Phosphorus availability in turfgrass rootzones after organic and synthetic N fertilizer apps

ORGANIC FERTILIZERS have increased in popularity over the past 10 years due to the belief they are more environmentally sound to use than synthetic fertilizers. Most fertilizers derived from organic materials contain phosphorus as well as nitrogen, so use may be affected in states that legislate the application of P to lawns. States are considering exempting organic fertilizers from their zero-P legislation, as Wisconsin did, because it is thought that P from organic sources is less likely to be lost in leachate or runoff.

Fertilizers are applied on turfgrasses as needed based on N form and content. Many organic fertilizers contain as much P as N in their formulations, and therefore similar amounts of P and N are applied with each application. Soil tests in native soil and a fairway sand and peat mix used in the Pacific Northwest showed that organic fertilizers applied at rates to provide adequate N for acceptable turf increased soil Bray-1 P levels from 16 to 18 mg/kg to 23 to 66 mg/kg within 3 years. Oxalate extractable Fe, Al, and P was determined for all treatments in both soils and used to calculate phosphorus saturation (PSI). PSI values from sand treated with one organic fertilizer source were significantly higher than measured in other treatments, indicating future risk of P loss with repeated applications of this organic fertilizer.

Because of concerns about phosphorus effects on eutrophication of surface waters, local and/or state governments New Jersey, Maine, Florida, Wisconsin, Minnesota, and Washington have adopted restrictions on residential use of phosphorus-containing fertilizers. Urban and suburban lawns pose a specific concern for potential P loss, because managed turfgrass often abuts impermeable surfaces such as sidewalks, driveways, and curbs, which provide a direct conduit for P transport to storm drains and surface water.

Increased recycling of organic waste streams into organic slow-release fertilizers has led to increased availability and popularity of these materials. Many homeowners and professional landscapers use these natural organic slow-release fertilizers to limit the loss of nutrients from lawns through leaching and runoff.

Some phosphorus-restriction legislation is considering exempting organic fertilizers based on the premise that risk of P loss is reduced with these materials. However, many natural organic-based fertilizers (particularly manures and municipal biosolids) supply an excess of P when applied at rates to meet plant N needs. When high-P organic fertilizers are applied repeatedly, excess P accumulates in soil, potentially increasing the risk of runoff and leaching loss.

The risk of loss of P from natural organic sources depends on the availability as well as the concentration of P in those sources. Although P from organic sources is generally less available to leaching and runoff than synthetic P sources, P availability varies widely by source. Biosolids P tends to be less available than manure P, but even among biosolids sources P availability can vary widely.

Understanding the effect of repeated applications of natural organic lawn fertilizers on soil test P can provide guidance for the suitability of these materials in P sensitive areas. If P availability is low enough in organic fertilizers, it could be possible to use them without increasing the risk of water quality degradation. Evidence shows that the risk of soluble P loss occurs at much higher soil test levels than those needed for agronomic sufficiency.

Researchers have proposed alternative soil tests to assess environmental risks, such as phosphorus saturation (PSI), dissolved P index, or water extractable P. No environmental soil P test is widely recognized and in common use.

Agronomic tests also have some value as environmental indicators. Another factor is the effectiveness of P fertilizers in changing

▼ **Table 1.** Fertilizer products applied to soil and sand root zones at WSU-Puyallup, RL Goss Research Facility in Puyallup, WA, 2008-2011.

Fertilizer product	Rate	Fertilizer formula	Ingredients
Organic 6-7-0	1×	6-7-0[a]	Biosolids, 75% insoluble N
Organic 6-7-0	1.5×	6-7-0	Biosolids, 75% insoluble N
Organic 8-3-5	1×	8-3-5	Feather, meat, blood, fish, poultry and bone meals, 90% insoluble N
Organic 8-3-5	1.5×	8-3-5	Feather, meat, blood, fish, poultry and bone meals, 90% insoluble N
PCSCU 20-5-10	1×	20-5-10	Proforma, 60% of N as PCSCU, mono-ammonium phosphate, potassium sulfate

[a] Organic 6-7-0 was originally labeled as 5-4-0, but analysis form 2008-2010 showed that it consistently contained 6% N and >7% P_2O_5. The label was changed to 6-7-0 to reflect that analysis in 2010.

soil test P (17), with greater effectiveness indicating more rapid change in soil test P per unit of fertilizer P applied (poorer buffering), and greater long term risk of P loss. The objective of this study was to determine how repeated N-based applications of organic fertilizer sources to established turfgrass affected soil test P and P saturation in native soil and a sand-based rootzone mixture under field conditions.

▼ **Table 2.** Annual nitrogen (N) and phosphorous (P_2O_5) application rates for soil and sand root zones.

Fertilizer product	Soil	Sand	Soil	Sand
	kg N/ha/yr		kg P_2O_5/ha/yr	
Organic 8-3-5 1×	147	245	55	92
Organic 8-3-5 1.5×	221	368	83	138
Organic 6-7-0 1×	177	294	206	343
Organic 6-7-0 1.5×	265	441	309	515
PCSCU 20-5-10	147	245	37	61

FERTILIZER APPLICATIONS AND MEASUREMENTS

For this study, fertilizers were applied on an N basis, using natural organic and synthetic fertilizer sources on perennial ryegrass plots on two rootzone media over 3 years (July 2008-June 2011). Soil samples from the plots were analyzed to determine changes in P availability in each treatment area after three years of applications. Application rates of the fertilizers were based on their N content for the original experimental design; therefore, P levels were not equalized among treatments.

Perennial ryegrass was grown on both a Puyallup fine sandy loam native soil (coarse-loamy over sandy, isotic over mixed, mesic Fluventic Haploxerolls) and a USGA sand/peat 90/10% rootzone mixture in the Puyallup Valley of western Washington, south of Seattle. The plots on the native soil were maintained at 62.5 mm as a home lawn and the plots on the sand/peat mixture were maintained at 12.5 mm as a golf course fairway. All grass clippings were returned to the plots. The experimental design for each site was a randomized complete block with five fertilizer treatments and four replications. Plot size was 1.5 m by 3 m.

Each plot was fertilized with one of five treatments. The treatments included two natural organic fertilizer sources at a 1× and a 1.5 × N rate and a synthetic slow-release product at a 1× N rate. The target annual N rate (1×) for the native soil plots was 147 kg/ha , consistent with recommendations for home lawns, while the target annual N rate (1×) for the sand/peat plots was 245 kg/ha, consistent with golf course fairway management. Fertilization was split into three equal applications per year on the native soil plots and five applications per year on the sand/peat plots. The 1.5× rate treatments received 50% more fertilizer on each application date.

