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Boron in Soil Plant System and Its Significance in Indian Agriculture

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ABSTRACT

Boron is one of the 17 essential plant nutrients, required for normal plant growth. Its widespread deficiency in ~30% of Indian soils have been observed to affect plant growth and economic yield. Because of its mobile nature, it tends to leach down in soil layers. Boron deficiency has more specifically been observed in light-textured alluvial soils with low content of organic matter. The higher active absorptive surface area of clays restricts its leaching losses. Boron becomes available to plants upon decomposition of organic matter by soil micro-organisms after its mineralization. The soils with high content of calcium carbonate are also prone to B deficiency. Boron availability decreases with an increase in soil pH, except in saline-sodic soils. Soil application of B has been observed to more credible option owing to its considerable residual effect on succeeding crops. Considerable yield response of B application has been found in cotton, cereals, legumes, oilseeds and alfalfa and citrus fruit plants, grown in B deficient soils. Therefore, assessment of B status in soils is crucial to ensure B application in deficient soils for the long-term sustainability of soils in terms of exploring crop genetic potential. Boron is a critical nutrient from a nutritional requirement point of view as it shows second most widespread micronutrient deficiency globally after Zn.

Key words: *B availability, Crop response, Deficiency, Residual effect*

Introduction

Boron (B) is the only non-metal among the plant essential micro-nutrients, quite rare and occurs chiefly as borates of calcium and sodium. Its average concentration in the earth crust is approximately 10 ppm and it is at 37th rank in abundance among different elements. Tourmaline is a B –containing mineral present in soil having about 3 to 4% boron. However, B from this source is not plant available (Gupta, 1978).

It is accountable for the synthesis, lignifications of cell wall components. It also aids in carbohydrate RNA metabolism, respiration, and phenol metabolism as well as membrane transportation (Brown *et al.*, 2002). Translocation of boron is somewhat difficult from actively growing tissue of the plants to other parts as it is relatively immobile in plants. Boron deficiency has been proved to be of the major constraints for crop production. At present, ~30% of Indian soils especially those that are coarse in texture, low in organic matter (OM) content and having high calcium carbonate (CaCO3) content and alkalinity problem, are B deficient (Sharma and Nayyar, 2004). Boron is involved directly and indirectly in the cell growth of new shoots and root as it is also highly important for boll formation, flowering, pollination, and seed development (Dordas *et al.*, 2007). It also increases the utilization of macro-nutrients by plants and promotes the translocation of photosynthetic products from the source towards the sink during the crop life cycle (Ali *et al.*, 2013). Therefore, it is essential to supply B to plant which is evidenced by the response of B application on the yield of different crops as reported by various scientists (Kumar *et al.,* 2018). Therefore, an attempt has been made to review the literature to compile a piece of information related to crop response to B application in B deficient soils with contrasting characteristics that affect its availability in the soil solution.

Boron deficiency in Indian soils

In Indian soils total boron ranges from 7-630 ppm and available boron in different states of India is on an average 12.2 ppm started from traces (Chaitanya *et al.,* 2014). Next to zinc (Zn), deficiency of B is widespread in India. Its deficiency is found in soils that are highly calcareous, leached and sandy. A critical level of B in soils below which B deficiency appears on crops has been <0.5 ppm. However, a critical level in crop leaves has been reported to be in the range 10-20 ppm for most crops. However, lack of B nutrients can cause serious physiological damage, thus retarding plant growth and reducing the crop yield substantially. Boron deficiency has also appeared in alluvium derived coarse-textured, low organic matter, alkaline and calcareous soils of Punjab, (India). About 5-10% of cultivated soils in Punjab (India) were reported to be B deficient (Sharma and Nayyar, 2004). Borkakati and Takkar (2000) reported that alluvial soils of Assam have been reported to have a greater magnitude of B deficiency (~44%), compared to lateritic soils (~34%), if a critical concentration of 0.5 mg B kg-1 soil is considered. However, soils under fruit crops (orchards) are more prone to B deficiency (~56-65%), followed by field crops (~42-47%), pasture land (37-45%) and forest ecosystem (~5-17%). About 35% of rice soils were found below critical B concentration in acid soils of Meghalaya (Nongkynrih *et al.,* 1996).

