

Boron status and tackling its widespread deficiency

Dhiraj Kumar^{1*}, Asha Ram², Inder Dev³ and Ram Newaj⁴

ICAR-Central Agroforestry Research Institute, Near Pahuj Dam, Gwalior Road, Jhansi 284 003, Uttar Pradesh

Boron is an essential nutrient for plants. Especially, its deficiency and toxicity range is very narrow. It is required for pollen-tube growth and germination and required at several reproductive growth stages of the plants. Thus the deficiency would set poor yield as well as poor quality of produce. Adequate B fertilization has been found to reduce the incidence of disease and pest. About 1/3rd of the soil samples from across 20 States have been found to be boron deficient. Several refined product or crushed ores of boron have been found to be source of boron and proper rate, method and timing of application should be matched for maximum efficient utilization of boron.

Keywords: Boron, Deficiency, Plant, Soil, Toxicity

BORON (B) is one of the essential micronutrient which is required for proper growth and development of plants. Apart from its role in cell wall structure, there are enough evidences for possible functions of boron in lignin synthesis, production of indole acetic acid (IAA), imparting drought tolerance, facilitating ion uptake, transporting potassium (K) in guard cells, carbohydrate metabolism, nucleic acid and phytohormone synthesis, structural integrity of plasma membrane, tissue development.

Status of Boron

The total boron content in India widely varied from 20 to 200 mg B kg⁻¹ soil. Generally less than 5-10% is in such a form which is available to plants. Globally boron deficiency considered to be the second most important micronutrient bottleneck to crop production after zinc. In India, out of 2.5 lakh soil samples analysed from over 20 states under the aegis of All India Coordinated Scheme on Micronutrients in Soils and Plants of the ICAR, about 1/3rd (33%) of the soil samples were found to be deficient in available boron. In India, B deficient soils widely found in Bihar, Tamil Nadu, Eastern Uttar

Pradesh and Gujarat (calcareous soil), Rajasthan, Haryana (sandy soil), Orissa, Karnataka, Maharashtra, Andhra Pradesh (Red laterite soil) and Hilly areas (sub-mountain soils).

Factors affecting boron availability in soil

The availability of boron in soil solution and subsequently by the plant root does not occur directly but it is dictated by the equilibrium between soil solution and solid phase and thus the adsorption of boron by the soil solids. The boron availability is affected by number of soil and non-soil environments.

Soil factors

There are several soil factors which governs the boron availability in soil.

- **Soil pH:** Soil pH is considered to be the most important determinant for assessing the level of boron in soil. There is a close association with the pH of the soil solution and the level of soluble B in soils. Boron is less available in acid soils mainly below pH of 5.0. If the soil is coarse then, at low pH, B lost due to leaching under high rainfall. On the other hand, in fine textured soils, B leaching is

not conspicuous, if the soil is not very low in pH.

- **Organic matter:** Organic matter is the life of soil. Though less in amount, but acts as a source of most of the nutrients including boron. A major portion of total soil boron also being firmly held with humic substances and on the action of soil microbes, through various processes the availability of boron in soil being dictated.
- **Clay minerals:** The adsorption of boron primarily occurs more in fine texture soils than coarse texture soils even in same equilibrium. Boron has been found more in illite dominated soils than kaolinite or montmorillonite. Apart from Fe and Al oxides, organic matter and carbonates also dictates the availability of boron in soil.
- **Interaction with other nutrients:** Several of the interactions have been expected between boron and other nutrients in both soil and plant. The interaction is positive (synergistic) when nutrients in combination results in a growth response that is > the sum of their individual effects. On the other hand, it would be negative

(antagonistic) when the combined effect is < the sum of their individual effects. There are evidences that the zinc deficiency increases B accumulation in some graminaceous crops. The Ca/B ratio in shoot and relative shoot dry matter shows, a curvilinear relationship.

