A PRACTICAL RESEARCH DIGEST FOR TURF MANAGERS

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PESTICIDES

Pesticide Runoff: How Does Turf Contribute?

By *Allison T. Walston, R. Chris Williamson and John C. Stier*

As urban areas expand, so do our urban landscapes, with turf areas being a major component. As golf continues to increase in visibility and higher values and expectations are placed on lawns and landscapes, response to these demands include increasing maintenance inputs in turf. Increased public expectations for high quality turf have raised concerns about environmental safety especially in reference to our drinking water.

Public advocacy groups as well as government agencies have initiated local and national reforms to protect ground and surface water from chemical contamination. Today's turf managers face the challenge of maintaining well-manicured turf with increasingly restricted inputs.

Turf industry challenges

The turf industry has increased rapidly since the 1960s, and turf areas cover more than 30 million acres, including 50 million home lawns, golf courses, parks, athletic fields, cemeter-

TABLE 1. RUNOFF STUDY APPLICATION DATES

DATE	PESTICIDE	APPLICATOR	ACTIVE INGREDIENT
8/17/99	GrubEX	Homeowner	Imidacloprid
	Merit	Professional	Imidacloprid
10/15/99	Weed-B-Gon	Homeowner	2,4-D, MCPP, Dicamba
	Horse Power	Professional	MCPA, Dicamba, Triclopyr
4/5/00	Scott's Turf Builder	Homeowner	Pendimethalin
	Barricade	Professional	Prodiamine
6/9/00	Diazinon	Homeowner	Diazinon
	Dursban	Professional	Chlorpyrifos
7/19/00	GrubEX	Homeowner	Imidacloprid
	Merit	Professional	Imidacloprid
10/23/00	Weed-B-Gon	Homeowner	2,4-D, MCPP, Dicamba
	Horse Power	Professional	MCPA, Dicamba, Triclopyr

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ies, sod farms, and other sites (Potter, 1998).

The value of the U.S. turf industry is estimated to be greater than $45 billion dollars per year (Potter 1998). Urban landscapes require specialized inputs for a desired quality, and pesticides, fertilizers, and irrigation are necessary tools. Advocacy groups, concerned citizens, media, public, as well as governmental regulators often closely scrutinize turf managers.

Regulators attempting to reduce pollution sometimes act hastily, and may not examine the various benefits for well-manicured turf (Peacock and Bowman 1999). Since the public is concerned about agrochemical applications (Cisar and Snyder 2000) in the urban setting, many fears and emotions are exposed and expressed. Consequently, the turfgrass industry must effectively educate, inform, or communicate the tremendous benefits of turf to all parties, public and government.

Potential problems exist when dealing in urban landscapes because they contain large areas of impervious surfaces. Driveways, sidewalks, and streets bisect areas of urban landscape settings that may have highly manicured turf. As cities continue to grow, so does the amount of land that is being paved with impervious surfaces.

Impervious vs. pervious

Large cities usually have a substantially greater ratio of impervious to pervious surfaces that generate a high potential for urban runoff. Pervious surfaces, like well-maintained turf, minimize surface runoff by trapping rainwater, irrigation, and snowmelt, filtering the water as it percolates into the ground. Such a system can prevent much potential runoff from reaching surface waters directly or from entering storm sewers.

Unlike pervious surfaces, impervious surfaces, such as concrete, do not allow the rainwater to percolate; thus the water remains on the surface, accumulates, and finally runs off in large, uncontrollable amounts.

The U.S. Environmental Protection Agency (EPA) estimates that impervious surfaces (concrete) in a typical city block can produce nine times more runoff than a wooded area of the same size (EPA, 2000). This provides a perspective of an idea of how much more runoff comes from impervious surfaces compared to pervious surfaces. Pesticides may present problems when applied to impervious surfaces. Rainfall or irrigation may carry the pesticide into the storm sewers and lead to water contamination.

