Zinc usage by turfgrasses

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When investigating the functions of micronutrients in turfgrasses, it quickly becomes apparent that the literature on this subject is virtually nonexistent (Turner and Hummel, 1992).

This is certainly true for zinc (Zn) and the remaining seven micronutrients with the exception of iron (Fe) that was the last nutrient element considered in this series (Hull, 1999a). Because iron deficiencies are not unusual and produce a rather dramatic foliar yellowing that is easily corrected by spraying with a solution of a soluble iron salts or chelates, this micronutrient has received considerable attention. Deficiencies of the other micronutrients are much less dramatic and rarely are identified on turf. That is the impression obtained from reading the various turfgrass management texts but recent evidence suggests otherwise.

Zinc is the third most abundant metallic micronutrient in turfgrass leaves (Table 1) ranging from 22 to 78 ppm. Jones (1980) indicated that Zn tissue concentrations ranging from 20 to 55 ppm should be sufficient for most turfgrasses. It is a reasonably mobile element within plants and can be mobilized from mature tissues toward new growth when the supply becomes limiting.

Because of this mobility, old leaves do not accumulate large amounts of Zn so the measured concentrations fall within a narrower range. Because it is required in relatively large amounts in rapidly growing regions for reasons that will be explained, Zn is often present at concentrations in excess of 200 ppm in shoot tips and other meristematic areas.

Functions of zinc

Zinc performs a greater array of essential functions in the physiology of plants than any other micronutrient. However, few of these functions are so dramatic that their failure due to a Zn deficiency causes symptoms that are immediately identifiable. For this reason an insufficiency of Zn can easily go undetected, especially in turfgrasses where leaves are small and there is no crop yield to monitor plant performance. Here are some of the plant functions for which Zn has been found essential:

ENZYME ACTIVATION: Zinc does not undergo a gain or loss of electrons but exists in plants as a divalent cation (Zn^{+2}) usually bound to an organic molecule. Because the Zn^{+2} cation has a strong capacity to bind with nitrogen (N^{-3}), oxygen (O^{-2}) and sulfur (S^{-2}), it plays an important role in stabilizing the structure of many enzyme proteins. It can bind to provide structural coordination of the enzyme (structural role) or it can bind partially leaving a site free to form a complex with the enzyme substrate, participating directly in the catalytic role of the protein (Marschner, 1995).

There are numerous enzymes that require Zn to stabilize their structure or serve a catalytic function. Besides being essential for the production of ethanol in the fermentation of spirits, alcohol dehydrogenase is essential for turfgrass roots to switch to fermentative respiration when the soil becomes waterlogged and oxygen is not available to support normal oxidative respiration. Alcohol dehydrogenase catalyzes the reduction of acetaldehyde to ethanol and in the process oxidizes NADH to NAD^+ which is essential for carbohydrate utilization to generate metabolic energy.

Most plant roots cannot sustain this anaerobic respiration for long but it does allow roots to remain alive during short periods of saturated soil. Because of this, Zn in alcohol dehydrogenase permits turfgrass roots to tolerate changeable aeration levels.

Photosynthetic CO_2 fixation requires the presence of dissolved CO_2 within the sap of chloroplasts at concentrations sufficient to support acceptable rates of photosynthesis. However, within solutions of pH 8.0, CO_2 comes to equilibrium with bicarbonate (HCO_3^-) such that the concentration of HCO_3^- is more than 50 times greater than CO_2. Thus, when CO_2 is consumed in photosynthesis, it becomes critical that HCO_3^- is quickly converted to CO_2.

This reaction will happen spontaneously but it proceeds more rapidly in the presence of the Zn-containing enzyme carbonic anhydrase (CA). This enzyme is most important in warm-season (C-4) turfgrasses because they fix carbon initially as HCO_3^- (Hull, 1999b). The CO_2 obtained from the atmosphere must be hydrated to HCO_3^- very quickly to maintain a sufficient supply of HCO_3^- to support rapid photosynthesis. CA is essential for this.

