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Boron: Essential Micronutrient for Plant and Animal Nutrition

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ABSTRACT

New exciting progress in boron research in the past few years significantly contributed to better understanding of the role of boron in plants and animals. Many experiments have been carried out to understand the role of boron in plant metabolism. From that it has been concluded that boron is mainly involved in carbohydrate metabolism and cell division. Except these two it also affects at least 14 functions in plant. And plants are the main source of Boron for animals as food. Recent studies have proved that Boron has the potential to influence a number of metabolic processes. Boron has been implicated to function in a variety of metabolic and physiological systems in humans and animals. This review study was done to explain the significant involvement of micronutrient Boron in the lifecycle of living organisms.

Key words: Boron, Micro Nutrient, Mineral, Plant nutrition, Toxicity, Deficiency

INTRODUCTION

Each and every life form required some essence for their growth and development. This essence is received by living organisms in the form of mineral nutrient. It can be defined as, "A nutrient is an element that an organism required for its life and growth or a substance which used in an organism's metabolism and must be taken in from its surroundings" (Whitney and Sharon, 2005) or "Any element that a plant needs in order to complete its life cycle under controlled conditions" (Arnon and Stout, 1939).

Plant require total 16 nutrient elements for growth i.e. C, H, O, N, S, P, B, K, Mg, Ca, Mn, Cl, Fe, Cu, Zn, Mo. Three essential nutrients—carbon (C), hydrogen (H), and oxygen (O_2)—are taken up from atmospheric carbon dioxide and water. The other 13 nutrients are taken up from the soil. And depending upon their requirement, these essential elements are classified as Macronutrients (primary nutrients and secondary nutrients), and micronutrients (Tucker, 1999; Benton, 1997).

Micro nutrient

Macro and micro nutrients are equally imperative for the plant life. The importance of micronutrient has been known since long time. Spectacular increases in yield have been recorded in experiments with micronutrients in many countries like Australia and New Zealand (Bhatti *et al*., 1988). Various applications of Fe and Zn resulted in high wheat crop yield and also it has been observed that treatment of Fe significantly increased the yield of pigeon pea compared to control (Wankhade *et al.*, 1995)

Observations also revealed that when macronutrients are supplied in relatively high proportions compared with micronutrients to stimulate growth of newly planted citrus trees, tremendous depletion of micronutrients can develop as a result of marked top growth, and micronutrient deficiencies can appear. Therefore, a balance between macronutrients and micronutrients is needed (Zekri and Obreza, 2003)

Micronutrient Boron

Boron is a semi-metallic element, exhibiting some properties of a metal and some of a non-metal. Its atomic number is 5 and its chemical symbol is B. In elemental form it is a dark, amorphous, un-reactive solid (An amorphous substance is one that does not form crystals). Boron is used mainly not as the element boron, but as compounds of boric oxide (B_2O_3) and boric acid (H_3BO_3). Boron was named for the mineral borax, thought to come from the Persian name "burah" for that mineral. Boron minerals, mainly borax, were traded over a thousand years ago, when sheep, camel and yak caravans brought borax from desert salt beds in Persia and Tibet to India and the Arab countries. There it was used mainly in making glass. Boron (B) is an essential element for plants and the only non-metal among the seven plant micro nutrient. In 1808 B was discovered by Gay Lussac and Thenard. And almost after hundred years of its discovery, it has been recognized as an essential micronutrient element for higher plants. The requirement of boron for plant growth was demonstrated in the early 1920s (Marschner 1995; Warington, 1923).

Boron availability

Natural sources

Most of the elements are absorbed by plants from the soil; it is the primary source of minerals. Boron is not uniformly distributed in the earth's crust. The primary sources of Boron in most soils are tourmaline and the volatile emanations of volcanoes (Chesworth, 1991). In igneous, metamorphic, sedimentary rocks, Boron occurs as borosilicates, which are resistant to weathering and not readily available to plants. Mobilization of immobile forms of rock Boron occurs by weathering in the pedosphere, which includes soil reactions of acid-base, oxidation-reduction, and dissolution precipitation. All this process converts immobile borosilicates into mobile borates, a negatively charged ion (anion), which is mobile and easily lost by leaching. In soils, this form of Boron can be taken up by vegetation, held by organic matter, or temporarily adsorbed on fine mineral fractions (Nable *et al.*, 1997; Muntean, 2009). Boron uptake by plants is influenced by moisture conditions in the soil. Symptoms of the deficiency are more likely during periods of low moisture availability (Dear and Weir, 2004).

