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Boron fertilization and crop production in India: A review

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ABSTRACT

Boron (B) is an essential nutrient for normal growth of higher plants, and B availability in soil and irrigation water is an important factor of agricultural production. Boron deficiency is now becoming very common in many states of India. In the previous years, various studies have been conducted on boron, viz. factors affecting B availability to plants, its function in plant, B response in various crops, etc. The aim of the present review is to provide an update on recent findings related to these topics, which can contribute to a better understanding of B fertilization and the role of B in plants.

Key words: Boron deficiency, Boron fertilization, Boron sources, Boron toxicity, Boron uptake

Boron is one of the important micronutrient among all essential micronutrients required for proper growth and development of plants. In India, around 33% soils are deficient in B (Shukla and Behera 2012). An estimated annual B requirement of 3.9 thousand tonnes by 2025 is an indication of its emergence as a major limiting nutrient to obtain optimum yield of many crops (Murthy 2006). As an essential micronutrient it plays very crucial role in several physiological processes and influences the yield and quality of agricultural produce. A steady fall in nutrient use efficiency is attributed due to the increased incidence of zinc and boron deficiencies in many parts of the country (Singh and Goswami 2014). In general, the humid regions with high precipitation are deficient in available B due to excessive leaching of B and therefore, B deficiency is common in highly leached acid sandy soils with low organic matter content. Poor availability of B may also occur in alkaline soils containing a high amount of free $CaCO_3$. On the other hand, the shallow ground waters in arid areas may contain toxic concentrations of B and the repeated use of such water for irrigation purpose may build up toxic levels of B in soil. The present paper reviews the research work on factors affecting uptake of B by crop plants and response of B application on crop production and quality of produce under Indian conditions.

Deficiency and sufficiency limits of boron: The most widely used soil test method for B estimation is hot water-soluble B (Berger and Truog 1939). The critical limit of B varies with the type of crop. The deficiency and sufficiency limits for some crops in India are given in Table 1.

Apart from soil analysis, plant tissue analysis is also useful for diagnosing B deficiency or toxicity. For plant tissue analysis, usually the first mature leaf below the growing point is suitable. In small grain crops, the leaf below the flag leaf at early spike emergence stage is appropriate for analysis. The deficient, optimum, and toxic ranges of B in different plant parts of several crops are presented in Table 2.

Factors affecting B uptake in crop plants

Boron is absorbed by roots as undissociated boric acid [$B(OH)_3$ or H_3BO_3]. Among all the elements, only B is absorbed by plants as an uncharged molecule not as an ion (Miwa and Fujiwara 2010). Boron uptake by crop plants is influenced by a wide array of factors which include mainly meteorological parameters and soil characteristics. Boron accumulation is affected more than water uptake by increasing root and air temperatures from 8 to 37°C and by raising the pH of the external solution from 5.7 to 7.0. However, water utilization fell more than B accumulation when RH was increased from 30±5% to 95±5%, when light intensity was reduced or daily exposure to light was shortened and also when the plants were pre-treated with 5×10^{-5} m phenyl mercuric acetate, an anti-transpirant.

Temperature: Among different meteorological parameters, temperature influences B uptake by plants. Based on the field observations and glass house studies, Huang-Long Bin *et al.* (2005) suggested links between

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Table 1 Boron deficiency limits in soil

Region	Test crop	Method of analysis	Deficiency limit (mg/kg soil)	Reference
Maharastra	Sweet orange	Hot water	<0.48	Srivastava and Singh (2003)
Maharastra	Cauliflower	Hot water	0.52	Malewar *et al*. (1999)
Bihar (Recent alluvial soil)	Blackgram	Hot water	<0.52	Sakal *et al*. (1987)
Bihar (Red loam soil)	Soybean	Hot water	0.47	Singh and Sinha (1987)
Bihar (Red loam soil)	Maize	Hot water	0.45	Singh and Sinha (1987)
Bihar (Calcareous soil)	Chickpea	Hot water	0.41	Sakal *et al*. (1993)
		Normal Ammonium acetate (*p*H 7.0)	0.31	
		Normal Ammonium acetate (*p*H 7.0)	0.57	
		10 mM $CaCl_2$ + 10 mM Mannitol (*p*H 8.5)	0.18	
		10 mM $CaCl_2$ + 50 mM Mannitol (*p*H 8.5)	0.28	
Meghalaya (Acidic Alfisol)	Pea	Hot water (relux)	0.7	Dwivedi *et al*. (1993)
		Hot water (boiling)	0.7	
		Mannitol-$CaCl_2$	1.0	
		DTPA- Ammonium carbonate	0.6	

