Boron is one of the important micronutrients 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 CaCO₃. 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 H₃BO₃]. 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 x 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
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    |
| 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 (Calciceneous soil)     | Chickpea           | Hot water          | 0.41                          | Sakal et al. (1993)     |
|                               |                    | Normal Ammonium acetate (pH 7.0) | 0.31                         |                         |
|                               |                    | Normal Ammonium acetate (pH 7.0) | 0.57                         |                         |
|                               |                    | 10 mM CaCl₂ + 10 mM Mannitol (pH 8.5) | 0.18                         |                         |
|                               |                    | 10 mM CaCl₂ + 50 mM Mannitol (pH 8.5) | 0.28                         |                         |
| Meghalaya (Acidic Alfisol)    | Pea                | Hot water (relux)  | 0.7                           | Dwivedi et al. (1993)   |
|                               |                    | Hot water (boiling)| 0.7                           |                         |
|                               |                    | Mannitol-CaCl₂     | 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          |
|------------|---------------------------|-----------------------------|-------------------------|--------------------|
|------------|---------------------------|-----------------------------|-------------------------|--------------------|
| Maize      |                           |                             | 7.6                     | Singh and Sinha (1987) |
| Pea        | Young leaves              |                             | 10.5 – 23               | Sinha et al. (1999) |
|            | Seeds                     |                             | 7.6 – 10.5              |                    |
| Pea        | Bonnaville (55 d old)     |                             | 23.8                    | Dwivedi et al. (1993) |
|            | Meghalaya (Acidic Alfisol)|                             | 233                     |                    |
| Chickpea   |                            |                             | 12.6                    | Sakal et al. (1993)  |
| Blackgram  | Leaves                    |                             | 23.5                    | Sakal et al. (1987)  |
| Gram       | Avrodhi                   | Leaves                      | 13.5-32                 | Chatte jee et al. (2005) |
| Groundnut  | T 3                       | Leaves                      | 6.8-15.74               | Sinha et al. (2002)  |
|            | Kernel                    |                             | 6.2-11.5                |                    |
|            | TMV-2                     | Leaves (30 d old)           | 50                      | 1010               |
|            | Leaves (105 d old)        |                             | 126                     | 3015               |
| Tomato     | DL-3                      | Young leaves                | 5-12                    | Sinha et al. (2006) |
| Sweet orange| Mosambi                  | Leaves (30-40 yr. old orchard) | 12-40                  | Jose et al. (1985)  |
| Coconut    | West Coast Tall           |                             |                         |                    |

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°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:
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. T9) 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 greenhouse 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$_2$B$_2$O$_4$·10H$_2$O | 11     |
| Boric acid        | H$_2$BO$_3$       | 17     |
| Disodium tetraborate (Borate-46, Agribor, Tronabor) | Na$_2$B$_4$O$_7$·5H$_2$O | 14-15  |
| Borate-65         | Na$_2$B$_4$O$_7$   | 20     |
| Solubor           | Na$_2$B$_4$O$_7$·5H$_2$O + Na$_2$B$_2$O$_4$·10H$_2$O | 20-21  |
| Sodium pentaborate| Na$_4$B$_5$O$_{16}$·10H$_2$O | 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 in 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 silique/plant, length of silique, number of seeds/silique, 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 petirole (5th leaf). It also hastens flowering by 10-20 d. Foliar spray of 0.5% borax + 0.25% ZnSO₄ 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 : peel 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% H₃BO₃ + 0.5% ZnSO₄.H₂O + 0.5% FeSO₄.7H₂O 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). Sathy (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% ZnSO₄ 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 Juna 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.

REFERENCES

Ali M R, Mehraj H and Uddin J F M. 2015. Effect of foliar application of zinc and boron on growth and yield of summer tomato. Bioscience Agriculture Research 6(1): 512-7.

Berger K C and Truong E. 1939. Boron determination in soils and plants. Indian Engineering Chemical Annual Ed. 11: 540-5.

Bhatt L and Srivastava B K. 2005. Effect of foliar application of micronutrients on physical characteristics and quality attributes of tomato (Lycopersicon esculentum) fruits. Indian Journal of Agricultural Sciences 75(9): 591-2.

Bowen J E. 1972. Effect of environmental factors on water utilization and boron accumulation and translocation in sugarcane. Plant Cell Physiology 13: 703-14.

Chander G, Verma, TS and Sharma S. 2010. Nutrient content of cauliflower (Brassica oleracea L. var. botrytis) as influenced by boron and farmyard manure in North West Himalayan Alfisols. Journal of the Indian Society of Soil Science 58(2): 248-51.

