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The Significance of Boron in Plant Nutrition and Environment-A Review

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Abstract: The concentration of boron in soils and plants not only varies with soil type, plant species and environmental conditions, but also its excess or deficiency may affect the plant growth and production. Because, there is a small concentration range between deficiency and toxicity in soil-plant systems. In the present study, the importance of boron in plant nutrition, its chemistry in soils, its physiological and biochemical role in plants and its relation to environment is reviewed and discussed.

Key words: Concentration, adsorption, precipitation, solubility, environment, biochemical and physiological functions

INTRODUCTION

More than eighty years ago it was known that boron is one of the essential elements for plant growth. The importance of boron as a plant nutrient was first demonstrated by Warington (1923) with characteristic deficiency symptoms of die prematurely broad beans and later on by Brandenburg (1931) found heart and dry rot in sugar beet and mangolds, respectively. On the other hand, boron is also regarded as a poisonous element (Buchel and Bergmann, 1964), because of its high potency, even small quantities gave damage to plants e.g, germination inhibition, root growth inhibition, shoot chlorosis and necrosis (Bergmann, 1984). According to Russell (1973) boron is probably the trace element which most commonly limits crops yield and consequently is most widely used in agriculture, horticulture and in forestry. Boron deficiency has been reported to be most pronounced on leguminous crops such as lucerne, red clover and alfalfa and cruciferous crops such as cabbage, cauliflower, rutabagas, turnips and radish (Murphy and Walsh, 1972), because of their relatively large boron demand. It is well documented in the literature that monocotyledons require less boron than dicotyledons, because the roots of monocotyledons had a lower capacity to adsorb boron than roots of dicotyledons (Tanaka, 1967). In connection with the significance of boron in plant nutrition and the occurrence of boron disorder symptoms, Bergmann (1984) stated that boron prevents the dropping of grapes and frost resistance of fruit trees presumably due to the beneficial effect on carbohydrate and protein metabolism. He further stated that the scab disease of potatoes should also be reduced by applying boron, through improvement of skin resistance. Ju *et al*. (1982) reported that at low boron supply boron deficiency was apparent as brown heart in turnip, although there were no external symptoms, but that growth was inhibited at toxic boron levels. Recently, these findings were also confirmed by Tariq and Mott, (2006a and b) on radishes, using sand culture technique. Kotur (1991) reported that higher boron rate increased the cauliflower yield 90% over control and reduced curd rot 3% over control. Moreover, he found the curd rot came down from 52 to 7% at normal boron supply due to correction of boron deficiency and reduction of incidence of black rot (Kotur and Kumar, 1989). Similarly, Mishra (1972) obtained a 210% increase over control in curd yield, when boron was applied at normal concentration. The assessment of boron nutrition and its requirement by various vegetable crops have been extensively studied and reviewed by Gupta (1983), Bergmann (1984), Shorrocks (1984), Francois (1986) and many other researchers. So, it has been found that boron is necessary for plant growth, especially for cruciferous and root crops. However, it is clear from the literature that boron plays a significant role in plant nutrition though with a very narrow range between deficiency and toxicity (Hesse, 1971; Tariq, 1997).

The chemistry of boron in soil: Boron is a member of the 3rd periodic group. It is a non metal among the micronutrients. Boron has an extremely complex chemistry and is capable of unusual bond types, especially in combination with hydrogen. However, in aqueous solution, the element shows a charge of 3^+ and has an approximate ionic radius of 0.023 nm and with an

