ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com
Journal DOI: 10.21474/IJAR01

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

BORON – ITS IMPORTANCE IN CROP PRODUCTION, STATUS IN INDIAN SOILS AND CROP RESPONSES TO ITS APPLICATION.

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Manuscript Info

Manuscript History:

Received: 18 March 2016
Final Accepted: 22 April 2016
Published Online: May 2016

Key words:
Boron, deficiency, crop response, future challenges

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Abstract

Boron (B) is unique, not only in its chemical properties, but also in its role in biology. Since boron discovery as essential plant nutrient, the importance of B element as an agricultural chemical has grown very rapidly and its availability in soil and irrigation water is an important determinant of agricultural production. Boron deficiency is the most common and widespread micronutrient deficiency problem, which impairs plant growth and reduces yield. Normal healthy plant growth requires a continuous supply of B, once it is taken up and used in the plant; it is not translocated from old to new tissue. That is why, deficiency symptoms starts with the youngest growing tissues. Therefore, adequate B supply is necessary for obtaining high yields and good quality of agriculture crops. Boron deficient soils include those which are inherently low in B, calcareous and coarse textured soils and those high in clay. Among micronutrients, boron deficiency is one of the most crucial constraint limiting nutrient use efficiency and crop yields. Boron toxicity in plants has been reported from many parts of the world but is mostly associated with the use of high- B contaminated water. In view of B deficiency and toxicity in soils and crops, delineation of critical B deficiency and toxicity levels or concentrations is very important. As B is emerging as second most deficient micronutrient in Indian soils, monitoring of its spatial and vertical distribution is very important in order to sustain the crop yields. Application of B at different rates in different crops have shown the positive influence on yield and other agronomic parameters of different crops reflecting the significance of B in enhancing the yield of different crops. In order to maintain an optimum level of B in soils, B fertilisation should form a part of fertiliser schedule for the predominant crops and cropping systems.

Introduction:-

India has achieved record food grain production of 264 million tonnes in 2013-14 with annual growth of 2.6% since independence. About 50% increase in food grain production is attributed to fertilizers. Country has 141 m ha cultivated area of which 78 m ha area is rainfed. The post green revolution era has made the country net exporter of food grains. But to ensure national food security, country will require about 294 million tonnes of food grain production by 2020 to feed 120 million mouths **(Shukla et al. 2014)**. The increased demand of food grain production has led to continuous depletion of soil micronutrient fertility. As a result there is steady fall of nutrient use efficiency and that is partly attributed due to the increased incidences of deficiencies of zinc and boron in many parts of the country **(Singh and Goswami, 2014)**.

Among micronutrients, boron is indispensable for the normal growth and development of plants. The importance of boron as a plant nutrient was first demonstrated by **Warington (1923)** with characteristic deficiency symptoms of die prematurely broad beans and later on **Bradenburg (1931)** reported heart and dry rot in sugar beet and mangolds, respectively. Boron is important in agriculture because both its deficiency and toxicity in soils can adversely affect plant growth. Boron is one of the most commonly deficient of all the micronutrients. As per the study of **Sillanpaa (1990)**, deficiencies of B could be suspected in almost every country in the globe. Besides India, B deficiency is prevalent in more than 80 countries of the world and it inhibits productivity of about 132 crops. Boron deficiency has become the most crucial constraint limiting nutrient use efficiency and crop yields. Boron deficiency has been realized as the second most important micronutrient constraint in crops after that of zinc (Zn) on global scale. Boron deficiency has been reported to result considerable yield reduction in annual, cereal, legume/pulse, oilseed and perennial crops **(Sinha et al., 1991, Johnson, 2006 and Niaz et al., 2007)**. The availability of boron is related to soil pH and is most available at low pH but is easily leached from acid, sandy soils. Therefore, although deficiency of boron is relatively common in acid, sandy soils, it occurs because of the low supply of total boron rather than low availability of the boron present. Coarse- textured acid soils of humid and per humid regions, calcareous soils and those with low organic matter content are more prone to B deficiency. B toxicity is reported in the arid and semi-arid areas owing to high levels of B in soils and addition of B through irrigation water. In view of B deficiency and toxicity in soils, delineation of critical B deficiency and toxicity levels or concentrations is very important.