Thus, the ability of warm-season grasses to grow well under high temperatures depends upon the activity of a Zn-containing enzyme.

Gene Transcription and Translation: All proteins present in plants and animals are the translation products of messenger RNA (mRNA) that is itself the transcription product of DNA present in the nucleus of each cell. Zinc performs essential roles in these processes, some of which have only recently been discovered.

Within the cell's nucleus, the enzyme that catalyzes the transcription of DNA to form analogous mRNA is called RNA polymerase II and its structure is stabilized by Zn.

In addition, some nuclear proteins that identify those genes (portions of the DNA) that will be transcribed are known as transcription factors and function by forming polypeptide loops that bind with specific bases of the promoter DNA strand, so that gene will serve as a template for mRNA synthesis. These loops in the regulatory proteins are formed by Zn binding with specific amino acids (cysteine & histidine) of the protein, thereby stabilizing the loops (Zn-fingers) so they are structurally capable of binding specific genes and activating their transcription.

The translation of mRNA by ribosomes to produce polypeptides (proteins) is also dependent upon the presence of Zn. It is a structural component of ribosomes and like magnesium (Hull, 1998) is essential for maintaining the 80s ribosome complexes that are capable of translating mRNA to a polypeptide product.

When Zn is in short supply, ribosomes disintegrate into smaller components and protein synthesis all but stops. When Zn is resupplied, protein synthesis resumes and fully functional 80s ribosomes can be seen using an electron microscope. There is also evidence that the actual translation process of mRNA reading by the ribosomes is dependent on the presence of Zn.

Because of its essential role in gene transcription and protein synthesis, Zn is

TABLE 1. ZINC CONTENT* IN LEAF TISSUES OF TURFGRASSES

Turfgrass	Waddington & Zimmerman (1972)	Butler & Hodges (1967) ppm	Turner (1980)
Annual bluegrass	78	-	-
Kentucky bluegrass	52	32	22
Colonial bentgrass	70	50	-
Creeping bentgrass	61	-	-
Tall fescue	50	47	-
Creeping red fescue	54	30	32
Perennial ryegrass	57	52	31
Bermudagrass	-	34	-
Zoysiagrass	-	35	-

* AS REPORTED IN TURNER & HUMMEL (1992)

required for turfgrasses to respond to environmental or management variables.

Any stimulus that would induce a grass plant to do something it was not already doing would likely require the presence of Zn. This would include defensive responses to the infection of a pathogenic fungus or bacterium. Thus, turf will be less resistant to disease if Zn is deficient.

Turfgrass responses to climatic stresses such as high temperatures or drought will also be dependent on Zn availability.

MEMBRANE FUNCTION: In an earlier article (Hull, 1997) I discussed the role played by calcium in stabilizing the structure of transport proteins in cell membranes, especially those responsible for the uptake of nutrient ions. We now know that in order for membranes to function, their structural integrity is also dependent on the presence of Zn. This could be the result of Zn^{+2} linking negatively charged phospholipids with membrane proteins.

When Zn is deficient, cell membranes become leaky and small solutes such as sugars, acids and nutrient ions can be lost. The addition of Zn quickly restores the structure and semipermeability of membranes (Marschner, 1995).

However, Zn may function more in a protective role by degrading toxic oxygen radicals especially superoxide ($O_2\bullet^-$). Membrane bound enzymes are capable of oxidizing NADPH in order to reduce soil Fe^{+3} to Fe^{+2} (Hull, 1999a) prior to its absorption by root cells. Although this process is less important in grasses, such membrane electron transfer reactions can be important for cell wall synthesis (lignin polymerization) and as a defensive measure to deter pathogen invasion and the onset of disease. In the presence of free oxygen (O_2), these reductase enzymes can contribute an electron to O_2 producing the $O_2\bullet^-$ radical via the reaction:

$$NADPH + 2O_2 \longrightarrow NADP^+ + 2O_2\bullet^-$$

Superoxide can attack membrane lipids causing the insertion of peroxide (-C-O-O-C-) groups or reducing double bonds, both of which will alter membrane structure and disrupt normal function.

