR., 1972. Plant tissue analysis for micronutrients. Pp: 477-521.In Micronutrients in agriculture (2nd ed.). Eds. Mordvedt, J.J., P.M. Giordano and W.L. Lindsay. Soil Sci. Soc. Am. Inc. Madison, Wisconsin, USA.

Kluge, R. 1990. Uptake of boron by sugar beets (*Beta vulgaris L.*) during vegetative growth on loess soils with a high supply of boron. Bodenkultur, 41:195-203.

Leece, H. R. 1978. Effects of boron on the physiological activity of zinc in maize. Aust. J. Agric. Res. 29:739-749.

McIlrath, W. J., J. A. Debruyn and J. Skok. 1960. Influence of boron supply on the micronutrients content of *setaria* shoots. Soil Sci. 89:117-121.

Mozafar, A. 1989. Boron effect on mineral nutrients of maize. Agron. J. 81:285-290.

Oertli, j. j and W.F. Richardson. 1970. The mechanism of boron immobility in plants. Plant Physiol. 23:108-116.

Orlova, E. D., YU. I. Ermokhim and L.M. Likhomanova. 1980. Boron content in plants and yield of table beets in relation to nutrient conditions. Agrokhimiya. 1:74 -79.

Parks, R. Q., C.B. Lyon and S. L. Hood. 1944. Some effects of boron supply on the chemical composition of tomato leaflets. Plant Physiol. 19: 404-419.

Salinas, R., A. Cerda and V. Martinez. 1986. The interactive effects of boron and macronutrients (P, K, Ca and Mg) on pod yield and chemical composition of Pea Pisum sativum). J. of Hort. Sci. 61:343-347.

Santra, G. H., D. K. Das and B. K. Mandal. 1989. Relationship of boron with iron, manganese, copper and zinc with respect to their availability in rice soil. Environ. and Eco.7:874-877.

Scripture, P. N and J. S. Mchargue. 1945. Boron supply in relation to carbohydrate metabolism and distribution in the radish. J. Am. Soc. Agron. 37: 360-364.

Shelp, B. J., V. I. Shattuck and J. T. A. Proctor. 1987. Boron nutrition and mobility and its relation to the elemental composition of greenhouse grown root crops. II: Radish. Commun. Soil Sci. and Plant Anal. 18:203-219.

Shorrocks, V. M. 1995. Mn toxicity = B Deficiency. In Micronutrient News and Information. A quarterly publication: Published by Micronutrient Bureau, M. B. House, Wigginton, Tring, Herts HP23 6ED, England. 15(13):195.

Sillanpaa, M. !982. Micronutrients and nutrients status of soils – A global study. FAO Soils Bull. No. 48: Rome.

Singh, J. P., D. J. Dahiya and R. P. Narwal. 1990. Boron uptake and toxicity in wheat in relation to zinc supply. Fert. Res. 24: 105-110.

Steel, R. G. D and J. H. Torrie. 1980. Principles and procedures of statistics: A biometrical approach. 2nd Ed. McGraw Hill, New York, USA.

Warnock, R. E. 1970. Micronutrient uptake and mobility within corn plants (*Zea mays L.*) in relation to phosphorus induced zinc deficiency. Soil Sci. Soc. Am. Pro.34:765-767.