Boron in plant nutrition:-

Boron imparts drought tolerance to crops. It is responsible for the cell wall formation and stabilization, lignifications and xylem differentiation. It facilitates transport of potassium to guard cells and is involved in stomatal opening. Leached sands and calcareous soils promote B deficiency. High B requiring crops like the ones belonging to Cruciferae family are its early victims. The need for boron fertilization is increasing because of higher crop yields and reduced levels of organic matter (the primary soil source) and because of continuous removal by intensive cropping; cultivation on soils that are inherently low in micronutrients reserves and adoption of high yielding cultivars. Borax is the most commonly used fertilizer for B in India. Generally utilization by crops seldom exceeds 5%, even when residual availability is aggregated for several sequences of crops constituting a cropping system. Where do the rest of the added nutrients go? While a fraction may be leached, large proportion gets sixed in the soil. The problem with soil-fixed B is its unavailability to immediate crops. This misalliance explains why total soil content of these micronutrients is unrelated to occurrence of their deficiencies in field crops. Unattended deficiencies impede sustainable growth in agricultural production even when all other factors are in optimum supply. Apparently, the priority is to catalogue information on the availability of the native nutrient pool and correlate this with the supplemental needs for arresting falling productivity of a cropping system. The over all strategy should include: (i) an appropriate B source from a diversified product portfolio, (ii) standard nutrient management techniques and (iii) cultivation of efficient reengineered or existing crop plants.

Factors affecting boron availability:-

Boron concentrations in soil vary from 2 to 200 mg B kg^{-1}, but generally less than 5-10% is in a form available to plants **(Diana, 2006)**. Boron concentration and its bioavailability in soils is affected by several factors including parent material, texture, nature of clay minerals, pH, liming, organic matter content, interrelationship with other elements, and environmental conditions like moderate to heavy rainfall, dry weather and high light intensity **(Moraghan and Mascagni, 1991)**. Therefore, knowledge of these factors affecting B uptake is essential for the assessment of B deficiency and toxicity under different conditions.

Parent material:-

Parent material is considered a dominant factor affecting supply of B from the soil. Soils are quite variable in their B and clay forming minerals contents, and therefore have a fundamental effect on the availability of B. In general, soils derived from igneous rocks, and those in tropical and temperate regions of the world, have much lower B concentrations than soils derived from sedimentary rocks, and those in arid or semi arid regions **(Ho, 2000)**. High B concentrations are usually found in the soils that have been formed from marine shale enriched parent material. Soils derived from acid granite and other igneous rocks, fresh-water sedimentary deposits, and in coarse textured soils low in organic matter have been reported with low B concentrations **(Liu et al., 1983)**. Boron bioavailability is also reduced in soils derived from volcanic ash **(Sillanpaa and Vlek, 1985)** and in soils rich in aluminum (Al) oxides **(Bingham et al., 1971)**. Soils along the sea shore as well as those derived from mudstone are usually B enriched. Conversely, lateritic soils, and soils derived from sandstone, slate or crystalline limestone do not contain much B.

Soil texture and clay minerals:-

Coarse-textured, well drained soils are low in B and crops with a high requirement respond to B applications of ≥ 3 lbs/a. Sandy soils with fine-textured subsoils generally do not respond to B in the same manner as those with coarse-textured subsoils. B added to soils remains soluble and up to 85% can be leached in low organic matter, sandy soils. Fine textured soils retain B longer than coarse-textured soils because of greater B adsorption. The fact that clay retains more B than sand does not imply that B uptake in clays is greater than sands. At equal solution B concentration, plants absorb more B from sandy soils than from fine textured soils, where B uptake can be impeded by higher levels of available Ca. More B adsorption is commonly found in illite as compared with kaolinite or montmorillonite clay types. In fact, kaolinite adsorbs B the least **(Fleet, 1965)**. **Frederickson and Reynolds (1959)** proposed that most of the B in the clay mineral fraction of sedimentary rocks is contained in the illite fraction. **Sims and Bingham (1968)** found that B adsorption was greater for iron (Fe) and Al coated kaolinite or montmorillonite than for uncoated clays. It was concluded that hydroxyl of Fe and Al compounds present in the layer as silicates or as impurities dominate over clay mineral species per se in determining B adsorption characteristics.

