A PRACTICAL RESEARCH DIGEST FOR TURF MANAGERS

TurfGrass TRENDS

Volume 7, Issue 2

February 1998

Sulfur Usage by Turfgrasses

Richard J. Hull
University of Rhode Island

Of the six macronutrients, sulfur is undoubtedly the most neglected by turf managers. This is not because sulfur is the macronutrient required in the lowest amount by plants, which it is, but because no effort is generally required to insure that turf receives all the sulfur it needs.

Living in an industrial nation virtually insures that sulfur will be available to plants through atmospheric sulfur dioxide (SO_2), a major air pollutant. Also, sulfur is normally present in mineral and organic fertilizers. Common (single) superphosphate is manufactured by reacting rock phosphate with sulfuric acid; the resulting product contains 14 percent sulfur. Sulfur-coated urea, which is commonly used by turf managers as a slow-release nitrogen source, contains about 10 percent sulfur. Many commercial grade fertilizer materials contain small amounts of sulfur as a contaminant and all naturally derived organic fertilizers or soil conditioners will deliver some sulfur.

This ambivalence toward sulfur may be changing. More refined inorganic fertilizer ingredients contain less sulfur as well as other contaminants. For example, triple superphosphate contains only 1.5 percent sulfur, but 2.3

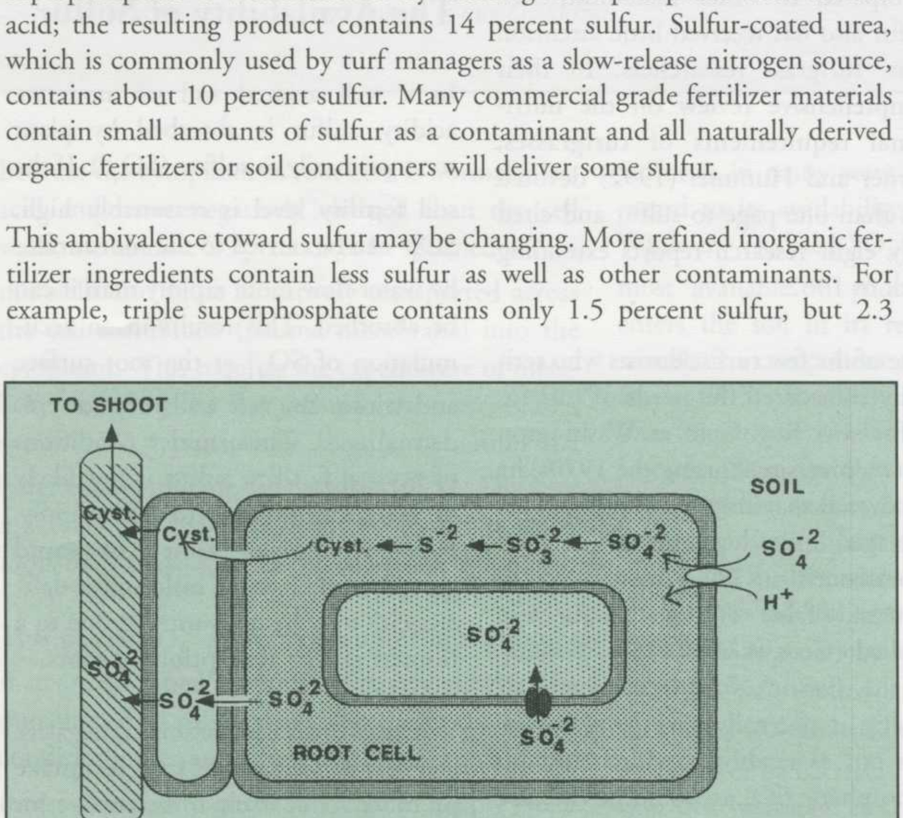

Figure 1. Path of sulfate transport and metabolism in roots of grass plants.

TurfGrass TRENDS •7500 Old Oak Blvd. • Cleveland, OH 44130-3369
Phone: 440-891-2709 • Fax: 440-891-2675 • e-mail: tmciver@advanstar.com

AN ADVANSTAR PUBLICATION

IN THIS ISSUE

TurfGrass TRENDS

Editor, Terence McIver
440-891-2709, 440-891-2675 (fax)

Production Manager
Linda O'Hara
218-723-9129; 218-723-9576 (fax)
lohara@advanstar.com

Circulation Manager
Karen Edgerton
218-723-9280

Layout & Production
Bruce F. Shank, BioCOM
805-274-0321

Group Editor
Vern Henry

Group Publisher, John D. Payne
440-891-2786; 440-891-2675 (fax)
jpayne@advanstar.com

CORPORATE OFFICE
7500 Old Oak Blvd.
Cleveland, OH 44130-3369

EDITORIAL OFFICE
7500 Old Oak Blvd.
Cleveland, OH 44130-3369

Abstracts: *800-466-8443*
Reprint: *440-891-2744*
Permission: *440-891-2742*
Single copy or back issues:
Subscription/Customer Service
218-723-9477; 218-723-9437 (fax)

ADVANSTAR HOLDINGS, INC.

Chairman and Chief Executive Officer
Robert L. Krakoff

Vice Chairman
James M. Alic

Vice President, Business Development
Skip Farber

ADVANSTAR COMMUNICATIONS

Executive Vice Presidents
William J. Cooke, Alexander S. DeBarr, Brian Langille, Glenn A. Rogers

VP-Finance, CFO & Secretary
David J. Montgomery

Treasurer and Controller
Adele D. Hardwick

times as much phosphate as single superphosphate. The plastic coatings now being used to slow the release of urea and other soluble fertilizers might contain no sulfur.

More stringent air quality regulations are reducing the amount of atmospheric SO_2. In northern Europe, industrial emissions have been so reduced that many crop plants are currently exhibiting yield increases when fertilizer sulfur is applied (Marschner 1995). As turf managers remove clippings from ever larger areas of their turf and more sand-based greens are installed, the likelihood of sulfur supplies within the rooting medium becoming insufficient increases.

Sulfur in Turfgrasses

Compared to other macronutrients, sulfur also has received little attention from turfgrass researchers. In their comprehensive review on the nutritional requirements of turfgrasses, Turner and Hummel (1992) devoted less than one page to sulfur and cited only eight research reports extending back to 1962.