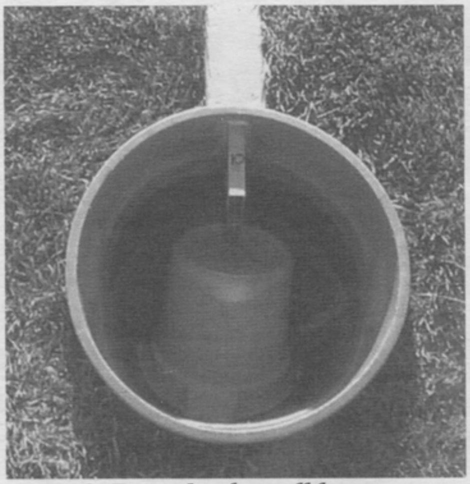

Figure 2. Example of runoff from a concrete plot after irrigation event.

Pesticide runoff defined

So what is pesticide runoff and are urban landscapes a potential source?

The EPA defines pesticide runoff under the category of nonpoint source pollution. Nonpoint source pollution occurs when rainfall, snowmelt, or irrigation runs over land or through the ground, picking up pollutants, such as pesticides, and deposits them in surface waters or groundwater.

However, pollutants, especially in urban nonpoint source pollution, do not only include pesticides. Pesticides are just a small part, and most of the runoff contamination consists of sediments, nutrients, pathogens, salts, oils, non-agrochemicals and heavy metals (EPA 2000).

Runoff occurs when the precipitation rate is greater than the infiltration rate. Factors like time between a pesticide application and a precipitation event, excessive soil moisture and the slope of the area are just a few examples of causes (Cole et al. 1997).

The EPA considers urban runoff a major component of nonpoint source pollution. Urban runoff was ranked first in source pollution for estuaries (bird sanctuaries) and third in largest sources of pollution in surveyed lakes by a Water National Quality Inventory in 1994 (EPA 2000).

Water quality issues

Approximately eighty percent of our drinking water comes from groundwater (EPA, 2000). The concern over the quality of our drinking water has initiated legislation by federal, state, and local regulations governing drinking water conditions. One example, the Safe Water Drinking Water Act of 1974, ensures that the public water supplies meet national standards to protect consumers from harmful contaminants in drinking water. It requires EPA to regulate contaminants that present health risks.

This Act was amended in 1986 and 1996 and now the EPA screens for over 50 chemicals. Most of the chemicals are used exclusively in agriculture with only a few used in turf. The Clean Water Act, passed in 1977, allowed the EPA to set standards for water quality of surface waters, including chemical contaminants.

Claims or allegations made by the media about the dangers of turf pesticides contaminating drinking water are not usually supported by scientific research. Many university studies show that less than one percent of pesticides leach from the application site with the majority remaining in the turf or soil/thatch layer until it is degraded (Cisar 1998).

Kussow found that 70% or more of the annual turf surface runoff occurs when the soil is frozen as it simulates an impervious surface and does not allow the snowmelt to infiltrate. Other studies show runoff concentrations of dissolved pesticides in turfgrass are low (Harrison et al. 1993), especially when irrigation is applied heavier than normal (Watshke et al. 2000).

So, if the soil is frozen, it reacts as an impervious surface, and as the soil thaws, nominal amounts of pesticide may be detected but usually the pesticide remains in the intended area. Consequently,

The EPA estimates that impervious surfaces (concrete) in a typical city block can produce nine times more runoff than a wooded area of the same size.

