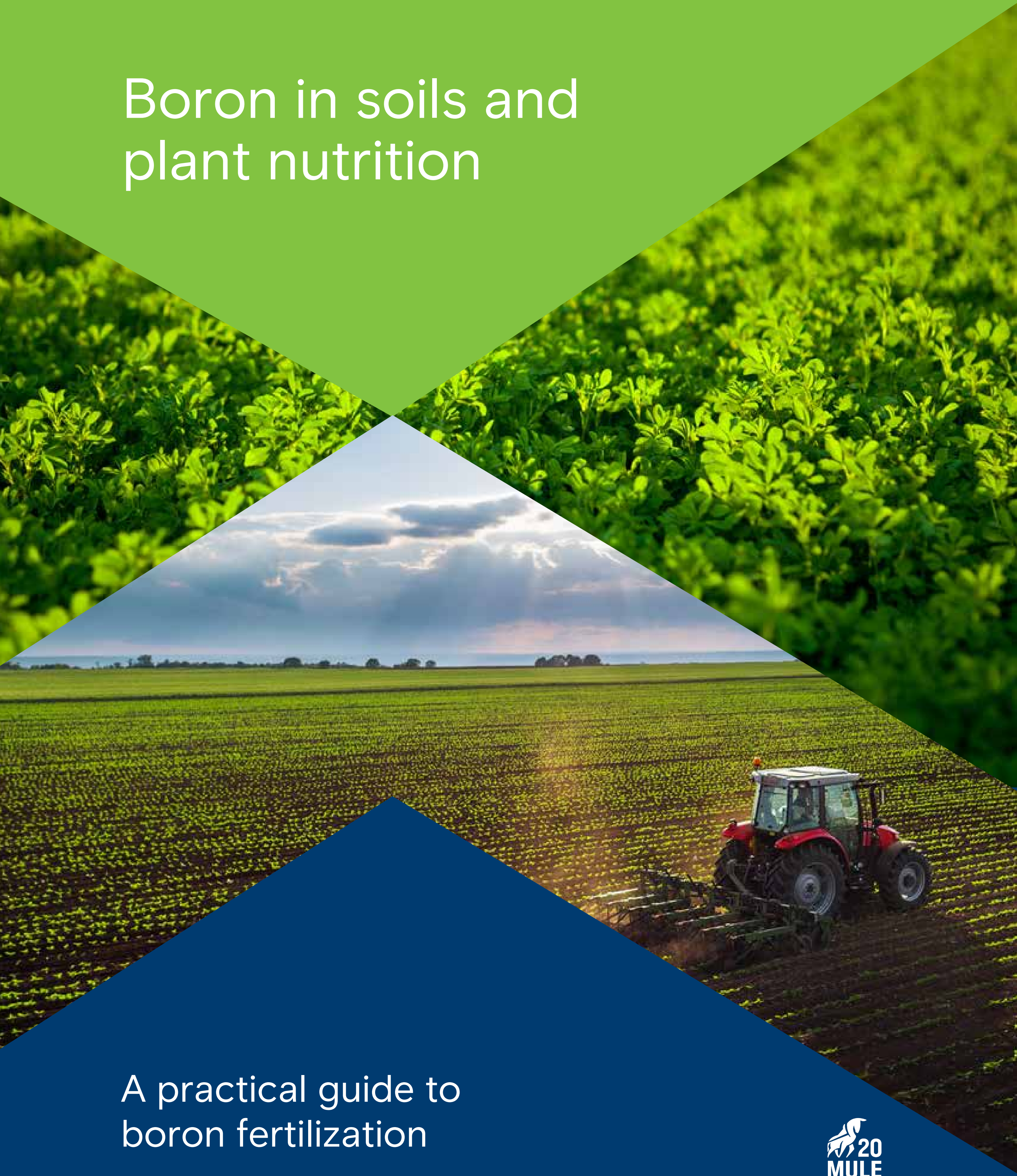
Boron in soils and plant nutrition



A practical guide to boron fertilization

20 MULE TEAM BORAX™

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About boron

Boron (B) is one of seven essential micronutrients—vital to fertilization, as well as fruit and seed production. Boron deficiency is the most widespread of all micronutrient deficiencies, affecting almost all major crops grown around the world.

About U.S. Borax

U.S. Borax, part of Rio Tinto, is a global leader in borate fertilization and science. The company has been at the forefront of crop micronutrient research since 1940, and offers quality products, backed by global technical expertise, supply reliability, and comprehensive customer service.

About our products

U.S. Borax mines and refines only top-quality boron to deliver the right amount of boron for every crop, soil, climate, and application method:

- *Anhybor*®: Depending on the grade, Anhybor can be used to produce boron-enriched compound fertilizers or to coat different fertilizer products, such as NPK blends with the aid of a binder.
- *Fertibor*®: A fine crystalline borate ideal for NPK compound fertilizers and suspensions
- *Granubor*®: Made especially for bulk blenders, *Granubor* helps to ensure uniform distribution in nutritional blends and in the field
- *Liquibor*®: The convenience of liquid boron fertilizer straight to your farm with no measuring or mixing required
- *Solubor*®: A concentrated, highly soluble, and fast dissolving powder that is ideal for foliar and other sprays
- *Solubor* Flow: The first and only aqueous suspension of sodium borate microcrystals
- *Zincubor*®: Because zinc and boron deficiency are widespread around the world, a product with both nutrients is a good fit in many regions

Introduction

The need for boron (B) as a plant nutrient in crop production was first demonstrated by Katherine Warington in 1923[84]. Since then, a vast amount of research has been reported on B in plant nutrition.

Soil plays a major role in determining the plant availability of B—through the effects of:

- pH
- Organic matter content
- Iron, aluminum oxides and clay mineral content
- Permeability
- Moisture retention

Knowledge of local soil types with respect to these factors is the first step in recognizing B needs. In addition, different plant species exhibit a wide range of need for B and may react differently to high or low levels of available B in soils.

Soils deficient in available B have been reported across the globe, generally in regions with more than 35" (89 cm) of annual rainfall. Additionally, low concentrations of boron are found in soils that:

- Have a low concentration of organic matter
- Are acidic and sandy
- Are in areas with high humidity

Within these regions, the most consistent responses to B fertilization have been observed on coarse-textured soils with low organic matter content, and on recently limed acidic soils over the whole range of soil textures.

Most of the economically important, agronomic fruit and vegetable crops have shown responses to applied B. Historically, the crops most responsive to B fertilization include alfalfa, clovers, cotton, mangolds, rapeseed (canola), sugar beets, sunflower, apple, asparagus, cabbage, cauliflower, celery, broccoli, Brussels sprouts, kale, pears, radish, red beets, spinach, and turnips. Least responsive are the grasses and cereal crops.

This publication will review the role of B in plant nutrition and the factors affecting the availability of B in soils. You will find practical solutions for diagnosing B deficiency and applying B fertilizers. Knowledge of plant B requirements and soil type, coupled with routine soil and plant chemical analysis, offer a means to assess B needs and apply B fertilizers for the best performance. Methods and suggested rates of applying B fertilizers are given for numerous agronomic, horticultural, and ornamental crops.

More information can be found on our website: https://agriculture.borax.com

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Boron in plant nutrition

Functions of boron in plant tissues

Boron (B) is required for all plant growth. Adequate B nutrition is critical for high crop yields and quality. Boron deficiencies result in many anatomical, biochemical, and physiological changes in plants.

Existing and ongoing research indicates that boron plays a significant role in the following:

Cell wall structure

Boron is involved along with calcium (Ca) in cell wall structure. B also is involved in the movement of Ca into the plant and in normal Ca nutrition in plants and animals. There is a similarity between bone development in animals and cell wall development in plants. For example, “hollow-heart” in peanuts can occur when a shortage of B limits Ca movement, normal cell wall development, and cell division.

Membrane function

Boron plays a fundamental role in plasma membrane integrity. Plants with adequate boron nutrition have good plasma membrane control, while B deficiency reduces plasma membrane permeability and water flow in plants.

Cell division

Boron is essential in the actively growing regions of plants, such as root tips and in new leaf and bud development. This involves the meristematic (growing) tissues in plants or the cells that are rapidly multiplying, allowing plant growth to occur.

A shortage of B is most often noted by a change in plant structure in these actively growing regions.

Boron ensures healthy plant storage and conductive tissues, necessary for transporting water, nutrients, and organic compounds to plants’ actively growing portions. Rosetting or stunting of plants—a common B-deficiency symptom—is due to a decrease in cell numbers in the apical (upper) growing regions of alfalfa, clovers, and other legumes, for example.

Plant hormone regulation

Plant hormones, like animal hormones, regulate many growth and reproduction functions. Flower initiation, fruit development, cell wall and tissue formation, and root elongation are all influenced by hormones. Boron plays an important role in regulating hormone levels in plants.

Flowering and fruiting

The B requirement is much higher for reproductive growth than for vegetative growth in most plant species. Boron increases flower production and retention, pollen tube elongation and germination, and seed and fruit development. A deficiency of B can cause incomplete pollination of corn or prevent maximum pod-set in soybeans, for example.

Boron has a significant effect in pollen germination and pollen tube growth. The viability of pollen grains also decreases when B is deficient. Yields of some species without visible B-deficiency symptoms may be increased by foliar application of B. Production of fruit, nut, and seed crops is adversely affected much more than vegetative growth when available B in soil is low. Boron deficiency increases bud and flower drop, resulting in significant reductions in seed and fruit set, and also in the quality of developing fruits, nuts, and seeds.

Susceptibility of various species to boron deficiency

Cereals and grasses are less sensitive than legumes and some vegetable crops to low levels of available B. Differences in B requirements among species may be related to differences in cell wall composition. The critical deficiency concentration of B is three to four times greater for younger than older leaves in dicots such as alfalfa and soybean—an indication of immobility of B in these species.

Plant species vary significantly in their susceptibility to B deficiency. Knowledge of these differences can be used to diagnose possible B deficiencies in various crops. The following table rates a number of crop species as susceptible, moderately susceptible, or tolerant.

Relative susceptibility of various crops to boron deficiency

Susceptible		Moderately susceptible		Tolerant
Alfalfa	Mangold	Banana	Flax	Barley
Apple	Oil palm	Brussels sprouts	Hops	Beans
Broccoli	Oil seed rape	Cabbage	Papaya	Grasses
Canola	Olive	Chinese cabbage	Pear	Oats
Carnation	Peanuts	Citrus	Poppy	Pea
Carrot	Pines	Clovers	Potato	Pineapple
Cauliflower	Red beet	Cocoa	Tea	Rice
Celery	Rutabaga	Coconut	Tobacco	Rubber
Chrysanthemum	Sugar beet	Corn	Tomato	Rye
Coffee	Sunflower			Soybeans
Cotton	Swede			Strawberry
Eucalyptus	Turnip			Sugar cane
Grapes				Wheat

Boron reactions in soil

Boron deficiencies in crops are found mainly in soils with low organic matter content and in acidic, sandy soils in humid regions. Reasons for this general condition are related mainly to the chemical reactions of the most common forms of B in soil—H_3BO_3 or $B(OH)_3$—with various soil components. The borate ion is very mobile; its mobility is considered second only to that of the nitrate ion in soils.

Reactions in soils that can affect boron's availability to plants vary significantly. The main soil factors affecting B availability are as follows:

Soil texture

Well drained, sandy soils in high rainfall or irrigated regions are most likely to be B deficient because of their greater leaching potential. These soils may need more frequent B fertilization. However, if subsoils are fine textured (higher clay content) below sandy surface horizons, less frequent B applications may be needed. Total B is usually highest in clay soils, but plant availability may be low in these soils because of the strength by which B is held onto the clay surfaces.

Soil pH and liming

Boron availability to plants generally decreases with increasing soil pH, especially above pH 6.5. However, strongly acid soils (soil pH less than 5.0) also tend to be low in available B due to B sorption to iron and aluminum oxide surfaces of soil minerals.

Some crops with a high demand for B—such as alfalfa—also require a soil pH above 6.5 for optimum growth. In this situation, liming may be necessary. However, overliming acid soils often results in temporary B deficiencies, especially when liming to pH levels above 7.0.

Soil organic matter

Most of the available B in soils is found in organic matter. Organic matter complexes with B to remove it from soil solution when levels are high after B fertilization. Soil organic matter must be decomposed to release complexed B, so conditions such as cool, wet weather or hot, dry weather—which decrease the rate of organic matter breakdown—will reduce available B in soils.

As soil organic matter decomposes, the soil solution is resupplied with B. This helps maintain adequate B levels when solution B is removed by crop uptake or leaching. Soils with low organic matter content have a reduced B-supplying capacity and will usually require more frequent B fertilization at lower application rates.

Soil microbial activity

Microorganisms break down soil organic matter, so plant-available B is released from organic complexes. Conditions favoring improved microbial activity are warm, moist soils with adequate aeration. Soil conditions which hinder optimum microbial activity are drought conditions, cold and wet soils, and poor soil tilth (poor aeration).

Soil tillage

Boron generally is more available to plant roots when the surface soil is tilled. Tillage allows soil mixing and improves aeration and drainage. These conditions are optimum for organic matter decomposition, which releases available B. As crop production systems shift to reduced tillage or no-till management, organic matter will accumulate on or near the soil surface and may not break down rapidly. Boron availability then will become more dependent on surface moisture conditions, and fertilizer management may become more crucial.

Drought conditions

During periods of drought, the topsoil dries out so plant roots are unable to feed in the uppermost soil layer where most of the available B occurs. Dry weather also limits the availability of B by restricting water flow, which transports available B in solution to plant roots.

Some subsoils may contain available B which may have leached from the surface soil horizon, especially after long term use of B fertilizers. During drought, plant roots may grow deeper into the subsoil and thus obtain sufficient available B for continued growth and development.

Summary

Boron deficiencies are found mainly in soils low in organic matter, as well as acidic, sandy soils—especially in humid regions where leaching can occur. An understanding of B reactions in soil will help predict where B deficiencies are most likely to occur.

Results of soil tests for available B will give the B status of soils in a particular field. Apply recommended rates if available B levels are low or marginal, especially for crops with a high B requirement, such as alfalfa.

Mobility of boron in plant tissues

Boron is required for new vegetative growth and reproductive development in plants. Therefore, B must remain available for plant uptake during the entire growth period unless it can be translocated in the plant from older to new tissues. Plant uptake of B is a passive (non-metabolic) process and B is transported in the xylem vessels (transpiration stream) of all plant species. Consequently, B is mobile in the xylem system of all plants.

It has been generally accepted that B is an immobile nutrient in the phloem tissue of plants. Once incorporated into a given tissue, such as leaves, B can't be remobilized to supply the needs of other plant tissues. However, results of research by Dr. PH Brown and associates of the University of California, Davis, have demonstrated that the phloem mobility of B varies significantly among plant species[9].

These results show that B is mobile in all plant species that use simple sugars (known as polyols) as primary compounds in photosynthetic processes. Boron forms a complex with these polyols and is transported in the phloem tissues to active growing regions in the plant.

However, in plant species that don't produce significant quantities of polyols, B cannot re-enter the phloem stream after it has been delivered to leaf tissues in the transpiration stream (xylem tissue). This B tends to accumulate in the leaves. Boron is immobile in these species.

