Balancing boron nutrition

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Boron (B) was identified as an essential plant nutrient more than 80 years ago.

Since then its role in agricultural crops has been documented in hundreds of reports around the globe.

World-wide, B deficiency is one of the most prevalent micronutrient deficiencies. In Australia there are relatively few reports of B deficiency but responses to B fertiliser have been documented in most States and low levels are seen on sandy soils on the slopes of the Great Dividing Range and in WA.

Lucerne and canola are the most common field crops with high B requirements but a large number of fruit vegetable and field crops should be assessed for potential B deficiency. B is also important in pine and eucalypt forests.

Boron in plants

The primary role for B in plants is in the cell walls, where it provides cross-links between polysaccharides to give structure to cell walls. It also plays roles in formation of sugar complexes for translocation within plants and in the formation of proteins. Cell membrane function, nodule formation in legumes, flowering and development of seed and fruit all require adequate B, as do flower initiation and pollen development.

CUPPED CANOLA LEAVES WITH THICKENED MARGINS AND INTER-VEINAL NECROTIC SPOTS ARE LIKELY TO INDICATE A LACK OF BORON. REMEDIATION NEEDS TO BE APPROACHED WITH CARE BECAUSE THERE IS ONLY A NARROW RANGE BETWEEN B DEFICIENCY AND TOXICITY.

B deficiency can reduce yield and quality of crops.

There is a relatively narrow range between B deficiency and toxicity in plants. For example, B deficiency can occur in canola with soil B levels (Hot Water Soluble) of 0.15 to 0.5mg B/kg, with toxicity occurring at values greater than 3mg B/kg. B toxicity typically occurs in low rainfall regions (<400 mm) where high levels of B occur naturally at depth in sodic soils.

In an Australia-wide survey, soil tests revealed low B levels in about 6% of samples, with lower values on kurasols and tenosols and the highest values on ferrosols and calcarosols.

SYMPTOMS OF BORON DEFICIENCY IN LUCERNE, WHICH REQUIRES GOOD LEVELS OF THE NUTRIENT FOR RHIZOBIAL NODULE FORMATION, FLOWERING AND SEED DEVELOPMENT, INCLUDE YOUNGER LEAVES TURNING RED OR YELLOW, SHORT INTERNODES AND STEMS AND DEATH OF TERMINAL BUDS.

Boron in soils

Total B concentrations in agricultural soils range from 1 to 467mg B/kg. The available forms of B, $B(OH)_3$ (boric acid) and $B(OH)_4$ (borate) are usually mobile in the soil solution but can be adsorbed to common constituents of soil including hydroxides of iron and aluminium (Al), clay particles and organic matter. Because of this, there are several factors that influence B availability in the soil.

- **Organic matter**
  This is the most important source of B in the soil. In hot, dry weather the rate of organic matter decomposition slows down, especially near the soil surface. This can result in plants showing a transient B deficiency that disappears

when the rate of organic matter turnover increases. Organic matter decomposition also slows in cold weather, and brassica crops including canola and early-planted vegetables like cabbage and broccoli and can be affected by low B release during winter.

- **Weather conditions**
  B deficiency can be induced by periods of low transpiration caused by dry conditions or water logging that cause stomata to close or cold weather that restricts root activity and can cause transient B deficiency in the surface soil. Fog or high humidity can also reduce transpiration and so inhibit B uptake. B deficiency symptoms may disappear as soon as root growth resumes, but yield potential can be reduced because of the transient B shortage.
- **Soil pH**
  Plant availability of B is greatest between pH_{Ca} 5.0 and 7.5. B uptake is reduced at higher pH values, although many Australian alkaline soils have high initial B concentrations. Liming acid soils can lower B solubility due to sorption of B to Al hydroxides, but this is a temporary effect. Table 1 shows the effect of liming on B uptake by lucerne in a pot experiment. Liming to raise pH reduced B uptake but it was only the plants that had no B applied B that showed B deficiency. This suggests liming may increase the risk of B deficiency where soil B is low. The suppressive effect of the lime declined over subsequent harvests.
- **Soil texture**
  Coarse-textured sandy soils, which are composed largely of quartz, are typically low in minerals that contain B. Plants growing on such soils commonly show B deficiencies.
- **Leaching**
  Plant-available B is mobile in the soil and is subject to leaching. Leaching of B from the root-zone is of greater concern on sandy soils and/or in areas or times of high rainfall.

