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Boron Fraction and the Kinetics in Relation to Behaviour in Soil

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Boron (B) is an essential microelement for plants, and its deficiency can lead to impaired development and function. Plants take up soil B in the form of boric acid (H3BO3) in acidic soil or tetrahydroxyborate [B(OH)4]- at neutral or alkaline pH. Boron can participate directly or indirectly in plant metabolism, including in the synthesis of the cell wall and plasma membrane, in carbohydrate and protein metabolism, and in the formation of ribonucleic acid (RNA). In addition, B interacts with other nutrients such as Ca, nitrogen (N), phosphorus (P), K, and zinc (Zn). Boron (B) is an essential element for growth, development, productivity and quality of crops and is distributed unevenly in soils solution and in organic and mineral fractions depending on the soil pH. Boron is considered as the most mobile, and often one of the most deficient, microelements in soils.

Introduction

Boron is an essential micronutrient in soil that plays a critical role in plant growth and development. It is involved in cell wall formation, cell division, sugar transport, and reproductive processes such as pollination and seed or fruit development, thereby significantly influencing crop yield and quality. Plants primarily absorb boron in the form of undissociated boric acid (H_3BO_3). This form remains available across a soil pH range of approximately 5.0 to 7.5; however, boron availability generally decreases in highly alkaline soils due to adsorption onto clay minerals and oxides. Insufficient boron restricts meristematic activity, reduces pollen viability, and leads to poor fruit or seed set, ultimately limiting crop productivity. Conversely, excess boron becomes toxic and may cause leaf chlorosis, necrosis, and reduced plant vigour. Because the range between deficiency and toxicity is narrow, precise boron management is necessary for sustainable crop production.

Absorbed Boron

Absorbed boron in soil exists in a dynamic equilibrium between the soil solution and solid phase, While the total boron content in soil can be high, typically ranging from 20-200 mg/kg, only a small fraction (roughly 0.1 to 2.0 mg/kg) is actually available to plants, primarily as undissociated boric acid (H_3BO_3).

Boron Adsorption is strongly influenced by;

- Soil pH (adsorption increase as pH rises above 6.0),
- Clay Content,
- Organic matter,
- Iron and Aluminium oxides

Boron availability is generally optimal in slightly acidic soils (pH 5.5 to 7.5). In calcareous or limed soils (high pH), boron becomes less available due to increased adsorption and possible formation of calcium borate complexes. In sandy and coarse-textured soils, boron is easily leached, especially under high rainfall.

Organic matter serves as an important reservoir of boron, releasing it through microbial mineralization. Because boron has a narrow range between deficiency and toxicity, careful soil and fertilizer management is essential.

Organically bounded Boron

Organic powdered boron fertilizer, commonly derived from natural mineral sources such as ulexite or colemanite, are used to correct boron deficiency in soil.

Boron deficiency commonly occurs in:

- Sandy soil,
- Heavily leached soils,
- Calcareous (high-pH) soils.

Boron is crucial for cell wall formation, sugar transport, and reproductive functions like pollen germination and seed set. The critical range between deficiency (< 0.5 mg/kg soil) and toxicity (> 3 mg/kg soil). Because of this narrow range, boron must be applied carefully. Soil incorporation before sowing improves efficiency. It enhances flowering, fruit set, and crop quality.

Iron and Aluminium Oxide -Associated Boron

Iron (Fe) and aluminium (Al) oxides are major boron adsorption site in acidic and weathered soils. These sesquioxides significantly influence boron availability.

Boron adsorption are increases with increasing soil pH (especially above 6.0) is stronger in soils rich in Fe/Al oxides. Above pH 7, boron adsorption increases sharply due to formation of borate anions ($B(OH)_4^-$), which bind strongly to oxide surfaces. Boron does not form insoluble compounds directly with Fe/Al oxides, but it is strongly adsorbed onto their surfaces. In acidic soils, boron can interact with aluminium hydroxides. Adequate boron nutrition may help reduce aluminium toxicity effects in plants.

Solution Boron

Plants absorb boron it in the form of boric acid (H_3BO_3) from the soil solution. Boron availability is highly dynamic and is influenced by soil pH, moisture, texture, and organic matter content, with deficiency most common in light-textured, acidic, or heavily leached soils. Ideal soil pH for boron availability is between 5.5 and 6.5, as higher pH levels (above 7) can lead to increased adsorption to clay minerals and iron/aluminium oxides, making it less available. In acidic soils, boron can interact with aluminium hydroxides. Adequate boron nutrition may help reduces aluminium toxicity effects in plants.

Total Boron

Total boron in soil, which represents the entire content of the element including structural components of minerals, typically ranges between 20 to 200 ppm. Despite these total amounts, only a very small fraction—often less than 5%–10%, or about 0.1 to 3 mg/dm^3—is generally available for plant uptake. The majority of total soil boron (up to 90% or more) is locked within primary minerals like tourmaline and, to a lesser extent, in secondary clay minerals, making it unavailable for immediate plant consumption. Total B content varies significantly depending on the parent rock material (marine shales greater than igneous rocks). Coarse-textured, sandy, and heavily leached soils tend to have lower total boron, while clay-rich soils tend to have higher concentrations. Although total B levels are rarely a constraint, they serve as a long-term reservoir that, through weathering and mineralisation, eventually replenish the available (water-soluble) boron pool.

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