Because Zn along with copper (Cu) is a component of the cytosolic CuZn-superoxide dismutase (CuZn-SOD) enzyme that effectively degrades $O_2\bullet^-$ rendering it less active, Zn likely owes its role in membrane function in part to its contribution to neutralizing the production of toxic O_2 radicals.

AUXIN STABILITY: For a long time, Zn has been linked with maintaining the proper hormonal balance in plants.

Many Zn deficiency symptoms such as stunted growth and little-leaf have been associated with a sharp decrease in the concentration of the auxin — indoleacetic acid (IAA). The addition of Zn normally restores plant growth and increased auxin levels.

Auxin can be synthesized via several biochemical pathways, but most use tryptophan (amino acid) as the starting material.

There is little evidence supporting a role for Zn in tryptophan synthesis and its function in IAA metabolism is also obscure. Auxin levels, like those of most natural growth regulators, are kept in balance to maintain proper growth by balancing synthesis with degradation. Because IAA has several paths, it is difficult to link Zn with either process.

Marschner (1995) suggests that IAA destruction (oxidation or decarboxylation) may be stimulated by oxygen radicals that accumulate when Zn is in short supply. This stimulation of IAA degradation could explain the low auxin levels when Zn is deficient. It also can explain the chlorotic and necrotic leaf symptoms often associated with Zn deficiency.

Zinc uptake

Zinc absorption by root cells has been shown to exhibit saturation kinetics (uptake rate does not increase in a linear fashion with increased external Zn concentration). A similar uptake pattern has been observed for most nutrient ions. However, laboratory measurements of Zn^{+2} concentrations required to support adequate root uptake are much greater than those present in the water phase of most soils (Kochian, 2000).

Zinc uptake is half saturated at 2-5 µM Zn^{+2} while soil concentrations of Zn^{+2} are

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generally in the nM range or two orders of magnitude lower than what would be required to meet plant needs. Recent molecular studies suggest that Zn transport proteins cloned from yeast can increase the root affinity for Zn^{+2} but still this was insufficient to deliver the Zn needed.

Much of the soluble Zn in soils is bound to natural soil chelates, and the phytosiderophores from grass roots could acquire some of this Zn and make it available for root uptake. This is a subject of active investigation.

This suggests that sources of Zn other than the free ion may be available to plant roots. For grass roots that release organic chelates (phytosiderophores) in response to iron deficiency (Hull, 1999a), a similar mechanism may operate for Zn recovery and uptake. Phytosiderophores released by grass roots can not only bind Fe^{+3} but also Zn^{+2}, Cu^{+2}, Mn^{+2}, Ni^{+2} and Co^{+2} and like iron, these may be absorbed by roots in the form of a bound chelate.

Much of the soluble Zn in soils is bound to natural soil chelates and the phytosiderophores from grass roots could acquire some of this Zn and make it available for root uptake. This is a subject of active investigation and raises the possibility of breeding turfgrasses having greater efficiency for Zn recovery from the soil.

Zinc deficiency and toxicity

Zinc deficiencies are not uncommon. The Food and Agriculture Organization of the UN has reported that 30% of the world's cultivated soils lack sufficient Zn for normal crop production (Kochian, 2000).

While Zn-deficient soils are likely to be less critical for turf management where annual crop removal is not a factor, there are numerous situations where Zn may become limiting for proper turf growth and quality. Zinc is much less available in high pH calcareous soils and in heavily leached sandy soils (Marschner, 1995). As turf management is pushed onto sites increasingly less suitable for grass growth, micronutrient deficiencies and toxicities become more likely.

In general, grasses are more tolerant to low Zn environments. This might be due to their ability to release phytosiderophores in response to Zn deficiency and these will mobilize and make available Zn not normally accessible to plant roots. A Zn deficiency normally reduces stem growth and reduces leaf size but these symptoms will not be very obvious in turfgrasses. Lower leaves are most likely to exhibit chlorosis between veins and a general reddening may be observed if Zn-deficient grass is growing in high light.