The organic fertilizer sources were Organic 6-7-0, made from anaerobically digested and heat-dried municipal biosolids, and a commercially available Organic 8-3-5, made from mixed animal by-products. In the field, the Organic 6-7-0 N application rate was slightly higher than the Organic 8-3-5 rate. This was because the product was originally labeled as 5% N (5-4-0), but subsequent analysis showed it to be 6-7-0. Based on the fertilizers applied to each treatment on an N basis, the amount of P added per year in the organic fertilizers ranged from 55 to 138 kg P O /ha for the Organic 8-3-5 and from 206 to 515 kg/ha for the Organic 6-7-0. The synthetic slow-release control N source was a 20-5-10 formulation containing polymer-coated, sulfur-coated urea (PCSCU). The P in this formulation was monoammonium phosphate. It was applied at the same N rate as Organic 8-3-5. Phosphorus rates for this material were 37 kg P O /ha/year for native soil managed as home lawn and 61 kg/ha/year for sand managed as a golf course fairway.

For the native soil plots managed as a home lawn, fertilizer application dates were August and October 2008; May, June, and Oct 2009; April, August, and October 2010; and April 2011. For the sand-based plots managed as a golf course fairway, fertilizer application dates were August, October, and November 2008; April, June, July, September, and November 2009; March, May, August, September, and November 2010; and March and May of 2011.

In July of 2011, six to eight 25-mm-diameter soil cores were removed to a 100-mm soil depth from each plot. Unfertilized control samples were taken at the same time from untreated areas surrounding the plots. Verdure and thatch were discarded. Samples were mixed, placed in paper bags, moved to a greenhouse, and allowed to air dry for 1 week. After drying the samples, they were analyzed for Bray 1-P and ammonium oxalate extractable Fe, Al, and P. This data was used to determine phosphorus saturation (PSI) in each treatment in each soil type. We also compared the effectiveness of the P fertilizers in changing Bray-1 P, calculated as the slope of the linear regression of Bray-1 P vs. total fertilizer P applied. All data were analyzed using SAS PROC ANOVA, with means separation by least significant difference following a significant F-test.

Phosphorus saturation was calculated as: PSI = P / [Fe + Al], where P, Fe, and Al are the molar concentrations of oxalate-extractable phosphorus, iron, and aluminum in the soil.

A similar oxalate extraction and calculation was done on the two natural organic fertilizers to determine the relative degree of P binding with Fe and Al in each material.

PHOSPHORUS LEVELS AND POTENTIAL LOSSES

Values for Bray-1 extractable P were significantly higher in most of the Organic 6-7-0 treatments when compared to the PCSCU fertilizer treatment. In the native fine sandy loam soil managed as home lawn, the plots receiving Organic 6-7-0 1.5× treatments were significantly higher in extractable P than the PCSCU treatment, and in the sand-based fairway soil, both sets of plots receiving Organic 6-7-0 treatments were significantly higher in extractable P than the PCSCU treatment.

The plots receiving Organic 8-3-5 treatments showed a trend for higher Bray 1-P than the plots receiving synthetic fertilizer, but differ-

▼ **Table 3.** Bray 1-P saturation (PSI_{ox}) in the soil root zone after three years of fertilizer application, 2008-2011.

Fertilizer product	Soil Bray 1-P	Soil test level[a]	PSIox[b]
	mg/kg		
PCSCU 20-5-10	19.3 B[c]	low	0.13
Organic 8-3-5 1×	22.8 B	medium	0.12
Organic 8-3-5 1.5×	21.3 B	medium	0.13
Organic 6-7-0 1×	35.0 A	medium	0.13
Organic 6-7-0 1.5×	38.5 A	medium	0.14
LSD	6.8	–	NS

[a] Low = < 20 mg/kg; medium = 20-40 mg/kg; high = 40-100 mg/kg; excessive = >100 mg/kg. Hor neck et al. (7).
[b] Phosphorous saturation index = P_{ox}/ [Fe_{ox} + Al_{ox}]
[c] Means followed by the same letter are notsignificantly different. *P* = 0.05. Mean of four samples. Control Soil Samples (untreated areas surrounding plots) Bray-1P Test = 18mg/kg.

▼ **Table 4.** Bray 1-P and P saturation (PSI_{ox}) in the sand root zone after three years of fertilizer application, 2008-2011.

Fertilizer product	Sand Bray 1-P	Soil Test Level	PSI_{ox}[a]
	mg/kg		
PCSCU 20-5-10	23.5 B[b]	medium	0.09 C
Organic 8-3-5 1×	27.3 B	medium	0.10 C
Organic 8-3-5 1.5×	28.0 B	medium	0.11 BC
Organic 6-7-0 1×	66.3 A	high	0.12 AB
Organic 6-7-0 1.5×	75.3 A	high	0.13 A
LSD	12.8	–	0.02

[a] Phosphorous saturation index = P_{ox}/ [Fe_{ox} + Al_{ox}]
[b] Means followed by the same letter are not significantly different. *P* = 0.05. Mean of four samples. Control Soil Samples (untreated areas surrounding plots) Bray-1P Test = 16mg/kg.

ences were not significantly different in either soil. Bray-1 test levels were in the low range in the pre-fertilization control soils and the PCSCU treatment in native soil, but were in the medium or high ranges following 3 years of application of natural organic fertilizers. In the Pacific Northwest, turfgrass shows little or no response to added P in soils that test in the medium or high range (> 20 mg P/kg soil).

To determine if the potential risk of soluble P loss had increased, oxalate extractions of Al, Fe, and P were run to determine if the fertilizer applications had affected P saturation (PSI) for each treatment and soil type. The results of these calculations showed no significant difference between PSI values for any of the fertilizer treatments on native soil after 3 years of fertilizer applications. However, on sand, both Organic 6-7-0 treatments had significantly higher PSI values than the other fertilizer treatments.

The change in Bray-1 P was much greater than the change in PSI, reflecting that the soils had exceeded the upper threshold for plant response to P, but had not yet reached a level of concern for soluble P loss. The PSI of the fertilizers alone was 16.6 for the Organic 8-3-5 compared with 3.8 for the Organic 6-7-0 biosolids product. The PSI of Organic 8-3-5 is similar to that of chicken manure (PSI = 15) as reported by Elliot et al., while the PSI for Organic 6-7-0 was higher than reported for a range of biosolids products (PSI = 0.47 to 1.4). The Organic 6-7-0 applications had a greater influence on Bray-1 P and soil PSI than the Organic 8-3-5, despite having a greater P binding capacity, because nearly four times as much P was applied in the Organic 6-7-0 than in Organic 8-3-5. Organic 6-7-0 applications added six to nine times as much P each year as the synthetic control, resulting in a large excess of applied P when products were applied to meet N needs.

We also calculated the relationship between the change in Bray-1 P applied for both natural organic fertilizers in both soils to compare the effectiveness of the fertilizers in raising soil test P. The change in Bray-1 P averaged 0.057 mg/kg for every kg/ha fertilizer P applied in the native soil, with no significant differences between the 8-3-5 and 6-7-0 fertilizers. In the sand/peat root zone mix the P effectiveness averaged 0.105 mg/kg Bray-1 P for every kg/ha fertilizer P applied, also with no differences between fertilizer sources. This suggests that the organic fertilizers had similar effects on soil test P per unit P applied, despite differences in the PSI of the two materials. Soil appeared to have a greater influence on P effectiveness than fertilizer, with the sand mix having a greater P effectiveness (less buffering) than the native soil. This is consistent with conclusions reached by Sneller and Laboski in agricultural soils fertilized with different types of manure. Because each experiment had only one synthetic P treatment, we could not calculate the P effectiveness of the synthetic P fertilizer in our soils.