One of the few turf scientists who seriously considered the needs of turf for sulfur was Roy Goss at Washington State University. During the 1970s, he discovered that colonial bentgrass turf managed under high nitrogen fertility experienced a 71 percent growth increase (Table 1) when sulfur was applied (Goss et al., 1979). Working in the Pacific Northwest where air quality is normally very good, sulfur was not as readily provided through atmospheric SO_2 as would be the case in the more industrial Midwest and East.

Turfgrass clippings normally contain between 0.25 and 0.45 percent sulfur on a dry matter basis depending on fertility level and how much sulfur is provided (Turner and Hummel, 1992). Sulfur levels as low as 0.15 percent have been found to be adequate for several turfgrasses. This value is lower than that for any other macronutrient although not much below that for magnesium. These low sulfur levels can be deceiving because sulfur does not circulate very well within plants and this causes new growth to experience the greatest deficiency (Marschner, 1995). Because of this, **sulfur must be supplied throughout the growing season so its content in growing tissues will be maintained** at about 0.35 percent (Table 1). Otherwise, serious growth suppression may result.

The Availability of Sulfur

In a well aerated soil of moderate acidity, sulfur is absorbed by plant roots primarily as sulfate (SO_4^{-2}). If the soil fertility level is reasonably high, SO_4^{-2} can be carried to the root surface by water flow more rapidly than it can be absorbed. This results in an accumulation of SO_4^{-2} at the root surface and within the cell walls of root epidermal cells. Thus, under conditions of normal fertility, sulfur is not likely to be limiting due to soil supply. However, **during times of rapid growth in the spring, mild sulfur deficiencies may be encountered due to a limited rate of absorption by roots.**

Sulfate is a divalent anion (2 negative charges per ion) and as such its uptake by roots is not likely to be passive for the same reasons that we explained for nitrate uptake (Hull and Liu, 1995).

Table 1. Sulfur content and quality of colonial bentgrass putting green turf fertilized with various combinations of N and S

Nutrients Applied N	P	K	S	Sulfur Content	Average Content
1 lbs/1,000 sq. ft./yr.				%	10=dark green
0	0	0	0	0.35 b	4.8 c
20	0	6.6	0	0.30 c	4.9 c
12	1.8	6.6	1.2	0.40 a	7.8 b
20	1.8	6.6	1.2	0.40 a	7.6 b
20	1.8	6.6	3.4	0.42 a	8.7 a

Values followed by same letter are not statistically different.
Adapted from Goss et al. 1979

Table 2. Various oxidation forms of sulfur in soils and plants

Chemical form of sulfur	Chemical notation	Oxidation/Reduction state
Sulfide	S^{-2}	S^{-2}
Sulfur-elemental	S	S^{0}
Sulfite	SO_3^{-2}	S^{+4}
Sulfate	SO_4^{-2}	S^{+6}

Sulfide is most reduced and sulfate is most oxidized.

Because the cytoplasm of root cells is normally less acid and more negatively charged than the cell walls, the anionic SO_4^{-2} tends to be retained within the walls and must be actively transported across the cell membrane (plasma membrane) into the cytoplasm. This requires the expenditure of metabolic energy by the root cells and the presence of a specific SO_4^{-2} transporter (Figure 1) within the outer cell membrane (Marschner 1995). Divalent ions also are generally absorbed less rapidly by roots than are single charged monovalent ions.

This places SO_4^{-2} within a group of nutrient ions that are absorbed by roots relatively slowly. The outcome of all this is that, even under the best of conditions, the rate of SO_4^{-2} transport through the roots is never very great. Thus, sulfur supply rate is not likely to push vegetative growth like nitrogen can.

Sulfur is in many ways similar to nitrogen with regard to its availability and activity in the soil. While the oxidized SO_4^{-2} ion is the form of sulfur most available to plant roots, sulfur generally enters the soil in its reduced sulfide (S^{-2}) form usually as a component of organic matter (Tisdale et al. 1985). In most noncalcareous soils, more than 90 percent of soil sulfur is in an organic form (mostly plant residues and humic substances). This organic matter is slowly utilized by soil microorganisms (bacteria and fungi) as an energy source and in the process sulfur is released (mineralized) into the soil as free S^{-2} along with carbon dioxide (CO_2), water and ammonium (NH_4^+). Within a well aerated soil of reasonable temperature, S^{-2} is readily oxidized to SO_4^{-2} by chemical processes or by bacteria (Table 2). Chemical oxidation can withdraw electrons from S^{-2} to produce elemental sulfur (S^0) and these two forms can be further oxidized by bacteria that use the energy contained in reduced sulfur to fix CO_2 and make carbohydrates.

$$CO_2 + S + 1/2\ O_2 + 2H_2O > [CH_2O]_n + SO_4^{-2} + 2H^+$$

This reaction occurs within several bacterial groups, but the genus *Thiobacillus* is most involved. The soil nitrifying bacteria that oxidize ammonia to nitrate are similar chemolithotrophic organisms which use the energy and electrons present in NH_4^+ to reduce CO_2 rather than the light driven reactions of photosynthesis. *Thiobacillus* is tolerant of acid conditions which make sulfur oxidation less dependent on a narrow pH range than is NH_{4+} oxidation. There are many other microbial reactions involving sulfur but many of them occur under anaerobic conditions and probably are less important in soils on which turf is grown.

You might notice that one product of the reaction printed above is H^+, which has the effect of making the soil more acid: lowering its pH. This reaction explains how the addition of elemental sulfur can be used to make a soil more acid.

Unlike soil organic nitrogen, as much as 50 percent of organic sulfur may be present as SO_4^{-2} esters (SO_4^{-2} bound to carbon through an oxygen). The presence of sulfatase enzymes in the soil releases this SO_4^{-2} from organic matter and constitutes a major part of sulfur mineralization.

$$R\text{-}C\text{-}O\text{-}SO_3^- + H_2O > R\text{-}C\text{-}OH + SO_4^{-2} + H^+$$

This mineralization involves no reduction of sulfur but releases SO_4^{-2} directly into the soil solution where it can be absorbed by plant roots. Organic SO_4^{-2} esters arise from secondary plant metabolites formed by the direct assimilation of SO_4^{-2} into organic compounds. These sulfur compounds are among the first to become mineralized in the soil which makes their SO_4^{-2} most available for plant uptake.