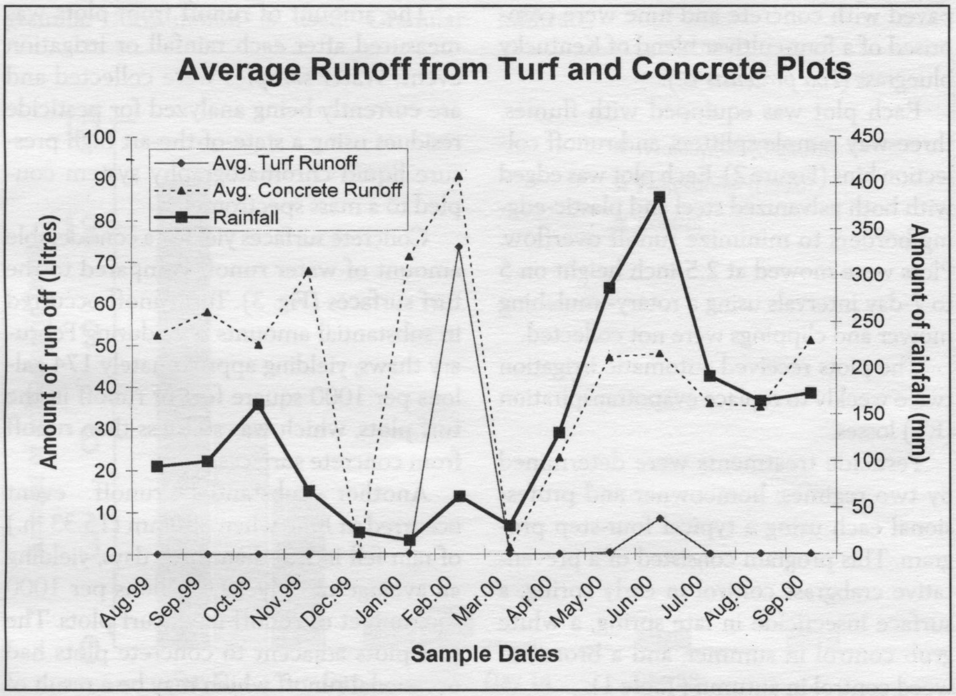

Figure 3. Runoff amounts from turf and concrete surfaces compared to rainfall (mm).

Keep lawn turf mowed between 2- to 3.5-inch height: taller grass reduces runoff rates.

researchers are continuing to better understand the roles that turf plays in fertilizer and pesticide runoff from urban areas.

What is not known is the relative amounts of runoff from turf compared to impervious surfaces, and how this influences pesticide contamination of runoff water.

Current research findings

At the University of Wisconsin-Madison, we are examining pesticide runoff from urban landscapes. Pesticides have a greater potential for contaminating drinking water, via surface runoff, when applied to impervious surfaces, driveways and sidewalks, compared to a pervious surface such as turf. The objective of this study is to quantify the potential runoff of lawn care pesticides commonly used by both professionals and homeowners on pervious and impervious surfaces.

Research plots were established at the O.J. Noer Turf Research Facility in Verona, Wisconsin (Fig. 1). The study site has an average slope of 5.78%. Eighteen 8 x 14 foot plots were established; nine were paved with concrete and nine were comprised of a four-cultivar blend of Kentucky bluegrass (*Poa pratensis* L.).

Each plot was equipped with flumes, three-way sample splitters, and runoff collection bins (Figure 2). Each plot was edged with both galvanized steel and plastic-edging borders to minimize runoff overflow. Plots were mowed at 2.5-inch height on 5 to 7-day intervals using a rotary- mulching mower and clippings were not collected.

The plots received automatic irrigation twice weekly to replace evapotranspiration (ET) losses.

Pesticide treatments were determined by two regimes: homeowner and professional each using a typical four-step program. This program consisted of a preventative crabgrass control in early spring, a surface insecticide in late spring, a white grub control in summer, and a broadleaf weed control in autumn (Table 1).

The homeowner plan used granular formulations of pendimethalin, diazinon, imidacloprid, 2,4-D, MCPP, and dicamba. The professional program used liquid applications of prodiamine, chlopyrifos, imidacloprid, MCPA, dicamba, and triclopyr. Treatments were started in June of 1999.

Figure 1. Pesticide runoff plots in Verona, Wisconsin at the O.J. Noer Turf Research Facility.

Granular pesticides were applied with a drop spreader and liquid products were applied with a CO2-powered backpack sprayer. After each application the treatment was irrigated as required by the label. Products were applied to turf and concrete plots for homeowner and professional product, respectively.

Untreated plots served as controls. The experimental design was a randomized complete block with three replications.

The amount of runoff from plots was measured after each rainfall or irrigation event. Water samples were collected and are currently being analyzed for pesticide residues using a state-of-the-art high pressure liquid chromatography system coupled to a mass spectrometer.