Table 2 Boron deficiency and sufficiency limits in plants

Crop	Variety	Plant part	B concentration (mg/kg)			Reference
			Deficient	Sufficient	Toxic	
Maize			7.6			Singh and Sinha (1987)
Pea		Young leaves	10.5 – 23		110	Sinha *et al*. (1999)
		Seeds	7.6 – 10.5		51	
Pea	Bonnaville	55 d old (Acidic alfisols of Meghalaya)	23.8 233 (Ca : B ratio)			Dwivedi *et al*. (1993)
Chickpea		Calcareous soils calciorthents	12.6			Sakal *et al*. (1993)
Blackgram		Leaves	23.5			Sakal *et al*. (1987)
Gram	Avrodhi	Leaves	13.5-32		190-310	Chatte jee *et al*. (2005)
Groundnut	T 3	Leaves	6.8-15.74		106	Sinha *et al*. (2002)
		Kernel	6.2-11.5		50-72	
	TMV-2	Leaves (30 d old)		50	1010	
		Leaves (105 d old)		126	3015	
Tomato	DL-3	Young leaves	5-12		102-250	Sinha *et al*. (2006)
Sweet orange	Mosambi			29.4		Srivastava and Singh (2003)
Coconut	West Coast Tall	Leaves (30-40 yr. old orchard)	12-40			Jose *et al*. (1985)

B-deficiency and leaf damage induced by low temperature in crop plants but the casual relationship between these two at physiological, biochemical and molecular levels have yet to be explored. Limited evidence at the whole plant level suggests that chilling temperature in the root-zone restricts B uptake capacity and/or B distribution / utilization efficiency in the shoot. The nature of this interaction depends on chilling tolerance of species concerned, the mode of low temperature treatment and growth conditions (e.g. photon flux density and relative humidity) that may exacerbate chilling stress, for sub-tropical/tropical species (e.g. cucumber, cassava, sunflower). Root-chilling at 10-17^{0}C decreases B uptake efficiency and B utilization in the shoot and increases the shoot : root ratio, but chilling tolerant temperate species (e.g. oilseed rape, wheat) require much lower root chill temperature (2-5°C) to achieve the same responses. Boron deficiency exacerbates chilling injuries in leaf tissues, particularly under high photon flux density. The suggested mechanisms for B and chilling interaction in plants are:

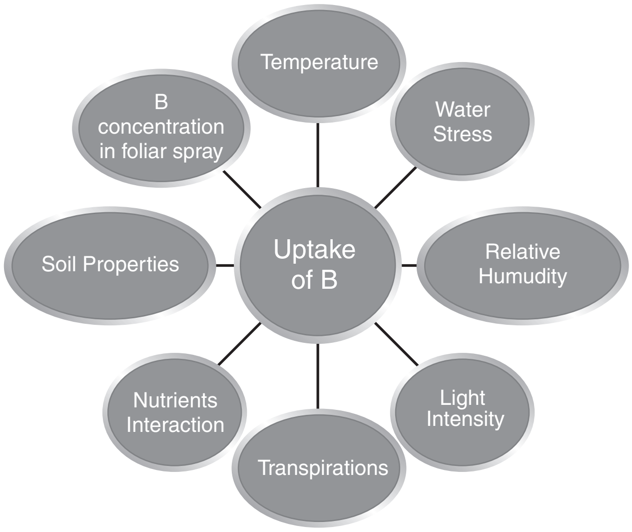

Fig 1 Factors affecting Boron uptake

(a) Chilling induced reduction in plasmalemma hydraulic conductivity, membrane fluidity, water channel activity and root pressure, which contribute to the decrease in root hydraulic conductance, water uptake and associated B uptake?
(b) Chilling-induced stomatal function affecting B transport from root to shoot and B partitioning in the shoot.
(c) B deficiency induced sensitivity to photo-oxidative damage in the leaf cells.