Chatterjee C, Pratima Sinha and Dube B K 2005. Biochemical changes, yield, and quality of gram under boron stress. Communications in Soil Science and Plant Analysis 36: 1763-71.

Clark M B, Mills, H A, Robacker C D and Latimer J G. 2003. Influence of nitrate: ammonium ratios on growth and elemental concentration in two alfalfa cultivars. Journal of Plant Nutrition 26: 2503-20.

Dinesh K and Sudheep S. 2009. Influence of soil applied sulfur and boron on yield and quality parameters of soybean. Annals of Biology 25: 105-11.

Dwivedi B S, Ram M, Singh B P, Das M, Prasad R N, Munna Ram and Madhumita Das. 1993. Comparison of soil tests for predicting boron deficiency and response of pea to boron application on acid Alfisols. Journal of the Indian Society of Soil Science 41: 321-5.

Ghanta P K and Dwivedi A K. 1993. Effect of some micronutrients on yield and quality of banana cv. Giant Governor. Environment Ecology 11: 292-4.

Ghatak R, Jana P K, Sounda, G, Ghosh, R K and Bandyopadhyay P. 2006. Effect of boron on yield, concentration and uptake of N, P and K by wheat grown in farmer's field on red and laterite soils of Purulia, West Bengal. Indian Agriculturist 50: 15-77.

Gitte A N, Patil S R and Tike M A. 2005. Influence of zinc and boron on biochemical and yield characteristics of sunflower. Indian Journal Plant Physiology 10: 400-3.

Gupta I C. 2002. Quality of irrigation waters and toxic ions. Current Agriculture 26: 1-13.

Huang L, Ye Z, Bell R W and Dell B. 2005. Boron nutrition and chilling tolerance of warmclimate crop species. Annals Botany 965: 755-67.

Jaiswal A D, Singh S K, Singh Y K, Singh S and Yadav S N. 2015. Effect of sulpher and boron on yield and quality of mustard (Brassica juncea L.) grown on Vindhyan red soil. Journal of the Indian Society of Soil Science 63, 362-4.

Jana P K, Ghatak R, Sounda, G, Ghosh, R K and Bandyopadhyay P. 2005. Effect of boron on yield, content and uptake on NPK by transplanted rice at farmer's field on red and laterite soils of West Bengal. Journal Interacademia 9: 341-4.

Jose A I, Venugopal V K, Sushama P K, Gopi C S and Saifudeen N 1985. Micronutrient status of soil and leaf of coconut palms growing on reclaimed marshy soil. Agricultural Research Journal of Kerala 23: 90-2.

Jyolnsa V K and Usha Mathew. 2008. Boron nutrition of tomato (Lycopersicon esculentum L.) grown in the laterite soils of southern Kerala. Journal of Tropical Agriculture 46(1-2): 73-5.

Kalyanasundaram D and Kumar D S. 2005. Studies on the effect of Ca-B and GHOM on yield and quality characters of rice-fallow cotton. Advance Plant Science 18: 915-8.

Kalyani R R, Sree Devi V, Satyanarayana N R, M Rao 1993. Effect of foliar application of boron on crop growth and yield of pigeonpea (Cajanus Cajan L.) (Mill sp). Indian Journal of Plant Physiology 36(4): 223-6.

Kumar D and Sidhu S 2009. Influence of soil applied sulfur and boron on yield and quality parameters of soybean. Annals of Biology 25: 105-11.

Kumar R. 2005. Cauliflower yield influenced by nitrogen and boron application. Journal of Applied Biology 15(1): 56-8.

Kumari S. 2012. Effect of micronutrients on quality of fruits and seed in tomato, Solanum lycopersicum L. International Journal of Farm Sciences 2(1): 43-6.

Mahmud Z U, Rahman M M, Salam M A, Saha S R and Alam M S. 2005. Effect of sulphur, boron and molybdenum on
curd yield of cauliflower. *Journal of Sub Tropical Agriculture Research and Development* 3(1): 82-6.

Malewar G U, Waikar S L and Siddiqui M B. 1999. Comparison of soil boron critical levels established by graphical and statistical approach in cauliflower (*Brassica oleracea*). *Agroecology Journal* 9: 119-24.

Meena D S, Baldev R and Tetarwal J P 2011. Productivity, quality and profitability of soybean (*Glycine max* (L.) as influenced by sulphur and boron nutrition. *Soybean Research* 9: 103-8.

Miwa K and Fujiwara T. 2010. Boron transport in plants: co-ordinated regulation of transporters. *Annals of Botany* 105: 1103–8.