- **Parent material:** The parent material is considered to be an important source of boron in soil. The B dominance in arid and semi-arid region in sedimentary rocks. Even within sedimentary rocks, the content of boron in shale is high enough than the sandstone.
- **Soil texture:** Leaching of boron is a major problem in sandy soils in high rainfall areas. However, the availability of boron to higher plant is more in coarse textured soils than the fine texture soils. Thus, the availability of boron in soil is a function of pH of the soil solution.
- **Liming:** The adsorption of boron in soil has been highly influenced by the calcium carbonate content. Boron fixation occurs with liming because addition of lime to soil increases the soil pH and also calcium carbonate itself which acts as an adsorbent of boron.
- **Irrigation water as a source of boron:** The source of irrigation water is of paramount importance in deciding that how much boron is brought to the soil surface by irrigation water. There is marked decrease in the growth of plant parts especially the growing tips of roots and shoots, which on further level lead to chlorosis and necrotic spots on leaf margins and then the mature tissues. One needs to know the amount of boron present in the irrigation water before the application.

Non-soil factors

Among the non-soil factors, transpiration rate is considered to be the most important factor for absorption of boron by plants. Thus temperature, relative humidity and light intensity all together affects the transpiration rate and ultimately the

uptake of boron by plants. There are evidences that shows, with increase in temperature and reduction in relative humidity, the boron uptake increases. This might be due to the interactive effect of soil moisture with soil temperature as the deficiency of B mingle with summer conditions. Even, when other factors were kept constant then also, root temperature dictates the uptake of boron.

Mechanism of boron uptake by plants

The presence of boron in soil solution varies in form but mostly it is present as undissociated boric acid (H_3BO_3). Under conditions of adequate or excessive B availability, boric acid absorption by roots is occurs through a passive process in which B diffusion happens across lipid bilayer. Further, several studies suggests that, B uptake may be mediated by MIPs channels. There are evidences that shows the occurrence of an active B uptake by roots under low B conditions. Further, B must be loaded into xylem after taken up by roots. Thus, in plants having sufficient B the process involves passive mechanism both B diffusion across lipid bilayer and facilitated permeation of boric acid via MIPs channel. However, an energy dependent high affinity transport system mediated via BOR transporters is induced in response to low B supply.

Further, after being uploaded in plants body, B transported by vascular system to shoot mediated by transpiration. Though B can also be taken up through phloem to both reproductive and vegetative parts. Nevertheless, the molecular mechanism involved in this B phloem transport is still unknown.

Boron deficiency symptoms and critical deficiency level (CDL) in plant tissues

As, the B is less mobile in plant system, thus the deficiency symptoms first appears on the younger leaves, flower-buds, stem tips etc. The growing tip of roots and shoots death along with non-development of flower buds occurs during boron deficiency. The inner tissues of especially brassica family showed visual symptom of blackening or

Table 1. Deficiency symptoms of boron in some of the prominent crops.

Crop	Deficiency symptoms
Cauliflower	Browning/Hollow stem
Tobacco	Top sickness
Citrus	Heart rot and hard and misshapen fruits
Grapes	Hen and chicken
Pomegranate	Fruit cracking
Tomato	Corky split/scar around calyx end of young fruits
Cotton	Die back and shedding of bolls
Groundnut	Hollow heart

death. The specific deficiency symptoms of born on different crops are presented in Table 1.

B critical deficiency level (CDL) in soil

Generally, the CDL of B in soil is 0.5 mg/kg soil (0.5 ppm), although it varies from soil to soil as reported by several researchers. For most of the crops, the soils are rated as deficient, normal and high in available boron if the B content is <1.0 ppm, 1.0-2.0 ppm and > 2.0 ppm, respectively. Based on solubility criteria the average concentration of H_3BO_3 in soil solution is approximately $10^{-5.5}$ M.

Boron toxicity symptoms and critical toxicity level in plants

If the content of boron is high in plants then, interveinal necrosis is induced with straw colour (dead) leaf margins in severe toxicity with distinct boundaries between dead and green tissue. Roots appear relatively normal. Similarly in soil, if the concentration of B goes above 3.0 mg B/kg soil, then toxicity occurs, causing reduction in growth, yield as well as quality.

As the range between toxicity and deficiency in case of boron is quite narrow, thus it becomes difficult to judge the need for B application. There lies the importance of indicator plants to be grown under similar set of conditions, so that they give sign for possibility of B deficiency most likely for other crops as well. There are certain plants which are quite sensitive for application of B (Sunflower, sugarbeet, rapeseed, lucerne, cauliflower, cotton, apple, celery etc.)

Soil analysis: Soil analysis is not

advisable for routine purpose though it indicates general level of boron in soil.