The sand/peat experiment can be considered a worst case for soil response to P application, because the coarse-textured soil is poorly buffered and P application rates were higher than those used for home lawns. When organic fertilizer with high P concentration and high PSI was applied to the sand/peat plots, significant increases in both Bray-1 P and soil PSI were observed after 3 years. Although it would take longer, similar changes would occur in the native soil, eventually increasing the risk of leaching and runoff loss of P.

These results show the importance of evaluating fertilizer sources for the amount and availability of P. The soil test results show that Bray-1 P was higher when using P-rich organic fertilizer, compared with synthetic fertilizer containing P, because of the greater P application rate from the organic fertilizer when applied at rates to meet N needs. The greatest increase in Bray-1 P occurred in the sand-based fairway treatment. Changes in soil PSI were smaller, indicating only small changes in P saturation and the risk of P loss from the soil over the 3-year duration of this study.

Some organic fertilizers could have sufficiently low P concentrations and PSI values that they could be used for years without risk of increasing P loss from soil, but that did not appear to be the case for the fertilizers used in this study. Our results suggest that use of high-P organic fertilizers to meet turf N needs would not likely lead to increased risk of P loss in the short run, but repeated use in the long run could increase future P loss risk. This information can provide guidance for legislation regarding turf fertilizer sources, fertilization practices, and water quality. ■

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▲ **WEBWORMS** — All photos provided by Rainbow Treecare Scientific Advancements

Entomology 101

Safe and effective management of shade tree pests

INSECTS ARE ONE OF THE MOST SUCCESSFUL GROUPS OF ORGANISMS ON THE PLANET. For hundreds of millions of years, insects and plants have co-evolved, sometimes antagonistically, sometimes to the benefit of both parties. Insects are also of considerable concern to arborists, but we are long past the days in which we just spray indiscriminately and hope we kill the bad ones. Insect management today requires knowledge of biology, ecology, tree physiology, phenology, and chemistry so we can protect trees with minimal impact on beneficial insects and the rest of the ecosystem. So what are the basics we need to know to safely but effectively manage shade tree insect pests?

First, we need to wrap our heads around the sheer number of insects and their diversity. The current count is more than one million named species, representing about half of all animal species alive on the planet today. The estimates of not-yet-named species is anywhere between six and 10 million species; so if you have an interest in discovering and naming new species, entomology may be the field for you. Insects are grouped with other invertebrates such as spiders, millipedes and lobsters, but have some distinguishing characteristics. Like these other arthropods (from the Greek word for "jointed leg"), insects have, of course, jointed appendages, exoskeletons made from chitin, and segmented body parts. Every organism classified into the Class Insecta will have six legs, two antennae, a three-part body consisting of a head, abdomen, and thorax, and two pairs of wings.

All insects go through some form of metamorphosis, but not all of them do it the same way. Some insects go through a complete metamorphosis (known as "holometabolis"), where the immature insect looks nothing like the adult. Look no further than the differences between a caterpillar and a butterfly to understand this process. Other examples would be grubs, maggots, and whatever you call those cool looking ladybug larvae — all of them start life with one body type, then go through a pupa stage where they emerge looking like something else altogether. The adults and their offspring not only look different, they often have completely different diets, and, often, completely different relationships to plants. As larvae, an insect may be a plant parasite eating the leaves and disfiguring the appearance, but, as an adult, they may be an important pollinator of their flowers.

Depending upon the source, North America has roughly 30 Orders of insects, 600 Families, 12,500 Genera, and, oh, let's say about 86,000 Species.

The other type of metamorphosis insects may undergo doesn't change their appearance much, just their size. Known as incomplete metamorphosis, or "hemimetabolis" if you prefer the Latin sound, these insects look pretty similar at all stages of life. Unlike the insects that undergo complete metamorphosis, you can often find hemimetabolic adults and immatures (called "nymphs") feeding right next to each other on the same leaf. As they grow, their rigid exoskeletons must be shed to make room for the next, larger exterior. Each time they go though one of these molting cycles, we call that an "instar." Some species may go through four to five instars before reaching maturity. This has some management implications, as certain treatments that may be effective on early instars are not as effective on more mature insects.

Depending upon the source, North America has roughly 30 Orders of insects, 600 Families, 12,500 Genera, and, oh, let's say about 86,000 Species. As noted earlier, insects are mind-boggling in their numbers and diversity, but, fortunately for arborists, not all of them are required reading. Due to their tremendous variety, it is easiest to lump them together and consider insects at the Order level. Of the dozens of recognized Orders, it really boils down to five that are of considerable concern for tree care. Just understanding the differences of these groups, and their management strategies, will go a long way toward successfully managing insects on shade trees.

Order: Coleoptera
Translation: "Sheath wing"
Holometabolis
Key tree pests: Bark beetles, leaf beetles, flathead borers, roundhead borers, weevils

When it comes to variety and diversity, no one is bigger than the beetles. With more than 400,000 recognized species, beetles make up nearly half of all known insects. Although there are certainly beetles than beneficial to trees (like the much-loved ladybug), the ones that are tree pests can be serious or even fatal health concerns. Beetles can be secondary pests, such as bark beetles affecting stress-weakened trees, or they can be primary pests, as in the case of emerald ash borer or Asian longhorned beetle. Management tools include sprays (bifenthin, pyrethroids), systemic treatments (imidacloprid, dinotefuran), and tree injection (emmamectin benzoate, imidacloprid).


Japanese Beetles


Ladybug

Order: Hymenoptera
Translation: "Membrane wing"
Holometabolis
Key tree pests: Sawfly larvae, leafminers, gall-forming wasps, carpenter ants

While bees and wasps are certainly not widely considered to be tree pests, other close relatives in this Order can do damage to trees. Sawfly larvae, often confused with caterpillars, have an appetite for pine needles, and many common leafminers are found in this Order as well. Similar to the Coleopteran pests, management tools include sprays (bifenthin, pyrethroids), systemic treatments (imidacloprid, dinotefuran) and tree injection (emmamectin benzoate, imidacloprid).

Sawfly

Order: Lepidoptera
Translation: "Scale wing"
Holometabolis
Key tree pests: Gypsy moth, winter moth, bagworms, clear-wing borers

The Order of moths and butterflies contains many common tree pests, but they tend to only be pests as larvae. Caterpillars are one of the most common leaf-feeding insects in the world. Most do insignificant damage and require no control efforts, but some — especially introduced species — can defoliate a full-size tree in just a few days. Lepidopteran larvae are mostly thought of as leaf-feeding caterpillars, but there are a few, such as the clear-winged moths, whose larvae are wood-boring pests that can be confused with other species and are considered difficult to control. Management tools include sprays (spinosad, pyrethroids, Bt), systemic treatments (acephate), and tree injection (emmamectin benzoate, acephate).