Factors affecting B availability

Parent Material

Soils resultant from shales and marine clays usually have satisfactory B for the plant growth. Coarse textured soils, having less organic matter, rich in aluminium oxides or derived volcanic ash have low B availability. Soils formed from sedimentary rocks have higher boron concentrations as compared to soils derived from igneous rocks. Ho (2000) also corroborated the same finding that soils originated from igneous rocks, and those in tropical and temperate regions of the world, have much lower B concentrations than the soils of sedimentary origin and arid and semi-arid regions.

Soil (pH)

Soil reaction can influence B mobility in the soil, and phyto-availability. Goldberg and Glaubig, (1986) studied that boron availability decreased with increasing soil pH. Decreased availability at higher pH levels is associated with decreased B concentration in soil solution (Niaz *et al*., 2007). In adsorption studies, Shafiq *et al.,* (2008) described that adsorption is linearly influenced by pH of the soil solution. Boron availability declines progressively as soil pH is increased. Liming acid soils in some susceptible plants may cause a temporary B deficiency. Further, the severity of deficiency also depends on other factors such as soil moisture status and time elapsed after liming. In high organic matter soils, liming facilitates the release of boron, thus increasing boron uptake through encouraging organic matter decomposition. In low pH soils with a sandy texture, B is susceptible to leaching particularly if rainfall is high. However, leaching is not considered a problem in fine-textured soils, if the soil is not very low in pH (Nazir *et al.,* 2016). The depressing effect of pH is more noticeable beyond pH 6.0. In the calcareous soils, B deficiency is because of their high pH. Boron in soil solution at pH below 7.0 occurs as boric acid (H_3BO_3) and as the pH increases above 7.0, the boric acid accepts hydroxyl ion from water and forms a tetraborate anion. This ion is adsorbed on adsorbing surfaces in soils; hence adsorption increases at higher pH values suggesting that B adsorption on soils is pH-dependent. This behaviour is often amplified when the pH increased from 3 to 9. Plants may not suffer from B deficiency in acid soil, while at the same levels of available B; plants may show deficiency under alkaline conditions.

Organic matter (OM)

Organic matter is considered to be the storehouse for B. It becomes available upon decomposition of OM by soil microorganisms. The presence of comparatively higher content of organic matter in surface soils vis-à-vis subsurface soils results in its higher availability of (OM) in surface soils. Application of organic matter to soils tends to increase B in plants and may even cause phytotoxicity. Boron may bind with OM or with carbohydrates released during humus formation. Association of B with humic acid is most important B pool for B availability to plants in most of the agricultural soils (Jones, 2003). OM affects the availability of soil B which is evident from studies that show a linear positive correlation between levels of SOM and the amount of hot watersoluble B. linear (Shafiq *et al*., 2008) Other researchers have opined that the level of soil organic matter (SOM) influences the nutrient bioavailability (Sarwar and Mubeen, 2009). Boron and OM association is responsible for B accumulation in surface soil by retarding leaching of boron. Organic matter also moderates the ill effect of rising pH on B availability.

Soil texture

As far as the texture of the soils is concerned coarsetextured soils often contain low amount of available B than finetextured soils (Raza *et al*., 2002). Niaz *et al*., (2002) concluded from a study in Punjab, Pakistan that B concentrations of plants grown on course and mediumtextured soils were lower than their requisite critical levels, as these soils were well-drained and subjected to leaching. Boron deficiency appears frequently in coarse-textured soils and finetextured contain more amounts of available B. It may be due to their higher absorption area and less leaching losses (Malhi *et al*., 2003) Greater amounts of hot watersoluble B were present in fine-textured, compared to coarse-textured soil. Chances of boron toxicity is high in soils of arid and semiarid region due to contribution of boron from irrigation water (Nazir *et al.,* 2016)

Soil temperature and moisture

Soil temperature and moisture are the key factors controlling B availability. Dry conditions cause the soils to become boron deficient. Under a low soil moisture regime, boron concentration in soil solution decreases. Boron uptake by plants is obstructed during dry conditions as moisture availability from the lower soil layers is reduced. Moist conditions are conducive to B availability. Gupta (1993) noticed the deficiency of boron in forage under low temperatures in the spring and autumn season of temperate regions.

B deficiency is often related to dry weather, where low soil moisture caused the reduction of B release from an organic matter affecting its transport to absorbing root surfaces consequently reducing B uptake (Nazir *et al*., 2016).

