

TURFGRASS TRENDS

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MICRONUTRIENT NUTRITION

Iron Usage By Turfgrasses

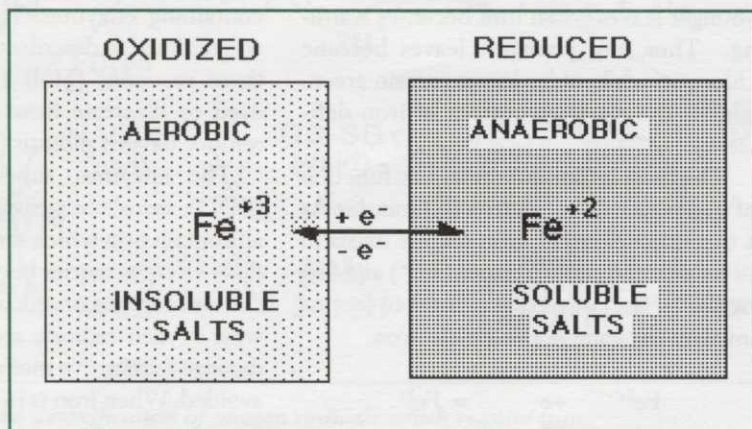
Richard J. Hull, University of Rhode Island

The functions of the six mineral macronutrients (often called major nutrients) in turf have been reviewed in these pages during the past two years. It is now time to consider the value of the eight micronutrients (minor). As their name suggests, micronutrients are required by plants in much lower concentrations than are the macronutrients (Table 1, page 5). While macronutrients are required in turfgrass tissues at concentrations measured in parts per thousand, micronutrients are present at concentrations of parts per million. This suggests that micronutrients are most likely to function as catalysts, where only small amounts are required and not as structural or ionic components, which would be needed in relatively large amounts.

Only within the past decade or two has there been much concern over micronutrient nutrition of turfgrasses. In the future, several of these nutrients could gain in importance as turf culture becomes more refined.

The use of fertilizer salts of ever greater purity does not provide the micronutrient elements as contaminants that was common in years past. Also, growing turf on artificial media often does not provide the source of micronutrients that normally would be supplied by the soil. Sand-based greens and tees are sites where micronutrient deficiency problems can be expected to occur. As turf is grown in ever more exotic locations, such as deserts, sand dunes, saline soils or other sites which have never grown turfgrasses, problems of micronutrient imbalances, deficiencies or toxicities are more likely to be encountered.

Figure 1.
Two oxidation/
reduction states
of iron and the
properties of
their salts in
aerobic or
anaerobic soils.



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The micronutrient of greatest interest to turf managers currently is iron (Fe). It has been applied to turf as a fertilizer material more than any other micronutrient to correct a number of problems. This is not to say that the other micronutrients are of lesser importance, only that they have received less attention from turf researchers and managers. Because its importance is becoming increasingly clear to turf managers, we will start our exploration of micronutrients with iron.

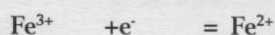
Functions of Iron

Iron has received interest in turfgrass management because it is recognized as the green-up nutrient. If a turf manager wants to spruce up a green or fairway, an application of a little iron will normally do the job. This green-up occurs with only a slight stimulation of leaf growth, which is frequently excessive following nitrogen fertilization used to improve turf color.

The green-up connection with iron use is fairly direct in that iron is required for the synthesis of chlorophyll — the green photosynthetic pigment in grasses. While iron is not a component of the chlorophyll molecule, it is required as a cofactor in three reactions leading to chlorophyll synthesis.

In short, with no iron there is no chlorophyll. Consequently, the most obvious symptom expressed by an iron deficient plant is chlorotic (pale green to almost white) leaves. Because iron is not readily remobilized or retranslocated within the plant, it does not move from older to younger leaves when iron becomes wanting. Thus, the youngest leaves become chlorotic, while older leaves remain green. This is the classic symptom of iron deficiency.