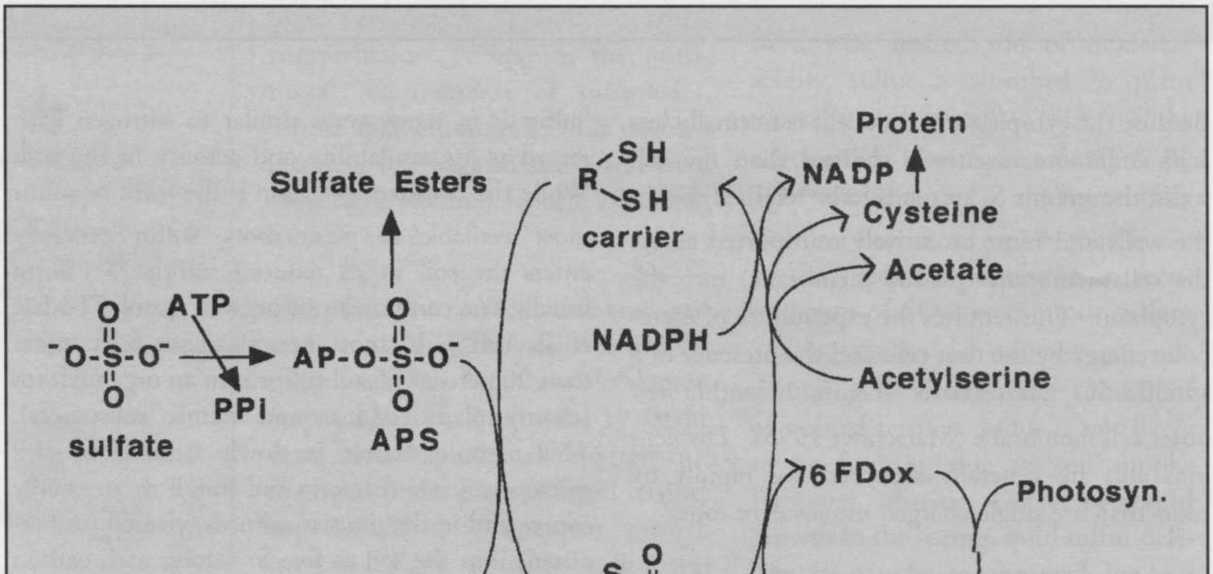

Figure 2. The pathway of sulfate reduction and assimilation into cysteine.

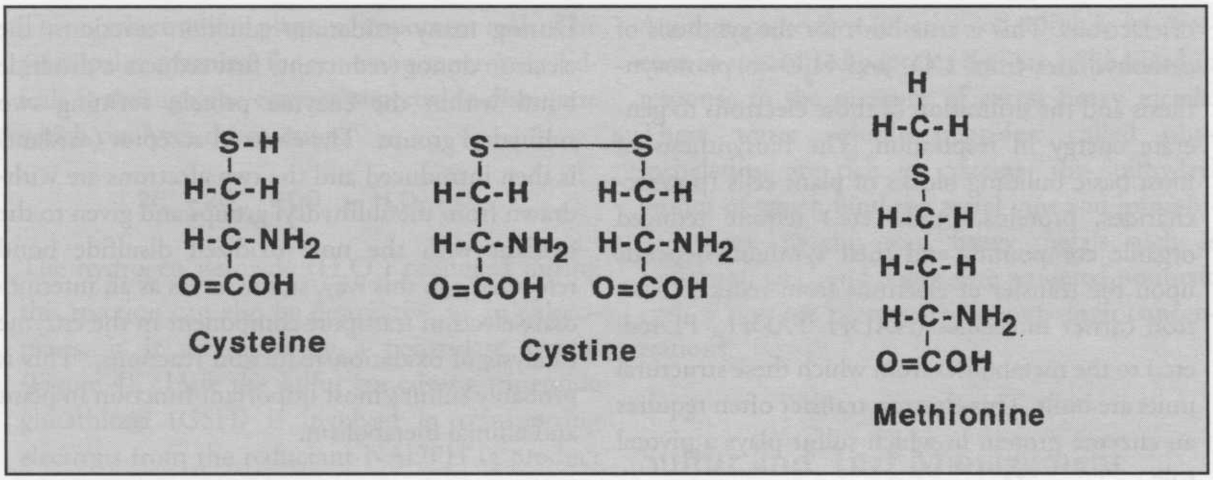

Figure 3. Structures of the three sulfur containing protein amino acids.

Sulfur Utilization Within Plants

Once absorbed by roots, SO_4^{-2}, can follow one of several paths similar to those available to NO_3^- (Figure 1). Sulfate can be transported into the large central vacuole of epidermal cells where it can be stored for some time. Sulfate can also be transported radially from cell to cell through plasmodesmate (cytoplasmic pores which connect adjacent cells) and deposited into xylem elements where it will be moved via the transpiration stream to leaves. Either in leaves or roots, SO_4^{-2} can be reduced to S^{-2} and assimilated into the amino acid cyseine which is a component amino acid of all proteins.

The process of SO_4^{-2} reduction also has many similarities with NO_3^- reduction. Initially SO_4^{-2} is activated by replacing the terminal two phosphates of ATP forming adenosine phosphosulfate (APS). This bound form of SO_4^{-2} is more chemically reactive and is necessary for its reduction and eventual assimilation into organic molecules (Figure 2). There is no comparable reaction required for NO_3^- reduction in plants. APS can undergo a further reaction and donate its SO_4^{-2} to the synthesis of SO_4^{-2} esters, a process that does not require sulfur reduction. Nitrate does not do this. To be assimilated into cysteine, however, SO_4^{-2} must be reduced to S^{-2} and for this to occur, APS must give up its SO_4^{-2} to a carrier molecule where it is bound to a pair of sulfhydryl (R-SH) units. In this reaction, each sulfhydryl group gives one electron to the SO_4^{-2} reducing it to sulfite (SO_3^{-2}). This is sort of analogous to the reduction of nitrate to nitrite (Hull and Jiang, 1998).

While bound to the disulfide carrier, SO_3^{-2} acquires an additional six electrons from the reduced form of ferredoxin (FDred) which is a product of photosynthesis. The SO_3^{-2} is not released from its carrier until it is fully reduced to S^{-2}. Again this reaction is similar to the reduction of NO_2^- to NH_4^+. Once fully reduced, S^{-2} binds to the serine part of an acetylserine molecule forming a cysteine and an acetate (Figure 2). The cysteine can then be utilized for protein synthesis or serve as the sulfur source for all other sulfur-containing amino acids (Figure 3) or sulfur metabolites. Plants, bacteria and fungi can carry out these reactions but, just as with nitrogen reduction and assimilation, animals cannot do so being dependent upon their food as sources of these essential amino acids.