Water stress: Poor boron availability is usually observed in a dry summer following a wet winter or spring. During a dry spell, the mobility of B in the soil medium is adversely affected, resulting in reduced availability of B to crop plants. Zerrari *et al.* (2000) reported that in sunflower (*Helianthus annuus* L.–Morocco 1) water stress decreased the B uptake and the effect was more pronounced in calcareous soil than in non-calcareous soil. Boron translocation from roots to shoots varied from 45.4 to 57.0%, 17.3 to 21.1% and 17.0 to 22.2% for the leaves, the stem and the head, respectively.

Relative humidity: The relative humidity in the atmosphere influences B uptake of plants by altering transpiration and by controlling the evaporation of water from foliar spray solution. Shu *et al.* (1994) noted that the mobility of B in peach (*Prunus persica* L. Batsch) plants was influenced by the relative humidity. Plastic coverage on the treated leaf helped the uptake of B from boric acid applied on leaf surface. Higher B content in leaves was noted under high RH (100%) treated plants than low RH treated (50%) plants.

Light intensity: Low light intensity is conducive to low B uptake and consequently the appearance of B deficiency in plants. Sotiropoblos *et al.* (2004) showed that there was a significant correlation between B concentration and shading period in kiwi fruit (cv. Hayward).

Transpiration: Low transpiration affects the translocation of absorbed B from roots to shoot part. Some investigations have ascertained environmental conditions conducive to low transpiration are responsible as a cause of B deficiency in the crop plants. Saifuzzaman *et al.* (1996) investigated the causes of wheat sterility in Bangladesh. Probable causes were supposed to be low light caused by foggy weather, low temperature over many days during wheat flowering and saturated or waterlogged soils. These factors affect transpiration, which in turn affects the uptake of B from the soil during critical pre-flowering or flowering period of wheat crop.

Nutrient interactions: Boron uptake by crop plants is influenced by the availability of nutrients other than B. Clark *et al.* (2003) studied the effect of varying NH_4: NO_3 ratios on growth and tissue concentration of nutrients in two alfalfa cultivars. Leaf concentrations of N, K, Ca, S, B and Mo were highest with NO_3 – N.

Sinha *et al.* (2003) studied P × B interaction in mustard (cv. T 9) in a sand culture experiment and reported that low P accentuated the effects of B deficiency. The toxic effects of excess B in mustard were also accentuated further by the combined toxicity of both nutrients. No seeds were produced at deficient B level even on increasing the P supply to twice that of adequate amount. Low P level accentuated boron excess effects.

Nibedita Bose *et al.* (2002) noted that in an Alfisol (West Bengal), the concentration of B in rape tissue increased due to combined application of B and lime at the lower level of B (1 kg/ha) giving a beneficial effect to the growth and nutrition of crop.

Soil properties: Soil properties play important role in governing the boron uptake of plants. All soil properties which tend to maintain optimum supply of B in soil solution are conducive to have positive relationship with B uptake by plants. The absorption of B by crop plants is also influenced by salinity level. Sotiropoblos *et al.* (2004) studied the effect of salinity levels (0.75, 2, 4 and 6 dS/m) and B conc. (0.025 and 0.2 mM B) on B uptake of kiwi fruit (cv. Hayward) in a solution culture experiment. They observed that with the increase in salinity level, B concentration in leaves decreased at 0.2 mM B.

B concentration in foliar sprays: Shu *et al.* (1994) studied the mobility of B in one year old potted Red Haven peach plants in green-house using enriched ^{10}B – boric acid solution evenly spread on the abaxial side of leaf. A solution of 0.12% B gave the highest absorption. About 0.2 to 0.3% of total ^{10}B applied was absorbed by the peach plants.

Boron sources

Some common sources of B are listed in Table 3. Borax is the commonly used B fertilizer for most of the agricultural crops. Apart from B fertilizers mentioned in Table 3, other B-containing materials such as borated superphosphate, borosilicate glass frits, ulexite, borated gypsum, and various other mixed fertilizers are used. Farmyard manure, sewage sludge, and compost also contain variable amounts of B, depending upon their source.