Leaf analysis: Analysis of recently matured leaves which are most likely to be deficient, will serve as the guide for boron status in plants. Thus depending on the level of boron in plant system, the dressing of B must be done especially in the areas which are prone to boron deficiency.

Tackling the deficiency

Diversified crop responses have been recorded to application of B @ 0.5 to 2.5 kg B/ha in B deficient soils. Soil plus foliar application of B results in higher crop response as compared to either soil or foliar application. The application of boron could be done directly through straight fertilizers or through the mixed products or by foliar application and even through fertigation.

Foliar application: The foliar application of boron is usually effective, if the deficiency occurs during the critical stages of the crop. Applying B as spray is quite effective and efficient in terms of crop need during critical stages of growth. While going for split application of B, the rate not exceeding 0.5 kg per ha can be applied at strategic times, such as just before flowering. Generally for field crops the application of B done at or before sowing to have maximum benefits.

Fertigation: The B could also be applied through irrigation water even throughout the growing season if need arise. The method operates well under conditions like coarse texture soil with no or little organic matter and where leaching is a major problem.

Sources of boron

Boron is generally available in the market as refined product which can be applied as solid and as soluble form and the crushed ores. Several sources of boron are available in the market (Table 2) which can be

Table 2. List of B containing materials used for correcting their deficiencies

Compound/ Material	Chemical formula	Element content (%)
Boric acid	H ₃ BO ₃	17.0
Borax	Na ₂ B ₄ O ₇ ·10H ₂ O	10.5
Solubor	Na ₂ B ₈ O ₁₃ ·4H ₂ O	20.0
Colemanite	CaB ₆ O ₁₁ ·5H ₂ O	10.0
Boron Frits	Fritted glass	2.0-6.0
Sodium pentaborate	Na ₂ B ₁₀ O ₁₆ ·10H ₂ O	18.0
Granubor II	Na ₂ B ₄ O ₇ ·5H ₂ O	15.0

applied for correcting the boron deficiency.

New insights in boron analysis

The colorimetric technique with Azomethine-H is the most extensively studied B determination method for soil and plant samples. The use of hot water or 0.05 M HCl even attributed with certain merits and demerits. Even hot water extraction technique encompasses difficulty due to time of extraction and temperature, reflux time. Even, the colour development during hot water extraction may create error during analysis. Overall, colorimetric methods, suffer from sample pH, complex formation in wet HNO₃ acid digest of plant and presence of Al, Mo, Fe, Al etc.

Now, potentiometer, chromatography, flame atomic emission and absorption spectrometry, inductively coupled plasma (ICP) optical emission (OES) and mass spectrometry (MS) and neutron activation analysis are extensively used for boron determination. However, mostly the above mentioned soil boron extractants, provide good correlation with B content in plant under controlled conditions. Thus, such B soil test extractants need to be developed which can predict not only B in deficient soils but also be used to predict soil conditions where B toxicity may be a problem. However, from the available technologies for B determination, ICP-MS to be the

considered to be a better method for determining B concentration.

Way forward

Interaction of boron with different nutrients under different crops need to be extensively studied. Recycling of crops in rotation system can yield useful information for management of boron. Research on physiological modifications of plants to accumulate more boron needs to be ascertained. Even, genetic bio-fortification involving efficient cultivars for Quantitative trait locus (QTL) identification for development of high yielding boron enriched cultivars. Effect of boron on quality of produce needs to be studied in length especially, in case of high B requiring crops. Further, research on management of boron for short as well as long term effect on crops under different agro-climatic regions should be given priority for future research. Moreover, soil test methods for predicting site specific deficiency/toxicity are essential since, there is a very narrow range between deficiency and toxicity of boron.

SUMMARY

Thus, it can be concluded that boron is a unique non-metal micronutrient requiring for successful completion of plant life and its application is must in boron deficient soils. Boron application to both soil as well as foliar proved effective in improving crop yield, quality, concentration and uptake of boron. More and more database for diagnostic techniques for boron determination and the advanced methods like ICP-MS could be deployed for correcting boron deficiency in order to have sustainable production of crops in intensive cropping systems in India.

^{1,2}Scientists, ^{3,4}Principal Scientists,
*Corresponding author's e-mail:
dhiraj.iari@gmail.com

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