Order: Hemiptera
Translation: "Half wing"
Hemimetabolis
Key tree pests: true bugs, leafhoppers, scales, aphids, adelgids, cicadas, psyllids

This Order has been split, lumped, and reworked more than any other in the past decade, so exactly who is now in the Hemiptera these days depends on the source, but many well-known tree pests are generally included. With a wide variety of body types, mouth parts, and feeding preferences, this group has many easy-to-control, and difficult-to-control members, so be sure you have properly identified your target for launching any control campaign. Management tools include sprays (bifenthin, pyrethroids), systemic treatments (imidacloprid, dinotefuran) and tree injection (emmamectin benzoate, imidacloprid).

Boxelder bugs

Order: Thysanoptera
Translation: "Fringed Wing"
Holometabolis
Key tree pests: thrips

Thrips, a name derived from the Greek word for "wood louse," can be disfiguring and damaging to tree leaves. In rare cases, a thrip infestation may be heavy enough to cause the death of a plant, but more often they are just damaging the leaves, buds, and flowers of trees. Although thrips are tiny, they are a well-documented vector of certain viruses that cause death to plants, particularly in agricultural or greenhouse settings. Management tools include sprays (bifenthin, pyrethroids), and systemic treatments (imidacloprid, dinotefuran).

Other Orders of insects than impact plants, but not considered prominent tree pests, include Isoptera (termites), Diptera (flies, mosquitoes), Phasmida (walkingstick) Orthoptera (grasshoppers), Odonata (dragonflies, damselflies), Mantodea (mantids) and Dermaptera (earwigs). ■

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The use of hygroscopic humectants in managing soil moisture

Editor's note: The author is president of BioPro Technologies; president and owner, Spindler Enterprises; agronomist and partner, Ecologel Solutions; and agronomical and research director, OJ Noer Turfgrass Research Foundation.

MOST TURFGRASS MANAGERS are familiar with the use of wetting agents, or surfactants, and super absorbent polymers in managing water movement and retention in soils. However, there is another class of chemistry that is gaining acceptance in the management of turfgrass and ornamental soil moisture. This class of chemistry is referred to as hygroscopic humectants.

Before discussing hygroscopic humectants, it is important to understand how they differ from other water management technologies. First, wetting agents are chemicals that "reduce surface tension of water, allowing the water molecules to spread out." Another definition is "any compound that causes a liquid to spread more easily across or penetrate into the surface of a solid by reducing the surface tension of the liquid." Therefore, a wetting agent is a material that allows water to more easily penetrate into soil and/or flow through (infiltrate) the soil. These materials are valuable when soils have become hydrophobic and will not wet easily.

Super absorbent polymers, another type of water management technology, are "materials that can absorb and retain extremely large amounts of liquid relative to their own mass." These materials are utilized to absorb large amounts of rainfall or irrigation to be used by the plant at a later date. These materials are commonly used in greenhouse and nursery industries, as well as in some agricultural settings.

However, the use of polymers in turfgrass is difficult for two reasons. The first is that polymers are difficult to incorporate into the soil profile. The second is that, as they absorb water, they expand, and can disrupt the soil and turfgrass surface. However, there are some new developments in polymer technology that may overcome these challenges.

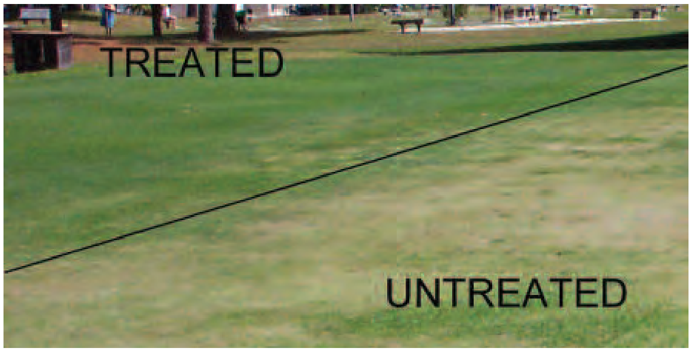
Hygroscopic humectants are materials that attract water vapor (the gas phase of water) from the atmosphere within the soil, condense it back into a liquid form, and retain the liquid for the plant to absorb. According to Merriam Webster's dictionary, a hygroscopic material is any material that "readily takes up and retains moisture." Most turf managers are more familiar with hygroscopic materials than they may realize. For instance, many fertilizer ingredients are hygroscopic. It is the hygroscopic nature of some fertilizers that cause them to "cake" or form chunks in the package.

The definition of a humectant is "a substance that promotes retention of moisture" (Merriam-Webster). These are substances that absorb, or help another substance to retain moisture. These types of materials are commonly used in the food and cosmetic industry. For example, humectants will help keep food from drying out and becoming stale. In cosmetics they help keep different types of make-up pliable so they may be applied to the skin in an even fashion without causing dryness.

The key to successfully using hygroscopic humectants to manage soil moisture is by using the right combination of raw ingredients. Some raw materials will attract moisture and condense it, but will hold it too tightly, not releasing the water to the plant. On the other hand, some raw materials may compete with the plant for soil moisture and be detrimental to plant health. Finally, some raw materials will be broken down in the soil by microbes too quickly, and have a short lived effect.

The best combination of raw ingredients are those that will attract soil water vapor to itself, condense it into a droplet, and then allow the plant root to remove that droplet for use in its metabolic activities. Another vital factor in the success of a hygroscopic humectant product is to have a certain resistance to microbial degradation. Many of the raw ingredients used in a hygroscopic humectant are organic in nature, and can be used by soil microbes as a food source. We see the same types of challenges in pesticide formulations.

Hygroscopic humectants have a variety of uses in the management of turf and landscapes. For example, they may be used in combination with wetting agents to relieve



localized dry spots. The wetting agent will allow the water to penetrate into the hydrophobic area causing the dry spot, eliminating the hydrophobic effect. Then, the hygroscopic humectant will prevent the area from drying out again, since it will be continually condensing water vapor into water droplets.

Using hygroscopic humectants is an excellent way to reduce overall landscape water use. When applied to large turf or landscape areas and watered into the rootzone, these products will allow plants to more effectively use any water they receive through rainfall and irrigation. When water is applied to the soil, it has one of three fates. First, it can be pulled down by gravity deeper into the soil and eventually added to the ground water. Secondly, it may evaporate and escape the soil back into the atmosphere above the soil. Finally and most favorably, it can be used by the plant. Hygroscopic humectants effectively minimize the loss of soil water to evaporation by condensing the escaping water vapor back into liquid form for the plant to use. In fact, these products have been documented to reduce overall water use by as much as 50%.

When seeding, hygroscopic humectants are a valuable tool to optimize seed germination and establishment. When applied over the seed and into the seedbed, these products will reduce the drying effects in between irrigation and rainfall events. Therefore, the seed is able to germinate more rapidly, and then establish and develop due to more favorable moisture conditions. This effect is also experienced in hydroseeding and sprigging.