Anthropogenic source 1.

Anthropogenic inputs of boron to natural 2. environments are considered smaller than inputs from natural processes. The following human activities release boron to the environment: agriculture, waste and wood burning, power generation using coal and oil, glass product manufacture, use of borates/perborates in the home and industry, borate mining/processing, leaching of treated wood, and sewage/sludge disposal. Contamination of water can come directly from industrial wastewater and municipal sewage, as well as indirectly from air deposition and soil runoff. Borates in detergents, soaps, and personal care products can also contribute to the presence of boron in water. (ATSDR, 1992; HSDB, 2003).

Factors affecting boron availability (Bangash, 2000)

pH: B availability is reduced by high pH and improved by low pH.

Leaching conditions: Coarse soil and high rainfall can cause a temporary boron shortage in soil as B is a mobile element.

Low Organic Matter: Organic matter is a reservoir for many nutrients including B.

Low Moisture: Boron uptake is in part determined by water uptake rate, therefore drought reduces B uptake. Also, B deficiency reduces root growth, thus aggravating the B stress.

Soil Ca:B Balance: Some work has indicated that high soil Ca levels, independent of soil pH can reduce B uptake. In most situations however, high soil Ca will be accompanied by higher soil pH, and the pH effect will dominate. In some cases of B toxicity, an application of a soluble form of Ca has reduced the toxic effects.

K:B Balance: Work has show that high K rates can sometimes depress corn yields if B is limiting.

Zn:B and P:B Balance: Work with barley showed that Zn applications can reduce B accumulation. This same work showed that high P applications increased B accumulation.

N Stress: Low N availability decreases the vigor of plants to an extent that it may fail to take up adequate amounts of many other nutrients. Boron uptake can be affected in this way.

Available forms of boron

Boron is available in the form of small number of borates, including ulexite ($NaCaB_5O_9.8H_2O$), borax ($Na_2B_4O_5(OH)_4.8H_2O$), colemanite ($Ca_2B_6O_{11}.5H_2O$) and kernite ($Na_2B_4O_6(OH)_2.3H_2O$). These minerals form when boron-bearing waters percolate into inland desert lakes and evaporate, leaving layers of borates, chlorides, and sulfates. These minerals are referred to as evaporite minerals. Very large deposits of evaporite boron minerals are found in the United States (especially California), Turkey, Chile and Argentina. Less-important deposits occur in Iran (formerly called Persia), and elsewhere. In addition, boron silicate minerals are mined as boron ores in China, Russia, and a few other countries.

Turkey, The United States and Russia are the largest producers of boron minerals. Argentina, Chile, and China have important ore production, and five or six other countries produce minor amounts. The U.S. production is all from the deserts of Southeastern California. In addition to its own production, the United States imports borate minerals and processed compounds, and exports a large amount of finished products containing boron.

Micronutrient Boron (B) and Plants

Boron (B) is an essential element for plants and the only non-metal among the seven plant micro nutrient. The requirement of boron for plant growth was demonstrated in the early 1920s (Marschner 1995; Warington, 1923; Glass, 1989).

Required B concentration by Plants

As the category of boron indicate it is a micro nutrient which is required in very less amount and the requirement of boron is varies from plant to plant. According to studies done by Kovancy (1979), cereal plants need much more Boron; grass plant, potato and strawberry require Boron less than 1.0 ppm; tobacco, cotton, tomato, carrot, onion and some fruits need Boron between 0.1-0.5 ppm; apple, clover, peppermint, beet, and cabbage need Boron more than 0.5 ppm. According to Marschner (1995), graminaceous species generally contain lower B content than dicotyledonous species.

Role of boron in plant metabolism

Boron investigation attracted many researchers since many years as its particular roles remained unclear even after many years of its discovery. In England, Brenchley and Warington and in America, Sommer and Lipman early showed the favorable effects of boron on the growth of various plants. Gauch and Dugger (1954) have presented and discussed a wide spectrum of proposed roles and effects of boron on higher plants.