TABLE 1. THE B CONCENTRATION (MG/KG) IN LUCERNE IN A POT TRIAL IN RESPONSE TO BORON AND RAISING SOIL PH APPROXIMATELY SIX WEEKS AFTER TREATMENT. HWS B WAS 0.28MG/KG. INTERACTION LSD (P=0.05) = 9. (SHERRELL 1983).

pHCa	Nil	0.23 kg B/ha	0.46 kg B/ha	0.91 kg B/ha	1.82 kg B/ha
5.1	12	33	44	57	85
5.6	13	31	38	49	60
6.2	9	26	35	39	69

As and Bs of boron

- Boron (B) is an essential plant nutrient but is required in relatively small amounts.
- The availability of B to plants depends on the source, soil organic matter, soil pH, soil texture and weather conditions. B deficiencies and toxicities are reported in Australia.
- B deficiency is most common on the granite slopes of the Great Dividing Range. Light soils and wet seasons also increase the possibility of B deficiency.
- The demand for B varies according to species, with canola and lucerne the most susceptible to B deficiency.
- Soil-applied or foliar-applied B can address B deficiency.
- Diagnosis using tissue testing requires care, with results influenced by the tissue sampled, crop stage and environmental conditions when the samples are taken.
- While not of major importance in Australian cropping systems, there are situations in which B may need to be considered as part of a balanced nutrition program.

Fertilising

It is important that B fertiliser be evenly applied because of the narrow range between deficiency and toxicity. Diagnosing the need for B fertilisation needs to include consideration of the factors that influence soil B availability. Plant analysis and visual symptoms are often more useful diagnostic tools than soil testing.

Boron fertiliser can be broadcast or banded into soil or applied as a liquid foliar treatment. Broadcast application requires higher rates than banded or foliar applications. Soil application rates for the most responsive crops may be as high as 3kg B/ha, with rates of 0.5 to 1.0kg B/ha for medium-responsive crops (Table 2).

Placing in-furrow applications of B adjacent to seed can cause poor emergence.

Common forms of B fertiliser are shown in Table 2. Ulexite, a mix of less-soluble calcium and more-soluble sodium borates, is often used in forestry applications. Most borate salts can be supplied either as powders or granules depending on the application method to be used. Soluble fertiliser forms are usually preferred, except in sandy soils where newer, low-solubility B phosphates can be used to reduce leaching out of the root-zone.

Foliar B can be applied when a deficiency has been diagnosed by tissue test or visual symptoms. In rapidly growing crops one or more applications may be required. Application at flowering will give immediate responses. Split foliar applications of 0.5kg 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, which typically occurs at concentrations of 0.5% w/v.

Foliar applications have little residual activity.

Deficiency symptoms

B is mobile in the soil but its mobility within the plant varies with the species. Nutrient deficiencies tend to appear on the youngest leaves or growing points. In species such as apples and almonds, B is mobile and moves throughout the plant.

The following B deficiency symptoms occur in specific crops:

- **canola** - red-brown youngest leaf, shortened cracked stems with cupped leaves and thickened margins. Inter-veinal necrotic spots. Leaf dies from edges to vein.

TABLE 2. RESPONSIVENESS OF CROPS TO BORON

Most responsive	Medium response	Least responsive
Apple	Clovers	Bean
Brassica vegetables	Cotton	Pea
Canola	Maize	Sorghum
Celery	Lettuce	Soybean
Lucerne	Pear	Rice
Sunflower	Spinach	Winter cereals
Beet/turnips	Tomato	

TABLE 3. COMMON BORON FERTILISERS

Source	Formula	B %	Water solubility
Borax	$Na_2B_4O_7 \cdot 10H_2O$	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 pentaborate	$Na_2B_{10}O_{16} \cdot 10H_2O$	18	High
Sodium tetraborate	$Na_2B_4O_7 \cdot 5H_2O$	14-15	High
Sodium octaborate	$Na_2B_8O_{13} \cdot 4H_2O$	20-21	High
Boron phosphate	PBO_4	10	Moderate/very low*
Boron frits	Boric oxide glass	2-11	Very low

* SOLUBILITY DEPENDS ON CONDITIONS OF MANUFACTURE (ABAT ET AL. 2014).

