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Boron: A critical micronutrient for crop growth and productivity

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Abstract
Boron is important non – metal micronutrient, which is distinctive in its physiological, metabolic activity hence it is essential element for optimum crop growth and development. Boron is the second most wide spread trace element in deficient in world next to zinc. In agriculture field management of boron deficiency is a major challenged due to the narrow difference in its deficiency and toxicity. Therefore, attention should be given to boron nutrition for crop to overcome deficiency by applying boron fertilizers at proper rate, time, source, method and balancing with other nutrients in soil. Foliar application of boron at right time of crop growth shows better performance than the soil application especially in zinc deficient soil to avoid boron toxicity in crops. In case of alkaline and calcareous soil boron interacts with other nutrients and going to adsorption in soil, which affects the availability of boron to crop growth, therefore the foliar application of boron is better than soil application for these soils.

Keywords: boron, deficiency, toxicity, availability, foliar spray

1. Introduction
Boron (B) is of interest whenever micronutrients are discussed from standpoint of deficiency or toxicity. Many Soil scientists suggest that Boron may be more important than any other micronutrient in obtaining high quality crop yields. Plants take up boron in H_3BO_3 and $H_2BO_3^-$ forms from soil. Boron deficiency is more widespread in crops next to Zinc due to its deficiency in most type of Indian soils. Boron deficiencies first appear at the growing point of plants. Growing tips may die and plant growth fails when no boron is present. It plays an important role in growth, nutrition of crops and promotes cell division, cell elongation, cell wall strength, flowering, pollination, seed set and sugar translocation (Gupta *et al.*, 1985) [9]. Some functions of boron interrelate with those of nitrogen, phosphorus, potassium and calcium in plant. The most important functions of boron in plants are thought to be its structural role in cell wall development; and stimulation or inhibition of specific metabolism pathways. Boron availability in soil depends on factors like soil texture, moisture, pH, EC, CEC, $CaCO_3$, OC and inter-relationship with other elements (Takkar *et al.* 1989) [20]. In India 33% of the soils are deficient in boron nutrition. Maze (1915) [16] first recognized boron is an essential nutrient for the growth of crops. Boron deficiency mainly causes sterility in crops ultimately reducing the yield. Hence to overcome the deficiency and to achieve optimum growth and yield, proper boron fertilizer application is necessary in crops.

2. Major functions of boron in plant growth and development
Boron plays a dynamic role in various plant structural, physiological and biochemical functions including cell wall formation and stability, maintenance of structural and functional integrity of biological membranes, plasma membrane electron transport reactions, carbohydrate metabolism and transport of sugar, phenol and auxin metabolism, root elongation and nucleic acid metabolism, nitrogen fixation and nitrate assimilation, water relations stimulated, movement of sugar or energy into growing parts of plants, plant reproduction, pollen tube growth and pollen germination, pollination, seed set and disease resistance.

3. Critical level and availability of boron in soil
Boron in the soil is exists in primary mineral such as tourmaline and boron rich micas. In secondary minerals within the clay mineral lattice; adsorbed on clays, hydrous oxide surfaces and organic matter; in solution as boric acid and borate anions, in organic matter and microbial biomass (Argust, 1998) [1]. Soil parent materials differ widely in their boron content (Table 1). Total soil boron content can range from around 2 to 200 mg kg^{-1}; however only a less fraction of this amount that is about 3 to 5% is available to the crop. A large amount of the total soil boron is present as a component of highly insoluble mineral tourmaline. Boron available forms for plants include inorganic borate complexes of Ca, Mg, Na and various organic compounds

formed from plant and microbial decomposition (Hou *et al.*, 1994) [13]. Plant available boron in agricultural soils varies from 0.4 to 5 mg kg^{-1}, most of the available boron in soil is derived from sediments and plant materials (Gupta, 1993) [9].

4. Boron sufficiency, deficiency and toxicity in crops

Deficient and toxic levels of boron are associated with plant disorders and reduction in the yield of crops. To encounter sufficiency, deficiency and toxicity level of boron in crop plants based on definite critical value is major challenge because sufficiency and toxicity is narrower compare to other nutrient elements. The adequate boron levels in dried leaf tissues range from 10 to 75 mg kg^{-1}, which is an optimum quantity for many crop plants. Boron requirements vary with plant type, in monocotyledons-leaf content ranges from 1 to 6 mg kg^{-1} and 20 to 70 mg kg^{-1} in case of dicotyledons. Generally, a soil application of boron is recommended when leaves contain less than 25 mg kg^{-1} in high-boron-demanding crops such as alfalfa, sugar beets, potatoes, sunflower, soybeans and canola (Benton, 2003) [2]. Average boron content in the soil is considered to be 30 mg kg^{-1}. Soil boron exhibits a large variation depending on the parental rock. Consequently plants need trace amounts of boron but it becomes toxic at 20 mg kg^{-1} or greater for most crops (Carlos, 2000) [3].