The roles of sulfur within plants are many and varied and most are well beyond the scope of this article. However, their participation in electron transfer as a component of enzyme proteins deserves at least some consideration. Metabolism in all living things depends on the orderly transfer of electrons. This is true both for the synthesis of carbohydrates from CO_2 and H_2O in photosynthesis and the utilization of those electrons to generate energy in respiration. The biosynthesis of most basic building blocks of plant cells (polysaccharides, proteins, lipids, etc.) require reduced organic compounds and their synthesis depends upon the transfer of electrons from reduced electron carrier molecules (NADH, $FADH_2$, FDred, etc.) to the metabolites from which these structural units are built. This electron transfer often requires an enzyme protein in which sulfur plays a pivotal role.

There are three sulfur containing amino acids in proteins: cysteine, cystine and methionine (Fig. 3). When the protein amino acid chain (polypeptide chain) folds on itself a disulfide bond (-C-S-S-C-) can form wherever sulfhydryl groups of two cysteines come together forming a cystine. This covalent bond links the chain at that point and stabilizes the protein's folded (tertiary) structure. This is important to insure the proper structure of the enzyme so it can do its catalytic work. The formation of a disulfide bond involves the oxidation of sulfhydryl groups of two cysteines where each sulfur loses one electron. The shared remaining electrons form the disulfide bond of a cystine. This bond can be reduced, given an appropriate electron donor, reforming the two sulfhydryl groups and eliminating the disulfide bond.

During many oxidation/reduction reactions, the electron donor (reductant) first reduces a disulfide bond within the enzyme protein forming two sulfhydryl groups. The electron acceptor (oxidant) is then introduced and the two electrons are withdrawn from the sulfhydryl groups and given to the oxidant with the now oxidized disulfide bond reformed. In this way, sulfur serves as an intermediate electron transport component in the enzyme catalysis of oxidation/reduction reactions. This is probably sulfur's most important function in plant and animal metabolism.

Stress Tolerance and Sulfur

Another highly important function of sulfur, especially in plants, is its role in neutralizing dangerous oxygen radicals that are produced as a natural consequence of biochemical pathways involving the transport of electrons. Two of the most harmful oxygen radicals are superoxide (O_2.-) and the hydroxide free radical (OH.). If these radicals accumulate at metabolic sites, they will destroy lipids of membranes and kill the cells. These radicals form most readily in chloroplasts during photosynthesis. When the light is strong and CO_2 concentrations are low, O_2 free radicals are readily formed (Figure 4). If not destroyed, these radicals will cause much damage to leaves.

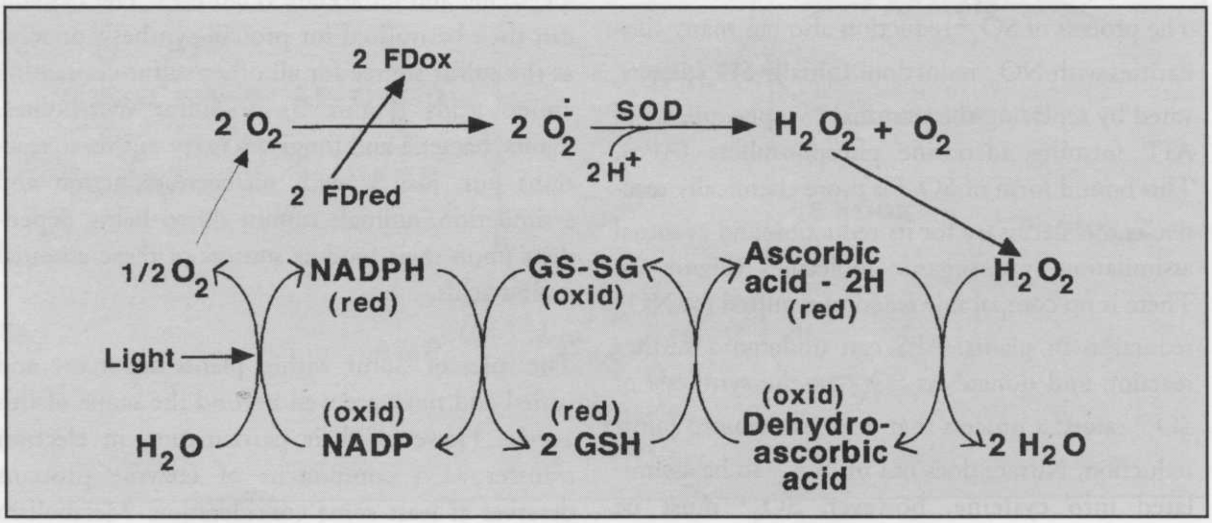

Figure 4. The role of glutathione in the detoxification of hydrogen peroxide.

This is where sulfur plays an important role. The principal mechanism for removing superoxide radicals is through the enzyme superoxide dismutase which catalyzes the reaction:

$$2H^+ + 2O_2^{\cdot-} \text{ SOD } > H_2O_2 + O_2$$

The hydrogen peroxide (H_2O_2) produced during this reaction can also be destructive so, in chloroplasts, it is destroyed by a peroxidase system (Figure 4). Here the sulfur containing tripeptide glutathione (GSH) is involved in transporting electrons from the reductant NADPH (a product of photosynthesis) through ascorbate to H_2O_2, degrading it to two water molecules (Figure 4). Here again the sulfhydryl groups of two glutathione molecules each lose an electron forming a disulfide bond between them (GS-SG). This bond is broken when NADPH donates two electrons to re-reduce the two sulfurs and regenerate sulfhydryl groups of the two glutathione molecules.

Whenever plants are subjected to stress conditions and the normal flow of energy through photosynthesis is impeded, oxygen radicals are formed. If they are not destroyed as described above, damage occurs and the leaves become chlorotic and exhibit dead spots. Large increases in glutathione are often observed in leaves of evergreen plants during the stressful conditions of winter (Marschner, 1995). When sulfur is in short supply, glutathione synthesis occurs slowly and leaf injury occurs.