Iron and aluminum oxides

Bingham *et al*., (1971) noticed a highly significant relationship between iron and aluminium oxides with B concentration. Elrashidi and O' Conner (1982) emphasized the importance of aluminium and iron oxides for B absorption on soils. Boron bioavailability is also reduced in soils derived from volcanic ash (Sillanpaa and Vlek, 1985) Various researchers have conducted studies on B adsorption as influenced by various crystalline and amorphous oxides of iron and aluminium indicated its positive correlation (Toner and Sparks, 1995).

Clay minerals

Well-drained coarse-textured soils are generally deficient in B and crops grown on these soils respond to B applications. Texture in subsoil also influences the magnitude of boron availability. It is seen that magnitude of response to boron is low in the case sandy soils having fine-textured subsoils competed to as those with coarse-textured subsoils.

It is observed that applied B up to 85% is lost through leaching in sandy low organic matter soils. On the contrary, due to the high adsorption capacity of fine-textured soils boron is retained for a much longer time. Despite high retention and presence of more boron in fine-textured soils, it is seen that at equal solution B concentration boron uptake in these soils is low compared to coarse-textured soils. The probable cause of low uptake of boron in fine-textured soils is the presence of higher levels of available Ca, hydroxyl of Fe and Al compounds in the layer silicates or as impurities dominate over clay mineral species per se in determining B adsorption characteristics (Nazir *et al.,* 2016). Layer silicate clay minerals are significant boron adsorbing surfaces in soils (Goldberg *et al*., 1996) and clay minerals showed increasing B adsorption at a pH range of 8 to 10 as reported by Mattigold *et al.,* (1985). Keren and Mezuman (1981) found that boron adsorption in different clay minerals followed an order: kaolinite<montmorillonite<illite. Couch and Grim (1968) found that adsorption appears to take place by two-step processes viz. initial adsorption onto the particle edges, and later on incorporates into tetrahedral sites replacing silicon and aluminium. Ligand exchange with surface hydroxyl groups on the clay particle was reported to be responsible for B adsorption on clay minerals (Keren *et al.,* 1994).

The effect of temperature on B adsorption by clays depends upon reaction time. Boron adsorption in a pH range of 5.5-9.5 showed a decreasing trend with increasing temperature for a short reaction time, whereas it exhibited an increasing trend with a rise in temperature for longer reaction times (Jasmud and Lindner, 1972). It, therefore, indicates that initial B adsorption follows an exothermic, while the subsequent B fixation follows an endothermic reaction.

Redox Potential- Boron does not take part in oxidation-reduction reactions. So, B concentrations are not affected in flooded conditions. (Ponnamperuma, 1985).

Boron carriers

Among the various B carriers borax, sodium tetraborate and sodium borate with 11, 14 and 20% B respectively, have been commonly used for soil application, however, boric acid has been used for foliar application of boron in crops (Table 1). Due to good solubility, Solubor is used for both soil and foliar application. Colemanite and B-frits are considered to be more reliable on leached sandy soils.

Methods and rates of application

The margin between deficiency and toxicity is narrow for this nutrient so there is a need for its judicial application at the right rate using the right source. Total boron content in soils varies considerably which depends upon parent material. The value of the mean total boron content in soil is considered to be 30 mg kg-1 Plant require boon in trace amount and its toxicity appears in most of the crops when its contents exceed 20 mg kg-1 (Carlos, 2000). But in boron loving crops like alfalfa, sugar beet, sunflower, soybeans and canola, Benton (2003) emphasized the need of applying soil application B when its concentration in leaves is below 25 mg kg-1. Boron deficiencies are cured both by soil and foliar application of B fertilizers (Table 2) but soil applications are more commonly used. Boron may be applied to soil either broadcast or banded before sowing. Top dressings have sometimes been successful. The rate of B should range between 1.2 to 3.2 kg ha-1 for high B requiring crops (legumes and some root crops) and 0.6-1.2 kg B ha-1 for low B requiring crops (Table 2). Knowledge of soil and climatic conditions is however necessary before precise recommendations can be made. Different workers reported that rate of boron application depended on soil type. It generally varied from 0.5 to 2 kg B ha-1among soil types (Table 3). Since the margins between optimum B level and toxic B level, as mentioned previously is very narrow, the rate of B must be regulated accordingly to crop needs, otherwise, B toxicity may occur. Foliar applications of B can be