Evidence of phloem mobility or immobility can also be found by studying the distribution of B within different tissues of a given species. For example, under field conditions, pistachio and walnut contain the highest B concentrations in their leaves and the lowest B concentrations in fruit and seed. This indicates that the B from these leaves doesn't translocate to the fruit and seed of these species. In contrast, almond and apple trees have the highest B concentrations in their hulls and fruit, respectively, with much lower B in their leaves.

The concentrations of B in leaves of different ages on the same plant also provides evidence of B mobility. Higher B concentrations in basal (older) leaves compared to apical (younger) leaves indicates B immobility. In contrast, higher B concentrations in younger leaves indicates B mobility, since younger leaves have transpired less water than older leaves.

Table 1 summarizes the current knowledge of grouping agronomic, vegetable, and horticultural crops as B-mobile or B-immobile. Most agronomic crops and some vegetables are B-immobile species. However, relatively more species of fruit and nut crops are B-mobile. Clearly, there is a need to study all economically important plant species with respect to B mobility. Such knowledge will improve growers' ability to diagnose B deficiencies and use the most effective method to apply B fertilizers for optimum crop yields.

Diagnosis of B deficiencies based on B mobility or immobility in plants

Knowledge of B mobility or immobility in various plant species is important in interpreting plant analysis results. Boron accumulates in the older leaves of B-immobile species. Therefore, do not sample recently matured or fully expanded leaves to diagnose deficiency in these species. The reason is that these leaves may not reflect the B status of the growing tissues, for which a constant B supply is critical. Diagnosis of B deficiency in B-immobile species can only be done by sampling growing tissues.

In contrast, sampling mature leaves of B-mobile species to diagnose for B deficiency is appropriate. The B content of mature leaves reflects the B status of the entire plant, including the young, actively growing tissues. In these species, a decrease in B uptake will not affect the growing tissues until the soluble-B pool of the mature tissues has been depleted by translocation to the younger tissues.

Correction of B deficiencies based on B mobility or immobility in plants

In B-immobile species, foliar-applied B won't be translocated from the site of application. This B cannot supply the requirements of tissues not yet formed.

Therefore, B must be applied directly to developing tissues, such as flower buds and flowers, to ensure an adequate supply during their development.

In contrast, foliar sprays of *Solubor* can be applied to B-mobile plants at any time functional leaves are present. The applied B can correct current deficiencies and also supply B to developing flowers and fruit tissues. Benefits of foliar B applications to fruit set have been observed in B-mobile tree species such as almond.

Table 1

Boron mobility or immobility in some agronomic and horticultural crops

B – immobile	B – mobile
Agronomic crops	**Agronomic crops**
Alfalfa	Canola (limited)
Corn	
Cotton	
Peanuts	
Sorghum	
Tobacco	
Wheat	
Vegetables	**Vegetables**
Bean	Asparagus
Lettuce	Beans
Potato	Broccoli
Tomato	Carrot
	Cauliflower
	Celery
	Onion
	Pea
	Radish
	Rutabaga
Tree and vine crops	**Tree and vine crops**
Figs	Almond
Pecans	Apple
Pistachio	Apricot
Strawberry	Cherry
Walnut	Coffee
	Grape
	Loquat
	Nectarine
	Olive
	Peach
	Pear
	Plum
	Pomegranate

Diagnosis of boron deficiency

Visible B deficiency symptoms

B symptoms become clearly visible when the deficiency is acute. At this point, growth and yield may be severely limited. For crops not listed, general B deficiency symptoms include:

Basic characteristics of deficiency

- Youngest leaves are the first affected. They are misshapen, thick, brittle, and small, but seldom exhibit any chlorosis—in fact, they are often very dark green.
- Stems are short, severely affected plants are liable to have a “shrunken” appearance
- Growing points become moribund and die
- Axillary meristems develop which will also show symptoms. Plant becomes bush shaped
- Necrotic and watery patches develop in storage tissue
- Cracks and splits occur in petioles, stems, and sometimes fruit
- Fruit formation is irregular as a result of incomplete fertilization. Fruit is likely misshapen
- Leaves tend to have a more simple shape. Root growth is impaired

Always confirm diagnoses from visible symptoms with results of soil tests and plant tissue analyses.

Short, bent cobs, poor kernel development and barren ears are signs of boron deficiency in corn.

Visible B deficiency symptoms in crops

Field crops	Visible symptoms
Alfalfa	Death of terminal bud, rosetting, yellow top, little flowering, and poor pod set.
Canola	Leaves distorted. Blank or partially filled seed heads.
Clover	Poor stands, growth, and color. Reduced flowering and seed set. Leaves cupped, shriveled, and become brittle.
Corn (field and sweet)	Short, bent cobs, barren ears, blank stalks, poor kernel development, elongated, watery or transparent stripes later becoming white on newly formed leaves, dead growing points.
Cotton	Shedding of squares and young bolls, ruptures at base of squares, dark fluid exuding from ruptures, internal discoloration at base of boll, half-opened bolls, green leaves until frost.
Dry bean	Interveinal chlorosis of leaves. Bushy appearance.
Peanut	Dark, hollow area in center of nut, called “hollow heart.”
Potatoes	Plants have a bushy appearance. Leaves thicken and margins curl upward.
Sorghum	Leaves are narrow and have a gray appearance with watery, transparent stripes. Seed heads are not filled.
Soybean	Yellow leaves, chlorotic between veins, downward curling of leaf tips, crinkling of leaves, dieback of tips, no flowering, roots stunted.
Sugar beet	Yellowing or drying of leaves, cracking of leaf midrib, brown discoloration of internal tissue, rotting of crown.
Sunflower	Leaves appear wilted. Abnormal head fall due to weak peduncles.
Tobacco	Leaf puckering and deformed buds.
Wheat	Distorted heads and chlorosis of leaves.
Fruit and nut crops	
Almond	Flowers fall and nuts abort or are gummy.
Apple	Pitting, skin discolored, cracking, and corking.
Apricot	Twigs die back and fruit fails to set.
Citrus	Thickened ring, gum pockets near axis, discolored patches.
Grape	“Hen and chick” symptom, dead main shoots.
Pear	Blossom blast, pitting, internal corking, and bark cankers.
Pistachio	Fruit set decreases, and blanks and non-split nuts increase.
Strawberry	Pale chlorotic skin of fruit, cracking, and dieback.
Walnut	Dieback from shoot tips, leaf fall.

Visible B deficiency symptoms in crops (continued)

Vegetable crops	Visible symptoms
Beet (red)	External spotting, cracking, and canker.
Broccoli	Hollow stems, internal discoloration, brown curds.
Cabbage	Hollow stem, watery areas, heads hollow, plants stunted.
Carrot	Reddening of leaves and root splitting.
Cauliflower	Leaves curled, hollow stem, curds dwarfed, brown.
Celery	Stem cracked and striped brown, heart blackened.
Lettuce	Stunted growth, discoloration of leaves, brittle.
Radish	Pale roots, brittle stems, watery flesh, and flecked coloration.
Rutabaga	Roots are tough, fibrous, and bitter. Upon cutting, they have soft, watery areas, often called “brown-heart.”
Sweet corn	Short, bent cobs, barren ears, blank stalks, poor kernel development, elongated, watery or transparent stripes later becoming white on newly formed leaves, dead growing points.
Tomato	Thickened leaves, brittle leaves, fruit fails to set.
Turnip	Hollow center or brown heart, watery areas.

Boron soil test results can show:

- Where available B is deficient
- Where B maintenance fertilization is needed
- Where available B is adequate

Hot-water extraction has been the standard soil test for available B in soils. However, many laboratories now report soil test B using the Mehlich-1 or Mehlich-3 extraction methods, which correlate well with results of the hot-water extraction method in acid soils[77]. In alkaline soils, B in extracts of soil test extractants which contain sorbitol or mannitol correlate well with hot-water soluble B[83].

Plant tissue analysis provides an excellent check on the actual crop availability of B from the soil and applied B fertilizer. You can use tissue analyses as an additional guide along with the B soil test level for adjusting B fertilization practices.

Plant B analyses can be used for:

- Confirming B deficiency in plants with visual symptoms
- Monitoring B tissue concentrations to ensure that B is in the optimum range for high crop yields and quality
- Complementing soil test information to adjust B fertilization rate, timing, and placement to meet the needs of the specific cropping situation

For example, tissue samples taken early in the growing season may signal the need for topdressing, sidedressing or foliar spraying of B along with nitrogen or other fertilizers applied later in the growing season, preferably before flowering and fruiting.

To achieve optimal B fertilization management, follow these guidelines:

- Use soil tests for available B
- Control soil pH within the optimum range for soils and crops in your area
- Use maintenance B fertilization where B soil test levels are in the response range for your soils and crops
- Observe the crop early and often
- Analyze plant samples for B early in the season
- Use proper B fertilizer placement, rate, and timing
- Where a strong need for B exists, consider banding at planting, sidedress applications, foliar sprays or fertigation

Soil test interpretation

Interpreting soil test values varies depending on the crop and the soil type. For example, critical soil test values for crops have ranged from 0.05 ppm for peanuts grown on acid, coarse-textured soils[18] to 1.8 ppm for rutabaga grown on similarly textured soils[36].

Critical soil test B levels also vary by soil type. For example, alfalfa needed 0.3 ppm B on sandy soils[81] and 0.9 ppm B on finer-textured soils[3]. Soybeans responded to B fertilization on a Cecil sandy clay loam[89] and a Sassafras sandy loam at a soil test level of 0.2 ppm[24], but they also responded to B at soil test levels of 0.8 ppm and 1.3 ppm B on Kokomo and Muscatine silty clay loam soils, respectively[6]. Corn responded to B where the soil test B was 0.02 ppm on a Dothan loamy sand[90], and where soil test B was 0.2 ppm on a Sassafras sandy loam[24]. A critical soil test B level for cotton was 0.19 ppm B on sandy soils[76], but a B response was reported on a Collins silt loam soil[41] with a soil test B level of 0.35 ppm (Personal communication, DD Howard, Univ Tenn).

A survey of 50 state agricultural soil testing laboratories in the USA[57] revealed that B soil test breakpoints used for determining low levels of hot-water soluble B varied from 0.05 to 1.1 ppm, depending upon the soil type and the crop used for calibration. The average of these values by 25 of these laboratories was 0.49 ppm B. With few exceptions, such as soils high in clay and/or organic matter, soils with hot-water soluble B exceeding 1.0 ppm supply sufficient B for most crops.

Based on soil test data, soil texture, and crop requirement, ranges of soil test B can be delineated according to crop requirement (see table 2).

Boron should normally be applied according to local experience and recommendations published for various crops.

Use boron soil tests to monitor B soil fertility levels. Your objective should be to:

- Add B where suggested
- Maintain soils in the desired range above deficiency for various crops
- Omit B where soil test results reveal high levels (soil test levels above 5 ppm are likely toxic for most crops[67])

Sample soils at least once during each crop rotation sequence. More intensive monitoring of soil B level is needed where high rates of fertilizers are applied, especially on low cation exchange capacity (CEC) soils subject to leaching. Under conditions of intensive management, it's advisable to sample annually to detect changes in soil pH 86 and other nutrient levels which may influence B nutrition. For example, a high pH level on freshly limed soils, or very high available K levels can accentuate the need for B[47,48].

Recommended B applications range from 0.1 to 4.0 lbs/acre and are based on specific crop, soil texture, method of application, and yield goals, as well as B soil test values.

Plant analyses interpretation

Boron uptake by plants is strongly affected by soil conditions and other environmental factors, especially soil pH and CEC. The dominant factor affecting the relationship between soil test B and plant B is CEC[15], which is directly related to the amount of clay and organic matter in the soil. Soil B is more available to plants on low-CEC soils (coarse-textured sandy soils) and less available on high-CEC soils (fine-textured clay soils), even though clay soils (containing >25% clay) normally contain relatively more available B than the coarser-textured soils in a given region[86]. Because much of the B is inactivated in fine-textured soils, higher rates of B fertilizer are required in order to achieve the same availability of B as in coarse-textured soils. In any given soil, soil test B is positively related with plant tissue B[78].

Table 2 Crops have been classified according to their B requirement as follows:

Soil texture	Range of soil test B	B fertilizer requirement
Sand and loamy sand	< 0.2 ppm	All crops
Sandy loam, loam, silt loam, and silt	0.2 – 0.5 ppm	Medium and high B-requiring crops
Clay	0.5 – 1.0 ppm	Medium and high B-requiring crops
Clay	1.0 – 2.0 ppm	High B-requiring crops
All soils	> 2.0 ppm	None

Recommended rates of applied B			
Crop	**Method**	**Rate of applied B (lb/ac)**	**Rate of applied B (lb/ac)**
Alfalfa	Topdress	1.0 – 4.0	30 – 50
Canola	Broadcast	1.0 – 2.0	25 – 50
Clover-grass	Topdress	1.0 – 1.5	20 – 45
Corn	Sidedress	1.0 – 2.0	10 – 25
Cotton	Foliar	0.3 – 0.6	30 – 80
Hybrid bermuda	Topdress	0.5 – 1.0	5 – 15
Nut crops	Broadcast	0.5 – 3.0	30 – 50*
Peanuts	Foliar	0.25 – 0.5	25 – 60
Small fruits	Foliar	0.1 – 0.5	20 – 35*
Small grains	Broadcast	< 0.2	3 – 20
Soybeans	Broadcast	0.25 – 0.5	25 – 60
Sugar beets	Foliar	1.0 – 3.0	30 – 50
Tobacco	Broadcast	0.5 – 1.0	20 – 100
Tree fruits	Broadcast	0.1 – 1.5	30 – 60*
		0.5 – 3.0	
Vegetables	Broadcast	0.5 – 3.0	25 – 60*

**Ranges will vary for specific crops.*

Plant B concentration where B-deficiency symptoms first appear (the critical level).

Range of plant B concentrations during normal growth in soil adequately supplied with available B (the sufficiency range).

Range of soil-test B level within which the plant grows normally (high, medium, and low B-requiring plants).

Relative tolerance of different plant species to various nutrient solution B concentrations (sensitivity ratings).**

Based on published data for normal ranges of B in plant tissues[7,13] and commonly recommended rates of applied B.[54,55,60] The table on the following page offers a useful guide for making B recommendations on selected crops.*

*A CLASSIFICATION OF PLANT SPECIES INTO CATEGORIES OF HIGH, MEDIUM, AND LOW B REQUIREMENTS WAS SHOWN BY BERGER[5]. A SIMILAR GROUPING IS PRESENTED IN THIS PUBLICATION. ANOTHER CLASSIFICATION OF PLANT SPECIES INTO B-SENSITIVE, B SEMI-TOLERANT, AND B-TOLERANT CATEGORIES WAS REPORTED BY EATON[23].

