Asian Journal of Plant Sciences

ISSN 1682-3974

Asian Journal of Plant Sciences 6 (1): 195-202, 2007
ISSN 1682-3974

Effect of Boron on the Behavior of Nutrients in Soil-Plant Systems-A Review

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Abstract: This review is based on the hypothesis that B induce changes of other nutrient-elements in soil-plant systems. Since B is related to many physiological and biochemical processes are likely to affect the utilization of other plant nutrients, but yet no clear physiological and chemical mechanisms were proposed in the literature. However, B interactions, either synergism or an antagonism, can affect plant nutrition under both deficiency and toxicity conditions. There are clear differences observed and contradictions in plant nutrient response with regard to B supply, which must be due to the use of different growth media, crop species and varieties, plant parts analyzed, various growth stages and environmental conditions. The evidence suggests that the deficiency or excess of B not only affects the relative values of individual elements, but it also affects the balance among certain nutrient elements within plants, causing either an increase or decrease of dry matter production. Therefore, one might expect that the effect of B on the nutrient elements to be very complex. It can be concluded from the literature review that B play a role in the nutrient interactions within plant, but it is still not clear whether B is directly or indirectly involved in the interaction of certain nutrients, however the nature of these complex interactions are still obscure.

Key words: Plant nutrients, behavior, interaction, cation-anion balance, ratio, utilization, accumulation, uptake and translocation

INTRODUCTION

Boron is thought to have a favorable influence on the absorption of cations particularly calcium, to have retarding influence on the absorption of anions and to have an essential part in carbohydrate and nitrogen metabolism (Batey, 1971).

The above quote aptly introduces the main theme of the present review. Boron is of course, one of the recognized micronutrients for plant growth. The response of crops to B not only varies with plant species, soil type and environmental conditions, but also its excess/deficiency may affect the availability and uptake of the other plant nutrients. In the literature, quantitative information on the relationships between B and other nutrients is neither common nor always clearly reported. An account of the few studies conducted on the behavior of nutrients with regard to B supply for various crops growing in different growth media i.e., sand, nutrient solution, vermiculite, peat and soils under glass house and field conditions is given in the various sections of the present review.

Plant aspects: It is certainly known that B appears to play a significant role in nutrient transport by plant membranes (Tanada, 1983). Some authors have concluded that B supply may influence, as a regulator or inhibitor, the accumulation and utilization of other plant nutrients (Alvarez-Tinaut *et al.*, 1979a,b). Because excessive amount of B may interfere with metabolic processes, thereby affecting the uptake of other nutrients by plants (Corey and Schulte, 1973). On the other hand, B deficiency may also reduce the levels of plant nutrients (Carpena-Artes and Carpena-Ruiz, 1987). Generally, it can be concluded from the findings of these investigators that B is involved in physiological and biochemical processes inside the plant cell, altering the concentration and translocation of nutrients. Singh *et al.* (1990) reported that high levels of applied B had an antagonistic effect on the uptake of nutrients in wheat plants. But in contrast, a synergistic effect was also reported due to excess B supply on the uptake of nutrients by tomato plants (Carpena-Artes and Carpena-Ruiz, 1987). However, there is a lack of agreement among investigators with regard to the specific effect of B on the behavior of any given element, either present in the nutrient substrate or in the plants. Some studies suggest that B effects are related to all the cation and anion values in plant. Wallace and Bear (1949) stated that increase B uptake resulted in a decrease cation-anion equivalent ratios in the leaves and increase

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in the roots of alfalfa plants. Similarly Valmis and Ulrich (1971) observed that with increasing the concentrations of B in the nutrient solution the cation-anion values decreases in the leaves of sugar beet. These results suggest that the B effect is related to the type of ions or valence of ions in the plants. Moreover, a further strand in soil B research has been the use of nutrient ratios, rather than simple amounts of individual elements in yield analysis. Shear *et al.* (1946) and Wallace and Bear (1949) reported that a high ratio of Ca+K/Mg and Ca+Mg/K in plants is associated with B toxicity, but high K+Mg/Ca ratio has little influence on B toxicity. Similarly Leece (1978) reported that in the presence of B, P/Zn, Fe/Zn, Cu/Zn and Mn/Zn ratios increased in maize crop. However, these results suggest that B may be indirectly involved in the nutrient balance of plants, causing either improvement or reduction of plant growth and production.