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electronegativity of 2.0 on the Pauling scale and around 50% ionic character of bond with oxygen. Boron occurs in aqueous solution as boric acid, $B(OH)_3$ and hydrolyses reversibly to the borate ion according to the reaction below (Baes and Mesmer, 1976):

$$B(OH)_3 + H_2O = B(OH)_4^- + H^+ \leftrightarrow pK_a = 9.2$$

When B occurs in solution at concentration above 0.1 M, poly borate species are formed by the addition of one OH^- ion per borate ion present. The most common species of boron are $B(OH)_4^-$, $B_2O(OH)_5^-$, $B_3O_3(OH)_4^-$ and $B_4O_5(OH)_4^{-2}$, with the trimeric anion being the poly borate formed under most conditions (Baes and Mesmer, 1976). Boron always occurs in combinations with oxygen, usually 3-fold coordination and occasionally with 4-fold coordination (Krauskopf, 1972). The chemistry of B in soils has been extensively reviewed by Evans and Sparks (1983) and Keren and Bingham (1985) and this material is not repeated in this review. In terms of the present study, which is concerned with the significance of boron in plant nutrition and environment, only the following points, pertinent to this theme, are noted: The principle B species expected to be found in soil are H_3BO_3 and, in part, $B(OH)^-_4$. The neutral species H_3BO_3 is the predominant species expected in soil solution. It is only above pH 9.2, that the species $H_2BO^-_3$ become predominant. Apparently, the higher polymers of B are unstable unless B concentrations exceed 10^{-4}M, which is a level seldom encountered in soils (Lindsay, 1972). Lindsay further indicates that most B fertilizers are in the form of $B_4O_7^{-2}$ and are expected to hydrolyse to H_3BO_3. In soils, B is considered to be the most mobile and often deficient element compared to other trace elements. According to Sillanpaa (1982) based on an FAO global study of micronutrient status of soils, boron deficiency is most widespread and the known boron deficiency areas worldwide is at least eight million hectares (Bussler, 1979). On the other hand soils over fertilized with boron, irrigated by sewage sludge, or saline water, may contain toxic amounts of boron.

Concentration: Boron in soil is found in a chemical pool and concentrations can be roughly categorized by climatic zone. The water soluble B concentration in most soils varies between 2 and 200 μg g^{-1} but a more frequent range is from 7 to 80 μg g^{-1} (Krauskopf, 1972). Temperate and boreal regions contain low concentrations of B ranging from 1-2 μg g^{-1} in sand and podzol soils (Evans and Sparks, 1983). Tropical humid regions also contain low concentrations of B, in the range of 1-2 μg g^{-1}. However, arid and semiarid region soils contain high boron concentrations from 10-40 μg g^{-1} or more (Aubert and Pinta, 1977). Soil B falls into three categories i.e., total, acid soluble and water soluble. Generally, less than 5% of total boron is available to plants (Berger and Truog, 1945). However, Fleming (1980) categorized water soluble B values in soils to give a general guide for B supplying power to plants:

Category I	:	<1 μg mL^{-1} (Insufficient for normal plant growth)
Category II	:	1-5 μg mL^{-1} (Sufficient for normal plant growth)
Category III	:	>5 μg mL^{-1}(Which could be toxic to plant growth)

The availability of soil B depends on soil texture, pH and liming, organic matter content, soil moisture and relationships with certain cations and anions in soils (Tisdale *et al.*, 1985). In fact it is not feasible to mention the detail of all these factors affecting the availability of boron in soils, however, keeping in view the present study, it would be useful to review the chemistry of B availability in relation to soil environment. The readers refers to detail study of the factors affecting the availability of boron (Evans and Sparks, 1983; Tisdale *et al.* 1985; Keren and Bingham, 1985).