*** RESEARCH HAS ESTABLISHED STANDARD OR OPTIMAL RANGES OF B CONCENTRATIONS FOR MANY CROP PLANT SPECIES, AS WELL AS DEFICIENT AND EXCESS RANGES OF B.[5,7,13,23,34,47,48,50,87]

***CURRENT B TOLERANCE STANDARDS FOR MOST MAJOR AGRICULTURAL CROPS ARE BASED ON STUDIES CONDUCTED BY EATON FROM 1930 - 1934[23]. THESE DATA, THOUGH WIDELY USED AND PERPETUATED, WERE OBTAINED FROM A SMALL PLANT POPULATION AND NO TREATMENT REPLICATION. IN ADDITION, HIS CLASSIFICATION FOR MANY CROPS WAS BASED ON THE OCCURRENCE OF LEAF INJURY AND NOT ON THE YIELD OF MARKETABLE PRODUCT. RECENT STUDIES HAVE SHOWN THAT WHEN THE PRODUCT IS HARVESTED FOR ANYTHING OTHER THAN THE LEAVES, THIS CLASSIFICATION IS NOT A RELIABLE INDICATOR OF B TOLERANCE. FRANCOIS, LE. 1988. "Yield and quality responses of celery and crisphead lettuce to excess boron." J AMER SOC HORT SCI. 113 (4): 538-542.

Leaf boron content delineating the B status of various crops

Leaf boron content, ppm B					
Beverage crops	**Deficient**	**Low**	**Normal**	**High**	**Excess**
Cocoa	<10	10 – 25	25 – 70		
Coffee	<20	20 – 40	40 – 140	140 – 200	
Hops	<20		25 – 60		
Tea	<12		12 – 80	>80	
Cereals and sugar cane					
Barley	<5		5 – 20		
Corn	<5		5 – 25	25 – 50	>50
Oats	<5		5 – 20		
Rice	<5		25 – 30	>40	
Sorghum	<5		16 – 140		
Sugar cane	<1	2 – 4	4 – 20		400
Wheat	<5		5 – 20	30	
Fiber crops					
Cotton	<16	16 – 20	21 – 80	80 – 200	>200
Sisal	<4	4 – 14	14 – 20		
Flowers					
Carnation	<20		20 – 25		
Chrysanthemum				>150	
Geranium	<15	15 – 30	30 – 300		>300
Rose			20 – 60		
Forage crops					
Alfalfa, Lucerne	<20	20 – 30	30 – 80	>80	
Red clover	<10		20 – 45	>60	
Trefoil	<10		30 – 45	>70	
Fruit and nut crops					
Almond	<30		30 – 50	>80	
Apple	<20	20 – 28	28 – 50	>50	
Apricot	<12		20 – 70		>90
Avocado	<12		50 – 100	100 – 250	>250
Banana			20 – 40	>70	
Cherry	<20		20 – 100		>182
Citrus	<15	15 – 30	30 – 100	100 – 250	>250
Fig	<15		50 – 100	300	>700
Grapes	<25		25 – 50	50	>200
Papaya	<20		20 – 60		
Peach	<10	10 – 30	30 – 60	60 – 80	>100
Pear	<20	20 – 30	30 – 50		>50
Plantain	<16		20 – 40		
Raspberry	<10	10 – 20	20 – 35		
Strawberry	<20		20 – 50	100	>125
Walnut	<25		40 – 200		

Leaf boron content delineating the B status of various crops

	Leaf boron content, ppm B				
Fruit and nut crops	**Deficient**	**Low**	**Normal**	**High**	**Excess**
Almond	<30		30 – 50	>80	
Apple	<20	20 – 28	28 – 50	>50	
Apricot	<12		20 – 70		>90
Avocado	<12		50 – 100	100 – 250	>250
Banana			20 – 40	>70	
Cherry	<20		20 – 100		>182
Citrus	<15	15 – 30	30 – 100	100 – 250	>250
Fig	<15		50 – 100	300	>700
Grapes	<25		25 – 50	50	>200
Papaya	<20		20 – 60		
Peach	<10	10 – 30	30 – 60	60 – 80	>100
Pear	<20	20 – 30	30 – 50		>50
Plantain	<16		20 – 40		
Raspberry	<10	10 – 20	20 – 35		
Strawberry	<20		20 – 50	100	>125
Walnut	<25		40 - 200		
Fumitory and masticatory crops					
Kola	<15				
Tobacco	<10	10 – 40	40 – 100	100	>360
Oil crops					
Canola (rape seed oil)	<20	20 – 30			
Coconut	<12				
Oil palm	<12	12 – 15	15 – 25		
Olive	<15	15 – 20	20 – 180		>250
Peanuts	<25				
Soybeans	<10	10 – 20	20 – 80	80 – 100	>100
Sunflower	<35		50 – 150		
Root and tuber crops					
Carrot	<18		32 – 200	>200	
Mangolds	<20		20 – 50		
Potato	<5	20 – 40	40 – 70	>70	
Red beet	<15	15 – 27	27 – 83		
Sugar beet	<20	20 – 25	25 – 50	50	>300
Sweet potato	<16		118		
Turnip, Swede	<15		45 – 50		
Rutabaga	<23	23 – 38	38 – 140		>250

Leaf boron content delineating the B status of various crops

	Leaf boron content, ppm B				
Trees	**Deficient**	**Low**	**Normal**	**High**	**Excess**
Birch	<14		28 – 33		
Eastern cottonwood	<9		68		
Eucalyptus	<35		40 – 70		
Holly	<20	20 – 25	>30		
Pinus radiate	<10			>20	
Rubber				>80	
Scots pine	<10		25 – 30		
Spruce	<8		25 – 30		
Vegetables					
Artichoke	38		112		
Asparagus	<15	50	55 – 150		>175
Bean (*phaseolus*)	<10				>150
Brussels sprouts	<19		70		
Cabbage	<18		22 – 38	>100	
Cauliflower	<23		36		
Celery	<15		15 – 48		>400
Cucumber	<25		30 – 60		>200
Lettuce			27 – 43	>70	
Okra				>70	
Onion			29 – 50		
Pea	<18		170		
Radish	<19		19 – 195		
Tomato	<10		30 – 100		>200

Much of the data has been taken from Diagnostic Criteria for Plants and Soils, *ed. HD Chapman.*

Methods of boron application

The most common methods of applying B are broadcast and/or band application to the soil—generally with other fertilizers—or as foliar sprays.

As with other micronutrients, B application rates are so low (usually <2 lbs/acre) that it's difficult to apply B sources to soil separately without possible over-application in some areas and none in others. For example, *Granubor* contains 15% B so it's difficult to uniformly hand apply this B source alone to soil at the recommended rates. Including B sources with other fertilizers also decreases application costs through combined nutrient applications.

Apply boron sources as follows:

- Mixed fertilizers by incorporating them during the manufacturing process
- Bulk blended with granular fertilizers
- Mixed with fluid fertilizers just before application

While some micronutrients are also applied as a seed treatment, this method is not recommended with B sources because seedlings of many plant species have a low plant tolerance for soluble B.

Incorporation during manufacture

Boron sources can be uniformly distributed through NPK fertilizers by incorporating them during the manufacturing process. This generally is done by dissolving or suspending the B source in the phosphoric acid before ammoniation of phosphates, or mixing the B source with a solid component of the final NP or NPK mixture before granulation[56]. These products usually are called "boronated fertilizers."

Most B sources do not react chemically with other fertilizer components during manufacture, which could affect the plant availability of B. Therefore, incorporating B during the manufacture of mixed fertilizers is a viable method of B application[55].

Another way to incorporate B during fertilizer manufacturing is by coating NPK fertilizer blends with B. This process provides a uniform coating of micronutrients on all NPK fertilizer granules, providing flexibility in the micronutrient rate and ensuring uniform distribution in the field.

Bulk blending

The primary advantage of bulk blends is flexibility. Growers can prepare only the needed amount of fertilizers containing the required ratios of nutrients for a given field. However, non-uniform application in the field can result if segregation of nutrients occurs during handling and application. Minimize segregation by properly matching the particle sizes of the granular B sources with those of the NPK components. Mechanical devices to minimize segregation are available[1].

Granular B sources, such a *Granubor*, can be bulk blended with NPK fertilizers to provide the recommended B rates for a given crop. *Granubor* is especially suited for bulk blending—its particle size range and density closely match those of most NPK blend components.

Mixing with fluid fertilizers

This method of B application is popular due to the convenience of mixing the desired amounts of B with fluid fertilizers just before application in the field. There are no segregation problems with fluids, so uniformity of application is easily achieved.

Solubility of B sources is important in this method of application; slowly soluble or insoluble sources will not mix well with some fluids. Soluble B sources such as *Solubor* are well suited for mixing into fluid fertilizers such as 10-34-0 and UAN solutions.

Sufficient B can be dissolved in these fertilizers to meet all B recommendations at the usual nitrogen and/or phosphate application rates.

Foliar spray applications

Foliar sprays are especially suitable for applying B to tree and nut crops, and to specialty crops such as vegetables. Spray application requires water-soluble B sources such as *Solubor*.

Advantages include:

- Easily achieved uniform B application
- Almost immediate response to the applied B
- Rates of B application are usually lower than for soil application[57]

Suspected B deficiencies may be diagnosed with foliar sprays. However, incipient B deficiencies such as those affecting the reproductive systems of some plant species may not be diagnosed for a longer period of time.

Some disadvantages of foliar sprays are:

- Leaf burn may result if the salt concentrations of the spray are too high
- Nutrient demand often is high when crop plants are small and leaf surface insufficient for foliar absorption
- It may be too late in the growing season to obtain maximum yields if spraying is delayed until B deficiency symptoms appear
- There are little residual effects from foliar sprays[56]

Solubor is well suited for inclusion in foliar sprays. They are compatible with most pesticide sprays so they may be combined to supply the needed B with pesticide applications during the growing season.

Inclusion of spreader-sticker agents increases the efficiency of B uptake from foliar sprays.

Before preparing a tank mix, test the compatibility of either of these B sources with a given pesticide spray solution using the “jar test” method.

Other methods

Soluble B sources also can be included in irrigation systems (both field and drip systems). This method is called fertigation and requires careful volume measurements and system calibration to ensure that the correct amounts of fertilizer sources—including B—are placed in the nurse tanks to provide the desired rates.

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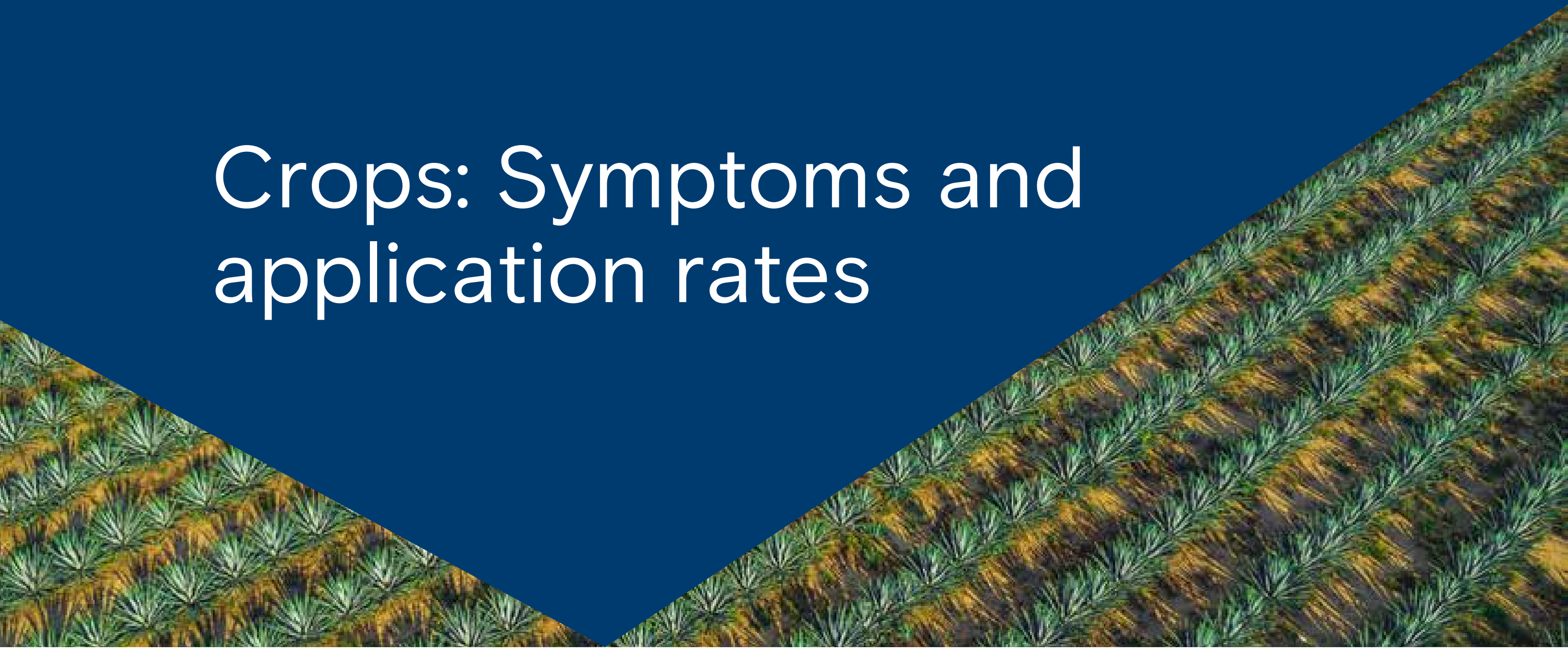
Crops: Symptoms and application rates



Beverage crops

Agave

(Agave tequilana)
The first signs of B deficiency are yellow spots, most numerous near the tip, on both surfaces of the leaf. These are followed by the formation in the epidermis of ramifying fingerlike depressions from the leaf margin, which may later become suberized. In sand culture experiments, symptoms have included hooked leaf tip and leaf spine that is absent or reduced to a white hair. In cases of severe deficiency, the growing point becomes disorganized and the leaves are short, narrow, twisted, and sometimes split. The plants have a flat-topped appearance.

Cocoa

(Theobroma cacao)

One of the first signs of B deficiency is profuse chupon formation and the appearance of a few curled leaves which are almost a normal green in color. When the deficiency is mild, normal, and B deficient flushes may alternate.
As the deficiency progresses, leaves on the new shoots become very chlorotic and are distorted and twisted. Most of the leaves which are formed under conditions of acute B deficiency fall before they harden. The leaves which mature become brittle and rough—they remain green but the formation of necrotic patches at the leaf tips is common and is the most typical symptom. Suberization of the veins also occurs.

Coffee

(Coffea arabica and C. canephora)

Boron deficiency causes the death of the terminal growing point. The later development of secondary branches (sometimes as many as seven at the same node) below the dead terminal bud gives the typical fan-like effect. In severe cases, the secondary branches quickly die resulting in dieback of terminal sections of the new shoots.

Defoliation can occur. The underside of the midrib of both chlorotic and otherwise healthy older leaves may become suberized. Production will be seriously reduced because of poor fruit formation.

Terminal dieback and the development of crinkled leaves towards the end of a dry period and at the start of the rainy season (due to reduced B absorption from the dry upper soil layers) are often the first signs that coffee is suffering from B deficiency.

Symptoms are also particularly noticeable at flowering and after liming due to the reduced availability of soil boron. Boron is mainly used on coffee to prevent the occurrence of the transient deficiency symptoms rather than to correct severe deficiencies which result in considerable branch dieback.

Hops

(Humulus lupulus)

The growing points turn brown and may die when they are only a few inches long. The root stocks produce many shoots with short internodes many of which will die, giving the plant a stunted, bushy appearance. Axillary buds on the shoots which survive may also become necrotic and die although some of the stunted lateral shoot eventually develop.