Soil aspects: Lal and Rao (1954) reported that B serves to regulate the accumulation of ions even from nutrient solutions. Similarly, Santra *et al.* (1989) reported that B not only functions within the plant but also in the nutrient medium, thereby affecting the intake of nutrients. These results suggest that B may also serve to regulate or retard the availability of ions from soils. Bartlett and Picarelli (1973) observed that applied B along with lime lowered the Al and Mn concentration to a greater extent than with lime alone of acid soil. Moreover, Belvins (1995) reported that higher than normal levels of B would alleviate Al toxicity, specifically by increasing the root growth of plants. These studies show that B may help in the amelioration of soil acidity and counteract the Al toxicity in acid soils. In the literature, there is considerable disagreement between those who have worked with plants grown in soils and those who used sand or solution culture techniques. In sand culture studies, Mozafar (1989) reported that with increasing B levels the concentration of plant nutrients were changed in the leaves as well as in the roots of maize plants. While, in soil studies, Miller and Smith (1977) reported that applied B did not consistently affect the concentration of elements in tips, upper and lower leaves, upper and lower stem of alfalfa plants. It is clear from the reported conflicting statements of the investigators, that B effects on the behavior of nutrients vary depending on crop species or genotypes, plant part analyzed, various growth stages and the use of different types of growth media.

