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EFFECTIVENESS OF BORON APPLICATION: SOIL VS FOLIAR FEEDING

PRATIBHA THAKUR AND PARDEEP KUMAR*
Department of Soil Science,
COA, CSKHPKV, Palampur - 176062,(HP)
e-mail: drpardeep1968@gmail.com

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***Corresponding author**

ABSTRACT
High yielding cultivars, are highly exhaustive but macronutrient status of the soils is little affected due to almost matching external replenishment of these nutrients. However the supply of micronutrients to soil is negligible, and organic manures, considered as the main source of micronutrients have been replaced by high analysis, nutrient specific fertilizers resulting in over mining from the soil at an alarming. Boron is one of the most important and deficient micronutrient in Indian soils. Boron performs a key role in diverse range of plant functions including cell wall formation and is essential for cell wall division, accelerating growth, sugar translocation, development, enhancing yield and upgrading crop quality. As boron is involved in pollination, and fruit and seed development, its requirements are much higher for reproductive growth. Even under adverse conditions, boron acts as a stress buster and helps the crops to survive. It also helps in improving the nutrient use efficiency of plants. Despite having unlimited advantages in crop production, boron is an underdog among micronutrients. Right sources, timing, methods and rates of boron application are not well established therefore it is considered as a trivial element and need focus in harnessing higher production and crop quality.

INTRODUCTION

Increasing population has left us with no choice of increasing the area under cultivation hence, the only option left with us to increase the productivity of crops per unit area. Imbalanced nutrition is one of the major constraints besides other reasons of low productivity. The farmers indiscriminately apply N fertilizer while the application of P and K fertilizers is limited and that of micronutrients is almost negligible and such conditions are responsible for low yields and deteriorated soil health. If due attention is paid to all the essential nutrients (macro and micro), the soil health and crop productivity and quality are bound to improve. Therefore, equal attention is needed on micronutrients also. Boron is one of the essential nutrient involved in diversified functions and is essential element for all vascular plants. Its toxicity or deficiency is responsible for causing metabolic and physiological damage (Herrera-Rodriguez *et al*., 2010). Boron has its crucial role in cyanobacteria, algae, and animals (Goldbach and Wimmer 2007). It is present in normal pHs as a charged-free molecule so is an exception among plant nutrients. It occupies a unique place among micronutrients as it has a very narrow range between deficiency and toxicity (Yau and Ryan 2008). Therefore, its optimum availability both in soil and water is an important factor in the production of agricultural products (Camacho-Cristobal *et al*., 2008). In order to achieve the maximum benefit of boron application the 4R (right source, right time, right method and right place) principals needs to be adopted in conjunction with other nutrients. The highest benefit cost ratio was obtained in tomato when the recommended dose of primary nutrients was supplemented with micronutrients (Zn and B) (Singh and Verma, 1991). The recommended dose of N, P & K when supplemented with foliar spray of Zn + B gave higher seed cotton yield and produced higher number of bolls and enhanced the boll weight (Ali *et al*., 2011). An imbalanced fertilizer use lead to multi nutrient deficiencies particularly of boron, resulting in yield reduction and deteriorated soil health. Importance of boron for crops is well established. A linear relationship was observed between boron & leaf area index and boron & dry matter yield in spring and autumn seasons respectively, and boron spray also increased the number of seeds and seed weight and decreased the empty seed percentage in sunflower (Amery *et al*., 2011). Soybean yield can be remarkably improved by combined foliar application of B + Mg (Reinbott and Blevins, 1995). Boron plays an important role in plant growth and development as translocation of sugar and quality of the produce depends on boron. Boron has emerged as one of the most deficient micronutrients and the deficiency is common in high rainfall areas with high temperature on acidic soils with coarse texture due to leaching losses. Boron dearth is an imperative soil constraint not only in Indian soils, but throughout the world. Because boron is very much liable to leaching so it requires special attention matching the 4Rs. Foliar and soil applications of boron improved the rice growth and yield, however, dipping seedlings in boron before transplanting caused B toxicity and reduced the straw yield (Hussain *et al*., 2012). Considering the multifarious functions of boron an attempt has been made to highlight the importance of boron,suitable application method for getting higher yields and enhancing its use efficiency.

