International Research Journal of Agricultural Science and Soil Science (ISSN: 2251-0044) Vol. 1(8) pp.293-300, October 2011
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Review

Importance of Boron for Agriculture Productivity: A Review

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Accepted 03 June, 2011

Boron is unique, not only in its chemical properties, but also in its roles 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 y of agriculture crops.

Keywords: Boron, physiological functions, chemistry and deficiency in soil.

INTRODUCTION

Boron belongs to the metalloid group of elements. The group includes silicon (Si), arsenic (As), and germanium (Ge). Boron has intermediate properties between metals and non-metals. Its requirement for healthy plant growth was described more than 80 years ago (Marschner, 1995). Boron in neutral solution is present as boric acid (H_3BO_3). Boric acid is a small molecule with three valence electrons. The molecular radius of boric acid is 2.573 Å, similar to some other small uncharged molecules such as urea (2.618 Å). Boric acid is a very weak Lewis acid with pKa of 9.24 (Woods, 1996). In plant and animal cells, assuming that the cytoplasm pH is about 7.5, more than 98% of B exists as H_3BO_3 (Devirian and Volpe, 2003).

Boron in Human and Animal Nutrition

Boron is of nutritional importance to humans, It affects the metabolism of macro minerals, energy, nitrogen, and reactive oxygen, brain function, psychomotor performance and the response to estrogen ingestion (Nielsen, 2008).Cui et al. (2004). Proved that dietary B intake is inversely related to prostate cancer, and its higher intake has a beneficial effect on prevention of this menace. Boron deprivation in animals causes impaired growth, abnormal bone development, increase in urinary calcium excretion, and change of macro mineral status (Devirian and Volpe, 2003). Excessive B intake causes acute neurological effects, diarrhea, anorexia, weight loss, and testicular atrophy in mice, rats, and dogs. Boron toxicity also causes decrease in fetal body weight, increase in skeletal malformation and cardiovascular defects in pregnant female animals (Yazbeck et al., 2005).

Physiological and Biochemical Functions of B in Plants

Boron is directly or indirectly involved in several physiological and biochemical processes during plant growth. Boron deficiency causes reduction in cell enlargement in growing tissues because of its structural role. Its deficiency is responsible for creating male sterility and inducing floral abnormalities (Sharma, 2006). Several

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physiological and biochemical functions of B in plants are summarized below;

Carbohydrate Metabolism and Transport of Sugar

Boron has been functional in the transport of carbohydrates and translocation of sugar, is enhanced by the formation of borate-sugar complexes (Katyal and Singh, 1983; Macus-Wyner and Rains, 1982). In sugar beet the sucrose content of the storage roots decreased under B deficient conditions (Tariq et al., 1993).

Phenol and Auxin Metabolism

The accumulation of auxins and phenols are associated with leaf necrosis due to B deficiency (Marcus-Wyner and Rains, 1982). Boron is responsible for the metabolic changes and cell damage in deficient tissue and it is thought that B complexes the phenolic compounds in plant cells by reducing their potential toxicity (Marschner, 1986).

Tissue Development and Formation of Cell Walls

Boron is required for proper development and differentiation of plant tissue. Boron may affect the deposition of cell wall material by altering membrane properties, and deficiency of B causes the breakdown of the walls of parenchyma cells (Marschner, 1995; Katyal and Singh, 1983). The effect of B deficiency on cell division causes slow down in root extension and followed by a degeneration of meristematic tissue in plants. Continous supply of B is required for maintenance of meristematic activity (Loomis and Durst, 1992). Boron is important in cell walls; both B deficiency and toxicity cause lower chlorophyll levels and the rate of photosynthesis, may induce cell wall synthesis by an influence on the activity of the plasmalemma and can disturb the maintenance of meristem in plants (Bolanos et al., 2004).

Reproduction and Disease Resistance

Boron is involved in the reproduction of plants and germination of pollen spikelet (Bolanos et al., 2004). The role of B in promoting pollen tube growth is well established and positive correlation could be found between B in the plant and number of flowers, the proportion of flowers not aborted and fruit weight (O'Niell et al., 2004 and Bergmann, 1984). Boron obstructs the abortion of ovaries in rape, clover, alfalfa and beet; it reduces the proportion of sterile seed in cotton, barley, corn, soybean, alfalfa, maize and sunflower (Bergmann, 1984).