Nutrient behavior in relation to boron supply: The effects of B deficiency, sufficiency and toxicity on the mineral nutrient content of plants are not well established. The results of investigations of this relationships appear to be conflicting, but the differences observed are probably the result of the various worker's using different crop species (Lombin and Bates, 1982) and varieties (Mozafar, 1989). Similarly, the use of solution (Wallace *et al.*, 1977; Gomez-Rodriguez *et al.*, 1981) or sand culture techniques (Smith and Reuther, 1951; McIlrath *et al.*, 1960) and various soils (Singh and Sinha, 1976; Agbenin, 1990), analysis of different plant parts (Miller and Smith, 1977; Singh and Singh, 1984), at different growth stages (Carpena-Artes and Carpena-Ruiz, 1987). Since B is related to many physiological and biochemical processes are likely to affect the utilization of other plant nutrients. Therefore, one might expect the relationship between B and other nutrients utilization to be very complex. In the literature, quantitative information on the effect of B on the availability and uptake of other nutrients is scarcely found. Even when information is available, reasons are by no means clear, because no physiological and chemical mechanisms were proposed. This review deals with the few studies and are presented as examples of cases where B had an effect on the availability and uptake of other plant nutrients. For example, Parks *et al.* (1944) were the first researchers who reported that with graded B levels the concentrations of NH_4-N, NO_3-N, Org-N, P, K, Ca, Mg, Na, Zn, Cu, Fe, Mn, Mo and B were altered in the tomato leaflets as much as several times. In addition, they stated that B supply had specific effects and the trends found were completely dissimilar with respect to different elements. Later on Steinburg *et al.* (1955) found that in the absence of B the concentrations of N, K, Ca, Mg, Na, Cu and Mn in tobacco leaves were increased and the concentrations of P, Fe and Al were decreased as compared to plants fed with a B adequate nutrient solution. Baker and Cook (1959) reported that P, K and Mg were higher and Ca was lower in severely B deficient alfalfa plant than healthy ones, perhaps due to the dilution effect which occurred in healthy plants. McIlrath *et al.* (1960) found that with increasing B the concentrations of Cu, Fe, Mn, Mo and B were increased in perennial fodder grass, but the reverse trend occurred in the case of uptake and ash content for these micronutrients except B. Tolgyesi and Kozma (1974) reported that Cu and K contents showed a highly significant positive correlation, while Ca and Mg contents showed a negative correlation with B contents of 98 grasses at the flowering stage. Touchton and Boswell (1975) observed that P, K, Ca, Mg, Na, Zn, Cu, Fe, Mn, Mo and Al concentrations varied slightly with location, but were not affected by the method or rate of B application. Only B concentration in tissue was significantly increased with regard to method, rate and location. Wallace *et al.* (1977) observed the phytotoxicity and some interactions due to increased concentration of Zn, Cu, Fe and Mn in the leaves, stem and roots of bush bean plants with increasing B in nutrient solution. But contradictory results were reported by Leece (1978) He observed that with high level of applied B the concentrations of N, P, K, Ca, Zn, Cu, Fe and Mn (not Mg) in maize crop were depressed. The reverse results were obtained where no B was applied. Aduayi (1978) reported that with increasing B supply in soil resulted in the decrease of leaf N and P in tomato, suggesting B antagonism. The contrary was the case with a B effect on leaf K, Ca, Mg and Na. Yadav and Manchanda (1979) noted that with an increase in the B content of soil, tissue Ca and Mg concentration in wheat and gram crops significantly decreased, whereas N, P and K contents were significantly increased. Alvarez-Tinaut *et al.* (1979 a and b) reported that both the B deficiency and excess significantly stimulated the uptake and translocation of N, P, Ca, Mg, Zn, Mn, Fe but not K and Cu in hydroponically grown tomato. After a year Alvarez-Tinaut *et al.* (1980) again reported that with differential supply of B in nutrient solution the concentration of Fe, Mn, P and Ca in shoots and roots of tomato increased and B reduced the translocation of Mn, enhanced P and Fe and Ca remained unchanged. Downton and Hawker (1980) reported that with added B to nutrient solution the concentration of N, P, Ca, Mg and B was decreased, K increased, while Na remained unaffected in lamina, stem and roots of cabernet sauvignon vine plants. Gomez-Rodriguez *et al.* (1981) found a highly significant inverse correlation between B and Mn concentration in the leaves of sunflower, while Cu, Fe and Zn concentrations were not changed by different B levels in nutrient solution. Similarly, Dave and Kannan (1981) observed that a marked reduction in Fe and Mn adsorption but an increase in Zn uptake was recorded in bean plants raised in a B deficient medium. The transport of Fe, Mn and Zn was increased in the trifoliate leaves, while that in shoots was reduced. Moreover, they suggested that B is involved in the physiological processes controlling the uptake and transport of Fe, Mn and Zn. Lombin and Bates (1982) found that with increasing B levels the uptake of K, Mn, Zn, Cu, Mo and B increased by alfalfa, peanut and soybean crops but had no apparent effect on the uptake of Ca and Mg in all crops. Similar detrimental effect of B on the uptake of Ca and Mg was reported by Singh and Singh (1983) they observed varying B levels significantly increased the concentrations of N, P, K, Na and B and decreased the Ca and Mg concentration in lentil plants. Similarly, Singh and Singh (1984) reported that applied B increased the N, P, K, Na and B contents, but decreased the Ca and Mg contents of barley crop. On the other hand, the uptake of N, P, Na and B by grain and straw significantly increased, whilst K uptake remained unaffected with an increase in B application. Francois (1984) reported that with increasing soil solution B the concentration of B, P, K and Mg tended to increase in tomato leaf, while Ca and Na showed inconsistent trend. After two years Francois (1986) again demonstrated the effect of B on chemical composition of radish, using sand culture technique. He found that Ca and P concentrations decreased significantly and K, Mg and Na remained unchanged with increasing B levels in the substrate. Morsey and Taha (1986) reported that applied soil B and foliar application increased the concentration and uptake of N, P, K, Mn and B in both tops and roots of sugar plants. Patel and Golakia (1986) demonstrated the effect of soil B on the uptake of N, P, K, Ca, Zn, Cu, Fe and Mn by a groundnut crop. It is interesting, they proposed the mechanism for some nutrients in relation to B effect. For example, B increased N uptake and could be responsible for a favorable effect on nodulation. A positive effect of B on P uptake, which altered the permeability of plasmalemma at the root surface, resulted in increase P absorption. Uptake of K increased because of their mutual synergistic relationship, but Ca decreased due to antagonistic effect. Uptake of Fe and Cu were positively correlated, while Mn and Zn negatively correlated with applied B. Similarly, El-Fattah and Agwah (1987) observed the tip burn percentage was negatively correlated with Ca and positively with N, P, K, Fe and Cu concentrations in the leaves of lettuce. Carpena-Artes and Carpena-Ruiz (1987) reported that the deficient states of B decreased the leaf N, P, Ca, Mg, Fe, Cu, Zn and B in tomato. On the other hand, excess B increased the concentration of nutrients with greater significance for K, Mg and Fe, followed by Ca and Mn and in smaller quantity Cu and Zn. Nable (1989) observed that B toxicity had no consistent effects on the tissue concentration of P, K, Ca, Mg, Zn, Cu, Fe and Mn of five barley and six wheat cultivars grown in nutrient solution and no interactions were found among B, nutrients and cultivars. In the same year Pal *et al.* (1989) observed that higher levels of applied B significantly depressed the N and enhanced P and K contents in the three cuttings of berseem crop. Singh *et al.* (1990) reported that the concentration of P, Mg and Zn in wheat increased and Ca, K, Cu, Fe and Mn decreased with increasing B in soil. On the other hand, an increasing supply of B significantly decreased the uptake of P, K, Ca, Mg and Mn while that of Zn, Cu and Fe increased. They concluded that high levels of applied B had an antagonistic effect on the uptake of nutrients and this could be due to the toxic effects of B on root cells, resulting in an impaired nutrient absorption process.