Concrete surfaces yielded a considerable amount of water runoff compared to the turf surfaces (Fig. 3). Turf runoff occurred in substantial amounts only during February thaws, yielding approximately 174 gallons per 1000 square feet of runoff in the turf plots, which was still less than runoff from concrete surfaces.

Another substantial runoff event occurred in June when 390mm (15.33 in.) of rain fell in less than three days, yielding an average of only 19.6 gallons per 1000 square feet of runoff in all turf plots. The turf plots adjacent to concrete plots had occasional runoff which may be a result of the concrete plots overflowing. Runoff from turf plots not adjacent to concrete plots occurred only on the two dates listed.

Preliminary sample analysis of the first application of imidacloprid shows pesticide runoff from concrete surfaces was greater for the granular formulation than for the liquid formulation (Fig.4). Imidacloprid concentrations in runoff decreased quickly after the day of application but were still detectable 28 days after application. Runoff from turfed plots had lower concentrations of imidacloprid compared to concrete samples, 3mg L^{-1} in turf samples and 16mg L^{-1} in concrete samples. Pesticide runoff from turfed plots was negligible except for one plot which was between two concrete plots.

It is likely some of the pesticide from the concrete plots overflowed into the turfed plot flume, a problem which has since been corrected. Consequently this treatment will be repeated.

Lessons learned

What should professional and homeowner applicators keep in mind during applications?

Pesticides in urban runoff can be prevented largely by keeping pesticides off impervious surfaces regardless if a liquid or granular formulation is used. Granular products should be applied with a drop spreader to minimize the potential for them to be accidentally applied to driveways, sidewalks or streets.

Deflection shields on the rotary spreaders can help but this often causes an over-application of the product in the area adjacent to the deflector shield. If granular products are inadvertently applied to impervious surfaces they should be immediately swept or blown into the turf.

The professionals' approach

How should professionals discuss turf runoff with homeowners?

The amount of irrigation applied is directly related to the amount of potential runoff from a residential landscape. Other factors include the type of soil (sandy soils will likely have less runoff than compacted and/or clay soils), mowing height, and amount of turf cover. The more irrigation that is applied increases the potential for runoff: if the lawn is irrigated to field capacity shortly before a rainstorm, then the rainwater will be more likely to runoff since there will not be space in the soil for it to infiltrate.

Many studies show that less than one percent of pesticides leach from the application site, with the majority remaining in the turf or soil/thatch layer until they are degraded.