Table 1. Different boron carriers, chemical formulation and approximate boron content

Source	Chemical formula	Boron (approx. %)
Borax	$Na_2B_4O_7.10H_2O$	11
Sodium tetraborate	Na[BO(OH)]·8HO	——
Fertilizer borate 46	$Na_2B_4O_7.5H_2O$	14
Fertilizer borate 65	$Na_2B_4O_7$	20
Solubor	$Na_2B_4O_7.5H_2O+ Na_2B_4O_7.10H_2O$	20
Boric acid	H_3BO_3	17
Colemanite	$Ca_2B_6O_{11}. 5H_2O$	10
Boron frits	-	2-6

Table 2. Rates and methods of soil application of boron

Crop	Source	Rate (kg B ha^{-1})		Method of application
		Range	Optimum	
Sugar beet	Fertilizer borate 46	1.6-3.2	3.2	Broadcast
Alfalfa	Borax	1.2-2.6	2.4	Broadcast
Cotton	Solubor	0.6-1.2	0.6	Banded
Red beet	Borax	1.2-3.6	2.4	Broadcast
Sweet corn	Borax	1.2-2.4	1.2	Broadcast
Sweet potato	Borax	0.6-3.6	0.6	Broadcast

preferably and successfully applied to fruit trees. Boron being immobile, number of sprays is required to alleviate its deficiency. It includes application of one spray in dormant season and further sprays when the tree has developed sufficient foliage. In annuals, first spray be made on noticing the deficiency during growing season and subsequently at weekly intervals to get best results. Any soluble boron fertilizer can be applied at a concentration ranging from 02-0.5 percent of spray solution but for sugar beet, concentration can go up to 2.5% (Katyal and Randhawa, 1983).

Boron deficiency symptoms

Borate ions being soluble and mobile in soil could leach from the root zone, resulting in the appearance of its deficiency on crop plants. Boron deficiency symptoms primarily appear at the growing tips and its shortage cause stunted look, infertile ears, hollow stems, brittle leaves, reduction in yield, size of fruits and nuts. Benton, (2003) also noticed that chlorosis and death of the growing points, distortion thickening and cracking of stems are the common symptoms. Common deficiency symptoms are stunted growth and loss of meristematic tissues. Boron deficiencies are more prominent when root activity is restricted due to water deficiency. Crops that are susceptible to B deficiency are alfalfa, sugar beets, clovers and some vegetable crops.

Response of crops to boron application

Substantial yield responses of several crops (cereals, pulses oilseeds, forages vegetables and fruits) to boron application from various studies are enumerated. In India, field studies involving B have been limited in number and geographical spread. Most of the studies have been conducted in eastern India where soils are relatively coarse-textured, prone to excessive leaching as they remain largely flooded. A lot of on-farm trials conducted in Assam, Bihar, Orissa and West Bengal indicated that rainy-season rice, wheat and mustard responded positively (response >200 kg ha-1) to soil-applied B (Takkar *et al.*, 1997). On silty loam acid soils of North Bengal, an increase in wheat grain yield by applying borax @ 20 kg ha-1 was observed by Mitra and Jana (1991). Patgiri (1995) found that borax applied at 10 kg ha-1 increased the toria yield, oil and protein content and B concentration in the seed. Dry matter and pod weight of peas increased from ~10.5 to 19.0 g plant-1 and 6.02 to 7.23 g plant-1, respectively with B application 0·033 to 0.33 mg L-1 (Sinha *et al.,* 1999). Results of the field experiments on sesamum and mustard grown on B deficient calcareous soils of Bihar, Sakal *et al.,* (1991) found that application of 1.5 kg B ha-1 increased the mean grain and straw yields in sesamum from 502 to 569 and 3121 to 3622 kg ha-1, respectively whereas grain and straw yield of mustard increased from 11.4 to 13.5 and 38.4 to 41.4 q ha-1, respectively. Renukadevi and Andi (2000) reported that application of B at 2.0 kg kg-1 soil increased the seed and stalk yield of sunflower significantly. In alluvial deficient soils, crop genetic potential particularly for leguminous crops could be achieved with B application (Sharma and Nayyar, 2004). (Katyal *et al.,* 1983). Substantial yield response has been found in crops such as cotton, rice, maize, soybean, groundnut, rape, citrus fruit orchards and alfalfa crops due to boron deficiency (Johnson, 2006).