Soil pH:-

Boron availability decreases with increasing soil pH. Liming acid soils can cause a temporary B deficiency in susceptible plants with the severity depending on crop, soil moisture status and time elapsed after liming. Heavy liming of soils high in organic matter may encourage organic matter decomposition and release of boron, thus increasing boron uptake. At low pH, most of the B compounds are soluble and thus B remains available to plants as boric acid. In sandy soils having low pH, B is lost down the profile by leaching if rainfall is high. In fine-textured soils, however, B leaching is not a major problem if the soil is not very low in pH.

Soil organic matter:-

Higher B availability in surface soils compared with sub-surface soils is related to increased soil organic matter (OM). Applications of organic matter to soils can increase B in plants and even cause phytotoxicity. Boron may bind with OM or with carbohydrates released during humification. Boron associated with humic colloids is the principal B pool for plant growth in most of the agricultural soils **(Jones, 2003)**. However, there is limited information on the role of OM in B nutrition. The strongest evidence that OM affects the availability of soil B is derived from studies that show a positive correlation between levels of SOM and the amount of hotwater-soluble B **(Shafiq et al., 2008)**.

Interactions with other elements:-

When calcium availability is high, plants can tolerate higher B availability. Under low Ca supply, many crops exhibit lower B tolerance. Greater Ca^{2+} supply in alkaline and recently overlimed soils restricts B availability; thus, high solution Ca^{2+} protects crops from excess B. The Ca:B ratio in leaf tissues has been used to assess B status of crops, where B deficiency for most crops is likely when Ca:B ratio is greater than 1,200:1. B deficiency in sensitive crops (e.g., alfalfa) can be aggravated by K fertilization to the extent that B is needed to prevent yield loss, since Ca^{2+} displaced from the cation exchange complex by K^+ can interfere with B absorption.

Other factors:-

B deficiency is often associated with dry weather, where low soil moisture reduces B release from organic matter and B uptake through reduced B transport (diffusion and mass flow) to absorbing root surfaces. Because of the narrow range between sufficient and toxic levels of available soil B, the sensitivity of crops to excess B is important.

Boron deficiency in Indian soils:-

Boron content in soils, which is extracted from soil with hot water varies from 0.01 to 237.50 mg kg^{-1} soil with an average value of 1.24 mg kg^{-1}. B deficiency is reported more in acid soils than other parts of the country due to leaching of available B and continuous depletion of total soil reserved B. In India about 33% of soil samples collected all over the country were found to be deficient in boron **(Shukla and Behera, 2012)**. Owing to B deficiency in soils, yield of almost all the crops grown in states like Odisha, West Bengal, Gujarat, Bihar, Maharashtra, Assam and Tamil Nadu is generally low despite application of recommended dose of N, P, K and Zn fertilisers. From the results of 73,630 samples analyzed for hot water available B, deficiency of B in highly calcareous soils of Bihar and Gujarat and acid soils of West Bengal, Odisha and Jharkhand are more common **(Shukla et al., 2014)**. Little more than half of the samples analyzed from Odisha state fell in the category of low B availability. The major reason of greater B deficiency reported in earlier years was that researchers have targeted known problem areas for sampling. Contrasting to that now more and more samples are brought under B analysis irrespective of the problems of deficiency reported in plants, the deficiency percentage has declined.

Mapping boron deficiency status:-

In soils, concentration of total B is reported to be in the range of 20 to 200 mg B kg^{-1} soil and its available concentrations also vary greatly from soil to soil. Boron deficiency has been realized as the second most important micronutrient constraint in crops after that of zinc (Zn) on global scale. In India, based on 74,000 GPS soil samples analyzed from 193 districts, 84 districts were found to have B deficiency less than 10 %. About 35 districts fall in B deficiency range of 10-20% and 15 to 16 districts each comes in range of 20-30, 30-40 and 40-50% deficiency range. Indian soils are very poor in organic carbon and B deficiency is linked with low organic matter level in the fields. Soils of Jharkhand, Odisha, West Bengal, Karnataka and part of Bihar, Tamil Nadu and four districts in Gujarat are highly deficient (more than 50%) in Boron. Boron deficiency has been commonly encountered in soils which are highly leached and/or developed from calcareous, alluvial and loess deposits. However, calcareous part of the country does not exhibit boron deficiency in crops due to sufficient B in irrigated water. Underground water used for irrigation purpose has been reported to contain toxic amounts of B in many parts (Uttar Pradesh, Rajasthan, Haryana, Punjab, and Gujarat) of India.