Another protective function of sulfur is its presence in specialized peptides that are synthesized in response to the presence of excess heavy metals. These water soluble peptides, called phytochelatins, are rich in cysteine; the sulfhydryl groups of which bind the metal ions and immobilize them. In this way, heavy metals such as cadmium, zinc, and copper are rendered nontoxic even if they are present in relatively high concentrations.

Sulfur and Turf Management

An understanding of how sulfur functions in plants can provide some insight into its role in turfgrass growth. Like nitrogen, sulfur is a component of three essential amino acids required for protein synthesis. Consequently whenever turf is expected to respond to a stress or to grow vigorously, sulfur must be available.

Goss (1979) noted that **turf lost more sulfur in clippings when its growth was stimulated by high applications of nitrogen** (Table 3). Even when no sulfur was applied, more was present in clippings of nitrogen stimulated turf. Under such conditions, sulfur deficiency symptoms became evident. **This suggests that intensively managed turf that is expected to recover from injury and fill in after being damaged must have adequate supplies of sulfur.**

Table 3. Influence of fertilization with and without sulfur on the volume of clippings and the sulfur contained in them.

Nutrient treatment *N-P-S*	Dry clipping yield/year *lbs/1,000 sq. ft.*	Total S removed in clippings *lbs/1,000 sq. ft.*
0-0-0	45.3	0.16
20-0-0	78.5	0.23
12-2-1	118.2	0.51
20-2-1	134.6	0.54
20-2-3	127.1	0.50

Adapted from Goss et al. 1979.

As mentioned at the beginning of this piece, sulfur is often taken for granted and in the past this often caused no problems. Today, I am not sure we can be so indifferent to sulfur. Turfgrasses are pushed more than ever before. Play is more intense and mowing heights are frequently lower than is agronomically sound. These are themselves or they directly contribute to stresses on the grass. For grass to respond effectively to stress, it must have adequate supplies of sulfur. It is not wise to leave this important ingredient in turf management to chance. Thus, **it makes sense to supply sulfur as part of a normal fertilizer program.**

Mechanical injury and climatic extremes are not the only stresses to which turfgrasses are exposed and must tolerate. Disease organisms also induce a response from turf which often prevents serious disease development. Such responses normally involve the synthesis of new enzymes and that requires sulfur. A low sulfur supply may delay the reaction of turfgrasses to pathogen attack providing time for disease to become established. Turner and Hummel (1992) describe several accounts of turf disease incidence being suppressed following the application of sulfur fertilizers.

Sulfur deficiency in turfgrasses is not well documented. Generally it appears as a light green coloration of new growth and might be confused with early iron deficiency. Once sulfur is assimilated into organic molecules (proteins) it becomes relatively immobile and is not readily redistributed from old leaves to new growth. By comparison, SO_4^{-2} is quite mobile moving readily from roots to shoots and from leaves to roots. Therefore, newly acquired sulfur is much more mobile within a plant than is sulfur that has been reduced and assimilated. **It is critical for sulfur to be available to the grass throughout its growing season.** Young leaves tend to exhibit yellowing first along the margins starting at the tip. This continues along the leaf as it grows and gradually advances toward the center of the blade. Dead tissue (necrosis) does not occur normally but can become evident if the grass is exposed to high light or other stresses. Inability to destroy oxygen radicals because of low glutathione levels probably explains this stress induced injury.

Because it is difficult to grow turf in the field under the complete absence of sulfur, deficiency symptoms are rarely extreme or even evident. They are also not so specific that they cannot be mistaken for low nitrogen, potassium or iron. Deficiency symptoms are not useful indicators of plant nutrient needs. By the time you can observe symptoms, considerable damage has already been done. This is especially true of sulfur which is required for so many metabolic functions.

Before a sulfur deficiency can be observed, much growth suppression has already occurred, disease has probably been more serious than normal, insects have fed more freely and high light, and drought and temperature extremes have been more damaging. Much of this, the turf manager will write off as bad luck when in fact it was easily avoided. That is the devious aspect of nutritional disorders, they can do so much damage before they are ever detected. When it comes to sulfur, one can easily assume that an ounce of prevention is worth a ton of cure.

Dr. Richard J. Hull is professor of Plant Science and Chairman of the Plant Sciences Department at the University of Rhode Island. His research has concentrated on nutrient use efficiency and photosynthate partitioning in turfgrasses and woody ornamental plants.

References

Goss, R.L., S.E. Brauen and S.P. Orton. 1979. Uptake of sulfur by bentgrass putting green turf. Agronomy Journal 71:909-913.

Hull, R.J. and H. Liu. 1995. Nutrient uptake: some turfgrasses do it better than others. TurfGrass Trends 4(6):7-13.

Hull, R.J. and Z. Jiang. 1998. Turfgrass nitrogen use efficiency. Golf Course Management (In press).

Marschner, H. 1995. Mineral Nutrition of Higher Plants, 2nd Edition. Academic Press, London.

Tisdale, S.L.; W.L. Nelson and J.D. Beaton. 1985. Soil Fertility and Fertilizers. MacMillan Pub. Co., NY.

Turner, T.R. and N.W. Hummel, Jr. 1992. Nutritional requirements and fertilizers. pages 385-439. IN D.V. Waddington, R.N. Carrow and R.C. Shearman (eds.) Turfgrass. Agronomy Monograph No. 32, ASA, CSSA and SSSA, Madison, WI.

FIELD TIPS

Sulfur Management Checklist

Even though I suggested that the turf manager normally does not need to be concerned about supplying turf with sulfur, it is not wise to ignore it either. What follows are some ideas on how you might handle your turf's sulfur requirements.

• To determine if your turf could benefit from sulfur, you can use a nitrogen source that contains sulfur for your next application on one or two greens, tees or other well-defined areas. Use ammonium sulfate as a soluble material or sulfur-coated urea as a controlled-release source. After a week or two, compare the areas that received sulfur with those that did not. If the sulfur treated turf is greener or generally looks better (less disease or evidence of stress), you might conclude that a sulfur application is justified.

• If your soil sulfur supply is marginal, you can make regular applications by using potassium sulfate (K_2SO_4) as your potassium source instead of potassium chloride (KCl - potash). The chloride does almost nothing for your turf while sulfate will be a readily available source of sulfur.

• A top-dressing program using composted clippings or some other organic material will provide a source of sulfur and pretty much eliminate the need to apply it in any other form. However, if you have a low-sulfur problem, clippings from your turf will also be low in sulfur and may not be returning enough in a compost derived from them to supply the turf's need. Better to bring your sulfur level up to standard using a sulfur source and after that rely on composts to maintain it.