It has been demonstrated that constant supply of B at very low concentration is very important for healthy broad bean plants (Warington, 1923). It also found to be essential for root development in stem cuttings of light grown seedlings such as *Phaseolus vulgaris* or *P. aureus* (Hemberg, 1951; Ali and Jarvis, 1988). The effect of boron on RNA has been studied in tomato root tip (Albert, 1965). Bonilla *et al.* (2004) revealed the fact that B has a role in remobilization of seed nutrient stores from the seed germination studies of *Pisum sativum*. In 2012, Gupta and Solanki have also mentioned that variation in B concentration is affecting the IAA, Phenol and sugar content of Brinjal (*Solanum melongena* L.) plant (Gupta and Solanki, 2012_a, 2012_b)

It has been hypothesized after experiments with squash plants and cultured tobacco cells that B may play an important role as a structural component of the growing (Primary) cell walls in developing plant tissues (Hu *et al.*, 1996). The B content in the cell walls of shoots of well-fertilized rice (*Oryza sativa*) plants was in the range of 5 mg B/ kg of cell wall (Matoh *et al.*, 1996). This value is 5- to 10-fold lower than the levels in dicotyledonous plants, the cell walls of which typically contain; 25 to 45 mg B/ kg of cell wall (Matoh *et al.*, 1996). However, numerous studies with light grown de-rooted sunfower seedlings revealed no role of exogenous B in the initiation of adventitious roots (Fabijan *et al.*, 1981*a*; Fabijan *et al.*, 1981*b*; Liu and Reid, 1992). B application can also affect the availability of other nutrient. The uptake of N, P and K significantly increased in peanut (*Arachis hypogaea* L.) plants after the foliar application of B (Nasef *et al.*, 2006).

Boron deficiency

Each plant has a specific requirement (optimum level) of boron for their growth and development, when plant gets lesser amount of nutrient (below the optimum level) it shows the deficiency symptoms which ultimately leads to retardant of growth. For example, symptoms of B deficiency appeared in rice plants when the boric acid concentration in the hydroponic solution supporting those plants were <0.2 mm (Yu and Bell, 1998). In Arabidopsis, B deficiency symptoms are evident in wild-type plants grown in hydroponic solution containing 0.5 mm boric acid (Miwa *et al*., 2006).

Boron deficiency was first recorded in Australia in the 1930s in apple trees growing in Tasmania and New South Wales (Dear and Weir, 2004). Some crops exhibit specific symptoms, Like Beets, turnips, and potatoes exhibit reduced tuber growth.

Apples have cork spot. Grapes form mixed clusters of small and large fruit, known as "hen and chicks." Cotton leaves become thick and leathery with abnormally long spongy petioles and the shorter leaf petioles are often twisted and have small ruptures along the stem. The fruit and leaves exude a sticky substance. Flower buds become chlorotic with flared bracts. The squares and bowls dry up and often abort. Bolls that survive generally are deformed, are smaller in size, and fail to open fully (Tucker, 1999).

Boron deficiency symptoms were studied in sunflower throughout the plant life at different stages. In the case of sunflower, the normal growth of plant has been seen till the development of flower buds. Young affected leaves were remain small and become mottled silvery yellow, first near their base, then curl downward becoming crinkled. Flower stalk become brittle and heads snap off easily or bend over. Seed set is uneven or segments of head may produce no seeds at all. Dead areas develop at base of upper leaves, while lower leaves remain normal. Shortened inter-nodes at top of plant give a compressed appearance with thickening of upper stem. Flower head did not form at all or dead tissue develops at its basis as scaly patch, causing twisting, collapse and death of flower head (Dear and Weir, 2004).

In case of beet root the plant growth remains stunted and distorted due to B deficiency. Multiple branching forms "multiple crowns" due to the death of apical growing points. Root cracks also observed which leads to rotting (heart rot of sugar beet). B deficiency in alfalfa showed yellowing or bronzing of leaves, followed by reddish discoloration along the margins of youngest fully developed leaves. Plant tops may be deformed. Plants may not flower or set seed. (Dear and Weir, 2004)