The most important metabolic function of iron is its role in electron (e^-) transfer. As a transition element, iron readily exists in two oxidation states: ferrous (Fe^{2+}) and ferric (Fe^{3+}). The conversion of ferric to ferrous involves the gain of a single electron.



In photosynthetic and respiratory metabolism, the basic idea is to establish a controlled flow of electrons from one component metabolite to another with energy being conserved or utilized in the process. Metallic atoms, which are capable of gaining or losing an electron, are frequently incorporated into these electron-carrying metabolites. Nutrient elements that serve this function are Cu, Fe, Mn, Mo and Ni. Of these, the most commonly used electron transporting element is iron. Iron can perform this function as the coordination center of large polycyclic cytochrome molecules or as iron-sulfur proteins. It is in these forms that iron transports electrons in both photosynthetic and respiratory electron flow processes. Thus, when iron is in short supply, the very core metabolic processes of a plant become sluggish.

Iron also plays an important role in detoxifying destructive oxygen radicals. Wherever oxidation/reduction (e^- loss or e^- gain) reactions occur, there exists the potential for forming oxygen-free radicals. These free radicals have an unpaired electron, which is a chemically unstable condition. Consequently, such radicals are highly reactive and can cause uncontrolled oxidation/reduction reactions. These reactions can attack proteins, fats, nucleic acids and other macromolecules resulting in their destruction or rendering them biologically inactive. Cell membranes consisting of fats and proteins are especially vulnerable to damage by free radicals of oxygen.

The chemical reactions that detoxify oxygen-free radicals are controlled by iron-containing enzymes. The scheme which was outlined to describe the role of sulfur in these reactions (Hull 1998) can also be used to illustrate how iron functions to remove oxygen radicals (Fig. 1).

The enzymes, superoxide dismutase (SOD), ascorbate peroxidase and catalase, all contain iron which serves as an intermediate electron carrier between oxygen radicals and a source or sink for electrons. In this way, oxygen radicals are neutralized and damage to sensitive membrane structures is avoided. When iron is in short supply, oxy-

gen radicals are not removed efficiently and membrane damage in the chloroplasts and mitochondria of the cells occurs.

In some cases these intermediate electron carrier roles serve a biosynthetic purpose. Cell wall peroxidase enzymes utilize oxygen radicals (H_2O_2) to catalyze the polymerization of phenolics to form lignin, one of the main structural compounds of woody plants. Reduced iron levels will affect this lignin formation process and iron deficiency has been associated with slower growth and weaker stems.

Another example of the involvement of iron in a plant protective function is the peroxidation of membrane lipids (fats). During rapid plant growth, such reactions are important for maintaining the proper saturation level (fluid character) of lipids in cell membranes. These reactions also mediate the hypersensitive response of plant tissues to disease causing microorganisms (pathogens). Through this mechanism, iron directly contributes to the resistance of plants to the onset of disease.

Iron Uptake

As demonstrated, iron is required for many metabolic functions in plants, including turfgrasses. There is a problem, however, for plants to acquire iron from the soil.

Most soils contain abundant iron, but most of it is immobilized as insoluble salts and soil structural components (primary

minerals, clays, etc.).

In a well aerated soil, virtually all iron is in the oxidized ferric form (Fig. 2) which readily combines with phosphate, sulfate, and hydroxide radicals to produce salts that are essentially insoluble. Because of this, the concentration of absorbable free iron cations (Fe^{3+} or Fe^{2+}) in most soils is often less than one part per trillion — far below that needed for adequate plant growth. Consequently, plants must absorb iron as either ionized ferric hydroxide ($Fe(OH)^{2+}$) from acid soils or $(Fe(OH)^4)$ from alkaline soils (Marschner 1995).

Soil pH plays a pivotal in determining the availability of these two forms of iron. At or near a neutral soil pH, ionic iron concentrations are especially low. Only when soil pH is less than 4.0 will the concentration of soluble inorganic iron be adequate to meet plant needs. However, when soils are so acidic, aluminum and manganese toxicity will normally restrict plant growth well below acceptable levels.