The establishment and maintenance of trees, shrubs and ornaments are an ideal use for hygroscopic humectants. The water capturing capability of these products will allow plants to establish quickly, and survive drought conditions more successfully. The use of hygroscopic humectants in potted plants is especially valuable in reducing watering events from every day during hot, dry periods to every other or every 2 or more days. This application not only saves water, but labor as well.

Hygroscopic humectants are a valuable tool for turf managers. Used alone or in combination with other technologies, these products are valuable in reducing overall water use on all parts of the landscape. ■

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Best fertilizer management: a blueprint for success

***Editor's note:** The author is a technical representative for Grigg Brothers.*

WHETHER YOU ARE MANAGING MUNICIPAL FIELDS or big league stadiums, the correct nutrient management programs will provide a blueprint for vigorous turf and prepare you—if you have not dealt with it already—if or when fertilizer use laws limit your resources. Nutrient management is one important cultural practice that forms the foundation for successful turf management; however the interpretation of soil test/water quality data, and selecting the appropriate source, timing, and rate of fertilizer is often overlooked. Many chapters in textbooks have been written on the topic of fertilizer source, selection and use so consider this short piece as a resource to help optimize your fertilizer programs and allow you to think "broad brush" about how you approach your role as a sports field manager.

UNDERSTAND PLANT COMMUNITY

First and foremost, a comprehensive understanding of the site will guide your fertilization approach. Clearly identify the turf(s) use, or function and its associated expectations. Consider safety improvements carefully. What grass(es) exist and what are their strengths, weaknesses, biology, and cultural requirements? What plants are unwanted? Soil physical and chemical properties and the time of year determine the source and frequency of fertilizer applications. For example, soil *texture* influences drainage, extent of compaction, firmness, all important factors for playability, but it also affects nutrient holding capacity and subsequently the potential effectiveness of fertilizer programs.

EXISTING OR PENDING FERTILIZER LEGISLATION

Get started now to determine how current or pending fertilizer use laws will affect your ability to manage turf in your state. New Jersey, New York, Wisconsin, Minnesota, Florida, Connecticut and Pennsylvania have or are cur-

▲ **Figure 1: IN STATES** where phosphorus (P) applications are banned, one exception is the ability to use P fertilizers on sites to establish turfgrass.

rently in the process of regulating fertilizer inputs such as nitrogen (N) and phosphorus (P) source and timing of application (see Figure 1). In Connecticut, schools and municipalities are moving toward an organic program mandate. Natural organic fertilizer sources have effectively escaped regulation in many states because the P cannot be removed from manure or compost. Source ingredients and the manufacturing process of natural organic fertilizers differ, so you should familiarize yourself with the benefits and potential disadvantages of these formulations before making a purchasing decision. Interestingly, many existing and future laws are not based on science, but perception. Poorly written laws produce unintended consequences such as reduced turf vigor and subsequently more leaching, weeds, soil erosion, and runoff. If possible, get involved! Find out what laws may be in the pipeline in our local community and fight for what you believe in; you can take it as far as you see necessary or have the available time to pursue.

SOIL TESTING

I recommend soil testing regularly (at least once a year) to determine if any major chemical problems exist. The pH should fall within a fairly wide range of 5.5 – 7.3. Most calibration and correlation data exists for *exchangeable* nutrient cations, so interpret this data to select fertilizer inputs. Sand sites often contain less calcium (Ca), magnesium (Mg), and potash (K) and hold fewer nutrients in general. If applicable, test the irrigation water. Many chemical problems such as high sodium (Na) and chlorine (Cl) or bicarbonate (HCO_3-) arise due to poor irrigation water quality, or construction/amendment with high lime or calcareous sands. Importantly, soil tests should be used as a rough guideline and your observation equally important. Become a keen observer by carefully assessing turf vigor and how its response to a fertilizer application and/or recovers from mechanical stress, lack of water, and/or divoting?

CONCEPTS OF BEST FERTILIZER MANAGEMENT

Beyond understanding the broad plant/soil community and collecting soil test data, best fertilizer management (BFM) includes selecting the correct fertilizer and applying it at the correct time. The concepts focus on fertilizer use and fate with the goal to maximize plant use of nutrient and minimize loss to the environment. Like everything else in our lives, efficiency is better. This starts with developing a master plan, staying fluid, and making good choices. BFM *requires* an integrated approach and using all available options.

Fortunately, turf mangers now have technologically advanced fertilizer options, from slow release granule formulations that can be applied at higher rates, to highly efficient liquid, or foliar, options generally applied frequently and in low doses. The latter, referred to as "spoon feeding," allows turf managers the ability to "meter" nutrient inputs. More athletic field mangers now use this approach particularly where resources exist to supplement a granular fertilizer program. Foliar fertilizers can increase the speed of establishment, maximize vigor, enhance recuperative capacity, improve wear tolerance, or maximize aesthetics (see Figure 2). These effects are more pronounced on sand soils, during environmental stress, or when root growth is compromised. The correct use of ef-

▲ **Figure 2: THE USE OF** efficient foliar fertilizers will maximize color and provide added control of nutrient inputs.

ficient foliar fertilizers and slow release granule carriers will improve nutrient use by turfgrass plants, maintain a high level of vigor needed to fill voids; and thus limit weed germination and growth, and minimize nutrient losses. Enhancing nutrient uptake efficiency provides an agronomic, environmental, and economic benefit.

A final, yet critically important concept of BFM includes calibration. With so much out of our control, why not fine tune every other aspect of a fertilizer application? Calibration ensures that you apply the correct amount of nutrient, not too little so that turf vigor suffers or too much so that you waste money or potentially cause pollution. Most fertilizer programs start with N because plants require it in the highest amounts, and it should be the focus of a successful Best Fertilizer Management Program.

SELECTING A FERTILIZER

Ratio and Grade: A fertilizer ratio determines the relative amounts of N, P, K, or primary macronutrients in fertilizer, for example 3-1-2, 7-1-3, or 1-0-1. Choose a ratio based on N and K requirements, and/or soil type. The grade refers to the fertilizer analysis and you can attain the desired ratios with different grades. For example, both 21-3-9 and 28-4-12 have the same 7-1-3 ratio. Many fertilizers also contain secondary macronutrients including Ca, Mg, and S and minor nutrients. Generally, I recommend a balanced and complete fertilizer such as the examples above for general maintenance. Synthetic organic sources generally have a higher nutrient analysis and more soluble nutrient compared to natural organic sources, which are used effectively on sandy soils, as a dormant feed, or where laws prohibit P applications to turf.

PHYSICAL CHARACTERISTICS

You have the choice of dry or liquid (foliar) fertilizer and this may be determined solely on the equipment available. Foliar fertilizer use represents a supplement to an existing granular program and liquids can also be an effective soil targeted application because the nutrients tend be highly soluble. Many also contain a wetting agent which increases uniformity of application. Among other things, particle size affects ease and distribution of application and rate of nutrient availability for slow release N sources.