In citrus plant Boron deficiency is known as "hard fruit" because the fruit become hard and dry due to knobs in the rind caused by gum impregnations. The chief fruit symptoms include early shedding of young fruits. Such fruit have brownish discolorations in the white portion of the rind (albedo). Older fruit are undersized, lumpy, and distorted with an unusually thick albedo containing gum deposits. Seeds fail to develop and gum deposits are frequent around the axis of the fruit. The first visual symptoms of B deficiency are generally the death of the terminal growing point of the main stem. Further symptoms are a minor thickening of the leaves, a tendency for the leaves to curl downward, and sometimes chlorosis. Young leaves show small water-soaked spots or flecks that become translucent as the leaves mature. Associated with this symptom is a premature shedding of leaves beginning at the treetop that soon leaves the tree almost completely defoliated. Continuation of the symptom is tree dieback and bushy upright growth similar to that of Zn deficiency. Fruit symptoms are the most constant and reliable tool to diagnose B deficiency. (Zekri and Obreza, 2003)

Albert and Wilson (1961) had studied the boron deficiency symptoms on tomato plant. They found that external symptoms of boron deficiency in roots of whole tomato plants were detected within 24 hours after boron was suspended from the nutrient solution. These symptoms consisted the cessation of root elongation as early as 6 hours after boron was withheld and the consequent development of a brown color and loss of fluorescence in the terminal portion (2mm) of the root tips. Internal symptoms were observed to occur in the post-meristematic region of the tip and were apparent as a darker staining of the cytoplasm followed by its disintegration, resulting in empty, apparently dead cells.

Other experiments also revealed the fact that primary effect of B shortage is to disturb the structural organization of cell walls. Goldbach's group has reported that the physical properties of squash root cell walls changed within minutes after B deprivation (Findeklee *et al.*. 1997 and Goldbach *et al.* 2001). It has been proven that B deficiency leads to significant decrease in cellular antioxidant pool, which is found to be responsible for the cell death in sunflower, squash (Cakmak *et al.,* 1995; Lukaszewski and Blevins, 1996; Cakmak and Römheld, 1997) and tobacco (Koshiba *et al*., 2009) cells under B deficient conditions. These studies concluded that oxidative damage is the immediate and major cause of cell death under B deficiency. Whittington (1957) reported that a deficiency of boron caused a cessation of cell division and later suggested (1959) that in the absence of boron, cell division ceases because abnormalities in the formation of the cell wall prevent the cell from becoming organized for mitosis. However, Skok (1958) concluded from radio sensitivity studies with sunflower plants that boron is required for some process or processes concerned with cellular maturation or differentiation rather than with cell division.

The role of boron in IAA metabolism is well studied. It has been revealed that sunflowers with boron deficiency contained more IAA than control group, that IAA-oxidase was inhibited due to high level of phenolic acid (Cohen and Bandurski, 1978). Bohnsack and Albert (1977) demonstrated a severe inhibition in root growth of squash and increase in IAA oxidation by boron deficiency. Resupply of boron to boron deficient squash plants rapidly stimulated root growth and reduced IAA oxidation. Rajaratnam and Lowry (1974) reported that IAA content in palm trees increased in the presence of boron deficiency.

Boron toxicity

Boron is required in very low concentration for plant growth. There is a very thin margin between the level of B deficiency and toxicity. An optimum concentration of B for a plant can be toxic for another plant. Plant growth can be affected very badly due to the higher concentration of B. It has been evaluated that up to 17% of the barley yield vanished in southern Australia were caused by B toxicity (Miwa *et al.,* 2007). A reduced plant growth with increased B concentration in plant tissues has been observed in tomato (Gunes *et al.,* 1999), sunflower (Ruiz *et al.,* 2003) and barley (Karabal *et al.,* 2003).

Karabal *et al.* (2003) observed in barley cultivars that B toxicity made oxidative and membrane damage in leaves. Recently, in apple (*Malus domestica*) and grapevine (*Vitis vinifera*), it has been reported that B toxicity induces oxidative damage by lipid peroxidation and hydrogen peroxide accumulation (Molassiotis *et al.*, 2006; Gunes *et al.*, 2006). Studying apple rootstock, Molassiotis *et al.* (2006) found that the non-enzymatic antioxidant activity increased with increasing B concentrations in the culture medium. It has been shown that excess B inhibited the formation of glutathione in sunflower (*Helianthus annuus*) leaves (Ruiz *et al.*, 2003) and tocopherol in orange (*Citrus sinensis*) plants (Keles *et al.*, 2004). Also it has been reported that higher B concentration in the medium boosted the concentration of ascorbate as well as that of glucose and fructose in orange plants (Keles *et al.*, 2004). Recently it has been found that excess B increased both MDA and H_2O_2 concentrations in apple rootstock (Molassiotis *et al.*, 2006) and grape (Gunes *et al.*, 2006). Experiments of Tomato plants resulted in decreased leaf biomass and RGRL as a result of higher B concentration in the root medium and also showed an increase in the total and free B concentration. The study shown that high B concentrations in the culture medium provoked oxidative damage in leaves of tomato (Luis *et al.*, 2007).