• Remember that pushing turf with extra nitrogen will aggravate any latent nutrient deficiency problems. Consequently, whenever you are making a nitrogen application, you should consider other nutrients that might become limiting when grass growth is stimulated. Adding some materials that will supply small amounts of available sulfur, magnesium, iron or zinc often is worth the additional effort and cost. Nutrient imbalances can sometimes be more damaging than a clear deficiency and often are more difficult to identify.

• Because sulfur cycles within the turf-soil ecosystem and there are few routes for sulfur loss, retaining clippings on turf is the best way of insuring that nutrients such as sulfur, magnesium and most micro-nutrients do not become lacking and detract from turf quality.

The Potential of Turfgrass Growth Regulators In Water Conservation

By Dennis P. Shepard, Ph.D.
Novartis Turf and Ornamentals, Overland Park, KS

Plant growth regulators (PGRs) have been used to suppress turfgrass growth and seedhead formation since their introduction in the 1950s. The development of new PGRs in recent years has lead to new research areas such as clipping reduction, water savings, improved turf quality and stress tolerance. The following is an overview of PGRs and their use as a turf management tool.

The first PGR to be used on turf was maleic hydrazide (Slo-Gro), developed in the 1950s. Its potential for phytotoxicity limited its use to turf areas such as highway roadsides and right of ways. Mefluidide (Embark) was introduced in the 1970s, and it was the first PGR to be extensively tested on high maintenance turf areas like golf courses and commercial lawn sites.

Flurprimidol (Cutless), paclobutrazol (Scott's TGR) and amidochlor (Limit) were developed in the 1980s. Various herbicides such as metsulfuron-methyl (Escort), imazapyr+imazethapyr (Event), sulfometuron (Oust), sethoxydim (Poast), glyphosate (Roundup), EPTC (Shortstop) and chlorsulfuron (Telar) were also used to suppress seedheads and growth in lower maintenance turf areas like highway roadsides. The newest PGR to date is Primo, registered in 1993. Unlike the other PGRs, Primo is used exclusively on fine turf areas like golf courses, athletic fields, sod farms and home lawns.

How Do PGRs Work?

It is important to review PGR mode of action because the way they work determines the type of turf setting they can be used. Plant growth regulators suppress growth by stopping cell division or by slowing cell elongation. Gibberellic acid (GA) is a plant organic acid that aids in cell elongation. Some PGRs slow gibberellic acid production.

In the past, PGRs were classified as Type I (cell division inhibitor) or Type II (gibberellic acid inhibitor). A more detailed classification is currently being adopted where PGRs are classified as Class A, B, C, or D. Class A PGRs (Primo) stop the production of gibberellic acid late in the biosynthetic pathway. This is important as there are over 100 forms of gibberellic acid in plants. Most of them contribute to the formation of GA20 which converts to GA1 — the final form of gibberellic acid which is the one that functions in cell elongation. Primo stops the conversion of GA20 to GA1. The other 100-plus forms of GA are allowed to carry on their respective plant processes.

This is likely a key reason why Primo can be used on high maintenance turf, because potential for phytotoxicity is minimal. Primo is absorbed by the foliage within one hour of application. Class B PGRs (flurprimidol and paclobutrazol) stop the production of all forms of GA early in the biosynthetic pathway. They are used on moderate to highly maintained turf, and are root absorbed. Class C PGRs (maleic hydrazide and mefluidide) stop cell division. They can do a good job of stopping seedhead production when applied at the correct time. Class D PGRs include herbicides that are used as PGRs. They are not used on high maintenance turf.

PGR Research

With the development of flurprimidol and paclobutrazol in the 1980s, and Primo in 1993, their potential for use on high maintenance turf lead to new areas of research. Several states had enacted regulations that banned green waste in landfills. Research was conducted to determine if PGRs could reduce mowing and clipping production in high maintenance turf areas. If mowing could be reduced, it was reasoned that equipment could last longer.

There were several challenges to overcome to make PGRs a part of routine turf maintenance. First was convincing turf managers that PGRs work. Many had heard or seen reports where PGRs performed poorly or were inconsistent. They often grouped PGRs as all alike with no difference in mode of action.

Others lacked a fundamental understanding of plant physiology and how plants grow. They did not understand how a chemical applied to a plant could slow its growth. Some referred to PGRs as another "snake oil." Foremost, many turf managers did not want to slow turf growth, since they make their living by mowing. A reduction in growth could mean reduced business.

Dramatic growth in the turf industry in the past decade was fueled in part by the popularity of golf. The demand for more golf courses brought about the demand for better quality turf. To accomplish this, improvements were made in a number of areas. New turfgrass cultivars, computerized precision irrigation systems, computerized business and turf management programs, safer pesticides for the environment, better maintenance equipment, and other factors have all contributed to the advance of better turfgrass. Plant growth regulators can also be included in the list of improvements.

PGRs Can Mean Water Savings

The potential for PGRs to reduce turf water use was not known until they were used on high maintenance turf areas. These areas usually have a quality irrigation system and often some type of device to monitor evapotranspiration (ET). Turf quality could be monitored and correlated to the irrigation needed to maintain that quality. Researchers hypothesized if a plant grew slower and had smaller leaves, it might not require as much water to maintain turf quality.

Primo has gained wide acceptance as a tool to reduce mowing in areas like Florida that receive a lot of rain — and in places where mowing is a frequent, year-round task. On the other hand, turf managers who have used Primo in areas of little rainfall, or in areas where turf irrigation is restricted, have reported Primo-treated turf has better quality during drought stress.

Research studies at Texas A&M University, Cornell University, University of California-Riverside, Colorado State University and Kansas State University have determined the influence of Primo in reducing water requirement. These studies have ranged from greenhouse trials to field experiments with lysimeters. Results have shown Primo can reduce water requirement from 7 to 26 percent. These results are supported by comments from numerous customers.

Reducing the water requirement

Research with Primo shows that while turf vegetative growth is reduced, root growth is enhanced. This makes more of the soil moisture available to the plant and less leaf area for transpiration. Stomates may remain closed longer, which could also reduce transpiration. There are likely other reasons that hope to be defined with future research.

Most turf managers must work within the parameters of a budget and are hesitant to use unfamiliar products. Plant growth regulators like Primo have gained wide acceptance and their use continues to increase. Turf managers report that while it is initially an "add-on" item into their budget, they feel Primo pays for itself in labor savings, increased equipment life and potentially with water savings.