Yield responses of different crops to boron fertilization:-

A large number of crops, especially pulses, oilseed, vegetable and fruit crops showed magnificent responses to boron application. The yield loss in cereals due to hidden hunger of B is also substantial. Since range of B deficiency and toxicity is narrow, it is imperative to be cautious while deciding the B rates and frequency for different crops, otherwise, continuous application may change deficient soil into the toxic-ones. A variety of B containing fertilizers has been tested for their efficiency and effectiveness for managing B deficiency in field and horticultural crops in India. Soil application of borax is the more common method for B fertilization. Boric acid, solubor, granubor, colemanite and B-frits etc are other B sources being used by the farmers and are equally effective.

Boron deficiency in wheat field was first observed almost concurrently on different parts of the world following the spread of semi-dwarf wheat in the 1960s **(Rerkasem and Jamjod, 2004)**. Its deficiency has been reported to cause grain set failure and considerable yield losses in the wheat belt of the world's wheat growing countries. Significant increase in the yield of wheat was reported due to addition of 20 kg borax ha^{-1} on silty loam acid soils of North Bengal; as high as 1890 kg ha^{-1} additional grain yield was recorded over control **(Mitra and Jana, 1991)**. Among the modes of application, half of the amount of B applied to soil and the remaining half sprayed on the foliage led to higher response as compared to individual applications (either to soil or foliage). Superiority of combining soil and foliar application was ascribed to more uniform availability of B throughout growing period of crop. In a study laid out on a leaching probe acid soil (Inceptisol), 20 kg sodium tetraborate per hectare applied directly to soybean proved superior in increasing yield to two foliar sprays. Not only that, but residual effect of soil application in increasing yield of following wheat also excelled that obtained with two fresh foliar sprays of boron **(Katyal et al., 2004**).

Severe boron deficiency has been reported in 1-69% (average 33%) rice fields in India **(Singh, 2001)**. Results of recent research have shown 15-25% increase in seed yield over N, P and Zn, coupled with appreciable improvement in grain/cooking quality (more recovery and less breakage of kernels during milling, greater grain elongation, less bursting and less stickness upon cooking) with application of B. It was also found that the B use in rice was highly profitable.

Maize is ranked second (after wheat) in the world cereal production. Contribution to world corn/maize production is 2% from India, while it is 10% from China, and U.S. contribution to the total maize production of the world is known to be 43%. In a study, **Mishra and Shukla (1986)** reported considerable increase in plant height, metabolic rate, content of photosynthetic pigment and all dry weight fractions measured after the application of B containing amendment to maize.

Cotton is an important fiber crop grown in many countries of the world. There are several factors responsible for low yields of cotton, and micronutrient deficiency is one among them. Boron has been recognized as the most important micronutrient for cotton production. Its deficiency inhibits petiole and peduncle cell development and reduces growth of cotton **(De Oliveira et al., 2006)**. Research has shown that as little as 1.1 kg of B ha^{-1} can increase cotton seed yield by more than 560 kg ha^{-1}.

China, India and Indonesia are the leading soybean growing countries after USA. Generally, B deficiency is a common problem for this crop, especially when grown on alkaline calcareous soils of the world. 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 Sidhu (2009)**. **Meena et al. (2011)** found that the 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 pods were recorded along with higher seed and biological yield with the application of 1.0 kg B ha^{-1} as compared to control. Results showed that application of 1 kg B ha^{-1} found suitable for obtaining higher productivity and quality of soybean with higher profitability under south-eastern plain zone of Rajasthan.