Studies on wheat plant showed the rapid inhibition of root growth (Reid *et al.*, 2004) and decreased dry weight of plant (Turan *et al*., 2009) in response to high B concentration. Wheat was grown in pots under greenhouse conditions and it has been observed that shoot dry matter yield and root yield decreased with increasing B applications. Also chlorophyll amount of leaf samples decreased with B application.

In young squash plants (*Cucurbita pepo*), an early effect of developing B toxicity is decreased chlorophyll concentrations, followed by reduced growth, loss of leaf area and decreased CO_2 fixation; all of these effects occurring well before the development of visible toxicity symptoms (Lovatt and Bates, 1984). Leaf cupping, a specific visible symptom of B toxicity in some species, has been suggested to result from inhibition of cell wall expansion, through disturbance of cell wall crosslinks (Loomis and Durst, 1992).

Wheat, being semi-tolerant for B toxicity (Gupta *et al*., 1985), can tolerate boron up to 2 mg B kg-1. Higher values may frequently cause toxicity symptoms such as chlorosis, necrosis and yield reduction of wheat plants. Application of higher (10 and 20 mg B kg-1) levels of boron increased the sensitivity of plant for B and result in greater occurrence of leaf injury due to B toxicity. The boron toxicity symptoms occurred as a dark brown spots and lesions with chlorotic border in the oldest leaf of wheat (Bergmann, 1992; Oyewole and Aduayi, 1992 and Turan *et al*., 2009).

Researchers determined that B concentration of maize plant decreased with the increasing P application. Also, B toxicity decreased with the high level N applications (Alpaslan *et al.*, 1996). Studies have revealed the accumulation of B in developing sinks rather than at the end of the transpiration stream in the species in which B is phloem mobile (e.g. *Prunus, Malus, Pyrus*). In these plants the symptoms of toxicity are fruit disorders (gummy nuts, internal necrosis), bark necrosis which appears to be due to death of the cambial tissues, and stem die back (Brown and Hu, 1996). Malus, Prunus and Pyrus do not accumulate high levels of B in their leaves, and that B toxicity is expressed as twig die-back and gum exudation in leaf axils and buds (Hansen, 1948; 1955; Woodbridge, 1955; Maas, 1984; Choe *et al.*, 1986; El-Motaium *et al.*, 1994). These 'unusual' symptoms of B toxicity are the result of the high phloem mobility of B in these species (Brown and Hu, 1996).

B effects are also influenced by the presence of other minerals. The interactions between minerals are negatively or positively correlated. Graham *et al.* (1986) and Swietlik (1995) showed in controlled solution culture experiments with barley (*Hordeum vulgare*) and orange (*Citrus aurantium*), respectively, under conditions of Zn deficiency, excess B can be accumulated by plants and B toxicity develop, even though the levels of B in the medium do not result in B toxicity when ample Zn is supplied.

The toxic effect of B seen at both 10 and 20 mg B kg-1treatments was alleviated by treatments of 100 and 200 mg Ca kg-1 (Turan *et al.*, 2009). Taban *et al.* (1995) reported that B toxicity was determined when high level of boron (10 mg B kg-1) was applied to the wheat plants, but this toxic effect was decreased when the growing medium was supplemented with Ca.

This approach was based on some evidence that showed an interaction between B and Ca. Boron and calcium interaction was reported by Gupta (1979) and Taban *et al.* (1995) who found a negative correlation between B and Ca, with high Ca inducing B deficiency. According to them, when B was applied, Ca concentration was decreased, Ca was applied to the plant B concentration was decreased. The application of Ca could reduce the availability of B, resulting in decreased uptake of B (Gupta and Macleod, 1981; Taban *et al.*, 1995). This result might be explained that Ca which was localized in cell wall caused to uptake boron by plant. In the other words, localization of Ca in cell wall leads to decrease cell wall boron permeability. Calcium applications increased total shoot calcium concentrations and decreased total shoot and root boron concentrations of wheat plants. Similar results were reported by Gupta (1972), Oyewole and Aduayi (1992) and Taban *et al.* (1995).