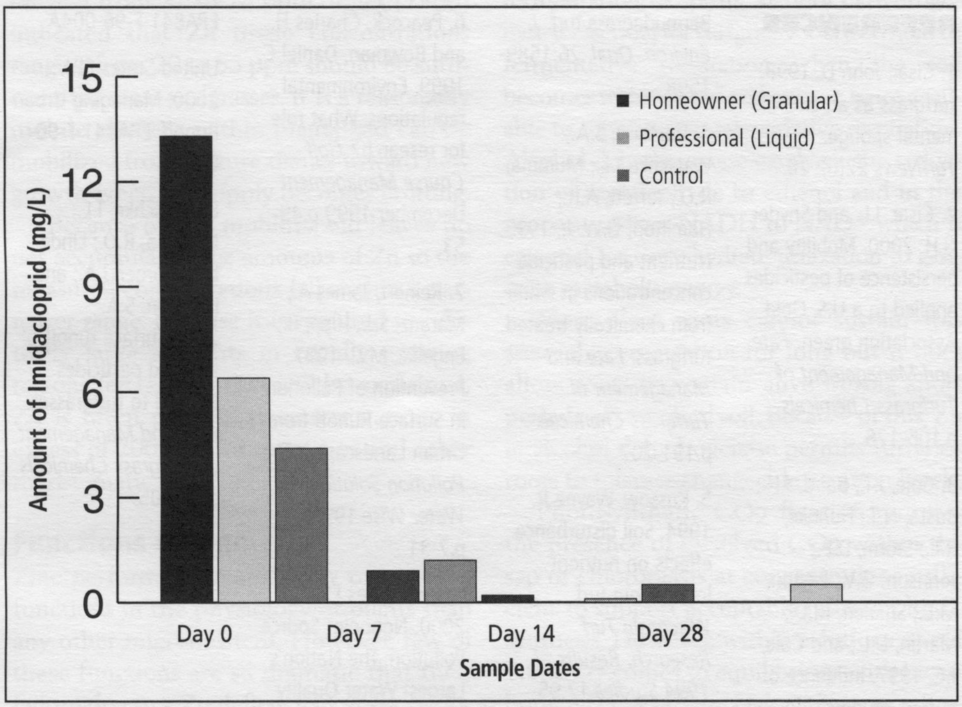

Figure 4. Imidacloprid concentrations in runoff from concrete plots, O.J. Noer Turf and Educational Research Facility, Verona, WI, 1999.

If soils are compacted, core aerate the areas periodically to allow better infiltration rates and encourage better turf growth. Reroute traffic if necessary to reduce compaction.

Keep lawn turf mowed between 2-3.5 inch height: taller grass reduces runoff rates.

Allowing the grass to grow too high causes other problems and can even reduce turf density as shading will occur. Keep the lawn properly fertilized. Lawns that do not get fertilization can have low turf density which results in more runoff.

Keep lawns mowed within the recommended mowing height and do not remove more than one-third of the leaf tissue at any one mowing (the One-Third Rule).

When possible, use plant materials that do not require high inputs of irrigation and pesticides to reduce the potential for runoff and contamination (Reinert 1997). When properly used and managed, turfgrass has many benefits for the urban environment.

The overall volume of runoff water is decreased, air temperatures and noise pollution are reduced, erosion is prevented, water is filtered as it percolates into the ground. Good turf areas are also useful for recreation and are part of an attractive landscape which can increase a home's value by up to 15%.

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Zinc usage by turfgrasses

By Richard J. Hull
University of Rhode Island

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)

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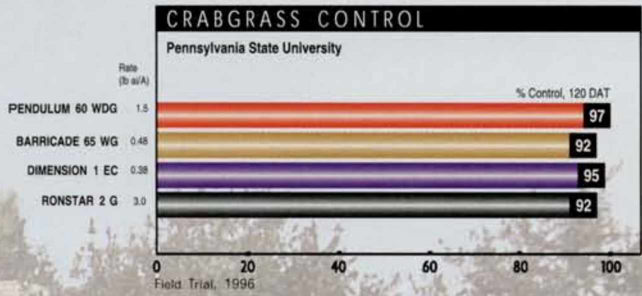

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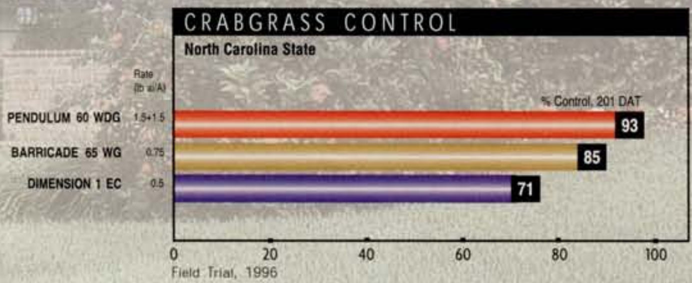

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required for turfgrasses to respond to environmental or management variables.

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

Zinc is the third most abundant metallic micronutrient in turfgrass leaves ranging from 22 to 78 ppm.

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.

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.

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 percipitate 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.

Sources of Zn other than the free ion may be available to plant roots.

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Where can I purchase entomopathogenic nematodes, such as those discussed in Parwinder Grewal's May 2001 article?

We received several questions from readers relating to Grewal's article on using nematodes for turfgrass pest management. They were looking for commercial sources of nematodes. In the section on Page 4 titled "Where to buy" several Web sites are given listing commercial sources (those sources are not listed in Table 1 or Table 2, so you have to read the "fine print" all the way through).

The following outlets are listed at Grewal's site (www2.oardc.ohio-state.edu/netmatodes/nematode_suppliers.htm):

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www.biocontrol.ch/

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