Dennis P. Shepard, Ph.D., is a technical representative with Novartis Turf and Ornamentals. He is in charge of Primo research and development in the United States welcomes any comments from the readers. Shepard can be reached at (913) 338-2829.

Reprinted with permission of The Irrigation Association, Irrigation Business & Technology, February 1998.

EDUCATIONAL MATERIALS

Second Edition

Turfgrass Management Information Directory

Edited by Keith J. Karnok

The second edition of the *Turfgrass Management Information Directory* is now available. The directory contains handy information needed daily for turfgrass managers. This edition is 40 percent larger than the first and includes six new sections. All information has been updated from the first edition. All royalties go to the non-profit Turfgrass Science Division of the Crop Science Society of America to support turfgrass teaching, research, and extension activities.

The Directory is available in quantity prices ranging from $17.47 to $34.95. Contact Ann Arbor Press, 121 South Main St., Chelsea, MI 48118. Phone: (313) 475-8787 or fax: (313) 475-8852.

Contents

- Teaching and training programs
- Instructional Tools (books, videos, slides)
- Industry Services (soil/plant labs, etc.)
- Green Industry Organizations
- University and Industry Personnel
- Poison Control Centers
- Scientific Names of Pests
- Turfgrass Chemicals
- Climatic Maps
- Conversions and Calculations
- Web Sites
- Glossary of Turfgrass Terms

American Society of Agronomy Publications

Turfgrass, Agronomy Monograph 32, is divided into five primary sections. The first section explores the turfgrass industry and includes chapters on historical aspects of research and education, current status of the industry, and artificial turf. The turfgrass physiology section focuses on ecological aspects, energy relations, carbohydrate partitioning, and stresses due to salinity, temperature, shade and traffic. The third section in on soils and water and emphasizes soils and amendments, nutrition, fertilization, water requirements and irrigation. The management section offers chapters on energy conservation and efficient maintenance, integrated pest management, turfgrass management operations, and plant growth regulators. The last section addresses research techniques related to the field and controlled-environment research, diseases, insects, weeds, and breeding. *D.V. Waddington, R.N. Carrow, and R.C. Shearman. Hard cover, 850 pages, 1992. ISBN 0-89118-108-3.*

Turf Weeds and Their Control. Addresses many modern concerns over herbicide use. Several chapters in this book emphasize herbicide action and metabolism, formulations, application methods, and practical uses. One chapter is devoted exclusively to herbicide-related turf injury, reduced growth and loss of competitive capacity. There are chapters on environmental fate, weed taxonomy, ecology, and control. *A.J. Turgeon. Hard cover, 248 pages, 1994. ISBN 0-89118-120-2.*

To order call the Book Order Dept. at ASA /CSSA/SSSA Headquarters, (608) 273-8080, e-mail: books@agronomy.org.

USGA Green Section Research

Initial Investigations of Mowing Height And Greens Rolling on Ball Roll of Penncross

Authors: Drs. D.M. Kopec, J. Long, D. Kerr, and J.J. Gilbert, University of Arizona, Tucson 1995

Increased ball speed is one of the greatest demands on the modern golf course superintendent. This is due in part to 1.) the increased popularity of the sport, 2.) increased competition within the sport, 3.) better mowing practices and specialized equipment, and 4.) more precise greens construction specifications. One such cultural practice is the use of rollers to increase ball speed of putting greens. Rolling turf is not new, but renewed interest has resurfaced in the last few years. The claimed benefits of rolling include 1.) increased ball speed, 2.) a truer ball roll, 3.) increased speeds at higher mowing heights, and 4.) consistency of performance from green to green.

With these considerations in mind, a study was devised to investigate the effects of mowing height, rolling, rolling frequency, and intial testing of surface hardness levels of greens as they relate to ball (distance) speed.

The effects of mowing height and rolling on ball speed performance were evaluated on a sand-based USGA "Penncross" putting green. Three tests were conducted addressing mowing height and rolling combinations, frequency of mowing (number of passes), and surface hardness measurements among treatments using a Clegg surface hardness decelerator.

When plots were rolled at one pass (twice per week) ball speed was generally increased by 8-11 percent at higher cut Penncross (11/64 inch). Plots rolled at one pass at low mowing heights (9/64 inch) showed increases in ball speed distances by 5-10 percent. While rolling did improve ball speeds for both mowing heights, rolling at the higher height of cut did not increase ball speed over unrolled low cut turf. Double rolled turf did not produce greater ball speeds than single rolled turf, when double rolling was performed once.

The effects of rolling on enhanced ball speed appear to last 48 hours at most. Surface hardness was positively correlated to ball speed for high cut turf, which received a single rolling event and was strongly negatively correlated when mowed at low height when double rolled.

Test One Results. The roll, low-cut treatment was fastest followed by no-roll, low-cut treatment. Generally there was a ten percent difference between these two treatments. The roll, high-cut treatment was faster than the no-roll, high-cut treatment. The average distance between these two treatments was 15 percent. Roll treatments did have greater speed than non-roll counterparts in all cases.

Test Two Results. Height of cut alone had a greater effect on ball speed than rolling alone. However, rolling did increase ball speeds at each cutting height considerably (6-11 percent).

Test Three Results. Rolling frequency increased surface hardness, more at the low mowing height.

Tolerance of Warm-Season and Alternative Turfgrasses to Salinity

Authors: Drs. K.B. Marcum, A.A.Maricic, and D.P. Kopec, University of Arizona, Tucson

As fresh water becomes more scarce, increasing use of brackish water sources and sewage effluent for irrigation has resulted in an increasing need for salt-tolerant turfgrasses. Though there are broad differences in salt tolerance among turfgrasses, little is known about how grasses adapt to salinity. Also, there are some alternative grasses which might hold promise for use as turfgrasses in extreme environments. (e.g. high salinity, extreme drought). This project was done to determine the relative salinity tolerances of a broad range of warm-season grasses adapted to Arizona.

Eight species of turfgrasses or turfgrass alternatives were examined for salinity tolerance by growing them in hydroponics culture in a greenhouse. Salinity tolerance decreased in the following order: alkaligrass (*Distichlis spicata*), alkali sacaton (*Sporobolus airoides*), Arizona common bermudagrass (*Cynodon dactylon*), Meyer zoysiagrass (*Zoysia japonica*), sand dropseed (*S. cryptandrus*), Prairie buffalograss (*Buchloe dactyloides*), Haskell sideoats grama (*Bouteloua curtpendula*), and black grama (*B. eriopoda*).

