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Boron nutrition of crops in relation to yield and Quality: A review

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Abstract
Boron nutrition of soil and crops has assumed greater importance with the introduction of high yielding crop varieties under intensive cultivation with high use of chemical fertilizers. The availability and transformation of B in soil, yield and quality of crops have a significant bearing in relation to B nutrition. The literature pertaining to the effect of B on yield and quality of crops are reviewed and presented below.

Keywords: Boron, nutrition, crop, yield, quality, cereals, Legums

Introduction
Boron is a chemical element with the symbol B and atomic number 5. Produced entirely by cosmic ray spallation and supernovae and not by stellar nucleosynthesis, it is a low-abundance element in the Solar system and in the Earth's crust. Boron is concentrated on Earth by the water-solubility of its more common naturally occurring compounds, the borate minerals. These are mined industrially as evaporates, such as borax and kernite. The largest known boron deposits are in Turkey, the largest producer of boron minerals (Garrett, 1998) [1]

Elemental boron is a metalloid that is found in small amounts in meteoroids but chemically uncombined boron is not otherwise found naturally on Earth. Industrially, very pure boron is produced with difficulty because of refractory contamination by carbon or other elements. Several allotropes of boron exist: amorphous boron is a brown powder; crystalline boron is silvery to black, extremely hard and a poor electrical conductor at room temperature. The primary use of elemental boron is as boron filaments with applications similar to carbon fibers in some high-strength materials.

Boron is similar to carbon in its capability to form stable covalently bonded molecular networks. Even nominally disordered (amorphous) boron contains regular boron icosahedra which are, however, bonded randomly to each other without long-range order (Delaplane, *et al.* 1988) [2]

It can be produced by compressing other boron phases to 12-20 GPa and heating to 1500-1800 °C; it remains stable after releasing the temperature and pressure. The T phase is produced at similar pressures, but higher temperatures of 1800-2200 °C. As to the α and β phases, they might both coexist at ambient conditions with the β phase being more stable (Oganov, *et al.* 2009, Van Setten *et al.* 2007, Widom and Mihalkovic, 2008) [3-5].

Consequently, graphite and h-BN have very different properties, although both are lubricants, as these planes slip past each other easily. However, h-BN is a relatively poor electrical and thermal conductor in the planar directions (Engler, 2007; Greim, & Schwetz, 2005) [6, 7]. Increased yield through intensive cultivation with high yielding crop varieties, use of chemically pure NPK fertilizers, and limited use of organic man ures and restricted recycling of crop residues are some important factors which have to accelerate exhaustion of micronutrients from soil. In several places, normal yield of crops could not be achieved despite balanced use of NPK due to micronutrient deficiency in soils. The incessant efforts for enhancing food grain production from shrinking land resources will further magnify the depletion of limited micronutrient reserves and would cause the deficiency of other micronutrients besides accentuating the existing ones.

Review
Present review paper indicates that among micronutrients, B stands next to Zn with its growing deficiency in the soils of our country. Because of its role in fertilization and flowering