The role of B in seed production is very important, even under moderate deficiency; plants fail to produce functional flowers and any seed (Gupta, 1993).

Boron increases the disease resistance in plant such as potato scab disease, ergot on barley and damping off fungi on tomato and cabbage (Bergmann 1984; Shorrocks, 1984).

Root Elongation and Nucleic Acid Metabolism

Boron deficiency rapidly holds back the elongation and growth of roots. Root elongation of squash seedlings were affected when B supply was stopped for 24 hours (Bohnsack and Albert, 1977). Boron fertilization increased numerous roots in the lower part of the hypocotyls in sunflower (Josten and Kutschera, 1999). Root growth is the result of cell elongation and cell division, and B is required for both processes. Its deficiency also decreases the nucleic acid content in plant tissue (Gupta, 1993).

Nitrogen Fixation and Nitrate Assimilation

Boron is vital for N_2 fixation into heterocyst of the cyan bacterium Anabaena PCC 7119 and in the vesicles of actinomyctes of the genus Frankia (Garcia-Gonzalez et al., 1990). Microorganism require B for the stability of the envelopes that protect nitrogenese from inactivation by oxygen when grown under N_2 fixing conditions and there exists a lower number of developed nodules with the capacity to fix N_2 in legumes under B deficiency (Bolanos et al., 1994). Boron deficient plant have reduced nitrate reduces activity and enhanced accumulation of nitrate, these effects being attributable to the role of B in the de novo synthesis of the nitrate reduces (NR) protein or facilitation of nitrate absorption (Ruiz et al., 1998). Boron deficiency can cause decline in root elongation and particularly leaf nitrate contents without affecting NR activity or the concentrations of other micronutrients such as magnesium, calcium, potassium or phosphate (Camacho-Cristobal et al., 2005).

Water Relations

Boron regulates the intake of water into the cell, B deficient plants shows decreased moisture percentage, less succulence, less metabolic activity, low water potential, stomata pore opening, transpiration and a lower growth rate, in comparison to B sufficient plants (Sharma and Ramchandra, 1990).

Boron Uptake and Transport in Plants

Plants respond to the B concentration which is present in soil solution as a primarily uncharged boric acid H_3BO_3. Generally it is absorbed as molecular boric acid in a physical process regulated by the diffusion due to differences in B content (Bingham et al., 1981). Plant B uptake is correlated with the concentration of H_3BO_3 in soil solution because leaf B increased in a linear fashion as the B concentration of the nutrient solution increased (Tariq et al., 2005). Boric acid uptake by the roots is carried out by different molecular mechanisms (Tanaka and Fujiwara, 2008). Boron uptake is a passive process as B transport rate is in proportion to the concentration gradients. This is due to the high permeability of boric acid to lipid bilayers because boric acid is a non-charged molecule (Brown and Shelp, 1997). After taken up by roots, B is loaded to xylem for upward transport to shoots. The long distance translocation of solutes in the xylem depends on transpiration as B is transported along the transpiration streams. This long distance transport has been considered passive because B accumulates at the site of high transpiration rate such as margins of large mature leaves (Brown and Shelp, 1997).

Boron is not efficiently remobilized in many plant species that is why B deficiency occurs in young parts of the plant and toxicity in mature parts of plants. In many plant species, plants exposed to deficiency maintain B concentration in old mature leaves, whereas young portions of plants do not receive sufficient B to support growth. In some plants such as, apple, almond, peach, and plum, B was found distributed uniformly under B deficiency conditions. It was also found that B concentration in young leaves was higher than that of old leaves in these plant species (Brown and Shelp, 1997; Brown and Hu, 1998). This pattern of distribution cannot be explained by B distribution along transpiration stream. These species commonly produce a significant amount of sugar alcohols including mannitol and sorbitol and use them for the phloem translocation of photosynthate, in place of sucrose. Sugar alcohols contain cis-hydroxyl groups, and thus, it can readily bind to boric acid (poly- B complex) and is likely to allow B to be transported through the phloem (Brown et al., 1999).

Recent evidences suggest that non-sugar alcohol-producing plants can transport boric acid to young tissues, including Arabidopsis, canola and sunflower (Takano et al., 2001; Noguchi et al., 2000). This translocation was detected under B limitation, but not under conditions of normal B supply. It can be concluded that even plants without the capacity to synthesize sugar alcohols have mechanisms to transport B to sink tissues. Boron transporters and channels may be involved in this translocation (Stangolius et al., 2001).