To accommodate this virtual unavailability of iron in most soils, plants have evolved two strategies for acquiring this essential element (Fig. 3).

The most common plant process involves the production of a cell membrane reductase that can reduce ferric to ferrous,

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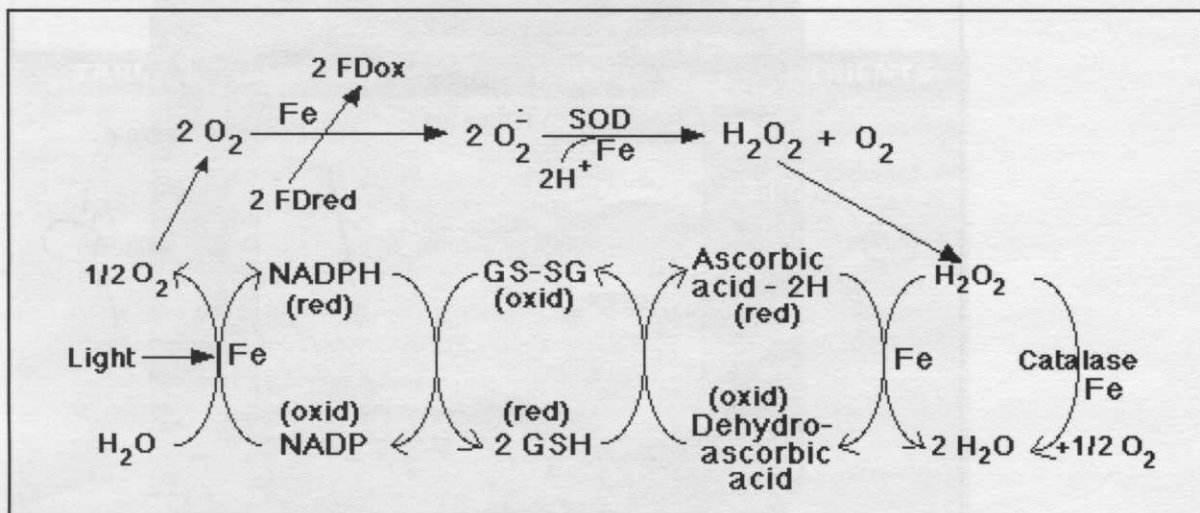


Figure 2. Sites in the detoxification of oxygen radicals which require iron.

which is the much more soluble form. This occurs within the cell walls at the outer surface of root cell membranes. To solubilize the ferric iron in the soil so it can move toward the root, root cells excrete hydrogen ions (H^+), which lowers the pH immediately around the root and makes the ferric salts more soluble. Trivalent cations, like Fe^{3+} , cannot easily cross biological membranes so reduction to ferrous (Fe^{2+}) is essential. In this form, the soluble iron crosses the cell membrane and enters the cell via a specific transporter or channel. This and other structural changes are triggered by a deficiency of iron within the roots — in other words, an induced process.

The above mechanism for iron recovery occurs in most plants, but not the grasses. In the grasses, an alternative strategy for iron acquisition has evolved. When grass roots experience an iron deficiency, the surface root cells (epidermis) excrete complex organic molecules (chelators) which can bind with ferric ions and make them soluble, enabling them to diffuse to the root surface. These ferric chelators are called phytosiderophores.

The phytosiderophore-bound ferric dif-

fuses to the surface of the root cell membranes and enters the cells via a specific membrane transporter that can accommodate the ferric-chelate complex (Fig. 3). The increased production of this membrane transporter is also induced by the iron-deficient condition of the roots. Other metal salts also can be solubilized by these phytosiderophores, but the membrane transporter is specific for the ferric chelate so chelates of copper, zinc and manganese are absorbed much less readily.