Adsorption: There are several descriptions in the literature of B reactions with other components in soil. However, the mechanisms of these reactions in soil are still not well understood. These reactions are highly pH dependent and always occur at pH above 7.0 (Kabata-Pendias and Pendias, 1984). As Overstreet and Dean (1951) and Bingham and Page (1971) reported, the mechanism of B retention by soils does not parallel that of other soil anions (Cl^-, SO_4^{-2}, NO_3^- and PO_4^{-3}). Boron retention is lowest in acid soils, but increases rapidly in the range pH 6 to 10, indicating that B availability is crucially dependent on soil pH. Heavy applications of $Ca(H_2PO_4)_2$ result in a lower availability of B in acid soils, because soil acidity produced by phosphate induced a greater fixation of B (Bingham and Garber, 1960). It is well understand that due to the liming of acid soils, Ca ions combine with soluble B to form the highly insoluble Ca-metaborate and thus reduce the availability of B. But the addition of K should increase the availability of B in the soil due to the formation of K-tetraborate of high solubility (Donald, 1964). However, it depends on the degree of K saturation of the soil colloids, as Hadas and Hagin (1972) found that K-saturated soils fixed more B than untreated soils. Bishop and Cook (1958) noted that both $CaCO_3$ and $MgCO_3$ were equally effective in decreasing water soluble boron in soil, but $CaSO_4$ was found ineffective. Similarly, NaOH increased the water soluble boron by increasing the soil pH. Similarly, Gupta and Macleod (1981) showed that at equivalent rates of Ca in acid soils, $CaCO_3$ reduced the B concentration in plants more than $CaSO_4$, indicating a pH rather than a Ca effect. Su *et al.* (1994) found that boron adsorption increases with pH increase as a result of increasing amounts of $CaCO_3$ addition to soil. The effect of pH on boron adsorption by oxides and clay minerals is well established with the maximum amount of boron adsorption occurring in the pH range 7 to 9 (Goldberg and Glaubig, 1986). However, the reasons for the increase in boron adsorption with increasing pH are complex, involving an increase in $B(OH^-)_4$ concentration, an increase in OH^- concentration, a change in the concentration of Al and Si in solution and an increase in net negative charge and of surface hydroxyl ion dissolution (Hingston, 1964).

Precipitation: In sodic soils B toxicity is ameliorated by the addition of gypsum, which converts readily soluble Na-metaborate to sparingly soluble Ca-metaborate (Bhumbla and Chhabra, 1982). Singh and Singh (1984) also observed that the increased absorption of Na and B by plants at high soil pH was due to the formation of Na-borate, which is the most soluble salt of B in soil. Singh and Randhawa (1978) studied the relative effect of various amendments ($MgCl_2$, $MgSO_4$, $CaCl_2$, $CaSO_4$, $AlSO_4$ and $FeSO_4$) on the solubility of boron in saline-alkali soils. They observed that all the amendments reduced the concentration of water soluble boron, but Mg salts were shown to be relatively superior to the others. Unfortunately, they did not speculate on possible mechanisms for the effect of Mg salts on reducing the solubility of boron. However, Rhoades *et al.* (1970) stated that boron is actually incorporated into the crystal lattice of MgOH (on a precipitated surface), which either distorts its lattice or else forms a new compound. Little is known about the relationships between B with metallic micronutrients such as Zn, Cu, Fe and Mn in soils.

Solubility: It is reasonably clear from the literature that the differences in the solubilities of K, Ca and Na-metaborates contribute to absorption and availability of boron. There are various boron compounds which are used as commercial fertilizers and the availability of boron to crops also depends on its solubility in soil. Boric acid and borax are the most common fertilizers. Borax is generally used for soil application, while boric acid is used for both soil and foliar application. Colemanite and Ulexite are slow in releasing boron as compared with other sources. Others kinds of boron-containing fertilizers and materials include: farm yard manure, sewage sludge, compost, borated gypsum, calcium nitrate and various mixed fertilizers (Gupta, 1979). However, the solubility of various boron compounds are given in Table 1.

Table 1: Boron solubility in (g L^{-1}) of cold water

Common name	Formula	Solubility
Boric acid	H_3BO_3	51.50
Potassium tetraborate	$K_2B_4O_7.5H_2O$	267.00
Sodium tetraborate (Borax)	$Na_2B_4O_7.10H_2O$	16.00
Calcium metaborate	$Ca(BO_2)_2.2H_2O$	3.10

Source: Souchelli (1969)

It is gathered from the overall literature review of boron chemistry that the solubility and retention of boron in soil is depend on the various soil components and ions, specifically cations (K, Ca, Mg and Na).