- **corn** - narrow white to transparent lengthwise streaks on leaves. Some branches emerging dead. Multiple but small and abnormal ears with very short silk, small tassels and small, shrivelled anthers devoid of pollen.
- **lucerne** - short internodes and stems. Younger leaves turn red or yellow. Death of terminal bud.
- **cotton** - ringed or banded leaf petioles with dieback of terminal buds, causing rosetting effect at the top of the plant. Ruptured squares and thick, green leaves that stay green until frost and are difficult to defoliate.
- **apple** - small, flattened or misshaped fruit. Internal corking. Cracking and russetting. Dead terminal buds, brittle leaves, blossom blast.
- **peanut** - hollow heart.
- **almond** - new shoots do not develop. Brown and gummy nuts.
- **celery** - crooked stem.

Toxicity symptoms

Toxic accumulation of B occurs in many low-rainfall regions. Toxicity symptoms, which appear first on the edges and tips of older leaves, only develop later in the season as crop roots reach toxic levels of B in the sub-soil. In dryland conditions, avoidance is the only management option available to counter B toxicity. Where water is available, extra irrigations can move B out of the root zone.

Soil mapping can help identify where sub-soil B may impact crop performance, opening the way to zone paddocks and sow more B-tolerant crops on high-B soils or altering crop management in those areas (Angus et al. 2004).

Predicting B response

- **Soil tests** can generally give reasonable prediction of B deficiency when tests are calibrated for soil groups and crop species. Depth of sampling is important because B is mobile and while the topsoil maybe depleted, the lower soil layers may provide adequate B. Results from Hot Water Soluble and hot 0.01M $CaCl_2$ tests both correlate well with plant response. The likelihood of the crop accessing subsoil B needs to be considered when interpreting a topsoil test.
- **Tissue tests** are a reliable guide to plant B status, although as with soil tests, the results need to be interpreted in terms of soil moisture, root depth and anticipated future B supply. Critical whole-plant levels for canola range from 22mg/kg (seedling) to 15mg/kg (rosette). Critical values for cereals are around 4-5mg/kg. Because B is relatively immobile in plants, sampling youngest fully expanded leaves may provide a more robust diagnosis than whole-plant sampling.

Crop responses

Crop species vary significantly in their responsiveness to B (Table 4). Canola a high B requirement and B concentrations in canola seed are about 10 times those in cereals.

There is also considerable species variation in efficiency of B uptake (Stangoulis et al. 2000), tolerance to toxicity (Kaur et al. 2006) and sensitivity to excess B. Most legumes, and several fruits and vegetables, are highly responsive to B and susceptible to B toxicity. Other vegetables show somewhat less response. Grains and grasses are generally less responsive to B.

Crops with high B requirements do not always tolerate high levels of the nutrient. Lucerne and cabbage, for example, show only moderate tolerance to high B levels.

For more information: http://anz.ipni.net

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TABLE 4. EXAMPLES OF CROP YIELD RESPONSE TO APPLICATION OF BORON FERTILISER

Crop	Source	Rate	Time	Place	Yield response	Reference
Canola	Na borate	0.6kg B/ha	Stem elongation	Foliar	39%	Myers et al. 1983
Canola	Boric acid	2kg B/ha	Sprayed at sowing	Soil	4-52%	Stangoulis et al. 2000
Lucerne	Na octoborate	0.4-1.1kg B/ha	After first cut	Foliar	37%	Dordas, 2006
Seed Lucerne	Na tetraborate	3-4kg B/ha	Annual	Soil	46-62%	Haby et al. 1996
Soybean	Na octoborate	0.25-1.0kg B/ha	V2 or R2	Foliar	0-130%	Ross et al. 2006