Alvarez-Tinaut (1990) found positive correlations between B and Fe and Cu contents of sunflower, suggested that B could indirectly affect catalase activity via Fe and Cu. Positive correlation between Zn and B also indicate that B could indirectly affect the enzyme through modification of the Zn content. Tyksinski (1993) reported the antagonism between B and Zn, Cu and Mo and synergism between B and Mn, Fe in lettuce leaves, grown under differential micronutrients fertilization. Tariq (1997) reported that the concentration, total uptake and ratios of certain nutrients in radish tops and roots were considerably changed with differential B supply to nutrient solution. However, his study also suggested that the changes occurred in the nutrients response were mainly due to B effect and partly due to antagonism between Ca and B. It is clear from the reported literature review that B interactions, either synergism or an antagonism, can affect plant nutrition under both deficiency and toxicity conditions. There are clear differences observed and contradictions in plant nutrient response with regard to B supply, which must be due to the use of different growth media, crop species and varieties and environmental conditions. Therefore, one might expect that the effect of B on the nutrient elements to be very complex (apart from few elements) which need further detail investigations.

Functional relationship with other plant nutrients: Beside the general functions of B, it is important to review the functions of B in relation to other plant nutrients. Lal and Rao (1954) stated that a physiological effect of B is as a carrier of essential elements. A brief description of some elements which have functional relations to B are as follows.

Nitrogen: Bonilla *et al.* (1980) observed that B deficiency and toxicity resulted in more NO_3-N accumulation in the sap of sugar beet due to the decrease in the activity of the N-Rase enzyme, suggesting a specific effect of B on N-Rase activity. Similarly, Shen *et al.* (1993) reported the N-Rase activity in rape plants was markedly increased with increasing N with B than without added B.

Phosphorus: Pollard *et al.* (1977) found that B deficiency in corn and broad beans reduced the capacity for the absorption of phosphate, due to the reduced ATPase activity, which could be rapidly restored by the addition of B. The evidence suggested that B functions in the regulation of plant membranes and that the ATPase is a possible component of transport processes. The possible mechanisms, whereby this control is exercised, include direct interaction of B with polyhydroxy components of the membrane and the elevation of endogenous levels of auxins. Chatterjee *et al.* (1990) observed that P deficiency i.e., (soluble protein, DNA, activity of ribonuclease and increase activities of peroxidase, acid phosphatase and polyphenol oxidase) were intsified by a combined deficiency of B and P. On the other hand, decrease in (starch, sugar content, DNA, RNA and activity of ribonuclease) were aggravated by a combined excess of B and P.

Potassium: Shorrocks (1990) reported that effects of B and membrane permeability could lead to association between B and K. The stimulation of K accumulation by the ATPase proton pump which may account for positive correlations between K and B.