Biochemical and physiological functions of boron in plants: As an essential micronutrient the mode of operation of boron differs considerably from that of other micronutrients. Metallic micronutrients such as Zn, Cu, Fe, Mn and Mo are effective as components or as activators or inhibitors of enzymes in the plant, but a similar function for boron has not been established (Sutcliffe and Baker, 1981; Bergmann, 1984), although its effect can be detected experimentally in various metabolic processes. In spite of the essentiality of boron for plants, the biochemical and physiological function of this element is still not well understood (Price *et al.*, 1972; Bergmann 1984; Kabata-Pendias and Pendias, 1992). However, the role of boron in plants has formed the subject of many investigations and several functions have been assigned to boron of which the following is summarized below:

Carbohydrate metabolism and transport of sugars: Boron has been considered to be functional in the transport of carbohydrates and translocation of sugar is thought to be enhanced by the formation of borate-sugar complexes (Gauch and Dugger, 1954; Price *et al.*, 1972; Marcus-Wyner and Rains, 1982; Katyal and Randhawa, 1983). In sugar beet the sucrose content of the storage roots tended to decrease in the same treatment at which limiting boron resulted lower yield (Valmis and Ulrich, 1971; Tariq *et al.*, 1993).

Phenol and auxin metabolism: The accumulation of auxins and phenols may be associated with leaf necrosis when boron is deficient (Bohnsack and Albert, 1977; Mengel and Kirkby, 1982; Marcus-Wyner and Rains, 1982). The boron is presumably responsible for the metabolic changes and cell damage in boron deficient tissue (Marschner, 1986) and it is thought that boron complexes the phenolic compounds in plant cells, reducing their potential toxicity (Lee and Arnoff, 1967).

Water relations: Boron is concerned with the water relations in cells and regulates the intake of water in to the cell (Wallace, 1961). In this connection Briggs (1943) in early work reported that boron deficient (*N. aquaticum* L.) plants showed decreased moisture percentage, less succulence, less metabolic activity and a lower growth rate, in comparison to boron-sufficient plants. This was confirmed many years later by Sharma and Ramchandra (1990) who also reported that boron deficient plants had low water potential, stomatal pore opening and transpiration.

Tissue development, differentiation and formation of cell walls: Boron is required for proper development and differentiation of tissues (Katyal and Randhawa, 1983). Boron may affect the deposition of cell wall material by altering membrane properties (Goldbach and Amberger, 1986) and the deficiency of boron causes the breakdown of the walls of parenchyma cells (Shorrocks, 1984). The responsive effect of boron deficiency on cell division causes slow down in root extension and followed by a degeneration of meristematic tissue in plants (Jackson and Chapman, 1975). Cohen and Lepper (1977) concluded that a continuous supply of boron is not essential for cell elongation of intact squash plants but is required for maintenance of meristematic activity. The evidence from the various literature review showed that boron is important in cell walls (Jackson and Chapman, 1975; Cohen and Lepper, 1977; Gupta *et al*., 1985). Both boron deficiency and toxicity cause lower chlorophyll levels and net photosynthesis (Petracek and Sams, 1987). Boron may induce cell wall synthesis by an influence on the activity of the plasmalemma (Sutcliffe and Baker, 1981). Whittington (1957) also reported that boron is essential for the maintenance of meristem in plants.

Reproduction: Boron is involved in the reproduction of plants and the germination of pollen (Wallace, 1961). Tompson and Batjar (1950) and Montgomery (1951) concluded that the boron nutrition of the pollen grain was of particular importance. Birnbaum *et al.* (1977) found that cotton ovules callus when boron is lacking in the growth medium. The role of boron in promoting pollen tube growth is well established but the mechanism of its action is still unknown (Sutcliffe and Baker, 1981). Thus a significant positive correlation could be found between boron in the plant and number of flowers, the proportion of flowers not aborted and the weight of fruit (Bergmann, 1984; Oyewole and Aduayi, 1992). In the case of rape, clover, alfalfa and beet, boron hinders abortion of the ovaries. Moreover, it reduces the proportion of sterile seeds in cotton, soybean, alfalfa, maize and sunflower (Bergmann, 1984).