processes of crops, B is being given special importance. If it is deficient, one of the first adverse effects is on flowering and fruiting and therefore, on the yield and quality of the crops. Adverse effects on the yield can occur even though no deficiency symptoms are evident on the foliage and it is known as hidden hunger. Boron deficiency is often an unsuspected enemy of crop production. Depletion of B from soils is mainly through leaching to the lower layers and through the uptake by crops, which removes a significant amount of B from the nutrient reserve each season. These two factors together deplete the B supply in the top soil or bring the B to the levels that are not accessible by the crops. Yield increase due to B application in almost all crops has been reported by several workers. Spectacular responses of cereals, pulses, oil seeds and cash crops to B application have largely been observed on B deficient soils. Importance of B in crop production B is one of the essential micronutrient required for normal growth of most of the plants. The essentiality of B as it affected the growth of maize was first reported by Maze (1914) in France [8] However, it was the work of Warrington (1923) in England that provided firm knowledge of B requirement for a variety of crops [9] The role of B in plant nutrition is the least understood of all the mineral nutrients. On molar basis, the requirement of B for dicotyledons is higher than any other micronutrient. Various authors have proposed different views on the possible role of this element in plant growth. According to Kolesnik (1962) B fertilization improves photosynthetic activity, enhances activity of enzymes and plays a significant role in protein and nucleic acid metabolism [10] Boron deficiency severely inhibits pollen germination and pollen tube growth as well as the viability of pollen grains (Dugger, 1973) [11]. Asokan and Raj (1974) studied the response of groundnut grown in pot culture to various forms and levels of B and reported that application of 15 kg of boric acid/ borax ha-1 increased the yield of crop appreciably and it also improved the formation of pods in plants [12]. Boron is unique among the essential mineral nutrients. It is the only element that is normally present in soil solution as non-ionized molecule over the pH range suitable for the plant growth (Oertli and Grgurevic, 1975) [13]. According to them boric acid as source of B is effectively absorbed by plant roots than other sources. Jarmillo *et al*. (1978) [14] reported that tomato fruit yield was higher with the application of 75 kg N, 50 kg P2O5, 50 kg K2O and 15 kg borax ha-1compared to NPK alone. Gulati *et al*. (1980) [15] studied the effect of different levels of B on the yield of tomato and revealed that highest yield of tomato was obtained in the treatment receiving 1.5 ppm of B. The yield of marketable fruits of tomato was increased with B application at 2 kg ha-1 (Verma *et al*., 1995) [16]. Cerda and Roorda van Eysinga (1981) also reported that the Growth of tomato plants in a split-root system as affected by various B levels in the nutrient solution [17]. Parr and Loughmann (1983) [18] reported that B is involved in sugar transport, cell wall synthesis, lignifications and IAA synthesis and phenol metabolism. Das and Patro (1989) [19] observed that the highest yield of tomato (298 q ha-1) was obtained with urea followed by 0.25 per cent B as foliar spray. Sharma and Tanuja (1991) [20] have suggested the involvement of B in stomata regulation. Effect of B on growth and yield attributes of crops Singh and Verma (1991) [21] from their study reported that application of borax 2 kg ha-1 increased the plant height and number of branches per plant of tomato. Kalyani *et al*. (1993) [22] observed that B applied as boric acid increased the plant height, relative growth rate, net assimilation rate and leaf area index in pigeon pea. Boron is essential micronutrients for plants, but at the same time, its range between deficiency and toxicity is narrower than that of any other element (Goldberg, 1997) [23]. Boron seems to be a crucial element for the maintenance of structural integrity and protect plasma membranes against peridoxidative damage (Ismail and Volkar, 1997) [24]. Foliar application of 100 ppm of boric acid three times viz., 40, 50, 60 days after sowing produced significant improvement in growth parameters of tomato which might be due to the enhanced photosynthetic activity and metabolic activity with the application of B (Lalit Bhatt *et al*., 2004) [25]. Combined application of micronutrients like Zn, Mn, Fe and B produced highest fruit yield with reduced cracking of fruits of tomato. This might be due to increasing RNA and DNA contents in reproductive tissues in the presence of Zn and B which may enhance