Nitrogen Release Characteristics/Burn Potential. Most general maintenance granular fertilizers contain some slow release N (SRN), many ≥ 50% SRN. A variety of SRN formulations are available including those where N is released by temperature, water, or microbial activity. As a consequence, soil physical properties influence the release of N (See Soil Type below). The most common soluble N sources, in the order of high to low burn potential, include *urea, potassium nitrate, ammonium sulfate, di-or monoammonium phosphate*. Focus on the plant community (dominant grass and stage of growth) to determine annual N requirements. Correctly formulated foliar fertilizers contain soluble nutrients with low burn potential.

Soil Type/Reaction Effects. Native soils often contain high levels of residual N, allowing a turf manager the option to cut back on N inputs during certain times of the year, saving money. How can you tell? Conduct a tissue test and target ≥ 5% leaf N. In addition, fewer N inputs will limit excess biomass production, decreasing organic matter and thatch production. Conversely high sand soils drain well, but promote nutrient leaching, such as K and nitrate-N (NO_3-). In this situation, a turf manager might select more foliar fertilizer, use slow release sources of N and K, and not apply too much soluble N in a granule form, particularly during periods of slow growth or prior to heavy rainfall.

Soil pH affects microbial activity and nutrient solubility, for example high pH or alkaline soils limit minor nutrient availability. In addition, high pH soil or water increases urea volatilization, particularly at high pH (≥ 7.3). Soil test P data usually fall in the 'above optimum' category, however P complexes with calcium (Ca) (high pH), Al or Fe (low pH), or clay minerals rendering it unavailable to the plant. With routine fertilizer additions that contain a small amount of P, plants are likely receiving adequate P nutrition. To know conclusively, conduct a tissue test.

▲ **Figure 3: COOL SEASON** root growth can be compromised by high soil temperatures rendering soluble granular sources ineffective with a high burn potential.

Seasonal Adjustments/Timing. For cool season grasses, the optimum timing for higher rates of soluble N is in the spring and fall, ideally fall. Conversely for warm season grasses, the optimum timing for higher rates of soluble N is in the summer months; however this also represents the rainy season in the some southern states like Florida so caution must be used when deciding on how much soluble N to apply at any one time during the summer. Supplement with liquid/foliar fertilizers when plant roots are compromised by temperature stress or on high sand soils due to lower nutrient holding capacity and high leaching potential (see Figure 3).

ADDITIONAL BFM STRATEGIES SPECIFIC FOR SPORTS TURF MANAGERS

Water Management: Do you have access to irrigation or rely on natural rainfall? If you irrigate, how is the water quality? Many fertilizers require post application irrigation to ensure safety, release nutrient, and increase uniformity of coverage. Do not over water. Many granule or liquid products need only 6-8 minutes of irritation to effectively water them in. If you are fortunate enough have to ability to control water inputs, you have the advantage to control soil moisture and speed establishment by supporting microbial activity and nutrient release (see Figure 4).

Wear tolerance/Increase Rooting: Do not over apply N; shoot growth at the expense of root growth, particularly in the spring of the year for cool season turf will negatively affect turf vigor and summer stress tolerance. Cultural practices such as aeration and sand topdressing, and the use soil targeted Ca and N will help wear tolerance and rooting. When you have the opportunity to cultivate, do it aggressively! Calcium supplied to growing root tips will increase overall root depth. For cool season turf, supply

▲ **Figure 4: A SOPHISTICATED IRRIGATION SET UP** provides the ability to control water inputs to the root zone, cool plants, and water in fertilizer.

low dose of soluble N (≤ 0.25 lbs/M) in the mid fall to increase carbohydrate storage in the roots and increase winter hardiness. For warm season turf like bermudagrass raise the height of cut going into winter. Maintain a balanced fertilization program in the fall and limit N fertilization. Be careful in the spring and do not try to push bermudagrass with heavy doses of soluble N; this can have a dramatic negative affect if you encounter extreme cold in late March or April.

IMPLEMENT THE PLAN

Develop a rough yet integrated fertilizer use plan based on your evaluation of the site, resources, and expectations and use it as a template for your agronomic plan. Consider fertilization a critical cultural practice along with water management, cultivation, seeding, and mowing which forms the foundation for turf vigor.

Get involved with state legislatures and understand existing or pending laws regarding fertilizer use. If necessary, begin to experiment or even implement programs to meet the requirements of these law(s). Given that you might as a consequence have to use more natural organic fertilizers, understand the benefits and limitations of these materials.

Education is the key to procuring the resources needed to provide safe, functional, and aesthetically pleasing turf for sports use. For fertilization, choosing the correct source, time and rate of N applications, (based on species) will have the biggest impact on rooting, turf vigor and recuperative capacity. Maximize efficiency and minimize environmental losses by supplementing soil targeted slow release fertilizer applications with low dose and soluble foliar nutrition. Use quickly available sources with low burn potential to speed recovery and during establishment. Evaluate new organic fertilizer technologies and always look for research to back up any claims. And lastly, become a keen observer and trust what you see! ■

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Healthy chloroplasts for healthy sports turf

Plant chloroplasts are large organelles that, like mitochondria, are bounded by a double membrane called the chloroplast envelope. In addition to the inner and outer membranes of the envelope, chloroplasts have a third internal membrane system, called the thylakoid membrane. The thylakoid membrane forms a network of flattened discs called thylakoids, which are frequently arranged in stacks called grana. Because of this three-membrane structure, the internal organization of chloroplasts is more complex than that of mitochondria. In particular, their three membranes divide chloroplasts into three distinct internal compartments: (1) the intermembrane space between the two membranes of the chloroplast envelope; (2) the stroma, which lies inside the envelope but outside the thylakoid membrane; and (3) the thylakoid lumen.