Boron Deficiency, Sufficiency and Toxicity in Plants

Deficient and toxic levels of B are associated with plant disorders and reduction in the yield of crops. Boron deficiency and toxicity levels depend on types and species of crops, as dicotyledons need more B than monocotyledons (Gupta, 1993). Boron deficient, sufficient and toxic levels in crop are given in a range of values rather than one definite number that could be considered as critical. The range of toxic level to adequate level of B is narrower from other nutrient elements. Thus, excessive and deficient levels could be encountered during the same season (Mortvedt and Woodruff, 1993). Boron levels in rice plant tissue are considered deficient if concentration is < 5 mg kg^{-1}, sufficient if concentration is about 6-15 mg kg^{-1} and toxic if concentration is > 30 mg kg^{-1} (Dobberman and Fairhurst, 2000). Average B content in most plants is 20 mg kg^{-1} on dry weight basis. Boron is unevenly distributed within plants and highest levels are found in reproductive structures such as anthers, stigma and ovaries. Boron requirements vary with plant type; in monocotyledons species, leaf content ranges from 1 to 6 mg kg^{-1}; in most dicotyledons from 20 to 70 mg kg^{-1} and in dicotyledons with latex systems from 80 to 100 mg kg^{-1}. Crops such as sugar beet, celery, apple, pear and grape have higher B requirement (Benton, 2003).

Boron Deficiency Symptoms

Boron deficiency is the most common and widespread micronutrient problem. Deficiency symptoms vary between crop species, but generally occur in the growing points or flower and fruiting parts of the plant. It is characterized by abnormal or retarded elongation of apical meristems (Benton, 2003). Commonly occurring B deficiency symptoms include chlorosis and death of the growing points, distortion thickening and cracking of stems, formation of rosettes, growth of auxiliary buds, bushy growth and multiple branching (Anonymous, 2003). Root may become thick, twisted and do not develop properly, roots may show excessive branching, root crops often fail to develop edible portions or affected by the presence of dark colored corky areas, cuttings may fail to take root, the dropping of buds or blossom, fruits and seed may also be affected by developing of brown sunken areas on it (Dell and Huang, 1997). Boron deficiency symptoms in some common crops are given below;

Wheat

A normal ear fails to flower and development of the inflorescence and setting of spikelets is restricted (Rerkasem and Jamjod, 2004).

Tomato

The growing point is injured, flower injury may also occur during the early stage of blossoming, fruits may be rigged and imperfectly filled by showing corky patches and ripen unevenly (Artes and Ruiz, 1983).

Cotton

Boron deficiency causes retarded internodal growth, terminal bud often dies, retarded linear growth, short internodes and enlarged nodes, deformed and reduced in size bolls and inhibited root growth (Leidi et al., 1992).

Soybean

Deficiency may cause yellow leaves, chlorotic between veins, downward curling of leaf tips, crinkling of leaves, dieback of tips, no flowering and stunted roots (Jeanicke et al., 1996).

Corn

Under B deficient conditions crop had short bent cobs, barren ears, blank stalks, poor kernel development, watery or transparent stripes and dead growing points (Randhawa and Katyal 1982).

Strawberry

Pale chlorotic skin of fruit, cracking and dieback are the common deficient symptoms (Gupta 1993).

Sunflower

Boron deficient plant leaves appear wilted and abnormal head fall due to weak peduncles (Josten and Kutschera 1999).

Rice

B deficiency results in white and rolled tips of emerging leaves, reduced plant height; severe deficiency can cause the death of growing point although new tillers continue to be produced. Boron deficiency at the panicle formation stage may fail to produce panicles (Dobberman and Fairhurst, 2000).

Boron in Soil

Boron in the soil is exists in five categories; primary minerals such as tourmaline and B rich micas; in secondary minerals within the clay mineral lattice; adsorbed on clays, hydrous oxide surfaces and organic matter; in solution as boric acid and borate anions; and in organic matter and the microbial biomass (Argust, 1998). Soil parent materials differ widely in their B content. Granite-derived soils often carry B deficient crops and these soils contain on average 0.07–0.15 mg hot water soluble B kg^{1}, soils derived from basalt contain 0.25–0.35 mg kg^{1} B and soils from sedimentary rocks have B up to 0.50 mg kg^{1}. Soils derived from granite and other igneous rocks, gneiss and sandstone are particularly low in both total and water soluble B, whereas soil derived from loess contains more B. Boron is lost during metamorphism, some contributing to tourmaline formation but most is released to the environment (Shorrocks, 1997).