Effect of boron supplementation on crops

Effects of boron on growth and yield attributes of crops

Supplementation of boron along with the recommended doses of macro and secondary nutrients is known to enhance both growth and yield attributes of the crops. Both soil and foliar applications of boron were effective in improving the growth and yield parameters of groundnut (Ansari *et al*., 2013). Significant improvement in yield, plant height, boron content in seed, germination rate, test weight of soybean was noticed by application of boron either through soil or foliar feeding and 1.09 kg/ha boron application was worked out to be the best dose for achieving maximum yield (Cirak *et al*., 2006). An increase in dry matter yield and starch content was observed in potato with two foliar sprays of 0.5% boron and 0.25% sulphur (Singh *et al*., 2018). Soybean yield can be essentially enhanced by combined foliar spray of B + Mg (Reinbott and Blevins, 1995).Soil application of $ZnSO_4$ @ 16-24 kg/ha and foliar spray of boron containing 0.1% of boric acid increased grain yield and decreased the number of partially filled grains in corn (Ziaeyan and Rajaie, 2009). Supplementation of Zn + B @ 0.75 + 1.00 kg/ha as foliar spray along with recommended doses of N, P and K was the best combination for higher seed cotton yield with higher number of bolls and boll weight (Ali *et al*., 2011). Boron increased the leaf area index and dry matter yield in a linear way in spring and autumn seasons respectively, and boron spray enhanced the seed weight and quantity of seeds as well as minimized the unfilled seed percentage (Amery *et al*., 2011). Boron supplementation as foliar spray @ 0.45% registered a positive impact on growth, yield and financial aspects of tomato (Kumar, 2011). Foliar application of boron and yeast extract @ 50 ppm and 5ml/l respectively, positively influenced the quantity, quality of green pods, seed yield of broadbean (Yazied and Mady, 2012). Conjoint use of N, P and K @ 180, 80 and 60 kg/ha, respectively with the supplementation of borax @ 0.25% notably increased number of leaves and plant height in cabbage (Kumar and Khare, 2015). Application of boron @ 1 kg/ ha not only enhanced the growth of wheat butalso increased straw and grain yield by 8.1% (Sharma *et al*., 2016). Foliar application of boron @ 0.3 kg/ha registered highest grain and straw yield of maize,however further increase in boron dose showed the negative impact on the yield (Tahir *et al*., 2012). A significant increase in growth and yield of wheat was observed with foliar application of boron or with combined foliar application of Fe and B (Rawashdeh and Sala, 2013). Dry matter production in corn improved when boron was applied as foliar spray (Shagholi *et al*., 2013). Growth, yield and quality of onion were remarkably improved with the foliar spray of boron @ 0.5% (Mana *et al*., 2014). Hybrid tomato produced maximum plant height, number of leaves, leaf area, number of branches, number of fruits, fruit length, fruit diameter, single fruit weight and highest yield when 12.5 ppm zinc sulphate + 12.5 ppm boric acid were applied through foliar application (Ali *et al*., 2015). An increase in polar and equatorial breadths of onion was observed when borax was applied to soil @ 10 kg/ha, whereas, the most note worthy number of bulblets per cluster were recorded with soil application ofborax @ 15 kg for every hectare alongwith its foliar application @ 0.25% (Acharya *et al*., 2015). Boron application upto 5 kg/ha affected the growth & yield attributes, quality and harvest index of cauliflower and 2.7 kg/ ha was found to be the optimum dose of boron for cauliflower (Nazir, 2015). For better grain yield of wheat, boric acid should be applied as soil application @ 1.5kg/ha or foliar application @ 0.4% at primordial or booting stage of wheat (Fakir *et al*., 2016). Foliar application of Ca and B increased the plant growth, improved the fertilization of flowers, enhanced the number of tillers per wheat plant and increased grain yield (Zoz *et al*., 2016). In rice, when recommended doses of FYM + NPK were supplemented with 8 kg/ha borax, a sharp increase in plant height, number of leaves, number of tillers and biological yield was noticed and enhancement in dry matter accumulation was also recorded (Prashanth *et al*., 2018).