The Structure and Function of Chloroplasts

Plant Cell Chloroplast Structure

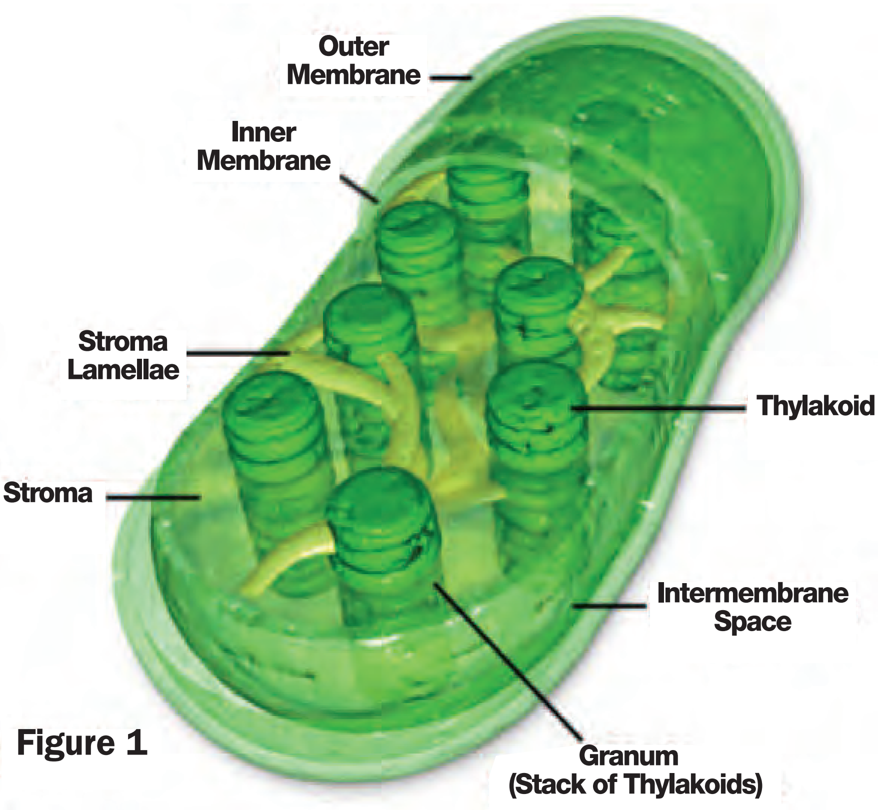

Figure 1

In addition to the inner and outer membranes of the envelope, chloroplasts contain a third internal membrane system: the thylakoid membrane. These membranes divide chloroplasts into three internal compartments.

The major difference between chloroplasts and mitochondria, in terms of both structure and function, is the thylakoid membrane. This membrane is of central importance in chloroplasts, where it fills the role of the inner mitochondrial membrane in electron transport and the chemiosmotic generation of ATP. The inner membrane of the chloroplast envelope (which is not folded into cristae) does not function in photosynthesis. Instead, the chloroplast electron transport system is located in the thylakoid membrane, and protons are pumped across this membrane from the stroma to the thylakoid lumen. The resulting electrochemical gradient then drives ATP synthesis as protons cross back into the stroma. In terms of its role in generation of metabolic energy, the thylakoid membrane of chloroplasts is thus equivalent to the inner membrane of mitochondria.

THE CHLOROPLAST GENOME

Like mitochondria, chloroplasts contain their own genetic system, reflecting their evolutionary origins from photosynthetic bacteria. The genomes of chloroplasts are similar to those of mitochondria in that they consist of circular DNA molecules present in multiple copies per organelle. However, chloroplast genomes are larger and more complex than those of mitochondria, containing approximately 120 genes.

The chloroplast genomes of several plants have been completely sequenced, leading to the identification of many of the genes contained in the organelle DNAs. These chloroplast genes encode both RNAs and proteins involved in gene expression, as well as a variety of proteins that function in photosynthesis. Both the ribosomal and transfer RNAs used for translation of chloroplast mRNAs are encoded by the organelle genome. These include four rRNAs (23S, 16S, 5S, and 4.5S) and 30 tRNA species. In contrast to the smaller number of tRNAs encoded by the mitochondrial genome, the chloroplast tRNAs are sufficient to translate all the mRNA codons according to the universal genetic code. In addition to these RNA components of the translation system, the chloroplast genome encodes about 20 ribosomal proteins, which represent approximately a third of the proteins of chloroplast ribosomes. Some subunits of RNA polymerase are also encoded by chloroplasts, although additional RNA polymerase subunits and other factors needed for chloroplast gene expression are encoded in the nucleus.

IMPORT AND SORTING OF CHLOROPLAST PROTEINS

Protein import into chloroplasts generally resembles mitochondrial protein import. Proteins are targeted for import into chloroplasts by N-terminal sequences of 30 to 100 amino acids, called transit peptides, which direct protein translocation across the two membranes of the chloroplast envelope and are then removed by proteolytic cleavage. As in mitochondria, molecular chaperones on both the cytosolic and stromal sides of the envelope are required for protein import, which requires energy in the form of ATP. In contrast to the pre-sequences of mitochondrial import, however, transit peptides are not positively charged and the translocation of polypeptide chains into chloroplasts does not require an electric potential across the membrane.

Protein import into the chloroplast stroma: Proteins are targeted for import into chloroplasts by a transit peptide at their amino terminus. The transit peptide directs polypeptide translocation through the Toc complex in the chloroplast outer membrane. Proteins incorporated into the thylakoid lumen are transported to their destination in two steps. They are first imported into the stroma, as already described, and are then targeted for translocation across the thylakoid membrane by a second hydrophobicsignal sequence, which is exposed following cleavage of the transit peptide. The hydrophobic signal sequence directs translocation of the polypeptide across the thylakoid membrane and is finally removed by a second proteolytic cleavage within the lumen.

The goal of every turfgrass manager is to provide a playable surface and aesthetically pleasing green turfgrass. Achieving the latter involves a reciprocal balance between soil, fertility, moisture, temperature, humidity, grass species, mowing techniques, cultural practices and cooperation from Mother Nature. All these aspects have to be working in sync for turfgrass to perform properly and be appealing color wise.

Protecting and strengthening chloroplasts would seem like the logical action to take because this is where chlorophyll, a pigment that gives turfgrass its green appearance, is developed.

The most important characteristic of turf plants is their ability to photosynthesize: to make their own food by connectinglight energy into chemical energy. This process is carried out in specialized organelles called chloroplasts. A photosynthetic cell contains anywhere from one to several thousand chloroplasts. The electrons from chlorophyll molecules in photosystem II replace the electrons that leave chlorophyll molecules in photosystem I.

Located inside the chloroplast are thylakoid membranes where light reactions take place. This is where chlorophyll is found, therefore, there's a synergistic relationship between keeping the chloroplasts and the thylakoid membranes as healthy as possible.

There are events that can be harmful to chloroplasts and thylakoid membranes, as well as necessary components that can prevent damage to them.

FREE RADICALS

One event that can damage chloroplasts is the development of free radicals. Typically, free radicals are stable molecules that contain pairs of electrons. When a chemical reaction breaks the bonds that hold the paired electrons together, free radicals are produced. They contain an odd number of electrons, which make them unstable, short-lived and highly reactive. As they combine with other atoms that contain unpaired electrons, new radicals are created, and a chain reaction begins.

This chain reaction or accumulation of reactive oxygen species, in turf plants is generally ascribed to several possible sources: cell-wall-bound perxidases, membrane-located NADPH oxidases, amine oxidases, xanthine oxidase, chloroplastic electron transport chains, mitochondrial electron transport chains, and peroxisomal fatty acid B-oxidation, which includes the H_20_2-generating argyl-coenzyme A oxidase steps. These sources can be attributed to environmental causes such as drought, heat, and ultraviolet light, or chemicals such as herbicides.

Accumulation of reactive oxygen species is central to plant response to several pathogens. One of the sources of reactive oxygen species is the chloroplast because of the photoactive nature of the chlorophylls. The free radicals, or reactive oxygen species, are singlet, hydroxyl, superoxide and hydrogen peroxide.

LIGHT

When photosynthetic organisms, such as turf, are exposed to ultraviolet radiation, significant, irreversible damage to important metabolic processes within the cell might occur (such as lesions in DNA and inhibition of photosynthesis). Through these reactions and others, radical forms of oxygen are often created. Many reports suggest this damage is because of oxidative stress resulting from UV-A exposure.