Leaves produced on such shoots tend to be small, distorted, and double-toothed rather than lobed. Stipules develop normally at first but quickly become necrotic from the tip downward as they age. Many inflorescences turn brown and die. The cones that form are small, loose, and have a scorched appearance which starts at the tip and progresses to the base. The yield is severely reduced. Root systems of deficient plants develop poorly.

Tea

(Camellia sinensis)

The first sign of B deficiency is the restriction in growth of the terminal bud which becomes dormant. The leaves become dark green, thick and leathery; and they are frequently misshapen and crinkled. The growing point ultimately dies and, as a result of the loss of apical dominance, many axillary buds try to grow but these also die back if B is in short supply. Clusters of small shoots fill the upper axils after a succession of abortive attempts at shooting. Translucent oil spots on the lower surface of mature leaves have also been reported but such spots don't persist.

As the deficiency progresses, excess cork develops—first on the upper side of the petiole, but later extending to the main and lateral veins outlining them with a corky streak on both upper and lower surfaces. The veins crack as the cork develops. Corky streaks may develop on the stem rather like elongated lenticels.

Soil application (suggested rates of application)

	Granubor (15% B) *Fertibor* (15% B)	*Solubor* (20.5% B)	
Crop	**lbs/acre**	**lbs/acre**	**gals/acre**
Cocoa	18 - 36	13 - 25	30 - 60
Hops	9 - 18	6 - 13	15 - 30
Tea	5 - 9	4 - 6	9 - 15
	oz/bush	**oz/bush**	**fl oz/bush**
Coffee	0.5 - 1.1	0.4 - 0.7	13

Foliar application (suggested rates of application)

	Solubor (20.5% B)	Minimum volume	Maximum concentration
Crop	**lbs/acre**	**gals/acre**	**% w/v**
Cocoa		0.25	
Tea	2	86 - 214	0.25
		oz/bush	**% w/v**
Coffee		0.3	

Shade trees for tea

Dadap

(Erythrina variegata)
The youngest leaves are the first affected—the pinnae are small and many segments don't develop, resulting in the formation of a very simple leaf. As the deficiency progresses, the growing points die back followed by the development of many shoots from the main trunk.

Bark cracking and gum exudation occur when the deficiency is very advanced. Necrosis of the cambium has been reported.

Silver oak

(Grevillea robusta)
Boron deficiency causes dieback and multiple side shoot development. The leaves are blunt, in marked contrast to healthy pointed leaves.

Cereals and sugarcane

Corn

(Zea mays)

Irregular distribution of kernels and a general reduction in growth are the first signs of B deficiency. Severe B deficiency results in short bent cobs of corn with under-developed tips and very poor kernel development. Yellow or white spots develop between the veins on young leaves, and the spots often coalesce forming streaks. These streaks—which may be waxy and raised from the leaf surface—don't normally develop on fully grown leaves. The leaf tips may be curled. There is also a shortening of the internodes and often the young leaves fail to open. There are indications that high-lysine corn is more susceptible than normal corn to B deficiency.

Soil application (suggested rates of application)

	Granubor **(15% B)** ***Fertibor*** **(15% B)**	***Solubor*** **(20.5% B)**	
Crop	**lbs/acre**	**lbs/acre**	**gals/acre**
Corn: Band	3 - 6		30 - 60
Corn: Broadcast	4 - 9	3 - 6	6 - 15
Rice	3- 6	2 - 4	4 - 11
Sugarcane	4- 13	3 - 9	6 - 21
Wheat	4 - 13	3 - 9	6 - 21
Cereals, general	3 - 13	2 - 9	4 - 21

Foliar application (suggested rates of application)

	Solubor **(20.5% B)**	**Minimum volume**	**Maximum concentration**
Crop	**lbs/acre**	**gals/acre**	**% w/v**
Corn	2 - 4	43 - 107	0.5
Rice	2 - 4	43 - 107	0.5
Sugarcane	3 - 9	64 - 214	0.5
Wheat	3 - 9	64 - 214	0.5
Cereals, general	2 - 9	43 - 214	0.5

Rice

(Oryza sativa)

The first symptoms are seen on the youngest leaves which don't elongate properly but remain short and narrow. A faint white/yellow chlorosis may possibly develop near the leaf tip. The next emerging leaves are folded, bent, and almost white. If such leaves open up, a large part of the blade will quickly dry up. When the deficiency is severe, growth stops completely.

The older leaves initially remain dark green but later many white chlorotic spots are likely to develop on both young and old leaves. New tillers may develop but these quickly show the same symptoms and remain stunted. Complete failure to set seed has been observed under severe B deficiency. Roots of severely affected plants are stubby, tough, and light brown in color.

Sorghum

(Sorghum vulgare)

Boron deficiency symptoms include white streaks on the young leaves, narrow gray leaves with transparent stripes, and ear sterility. In addition, sorghum seed heads may not be fully filled.

Millet

(Panicum millaceum)

The limited work on these species indicates that B deficiency results in the symptoms that are common in the graminae; namely, white streaks on the young leaves and ear sterility.

Sugarcane

(Saccharum officinarum)

The first symptoms appear as small, narrow watery spots which develop parallel to the vascular bundles on the young leaves, resulting in a distinct striping. The lesions soon enlarge and the leaf tissue may later separate forming a fracture, the inner edge of which is serrated. Leaf tips can become necrotic, apical growth is retarded, and the young leaves are small, narrow, and somewhat chlorotic. Internal brownish streaks frequently develop at, and slightly below, the growing point. Young plants are bunched with many secondary stalks. The spindle leaves turn white and dry out. "Pokkah boeng," a disease caused by *Fusarium monoliforma* and injury from the herbicide Dalapon, can cause symptoms similar to B deficiency.

Wheat *(Triticum spp.)* Oats *(Avena sativa)* Barley *(Hordeum vulgare)* Rye *(Secale cereale)*

Boron deficiency causes similar symptoms in these crops. Small chlorotic spots form between the veins of the youngest unfolded leaves. The spots enlarge and coalesce to form characteristic white stripes. The stripes don't develop on mature leaves. Leaf unfolding is likely delayed and abnormal. Sterility of ears occurs, probably as a result of impairment of pollen germination and growth.

You may see some increased tillering and internodes can be short. There are indications that B deficient wheat and barley is more susceptible to mildew (*Erysiphe graminis*) than healthy plants.

Boron applications have been known to reduce the incidence of ergot (*Claviceps purpurea*) on barley. It's likely that infection is facilitated by the sterility of the flowers and by the open configuration of the spikelets when B is deficient.

Drug, fumitory and masticatory crops

Fenugreek

(Trigonella foenum-graecum)

In the field, B deficiency is normally evident as stunted growth, following poor extension of the internodes; very few pods are formed. When the deficiency is more severe, growing points cease to grow and the upper leaves are small and spoon shaped. Stems are stiff and brittle, flowers don't expand normally.

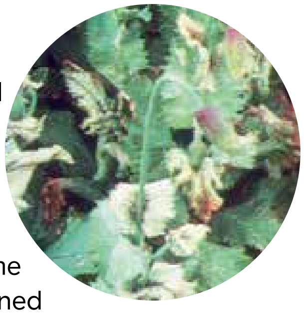
Kola

(Cola nitida)

Boron deficiency causes dieback of the growing point, and the loss of apical dominance results in profuse lateral bud break and multiple, stubby shoot formation. The malformed leaves are often broad, very small, thick, and twisted. Internodes are short. Boron deficiency causes profuse flowering, increases the flower size, and results in a preponderance of female flowers. Typically these female flowers don't set fruit and they fail to abscise. Fruit set is reduced and there is an increased incidence of parthenocarpic fruit.

Poppy

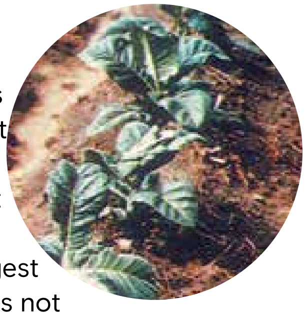
(Papaver somniferum)



In young plants, the leaves roll back along the midrib. The heart of the plant is stunted or deformed and soon rots, becoming dark violet in color. The midribs also show the same color. Death of plants is hastened by fungal and bacterial attack. In other cases, the leaves may appear normal but the young seed heads turn blue and the capsules are deformed. In these capsules, seed set is poor. The stalks often show blister-like swellings and later split.

Tobacco

(Nicotiana tabaccum)



The characteristic symptoms of boron deficiency are short internodes and dieback of the apical meristem. The first sign is the development of a basal chlorosis on the youngest leaves. When the whole leaf is not affected, the leaves subsequently expand but become distorted. They are often one-sided and twisted. Likewise, the stem near the top of the plant is often twisted.

After the death of the apical growing point, suckers are likely to develop but these are also prone to dieback. The leaves become stiff and brittle as they mature and as a result, the midribs frequently break.

When the deficiency doesn't become acute until the flowering stage, many flowering buds are shed and very few seed pods set.

Soil application (suggested rates of application)

	Granubor (15% B) *Fertibor* (15% B)	*Solubor* (20.5% B)	
Crop	**lbs/acre**	**lbs/acre**	**gals/acre**
Fenugreek	6 - 25	4 - 18	11 - 43
Poppy	6 - 13	4 - 9	11 - 21
Tobacco	2 - 6	1 - 4	2 - 10
	oz/tree	**oz/tree**	**fl oz/tree**
Kola	0.3 - 0.5	0.2 - 0.4	13

Foliar application (suggested rates of application)

	Solubor (20.5% B)	Minimum volume	Maximum concentration
Crop	**lbs/acre**	**gals/acre**	**% w/v**
Poppy	4 - 9	107 - 214	0.5
Tobacco	1 - 4	21 - 107	0.5
	oz/tree	**gals/tree**	**% w/v**
Kola		0.25	

Soil application (suggested rates of application)

	Granubor (15% B) *Fertibor* (15% B)	*Solubor* (20.5% B)	
Crop	**lbs/acre**	**lbs/acre**	**gals/acre**
Cotton	3 - 13	2 - 9	5 - 21
Kenaf	3 - 6	2 - 4	4 - 11
Sisal	3 - 9	2 - 6	4 - 15

Foliar application (suggested rates of application)

	Solubor (20.5% B)	Minimum volume	Maximum concentration
Crop	**lbs/acre**	**gals/acre**	**% w/v**
Cotton	2 - 9	53 - 215	0.5

Fiber crops

Cotton

(Gossypium spp.)
While severe symptoms of boron deficiency may not be found frequently, B deficiency without the appearance of any visible foliage and flower symptoms can significantly limit the yield of seed cotton.

Apart from flower and boll shedding, a large number of symptoms on the leaves, petioles, flowers, and bolls have been described. However, don't expect to see all of the symptoms at the same time in any one field.

One of the more characteristic symptoms is the development of bands (often excessively hairy) on the petioles. The pith at such regions is necrotic. The terminal bud often dies and many lateral branches, which have short internodes and enlarged nodes, then develop. The leaves, which usually don't show any malformation, remain green until the first frost. In cases of extremely severe deficiency, excessive and abnormal vein development results in the buckling of the leaf and in irregular leaf shapes.

The petals are frequently crumpled and misshapen. Excessive shedding of squares or young bolls occurs. Discoloration of the extra-floral nectaries is common. Cracks may develop on the stems, at the base of the squares or bolls, and there may be some exudation.

Kenaf

(Hibiscus cannabinus)
In the early stages, the shoots are dark green and the young leaves may be malformed. The midrib and main veins become necrotic which results in the leaf curving backwards. Ultimately, young leaves fail to expand and the shoots die back. Petiole collapse, caused by an internal necrosis, can cause the death of otherwise normal leaves. Root growth is reduced and roots are short and dark with thick tips.

Sisal

(Agave sisalana)
The first signs of B deficiency are yellow spots, most numerous near the tip, on both surfaces of the leaf. These are followed by the formation in the epidermis of ramifying fingerlike depressions from the leaf margin, which may later become suberized. In sand culture experiments, the tip of the leaf may be hooked and the leaf spine absent or reduced to a white hair. In cases of severe deficiency, the growing point becomes disorganized and the leaves are short, narrow, twisted, and sometimes split. The plants have a flat-topped appearance. Boron deficient plants may be more prone to *Fusarium* wilt.

Flowers and ornamentals

Areca palm

(Chrysalidocarpus lutescens)
The older leaves show a mottled chlorosis starting at the tips. Narrow transverse chlorotic streaks develop interveinally and the streaks coalesce forming necrotic lesions. The youngest leaves and growing point eventually die.

Azalea

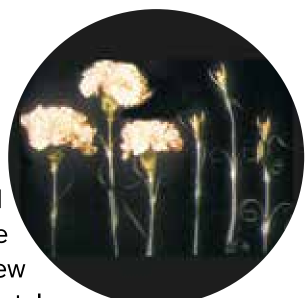
(Rhododendron spp.)
Brown flecks, which become translucent, are the first signs of B deficiency and are seen on the young expanding leaves. Leaves developing later are distorted and show necrotic patches round the margins. Apical growing points die back.

Begonia

(Begonia spp.)
The terminal buds and leaves show a rosette condition with a puckering of the tip leaves—later becoming necrotic. Growth is generally stunted. The bulb has corky patches or nodules.

Carnation

(Dianthus caryophyllus)



A high incidence of calyx splitting is usually the first sign of B deficiency. The leaves split at the nodes and the flower buds abort. Where buds don't abort there are few petals which dry off and the style is pronounced. Red patches, which develop along the central veins on the lower leaves, later spread over the leaf and become necrotic. The leaves tend to be spoon-shaped with serrated tips. The uppermost lateral shoots may have a "witch's broom" appearance. Both total bloom production and the yield of marketable blooms can be increased by B application. Where B supply is marginal, liming can markedly increase calyx splitting in the absence of a B supply in the liquid feed or fertilizer.

Chrysanthemum

(Chrysanthemum spp.)

In mild cases of B deficiency, the petals fail to unroll properly and become "quilled." When the deficiency is severe, you will see symptoms in the leaves which are brittle and closely spaced. Some down-curling of the leaves may occur and leaf tips may become chlorotic and eventually die. In old palms, B deficiency causes stunting with the stem tapering abruptly. Flowers and fruits are small and often die on stunted inflorescences. There may be some loss of flower color. When the deficiency is acute, the buds fail to open properly. Growing point death is followed by multiple shoot formation.

Cyclamen

(Cyclamen spp.)
The first sign of B deficiency is the development of uneven yellow patches on the lamina close to the petiole and the main veins. The patches become necrotic and, in severe cases, the leaf dies.

Dracaena sanderiana

A pronounced marginal necrosis develops on the leaves, which tend to be leathery.

Gardenia

(Veitchii spp.)
The young leaves are chlorotic and necrotic patches develop. The new leaves are very crinkled and deformed. The growing points ultimately die in cases of severe B deficiency.

Geranium

(Pelargonium hortorium)
Leaves become very brittle and puckered. Small lesions which develop on young leaves eventually form holes.

Gerbera

(Gerbera)
The first symptoms occur on the flowers, which are distorted and carry fewer petals. Pollen production is restricted and stigmas absent or poorly developed. Flowering stalks are short and may split.

Only expect leaf symptoms after you see symptoms on flowers and when the deficiency is more severe. Some chlorosis may occur and red/violet spots develop near the margin and tips of older leaves. Newer leaves are distorted, often cupped, wrinkled, and much thicker than healthy leaves.