the flower bud initiation and fruit setting (Bose and Tripathi, 1996) [26]. Singh and Verma (1991) [27] observed that application of B at 2 kg ha-1 either alone or in combination with potassium and zinc resulted in optimum plant growth and highest fruit yield of tomato. Oyewole and Aduayi (1992) [28] noted that application of B at 2 ppm to tomato plants increased the leaf number, stem diameter, number of flowers, fruit yield, and reduced percentage of flower abortion. Boric acid spray had favourable effect on vegetative growth, retention of flowers and fruits. Application of 0.25 to 0.50 kg B ha-1 significantly increased pod yield of groundnut (Mahesh kumar and Sen, 2004) [29]. B deficiency had largely been reported in high calcareous soils of Bihar, Orissa, West Bengal and Assam as well as some coarse textured soils of Punjab and significant response to B application had been reported by Arora *et al*. (1985) and Sakal and Singh (1995). Pulses and oilseeds gave higher economic response as compared to cereals. The response of chickpea to B application varied from 167 to 182 kg ha-1 with 2 kg B ha-1 except in severely deficient sites where it was 3 kg ha-1 (Sakal *et al*., 1990). Reskasem *et al*. (1993) observed “hallow heart” symptoms on groundnut without the addition of B. Boron increased seed yield of sesamum and mustard varieties at application rate of 1.5 and 2.5 kg B ha-1. In a field experiments conducted in coarse textured soils of Ludhiana, the optimum yield of groundnut was recorded at 0.5 kg B ha-1 (Arrora *et al*., 1983) [30]. Spectacular response of cereals, pulses, oilseeds and cash crops to B application (0.5 to 2.5 kg ha-1) had largely been observed on B deficient soils of Bihar, Orissa, West Bengal, Punjab and Assam (Sakal and Singh, 1995) [31]. Average yield response of groundnut, sesamum, mustard and sunflower to 1 to 2 kg B ha-1 was 370, 70, 210 and 320 kg ha-1 respectively (Sakal *et al*., 1996) [32]. In acid soils of Orissa, application of B at 2 kg ha-1 to groundnut gave yield response of 29.9 per cent. In B deficient acid sedentary soils having 0.3 kg ha-1 of hot water soluble B at Ranchi, groundnut responded significantly to boron application and pod yield increased remarkably from 1140 kg ha-1 in control to 1530 kg ha-1 with 3 kg B ha-1. However 4.5 kg ha-1 reduced pod yield in groundnut (Kumar *et al*., 1996) [33]. The magnitude of yield response to soil applied B ranged from 0.10 to 11.9 q ha-1 in cereals, 1.2 to 15.5 q ha-1 in pulses, 0.14 to 5.0 q ha-1 in oil seeds, 28.3 to 79.5 q ha-1in onion and 105 q ha-1 in sugarcane (Sakal *et al*.,1996) [34]. Effect of B on quality of crops Govindan (1952) [35] observed the influence of B on the carbohydrate balance in tomato crop and reported that increasing levels of B increased the reducing and non-reducing sugar content of tomato. The significant increase in nodule number in groundnut was observed due to application of graded levels of boron. The maximum number of nodule was recorded at 2 ppm B level (Patil and Golakiya, 1986 and Bhuiyan *et al*., 1997) [36, 37]. Though B is not required by rhizobia like other free living organisms, it is also considered essential element for N fixation (Lewis, 1980 and Parr and Loughmann, 1983) [38, 18]. The reduction of nitrogenase activity in B deficient soil was also reported by Garcia Gonzales *et al*. (1991) [39]. Boron fertilization improves photosynthetic activity, enhances activity of enzymes and plays a significant role in protein and nucleic acid metabolism (Kolesnik, 1962) [10]. Boron and Zinc when applied to tomato and capsicum crops significantly increased the total fruit sugar content (Rawat and Mathpal, 1984) [40]. Reddy and Reddy (1986) [41] reported that application of Zn and B at 500 ppm each, improved the quality indices in brinjal. The highest groundnut pod protein content was recorded at 1.0 ppm and further increase in B levels the protein content get decreased correspondingly (Muthukrishnan, 2007) [42]. Islam *et al*. (2015) [43] Contribute of boron doses on growth and yield of different broccoli genotypes

Conclusion
Boron is a unique micro mineral nutrient required for normal plant growth and optimum yield of crops. Its deficiency is widespread in coarse-textured and low organic matter soils in many countries of the world. Annual cotton, cereal, legume/pulse, oilseed, vegetable and perennial crops grown on such soils usually suffer from B deficiency. The factors affecting B availability in soils, including parent material, soil pH, texture, clay minerals and organic matter, irrigation sources, nutrient interactions, and plant species. The paper also documents the diagnosis and correction of B deficiency in several important crops in a wide range of soils.

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