Soil application of B has increased yield in cotton crops. In field experiments, 1.1 to 3.3 kg B ha-1 was adequate for the correction of boron deficiency in cotton. It is to be noted that B is involved in the transfer and assimilation of sugars and nitrogen to form fibre (lint) and proteins so its requirement becomes maximum during lint seed formation stages. De Oliveira *et al.*, (2006) talked about the importance of boron for cotton productivity and its deficiency overall retards the growth through particularly inhibiting cell development of petiole and peduncle. Khurana *et al.,* (2012) on boron deficient soil found that berseem fodder yield in first and second cuttings require 0.75 kg B ha-1 whereas 1.0 kg B ha-1 essentially to be applied to third cutting for getting significant higher yield over no boron application. While comparing the efficacy of different methods of B application through soil and foliar under the rainfed condition on sandy loam soil Ansari *et al.*, (2013) found there was a positive influence on yield attributes and pod yield of groundnut regardless of whether the boron was applied as soil and foliar. Ansari *et al.,* (2013 concluded that pod yield of groundnut when grown as rain fed crop on sandy soil increased regardless method (soil or foliar) of boron application.

They further concluded that soil-applied @ 10 kg ha-1 proved superior for better land utilization, high yield, productivity and profitability compared to other treatments. Dhaliwal and Khurana (2016) studied the effect of soil boron application ranging from (0.5 to 2.0 kg B/ha) on boron deficient coarse-textured alluvial soils taking garlic as a test crop. They found that application of 1.0kg B ha-1 enhanced all yield attributing parameters like plant height, the number of leaves per plant, the diameter of the bulb, the average number of cloves per bulb, the weight of 100 cloves which eventually resulted in higher bulb yield over no-B control, beyond this application rate non-increase in bulb yield of garlic was observed.

From the experiment conducted to study the response of wheat, rice and cotton to B application, Riaz and Muhammad (2011) found that boron applied at 1 kg ha-1 as Borax decahydrate (11.3% B) at sowing time to wheat enhanced significantly all the yield attributing parameters namely the number of tillers plant (15%), number of grains spike (11%), 1000-grain weight (7%) and grain yield (10%) over control. This treatment was found to be superior compared to B application at 1st irrigation and booting stage. Similarly, in both coarse and fine rice varieties, B applied before transplanting considerably increased all the yield attributing parameters. Cotton also responded significantly to B application through its positive and stimulating effect on all the yield parameters which showed increasing trends namely plant height (3%), seed weight boll (8%), mature bolls/plant (12%) and seed cotton yield (9%) over control. While assessing the influence of boron on nutrition and productivity of cocoanut palm trees. Moura *et al.,* (2013) found a substantial increase in production of ninety-five per cent of trees with the application of 2.0 kg of boron signifying that not only the field crops but trees also got benefited from its application. During a study on boron application on oilseed at the Research–Breeding Station at Víglaš–Pstruša, Maria, Ladislav (2014) observed that by applying the increasing level of boron (200, 400 and 800g B. ha1) along with nitrogen and sulfur (183 kg N. ha1, 46.5 kg S. ha^{-1}) indeed positively influence the oil content in oilseed crop (*Brassica napus* L.).

After reviewing the literature on the crop response to boron Gazala *et al.,* (2016) found that rate of B application differed among the crops. They concluded that showed that the yield response of boron application differed in magnitude in different pulse crops. Applied boron caused motivating influence on all the yield parameters irrespective of the crop. Both in Pakistan and India rice crop suffers from B deficiency. It ranged from 10 45% in Pakistan (Tahir *et al.,* 1990) whereas in India it varied from ~1-69% with an average of ~33% (Singh, 2001), respectively. A significant 15-25% augmentation in rice yield was revealed by Rashid *et al.,* (2009) in alkaline soils with low organic content where a rice-based cropping system is practiced. Boron fertilizers are not or inadequately applied which obstructed B uptake and its deposition in grain (Atique-ur- Rehman *et al.,* 2018). Though wheat, a cereal crop having a low B requirement, but its deficiency is globally observed in this

Table 3. Response dose as affected by soil type in ground nut and wheat.