Table 3 Boron sources (B containing fertilisers)

Fertilizer	Chemical formula	B (%)
Borax	$Na_2B_4O_7.10H_2O$	11
Boric acid	H_3BO_3	17
Disodium tetraborate (Borate-46, Agribor, Tronabor)	$Na_2B_4O_7.5H_2O$	14-15
Borate-65	$Na_2B_4O_7$	20
Solubor	$Na_2B_4O_7.5H_2O$ + $Na_2B_4O_7.10H_2O$	20-21
Sodium pentaborate	$Na_2B_{10}O_{16}.10H_2O$	18

Correction of B deficiency

In order to correct B deficiency, the B fertilizer is applied either to soil or used as foliar spray. The usual method is to apply 0.3 kg B/ha (for sensitive crops like bean) to 3 kg B/ha (for tolerant crops like alfalfa) in soil through broadcasting before sowing of the crop. Murthy (2006) recommended application of 10-15 kg borax/ha in coarse textured soils and 15-20 kg borax/ha in calcareous and fine textured soils. Singh *et al*. (2016) reported that application of boron @ 1.0 kg/ha along with N, P, K, S and Zn in SSNM approach gave maximum yield in rice – wheat crop rotation in Haryana. For foliar spray 0.2 per cent borax solution is used to supply 0.5-1.0 kg B/ha. Boric acid and other complex borates of high solubility can also be used as B source for foliar sprays. Boric acid as a foliar spray at 0.1 to 0.2% is being recommended.

Foliar spray is more common in perennial orchard crops. In annual field crops, foliar spray at early growth stages is recommended for better absorption. Early morning sprays are better for efficient B absorption owing to the relatively high humidity in the atmosphere and open stomata in the foliage. 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 (Bhatt and Srivastava 2005). Combined application of boron and zinc as foliar spray is more effective than the individual application of B or Zn on growth and yield of summer season tomato (Ali *et al*. 2015).

Band application and foliar sprays particularly, at the early stage of the crop, are more efficient methods of B application to the crop than broadcasting. The residual effect of B fertilizer is not persistent in sandy soils because of their low retention capacity. With such soils, boron fertilizer should be applied just before sowing or planting of responsive crops in the crop rotation. In heavy textured calcareous soils, the residual effect is persistent for a considerable period, i.e. for two to three seasons or more. Sarkar *et al*. (2007) suggested that split applications of B either through soil or foliar sprays were more effective than a single B application for mustard and potato in light textured soil. However, for wheat a single late application of B was more effective than early or split application in increasing wheat yields on B-deficient soils.

Response to B fertilization in crops

In general, dicots have a higher B requirement than monocots. Therefore, B deficiency is less common in cereal crops. Legumes and other dicots with latex system also have a very high requirement of B. Beans, cauliflower, cabbage, apple, pear, grape, and tomato are sensitive to B deficiency and respond to B fertilization. Among monocots, maize is more sensitive to B deficiency but wheat is relatively less sensitive.

Different genotypes of a plant species may also differ in their B uptake and response to B fertilization. The inefficient genotypes usually lack the ability to translocate B to shoot part. Spectacular response of cereals, pulses, oilseeds and cash crops to B application (0.5 to 2.5 kg/ha) had largely been observed on B deficient soils of Bihar, Odisha, West Bengal, Punjab and Assam. Reddy *et al*. (2003) discussed the variation in harvest index (HI) approaches to improve HI and productivity in sunflower. They observed that medium duration sunflower types (100 – 110 d) had higher HI compared to the early or long duration cultivars. Genotypes which had low partitioning of dry matter to stem and thalamus had high HI. Genotypes which accumulated high biomass during post-flowering stages of development also showed high HI and seed yield. In experiments, it has been observed that the foliar application of B and application of growth regulators to the head improved the translocation of photosynthate to the head and thus, help increase in HI and seed yield.

Legumes are more sensitive to B toxicity than cereals. Different cultivars also differ in their tolerance to B toxicity. Boron application in deficient soils improves not only yield but also the quality of the produce especially in vegetables and fruits. The effects of B fertilization on the quality of produce for different crops are listed here.

Cereals: In basmati rice, B application increases plant height, number of productive tillers and grain weight. The yield increase is mainly due to reduced panicle sterility. Milling return and head rice recovery greatly improves by B application in both Basmati 385 and Superbasmati. Desirable cooking traits like elongation ratio, bursting on cooking, and alkali spreading value are also attained (Rashid *et al*. 2004). In rice (cv. MTU 7029), B application increases the plant height, effective tillers, panicle length, grains/panicle, test weight, grain and straw yields (Jana *et al*. 2005), In wheat, B application increases the 1000 grain weight, number of grains/spike (Ghatak *et al*. 2006).