Disease resistance: There have been several reports of increased disease resistance with the application of boron, such as potato scab disease (Bergmann, 1984) and ergot on barley and damping off fungi on tomato and cabbage (Shorrocks, 1984). Although, Kabata-Pendias and Pendias (1992) reported that unlike other micronutrients, boron is not essential to the life of fungi and some algae (Shoklnik, 1974). But mycorrhizal plants appear to have a greater need for boron supply than do non-mycorrhizal plants (Lambert *et al*., 1980).

Boron in soil-plant relations: According to the observations of Rayans *et al.* (1977) and Bingham *et al.* (1981) plants respond mainly to the concentration of boron in soil solution. The chemical species in soil solution is primarily uncharged boric acid H_3BO_3. It was suggested that boron is absorbed as molecular boric acid in a physical process regulated by the boron concentration gradient (Oertli and Grgurevic, 1975; Bingham *et al*., 1970). Boron uptake has been correlated with the concentration of H_3BO_3 in solution, because leaf boron generally increased in a linear fashion as the concentration of the nutrient solution or soil solution increased (Gomez-Rodriguez *et al*., 1981; Salinas *et al*., 1986; Szabo, 1988; Taylor and Macfie, 1994; Tariq *et al*., 2005; Tariq and Mott, 2006a and b). There is still controversy in the literature about whether boron uptake is either a passive or active process. Generally, boron is taken up as undissociated boric acid or in borate form, presumably through transpiration in the xylem stream of plants and its uptake also varies with the stage of plant growth. Bowen (1972), Bowen and Nissan (1977) and Reisenauer *et al.* (1973) indicate that boron is actively absorbed by plants in ionic form particularly when boron concentration is low in soil and in plants boron translocates readily through xylem in the transpiration stream. Oertli and Richardson (1970) have also emphasized that transpiration, xylem stream and leaf venation are factors primarily involved in the accumulation of boron in leaves. Gopal (1970) stated that most of the boron absorbed by roots is insoluble in water and is carried by a passive stream from the roots to the upper parts of the plant and accumulated in higher quantities in leaves as they are the chief organs and also end points of transpiration. Generally, boron has a tendency to accumulate in the margins of plant leaves (Jones, 1972) and once accumulated it cannot be redistributed under any conditions (Gomez-Rodriguez *et al*., 1981). Thus boron concentration often increases from the lower to the upper portion of the plant (Shuman, 1994). Rashid *et al*. (1994) and Jones (1991) observed that boron concentration in leaves of rape seed and mustard was greater than in the whole shoots, as its accumulation occurred in leaves as boron carried in the transpiration stream and deposited at the leaf margins when water is transpired. Since boron is immobile in plants, once transpired a large accumulation occurs in the tips and margins of older leaves (Szabo, 1988). Therefore, its concentration also varies among plant parts (Tariq, 1997). Miller and Smith (1977) reported that the alfalfa (*Medicago sativa* L.) lower leaves contained 98, upper leaves 75, tips 47, upper stem 27 and lower stem 22 $\mu g\ g^{-1}$of boron. Gupta (1971) also reported that the seeds of some cereals contain less boron than the rest of the plant. Gupta *et al.* (1985) stated that boron is readily translocated from old leaves to young plant parts, the first deficiency symptoms will be in the growing points i.e., the stem tips, root tips, new leaves and flower buds. In contrast, toxicity symptoms typically show first on older leaf tips and edges as either a yellowing, spotting or drying of leaf tissues. It is also evident from the previous work of Valmis and Ulrich (1971) that the supply of boron affects the distribution of boron in various plant parts. They found in sugar beet plants the blades had a higher boron content than the petioles where the boron supply was adequate, but this relation was reversed in the boron deficient plants. However, in monocotyledons plants like corn boron accumulation was found greater in the marginal section of leaves than in the midrib section (Touchton and Boswell, 1975).