Gladiolus

(Gladiolus spp.)
The symptoms of B deficiency include cracked leaf margins (especially on the first leaves to emerge), translucent streaks between the veins, hooked leaf tips, and failure of the lower petals to expand normally. The flower petals are mottled and the flower stems may be hollow, lacking a normal pith.

Gloxinia

(Sinningia speciosa)

A rapid blackening and wilting of the foliage is followed by death of the growing point. The bulb has corky nodules.

India rubber plant

(Ficus elastica)

Boron deficiency causes a stunting and malformation of the small immature leaves together with a necrosis of the terminal growing point. Young leaves are liable to show transverse splits which exude latex.

Larkspur

(Delphinium spp.)

Terminal growth ceases. Leaves are chlorotic and die at the tips. Stalks are short.

Nasturtium

(Tropaeolum majus)

The growth of the terminal growing point, which is usually dark green, is considerably reduced. The leaves are small and distorted.

Poinsettia

(Euphorbia pulcherrima)

The buds, particularly those near the tip, stop growing. The young terminal leaves are thick and tend to roll. The midrib on the underside of the leaf may crack and the bracts, which develop slowly, are abnormal.

Pyrethrum

(Chrysanthemum cinerariaefolium)

Boron deficiency causes the development of misshapen and malformed flowers with apical dieback. Ray florets may be reduced to one-third their normal length. They have ragged tips and they may be formed on only part of the circumference. In some cases, ray florets may be completely absent.

Rose

(Rosa spp.)

The leaves are distorted and elongated with irregular serrations. The loss of apical dominance results in multiple branching of the flowering stems which are distorted. The petals may have serrated margins and show irregular pigmentation. In cases of severe B deficiency, necrosis of the growing points and flowering shoots may be expected.

Soil application (suggested rates of application)

	Granubor (15% B) *Fertibor* (15% B)	*Solubor* (20.5% B)	
Crop	**lbs/acre**	**lbs/acre**	**gals/acre**
Carnation	6 - 13	4 - 9	11 - 21
Chrysanthemum	3 - 13	2 - 9	4 - 21
Gladioli	3 - 13	2 - 9	4 - 21
Roses	6 - 13	4 - 9	11 - 21
Flowers, general	3 - 13	2 - 9	4 - 21

Foliar application (suggested rates of application)

	Solubor (20.5% B)	Minimum volume	Maximum concentration
Crop	**lbs/acre**	**gals/acre**	**% w/v**
Gladioli	2	214	0.1
Roses	4	267	0.2
Flowers, general	2	107	0.2

Stocks

(Matthiola spp.)
Growing points die and the young leaves are thick and distorted.

Sweet pea

(Lathyrus odoratus)
Leaves are likely to become chlorotic. Growing points quickly die when deficiency is severe.

Tulips

(Tulipa spp.)
The petals are discolored petals often with a central or marginal white patch. The flower and stem, which are stunted, break easily. The bulb shows some browning.

Zinnia

(Zinnia spp.)
Boron deficiency causes a marked wrinkling and deformation of the young leaves which become thick and brittle. Some chlorosis can occur, which starts at the leaf margins.

Forage crops

Leguminous fodder crops

Apart from the normal B requirement for growth and development, these plants have a special B requirement for nodulation and nitrogen fixation, both of which are normally impaired in B deficient plants. As in most plants, boron deficiency has a marked effect on root growth and this in itself is likely to reduce nodulation.

Soil application (suggested rates of aplication)

	Granubor (15% B) *Fertibor* (15% B)	*Solubor* (20.5% B)	
Crop	**lbs/acre**	**lbs/acre**	**gals/acre**
Alfalfa	6 – 24	4 – 18	11 – 43
Clovers: Alsike, crimson, ladino, red, and white	6 – 9	4 – 6	11 – 15
Clovers: Berseem, burr, subterranean, and sweet	6 – 13	4 – 9	11 – 21
Grasses, general	3 – 6	2 – 4	4 – 11
Kale	6 – 13	4 – 9	11 – 21
Mustard	6 – 13	4 – 9	11 – 21
Trefoil	6 – 15	4 – 11	11 – 26
Vetch, hairy, and common	6 – 13	4 – 9	11 – 21

Foliar application (suggested rates of application)

	Solubor (20.5% B)	Minimum volume	Maximum concentration
Crop	**lbs/acre**	**gals/acre**	**% w/v**
Alfalfa	4 – 9	107 – 214	0.5
Clovers: Alsike, crimson, ladino, red, and white	4 – 6	107 – 150	0.5
Clovers: Berseem, burr, subterranean, and sweet	4 – 9	107 – 214	0.5
Kale	4 – 9	107 – 214	0.5
Trefoil	4 – 9	107 – 214	0.5

Alfalfa

(Medicago sativa)

Boron deficiency in alfalfa, in its mildest form, can easily pass unrecognized—it appears as a reduction in flowering and seed set. Such mild deficiency is seldom detectable in hay yields from a single cutting. However, reduced flowering may delay cutting and the result is a poorer quality hay. Eventually, the total quantity of hay may be reduced.

The main symptoms of B deficiency are yellowing and reddening of the upper leaves. As deficiency develops, the internodes of the top growth become progressively shorter and the short side branches help to give the plant a "rosetted" appearance. At this stage, the growing point becomes dormant or dies.

Boron deficiency is closely associated with moisture stress and drought. Alfalfa yellowing caused by B deficiency is frequently mistaken for drought damage. Flowering is often reduced and the flowers fall before setting seed. Boron deficiency symptoms are contrasted with leaf hopper injury, potassium deficiency, and certain diseases, which cause yellowing of both the lower and upper leaves. With B deficiency, yellowing is confined to the upper leaves and doesn't occur at random as is the case with leaf hopper injury.

Bermudagrass

(Cynodon dactylon)

The most common symptom of B deficiency is decreased forage yields, especially during late spring and early summer cuttings when weather conditions are hot and dry.

Buffel grass

(Cenchrus ciliaris)

The newly emerging leaves fail to unroll. They remain white, wither, and then die back from the tip. Tips of older leaves may also die back. Leaf margins may crack and white streaks, which coalesce, often develop between the veins. Plants are likely stunted but no reduction in tillering is expected.

Clovers

Seed production appears particularly sensitive to B deficiency. Crops that don't show obvious symptoms or whose growth is only slightly improved by B applications can respond dramatically to B applications in the seed production year.

Boron is needed for proper pollen germination and tube growth. There is also evidence that increased nectar secretion (and possibly flower modification) brought about by B application can increase the numbers of bees working over clover flowers and thereby improve seed set.

Alsike clover

(Trifolium hybridum)

Plants are stunted. The leaflets are likely to show an interveinal yellowing and often have a bronzed appearance with the veins remaining dark green. Leaves at the shoot tips are malformed. Flower stems are short and few flower heads are likely to develop. Pollen germination and tube growth is poor when either pollen or pistil is B deficient.

Burr clover

(Medicago hispida)

The plants are reduced in size and young leaves near the growing points are twisted, thickened, and curled at the leaf margins.

Crimson clover

(Trifolium incarnatum)

Crimson clover is rated, together with alfalfa and berseem clover (*T. alexandrinum*), as being very sensitive to B deficiency. The symptoms of B deficiency are very similar to those in other clovers, namely stunting and eventual malformation of young leaves and shoots, with red and yellow tints developing on leaves.

Red clover

(Trifolium pratense)

If B deficiency occurs on very young seedlings, the first trifoliate leaf is small and imperfectly shaped. Young leaves are small and distorted, and eventually the growing points die. The leaves develop red and purple tints (sometimes following a general chlorosis). The colors are usually more pronounced on the under surface of the leaf. Leaf margins may become necrotic. Red tints may develop on older unifoliate leaves. On older plants, growth is gradually stunted with the stems often swollen and thickened near the growing points.

Clovers (continued)

Subterranean clover

(Trifolium subterraneum)

Symptoms first appear on the young leaves which are chlorotic, stunted, and distorted. The older leaves usually show some intense purple or red pigmentation along the margins. Stem growth is reduced. Seed set and quality may be impaired leading to poor regeneration.

Sweet clover

(Melilotus spp.)

The leaves turn red and later yellow. Growth is slow and stunted.

White clover

(Trifolium repens)

If B deficiency occurs on very young seedlings, the first trifoliate leaf is small and imperfectly shaped. Red tints may develop on older unifoliate leaves. On older plants, growth is gradually stunted with the stems often swollen and thickened near the growing points. Young leaves are small and distorted, and eventually the growing points die. The leaves develop red and purple tints (sometimes following a general chlorosis). The colors are usually more pronounced on the under surface of the leaf. Leaf margins may become necrotic.

Kale

(Brassica oleracea var. acephala)

The leaves of B deficient kale are curled, rolled, and somewhat chlorotic or mottled—particularly around the leaf margins. The growing point dies in cases of severe deficiency and is replaced by lateral shoots. Brown and water-soaked areas may appear in the pith of the stem which may also be hollow.

Leucaena leucocephala

Growing points become malformed and young leaves are thick and dark green. The rachis bends downwards. The pinnules are narrow and of unequal size. Expect some axillary development. Roots are dark in color, stunted, and show little branching.

Lotononis bainesii

Young leaves are thick and dark green with the lateral leaflets misshapen and uneven in size. The leaflets curl backwards. In older leaves, some veinal chlorosis can occur followed by loss of turgor. Many new, but malformed, shoots are likely to form. Leaves may show red pigmentation around leaf margin. Root growth is stunted with the roots thick and dark in color.

Mustard

(Sinapis alba)

Boron deficient mustard plants are dwarfed and have rough leaves which roll downwards from the tip. Leaves may show a marginal yellowing which sometimes develops over the entire leaf surface. The number of flowering stalks is reduced and sudden petal fall may occur. Lateral shoot development from the older leaf axis is common.

Neonatonia wightii

In the early stages, leaves and shoots are dark green. The leaves are thick and narrow and may be malformed, with the two lateral leaflets being of unequal size and shape. When the deficiency is severe, the shoot tip becomes necrotic and secondary growth is initiated. In older plants a mild deficiency is manifested by yellow and orange tints in the upper leaves.

Root growth is reduced, there is little branching, and the root tips are brown and bulbous.

Panicum

(Panicum maximum)

Growing points die, causing stunting and excessive tillering. Leaves are short and dark green. White streaks develop near leaf margin parallel with veins.

Paspalum

(Paspalum dilatatum)

White streaks develop on the youngest leaves of B deficient plants. The leaf margins tend to roll inward and the leaf blades are stunted. Ultimately, the growing points die and there is an increase in tillering.

Perennial African grass

(Setaria sphacelata)

The short internodes and leaf sheaths result in a cluster of leaves at the top of each tiller. The growing points on some tillers of each plant die. Where ears develop, they usually fail to emerge completely.

Phaseolus atropurpureus

Symptoms first appear on the youngest leaves, which will be dark green, thick, turgid, and brittle. New secondary growths are also likely to be affected. Roots will be brown and tips swollen.

Rhodes grass

(Chloris gayana)

White streaks develop between the veins, particularly near the leaf margins on the youngest leaves of B deficient plants. The leaves tend to roll inwards. As the deficiency becomes more severe, larger and more numerous white areas develop and the new leaves wither and die shortly after emergence. There is an increased tillering and death of some of the growing points can be expected.

Townsville stylo

(Stylosanthes humilis)

Boron deficient plants are prostrate and have thick dark green stems and short internodes. The young leaves may have an irregular interveinal chlorosis and show some red and yellow tints.

Emerging leaves and recently expanded leaves are often nearly normal in color but will be distorted, with unevenly sized leaflets.

Trefoil

(Lotus corniculatus)

Symptoms are very similar to those described for *T. repens* (white clover) and *T. pretense* (red clover).

Fruit and nut crops

Acerola

(Malpighia punicifolia)

Growth is stunted. Leaves show an apical chlorosis which turn necrotic. Fruit production is likely to be severely limited.

Almond

(Prunus amygdalus)

The young branches die back from the tip and the development of shoots from near the base of the branch gives a "witch's broom" effect. Poor nut development and premature fall can be expected. The nuts turn yellowish and may later blacken. Brown gummy areas in the nuts may extrude on the surface.

Aonla

(Emblica officinalis)

A fruit necrosis has been associated with B deficiency. The mesocarp tissue turns brown and eventually the affected tissue extends to the fruit surface, resulting in dark areas.

Apple

(Malus sylvestris)

Boron deficiency causes cracking and external cork symptoms on the frui. This may occur even though the foliage shows no symptoms, such as rosetting of thickened brittle leaves and dieback of the growing points.

Premature fruit drop occurs and fruit quality can be badly impaired by the cork formation. When the internal cork develops early in the season, the affected fruit will become badly deformed.

In severe cases, dead areas appear in the bark of young branches (apple measles). The bark may be rough and cracked. Boron deficiency may affect the translocation of calcium in the tree and in this way B may be associated with "bitter pit."

Apricot

(Prunus armeniaca)

The fruit shows severe cracking, internal cork (particularly round the stone), and a tendency toward premature ripening in the center. Brown dried areas may also appear on the surface of the fruit. The leaves are narrow, brittle, and often curled at the margins. Branch dieback occurs.

Avocado

(Persea americana)

Lack of B can cause a gradual death of both the apical and axillary growing points, the leaves are distorted, somewhat crinkled, often lanceolate, and have necrotic patches, malformed fruit, necrotic spots on the fruit and seed, spongy stem tissue, poor fruit set from improper pollen tube elongation, the midrib and main veins on the lower surface of the leaves frequently split and become suberized. The young twigs may swell and show internal corky pockets.

Research has shown that B amendments in avocado affected by B deficiency can increase yield, increase quality of fruit produced, and strengthen root development.

Banana

(Musa spp.)

Incomplete expansion and unfolding of the youngest leaf is probably the most typical symptom of B deficiency. In very severe cases, interveinal chlorosis and leaf malformation occur. The leaves may be narrow, rolled, and incompletely developed. Sucker development is likely to be very poor.

Boron deficiency first results in the development of small chlorotic streaks aligned perpendicular to and crossing the primary veins of the leaf blade. As the deficiency becomes more severe, the chlorotic streaks become longer and more concentrated, eventually extending through the leaf and, in some cases, appearing as slight protrusions on the lower surface.

Leaf streaking has been recorded in cases of B deficiency. However, such streaks usually coalesce, forming patches, and ultimately become large necrotic patches. Boron deficiency is distinguished from sulfur deficiency by the absence of necrotic patches and the appearance of malformed leaves.

Blackening in the center of the pulp of the fruit has been observed in sand culture experiments. In the field, the presence of amber colored gummy deposits (mostly towards the flower end) has also been associated with B deficiency.

Blackberry

(Rubus spp.)

The terminal buds stop growing. Numerous short branches develop below the tips.

Blueberry

(Vaccinium spp.)

Similar B deficiency symptoms have been described for both *V. corymbosum* (highbush blueberry) and *V. angustifolium* (lowbush blueberry). The first sign is the development of small necrotic lesions associated with the veins of the youngest unexpanded leaves. The lesions merge, causing the leaf to curl backwards. This is followed by terminal dieback and new shoot development. Leaf fall is likely and the remaining lower leaves become dark blue-green. Internodes are short.