Murthy I Y L N. 2006. Boron studies in major oilseed crops. *Indian Journal of Fertilisers* 1:11-20.

Muthanna M A, Singh A K, Tiwari A, Jain V K and Padhi M. 2017. Effect of boron and sulphur application on plant growth and yield attributes of potato (*Solanum tuberosum* L.). *International Journal of Current Microbiology and Applied Sciences* 6(10): 399-404.

Muthukrishnan A. 2007. Effect of boron on yield attributes, yield and quality parameters of groundnut (*Arachis hypogaea* L.). MSc (Ag) thesis, Agricultural College and Research Institute, Madurai.

Nibedita Bose, Das D K and Debanu Maiti. 2002. Interaction effect between lime and boron on changes in different fractions of boron in Alfisol and boron content in rape (*Brassica campestris* L.). *Indian Agriculturist* 46: 177-90.

Ningawale D K, Singh R, Bose U S, Gujjar P S, Sharma Anchal and Gautam U S. 2016. Effect of boron and molybdenum on growth, yield and quality of cauliflower (*Brassica oleracea var botrytis*) cv. Snowball 16. *Indian Journal of Agricultural Sciences* 86(6): 825-9.

Patil S B, Vyakaranahal S B, Deshpande V K and Shekhargouda M. 2006. Effect of boron and zinc application on seed yield and quality of sunflower restorer line, RHA-857. *Karnataka Journal of Agricultural Sciences* 19: 708-10.

Patil S R, Gitte A N, Shelke B M and Tike M A. 2006. Influence of zinc and boron on yield and yield contributing characters in sunflower. *Journal of Maharashta Agriculture University* 31: 247-8.

Panwar G S, Waybase T K, Bhatade S S and More S S. 2005. Influence of supplementary foliar spray of micronutrients on seed yield and seed quality characters of cotton. *Journal of Cotton Research Development* 19: 211-2.

Rana K S, Rana D S and Gautam R C. 2005. Influence of phosphorus, sulphur and boron on growth, yield, nutrient uptake and economics of Indian mustard (*Brassica juncea*) under rainfed conditions. *Indian Journal of Agronomy* 50: 314-6.

Rashid A, Yasin M, Ashraf M and Mann R A. 2004. Boron deficiency in calcareous soil reduces rice yield and impairs grain quality. *International Rice Research Notes* 29: 58-60.

Reddy Y A N, Shaananker R U, Prasad T G and Kumar M U. 2003. Physiological approaches to improving harvest index and productivity in sunflower. *Helia* 26: 81-90.

Rerkasem B, Bell RW, Lodkaew S, Lonnerang J F 1993. Boron deficiency in soybean (*Glycine max* (L.) Merr.), peanut (*Arachis hypogaea* L.) and black gram (*Vigna mungo* (L.) Hepper): Symptoms in seeds and differences among soybean cultivars in susceptibility to boron deficiency. *Plant and Soil* 155/156: 309-12.

Saifuzzaman M, Meinsner C A, Rawson H M and Subedi K D. 1996. Wheat sterility in Bangladesh: an overview of the problem, research and possible solutions. *Proc. workshop: Sterility in wheat in subtropical Asia: extent, causes and solutions*. Lumle Agricultural Research Centre, Pokhara, Nepal, Sept. 18-21, 1995, pp 104-8.

Sakal R and Ali M H. 1993. Micronutrient status of Bihar soils and response of crops to micronutrient application. *Proceeding of Workshop on Micronutrients*, 22-23 Jan., 1992, Bhubaneswar, India, 199-213.

Sakal R and Singh A P. 1995. *Micronutrient Research and Agricultural Production*, pp 1-31. Tandon H L S (Ed). Fertiliser Development and Consultation Organisation, New Delhi, India.

Sakal R, Singh A P, Sinha R B and Bhogal N S. 1996. Annual Progressive Report of AICRP on Micro and Secondary Nutrients, Pllolluant Elements in Soils and Plants. Department of Soil Science, RAU, Pusa, Bihar.

Sakal R, Singh B P, Singh A P and Sinha R B. 1987. Determination of critical limit of boron in relation to response of black gram to boron application in recent alluvial soils. *Annals of Agriculture Research* 8: 273-9.

Sakal R, Singh S P, Singh A P and Bhogal N S. 1993. Evaluation of soil test methods for response of chickpea to boron in calcareous soil. *Annals of Agriculture Research* 14: 377-87.