Deficiency, sufficiency and toxicity

Soil: Boron, from the stand point of plant nutrition, is unique among the trace elements in that very small quantities are necessary for normal crop production, but slightly higher concentrations cause injury. As is frequently reported in the literature the range between deficiency and toxicity of boron is very small. Soils were classified by Kalmet (1963) according to the water soluble content into deficient (< 0.1 $\mu g\ g^{-1}$), inadequate (0.1-0.2 $\mu g\ g^{-1}$), moderate (0.4-0.6 $\mu g\ g^{-1}$) and rich (>0.6 $\mu g\ g^{-1}$). Sillanpaa (1982) also classified the water soluble boron concentration in soils based on FAO, global study into deficient (<0.3-0.5 $\mu g\ g^{-1}$) and excess (>3-5 $\mu g\ g^{-1}$). Later on, Shorrocks (1993) reviewed the categories of water soluble boron in soils and his categories are:- very low (< 0.25 $\mu g\ g^{-1}$), low (0.25-0.5 $\mu g\ g^{-1}$), medium (0.51-1.0 $\mu g\ g^{-1}$), high (1.1-2.0 $\mu g\ g^{-1}$) and very high (> 2.0 $\mu g\ g^{-1}$). It is evident from the above classification of water soluble boron in soil that in general, > 0.5 $\mu g\ g^{-1}$ of boron in soil is sufficient for the normal growth of most crop plants (Cox and Kamprath, 1972). However, the classification of water soluble concentration depends on soil type, plant species, source of irrigation and environmental conditions. The recommendation for the boron fertilization is based on these water soluble boron categories, nature of soils, environmental conditions and the requirements of crop species.

Plant: Gupta (1979) reported that the deficient and toxic levels of boron are associated with plant disorders and/or reductions in the yield of crops. The deficient, sufficient and toxic concentrations of boron in the cruciferous and root crops are reviewed as reported by several investigators, because these crops are dicotyledons and the requirement for boron is more than monocotyledons. Gupta (1983) listed the deficient, sufficient and toxic levels of boron for radish (*Raphanus sativus* L.) cv. Cherry belle, tops when roots began to swell as < 29, 96-217 and > 217 μg B g^{-1} DM, respectively. Shelp *et al.* (1987) found good growth of radish (*Raphanus sativus* L.) cv. Cherry belle, at boron levels of 150-170 $\mu g\ g^{-1}$ DM in the leaves and 28-60 $\mu g\ g^{-1}$ DM in the roots. Toxic levels were attained when leaves and roots contained 260 and 40 $\mu g\ g^{-1}$ DM, respectively. Similarly, Tariq (1997) observed good growth of radishes cv. French breakfast when boron concentration was 74-159 $\mu g\ g^{-1}$ DM in the leaves and 23-24 $\mu g\ g^{-1}$ DM in the roots. Toxic concentrations were possibly attained, when leaves and roots contained 256-586 and 48-51 $\mu g\ g^{-1}$ DM, respectively. The differences found in the findings of Gupta (1983), Shelp *et al.* (1987) and Tariq (1997) for the sufficiency levels of boron, seems to be due to different crop variety and growth media used. In the case of rutabaga (*Brassica napobrassica* L.) the concentration of boron in leaf tissue at harvest were classified 20-38 $\mu g\ g^{-1}$ deficient, 38-140 $\mu g\ g^{-1}$ sufficient and >250 $\mu g\ g^{-1}$ toxic (Gupta and Munro, 1969). Similarly, Neubert *et al.* (1970) categorised the boron concentration <20 $\mu g\ g^{-1}$ deficient, 31-200 $\mu g\ g^{-1}$ sufficient and >800 $\mu g\ g^{-1}$ toxic for sugar beet (*Beta vulgaris* L.) at fully developed leaves stage. Generally, it can be concluded from the critical boron deficiency and toxicity levels that for most cruciferous and root crops the concentration of boron in plants <15 $\mu g\ g^{-1}$ to be deficient, 25-100 $\mu g\ g^{-1}$ adequate and >200 $\mu g\ g^{-1}$ toxic for growth and production. It is clear that both boron deficiency and toxicity will result in reduction of crop yield and quality.