Total soil B content can range from around 10 to 100 mg kg^{-1}; however only a small fraction of this amount that is about 3 to 5% is available to the crop. A large amount of the total soil B is present as a component of highly insoluble mineral tourmaline. Boron available forms for plants include inorganic borate complexes of Ca, Mg, and Na, plus various organic compounds formed from plant and microbial decomposition (Hou et al., 1994). Tourmaline is a common B containing mineral but it is very resistant to chemical breakdown in the weathering and thus accumulates in the clastic fraction of sediments and sedimentary rocks. In igneous, metamorphic and sedimentary rocks, B occurs as borosilicate, which are resistant to weathering and not readily available to plants (Zerrari et al., 1999). Plant available B in agricultural soils varies from 0.05 to 5 mg kg^{-1}, most of the available B in soil is derived from sediments and plant materials (Gupta, 1993).

The Chemistry of B in Soil

Boron has complex chemistry and is capable of unusual bond types in combination with hydrogen. In aqueous solution, the element has a charge of 3^+, an ionic radius of 0.023nm, with an electro negativity of 2.0 on the Pauling scale and around 50% ionic character of bond with oxygen. Boron occurs as boric acid, H_3BO_3 in aqueous solution and hydrolyse reversibly to the borate ion (Goldberg, 1997). $B(OH)_3 + H_2O = B(OH)_4 + H^+ \leftrightarrow pK_a = 9.2$

The most common B species are $B(OH)_4^-$, $B_2O(OH)_5^-$, $B_3O_3(OH)_4^-$ and $B_4O_5(OH)_4$. Boron occurs in combination with oxygen in 3-fold and 4-fold coordination (Evans and Sparks, 1983). The principle B sources in soils are H_3BO_3 and $B(OH)_4$. The neutral species H_3BO_3 are predominant in soil solution. It is only above pH 9.2 that the species $B(OH)_4$ become predominant (Keren and Bingham, 1985).

Boron Adsorption in Soil

Boron concentration in the soil solution is controlled by B adsorption reactions. These reactions restrict the amount of water-soluble B available for plant uptake, because plants respond directly to the B concentration in soil solution and only indirectly to the amount of B attached to soil surfaces. Thus, the soil adsorption complex acts as both a source and a sink for dissolved B (Chen et al., 2002 Keren and Bingham 1985). The pH is the most important factor affecting B adsorption in soils, with increasing soil solution pH, B fixation also increases and maximum adsorption is near pH 8 to 9, further increase in solution pH decreases the adsorption. Boron adsorption surfaces in the soil are oxides, clay minerals, calcium carbonate and organic matter (Goldberg 2007).

Soil Factors Affecting B Availability to Plants

Boron nutrition to crop is influenced by many soil and plant factors. Among the most important are soil pH, soil texture, organic matter, soil moisture, lime application and plant physiological factors. These all are briefly defined below;

Soil pH

The soil pH is one of the most important factors affecting the availability of B, with increasing pH it becomes less available to plants (Gupta, 1993). Boron adsorption on soil constituents is also affected by solution pH. Available B in the soil decreases with increasing pH because of more fixations at high pH values. Maximum B fixation takes place at 6 to 9 pH (Peterson and Newman, 1976).

Soil Texture

Boron availability very much depends on soil texture. Coarse textured soils contain less B in comparison to fine textured soils, so it is usual to observe B deficiency in plants growing in sandy soils. Leaching losses B from sandy soils are very high, so these soils are mostly deficient in available B. Silty and clay soils are not usually as B deficient as sandy soils (Zhu and Liu, 1999; Fleming, 1980).

Organic Matter

Organic matter is an important factor affecting the availability of B. Soil B is positively correlated with organic carbon content (Zhu and Liu, 1999). Organic matter is a major storehouse of available B for crop use and it also adsorbs B. (Yermiyahu et al., 2001).