Cashew

(Anacardium occidentale)

The first sign of B deficiency is the swelling of the terminal section of the stem, which is followed by a stem necrosis in the same region. Necrotic spots may occur at random over the leaf surface. The youngest leaves tend to be deformed, being narrow and curled. When the deficiency is severe, the growing point dies back and axillary shoots develop.

Cherimoya

(Anona cherimolia)

Leaves are hard, thick, and tend to bend backwards. Initially leaves are dark green but they later show an irregular chlorosis. Longitudinal growth stops and the growing points die. Side shoots also die back.

Cherry

(Prunus cerasus)

The fruit of B deficient cherry trees has a pale chlorotic skin which may break. Gray spots develop in the fruit. The leaves are small, cupped, and often yellow with red veins. The leaf margins are corrugated. Branch dieback, which is particularly evident in the spring, is followed by lower shoot development giving rise to an excessively branched condition known as "witch's broom." Blossoms fail to develop.

Citrus

(Citrus spp.)

Foliar symptoms of B deficiency on citrus are not very characteristic. A deficiency suspected on the basis of leaf symptoms should be confirmed by fruit symptoms. The first signs appear on the younger leaves as water-soaked spots which become translucent. The veins tend to be thick, cracked, and somewhat corky. The young leaves wilt, curl, and have a dull brownish-green color without any luster. Dieback of leaf tips is common. A gummy exudate may appear on the twigs and fruit pedicels.

The fruits, which are small, shrivel and go hard on the tree. They characteristically show internal gum formation, usually in the albedo but also in the pith.

Soil application (suggested rates of application)

	Granubor (15% B) *Fertibor* (15% B)	*Solubor* (20.5% B)	
Crop	**lbs/acre**	**lbs/acre**	**gals/acre**
Almond	18 – 36	13 – 27	32 – 64
Banana	13 – 24	9 – 18	21 – 43
Blackberry	6 – 13	4 – 9	11 – 21
Blueberry	3 – 13	2 – 9	4 – 21
Cashew	6 – 13	4 – 9	11 – 21
Currant	6 – 13	4 – 9	11 – 21
Fig	6 – 13	4 – 9	11 – 21
Grape	13 – 45	9 – 31	21 – 75
Pineapple	6 – 13	4 – 9	11 – 21
Plantain	13 – 36	9 – 27	21 – 64
Raspberry	6 – 25	4 – 18	11 – 43
Strawberry	3 – 6	2 – 4	4 – 11
	oz/tree	**oz/tree**	**fl oz/tree**
Apple	3.5 – 12.4	2.5 – 8.8	50 – 170
Apricot	3.5 – 7.1	2.5 – 4.9	50 – 100
Avocado	2.5 – 7.1	1.8 – 5.3	34 – 100
Cherry	3.5 – 8.8	2.5 – 6.3	50 – 120
Citrus	1.4 – 3.5	1.1 – 2.5	17 – 50
Papaya	0.1 – 0.4	0.1 – 0.3	4 – 8
Peach	2.5 – 3.5	1.8 – 2.5	34 – 50
Pear	3.5 – 12.4	2.5 – 8.8	50 – 170
Plum	3.5 – 7.1	2.5 – 4.9	50 – 100
Walnut (>10 yrs)	up to 35.3	up to 26.5	

Foliar application (suggested rates of application)

	Solubor (20.5% B)	
Crop	**% w/v**	**gals/acre**
Apple	0.20	107 – 214
Banana	1.0	54 – 107
Cherry	0.25	107 – 214
Citrus	0.25	107 – 214
Grapes	0.25	214 – 428
Papaya	0.3	107 – 214
Peach	0.25	107 – 214
Pears	0.25	107 – 214
Pineapple	0.25	214 – 428
Plum	0.25	107 – 214

Normally, the gummed spots cannot be seen unless the fruit is cut. This feature helps to distinguish the deficiency from citrus impietratura disease. The rind is thick and the fruit has a low juice content.

Excessive fall of young fruit occurs, resulting in very poor yields. This may be the first sign of a B problem. The seeds are likely under-developed and the seed coat dark and shriveled.

Currant, red

(Ribes sativum)

The main symptom is the shriveling and blackening of the petioles and lamina of the youngest leaves. Neighboring leaves are edged with light brown bands.

Date palm

(Phoenix dactylifera)

Growing points become moribund and ultimately die, with the youngest leaves becoming necrotic.

Figs

(Ficus carica)

The terminal bud ceases to develop, followed by the appearance of numerous axillary branches just behind the tip. The leaves are chlorotic, necrotic near the margins and distorted. The internodes are short.

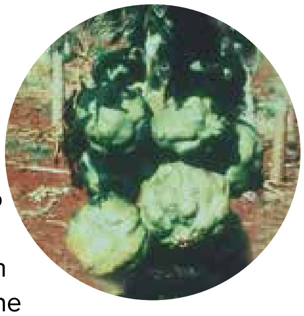
Grapes

(Vitis vinifera)

Boron deficiency reduces fruit set with bunches of small seedless berries and bunches of berries of varying sizes—“hens and chicks.” In severe cases, no normal fruit develops. The young leaves show an interveinal chlorosis, and when the deficiency is severe they may be deformed. Internodes are short and ultimately the growing points die.

Papaya

(Carica papaya)



One of the earliest signs of boron deficiency is a mild chlorosis in mature leaves, which are brittle and liable to curl downwards. A white “latex” exudate may flow from cracks in the upper part of the trunk, from leaf stalks, and from the underside of the main veins and petioles. The death of the growing point is followed by a regeneration of the sideshoots which ultimately die.

In fruiting plants, the earliest indication is flower shedding. When fruit develop, they are likely to secrete a white latex. Later, the fruit become deformed and lumpy. The deformation is very probably the result of incomplete fertilization as most of the seed in the seed cavity are either abortive, poorly developed or absent. If the symptoms begin when the fruit are very small, then most don’t grow to full size.

Peach

(Prunus persica)

Typical B deficiency symptoms are small, thick, misshapen, and brittle leaves carried on branches with short internodes. A water-soaked dieback is followed by excessive branching.

Veins and midribs are pronounced and are often corky and red in color. The bark may split and have pronounced lenticels. Reduced fruit set occurs. Fruit are often small and abnormal, with internal necrotic patches and sometimes without seed. Fruit may crack.

Peaches are particularly sensitive to boron excess. Flower bud and flower shedding can both be caused by B toxicity.

Pear

(Pyrus communis)

The fruit become misshapen with cork developing under the large depressions. The upper leaves are small and cupped. The small branches die back as the deficiency becomes more severe.

Pecan

(Carya illinoensis)

Small water-soaked areas develop on otherwise normal leaves. These areas turn purplish and then a reddish-brown. As the deficiency becomes more severe, more spots appear but they don’t coalesce. The lower leaves on the rachis develop normally, but the distal ones become small. Internodes are short and the growing points die back.

Pineapple

(Ananas comosus)

Lack of B can cause malformed fruit, broken core, separation and cracking of fruitlets, poor fruit set, and reduced sugar content.

Few leaf symptoms have been reported. In very severe cases, the growing point may die, followed by profuse development of side shoots and suckers. Root growth is poor. Main roots may be brown and few fibrous roots are produced. The deficiency is more pronounced on the ratoon than on the plant crop.

Research has shown that B amendments in pineapple affected by boron deficiency can increase sugar content, increase quality of fruit produced, and strengthen root and slip development. Boron has also been found beneficial when adding ethephon to induce flowering.

Plum

(Prunus domestica)

Tip dieback and leaf fall, particularly on the upper branches, can be expected, but the main symptoms of B deficiency are formed on the fruit. Brown sunken areas appear in the flesh and sometimes gum pockets are also formed. Multiple branching occurs which is prominent at the tops of the trees. Flowering is seldom impaired by B deficiency, but as very many flowers fail to develop, there is usually a marked reduction in fruit set.

Raspberry

(Rubus idaeus)

Failure of the fruiting canes to develop normally in the spring is one of the first signs of B deficiency. Death of buds on the canes and failure to produce normal laterals give the bush the appearance of suffering from a "dieback." Berry production in such plants is likely to be considerably reduced.

Buds which develop are likely to show distorted leaves with some edge necrosis and unusually large petioles. Pith necrosis occurs. In less severely affected buds, leaves are small, thin, and deeply indented, giving a "feathery" appearance. Leaf crinkling also occurs. The lack of development of the old canes often results in a profusion of new canes from the base of the plants which will usually carry fairly normal leaves.

Strawberry

(Fragaria spp.)

The first symptom appears on the young leaves as a tip necrosis. These leaves are likely to be misshapen (often "squared off"), cupped and reduced in size. Many small lateral buds may form in the crown but their development is very restricted. The runner plants become progressively more stunted with small distorted chlorotic leaves. Boron deficiency also causes fruit distortion, probably due to incomplete fertilization. Fruits may split before ripening and corky patches may develop. The flesh has a leathery texture. In the latest stages, flowers fail to set fruit.

Walnut

(Juglans regia)

Large, irregular, necrotic patches develop between the veins, particularly on the terminal leaflets. When the deficiency is severe, the leaves are twisted and the veins are very prominent. Dieback from tips of the shoots results in very evident leafless branches. The nuts don't set properly and a marked reduction in yield can be expected. Walnut trees don't usually need B until they reach bearing age (12 years).

Oil crops

Canola

(Brassica napus var. oleifera)

Canola (rape seed oil), like all its relatives in the *Brassica* family, has a very high B requirement and is severely affected by B deficiency. Canola seed production is critically dependent on B—so much so that grain yields have been doubled when 2 lbs of B per acre were applied to canola fields that showed no visual abnormalities.

Canola needs more B through all growth stages—vegetative and flowering—than most other crops. Although B deficiency can markedly affect vegetative growth, it is more usual to find that yields are reduced even when the plants show no obvious symptoms. This is probably due to the fact that B is required for pollination and because a slight deficiency can result in poor seed set, even though pods may be formed. Brown necrotic areas which form in the pith of the stem may be one of the earliest signs of B deficiency.

When the deficiency is severe, the new leaves will be very deformed; they may have cracked petioles and be bent back. Stem elongation will be restricted, the plants will be stunted, and ultimately the growing point may die. Branching may be excessive.

Coconut

(Cocos nucifera)

Leaf malformations caused by B deficiency were first seen in the 1960s. They are shown by the youngest leaves and are more or less identical with the ones found in oil palms.

The symptoms, in increasing order of severity, are:

1. Fusion of terminal pinnae on the frond
2. "Hook" or "bayonet leaf" in which the pinnae are bent into a double or single hook near the tip
3. Development of the fronds with very short pinnae either on one or both sides of the rachis
4. In the most severe cases, the frond develops without any pinnae

The first two symptoms are the most common. Occasionally, the apical growing point dies.

The first sign of B deficiency on 1 year old coconuts is the development of small chlorotic spots on the young leaves, the spots being symmetrically orientated in relation to the main veins on the leaf. These B deficiency symptoms on very young palms bear a striking resemblance to those on young oil palms.

Indian mustard

(Brassica juncea)

The young leaves become deformed and curled. They are usually rough, thick, and leathery. The growing points die and axillary shoots develop, which themselves become moribund and die. In severe cases, flower buds shed prematurely and the flowers that form are likely malformed. In less severe cases, seed set is restricted.

Linseed, flax

(Linum usitatissimum)

The young leaves are chlorotic and, in cases of severe deficiency, the growing points ultimately die and shoots will develop from many nodes. Growth is generally reduced and the stems may be thick, twisted, and possibly fasciated. The tips of the shoots turn yellow, wilt, and die. In old plants, the top part may be affected while the lower part remains healthy. Seed and straw yield is reduced and the fiber may be poor quality.

Boron deficient flax appears more susceptible to *Fusarium* than healthy flax. Roots are dark and short when the deficiency is severe.

Oil palm

(Elaeis guineesis)

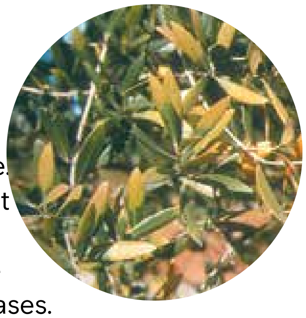
Several symptoms of various leaf malformations are associated with boron deficiency. "Hook leaf," which consists of a single or double hook on the pinnae near the tip, and transverse corrugations on the pinnae are usually the first symptoms to appear.

Fasciation, a flattened fan-like growth pattern, and the inability of pinnae to expand are associated with more severe boron deficiency. The leaf tissue is fragile and the leaflets break easily, resulting in the condition known as leaflet shatter. With "blind leaf," another symptom of boron deficiency, the pinnae develop incompletely as a tuft of bristles at the terminal end of the frond. A very severe boron deficiency results in "fishbone leaf," identified by extremely small, thin pinnae. The breakdown of the growing point results in a dry heart rot as a final characteristic symptom.

On young seedlings, there are a few signs of boron deficiency. The dark green lamina is sprinkled with white dots and streaks, which become more pronounced on older leaves. There is a tendency for seedlings to show juvenile tendencies with the entire bifurcate leaf remaining undeveloped.

Olive

(Olea europaea)



Boron deficiency makes leaves fall and branches die in the upper parts of the tree. Secondary shoots develop at the base of the dieback, and the number of suckers in the lower part of the trunk increases.

The leaves show a distinct apical browning which can extend up to two-thirds of the leaf while the rest of the leaf remains a normal green color. Subsequently, the leaves may become completely yellow and later turn a leathery brown from the apex. In cases of mild boron deficiency, some fruit may ripen normally but most will drop prematurely or become deformed and corky. As the boron deficiency becomes more severe, the olive tree will become increasingly less productive and may ultimately die.

Peanut

(Arachis hypogaea)

Symptoms of B deficiency are particularly evident in the nuts and are not frequently found on the foliage under field conditions. While the effects on yield may be slight, the deficiency can markedly reduce the quality of the crop and the yield of marketable peanuts. The main symptom is of a hollow darkening of off-color area in the center of the cotyledon. The depression may vary from being shallow and slightly colored to being deep and dark brown according to the severity of the condition. Cracks may also develop on the pods.

The first sign of B deficiency on the typically dark green leaves is the development of water-soaked areas which give the leaves a mottled appearance.

Prolific secondary branching occurs on short woody stems after dieback of terminal growing points. When boron deficiency is less severe, flowers aren't followed by any fruit development, possibly as a result of pollen tubes failing to grow properly. When boron deficiency is extremely severe, flowers don't develop.

Soybean

(Glycine max)

Soybeans are considered non-responsive to B. And, soybeans appear to be sensitive to B toxicity, especially when the boron is applied to the leaves. However, yield reductions do not necessarily accompany leaf spotting and marginal necrosis caused by excessive B accumulation.