Effect of boron on quality parameters of crops

Different crops possess different quality parameters, such as protein and carbohydrate level in maize, firmness, brightness, TSS, ascorbic acid and colour in fruits, oil content in oilseeds etc. Surprisingly, boron has its role in enhancing the maximum of these parameters. The quality of strawberry was greatly enhanced with the foliar application of Ca + B before harvest and it helped in keeping the fruits firm and bright and also increased the ascorbic acid content of the fruits (Singh *et al*., 2007). In seed production of sugarbeet, foliar application of boron can essentially improve the quality and yield of seed (Dordas *et al*., 2007). Foliar application of boron on pecan at right rates invigorated the pollination & fertilization, improved the fruit retention period and movement of sugars within plants (Wells *et al*., 2008). Foliar spray of Zn as zinc sulphate @ 4.5 g/l or boron as boric acid @ 20 ppm and their blend expanded the growth & yield of iris plants and furthermore improved chemical constituents of the plants *viz*., colour, carbohydrate and oil concentration of flowers (Khalifa *et al*., 2011). Inadequacy of boron was one of the main reasons for internal necrosis and fruit cracking in mango and foliar application of boron as disodium octaborate @ 0.10% was very effective in increasing yield and decreasing internal necrosis and fruit cracking in mango (Saran and Kumar, 2011). The protein quality of frenchbean could be improved with the combined application of recommended NPK, FYM and 45.0 kg/ha S and 1.0 kg/ha B (Ganie *et al*., 2014). Quality of sunflower oil was remarkably upgraded with the foliar application of boron, as an increase of 26.85% and 34.81% in per plant yield was registered when boron concentration was doubled from 300 ppm to 600 ppm compared to control plants (Mekki, 2015). An increase in protein and oil content of mustard was reported with the application of S @ 40 kg/ha and B @ 2 kg/ha along with the recommended dosages of N, P and K (Jaiswal *et al*., 2015). Application of boron @ 10 kg/ha and vermicompost @ 20 kg/ha improved the overall quality of tomato fruits by its positive influence on the fruit size, shape, firmness, colour, smoothness, ascorbic acid and sugar content and decreased fruit cracking (Sarangthem *et al*., 2015). Combined application of 18 kg/ha boron + 1.5 kg/ha ammonium molybdate proved to be efficient in upgrading the quality of broccoli by increasing the reducing sugars, TSS, vitamin C content and chlorophyll content of the plants (Thapa *et al*., 2016). Foliar feeding of Zn, Fe and B significantly improved the biochemical characteristics of maize like chlorophyll content of leaves and sugar & protein content in grains (Deswal and Pandurangam, 2018). In broccoli, maximum ascorbic acid content and TSS were

recorded with the supply of B + Mn + Zn @ 3.0 + 2.0 + 2.5 kg/ha respectively (Pankaj *et al*., 2018). Foliar spray of boric acid @ 0.40% improved the TSS and starch content in broccoli and hence, improved its overall quality (Singh *et al*., 2018).