Crop	State of India	Type of soil	Response dose (Soil application)	Reference
Groundnut	Punjab	Coarse textured alkaline soil	0.5kg B ha^{-1}	Arora *et al.,* 1985
Groundnut	Bihar	Calcareous soils	2.0 kg B ha^{-1}	Sakal*et al.,*1980
Wheat	Bihar	Calcareous soils	1.0 kg B ha^{-1}	Sakal*et al.,*1980
Wheat	Assam	Acid soils	1.0 kg B ha^{-1}	Ali and Monoranjan, 1989

Table 4. Response dose as affected by soil type in various crops

Crop	State	Type of soil	Response dose	Reference
Garlic	Punjab	Coarse textured alkaline soil	1 kg B ha^{-1}	Dhaliwal and Khurana, 2016
Berseem	Punjab	Coarse textured alkaline soil	0.75kg B ha^{-1}	Khurana *et al.*, 2012
Soybean	Punjab	Coarse textured alkaline soil	0.75kg B ha^{-1}	Khurana and Arora, 2012
Lentil	Punjab	Coarse textured alkaline soil	0.75 kg B ha^{-1}	Khurana and Arora, 2012
Groundnut	Punjab	Coarse textured alkaline soil	0.5 kg B ha^{-1}	Arora *et al.*, 1985
Groundnut	Bihar	Calcareous soils	2 kg B ha^{-1}	Sakal *et al.*, 1980
Wheat	Bihar	Calcareous soils	1 kg B ha^{-1}	Sakal *et al.*, 1980
Wheat	Assam	Acid soils	1 kg B ha^{-1}	Ali and Monoranjan, 1989

crop across countries. Boron application at 4.0 kg ha1 significantly improved yield contributing attributes viz tillers, spikelet and grains number per spike and grain yield of wheat over the control in a silty clay soil having 0.8 mg kg-1 of available B. Khurana and Arora (2012) studied comparative efficacy of B sources viz borax and granubor on lentil and soybean in B deficient soil. Application of 0.75kg B ha-1enhanced lentil seed yield by 21.4 and 23.3 per cent when applied through borax and granubor respectively over control signifying superiority of granubor over borax. However, in soybean significant increase in seed yield was obtained at an application rate of 1.25 kg B ha^{-1}. In B deficient calcareous of Bihar having (0.4 mg B kg ha^{-1}) available boron, Sinha *et al.*, (1991) observed that application of boron at the rate of 1.5 kg B ha-1 to various crops namely groundnut, maize, onion, yam bean and sweet potato resulted in yield response of ~ 2.4, 5.2 44.8, 16.7 and 70 q ha^{-1}, respectively. However, for rabi crops magnitude of yield response was 3.1, 8.7, 3.2, 28.3 and 2.4 q ha-1 for mustard, maize, sunflower, onion and lentil, respectively. They further concluded that the optimum rate of B application ranged from 1- 2.5 kg B per hectare for different field crops for such soils (Sinha *et al.,* 1991). Sarkar *et al.,* (2007) concluded from field experiments that for increasing B use efficiency, scheduling the time and methods of B application for crops particularly in light-textured acidic soils receiving high rainfall prone to leaching that low B use efficiency of applied fertilizer-B was due to leaching environment. Therefore, for such areas, optimum timing and methods of B application would vary with the crop sensitivity to B deficiency and periods of peak demand for B. Foliar application, in general, had higher economic benefits compared to its soil application in such areas. Similarly, the dry matter yield increased with an increased level of boron application up to 1.0 mg per kg in pea as reported by Debnath and Ghosh (2014). In a field experiment on a boron (B) deficient alluvial loamy sand soil of Punjab, Dhaliwal and Khurana (2016) observed that soil application of B (1.0 kg B ha^{-1}) has resulted in a significant ($p<0.05$) augmentation in garlic plant height, number of leaves per plant, the diameter of the bulb, average number of cloves per bulb, weight of 100 cloves, foliage yield and bulb yield over no-B control. Higher rates of B application (>1.0 kg B ha-1) resulted in non-significant increase in bulb yield and yield determining attributes.