Salam P K, Rajput R S, Mishra P K, Anita and Shrivastava G K. 2004. Effect of micronutrients fertilization on productivity potential of urdbean (*Phaseolus mungo* L.). *Annals of Agriculture Research* 25: 329-32.

Sarkar D, Mandal B and Kundu M C. 2007. Increasing use efficiency of boron fertilisers by rescheduling the time and methods of application for crops in India. *Plant and Soil* 301: 77-85.

Sarkar D, Sheikh A A, Batabyal K and Mandal B. 2014. Boron estimation in soil, plant, and water samples using spectrophotometric methods. *Communications in Soil Science and Plant Analysis* 45: 1538-50.

Sathyia S. 2006. Effect of different levels of boron on yield of PKM 1 tomato. Thesis, Agricultural College and Research Institute, Madurai.

Shu Z H, Oberly G H and Cary E E. 1994. Mobility of foliar-applied boron in one-year-old peaches as affected by environmental factors. *Journal of Plant Nutrition* 17: 1243-55.

Shukla A K and Behera S K. 2012. Micronutrient fertilizers and higher productivity. *Indian Journal of Fertilisers* 8(4): 100-17.

Singh D K, Paul P K and Ghosh S K. 2005. Response of papaya to foliar application of boron, zinc and their combinations. *Research Crops* 6: 277-80.

Singh J P, Tomar D and Goyal N K. 2016. Maximizing rice-wheat productivity using site-specific nutrient management strategy. *Indian Journal of Fertilisers* 12(5): 30-6.

Singh M V and Goswami V. 2014. Boron management in Indian agriculture. *Indian Journal of Fertilisers* 10(5): 104-15.

Singh M V and Maurya K L. 2006. Effect of boron on growth and fibre yield of mesta. *Haryana Journal of Agronomy* 22: 96-7.

Singh R, Sharma R R and Tyagi S K. 2006. Preharvest foliar application of calcium and boron influences physiological disorders, fruit yield and quality of strawberry (*Fragaria ananassa* Duch.). *Scientific Horticulture* 112: 215-20.

Singh R N and Sinha H. 1987. Evaluation of critical limits of available boron for soybean and maize in acid red loam soil. *Journal of the Indian Society of Soil Science* 35: 456-9.

Singh R N, Binod Kumar, Surendra Singh and Prasad N K. 2004. Effect of boron application in groundnut (*Arachis hypogaea*) and pigeonpea (*Cajanus cajan*) production. *Journal of Research*
Singh R N, Surendra Singh and Binod Kumar. 2006. Interaction effect of sulphur and boron on yield, nutrient uptake and quality characters of soybean (Glycine max L. Merill) grown in acidic upland soil. *Journal of the Indian Society of Soil Science* 54: 516-8.

Sinha P, Chatterjee C, Sharma C P and Sinha P. 1999. Changes in physiology and quality of pea by boron stress. *Annals of Agriculture Research* 20: 304-7.

Sinha P, Dube B K and Chatterjee C. 2002. Influence of boron stress on biomass, yield, metabolism and quality of groundnut. *Indian Journal of Plant Physiology* (India) 7: 131-4.

Sinha P, Dube B K and Chatterjee C. 2003. Phosphorus stress alters boron metabolism of mustard. *Communications in Soil Science and Plant Analysis* 34: 315-26.

Sinha P, Dube B K, Singh M V and Chatterjee C. 2006. Effect of boron stress on yield, biochemical parameters and quality of tomato. *Indian Journal of Horticulture* 63: 39-43.

Sotiropoblos T E, Therios I N and Dimassi K N. 2004. Uptake of boron by kiwifruit plants under various levels of shading and salinity. *Journal of Plant Nutrition* 27: 1979-89.

Srivastava A K and Shyam Singh. 2003. Soil-plant nutrient limits in relation to optimum fruit yield of sweet orange (Citrus sinensis) cultivar 'Mosambi'. *Indian Journal of Agriculture Sciences* 73: 209-11.

Yadav S N, Singh S K and Omkar Kumar. 2016. Effect of boron on yield attributes, seed yield and oil content of mustard (Brassica juncea L.) on an Inceptisol. *Journal of the Indian Society of Soil Science* 64(3): 291-6.

Yadav V, Singh P N and Yadav P. 2013. Effect of foliar fertilisation of boron, zinc and iron and on fruit growth and yield of low-chill peach cv. Sharbati. *International Journal of Scientific and Research Publications* 3(8): 1-6.

Zerrari N, Moustaoui D and Verloo M. 2000. Effect of different soil water regimes on behaviour of boron in sunflower (Helianthus annuus L. Morocco) nutrition. *Agrochimica* 44: 250-8.