Relation with animals

Boron is widely present in soil and water and it is utilized by plants for various metabolic activities. Directly by water or indirectly by plants, animals and humans are having exposure to this element. Recent studies have proved that B has the potential to influence a number of metabolic processes. Boron has been implicated to function in a variety of metabolic and physiological systems in humans and animals (Nielsen, 1997).

Major roles

Although the essentiality of B has long been established in plants (Warington, 1923), primary role of B in animals has not yet been recognized. Roles of this non-metallic element which possesses properties that are intermediate between metal and non-metals (Naghii and Samman, 1997) have been proposed in numerous major physiological processes in animals by researchers. These include cognitive function (Penland, 1998) and bone formation (Chapin *et al.*, 1998; Armstrong *et al.*, 2000). Embryonic defects related to boron depletion have been reported for zebra fish (Rowe and Eckhert, 1999), frogs (Fort *et al*., 1998, 1999, 2000) and trout (Eckhert, 1998).

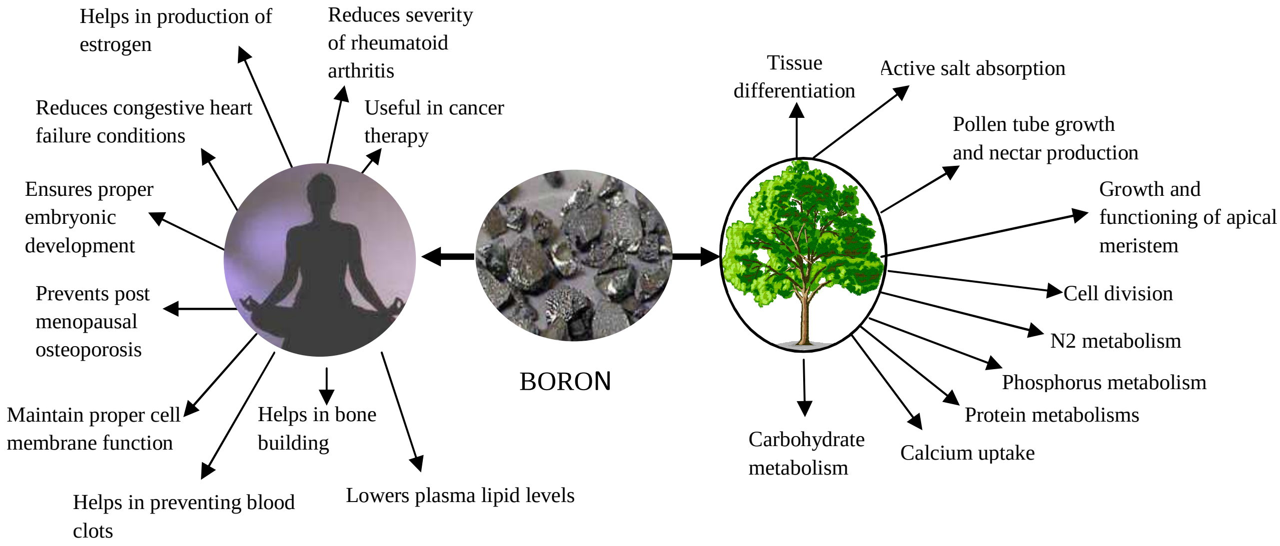

Figure 1 Importance of Boron in Plant and Human life

Boron affects human steroid hormone levels. And recently, an explosion of athletic supplements has been marketed touting boron as an ergogenic aid capable of rising testosterone level (Green and Ferrando, 1994). Boron seems to be essential for healthy bone and joint function, possibly via effects on the balance and absorption of calcium, magnesium and phosphorus (McCoy *et al.*, 1994 and Kirschmann, 1996).

Daily intakes of boron comparable to those supplied by boron-rich natural diets have been shown to ameliorate the effects of vitamin D deficiency in rats and chickens (Hunt and Herbel, 1991(a & b); Hegsted *et al*., 1991; Hunt, 1994; Dupre *et al*., 1994; Hunt, 1997; Kurtoglu *et al*., 2001). Boron is essential for the utilization of vitamin D, which enhances the absorption of calcium. Recent research demonstrates that boron may be essential in the conversion of vitamin D to its active form (Murray, 1996). And thus, boron is essential for healthy bones. Boron is useful for women suffering from postmenopausal osteoporosis.

