Recent Research Offers Clues to Boron's Purpose

By Richard J. Hull

As we examine the role of micronutrients in turfgrass nutrition, we enter murky waters when we consider the functions of boron. There is a scarcity of specific research on turfgrasses, so there remain questions about its roles. Since this subject has been reviewed recently (Blevins and Lukaszewski 1998), we interpret the current state of knowledge about boron's importance to turfgrass management.

Boron is required by turf in extremely small amounts and normally is present in dry plant tissues in a range of 6 parts per million (ppm) to 30 ppm (Table 1). Jones (1980) proposed a sufficiency range for boron in turfgrasses of 10 ppm to 60 ppm. Table 1 demonstrates, however, that boron levels of less than 10 ppm are commonly observed in turf with no deficiency symptoms evident.

It's also doubtful whether 60 ppm boron is a critical concentration for any turfgrasses. Plants differ in their boron requirements, with grasses generally having a much lower demand than dicotyledonous plants. Marschner (1995) reports a critical boron concentration range for grasses of 5 ppm to 10 ppm while that for broad-leaved plants ranges between 20 ppm and 70 ppm. Some latex-producing plants have an exceptionally high boron requirement in the 80 ppm to 100 ppm range.

Turfgrasses will respond to small amounts of boron (1.5 pounds/acre to 7.5 pounds/acre) with color, root growth and stand density all improving for five weeks following application (Deal and Engel 1965). Because boron deficiency symptoms can be subtle, slowly affecting meristems of roots and shoots preferentially, an insufficiency may be difficult to spot.

As is the case for most micronutrients, turf grown on sand-based media may suffer mild boron deficiency without the manager ever noticing or recognizing the problem. Thus, it's prudent to know something about boron and how to tell if this essential element might be lacking.

Boron in the soil

Soils generally contain relatively little boron. The earth's crust averages about 10 ppm boron with igneous rocks containing 5 ppm to 15 ppm and sedimentary shales as much as 100 ppm. Most boron containing minerals are weakly soluble, so the release of soluble boron through weathering is slow.

Boron can form complexes with clays and amorphous soil minerals and also become incorporated into organic matter. Hence, the 7ppm to 80 ppm present in most soils, less than 5 percent is in the soil, where it's available to plants.

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Boron is one of only two nonmetallic micronutrients and is sometimes referred to as a metalloid element. It does not undergo oxidation or reduction, having a constant redox state of plus-3. It exists in soil minerals as oxy- or hydroxy- complexes with silicon, aluminum, iron and magnesium. The form of boron in the soil is mostly boric acid and, in alkaline soils, some borate anion.

Also in alkaline soils, boric acid can acquire an additional hydroxide through hydration and become a tetrahydroxy anion.

Boron absorption by plant roots

Under the pH of most soils, boron is present primarily as the uncharged boric acid molecule and is absorbed by plant roots in that form. Roots absorb the anionic forms, which exist only in soils with a pH of more than 7, much less readily. This contributes to a marked decline in boron uptake from solutions when their pH exceeds 7.

The mechanism of boron absorption by plant root cells is unclear, but it likely occurs through a hydrogen ion/boric acid co-transport. In this mechanism, a boric acid molecule crosses the plasma membrane of root cells against a concentration gradient accompanied by a hydrogen ion (H^+) that enters the cell along an electrochemical gradient. The pH of the cell wall space is normally two pH units more acid than the cytoplasm of root cells. Thus, a hydrogen ion would be energetically favored to enter a cell dragging a boric acid molecule with it.

The inhibition of boric acid uptake by roots in alkaline soils is consistent with this idea. In alkaline soils, the hydrogen ion concentration in the soil solution and cell wall volume would by low, thereby reducing the pH gradient favoring hydrogen ion entry into the cell.

Boron mobility in plants

Once inside root cells, boric acid moves into the xylem vessels with the transpirational flow of water, although specific transporters may be involved in xylem loading. The transpiration stream carries boric acid into the leaves and into any other plant organs that are losing water. In the leaves, much of the boron (about 90 percent) remains within the cell wall where it can bind with cell wall polysaccharides. The boron that enters leaf cells is thought to remain there, with little being transported out of the leaves through the phloem with the photosynthate stream.

This immobility of boron in the phloem is supported by observations that boron accumulates in leaves, especially in older leaves. Boron toxicity symptoms are normally observed first at the tips of the oldest leaves, which is exactly where a nutrient immobile in the phloem would be expected to accumulate. Boron deficiency is observed most often in apical meristems and fleshy fruits or stems that receive most of their water and nutrients through the phloem.