Soil Moisture

Low soil water status may depress B uptake, even though its level is high in soil. Drying of soil depresses water uptake therefore decreased the supply of B reaching the plant roots through mass flow (Evans and Sparks, 1983). Low water may cause depressed mineralization of B from organic matter by micro-organisms. Low plant transpiration may also induce B deficiency (Fleming 1980)

Liming

Application of lime increases the soil pH and this may cause B deficiency because pH has negative correlation with B availability (Evans and Sparks, 1983). Due to liming of acid soils, soluble B combines with Ca ions and forms the highly insoluble Ca-metaborate which reduces the availability of B (Goldberg and Chuming, 2007).

Plant Factors Affecting B Availability

Plant species exhibit a wide range of response to B. Cruciferous crops is very responsive to fertilization.Dicotyledonous crops have higher B requirement than monocotyledonous. Boron uptake is a passive process, after taken up by roots; it is loaded to xylem for upward transport to shoots. The long distance translocation of solutes in the xylem depends on transpiration, and B is transported along the transpiration streams (Brown and Shelp 1997). Plants are classified into two categories; one category includes species with restricted B mobility and other one with significant mobility. In the former case, water is the translocation agent for the movement of B.

The B uptake is proportional to its concentration and water flow. In the later case, B shows rapid and significant phloem mobility in species for which sorbitol is the primary photosynthetic product (Brown and Hu, 1998). The pattern of B concentration in plants and symptoms of B deficiency or toxicity are correlated with leaf ventilation. Boron in leaves can be mobile and accumulated at the sites of the termination of leaf veins (Matoh and Ochiai, 2005). Boron may react with organic compounds which prevent its translocation to other tissues. Plant ability to adopt at high or low concentrations of B may depend on the germplasma, physiological mechanisms and genetic diversity of species (Bolanos et al., 2004).

Boron Deficiency, Sufficiency and Toxicity Levels in Soil

Boron is unique among the trace elements because very small quantities are necessary for normal crop production. However, slightly high concentration may become toxic for the plant, as range between B deficiency and toxicity is very narrow (Gupta, 1993).

Table 1. Available boron critical levels in soil

Sufficient for normal plant growth	Insufficient for normal plant growth	Toxic for plant growth	Reference
………………………………..mg kg^{-1} ………………………………….			
< 1	1-5	5	Fleming (1980) Bingham (1982)
< 0.25	0.51-1.0	>2.0	Shorrocks (1997)
< 0.5	0.5-3	> 3 to 5	Sillanpaa (1982)
< 0.1	0.4 to 0.6		Kalmet (1963)

Classification of water soluble B concentration depends on soil type, plant species, sources of irrigation, environment conditions and recommendation of fertilizers (Tariq and Mott 2007) (Table 1).

Boron Deficiency in Global Crop Production

Nutrient mining (extracting more nutrients than are returned) is a major factor impoverishing the soil. High yielding crops remove considerable quantities of nutrients from the soil. Annual depletion of nutrients in areas under intensive cultivation is very high. This nutrient mining poses an immediate threat to food production and could result in a catastrophe, no less serious than from other forms of environmental degradation (Defoer and Budelman 2000). Micronutrients are removed with each cropping season in the harvested crop and are not being replaced. The result of this mining of nutrients is widespread in the shape of micronutrient deficiency problems all over Asia. These include shortages of zinc, iron, molybdenum, boron, manganese and copper (FFTC 2006).