Boron is best if taken with a well balanced vitamin and mineral supplement including calcium, magnesium, and riboflavin (vitamin B2) (Hendler, 1990). Boron supplementation may also be useful for arthritis. Several studies show that boron may provide relief for patients suffering from osteoarthritis, juvenile arthritis, and rheumatoid arthritis (Murray, 1996). It may also be beneficial for ischemic heart disease and other types of cardiovascular disease (Kirschmann, 1996).

Optimum level (RDA- Recommended Dietary Allowance status of boron)

Although healthful natural diets rich in fruits, vegetables, and legumes can provide up to about10 mg boron daily, surveys show that many people obtain no more than 1 mg boron from their habitual diets (Nielsen, 1998) – high in refined grains, sugars, oils, and animal products. Despite evidence of the essentiality of boron in animals, currently there is no recommended daily allowance (RDA) for boron intake. But daily intakes of boron up to 20 mg are considered completely safe (Miljkovic *et al*., 2004). And recently the United States Food and Nutrition Board (2001) have set a Tolerable Upper Intake level (UL) for boron of 20 mg/day.

Source of B for animal

The boron exposure for the animals and humans is mostly through the intake of food and, to a smaller extent, water. Levels of boron in food products are associated to boron in the soils where they are grown and, accordingly, show several geographic variations (Hunt *et al*., 1991). Product categories having high levels have been identified as tubers, legumes, fruits, nuts and fruit-based beverages (IOM, 2001). In one nutritional study, coffee, milk, apples, dried beans and potatoes accounted for 27 percent of the boron in the diet (Rainey *et al*., 1999).

In the 1994 Total Diet Study from the United Kingdom, the food groupings with the highest boron concentrations were nuts (14 mg/kg fresh weight), fruits and fruit products (2.4-3.4 mg/kg), green vegetables (2.0 mg/kg), and potatoes and other vegetables (1.2-1.4 mg/kg). The levels were below 1 mg/kg for other food categories (Ysart *et al*., 1999). Most foods contain less than 6 mg boron/kg of food. Some individual foods may contain more than 20 mg B/kg of food (Seiler *et al*., 1988). A diet high in fresh fruits and vegetables is known to offer significant protection against osteoporosis and osteoarthritis (Murray, 1996).

Deficiency

As B availability is correlated with other nutrients also its deficiency seems to affect calcium and magnesium metabolism, and affects the composition, structure and strength of bone, leading to changes similar to those seen in osteoporosis (Nielsen, 1994). This is likely to be due to decreased absorption and increased excretion of calcium and magnesium. Boron deficiency combined with magnesium deficiency appears especially damaging in cases of osteoporosis (Nielsen, 1990). Because of its effects on calcium and magnesium metabolism, boron deficiency may also contribute to the formation of kidney stones. Boron deficiency also seems to reduce psychological alertness (Penland, 1994).

There may also be a linkage between boron deficiency and osteoarthritis. Epidemiological studies indicate that in countries such as Mauritius and Jamaica, where boron intake is low, the incidence of osteoarthritis is around 50 to 70 percent. In countries such as the USA, UK and

Australia, where boron intake is relatively high, the incidence of osteoarthritis is around 20 percent. Boron concentrations in bones next to osteoarthritic joints may be lower than in normal joints (Helliwell *et al.*, 1996). Inadequate intake of boron causes bone changes similar to those seen in osteoporosis. Boron deficiency results in decreased blood levels of calcium and calcitonin and increases urinary excretion of calcium and magnesium levels. Boron deficiency also causes decreased serum concentrations of estrogen and testosterone, all of which are associated with calcium loss and bone demineralization (Murray, 1996 and Somer, 1995).

Toxicity

If the boron level reaches to above tolerable level it creates adverse effects and generally these toxic effects appear at intakes of about 100 mg. Toxic effects include a red rash with weeping skin, vomiting, diarrhea characterized by a blue green color, depressed blood circulation, coma and convulsions (Murray, 1996).

Boric acid and inorganic borates ate plentiful in nature. They are widely used in industrial, agricultural, cosmetics and abundant smaller applications. These compounds are toxic to all species tested at high doses, but they are neither carcinogenic nor mutagenic. The major toxicities are reproductive and developmental. New data on endocrine toxicity includes altered follicle stimulating hormone and testosterone. Because these hormonal changes may be secondary effects of testicular toxicity, borates are not suspect as endocrine disrupters (Fail, 1998).