Application of 5 kg borax ha-1 has resulted in a significant increase in grain yield of pearl millet (Gupta *et al.,* 2000). Further application of 20 kg borax ha-1 decreased the grain yield significantly its toxic effect at higher application. Boron concentration and uptake by pearl millet grain increased significantly with the increase in levels of boron. Singh and Singh (1990) noticed an application of 1.0 kg B ha^{-1} produced an additional pod yield of ~7.38 q ha-1 in French bean and application of B above a certain level was detrimental. Sakal *et al.,* (1988b) observed that in coarse-textured highly calcareous soils, application of 2.0 and 2.5 kg B ha^{-1} enhanced grain yield of black gram and chickpea by ~63 and 38%, respectively. In calcareous soils of Bihar, Sinha *et al*., (1991) concluded that the dose of boron varied from 1 to 2.5 kg B ha^{-1} for different crops (Table 8). Sarkar *et al.,* (2007) studied the effect of boron applied either as split dozes or single application on B-deficient soil taking mustard, wheat and potato as test crops. Boron when applied in split doses either to soil or foliar application (at different days after sowing for mustard and potato, respectively) proved better over a single application. But the single foliar application of B when applied either at 45 or 60 days after sowing (late) respectively proved more useful.

Owing to considerable residual effect, boron application benefits more than one crop in cropping sequence Sakal *et al*., (1999) evaluated the direct and residual effect of varying B levels under the maize-lentil cropping system practiced on calcareous soil.

Table 5. Effect of modes of B application in soybean-wheat system

Treatment	Grain yield (t ha^{-1})	
	Soybean	Wheat
Soil application (20 kg sodium tetraborate ha^{-1})	1.41	1.46
Foliar application solution) (0.2% sodium tetraborate soil.	1.33	1.35
Control	0.89	0.66
LSD ($p<0.05$)	0.1	0.11

(Source: Dwivedi *et al.,* 1990)

They reported that increasing levels of B significantly increased the maize and lentil yield up to 16 kg borax ha-1. However, lentil was found to be more responsive to B as compared to maize. In a study laid out on a leaching prone acid soil (Inceptisol), Dwivedi *et al*., 1990) observed that soil application of B at 20 kg sodium tetraborate ha-1 or 2-foliar sprays with 0.2% sodium tetraborate solution proved equally effective in increasing soybean grain yield. It is to be noted that residual supply of boron provided by soil application not only increased yield of following wheat crop but also excelled that obtained with two fresh foliar sprays of boron (Table 5). Sakal *et al*., (1996) studied the scheduling of boron application in rice-wheat and maize-mustard cropping systems. They recommended either apply 8 kg borax ha^{-1} to each crop or16 kg borax ha-1 to alternate crops. This practice helped to get higher crop yields, ensured higher B uptake and even maintained higher levels of the hot water-soluble B levels in the soil. Singh (2000) conducted a field experiment on B deficient coarse-textured soils of Tamil Nadu taking a groundnut-maize cropping system. It was observed that the initial application of 2 kg B ha^{-1} followed by application of 0.5 kg B ha^{-1} to alternate crops is sufficient for the highest system's productivity and total B uptake.

Summary and future research needs

From the above discussion, it is concluded that amelioration of B deficiency in crops is a must and its requisite application show a positive influence on yield and produce quality of many crops. Response varied with the crop. From different research experiments 1430% in rice, 58% in soybean, 30% in potato, 45% in oilseed rape, 10% in groundnut/peanut, 20% in maize/corn, 14 % average response for cotton, 37% in alfalfa seed and wheat 159 % in alfalfa forage is reported through B fertilization. Thus, Response ranged from as low as 14 % to as high as 159% depending upon the crop. Rate, source and method of boron application (soil and foliar) have strong control on the yield and quality of the produce. For example, rice receiving boron application on B deficient soils has shown striking improvement in milling recovery, head rice recovery and kernels quality traits like stickiness and cooking quality. Residual influence of soil-applied B lasts for years because only 1-2% of total applied B is utilized by crops. This aspect needs to be taken for adaptive research while calculating the B requirement. So, the boron requirement for various cropping sequences needs to be established so that B use efficiency may be enhanced and consequently the cost of cultivation may be brought down. Boron may also be supplied through irrigation water. So, its availability from irrigation must be considered before formulating the response dose. It also becomes more unavoidable as the toxic and deficiency level for this nutrient element is narrow.

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