When iron is not deficient, the supply of iron, either as inorganic ions or as organic chelate forms derived from soil organic matter, is adequate to meet plant needs. The iron transporters are always present to some extent and can supply the roots with iron when external supplies are adequate. When soil sources become inadequate, a deficiency condition results and this induces a mobilization and recovery strategy for increasing the iron supply.

This iron acquisition strategy of grasses is more adaptable to a broader range of conditions than is the non-grass strategy. The latter depends on acidifying the root zone (rhizosphere) which becomes diffi-

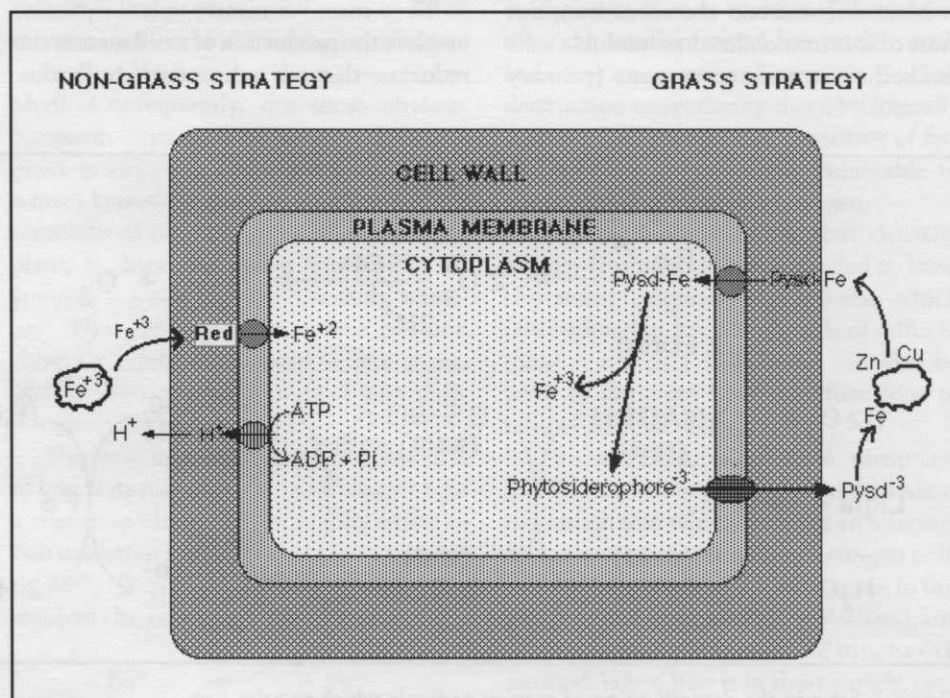


Figure 3. The two strategies by which plants acquire insoluble ferric iron from the soil.

cult in alkaline soils or where the carbonate levels are high. Grasses, which depend less on making the rhizosphere acid for iron solubilization, can better tolerate high soil pH and high carbonate conditions. However, even the grass strategy will become less efficient in recovering iron, if soil conditions are such that the free ferric concentration is too low for ferric-phytosiderophore complexes to form. There is little evidence that such problems often occur, but it clearly could be a problem under extreme soil conditions.

Iron Use Strategies

Based on the above discussion, we can now consider some of the issues involving iron use in turf management. The amount of research on iron, specific to turf, is limited so some of what follows should be viewed as "informed" speculation.

Green Turf With Less Nitrogen:

Ever since the possibility of nitrate contamination of groundwater from the use of nitrogen fertilizers on turf was proposed, methods to reduce nitrogen use, while retaining good turf color, have been investigated.

One of the more frequently employed alternatives to high nitrogen fertilization has been the foliar application of iron (Yust et al. 1984; Carrow et al. 1988). Since the green color of turf is the product of chlorophyll synthesis and iron is essential for this process, it appears reasonable that in many situations favorable color could be obtained

or retained by applying iron while reducing the use of nitrogen. In most studies, a 50 percent reduction in nitrogen fertilization could be tolerated if the nitrogen was supplemented with 2-3 lbs./acre of a foliar applied iron source.