Soil application (suggested rates of application)

	Granubor (15% B) *Fertibor* (15% B)	*Solubor* (20.5% B)	
Crop	**lbs/acre**	**lbs/acre**	**gals/acre**
Indian mustard	3 - 6	2 - 4	4 - 11
Linseed	3 - 9	2 - 6	4 - 15
Oil seed rape	6 - 15	4 - 11	11 - 26
Peanut	2 - 3	1 - 2	2 - 4
Soybean	3 - 6	2 - 4	4 - 11
Sunflower	6 - 18	4 - 13	11 - 32
Tung	6 - 13	4 - 9	11 - 21
	oz/tree	**oz/tree**	**fl oz/tree**
Coconut	1.1 - 2.8	0.8 - 2.5	4 - 16
Oil palm	2.1 - 8.5	1.4 - 5.6	10 - 27
Olive	3.5 - 13.1	2.5 - 9.5	16 - 55

Foliar application (suggested rates of application)

	Solubor (20.5% B)	Minimum volume	Maximum concentration
Crop	**lbs/acre**	**gals/acre**	**% w/v**
Oil seed rape	4 - 11	32 - 77	1.6
Olive		0.2 - 0.5	
Peanut	1 - 2	(applied on a dust)	
Sunflower	4 - 13	214 - 642	0.25

As with many plants, the earliest sign of B deficiency occurs in the roots. The root tips die and new roots are initiated giving a rosette appearance. Likewise, the death of the shoot growing point is followed by prolific development of lateral shoots with brittle petioles.

Sunflower

(Helianthus annuus)
Boron deficiency symptoms first appear on the youngest leaves which become progressively smaller and malformed. The stem is short due to lack of extension of the cells in the internode. Distortion of flower heads is common and seed set on the head is very uneven—sections of the head may show no seed set at all. This symptom is associated with the B requirement of the pollen tube. When the deficiency is very severe, the growing point dies and no flowers will form.

Tung

(Aleurites spp.)
Symptoms of B deficiency first appear on the petioles of the young developing leaves as dark green rings, which later become ridges. The young leaves are light green and glossy and the interveinal tissue expands more rapidly than the veins giving the leaves a "puffy" appearance. The leaf veins may crack and become suberized, internodes are short, and terminal and lateral growth stops.

Root and tuber crops

Carrot

(Daucus carota var. sativa)
In the field, B deficiency typically causes a superficial pinhead-sized discoloration just under the skin of the carrot. The grayish irregularly shaped areas are ordinarily only seen after steam peeling of the carrots and are usually removed by normal domestic peeling. Severe B deficiency causes further symptoms to develop. The tap roots frequently split and are often brittle. Leaves may ultimately be affected turning a red or yellow color and later, just before the growing point dies, very small leaves are formed.

Cassava

(Manihot utilissima)
Plants are typically short because of reduced internodes. Young leaves are normally dark green, small, and deformed, and carried on short petioles. Lower mature leaves may be flecked with grey, brown or purple spots near the tip and margins. Resin may exude from lesions on petioles. Root growth is suppressed. Ultimately the growing point dies.

Japanese radish

(Raphanus sativus var. longipinnatus)
The root develops a black/brown discoloration which runs from the leaves down the core of the root.

Mangold

(Beta vulgaris var. vulgaris)
Root and leaf symptoms of B deficiency are very similar to those in sugar beet, although the cracking of the epidermis on the midribs is possibly more common on mangold than on sugar beet.

Apart from the characteristic heart rot, death and blackening of the younger leaves, scabs and galls may be found on the petioles of B deficient mangold.

Parsnip

(Pastinaca sativa)
The young leaves are small and die off while the older leaves show a marginal yellowing followed by a brown scorch. The petioles, which are thick and stiff, may crack and bend over.

Potato

(Solanum tuberosum)
Symptoms of B deficiency are seldom seen on the shoot, although reduced growth with short internodes and curled leaves have been reported.

Soil application (suggested rates of application)

	Granubor (15% B) *Fertibor* (15% B)	*Solubor* (20.5% B)	
Crop	**lbs/acre**	**lbs/acre**	**gals/acre**
Carrot	6 - 13	4 - 9	11 - 21
Cassava	3 - 6	2 - 4	4 - 11
Fodder beet	6 - 18	4 - 13	11 - 32
Japanese radish	6 - 13	4 - 9	11 - 21
Mangold	6 - 18	4 - 13	11 - 32
Parsnip	6 - 13	4 - 9	11 - 21
Potato	3 - 6	2 - 4	4 - 11
Red beet	6 - 18	4 - 13	11 - 32
Rutabaga	6 - 18	4 - 13	11 - 32
Sugar beet	6 - 18	4 - 13	11 - 32
Swede	6 - 18	4 - 13	11 - 32
Sweet potato	3 - 6	2 - 4	4 - 11
Turnip	6 - 18	4 - 13	11 - 32

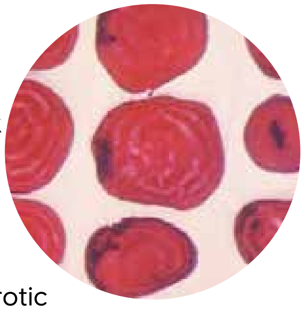
Foliar application (suggested rates of application)

	Solubor (20.5% B)	Minimum volume	Maximum concentration
Crop	**lbs/acre**	**gals/acre**	**% w/v**
Carrot	4 - 9	107 - 214	0.5
Cassava	2 - 4	86 - 214	0.25
Fodder beet	4 - 13	11 - 64	0.25 - 5.0
Japanese radish	4 - 9	107 - 214	0.5
Mangold	4 - 13	11 - 64	0.25 - 5.0
Parsnip	4 - 9	107 - 214	0.5
Potato	2 - 4	43 - 107	0.5
Red beet	4 - 13	107 - 321	0.5
Rutabaga	4 - 9	107 - 214	0.5
Sugar beet	4 - 13	11 - 64	0.25 - 5.0
Swede	4 - 9	107 - 214	0.5
Sweet potato	2 - 4	43 - 107	0.5
Turnip	4 - 9	107 - 214	0.5

Symptoms are more readily seen in the tubers in the form of brown necrotic patches. The condition known as "internal rust spot" is responsive to B application, but it's yet to be proven whether it's due to B deficiency or whether it's only an indirect association with B. The tuber cooking quality may be impaired.

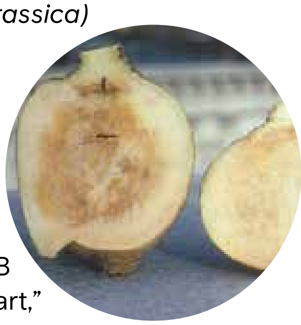
Red or garden beet

(Beta vulgaris)



Boron deficiency causes the development of internal black spots. Necrotic areas occur at random in the root or at the surface where disease organisms may enter causing a canker to develop. The necrotic areas render the beet unsuitable for canning. The growing point may die and multiple crowns develop.

Rutabaga *(Brassica napobrassica)*
Swede *(Brassica rutabaga)*
Turnip *(Brassica rapa)*



Brown, water-soaked areas develop in the root—normally in the outer regions of the xylem. These symptoms give rise to the various names for B deficiency such as "brown heart," "water core," and "Raan." In severe cases, the central tissue may break down and the root become hollow. The feeding value is reduced and the roots are likely to be tough, fibrous, and bitter. Keeping quality is poor and affected roots lose weight through loss of moisture in storage.

Normally, no symptoms are seen on the leaves. The roots will be of normal size and the problem is only apparent after harvest.

Sugar beet and fodder beet

(Beta vulgaris)

Boron deficiency characteristically causes the death of the growing point and the development of a black heart rot. Before the deficiency has reached this stage, the leaves, which may have cracked petioles, will have become progressively smaller and somewhat misshapen. After the death of the growing point, small bunches of leaves develop in the older leaf axils and the crown is very liable to become hollow and rot.

Sweet potato

(Ipomoea batatas)

Brown necrotic areas are found in the flesh of the root, particularly near the cambium around the periphery of the root. The flesh and roots are misshapen and the skin is rough and leathery in texture. Severely affected roots show surface cankers and splits covered with a hardened and blackened exudate. Boron deficiency symptoms usually appear in the latter part of the season. The terminal growth of the vines is restricted and the internodes are shortened. As the deficiency becomes more severe, the petioles are curled and twisted, and the growing points may die. Premature abscission of leaves also occurs.

Trees and cover crops

Birch

(Betula sp.)

The development of the lamina is restricted, resulting in an uneven growth and giving the leaves a blistery surface. The leaves are normally dark green in color but a few chlorotic and necrotic spots may appear on the older leaves.

Eastern cottonwood

(Populus deltoides)

Reduced extension growth and the development of small leaves.

Eucalyptus

(Eucalyptus spp.)

Similar symptoms of B deficiency have been recorded in a number of eucalyptus species (*Eucalyptus grandis, E. citriodora, E. cloeziana, E. torelliana, E. saligna, E. resinifera, E. tereticornis,* and *E. alba*). However, there are indications that species differ in their requirement for B, eg *E. grandis* appears more susceptible to B deficiency than *E. cloeziana.*

The first typical symptom is the crinkling and discoloration of the young unfolding leaves. The buds, which are brittle, die and the lower leaves in the upper crown often become discolored and fall. In some species the leaves become a reddish-purple, but in others a yellowing takes place. Normally the discoloration progresses down the tree in advance of the dieback. A bark necrosis can later be expected to start at the buds and progress down the stems, resulting in a gradual dieback. Boron deficiency is known to reduce the frost hardiness of eucalyptus.

Holly

(Ilex aquifolium)
Irregularly shaped red or purple spots can be expected on the upper surface and water-soaked spots on the under surface.

Kauri

(Agathis australia)
Young leaves are pale green and deformed. Apical growth is distorted.

Mulberry

(Morus alba)
The young leaves show broken veins and have cracked petioles. Growing points eventually die.

Pines

(Pinus spp.)
Most species of pine exhibit similar symptoms of boron deficiency including the cessation of growth of the main leader, terminal dieback associated in some species with resin exudation, and crooked leader growth have been reported in several species of pine.

The most characteristic symptom is the cessation of apical growth and the repeated death of the leading shoot. In *P. radiata* and *P. taeda*, the growing points may become necrotic and the stem apex swell. Young needles adjacent to the apical bud may die and resin exude from the bud. In these two species, the juvenile needles may be bluish-green color and the mature needles show a tendency to fuse.

Crooked leader growth has been especially reported on *P. caribaea*, *P. khasya,* and *P. patula*. *P. khasya* and *P. patula* seem less susceptible to boron deficiency than *P. radiata* and *P. caribaea*. In *P. strobus*, the primary needles become light blue-green, with yellow/orange tips.

Rubber

(Hevea brasiliensis)
Boron deficiency in rubber would only be expected on soils of extremely low B status as the rubber tree is efficient in absorbing boron. It's particularly sensitive to excess B supply.

Boron deficient leaves are distorted, reduced in size, and somewhat brittle. The leaf deformation doesn't follow any consistent pattern and there is no loss of color. On young unbranched trees, the first sign of B deficiency is found in the younger, upper stories of leaves on the plant, which will not be separated by any discrete internode. The individual stories cannot be distinguished, resulting in the "bottle brush" appearance of the stem. When the deficiency is severe the apical meristem may die and axillary meristems develop prematurely.

Wattle

(Acacia mollissima)
Symptoms of B deficiency usually first appear on 2-year-old trees during the dry season. The first signs are leaf chlorosis, cambial necrosis, and the drying and death of the growing point on the main shoot.

The branches also die back. Defoliation and death then spreads steadily downward and inward from the apical growing points. If the rains start before the tree is dead, there may be a partial recovery, but further attacks can be expected in subsequent dry seasons, and ultimately the tree dies.

Soil application (suggested rates of application)

	Granubor (15% B) *Fertibor* (15% B)	*Solubor* (20.5% B)	
Crop	**lbs/acre**	**lbs/acre**	**gals/acre**
Birch	0.4 - 1.8	0.2 - 1.2	3 - 24
Eastern cottonwood	0.4 - 1.8	0.2 - 1.2	3 - 24
Eucalyptus	1.1 - 3.5	0.7 - 2.4	14 - 47
	lbs/acre	**lbs/acre**	**gals/acre**
Pines	6.3 - 31.2	4.5 - 22.3	10.7 - 53.5
Wattle	12.5 - 37.9	8.9 - 26.8	21.4 - 64.2

Leguminous cover crops

(Calapogonium mucunoides, Centrosema pubescens, and *Pueraria phaseoloides)*
Growth is stunted. Short thick bines are produced which don't spread over the soil surface. Leaves are very small, thick, brittle, and misshapen. The veins are frequently prominent. Axillary meristems will develop to a limited extent resulting in "prostrate clump" growth habit.

Vegetable crops

Artichoke

(Cynara scolymus)
Breakdown of the tissues in the pith, which is seen when the flower is split vertically and a general crown rot have been associated with B deficiency.

Asparagus

(Asparagus officinalis)
The first symptom of B deficiency is the wilting of the tips of spears on young branched shoots. This is followed by a dying back of the wilted tissue and the development of side shoots which frequently die back. Development of buds on the rhizome is poor growing point being small and chlorotic. The growing point becomes blackened and dies, lateral shoots develop near the base of the plant. The flower buds may shrivel and be shed without opening.

Bean

(Phaseolus spp.)
There have been very few cases of B deficiency on beans, which are particularly sensitive to excess application of boron. As little as 2.5 lbs/acre of B has been known to reduce yield. However, boron deficiency also reduces growth, with leaves near the growing point being small and chlorotic. The growing point becomes blackened and dies, and lateral shoots develop near the base of the plant. The flower buds may shrivel and be shed without opening.

Broad bean

(Vicia faba)
The terminal bud blackens and dies back. The leaves, which are dark green and leathery, fall prematurely. Lower leaf surfaces may be yellow/red in color. Root development is restricted.

Brussels sprouts

(Brassica oleracea var. gemmifera)
The first signs of B deficiency are swellings on the stem and petioles which later become suberized. The leaves are curled and rolled, and premature leaf fall of the older leaves may take place. The veins are frequently wrinkled. The growing point may die, followed by the development of two axillary buds leading to twinning of stems. If the deficiency becomes established before the sprouts are formed, very few develop. If the sprouts have started forming, they remain small, fail to heart and have a loose appearance. The stem pith may be hollow and discolored.

Cabbage

(Brassica oleracea var. capitata)
The characteristic symptom of B deficiency found in the field is the breakdown of the pith of the stem—easily seen when the head is split vertically. Water-soaked spots first develop in the pith, the tissue gradually becomes necrotic and sometimes a cavity may form. If the deficiency occurs at the young seedling stage, the new leaves will be small, distorted, and often thicker than normal. The death of the growing point can follow, but this is not expected under field conditions. Boron deficiency occurs more often on cauliflower and broccoli than on cabbage.

Cauliflower, broccoli

(Brassica oleracea var. botrytis)
The common symptoms of B deficiency in the field are poor and discolored curd and bud formation respectively, which frequently render the crops unsuitable for marketing.

The pith, especially in cauliflower, is liable to develop water-soaked areas, and to become necrotic and ultimately hollow. An early symptom on young seedlings is the rolling and down-curling of the newest leaves which are normally small, brittle and deformed. Under severe boron deficient conditions, cauliflower plants showing such symptoms are unlikely to form a head.