India is among the largest vegetable oil economies in the world, next only to USA and China. Currently, India accounts for about 13% of world's oilseeds area, 7% of world's oilseeds output and 10% of world's edible oil consumption. Mustard is the second most important oilseed crop, contributing nearly 25-30% of the total oilseed production in the country **(Anonymous, 2006)**. Likewise, sunflower ranks third in the world and fifth in our country. The major reason of low productivity of these crops is mainly their cultivation on highly nutrient leached marginal lands. Apart from major plant nutrients (N, P and K) sulphur and boron play important roles in the production phenology of oilseed crops and these crops respond well to applied sulphur and boron **(Chatterjee, 1985)**. **Karthikeyan and Shukla (2008)** found that the interaction effect between boron and sulphur significantly and synergistically influenced the dry matter and seed yields of both mustard and sunflower, which were observed the highest at 60 mg kg^{-1} of S in conjunction with 2 mg kg^{-1} of boron. The oil and protein contents of sunflower and mustard were significantly and synergistically improved by the application of both sulphur and boron.

Boron also plays a significant role in increasing the production of vegetable crops. Broccoli is an important vitamin rich winter vegetable. Successful production of broccoli depends on various factors of which fertilizer application is the most important one. Hollow stem disorder is a major problem in broccoli production which is responsible for yield reduction and is commonly associated with B deficiency **(Shelp et al., 1992)**. In a number of studies, it has been shown that application of boron has increased yield of broccoli. **Hussain et al. (2012)** observed that the curd yield of broccoli was significantly increased with boron application upto 1.0 kg ha^{-1}. This rate thus showed a remarkable impact on reduction of hollow stem disorder.

Cauliflower is an important vegetable crop grown everywhere. The soils which are sandy, acidic are deficient in boron and the crop suffers from boron deficiency (dead heart rot and hollow stem) under such soils specially during the rainy season. **Chander et al. (2010)** found that cauliflower responded significantly to B application in terms of dry matter yields of leaves, curd and roots upto 1 mg kg^{-1} in Junga soil and upto 2 mg kg^{-1} in Bajaura soil of Himachal Pradesh. **Kumar et al. (2010)** observed that among the various treatments borax 20 kg ha^{-1} + sodium molybdate 2 kg ha^{-1}as soil application in combination of recommended dose of NPK @ 120:60:60 kg ha^{-1} gave the maximum width of curd, average weight of curd and yield of curd, while foliar application of boron @ 100 ppm + molybdenum @ 50 ppm along with recommended dose of NPK @ 120:60:60 kg ha^{-1} recorded highest growth and yield. **Singh et al. (2011)** recorded the maximum values of all the characters *viz;* plant height, curd diameter and yield in the plots receiving boron @ 1.5 kg ha^{-1}. **Kumar et al. (2012)** observed that the granubor-II as a boron source improved not only quality but the productivity of cauliflower and the boron levels of 1.5 kg ha^{-1} improved yield and quality over other rates (0.5 and 1.0 kg ha^{-1}). The promotive effect of B may be interpreted in terms of manufacturing more carbohydrates and proteins along with its role in enhancing their translocation from the site of synthesis to the storage organs **(Sharma, 2002)**.

Tomato is India's most extensively grown vegetable crop after potato. Tomato is considered a heavy feeder of micronutrients and B in particular is important for its growth, fruit set and disease resistance **(Srinivasamurthy et al., 2003)**. **Jyolsna and Mathew (2008)** observed that B significantly increased plant height and number of primary branches. It also reduced the days to flowering and increased fruit set. Quality parameters like reducing sugars, total sugars, vitamin C and lycopene concentrations also improved by B application.

Areas of future research:-

- Information on effect of B in countering physiological stress like seed filling and grain sterility, chaffy grain, drought tolerance in plants, reproductive physiology like flowering and fruiting disorders, yield and quality improvement and resistance to disease and pest is very much lacking, hence such information is very much needed.
- Boron fertility of Indian soils is depleting at a faster rate due to intensive cropping of high yielding crop varieties; therefore depletion rate of B under different soils, crops and management systems needs to be studied to forecast emergence of B deficiencies.
- Studies on choice of suitable source, method and time of B application needs research for enhancing the efficiency of other nutrients.
- Systematic GIS based mapping is very much needed. Effect of pedofactors on emergence of B deficiency needs to be studied.
- Boron fertilization practices and choice of crop in different cropping systems need to be evaluated considering direct and residual effect and nutrient use efficiency.
- Boron in Indian agriculture needs to be promoted by favourable simplified government policy for registration of new products, boron fortification in NP/NPK and financial support. Finally these findings will help our farmers' to apply balanced fertilizer application which will be synchronized with crop demand and also will reduce the cost of production.