Rooting parameters (depth and weight) were directly associated with salinity tolerance. Root weights increased under salinity in two grasses: alkaligrass and alkali sacaton. Leaf osmotic potential (a measure of the amount of saline ions and other solutes) was highest in the most salt-sensitive grasses, indicating that salt tolerance in turfgrass is associated with salt exclusion from leaves.

Alkaligrass and alkali sacaton are a bit too coarse for many turfgrass scenarios, but make good ground covers and golf course roughs. We are currently selecting strains of alkaligrass that are finer and denser.

Rooting is an important salt tolerance mechanism in these grasses. The more salt tolerant grasses had greater rooting depth and greater total root dry weight under salinity stress. Perhaps this is an evolutionary mechanism to seek out less salty water occurring deep in the soil profile. Finally, in salt-tolerant grasses, osmotic potential was controlled (kept at lower levels) better than in susceptible plants. This means that saline ions were excluded from shoots to a greater degree in salt-tolerant grasses.

Alkaligrass and alkali sacaton are suitable grasses to use as ground covers in extremely saline areas. However, bermudagrass and zoysiagrass can also be successfully grown using poor quality irrigation water under relatively high saline conditions.

Tolerance of Common Bermudagrass To Confront Herbicide

By Drs. D.M. Kopec, J.J. Gilbert, and M.W. Rothenberg, University of Arizona, Tucson.

Alternatives to non-phenoxy type herbides are receiving greater interest among users for control of broadleaf weeds. The commercial product Confront (mixture of triclopyr and clopyralid) was applied to common bermudagrass turf to assess the response to the herbicide. Triclopyr alone, especially in the ester formulation, often affects bermudagrass by producing off-colored turf, slight twisting or spiraling of leaves, and reduced growth. Trimec Classic was included as an industry standard.

Two rates of Confront liquid herbicide, one rate of a granular formulation with fertilizer (Confront-On), and Trimec Classic were applied to common bermudagrass turf. At 11 and 17 days after treatment (DAT), Confront products tended to have slightly higher mean turf color scores than Trimec, although differences were subtle.

Confront-On herbicide had decreased color scores at 7 DAT, perhaps due to the higher rate of active ingredient applied (0.84 lbs. ai/a) or an unknown amount of fertilizer in the carrier. Turfgrass quality was significantly affected by herbicide treatments at 7 and 15 DAT, but not at 21 DAT.

Confront alone at 0.56 lbs. ai/a produced some discoloration, leaf curling and cupping at 7 DAT. By 11 DAT, overall color scores were not significant due to treatments. All treatments showed some marginal discoloration over the check.

By 15 DAT, discoloration was no longer noticeable and turfgrass color and quality was equal or greater to that of the bermudagrass control plots.

By 21 DAT, color differences due to treatments exhibited the greatest effect. Confront at 0.38 lbs. ai/a had the highest mean color score (7.0) followed by the 0.56 lbs. ai/a rate (6.8). Nitrogen in the compounds or regrowth may have increased color response by 21 DAT.

FROM THE EDITOR: China's 'NTEP'

Dave Nelson of the Oregon Fine Fescue Commission, tells TGT nationwide variety trials similar to the US NTEP trials will soon begin in China, to help the Chinese benefit from US turf varieties, and as a way to soften price swings stateside. (Exports of turfgrass seed from Oregon to China now total 3-½ million pounds per year, says Nelson.)

"Nationwide variety trials will start in the spring of 1998, with national, regional and provincial universities in China taking part," says Nelson. "The China National Turf Variety trials will include 110 cultivars from about 30 seed companies." Included will be bermudagrasses, perennial ryegrasses, tall and fine fescues and a "sprinkling" of every other seed variety, says Nelson.

Total annual cost to the seed industry to support this program is $150,000. This program, says Nelson, reflects the rapid growth of the Chinese economy and the investment of foreign capital. Aesthetically, says Nelson, the Chinese nation will benefit, too. As he describes it, it's a choice between "red clay or green grass." The China Institute of Turfgrass Science has done similar testing for about 10 years, says Craig Edminster of International Seeds, but adds that "this set of trials appears to be the best organized."

Nanjing Agriculture University and the China Agriculture University (CAU) and nine regional ag universities will hold also conduct variety trials. Training seminars for turf scientists begin in Beijing at CAU March 2. This is a US program, reminds Nelson, who sees this program as a great expression of confidence in the quality of US seed.

"I'm excited about the support the industry has given the program. Over time, we want to expand the market in China, to help take wild [domestic] price swings out of the production process. If we have a cold spring, in the Eastern US, we have a glut; prices fall and production is cut. If we can have seed overseas, we can take the peaks and valleys out," explains Nelson.

—Terry McIver, editor

TurfGrass TRENDS is published monthly. ISSN 1076-7207.

Subscription rates: One year, $180 (US) $210 (all other countries.)

Postmaster: Send address changes to TurfGrass TRENDS, 131 West First St., Duluth, MN 55802-2065.

ADVANSTAR COMMUNICATIONS

In Future Issues

- Potassium's role in turfgrass, by Dr. N.E. Christians
- State-of the-science in turfgrass breeding, by Dr. Doug Brede

TurfGrass TRENDS Field Advisors

TurfGrass TRENDS Quick Reference Numbers

Editorial: 440-891-2709

Subscription: 218-723-9477

Permission: 440-891-2742

Reprints: 440-891-2744

Single copy or back issues: 218-723-9477

Use of TGT articles

Permission may be granted on request for TGT articles as course material and for reprints in publications.
For course material: We can group articles by subject for you.

Please send request to:
TurfGrass TRENDS
Advanstar, Attn: Permissions
7500 Old Oak Blvd.
Cleveland, OH 44130
Phone: 800-225-4569, ext. 742

Index and abstracts are available electronically through: Michigan State University, TGIF 800-466-8443; PLCAA, at http://www.plcaa.org. TurfNet at http://www.turfnet.com

ADVANSTAR COMMUNICATIONS

TurfGrass TRENDS

131 West First Street
Duluth, MN 55802-2065

PRE-SORTED
FIRST CLASS
US POSTAGE
PAID
DULUTH, MN
PERMIT NO. 1900