Photosynthetic light absorption and energy usage must be kept in balance to prevent formation of reactive oxygen species in the chloroplasts. Drought causes stomatal closure, which limits the diffusion of carbon dioxide to chloroplasts and thereby causes a decrease of carbon dioxide assimilation in favor of photorespiration that produces large amounts of hydrogen peroxide. Under these conditions, the probability of singlet oxygen production at photosystem II and superoxide production of photosystem I is increased. These can cause direct damage or induce a cell suicide program.

It has been known for a long time wavelengths in the ultraviolet-B region of the spectrum are effective in inactivating photosynthesis, and the molecular target is photosystem II. An excess of light brings about the inactivation of oxygenic photosynthesis, a phenomenon known as photoinhibition, and the molecular target of photoinhibition is photosystem II, a thylakoid multisubunit pigment-protein complex. The major effect of ultraviolet-B light on the thylakoid proteins is the breakdown of the reaction centre D1 protein.

SENESCENCE

Senescence results in massive levels of cell death, but the purpose of senescence isn't cell death; rather death only occurs when senescence has been completed. Senescence occurs in two stages. The first stage is reversible, and the cells remain viable throughout. The second stage results in cell death.

The key enzyme in the pathway to chlorophyll degradation during senescence appears to be pheophorbide-a-oxygenase. The activity of pheophorbide-a-oxygenase increases dramatically during senescence, implicating this enzyme as a control point in the process. Light absorption by pheophorbide-a-oxygenase also is believed to cause the production of singlet oxygen, which is a free radical.

Because senescence is reversible, it suggests that fully developed chloroplasts retain enough genetic information to support re-greening and chloroplast reassembly.

CALCIUM AND POTASSIUM

From a nutritional standpoint, there are various nutrients and compounds that can be applied in the process of strengthening and defending chloroplast damage.

Because the chloroplasts and thylakoid membrane are located inside the plant cell, the first line of defense would seem to be to strengthen the plant cell by keeping calcium and potassium at optimal levels. Calcium plays a key role in strengthening the cell walls of the turf plant, while potassium helps strengthen cell walls inside the turf plant, which makes it harder for physiological problems to occur inside the cell wall.

AMINO ACIDS

Amino acids are the building blocks of proteins. Under optimal conditions, proteins are able to perform the normal physiological function to synthesize amino acids, but intensively manicured turfgrass, such as golf courses and athletic fields, are rarely operating under optimal conditions because of stress caused by low mowing heights and traffic.

To date, 154 proteins in the turfgrass plant have been identified – 76 (49 percent) are integral membrane proteins. Twenty-seven new proteins without known functions, but with predicted chloroplast transit peptides, have been identified – 17 (63 percent) are integral membrane proteins. These new proteins are likely to play an important part in thylakoid biogenesis.

The application of amino acids plays an extremely important part in developing the proteins specifically designed to help chloroplasts, thylakoid membranes, photosystem I and photosystem II to function properly. These proteins are known as D1, D2 CP43, CP47 and cytochrome b559. Of special

importance is the D1 protein because it exhibits the highest turnover rate of all the thylakoid proteins, and is highly vulnerable to singlet oxygen, a free radical.

ANTIOXIDANTS

The antioxidants a-tocopherol (vitamin E), ascorbic acid (vitamin C), carotenoids (B-carotene), vitamin B6 and mannitol in some biostimulants play a vital role in scavenging free radicals and helping protect chloroplasts, thylakoid membranes inside the chloroplasts, photosystem I and photosystem II.

In terms of its antioxidant properties, carotenoids can protect photosystem I and photosystem II in one of four ways: by reacting with lipid peroxidation products to terminate chain reactions; by scavenging singlet oxygen and dissipating the energy as heat; by reacting with triplet or excited chlorophyll molecules to prevent formation of singlet oxygen; or by dissipation of excess excitation energy through the xanthophyll cycle.

Xanthophylls function as accessory pigments for harvesting light at wavelengths that chlorophyll can't and transfer the light energy to chlorophyll. But, they also absorb excess light energy and dissipate it to avoid damage in the xanthophyll cycle.

A-TOCOPHEROL (VITAMIN E)

A-tocopherol (vitamin E) is considered a major antioxidant in chloroplasts in at least two different but related roles. It protects photosystem II from photoinhibition and thylakoid membranes from photooxidative damage. The antioxidant properties of vitamin E are the result of its ability to quench singlet oxygen and peroxides.

ASCORBIC ACID (VITAMIN C)

It's generally believed maintaining a high ratio of ascorbic acid is essential for the scavenging of free radicals and is needed in high concentrations in the chloroplasts to be effective in defending the turfgrass against oxidative stress. Although ascorbic acid can directly scavenge the free radicals superoxide and singlet oxygen, the main benefit ascorbic acid plays in the prevention of free radicals is that it's an excellent scavenger of the hydroxyl radical. The hydroxyl radical is dangerous to turfgrass because it can inhibit carbon dioxide assimilation by inhibiting several Calvin cycle enzymes.

VITAMIN B6

Apart from its function as a cofactor, vitamin B6 is also thought to act as a protective agent against reactive oxygen species,

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such as singlet oxygen. Vitamin B6 is also the master vitamin in processing amino acids and plays an important role in developing proteins specifically designed to help chloroplasts, thylakoid membranes, photosystem I, and photosystem II to function properly.

MANNITOL

The antioxidant mannitol has the ability to protect and quench two damaging free radicals: singlet oxygen and hydroxyl. Singlet oxygen is damaging because it can react with proteins, pigments and lipids and is thought to be the most important species for light-induced loss of photosystem II activity, as well as the degradation of the D1 protein. It has been demonstrated that when mannitol is present in the chloroplasts, it can protect plants against oxidative damage by the hydroxyl radicals.

MANGANESE AND MAGNESIUM

Both of these nutrients are attached to the chlorophyll molecule that's located inside the chloroplasts. These two nutrients play a part in making turfgrass greener by helping develop chlorophyll. They also transport other vital nutrients and are responsible for many enzymatic functions and help prevent chlorophyll degradation in the cells.

CARBON

There's new evidence carbon plays a role in the development of the turfgrass plant leaf, and that a reduction in carbon reduces photosynthetic activity, which reduces carbohydrate availability to the turfgrass plant. There's also new evidence to suggest proper development of the turfgrass plant can't occur without proper amounts of carbon in the chloroplast. There's more evidence to suggest that, if there's an abundant source of carbon in the thylakoid membranes inside the chloroplasts, it can be mobilized for use as an energy source during senescence.

HUMIC ACIDS

Humic acids are another compound that contain antioxidant properties that promote the scavenging of free radicals. The added benefits of humic acid are that they increase the availability of micronutrients, phosphate and potassium to the plant and enhance the chlorophyll content of turfgrass.

Humic acids also stimulates root initiation because of the auxin-like activity they contain, which is most likely because of their ability to inhibit indoleacetic acid oxidase breakdown. ■

Jeff Haag is sports turf specialist at John Carroll University, University Heights, OH.