References:-

1. **Anonymous. (2006).** India - A Reference Annual. Ministry of Information and Broadcasting, Government of India.
2. **Bingham, F.T., Page, A.L., Coleman, N.T. and Flach, K. (1971).** Boron adsorption characteristics of selected soils from Mexico and Hawaii. Soil Sci. Soc. Am. J. 35: 546-550.
3. **Bradenburg, E. (1931)**. Heart and dry rot of beet-causes and treatment. J. Appl. Bot. 14: 194-228.
4. **Chander, G., Verma, T.S. 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. J. Ind. Soc. Soil Sci. 58(2): 248-251.
5. **Chatterjee, B.N. (1985).** Response of mustard to sulphur and micronutrients. Ind. J. Agron. 30: 75-78.
6. **De Oliveira, R.H., Milanez, C.R.D., Moraes-Dallaqua, M.A. and Rosolem, C.A. (2006).** Boron deficiency inhibits petiole and peduncle cell development and reduces growth of cotton. J. Pl. Nut. 29: 2035-2048.
7. **Diana, G. (2006).** Boron in the soil, from deficit to toxicity. Informatore Agrario. 62: 54-58.
8. **Dinesh, K. and Sudkep, S. (2009).** Influence of soil applied sulfur and boron on yield and quality parameters of soybean. Anna. Biol. 25: 105-111.
9. **Fleet, M. E. L. (1965).** Preliminary investigations into the sorption of boron by clay minerals. Clay Minerals. 6: 3-16.
10. **Frederickson, A.F. and Reynolds, R.C. Jr. (1959).** Clays. In: Clay Minerals Proceedings, 203-213, 8th Conf.; Pergamon Press, Oxford, England.
11. **Ho, S.B. (2000).** Boron deficiency of crops in Taiwan. Department of Agricultural Chemistry, National Taiwan University, Taipei, Taiwan.
12. **Hussain, M.J., Karim, A.J.M.S., Solaiman, A.R.M. and Haque, M.M. (2012).** Effect of nitrogen and boron on the yield and hollow stem disorder of broccoli (*Brassica oleracea* var. italic). The Agriculturists. 10(2): 36-45.
13. **Johnson, G. (2006).** Pakistan citrus industry challenges: Opportunities for Australia-Pakistan collaboration in research, development and extension. Islamabad, Pakistan.
14. **Jones, J.B. (Jr). (2003).** Plant mineral nutrition. In: Agronomic handbook: Management of crops, soils and their fertility, Pages 325, CRC Pres, Boca Raton, FL, U.S.A.
15. **Jyolsna, V.K. and Mathew, U. (2008).** Boron nutrition of tomato (*Lycopersicon esculentum* L.) grown in the laterite soils of Southern Kerala. J. Trop. Agri. 46(1-2): 73-75.
16. **Karthikeyan, K. and Shukla, L.M. (2008).** Effect of boron-sulphur interaction on their uptake and quality parameters of mustard (*Brassica juncea* L.) and sunflower (*Helianthus annus* L.). J. Ind. Soc. Soil Sci. 56(2): 225-230.
17. **Katyal, J.C., Rattan, R.K. and Datta, S.P. (2004).** Management of zinc and boron for sustainable food production in India. Fert. News. 49(12): 83-99.