Pulses: In urdbean, soil application of B increases the number of pods/plant, seed/pod, 100 seed weight, seeds/plant, seed yield and harvest index (Salam *et al*. 2004). Kalyani *et al.* (1993) observed that B applied as boric acid increased the plant height, relative growth rate, net assimilation rate and leaf area index in pigeon pea.

Oilseeds: A positive response of mustard to B fertilization has been reported (Jaiswal *et al*. 2015). Yadav *et al.* (2016) studied the effect of different level of boron on yield attributes, seed yield and oil content of mustard (*Brassica juncea* L.) in an Inceptisol and found that the highest number of siliquae/plant, length of siliqua, number of seeds/siliqua, seed yield, oil content were recorded where 1.5 kg B/ha was applied, while maximum protein content was noticed with application of 1.75 kg B/ha.

In sunflower, B fertilization increases harvest index, capitulum (head) diameter, % of filled seeds, total no. of seeds and 100 seed weight (Patil *et al*. 2006, Gitte *et al*. 2005).

The increase in oil content and other quality parameters in soybean with combined application of B and sulfur in India have been noticed by Dinesh and Sudkep (2009) and Kumar and Sindhu (2009). Meena *et al.* (2011) found that soybean responded significantly to the application of boron (B). In case of different levels of B an increase in growth, i.e. number of branches per plant and major yield components, viz. pods per plant and seeds per pod were recorded along with higher seed and biological yield with the application of 1.0 kg B/ha as compared to control. Results showed that application of 1 kg B/ha found suitable for higher productivity, profitability and quality of soybean under south-eastern plain zone of Rajasthan. In sunflower, B fertilization increases oil and protein content in seeds (Gitte *et al*. 2005) and seed quality (Patil *et al*. 2006). In soybean, the maximum protein content (37.99%) in seed was recorded with application of 40 kg S + 0.5 kg B/ha (Singh *et al*. 2006). 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).

Cash crops: Muthanna *et al.* (2017) studied the effect of boron and sulphur application on plant growth and yield attributes of potato (*Solanum tuberosum* L.) and found that application of sulphur along with B @ 3 kg/ha had significantly increased the plant morphology and yield of potato plant.

In mesta (*Hibiscus cannabinus*), foliar spray of B increases the plant height, basal diameter, no. of leaves, plant and fibre yield (Singh and Maurya 2006).

Foliar spray of B in cotton improves the ginning percent, seed index, lint index, fiber fineness, Bartlett's index and bundle strength (Kalyanasundaram and Kumar 2005) and seed and ginning percent, mature healthy seed percent, seed vigour index, seed germination percent and seed viability (Panwar *et al*. 2005).

Fruits: In papaya, foliar spray of B and Zn increases the plant growth, number of leaves/plant, length of petiole (5^{th} leaf). It also hastens flowering by 10-20 d. Foliar spray of 0.5% borax + 0.25% $ZnSO_4$ at 2 months after transplanting increased the individual fruit weight, fruit size, pulp thickness, and reduced the seed content in papaya (Singh *et al*. 2005).

In banana, foliar spray of 0.2% B + 0.3% Zn + 0.1% Cu at 3 and 5 months after transplanting increased individual fruit size, pulp : peal ratio with the combined treatment, TSS, total sugar, reducing sugar, sugar : acid ratio and ascorbic acid (Ghanta and Dwivedi 1993). Yadav *et al.* (2013) found that foliar spraying of peach trees with 0.1% H_3BO_3 + 0.5% $ZnSO_4$, H_2O + 0.5% $FeSO_4$, $7H_2O$ recorded maximum fruit retention, fruit growth, fruit length, fruit diameter, fruit volume, firmness and fruit yield.