Boron as a stress buster for plants

Apart from yield and quality enhancement, boron acts as a good stress buster under different adverse conditions and helps the plants to survive under such conditions. Under calcareous soil conditions, foliar spray of boron was effective in seed quality improvement of cotton and enhancing the seed & lint yield (Dordas 2006). Foliar application of Mn and B proved effective in reducing the toxic effects of excessive levels of sodium and helped in reaping higher yields even when the salinity was beyond thre shold value (5.5 dS/m) (Jabeen and Ahmad, 2011). Foliar spraysof Zn, B & Mn enhanced the grain yield of winter wheat under drought conditions. Also, supplementation of micronutrients to the wheat under drought stress improved its water use efficiency, pollen viability, number of fertile spikes and number of grains per spike (Karim *et al*., 2012). Soil application of B @ 0.5mg/kg and its foliar application @ 0.1% in green gram resulted in better growth and yield in calcareous soils (Padbhushan and Kumar, 2014). Rather than using more drought tolerant genotypes, hardening of crop plants with the foliar application of boron can be a better strategy to avoid the water stress in drought prone areas (Naeem *et al*., 2017). Under drought conditions, foliar application of boron at booting and anthesis stages of wheat was found an efficient way to decrease the water stress in the plants and the same spray at booting stage increased plant height, spike length, spikelet number, 100 grain weight, yield per plant and total grain yield (Motagally and Zohri, 2018). Supplementation of Si and B in sunflower fields was found to reduce the damage of sunflower plants due to water stress (Neves *et al*., 2019).

Effect of boron on nutrient uptake by plants

Boron affects the uptake of other nutrients from the soil. A significant variation in concentration of N, P, Mn, Zn, Fe and Mo in ear leaf and concentration of Ca, Mg, Mn, Fe, Zn, Cu and Mo in roots of maize was observed when boron supply was altered (Mozafar, 1989). For enhancing the nutrient uptake by the plants from the soil, combined application of Zn, B and Mo @ 5, 3 & 2 kg/ha, respectively was recommended (Hossain *et al*., 2001). B and Zn when applied @ 0.2 - 0.6 mg/dm3 each, in white oats, a sharp increase was registered in the absorption of nutrients and their accumulation in plant tissues (Castagnara *et al*., 2012). A significant increase in nutrient status and organic matter of the soil was noticed with the application of boron in Bt cotton. With the boron application, cotton stalk yield, seed cotton yield and number of bolls per plant also increased (Tekam *et al*., 2013). In Red bayberry, N, P & K uptake improved with the application of boron and different methods of B application had different impacts on nutrient uptake. (Meng *et al*., 2014). Application of boron in tobacco helped in balancing nutrient concentration in the soil, enhanced the availability of macronutrients and also increased the yield (Ali *et al*., 2015). Physico-chemical properties of soil like EC, pH, organic carbon and availability of N, P, K & B were improved with the combined application of N @ 200 kg/ha and B @ 2 kg/ha (Thomas *et al*., 2015). Zn + B @ 3.0 + 1.5, when applied together, improved the soil organic matter and also enhanced the overall nutrient status (N, P, S, Zn & B) of the soil (Quddus *et al*., 2018). Application of sulphur and boron in summer groundnut improved the availability of N, P & K from the soil and also enhanced their uptake by the plants (Patel and Zinzala, 2018).

