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Boron

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Boron (B) deficiency is one of the most prevalent micronutrient deficiencies seen in agricultural soils around the world. In Australia, while there are relatively few reports of B deficiency, low levels are seen on sandy soils on the slopes of the Great Dividing Range and in Western Australia, and responses to fertilization have been documented in most states. Lucerne and canola are the most commonly crops grown in Australia with a high demand for B.

Boron in Plants

The primary role for B is to provide structure to cell walls. Boron also plays a role in the formation of sugar complexes for translocation within plants, the formation of proteins, cell membrane function, nodule formation in legumes, flowering, and the development of pollen, seed and fruit[1]. Deficiency can reduce both the yield and quality of crops.

Boron in Soils

Boron concentrations in the soil are of particular importance as the range between deficiency and toxicity in plants is relatively narrow. For example, B deficiency in canola can occur with soil B levels (Hot Water Soluble) of 0.15 to 0.5 mg B/kg while toxicity occurs at values greater than 3 mg B/kg.

Agricultural soils range from 1 to 467 mg B/kg in total B concentration. The available forms, $B(OH)_3$ (boric acid) and $B(OH)_4$ (borate) are usually mobile in the soil solution, but there are several factors that influence their availability to plants:

Organic matter. Organic matter is the most important source of B in the soil. In hot, dry, and cold weather, the rate of organic matter decomposition slows down especially near the soil surface. As a result, plants can show a temporary B deficiency that tends to disappear when the rate of organic matter turnover increases.

Weather conditions. Dry and cold weather can cause temporary B shortages by restricting root activity in the surface soil and reducing transpiration, therefore reducing B uptake by the plant. Root growth may resume, but yield potential is often reduced after such conditions.

Soil pH. Plant availability of B is greatest between pH_{Ca} 5.0 and 7.5. At higher pH values, B uptake is reduced due to sorption of B to aluminium hydroxides in the soil. Liming acid soils increases soil pH and can therefore reduce B uptake by plants, but this is generally a temporary effect.

Soil texture: Coarse-textured sandy soils, which are composed largely of quartz, are typically low in minerals that contain B.

Table 1. The B concentration (mg/kg) in lucerne in a pot trial in response to B and raising soil pH approximately 6 weeks after treatment[2].

pH_{Ca}	Boron application, kg B/ha				
	Nil	0.23	0.46	0.91	1.82
5.1	12	33	44	57	85
5.6	13	31	38	49	60
6.2	9	26	35	39	69

Boron Deficiency

Boron deficiency symptoms vary greatly as the nutrients mobility within plants is not consistent between different crop species. Symptoms most typically appear on the youngest tissue, however symptoms can be seen all over some plant species.

Deficiency symptoms in canola include the youngest leaf turning a red-brown colour, shortened cracked stems with cupped leaves, and interveinal necrotic spots that eventually lead to the leaf dying from the edges to main leaf vein. Deficiency in lucerne causes internodes and stems to be shorter, younger leaves turn yellow or red and the terminal buds may die.

Boron Toxicity

Boron toxicity has been found extensively across the cereal-growing regions of South Australia and Victoria[3,4], as well as the Western Australian Mallee[5]. Toxic accumulation of B in soil occurs in many low rainfall regions especially in areas with naturally occurring sodic subsoils. Boron toxicity symptoms are not visible until the roots of the plant have penetrated the B rich layer in the soil. Symptoms appear first on the edges and tip of the older leaves. Because B is mobile in the soil, extra irrigations can move B out of the root-zone, but in dryland conditions, avoidance and the use of more tolerant varieties are the only management option available.

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Boron deficiency in alfalfa is often seen in drought conditions.

Prediction of Boron Responses

Soil tests can give a reasonable prediction of B availability when tests are calibrated for soil groups and crop species. Both Hot Water Soluble and hot 0.01M $CaCl_2$ extractant are used to test B availability in soil and have been proven to correlate well with plant response. Depth of sampling is important because B is mobile in the soil and while the topsoil bay be depleted, the lower soil layers may contain higher amounts of B.

Tissue tests, in conjunction with visual analysis, may be a more reliable guide to plant B status than soil tests. Like soil tests, tissue test results need to be interpreted in terms of soil moisture, root depth and anticipated future B supplies. Critical whole plant levels for canola range from 22 mg/kg (seedling) to 15 mg/kg (rosette). Critical values for cereals are around 4 to 5 mg/kg. Sampling the youngest fully expanded leaves may provide a more robust diagnosis than whole plant sampling.

Fertilizing with Boron

Source. There are many fertilizers on the market that contain different concentrations of B and vary in their levels of solubility. Soluble forms are usually preferred, except in sandy soils where low solubility B-phosphates can be used to reduce leaching out of the root zone.

Rate. Soil application rates for the most responsive crops may be as high as 3 kg B/ha, and for medium responsive crops, 0.5 to 1.0 kg B/ha (**Table 2**). The rate of fertilizer application should take into consideration the solubility and form of B it contains, as well as factors that affect B availability such as soil moisture and temperature. Split foliar applications of 0.5 kg B/ha applied between stem elongation and flowering are effective but care needs to be taken to keep concentrations to levels that will not injure leaves. This typically is at concentrations of 0.5% w/v. Foliar applications will have little residual activity.

Time. Foliar B can be applied when a deficiency has been diagnosed either by tissue test or visual symptoms. Application at flowering has the potential to give immediate responses.

Place. Boron fertilizer can be broadcast or banded into soil, or applied as a liquid foliar treatment. In-furrow applications of B if adjacent to seed can cause poor emergence. It is important that B fertilizers be evenly applied because the range between deficiency and toxicity in plants is relatively narrow and uneven application can easily result in strips of deficiency and toxicity occurring across the paddock.

Crop Response to Boron

Crop species vary significantly in their responsiveness to B (**Table 3**). Canola has been identified as a crop with a high B requirement, with seed concentrations around ten times that for cereals. There is also considerable variation in response with species in terms of efficiency of uptake[7] and tolerance to toxicity[8]. Most legumes are highly responsive to B and also susceptible to B toxicity. Grains and grasses are generally less responsive to B. Crops vary in sensitivity to excess B, but those with high requirements do not always have high tolerance.

Table 2. Common Boron fertilizers.

Source	Formula	B, %	Water solubility
Borax	$Na_2B_4O_7·10H_2O$	11	High
Boric acid	$B(OH)_3$	17	High
Ulexite	$NaCaB_5O_6(OH)_6 • 5H_2O$	13	Slight
Colemanite	$Ca_2B_8O_{11} • 5H_2O$	20	Low
Sodium pentabo-rate	$Na_2B_{10}O_{16} • 10H_2O$	18	High
Sodium tetraborate	$Na_2B_4O_7 • 5H_2O$	14 to 15	High
Sodium octaborate	$Na_2B_8O_{13} • 4H_2O$	20 to 21	High
Boron phosphate	PBO_4	10	Moderate/ Very low*
Boron frits	Boric oxide glass	2 to 11	Very Low

*Solubility depends on conditions of manufacture[6].

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Table 3. Examples of crop yield response to application of Boron fertilizer.

Crop	Source	Rate, kg B/ha	Time	Place	Yield response	Reference
Canola	Na borate	0.6	Stem elongation	Foliar	39	9
Canola	Boric acid	2	Sprayed at sowing	Soil	4 to 52	7
Lucerne seed	Na octoborate	0.4 to 1.1	After first cut	Foliar	+37	10
Lucerne	Na tetraborate	3 to 4	Annual	Soil	46 to 62	11
Soybean	Na octoborate	0.25 to 1.0	V2 or R2	Foliar	0 to 130	12