Therapeutic uses of supplements

Supplements of around 3 mg per day have been shown to enhance the effects of estrogen in postmenopausal women. This is likely to contribute to its beneficial effects on bone health (Nielsen *et al*., 1987). Studies done in 1994 on athletic college women suggest that boron supplements decrease blood phosphorus concentration and increase magnesium concentration. Both of these changes are beneficial to bone-building (Meacham *et al*., 1994). Because of its sex hormone-enhancing effects, boron may help to protect against atherosclerosis (Naghii and Samman, 1997). Boron supplements of 6 to 9 mg per day have been used to treat osteoarthritis with some improvement of symptoms. Boron content in arthritic bones may be lower than that of normal bones and extra boron may increase bone hardness (Newnham, 1994).

Other uses

A high boron concentration in the soil is toxic to plants and some boronated derivatives are used as herbicides (Fail *et al*., 1998). Boron, in the form of boric acid, has been used as a dusting powder or lotion to treat bacterial and fungal infections. It is also a component of some commercial mouthwashes. In borax solution form, boron has been used to treat mouth ulcers, eye infections and as a nasal douche (www.jctonic.com).

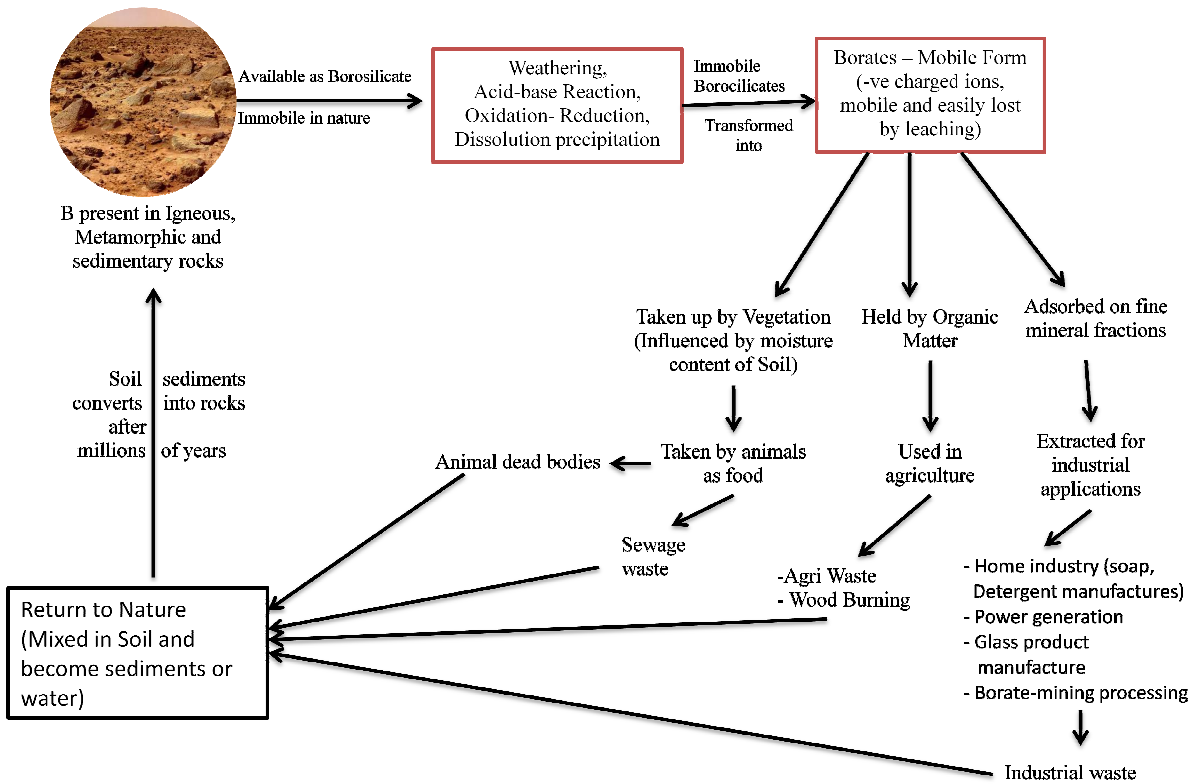

Figure 2 Boron Cycle

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