Vegetables: In tomato, B application enhances germination (Kumari 2012) and increases the number of branches and fruits. Foliar application of 100 ppm of boric acid three times, *viz.* 40, 50, and 60 DAS produced significant improvement in growth parameters of tomato which might be due to the enhanced photosynthetic and metabolic activity with the application of B (Bhatt and Srivastava 2005). Sathya (2006) conducted an experiment to evaluate the various levels of B on yield of PKM 1 tomato. The results revealed that the highest fruit yield of 33 t/ha (33.6% more than control) was recorded with 20 kg borax /ha. In tomato, foliar spray of 0.5% borax + 0.25% $ZnSO_4$ at 2 months after transplanting reduced the fruit cracking from 16.5% (control) to 4.76 %. Jyolsna and Usha Mathew (2008) studied the effects of 0, 0.5, 1.0, and 1.5 kg B per ha on growth, yield, and quality of tomato as well as the B status of a lateritic soil in southern Kerala and observed that B significantly increased plant height, number of primary branches and reduced the days to flowering and increased fruit set (12.5 to 20% more at the highest level). B application also improved quality parameters like reducing sugars, total sugars, vitamin C, and lycopene content.

Ningawale *et al.* (2016) studied the effect different level of B and molybdenum on various yield and quality parameter of cauliflower and reported that soil application of 10 kg borax/ha and 2 kg ammonium molybdate/ha gave maximum yield. Similar results also reported by Kumar (2005) and Mahmud *et al*. (2005). Chander *et al.* (2010) found that cauliflower responded significantly to B application in terms of dry matter yields of leaves, curd and roots up to 1 mg/kg in Junga soil and up to 2 mg/kg in Bajaura soil of Himachal Pradesh.

Economics of B Fertilization

Under B deficiency, the yields of most of the agricultural crops are low, therefore under such situation, use of B fertilizers either by soil application or foliar sprays increases the better quality production and gives higher profit to the farmers. Among cereals, application of borax @ 30 kg borax /ha to red and laterite soil gave the highest net return of ₹ 1191.50/ha for rice crop (Jana *et al*. 2005). In basmati rice, application of 10 kg borax /ha to a calcareous soil increased benefit: cost (B: C) ratio to 55:1 in Basmati 385 and 41: 1 in Super Basmati (Rashid *et al*. 2004).

Soil application of 2 kg B/ha gave an additional yield 320 kg/ha for groundnut and 635 kg/ha for pigeon pea with a profit of ₹ 2995/ha and ₹ 8475/ha, respectively (Singh *et al*. 2004). In rainfed Indian mustard, foliar spray of 0.2% borax spray at 50% flowering gave 10.6% higher seed yield and a benefit: cost ratio of 4.8 (Rana *et al*. 2005). Singh *et al*. (2006) observed an increase in marketable fruit yield of strawberry by foliar application of boron and/or calcium.

Muthanna *et al.* (2017) found increased marketable yield of potato with application of 2 kg boron and 40 kg sulphur per ha.

Practical cases of B toxicity in India

Toxic levels of B may develop in arid areas either because of high B level in soil or as a result of high B level in the irrigation water. Available boron (B) content in coastal soils is high enough to be toxic to almost all plants (Sarkar *et al*. 2014). Boron toxicity may also result with the misuse of B fertilizer or excessive application of coal fly ash from thermal power station. Gupta (2002) assessed the quality of irrigation waters in Rajasthan. Boron could occur in soils and waters up to 10 mg/l but only 1% waters contained more than 5 mg/l. Due to adsorption of B on clay particles, the waters containing 10 mg B/l could be used successfully in heavy textured soils, whereas this limit is reduced to 5 mg/l in coarse textured soils. The suppressive effect of B on crops is more accentuated in high salinity conditions. The tolerance limit of B is considered as 5 mg/l for tolerant crops in semi-arid zone. Murthy (2006) reported that the problem of potential B toxicity may come up when fertilizer application rates are >3 kg B/ha for oilseed crops. Boron can be leached out from saline soils and could be detoxified with the use of gypsum in sodic soils. Extensive leaching of soils is required during reclamation. Therefore, reclamation might be pursued along with cultivation of B-tolerant crops in such soils. A more effective and rapid reclamation of soils with toxic B levels can be achieved with application of sulphuric acid.

Thus, boron as a micronutrient is increasingly gaining importance in Indian agriculture. As boron plays a crucial role in determining the quality of oilseeds, vegetable and fruits, the application of B in these crops would give a higher benefit: cost ratio as compared to grain crops. More field based evidences for the optimization of application doses, effective and economical method of application are required in different cropping patterns to validate the profitability of B application in different agro-climatic zones of India.

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