Soil application or foliar spray :which one has an edge

Effect of methods of B application on its use efficiency

Method of application of any nutrient is one the important factors on which its use efficiency depends. As split application of nitrogen is recommended for majority of the crops to avoid its losses and to improve use efficiency. Similarly, for boron also, we need to figure out the right method of application so that its use efficiency can also be enhanced. When applied through soil, some constituents of soil interact with boron and influence its efficiency. Foliar application of B when contrasted with soil application, it was observed that crops performed better in response to foliar application. Moreover, in calcareous and alkaline soils, soil applied boron interacts with the other nutrients present which adversely affects the boron availability to the plants and in this way foliar feeding is a better choice under these conditions (Arunkumar *et al*., 2018). Foliar feeding of boron recorded higher monetary outcomes when contrasted with soil application. The studies further uncovered that higher yields were obtained with split applications of boron over a long stretch for potato and mustard though use efficiency of boron was better in wheat with single late foliar application (Sarkar *et al*., 2007). Foliar spray of boron was found to be more advantageous for sunflower seed and total dry matter yield when contrasted with soil application. The greatest boron recoveries, B-use efficiencies and seed yields of sunflower were recorded with foliar application of 0.2% B (Bhattacharya *et al*., 2015). A huge enhancement in the yield of tomato was registered with foliar spray of boron and zinc @ 0.03% and 0.05% respectively and it was further noticed that foliar application of boron and zinc had an edge over soil application (Sultana *et al*., 2016). Efficiencies of basal and foliar application of N, B and Zn on growth and yield attributes of corn were compared and maximum growth and yield was recorded with 150 kg/ha N as basal dose along with P & K each @ 75 and 60 kg/ha in combination with Zn @ 25 kg/ha as basal and boron @ 0.3% as foliar spray (Humtsoe *et al*., 2018). Similarly, application of recommended NPK alongwith 10 kg Zn/ha and 1.0 kg B/ha increased wheat yield significantly besides enhancing phosphorus use efficiency (Kaur *et al*., 2015). Green gram when sprayed with 0.2% boron at 20 and 35 DAS + Zn @ 5.0 kg/ha as basal dose improved the growth parameters and upgraded the yield attributes (Praveena *et al*., 2018). The treatment with Zn @ 7 kg/ha + soil application of B @ 0.25 kg/ha + foliar application of boron @ 0.25 kg/ha produced higher protein content in wheat grains and also improved the plant height, development of tillers, dry matter production & yield attributes (Singh *et al*., 2015). For enhancing the yield and quality of cauliflower, foliar application of boron was found to be superior over soil application (Thakur, 2019). Despite having enough evidences about the superiority of foliar application, it cannot be conclusively inferred because there are some advantages of soil application also and many studies

have demonstrated that soil application is a better option. Soil application of boron @ 20 kg per hectare as borax along with recommended dosages N, P and K recorded significantly higher yields. Also, soil application assists with keeping up the dynamic harmony among different boron fractions in soil (such as oxide bound boron, organically bound boron, readily soluble boron, specifically adsorbed boron, residual boron and total boron) (Sathya *et al*., 2013). Better outcomes were recorded in rice with soil application of boron at blooming stage @ 1.5 kg/ha when different methods of boron application were compared. Both foliar and soil application improved the rice growth and yield parameters, however, diping seedling in 1.5% boron solution was found to cause toxicity in seedlings and decreased the straw yield (Hussain *et al*., 2012). Proper method of application can enhance the use efficiency of the nutrient only when applied at the right time, *i.e.* at the critical stages of the crop growth. The yield and yield attributes of wheat were upgraded with the foliar showers of nutrient solution at 3 development phases of wheat, *i.e.* at tillering, jointing and booting (Arif *et al*., 2006). Most elevated grain yield, test weight and greatest number of grains per spike were registered when boron was applied as foliar spray at the booting stage of wheat (Tahir *et al*., 2009). An improvement in boron uptake by processing grade potato plants was noticed when three sprays of boric acid were done at 40, 50 and 60 days after planting and also yielded maximum tubers (Sarkar *et al*., 2018). Foliar application @ 0.5% boron was found more viable when contrasted with soil applied boron @ 2kg/ ha. It was seen that the foliar spray of boron @ 0.5% as boric acid at early, mid and late development stages resulted in taller and thicker plants, expanded number of green leaves, diminished thenumber of dry leaves and improved fresh and dry fodder yield in maize (Soomro *et al*., 2011). Both qualitative and quantitative enhancement in seed yield were observed in black gram with the foliar application of boron @ 0.1% especially after bud formation (Pandey and Gupta, 2013). Foliar spray of boron at V4-V6 (4-6 leaves with visible collars) stage of corn @ 2.24 kg/ha was found most efficient timing and dose of boron application in fine textured soils (Kaur and Nelson, 2015).