Soil application (suggested rates of application)

	Granubor (15% B) *Fertibor* (15% B)	*Solubor* (20.5% B)	
Crop	**lbs/acre**	**lbs/acre**	**gals/acre**
Asparagus	6 – 13	4 – 9	11 – 21
Brussels sprout	6 – 13	4 – 9	11 – 21
Cabbage	6 – 13	4 – 9	11 – 21
Cauliflower, broccoli	6 – 13	4 – 9	11 – 21
Celery	6 – 13	4 – 9	11 – 21
Chicory	6 – 13	4 – 9	11 – 21
Chinese cabbage	6 – 13	4 – 9	11 – 21
Cucumber	6 – 13	4 – 9	11 – 21
Garlic	6 – 13	4 – 9	11 – 21
Kohlrabi	6 – 9	4 – 6	11 – 15
Leek	3 – 6	2 – 4	4 – 11
Lettuce	6 – 13	4 – 9	11 – 21
Okra	3 – 6	2 – 4	4 – 11
Onion	6 – 13	4 – 9	11 – 21
Pea	3 – 6	2 – 4	4 – 11
Radish	6 – 13	4 – 9	11 – 21
Rhubarb	3 – 6	2 – 4	4 – 11
Spinach	6 – 13	4 – 9	11 – 21
Tomato	6 – 9	4 – 6	11 – 15

Foliar application (suggested rates of application)

	Solubor (20.5% B)	Minimum volume	Maximum concentration
Crop	**lbs/acre**	**gals/acre**	**% w/v**
Asparagus	4 – 9	107 – 428	0.25 – 0.5
Brussels sprouts	4 – 9	107 – 428	0.25 – 0.5
Cabbage	4 – 9	107 – 428	0.5
Cauliflower	4 – 9	107 – 428	0.5
Celery	4 – 9	107 – 428	0.5
Chicory	4 – 9	107 – 428	0.5
Chinese cabbage	4 – 9	107 – 428	0.25 – 0.5
Cucumber	4 – 9	107 – 428	0.25 – 0.5
Garlic	4 – 9	107 – 428	0.25 – 0.5
Kohlrabi	4 – 6	107 – 299	0.25 – 0.5
Leek	2 – 4	43 – 107	0.5
Lettuce	4 – 9	107 – 428	0.25 – 0.5
Okra	4 – 6	107 – 299	0.25-0.5
Onion	4 – 9	107 – 214	0.5
Radish	4 – 9	107 – 214	0.5
Rhubarb	2 – 4	42.8 – 107	0.5
Spinach	4 – 9	107 – 214	0.5
Tomato	4 – 6	107 – 299	0.25

Celery

(Apium graveolens var. dulce)

Brittle stems and the development of brown stripes in the epidermis above the vascular bundles of the petioles is usually the first sign of B deficiency. Sometimes, the brown stripes are so close together that they form a continuous line over the vascular bundles. Transverse cracks develop on the outer surface. The broken tissue curls outwards giving the petiole a hairy appearance.

Blackened and diseased hearts are the most severe symptoms, but they are only found in stunted plants, accompanied by cracked petioles.

Chicory

(Cichorium intybus)

Boron deficient plants are stunted. When deficiency is severe, the leaves are twisted and reddened with weak, brittle petioles and midribs.

Chinese cabbage

(Brassica chinensis)

The midribs crack and turn brown.

Cow pea

(Vigna sinensis)

Upper leaves are pale green and curve down at edges. Growing points die. Seed set is very reduced.

Cucumber

(Cucumis sativus)

The internodes are short and the young leaves are crinkled and deformed. Yellow streaks on the rind become corky, seriously affecting the value of the crop.

Garlic

(Allium sativum)

Boron deficiency has been reported to cause the leaves to bend backwards and to impair the storage properties of the bulbs.

Gilo

(Solanum gilo)

The growing point dies and the upper leaves are small, deformed, and twisted. Few flowers form.

Kohlrabi

(Brassica oleracea var. gongylodes)

Leaf symptoms are only observed in cases of severe deficiency. The leaves become slightly curled and crinkled and are held in an unusually erect position. If the B supply is very limited in the early stages of growth, the edible part of the stem doesn't develop, but if the supply is not so limited, the kohlrabi will develop further and the surface becomes rough and watery.

Leek

(Allium ampeloprasum)

Leeks seem to tolerate very low B supplies without showing any symptoms. Transverse cracks known as "cat scratch" appear to be a characteristic B deficiency symptoms.

Lettuce

(Lactuca sativa)

Boron deficiency causes a reduction in growth, malformation of the young leaves, and development of dark spots—usually near the leaf tip—which later develop into a marginal necrosis. The leaves are thick, brittle, and frequently cupped. Head development is poor, chlorosis also occurs, and the yellow heads become rotten in the center following the death of the growing point.

Tip burn on younger leaves has been associated with B deficiency but this symptom is likely due to other factors. The early stages of B deficiency can be confused with tip burn which, unlike B deficiency, doesn't lead to lack of "hearting" and death of growing point. Roots on B deficient plants are brown, short, and knotted in appearance.

Marrow

(Cucurbita pepo)

New leaves are small, brittle, and misshapen with long lobes. Cracks appear at regular intervals across the upper surface of the petiole. The petioles become "S" shaped when seen from the side. Longitudinal cracks develop on the fruit.

Melon, Cantaloupe

(Cucumis melo cantalupensis)
The terminal bud fails to elongate.

Okra

(Hibiscus esculentis)
The leaves become distorted and brittle. They are reduced in size and have irregular lobe development. The pods remain as short stumps. They don't elongate but remain attached for a long time.

Onion

(Allium cepa)
The leaves turn blue/green and the younger leaves become mottled with distorted shrunken areas. Cracks may appear on the upper surface of the lower leaves, which become stiff and brittle. Root development is poor. Over-wintering may be impaired by B deficiency.

Pea

(Pisum sativum)
It's likely that seed reserves of B will be sufficient for normal growth and a deficiency is only expected when seed produced in a B deficient area is used. Boron deficient seedlings are stunted and have short internodes. The stems are thick and the plant will have a bushy appearance. The young leaflets show a marginal chlorosis and have a tendency to curl inwards. Pod abortion occurs and pods that develop will have thick walls, be small and often contain few or even no seed.

Radish

(Raphanus sativus)
The leaves of B deficient radish are deformed, brittle and chlorotic. In cases of severe deficiency the leaf tip dies. The roots crack and are pale in color. The water-soaked flesh may show brown flecks. Boron deficiency can increase the production of thiocyanates which are known giotrogens.

Rhubarb

(Rheum rhaponticum)
The leaves show reddish markings around the margins and, in the case of severe deficiency, eventually die. The plants are dwarfed and die back.

Spinach

(Spinacia oleracea)
The first sign of B deficiency is the development of small pale green leaves. The plants are stunted and tend to lose their upright growth habit, the leaves spreading outwards. The young leaves are liable to be very small and deformed. The roots are dry and dark in color.

Squash

(Cucurbita spp.)
The leaves are dark green, cupped, brittle, and somewhat rough. The veins—which are thick and contorted—are very prominent especially when they become chlorotic. The petioles are thick and curled. The growing points die back. Roots are stunted and discolored.

Tomato

(Lycopersicum esculentum)

The first sign of B deficiency is a terminal chlorosis on the younger leaves. In severe cases the young leaves are grossly misshapen and the growing points die. The stems are short and thick. Failure to set fruit is common and the fruit may be ridged, show corky patches and ripen unevenly.

FAQ
Boron and micronutrient questions

What is the recommended maximum concentration of B in irrigation waters for continuous use on all soils?

Irrigation waters containing 0.75 ppm B may be continuously used on all soils. One acre-inch of water delivers 0.17 lbs B per acre in waters containing 0.75 ppm B. On fine-textured soils at pH 6.0 to 8.5, irrigation waters containing between 2.0 and 10.0 ppm B may be used for up to 20 years, except for citrus which has a maximum recommendation of 0.75 ppm B.

Branson RL, et al. "Water Quality in Irrigated Watersheds." J Environ Quality. 1975;4:33-40.

How much will increased foliar spray solution pH affect pesticide efficiency?

Pesticides vary in response to pH. Most pesticides take hours or days to break down and some are affected very little by moderate pH changes. Solubor at a rate of 1 lb per 5 gallons of water will typically raise the solution's pH to 8.4. This pH level may not be much higher than many areas where water pH is often above 8.0. There is no strong evidence that pest control has been affected where chemicals are mixed and sprayed immediately.

Gorsuch CS and Griffin RP. Extension Entomologists, Clemson University, Clemson, SC. 29634-0365.

What is the effect of B on animals, such as cattle, consuming forage or hay where excessive rates of B have been applied?

Cows fed 2.5 g B/day for 40 days were not affected in any way. This means that if hay contained 240 ppm B (three times the normal level for alfalfa), a cow could eat 23 lbs of hay per day with no ill effect. An acute lethal dose where 1/2 of test animals (rats) died would be equivalent to 150 g B per 500 lbs animal, or 1,380 lbs of alfalfa in one day if the alfalfa contained 240 ppm B. Two-year studies with rats and dogs showed no effect on reproduction when 350 ppm B was included in the diet, and no effect on fertility, lactation, litter size, weight, or appearance.

Sprague RW. The Ecological Significance of B. Valencia, CA: U.S. Borax, Inc.; 1972.

How much B is supplied in manure?

The average farm manure contains 0.03 lbs of B per ton. If it's assumed that all of the B in the manure is plant available, 10 tons of manure would supply 0.3 lbs of B. This rate of B per acre per year will not supply alfalfa or many other crops with their total B requirements. Poultry manures contain approximately the same B content as average farm manures, but in some situations, B materials are applied to poultry house floors to control insects. Based on the maximum rate of B applied and manure produced, B-treated poultry manure will contain approximately 0.7 lbs of B per ton. If it's assumed that all of the B in poultry manure is plant available, 4 tons of poultry manure (the average rate applied per acre) would supply 2.8 lbs of B. This rate of B per year would supply most crop B needs. Untreated poultry litter however contains only 0.30 lbs of B per ton, and the 4 ton rate would supply only 0.12 lbs of B. This rate of B per acre wouldn't supply most crop needs. Rates of supplemental B and other plant nutrients applied in addition to manure should be based on yield goals along with soil tests and/or plant analyses.

Blanck FC. Handbook of Food and Agriculture. Reinhold Pub Co.; 1955. Chapter, Manure Analyses p. 91.

What is the importance of B/Ca interaction?

Damages to plant tissues occur when calcium and B get far out of balance. A good example of this was shown with peanuts when internal damage (hollow heart) was greatly increased where gypsum (calcium sulfate) was applied without B, causing a wide shift in plant tissue calcium-boron ratio. Hollow heart of peanut completely disappeared where only 0.25 lbs/acre B was applied along with the gypsum, bringing about approximately a five-fold decrease in the plant tissue calcium-boron ratio.

Morrill LG, et al. "B Requirements of Spanish Peanuts in Oklahoma: Effects on Yield and Quality and Interaction with Other Nutrients." Oklahoma Agr Exp Stn. 1977;MP-99.

How do B and nitrogen interact in broccoli and other crucifers?

One possible explanation is that high ammonium nitrogen fertilization levels increased pith calcium concentration (in cauliflower), resulting in a wide calcium-boron ratio and increased pith discoloration. Foliar sprays of B reduced but did not eliminate discoloration.

Bryan HH. Pith Discoloration and Breakdown in Cauliflower [dissertation]. Cornell University; 1964.

How accurate and precise are B soil tests?

Soil scientists have found that the development of common soil test extractants, interpretations, and recommendations have to be limited to physiographic units and common soil characteristics. B soil testing is no exception. Soil texture, organic matter, and soil pH will strongly influence interpretation of the test results. The soil test methods used today accurately reveal the amount of plant available B with an average precision of +/- 0.1 ppm B.

Gartley KL. "1999 Sample Exchange Results Soil, Plant and Manure Samples." Mid-Atlantic Soil Testing and Plant Analysis Work Group, University of Delaware Soil Testing Laboratory. Newark, DE: 1999.

Why do crops grown on soils testing low in B sometimes show no response to B fertilization even when no other limiting factors such as moisture and other nutrients are adequate?

On coarse- or medium-textured surface soils and finer- textured subsoils, B additives from previous years may leach and accumulate in the subsoil where they are available to plant roots.

Sedberry JE, Jr., et al. "Boron Investigations with Cotton in Louisiana." LSU Agr Exp Sta Bull. 1969:635.

How rapidly does B leach out of the topsoil?

Soil texture and the amount of water moving through the soil profile largely determine the potential for B leaching. Soils with plow layer clay contents above 20% (sandy clay loam, clay loam, and finer texture) have a lower potential for B leaching. Soils with less than 20% clay (sand, loamy sand, and sandy loams) are more likely to leach. An application of 4.4 lbs/acre B was shown to leach out of the surface 8 inches of a sandy loam soil within 6 months. B applied at planting will normally remain available for the cropping season on most soils. The recommended annual B application would be better than larger, less frequent additions to minimize leaching losses.

Touchton JT and Boswell FC. "B Applications for Corn Grown on Selected Southeastern Soils." Agron J. 1975;67:197-200.

Would a 10% B material in a bulk blend, or also a homogeneous complete fertilizer granule with 0.25% B supply more granules per sq ft and better supply B than a 15% B material in a bulk blend?

It's true that for a given rate of B applications, the number of granules per sq. ft. is inversely proportional to the percent B in the particle, eg based on a standard granule weight of 2.2 grams/100 granular, a 15% material spread at the rate of 1 lb/acre B would supply 3.15 granules/square foot; a 10% material, 4.74 granules/square foot; a 0.25% material, 189.3 granules/square foot. Plant roots, however, contact only 1% of soil surface area. B moves to plant roots by mass flow and diffusion through soil pores and moisture films. B from 3.15 granules of the more concentrated 15% material would be more likely to sustain an adequate level of soil solution B than would the B from more granules with lower percentage B concentration. In general, yield responses from granulated and from blended fertilizers have been similar.

Aldrich SR. Illinois Fertilizer Conf. 1962.

U.S. Borax product questions

Are U.S. Borax agriculture products approved for use in organic production?

The following products are listed appropriate for organic growers by the Organic Materials Review Institute (OMRI): *Fertibor*, *Granubor*, and *Solubor*. You can find our OMRI certificates on our website.

How do you test your products for accurate boron content?

We use titration to measure wt% of B_2O_3 at our Quality Lab in Boron, California. There, our experts routinely test U.S. Borax borate products.

How do zinc, copper, and manganese sulfate react in spray mixes with *Solubor*?

Solubor spray mixes of 1 or 2% *Solubor* concentration are common. The pH of these mixes rises above 8. At this pH, zinc sulfate converts to zinc hydroxide which is slightly soluble. (Copper and manganese also form hydroxides in pH 8 solutions.) The efficacy of the B and zinc is not altered drastically as far as the plant is concerned, but agitation of the mix is important to maintain particle suspension. Acidifying agents in tank mixes can prevent precipitation.

Handbook of Chemistry and Physics, 30TH ed. Cleveland, OH: Chem Rubber Pub Co; 1948.

Why is adding *Solubor* to high pressure nitrogen solutions not recommended?

The reaction of dry sodium borate with moisture produces boric acid and sodium hydroxide. The ammonium ion in the presence of excess hydroxyl reverts to ammonia and water. The ammonia volatilizes. In high pressure nitrogen solutions, with free ammonia, the evolution of ammonia is accelerated by adding sodium borate to the solution. If these nitrogen fertilizer materials (urea ammonium nitrate solutions, or dry ammonium nitrate blended with sodium borate fertilizer) are combined and incorporated directly into the soil, they can be used together.

Winter KT, et al. "Ammonia Volatilization from Lime-Urea Ammonium Nitrate Suspensions Before and After Soil Application." Soil Sci Soc Am J. 1981;45:1224-1228.

Crop index

Botanical names

20 MULE TEAM BORAX™

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