Calcium: Regarding the similarity of B functions to other plant nutrients, Ca-B relationship is out standing. Both elements play an important role in cell wall metabolism and are required for auxin transport process (Dela-Fuente *et al.*, 1986). Boron deficiency induces abnormal changes in the metabolism of the cell wall. However, in tomato B deficiency slightly increased Ca uptake but inhibited Ca translocation to the upper leaves (Yamauchi *et al.*, 1986). Boron tends to keep Ca in a soluble form within the plant: effects are probably on a tissue basis rather than on a cellular basis (Wallace, 1961). The results of Ramon *et al.* (1990) also suggested that B deficiency has a specific effect on Ca translocation and incorporation into an insoluble form i.e. as cell wall components. It is well known 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). Chatterjee *et al.* (1987) studied the metabolic changes associated with B-Ca interaction in maize and found when both B and Ca were deficient together the activity of starch, phosphorylase, ribonuclease and polyphenol oxidase markedly increased, suggesting that the deficiency of both elements was associated to metabolic changes in maize plants.

Copper: Literature indicated that B functions are different from other metabolic micronutrients, but there is some evidence that B may be involved in the enzymatic activity of plants. Brown (1979) reported that B stressed plants had a higher ascorbic acid oxidase activity than B sufficient plants. Similarly Adams *et al.* (1975) reported that accumulation of phenolic compounds also to be a factor in Cu deficiency of chrysanthemums, that prevented bud initiation.

Zinc: Leece (1978) reported that B deficiency rendered Zn inactive in maize plant, possibly due to the accumulation of IAA excess some form of feedback inhibition along its pathway of synthesis, which in turn leads to maize inactivation in some unspecified manner. Pilipenko and Solovieva (1979) also observed that Zn uptake was decreased in B deficient navy bean plants. The distribution of Zn in different organs corresponded to the ATPase activity localized in cell walls of roots and stems.

Iron: It appears that B may be concerned with the oxidation-reduction equilibria in cells (Wallace, 1961): such oxidation-reduction processes arise when metals acting in electron transfer systems change their valance. The early work of Cook and Millar (1940) showed that in the absence of B possibly Fe became fixed in the different parts of sugar beet and spinach plants as relatively insoluble and non-movable forms, perhaps as ferric ion. The evidence indicates that B may be involved in changing the valence of Fe.

Molybdenum: Bonilla *et al.* (1980) studied the effect of B deficiency and toxicity on the N metabolism of sugar beet and found Mo and N-Rase activity in leaf decreased, while NO_3-N in the sap, K and B in the leaf increased with increasing B supply. The authors suggested that the drop in Mo and increase in NO_3-N and K were probably related to reduced N-Rase activity and K-NO_3 synergism. In general, B functions in relation to other plant nutrients has led to the conclusion of some investigators (Tanada, 1983 and Mozafar, 1989) that B plays a role in the integrity and function of plant membranes. However, the information regarding the physiological relationships of B with certain plant nutrients such as Mg, Na and Mn is very scarce.

Nutrient interactions: It is evident from the literature that the supply and uptake of B brings a shift in the internal physiological balance amongst certain nutrients, which result in secondary changes and alteration in the absorption and accumulation of other ions. For example, the out standing interactions of P-Mg and Ca-Mg in tomato plants were caused by varying B supply in a sand culture study conducted by Parks *et al.* (1944). They suggest that B may be a component of one or more interactions or that complex interactions involving more than two elements may exists. Their statement suggests that B is involved in the interaction of other plant nutrients, although the nature and mechanisms of these interactions are not very clear. Similarly Patel and Mehta (1966) also found a Mg-P interaction, which led to them draw a conclusion that the effect of B on P content may be indirect and may be due to a primary effect on Mg content, which is considered a carrier of P, because the increase or decrease in Mg content at different B levels ran parallel with P content and showed a highly significant correlation ($r = + 0.95$) with one another. Ohki (1975) reported that the concentration of Mn in leaf blade of cotton was increased with low and high B in the substrate, while the concentrations of Cu, Fe and Zn drastically reduced due to the interaction of Mn with these micronutrients. Alvarez-Tinaut *et al.* (1980) found significantly positive correlation between Fe-P, Ca-P and P, Fe and Ca and suggested that the differential absorption of these nutrients could be governed by B through a large or small nutrient absorption and distribution. Oyewole and Aduayi (1992) found negative and non-significant correlations between leaf N and Ca, leaf Mg and Ca, leaf P and Ca and leaf K and Ca and concluded that these relationships were obtained when leaf N and P decreased and leaf K, Ca, Mg and Na increased with increasing B levels in soil. It can be concluded from the literature review that B play a role in the nutrient interactions within plant, but it is still not clear whether B is directly or indirectly involved in the interaction of certain nutrients, however the nature of these complex interactions are still obscure.