Economic viability of the application methods

Suitability of any fertilizer application method cannot be defined only on the basis of its efficiency. The best application method is the one which is efficient as well as economically viable, *i.e.* it should be able to maximize the profits with minimum cost usage. Some scientists consider foliar spray of boron as more viable method while others considersoil application better. Foliar application of borax @ 0.2%, Iron sulphate and Zinc sulphate @ 0.5% each was proved to be the best combination to be applied on cauliflower because it gave the highest benefit cost ratio (Moklikar, 2018). Benefit-cost ratio is directly proportional to the economic viability of the method. Maximum net returns and benefit cost ratio was obtained in processing grade potato (cultivar - Kufri Chipsona 3) with the application of three foliar sprays of 0.1% boric acid at 40, 50 and 60 Days After Planting (Sarkar *et al*., 2018). It was observed that supplementation of boron and sulphur as foliar spray to the recommended dose of N, P & K produced more potato tuber yield and increased that benefit cost ratio (Singh *et al*., 2018). Moreover, the foliar spray with a 100 ppm mixture of micronutrients (B, Zn, Mo, Cu, Fe and Mn) on bitter gourd gave the highest benefit cost ratio and also improved the quality of the produce (Bharti *et al*., 2018). When different methods of boron application (seed priming, soil application and foliar spray) were compared, it was found that foliar spray of boron in flooded rice gave maximum net returns and foliar application and seed priming of boron can be considered as economically viable options to reduce panicle sterility, improve kernel quality, rice growth and yield (Rehman *et al*., 2014). Economic assessment of different methods of boron application revealed that basal application of FYM @ 7.5 t/ha followed by foliar application of boron @ 1.5 ml/l at 30 DAP was the best combination to collect the highest net returns (Banerjee *et al*., 2015). Foliar application of K & Zn is the most efficient technique of fertilizer use for increasing yield and enhancing net income under rainfed conditions (Anees *et al*., 2016). A maize trial which was conducted to compare the soil and foliar application of boron indicated that maximum marginal rate of returns were obtained with foliar spray of 1% Zn and 0.5% B at 9 leaf stage (Anjum *et al*., 2017). A remarkable improvement in the yield of maize and net returns was seen with combined foliar spray of boron and zinc (Wasaya *et al*., 2017). A wheat experiment revealed that foliar spray of boron at primordia and booting stages of wheat required the highest input cost but also gave the highest gross returns (Fakir *et al*., 2018). Different sources of boron that are used for foliar application have different prices and they also affect the benefit cost ratio.In cauliflower, foliar spray of boron calcium metalosate gave higher returns, but the benefit cost ratio was higher in case of boric acid because of its low cost (Thakur, 2019). It cannot be clearly said that foliar application is the only economically suitable method for boron supply because there are some evidences of economic viability of its soil application also. Higher profitability was recorded in groundnut with the soil application of boron @ 10 kg/ha and it achieved better utilization of land, produced higher yield and better productivity (Ansari *et al*., 2013). On analysing the benefit cost ratio of different treatments of sesame it was seen that maximum benefits were obtained when S and B were applied @ 30 kg/ha and 2.5 kg/ha respectively as soil application (Mathew and George, 2013).

CONCLUSION

Role of boron in crop production is not very popular among farmers as other major nutrients, but it has an outstanding impact on crop growth, yield and quality and its positive effects can be seen in adverse soil and climatic conditions also, like it provides drought tolerance to many crops. The multidimensional role of boron in plant growth and development demands that it should be brought to limelight because it can remarkably enhance the production and can upgrade the quality of crops. One of the biggest reasons for the obscurity of boron is less scientific research in the past on its methods and frequencies of application. The available literature on methods of boron application is not able to give a clear upshot about the best methods and timings of application of boron. Not only right timing and right methods, but right rates and right sources also need to be investigated.

To achieve the multiple targets of food security, its quality and simultaneously sustaining/improving the soil health, a holistic approach need to be adopted encompassing complete package of nutrient management.Boron application should be an integral part of nutrient management strategy across the soils and climatic conditions.

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