5. Deficiency symptoms of boron

Boron deficiency has been reported in more than 100 crops on different parts of the earth. It causes many structural, physiological and biochemical changes. Most crops are not able to mobilize boron from vegetative parts to actively growing plant tissues such as shoots, root tips, flowers, anthers, pollen, seeds or fruits. Boron transport occurs primarily in the xylem channel, resulting from transpiration. Because of this, deficiency symptoms first develop in newly developed plant tissue such as young leaves and reproductive structures. Commonly occurring B deficiency symptoms include chlorosis and death of the growing points, distortion thickening and cracking of stems, formation of rosettes, growth of auxiliary buds, bushy growth and multiple branching (Benton, 2003) [2]. Root become twisted and thick, roots show excessive branching, root crops often fail to develop edible portions and dark colored corky areas are present, the dropping of buds or blossom, fruits and seed also be affected (Dell and Huang, 1997) [4]. Classification of water soluble boron concentration in soil based on sufficiency, deficiency and toxicity to crop plants (Table 2).

6. Factors affecting boron availability in soils

Boron concentration and its availability in soils is affected by several factors including parent material, texture, nature of clay minerals, pH, liming, organic matter content and interrelationship with other elements. Therefore, knowledge of these factors affecting boron uptake is essential for the assessment of boron deficiency and toxicity under different conditions.

6.1 Parent material

Parent material is considered a dominant factor affecting supply of boron from the soil. In general, soils derived from igneous rocks, those in tropical and temperate regions of the world, have much lower boron concentrations than soils derived from sedimentary rocks and those in arid or semi arid regions. High boron concentrations are usually found in the soils that have been formed from marine shale enriched parent material. Soils derived from acid granite, other igneous rocks, fresh-water sedimentary deposits and in coarse textured soils low in organic matter have been reported with low boron concentrations (Liu *et al.* 1983) [1]. The levels of total boron in common rocks are presented in Table 1.

6.2 Soil texture and clay minerals

Coarse-textured soils often contain less available boron than fine-textured soils (Takkar *et al.* 1989) [20]. This might be one of the reasons that boron deficiencies in crop plants have often been observed on sandy soils (Gupta, 1968) [10]. Leaching losses of boron from sandy soils are very high, so these soils are mostly deficient in available boron. Silty and clay soils are not usually as boron deficient as sandy soils (Zhu *et al.,* 1999; Fleming, 1980) [7]. Boron adsorption in fine-textured soils is higher compared with the coarse- and medium-textured soils at the same equilibrium concentration. The level of native boron is also closely related to the clay content of the soil (Elrashidi and O'Connor, 1982). At the same time, water soluble boron concentration and boron uptake are reported to be higher in plants grown in coarse-textured soils. More boron adsorption is commonly found in illite as compared with kaolinite or montmorillonite clay types. Sims & Bingham (1967) [19] found that boron adsorption was greater for iron (Fe) and Al coated kaolinite or montmorillonite than for uncoated clays.

6.3 Soil reaction (pH) and liming

Boron availability to plants decreases with increasing soil pH, especially above pH 6.5. However, strongly acid soils (pH less than 5.0) also tend to be low in available boron because of boron sorption to iron and aluminium oxide surfaces of soil minerals. Some crops with a high demand for boron such as alfalfa also require a soil pH above 6.5 for optimum growth, so liming may be necessary. However, over liming acid soils often has resulted in temporary boron deficiencies, especially when liming to pH levels above 7.0.

6.4 Soil organic matter

Most of the available boron in soils is found in soil organic matter. Soils with low organic matter content have reduced boron-supplying capacity and will usually require more frequent boron fertilization at lower application rates. Soil organic matter must be decomposed to release complexed boron, so conditions such as cool, wet weather or hot, dry weather which decrease organic matter breakdown will reduce available boron in soils.

6.5 Soil Moisture

Low soil moisture content decline boron uptake, even though its level more than optimum in soil. Drying of soil depresses water uptake therefore decreased the movement of boron to plant roots through mass flow (Evans and Sparks, 1983) [6]. Less soil moisture decrease mineralization of boron from organic matter by microorganisms. Low plant transpiration may also induce B deficiency (Fleming 1980) [7].

6.7 Soil microbial activity and Soil fertility

Microorganisms break down soil organic matter, so plant available boron is released from organic complexes. Conditions favouring improved microbial activity are warm, moist soils with adequate aeration. Soil conditions which hinder optimum microbial activity are drought conditions, cold and wet soils, poor soil tilth (poor aeration) and balanced soil fertility generally results in improved boron uptake by plants. The resulting improved plant vigour and root growth allows greater uptake of boron and other nutrients. This is why soil test results should be carefully examined and nutrients which are marginal or deficient should be applied at recommended rates.

6.8 Liming

Soil amelioration with lime increases the soil pH and this causes boron deficiency because pH has negative correlation with boron availability. Due to liming of acid soils, soluble boron combines with calcium ions and forms the highly insoluble Ca-metaborate which reduces the availability of boron to crops (Goldberg and Chuming, 2007) [8]. However, over liming acid soils often has resulted in temporary boron deficiencies, especially when liming to pH levels above 7.0.