However, there are instances where boron transport in the phloem does appear to occur (Marschner 1995). The ability of some plants to redistribute boron within their cells appeared to be linked with their capacity for synthesizing sugar alcohols, especially sorbitol. In an ingenious experiment, Brown et al. (1999) transformed tobacco plants by inserting the gene that encodes for sorbitol biosynthesis. Tobacco normally does not exhibit boron mobility in its phloem and shows obvious deficiency symptoms soon after boron is withheld.

The transgenic tobacco capable of synthesizing sorbitol exhibited delayed deficiency symptoms when boron was withdrawn. When it was applied to mature leaves, plants failed to show any signs of deficiency. Wild-type tobacco quickly exhibited deficiency symptoms when boron was applied only to mature leaves, indicating that redistribution through the phloem could not occur.

In the transgenic tobacco, boron was found to be transported in the phloem as a B-sorbitol complex. Thus it appears that the lack of boron mobility in plants is the result of the plant's inability to synthesize an appropriate carrier molecule that can produce a phloem mobile complex with boron. This research demonstrates that genetically altering plants for more efficient boron use is a serious possibility.

TABLE 1

Boron content in leaf tissues of several turfgrasses

BORON CONTENT*

Turfgrass	Waddington & Zimmerman (1972)	Butler & Hodges (1967)	Turner (1980)
			ppm
Annual bluegrass	36	-	-
Kentucky bluegrass	16	7.5	7.9
Colonial bentgrass	26	6	-
Creeping bentgrass	30	-	-
Tall fescue	22	9	-
Creeping red fescue	26	6.5	9.2
Perennial ryegrass	24	14	9.4
Bermudagrass	-	9.5	-
Zoysiagrass	-	6	-

* AS REPORTED IN TURNER & HUMMEL (1992)

Boron's physiological functions

Since boron was first identified as an essential nutrient element in higher plants in 1923 by the British physiologist Katherine Warington, much research has been performed to determine its function in plants. This effort not withstanding, a well-defined function for boron has yet to be discovered, although it appears we may be getting close (Blevins and Lukaszewski 1998). A list of roles proposed for boron is presented in Table 2.

This long list of possible functions, each of which has research findings that support it, may be interpreted in one of two ways. Either boron may serve many functions in plants or it performs one master function, with the rest being secondary roles. Current thinking favors the master function hypothesis. Therefore, I would like to concentrate on what now appears to be boron's primary function: the formation of cross links among cell wall polysaccharides, as well as between them and membrane surface groups.

Boron has the ability to form di-ester complexes with sugars that contain a cis-diol configuration. Such configurations with boron form links between carbohydrate subunits of cell wall polysaccharides wherever a pair of C-OH groups occurs that is oriented toward the same side of the molecule.

The ring forms of 5-carbon sugars ribose and apiose are most likely to produce such links, but 6-carbon sugars such as mannose and the pectin chains of galacturonic acid may also participate in these boron links. In this way, boron binds hemicellulose chains to pectin polymers at specific sites giving a somewhat ordered structure to this otherwise disorganized gel.

Because boron links can be easily broken by changes in pH, they likely participate in cell wall loosening during cell expansion, which is promoted by auxin-stimulated acidification of the cell walls. Boron links may also form between cell wall carbohydrates and sugar containing membrane proteins (glycoproteins).

All these links give structure to the cell-wall matrix and provide for a close association with the plasma membrane. This allows for orderly cell expansion, regulated hydrogen ion release into the cell wall, retention of essential calcium and control over lignin formation when cell expansion is completed.

If boron is not available, these processes do not occur or become uncoordinated. Normal cell elongation and wall differentiation are also disrupted. This appears to be the primary function of boron. Most other deficiency symptoms are probably indirect effects of a disrupted cell wall-plasma membrane system.

Grass cell walls have a different structure from those of dicotyledonous plants and even other monocots. The major differences are the amount of pectin present and the types and abundance of sugar polymers produced. Grasses appear to depend less on boron to stabilize primary wall structure, although this role remains essential.

Because grasses depend less on extracellular reduction of iron in order to obtain this nutrient from iron-poor soil, they also rely less on boron to regulate the reductant transfer of nutrients across the cell's plasma membrane.

Boron also functions to stabilize cell-wall structure during pollen tube growth. For this, there appears to be no difference between grasses and other plants. However, pollen tube growth is only important during flowering and egg-cell fertilization, which leads to seed development. Thus, grasses experience a substantial decline in seed yield when boron is in short supply, even if no other deficiency symptoms are noted.

Grasses will normally be much less likely to exhibit visible boron deficiency during vegetative growth than most other plants. For this reason, boron is rarely considered to be critical for turf management.