Deal and Engel (1965) observed little response by Kentucky bluegrass to Zn applications. However, root growth was stimulated by a 5.6 pounds per acre application and rhizome growth was inhibited by a 28 pounds per acre treatment.

Root growth should be most responsive to Zn applications because roots are the first organs to receive the nutrient and its presence will stimulate nuclear division and protein synthesis both of which promote growth. A Zn deficiency will normally cause an increase in the root:shoot ratio since root growth will be less depressed than shoot growth. When excess Zn is applied, leaf growth also will be stimulated and this may divert energy away from rhizomes and roots resulting in less below ground development and vegetative spread.

It has been recognized for some time that high phosphorus (P) levels can accentuate a Zn deficiency. Because phosphate salts of Zn are virtually insoluble in water, it was assumed that high P levels would precipitate Zn in the soil and even in plant cells making it less available. We now know that the P interaction with Zn may have a more physiological explanation.

When plants were grown under conditions deficient in several micronutrients, Cakmak and Marschner (1986) found that the P level within the leaves was unaffected except when Zn was lacking. Then, the P concentration in shoots increased to more than two times that of normal plants (Fig. 3). Because Zn is required for proper functioning of cell membranes, a lack of this nutrient could allow free uptake of excess phosphate causing a P toxicity to develop. Because P did not accumulate in the roots, it was concluded that low Zn levels did not inhibit, and may even facilitate, P loading into the xylem and transport to the shoots. Thus, it now appears that some Zn deficiency symptoms may actually be signs of P toxicity especially when soil P levels are high (Marschner, 1995).

Sources of zinc

Should you be concerned about the Zn status of your turf? For turf growing in slightly acid soils that are not excessively sandy, Zn supply is not likely to be a problem. However, on sandy or calcareous soils or sand-based greens, Zn availability may be a matter of concern.

In high pH calcareous soils, Zn is rapidly bound to clay and $CaCO_3$ from which it is very poorly available to plants. Adding a Zn source to such soils may have little benefit because the immobilization is so rapid that little remains available to the roots. If a general soil modification lowering the pH is not practical, foliar applications of $ZnSO_4$ or a Zn-chelate may be the only option. Because Zn is reasonably mobile within plants, the benefits of a foliar feeding will last for a month or more.

It is best to make a foliar application late in the day when the humidity is high and the spray will remain liquid for several hours. It is in the free liquid form that Zn will be most readily absorbed into the leaves.

Delay mowing after spraying a micronutrient since much of the material will be lost in the clippings and little opportunity will be provided for the Zn to translocate to the grass crowns and roots.

Thorough coverage of leaf surfaces is important so a surfactant (wetting agent) should be added to the spray solution. A Zn concentration of 0.25 to 1.0% should be appropriate for turf.

If immobilization in the soil is not a problem, Zn can most effectively be applied through the soil. Here, $ZnSO_4$ is the most cost effective source to apply Zn at rates of 2 to 20 lbs. per acre. Zinc chelates have been found less effective than inorganic $ZnSO_4$ for soil applications. Composts can be a good source of micronutrients including Zn and can be applied as a topdressing to insure against deficiencies.

If you have a Zn deficiency problem, compost prepared from clippings derived from your turf may not supply adequate amounts unless it is reinforced with $ZnSO_4$ or some other source of available Zn.

Zinc can become toxic if available in excessive amounts. However, making periodic applications at recommended rates should not lead to toxicity. Tissue analysis is the best guide to Zn nutritional status. If your turf contains Zn at the lower end of the ranges presented in Table 1, you might apply Zn following the guidelines above.

Deficiency symptoms are a poor guide to Zn requirements since they are difficult to detect and will not be evident until substantial injury has already occurred.

— The author is on the Editorial Review Board.

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