18. **Kumar, A., Parmar, D.K. and Suri, V.K. (2012).** Effect of boron fertilizers and organic manure on autumn cauliflower in western Himalayas. Annal. Hort. 5(1): 17-24.
19. **Kumar, D. and Sidhu, S. (2009).** Influence of soil applied sulfur and boron on yield and quality parameters of soybean. Annal. Biol. 25: 105-111.
20. **Kumar, S., Singh, S.S., Singh, P.K. and Singh, V.N. (2010).** Response of cauliflower (*Brassica oleracea* L. Var. botrytis) to boron and molybdenum application. Veg. Sci. 37(1): 40-43.
21. **Liu Z., Zhu, Q.Q. and Tong, L.H. (1983).** Microelements in the main soils of China. Soil Science. 135: 40-46.
22. **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 Res. 9: 103-108.
23. **Mishra, L.C. and Shukla, K.N. (1986).** Effects of fly ash deposition on growth, metabolism and dry matter production of maize and soybean. Environmental Pollution Series A: Ecol. Biol. 42: 1-13.
24. **Mitra, A.K. and Jana, P.K. (1991).** Effect of doses and methods of boron application on wheat in acid tarai soils of North Bengal. Ind. J. Agron. 36(1): 72-74.
25. **Moraghan, J. T. and Mascagni, H. J. (1991).** Environmental and soil factors affecting micronutrient deficiencies and toxicities. In: Micronutrients in agriculture, 371-425, R.J. Luxmoore (Ed.), Soil Sci. Soc. Am.; Madison, WI, U.S.A.
26. **Niaz, A., Ranjha, A.M., Rahmatullah, H. A. and Waqas, M. (2007).** Boron status of soils as affected by different soil characteristics–pH, $CaCO_3$, organic matter and clay contents. Pak. J. Agril. Sci. 44: 428-435.
27. **Rerkasem, B. and Jamjod, S. (2004).** Boron deficiency in wheat: A review. Field Crops Res. 89: 173-186.
28. **Shafiq, M., Ranjha, A.M., Yaseen, M., Mehdi, S.M. and Hannan, A. (2008).** Comparison of freundlich and langmuir adsorption equations for boron adsorption on calcareous soils. J. Agril. Res. 46: 141-148.
29. **Sharma, S.K. (2002).** Effect of boron and molybdenum on seed production of cauliflower. Ind. J. Hort. 59: 177-180.
30. **Shelp, B.J., Penner, R. and Zhu, Z. (1992).** Broccoli (*Brassica oleracea* var. Italic) cultivar response to boron deficiency. Canadian J. Pl. Sci. 72: 883-888.
31. **Shukla, A.K., Tiwari, P.K. and Prakash, C. (2014).** Micronutrients deficiencies vis-a-vis food and nutritional security of India. Ind. J. Fert. 10(12): 94-112.
32. **Shukla, A.K. and Behera, S.K. (2012).** Micronutrient fertilizers and higher productivity. Ind. J. Fert. 8(4): 100-117.
33. **Sillanpaa, M. and Vlek, P.L.G. (1985).** Micronutrients and the agroecology of tropical and mediterranean regions. In: Micronutrients in tropical food crop production, 151- 167, P. L. G. Vlek, (Ed.), Martinus Nijhoff and W. Junk Publishers, Dordrecht, Netherlands.
34. **Sillanpaa, M. (1990).** Micronutrients- An assessment at country level-An international study. FAO Soils Bulletin. 63: 208.
35. **Sims, J.R. and Bingham, F.T. (1968).** Retention of boron by layer silicates, sesquioxides and soil materials: III. Iron- and aluminum-coated layer silicates and soil materials. Soil. Sci. Soc. Am. Proceedings. 32: 369-373.
36. **Singh, K.P., Singh, V.K., Kamalkant, and Roy, R.K. (2011).** Effect of different levels of boron and its methods of application on growth and yield of cauliflower (*Brassica oleracea* var. botrytis L.). Veg. Sci. 38(1): 76-78.
37. **Singh, M.V. (2001).** Evaluation of micronutrient stocks in different agroecological zones of India. Fert. News. 42: 25-42.
38. **Singh, M.V. and Goswami, V. (2014).** Boron management in Indian agriculture. Ind. J. Fert. 10(5): 104-115.
39. **Sinha, R.B., Sakal, R., Singh, A.P. and Bhogal, N.S. (1991).** Response of some field crops boron application in calcareous soils. J. Ind. Soc. Soil Sci. 39: 342-345.
40. **Srinivasamurthy, A.A., Mruthuniya, S. and Siddaramappa, R. (2003).** Nutrition for Intensive Vegetable Production. Krishivikas Publications, Bangalore.
41. **Warrington, K. (1923).** The effect of boric acid and borax on broad bean and certain other plants. Annal. Bot. 37: 629-672.