TABLE 2

Postulated roles for boron in plants (MARSCHNER 1995)

1. Sugar transport
2. Cell-wall synthesis
3. Lignification
4. Cell-wall structure
5. Carbohydrate metabolism
6. RNA metabolism
7. Respiration
8. Indol acetic acid metabolism
9. Phenol metabolism
10. Membrane function

Boron toxicity in turf

A much more likely problem for the turf manager is boron toxicity. It's rarely encountered along the Atlantic seaboard or Great Lakes region where soils are typically low in boron. In the West, on the other hand, boron toxicity can be a chronic problem, especially where turf maintenance depends on irrigation.

Based on their experiences in California and Colorado, Ali Harivandi and his colleagues at the University of California-Davis (1992) examined the effects of managing turf using boron-contaminated irrigation water. In dry climates, boron from irrigation water can accumulate to concentrations in the soil of 10 ppm or greater. However, their research indicated that, if turf is growing rapidly, it will dilute boron sufficiently that toxic levels in plant tissues will not occur.

Regular mowing will remove the injured tissues if the tips of the leaves burn, which is the most common symptom of boron toxicity. Turf quality will not be compromised as a result.

Boron will leach from fine-textured soils and sand-based greens when water percolation occurs regularly. However, if the turf culture depends on irrigation and there is insufficient winter or spring rain to leach excess boron out of the soil, it will accumulate to potentially toxic concentrations.

Oertli et al. (1961) compared the amount of boron accumulation in leaves of several turfgrasses. Warm-season grasses appear to accumulate less boron than cool-season species, but this could be a function of the greater growth rate of warm-season grasses during the summer, with a consequent dilution of absorbed boron.

Once in the soil, boron may be slow to leach, requiring twice as much water to carry it below the root zone as do soluble salts (Harivandi et al. 1992). A thorough leaching conducted periodically during the season, along with the capacity to remove injured leaf tips through mowing, should make boron toxicity manageable.

Sources of boron in fertilizer

There are a number of boron sources that can be applied as fertilizers (Table 3). The sodium salts are reasonably soluble and are a source of readily available boron. Solubor is a mixture of sodium pentaborate and sodium tetraborate, and contains 20 percent to 21 percent boron. It's the most concentrated source of boron and, being completely soluble, it's suitable for liquid applications and as a foliar feed.

Colemanite is a natural mineral that is less soluble and can be applied to sandy soils with less probability of leaching. Boron frits consist of finely ground borosilicate glass that release boron slowly and are suitable as a controlled-release material for greens and other sites of high leaching potential.

Organic topdressings and composts are also a source of boron and can supply the modest requirements of turfgrasses. However, if these organic materials are homegrown and are used in an area chronically deficient in boron, they may not contain sufficient boron to support normal plant growth. In such cases, a boron source could be incorporated in the topdressing to address any concern over this nutrient.

What appears to be boron's primary function is formation of cross links among cell-wall polysaccharides, as well as between them and membrane surface groups.

Is boron a problem for turf managers?

The answer to this question is generally "no" unless there is boron toxicity. Since grasses require about one-quarter the amount of boron needed by most other plants and its greatest need is during flowering and seed development, boron deficiency is unlikely to be a problem for the turf manager.

TABLE 3

Boron fertilizer materials and their boron content

SOURCE	FORMULA	% BORON
Borax	Na2B4O7o10H2O	11
Boric acid	H3BO3	17
Colemanite	Ca2B6O11o5H2O	10-16
Sodium pentaborate	Na2B10O16o10H2O	18
Sodium tetraborate	Na2B4O7o5H2O	14-15
Ulexite	NaCaB5O9o8H2O	9-10
Boron frits	Complex borosilicates	11-2

Even so, there may be situations where boron deficiency could cause a subtle decline in turf quality that could be easily overlooked or difficult to diagnose. Sand-based greens and turf growing on very sandy, leached soils could experience a boron insufficiency. Since boron sources are inexpensive and are easy to apply, a periodic application once every three to four years might be good insurance.

Applying boron and other micronutrients in topdressing would be relatively easy and should meet turfgrass needs.

Since excess boron can be toxic to grass,

If tissue levels exceed 50 ppm boron, it would be best not to include it in fertilizers or topdressing.

tissue levels should be monitored from time to time. If tissue boron exceeds 50 ppm, it would be best not to include boron in fertilizers or topdressing. Monitor your turf for tip burn prior to mowing. This is not a danger level for most plants, but it indicates that your turf is not lacking boron and there may be some accumulation occurring.

The amount of boron in turf leaves is a function of growth rate. When growth slows, the amount of boron could increase to near toxic levels. This is normally not a problem, but it's something worth monitoring.

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TURFGRASS TRENDS

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