6.9 Interactions of boron with other nutrients

Some functions of boron (B) interrelate with those of nitrogen (N), phosphorus (P), potassium (K) and calcium (Ca) in plants. Its interaction (synergistic, antagonistic) with most of the nutrients (N, P, K, Ca, Mg [magnesium], Al [aluminium] and Zn [Zinc]) may be sometimes influential in regulating B availability to plants in soil. The availability of native and applied boron is modified either favourably or adversely by the presence of other elements in the soil. Example- Low level of B content in soil helped increasing Zn content, but presence of high level B in soil prevented increasing of Zn content in plants (antagonism). Low level of Zn content in soil helped increasing B content, but presence of high amount of Zn in soil prevented from increasing of B content in plants (antagonism). Increasing level of boron application has synergetic effect on concentration of Ca in leaf and stem of plants. As like increasing level of boron application has antagonism effect on concentration of Zn in leaf and stem. A significant relationship has been found between K and B fertilizers regarding their assimilation/uptake by crop as well as crop produce (Hill & Morrill, 1975) [12].

7. Amelioration of boron deficiency

The research studies on boron nutrient in agriculture field greatly contributed to better understanding the role of boron in crop plants. Much need to include boron nutrient in the fertilizer recommendation is determined by crop requirement and soil boron test level. High rate of boron may require for sandy-type soils, soils with acidic and basic pH, high calcium content and low organic matter content. For optimum growth and yield requires knowing the application rate, the method and time of application, the source of nutrients to use and how the elements are influenced by soil and climatic conditions. Since boron is non-mobile in plants, a continuous supply through soil or fertigation or foliar application is required for a better growth of plant. The only way to overcome the boron deficiency is its external application.

8. Boron Fertilizer

Boron may be applied to the soil as a straight boron material such as borax, or it may be purchased mixed with a fertilizer. Alternatively it can be dissolved in water and sprayed (foliar application) on to the crop or the soil. It can also be fed into irrigation water (fertigation). Several fertilizer sources of boron are available for use in India suitable boron fertilizers for soil and foliar application are borax, granubor, boric acid andsolubor etc. A number of boron containing fertilizers are listed Table 3.

8.1 Method of Application, dose and precautions

Broadcast is the application methods of choice instead of row/banded methods. It is suggested that broadcast applications occur 1 to 2 weeks prior to seeding/planting. Typical boron application rates are 0.5 to 2.0 kg ha^{-1} on soils with a pH less than 6.5 to avoid boron toxicity problems but 2 kg ha^{-1} for calcareous soil. Boric acid, solubor and sodium borate are good for foliar spray. Foliar application of 0.2 to 1.0 per cent boric acid or borax at pre flowering, pollination stage and head formation stages enhance crop yield, but it should not exceed 1.5 per cent to avoid toxicity. Care should be taken while applying of boron containing fertilizers because if it comes into contact with the seed at planting time reduce the germination and should not combined with ammonium sulphate, to avoid liberation of ammonia (NH_3).

9. Conclusion

Boron deficiency causes severe reduction in crop growth and yield, hence boron nutrition is important for optimum growth and yield. Source, rate, time and method of boron fertilizer application and proper balancing of boron with other nutrients in soil affect crop yield on boron-deficient soils. Foliar application of boron at right time of crop growth shows better performance than the soil application especially in zinc deficient soil to avoid boron toxicity in crops and in alkaline, calcareous soil to avoid interaction and adsorption in soil, which affects growth and yield of crop.

Table 1: Total boron concentrations in major rock types

Rock type	Minerals	Boron (mg kg^{-1})
Igneous	Basic: Gabbro, Basalt	5-20
	Intermediate: Diorite	9-25
	Acid: Granite, Rhyolite	10-30
Metamorphic	Gneiss	10-30
Sedimentary	Shale	120-130
	Sandstone	30
	Limestone dolomite	20-30

Table 2: Available boron (mg kg^{-1}) critical levels in soil

Sufficient for normal plant growth	Deficient for normal plant growth	Toxic for normal plant growth	Reference
<1	1-5	5	Fleming(1980) [7]
<0.25	0.50-1.0	>2.0	Shorrocks(1997)
<0.5	0.50-3.0	>3.0-5.0	Sillanpaa (1982)
<0.1	0.40-0.60	-	Kalmet (1963)

Table 3: Boron fertilizer sources

Boron fertilizer	Nutrient content (%)	Chemical formula
Borax	11	$Na_2B_4O_7. 10H_2O$
Boric acid	17	H_3BO_3
Colemanite (portabor)	10 -16	$Ca_2B_6O_{11}. 5H_2O$
Solubor	20-21	$Na_2B_4O_7.5H_2O + Na_2B_{10}O_{16}. 10H_2O$
Boron frits	2 – 6	Complex borosilicates
Sodium tetraborate (Fertilizer	15.2	$Na_2B_4O_7. 5H_2O$

Borate-48, Agribol, Fertibor)		
Granubor	14.3	$Na_2B_4O_7.5H_2O$
Boronated SSP	0.18	-

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