Cation-Anion balance: In the literature some evidence suggests that B effects are related to all the cation and anion values in the plants. Probably, Rehm (1937) was the first pioneer in the determination of cation-anion balance in plants with regard to B supply. He found that the addition of B to the nutrient medium increased the intake of cations and retarded the intake of anions in *(Impatiens L. balsaminaceae)* as compared with cultures lacking B. Similarly the work of Wallace and Bear (1949) indicated that increased B uptake resulted in decrease cation-anion equivalent ratios in the leaves and in roots, but a complication of the ratios in the stem of alfalfa. The tendency for the cation-anion equivalent ratios of the whole plant to be constant suggested the differences found in the chemical composition of the various plant parts. This was confirmed about twenty years later by Valmis and Ulrich (1971) who reported that with increasing B levels in the nutrient solution the sum of total cation and anion decreased in the mature blades of sugar beet, indicated that high B levels reduced the cation-anion values, presumably due to the dilution effect. However, this early work does not appear to have been followed up in more recent times. The evidence suggests that the deficiency or excess of B not only affects the relative values of individual elements, but it also affects the balance among certain nutrient elements within plants, causing either an increase or decrease of dry matter production.

Nutrients ratio: Balance ratios among the essential elements in plant are one of the most important criteria in plant nutrition and if this balance becomes upset due to the variation of any essential element, the crop yield is some times considerably reduced and some times shows nutrient disorder symptoms. A long time ago Shear *et al.* (1946) reported that both B deficiency and toxicity are consistently associated with an unbalanced ratio between B and K, Ca and Mg in plants. They found high ratios of Ca+K/Mg and Ca+Mg/K resulting in B toxicity, but high ratio of K+Mg/Ca had little effect on the appearance of B toxicity. Similarly Wallace and Bear (1949) observed that an extreme B deficiency increased the Ca+Mg/K and K+Mg/Ca ratios and decreased the Ca+Mg/K ratio in the tops of alfalfa as compared to B toxicity, indicating a close association of these cations with B. Kelly and Gabelman (1960) found significantly positive correlation between black rot, in beet roots and Ca+Mg/K and Ca+Mg+Na/K ratios. In the same year 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. Singh and Sinha (1976) reported that with increasing B fertilization of soils, K/Ca ratio in wheat and cauliflower plants significantly decreased, because of decrease in K and increase in Ca content of plants due to B fertilization. However, besides the interrelationships of B with the bases ratios, there is an association found between B with the ratio of micronutrients in plants. Leece (1978) stated that the reduction in Zn concentration due to B produced large increases in the P/Zn, Fe/Zn, Cu/Zn and Mn/Zn ratios, indicating that B is involved in balancing of nutrient ratios through Zn in maize. Subsequently, Alvarez-Tinuat *et al.* (1980) observed that the Mn/Fe ratio in the shoots of tomato plants decreased when B levels increased, reaching its minimal value at that B level producing the maximum yield. It is evident from the literature that the deficiency or excess of B may affect the other nutrients ratio in plants, indicated that B takes part in the mechanisms of the nutrients absorption and transport of other nutrient-elements.

CONCLUSIONS

From the world wide gathered literature review indicate that an extreme deficient or toxic levels of B may be responsible for secondary effects on account of the reduction in plant growth and resulting in change of nutrients uptake due to direct or indirect interactions of B with other plant nutrients. However, the interactions of B with other plant nutrients are highly complex and the effects can be antagonistic or synergistic depending on plant species and varieties, growth medium and environmental conditions.

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