Boron deficiency is the second most widespread micronutrient problem globally (Alloway, 2008). Boron deficiency has been reported from 80 countries and 132 crops around the world including Malaysian oil palm growing areas. Soil orders with prevalent B deficiency are Ultisol, Lithic Inceptisol, Lithic Fluvent, Alfisol, Psammnet, Oxisol, Spodosol and Andept (Shorrocks, 1997). Sillanpaa (1982) conducted an analytical survey of the macro-nutrient and micronutrient status of arable soils in 30 countries around the world for the FAO. According to him, B deficiencies occur in the Far East and south Asian countries especially India, Nepal, Philippines and Thailand, Korea, Nigeria, Malawi, Zambia, Sri Lanka, Fin land , Peru, Pakistan, Iraq, Syria, Turkey and Ethiopia. Rerkasem and Jamjod (2004) reported that yield responses in wheat to B application have been observed in Bangladesh, Brazil, Bulgaria, China, Finland, India, Madagaskar, Nepal, Pakistan, South Africa, Sweden, Tanzania, Thailand, USA, Russia, former Yugoslavia and Zambia. Singh (2008) concluded that 33% soils of the India are deficient in B. In China B deficiency is widespread especially in the south, southeast regions of oil seed-rape, cotton and sugar beet growing areas (Chunqin et al., 2008). Boron deficiency was observed in the soils of South Africa; most affected crops were maize, sunflower, groundnut tobacco, banana and other fruit crops (John et al., 2008). Boron deficiency is wide spread throughout Europe on calcareous soils especially under semiarid conditions (Alex et al., 2008). Annual crops rice, corn, wheat, soybean and common bean suffer from B deficiency in South America, micronutrient deficiencies are an emerging limiting factor in this region (Fageria and Luis, 2008). Boron deficiency occurs in many regions throughout the USA without any obvious relationship to a particular soil type (Brown, 2008). Craswell and Kerjalainen (1990) pointed out a major problem of B deficiency in upland Asian agriculture soils.

FAO global study on micronutrients observed that 49% of soil in Pakistan is B deficient (Sillanpaa, 1982). Chaudhry et al. (1977) observed rice yield increase with the application of B fertilizers in B deficient soils. Abid et al. (2002) reported that cotton growing areas of Pakistan are deficient in B. Both soil (light and medium textured) and plant samples were deficient in available B from these regions. Calcareous soils of rice and wheat growing areas of Pakistan are deficient in available B; application of fertilizers increased the yield of these crops (Rashid and Ryan, 2008, Rashid and Ryan, 2004). Pakistan s' calcareous soils of cotton growing areas are deficient in plant available B (Yasin et al., 2002). Zia (1995) and Tahir et al. (1990) reported that up to 45% rice fields are deficient of B in Pakistan.

Field surveys have shown that B deficiency is widespread in many countries including the Philippines, Thailand, Korea, Malaysia, Taiwan ROC and Japan (FFTC, 1999). FAO global study on micronutrients conducted by Sillanpaa (1982) reported that oil palm growing areas of Malaysia are B deficient and plant responded to B application. Boron deficiency occurs on a wide range of Malaysian soils particularly on soils replanted with oil palm to oil palm (Ng et al., 1974). Musa et al. (1992) reported that soils of cocoa growing areas which include soil series Rengam, Serdang, Durian, Munchong, Melaka, Holyrood and Selangor are deficient in plant available B. Southeast Asian 50% soils are Acrisols. The occurrence of B deficiency in Acrisols of Malaysia, Thailand, Indonesia, Laos and Vietnam is recognized (Gyul' akhmedov and Mamedov, 1984). Domingo and Kyuma (1983) had collected soil samples from paddy growing areas of ten tropical Asian countries and analyzed for total content of eleven trace elements i.e. B, Cr, Co, Cu, Mo, N, Rb, Sr, V, Zn, and Zr and reported that Malaysian soils are generally poor in B and other trace elements.

Sources of Boron

There are two types of B sources, the refined completely soluble materials which can be applied either in solution or as solids, and secondly the crushed ores. The ores can be slightly less soluble than the refined products due to the ore composition and amount of insoluble material, which have variable chemical and physical properties (Bell and Dell, 2008). The refined products are sodium pentaborate, ($Na_2B_4O_7.5H_2O$) borax ($Na_2B_4O_7.10H_2O$), sodium tetraborate ($Na_2B_{10}O_{16}.10H_2O$), solubor ($Na_2B_8O_{13}.4H_2O$) and boric acid (H_3BO_3). The crushed ores are colemanite ($Ca_2B_6O_{11}.5H_2O$), ulexite ($Na_2O.2CaO.5B_2O_3.16H_2O$), datolite ($2CaO.B_2O_3.2SiO_2.H_2O$), hydroboracite ($CaO.MgO.3B_2O_3.6H_2O$) and ascarite ($2MgO.B_2O_3.H_2O$). Sodium borates borax and boric acid are easily dissolved in soils and are rapidly available for plant uptake, but at the same time B can be leached from the soil root zone. The two crushed ores ulexite and colemanite are only used for soil application (Bell, and Dell, 2008). Boron can be satisfactorily applied to the soil to provide season long elevation of the B status of a crop. (Shorrocks, 1997).

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