Boron in relation to environment: Boron is released to the environment from natural sources such as oceans, volcanoes and geothermal steam. Argust (1998) identified and quantified the orders of magnitude for major reservoirs and flows of boron in the environment and reported that the largest flows of boron in the environment arise from the movement of boron into the atmosphere from oceans, at between $1.3\times10(9)$ kg and $4.5\times10(9)$ kg B $annum^{-1}$, drainage from soil systems into ground waters and surface waters accounts for between $4.3\times10(8)$ kg and $1.3\times10(9)$ kg B $annum^{-1}$, while boron mining and volcanic eruptions represent the next most significant boron flows, accounting for approximately $4\times10(8)$ kg and 3×10 kg B, respectively. It may also release from the industries that use it, e.g., manufacturing glass, combusting coal, melting of metals and through the addition of agricultural fertilizers. Cosmetics and laundry products also containing boron. For example, use of domestic and industrial detergent is the single most significant source of borates in the environment (Wells *et al*., 1998). Boron is readily leached from coal ash at ambient environmental conditions and represents a potential threat to water and soil environments in proximity to coal-ash wastes dumps and landfill with large quantities of ash (Wood and Nicholson, 1998). Similarly, reduced growth of lettuce after the use of fly ash was considered to be due to excessive salinity and boron (Page *et al*., 1979). Boron accumulates in plants and is found in foods, especially fruits and vegetables. Richardson (1980) reported that boron contents were consistently higher in vegetable crops on treated land and than in adjacent fields which received no sewage sludge. Hermann (1994) examined boron pollution within 10 km radius emission from coal-fired power station. He observed that both in soils and plants the boron concentration significantly depended on the distance to emitter, most frequent wind directions and depth of sampling. Periodic increase in boron concentration may be expected even up to the toxic levels to cultivated plants. In other study, fly ash-amended compost used as manure for certain crops (Menon *et al*., 1993) showed the string beans, bell pepper and egg plants assimilated high levels of boron and this may be the reason for their poor growth. Prausse (1991) also reported that amounts of boron recorded from a highly contaminated arable area (3000 ha) in Germany, that has received air emissions, fly ash and coal dust over the past 50 years. He noted that boron was the dominant pollutant in soil and showed negative correlation with yield from crops harvest. Francois (1991) also found direct correlation between $B_{sw.}$ and boron concentration in the leaves and bulbs of garlic and onion plants. Mehrotra *et al*. (1989) indicated an antagonistic relationship between soil boron and SAR of irrigation waters. Ayars *et al.* (1993) concluded that accumulation of boron poses a major threat to the sustainability of agriculture if drainage volumes are to be reduced by using drainage water for irrigation. The overall literature review regarding the impact of boron on environment indicate that boron is especially toxic to human and animals and their entry in to the food chain and the environment must be kept with in acceptable limits.

CONCLUSIONS

Boron chemistry in soil is depend on the various soil components and ions and in plants the mode of operation of boron differs considerably from that of other micronutrients. Boron plays a significant role in plant nutrition and in environment. From the foregoing literature, it is obvious that an extreme deficient or toxic levels of boron may be responsible for secondary effects on account of the reduction in plant growth and resulting in a change of physiology and biochemistry of plants. There is a small range for boron between deficiency and toxicity in soil, plant and water systems.

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