It should be remembered that iron is not part of the chlorophyll molecule, but is an essential catalytic cofactor in its synthesis. In reality, chlorophyll synthesis actually requires much more nitrogen than it does iron. This means that a favorable iron response will not be obtained unless nitrogen is available in sufficient amounts. By the same logic, the results from a nitrogen application might fail to enhance turf color unless iron is available. Thus, the desired turf quality can only be achieved when both nutrient elements are available in their respective sufficient amounts.

Normally, well maintained turf receives adequate nitrogen and an off-color might very well be corrected by adding iron. However, if iron is being used as a substitute for nitrogen, the results may be less than satisfactory, if the nitrogen half of the team is inadequate. For this reason, most research has shown that turf responds best to an iron application if it is supplied with a small amount of nitrogen at the same time.

Iron supplied as a foliar spray requires relatively small amounts to be used (2-10

The desired turf quality can only be achieved when both nutrient elements are available in their respective sufficient amounts.

TABLE 1. TISSUE CONTENT OF MACRO, MICRONUTRIENTS

Chemical Element	Tissue Content		Micronutrients	parts per million (mg/Kg)	
	Sufficient	Normal			
	parts per thousand (g/Kg)				
Macronutrients*					
Nitrogen	28-35	20-60	Chlorine	1000†	2000-20K†
Potassium	10-25	21-45	Iron	35-100	111-934
Phosphorus	3-6	2-7	Manganese	25-150	20-400
Calcium	5-12	3-15	Zinc	20-55	22-70
Magnesium	2-6	1-5	Copper	5-20	7-30
Sulfur	2-5	3-5	Boron	10-60	6-30
			Molybdenum	0.1†	2-8
			Nickel	0.1†	1-10†

† Based on plants other than turfgrasses (Marschner 1995).

*Data based on Jones 1980 or data reported by Turner & Hummel 1992.

Greater root growth, improved turf quality and greater recovery from drought result when frequent iron applications are supplemented with nitrogen applications.

lbs./acre) and for that reason the foliar application has been the preferred method of application over the granular form.

In agricultural crop management, iron is often applied to the leaves because the iron in soil-applied granular applications is often bound so tightly that it is virtually unavailable for uptake by the roots. Applying

iron through the soil would be ineffective in such situations, making foliar sprays the most reasonable alternative.

In most turf situations, soil immobilization of iron might not be a problem. This is especially true for sand greens or other turfs grown on artificial media that lack iron because it was never added, not because it is fixed in unavailable forms. Consequently, for many turf managers, iron should be considered during turf installation and included in medium preparation.

A problem with foliar applications of iron to turf resides in the fact regular mowing removes the treated leaves. Since iron is not very mobile within the grass plant, it does not move from old leaves to newly forming leaves. This means that following an application of soluble iron, those leaves actually receiving the spray will respond if iron enters the leaf cells, but any subsequent newly formed leaves are unlikely to gain any benefit.

When sprayed leaves are removed during mowing the benefit of the iron application can be lost rapidly. This explains why iron applications to vigorously growing turf often exhibit a short-lived greening response (Yust et al. 1984; Carrow et al. 1988). Slower growing turf usually retains iron-induced greening for a longer time, often several weeks.

In some cases, an iron response from foliar application will last for a month or two (Turner and Hummel 1992). I suspect this occurs when clippings are retained on the turf and where rain or irrigation has washed the iron in the leaves into the

thatch or surface soil. Fine roots growing in the thatch can recover iron washed from the leaves and deliver it via the xylem to newly forming leaves. Thus, if conditions are favorable, iron applied to turf may cycle through the grass-thatch-soil system extending the beneficial effects of the iron for some time.

Promoting Root Growth: Another consideration, that has prompted many turf managers to try the 'iron for nitrogen' strategy, is the inhibition of root growth that is commonly associated with high nitrogen fertility (Hull 1996).

Elevated applications of nitrogen promotes leaf growth, often at the expense of root extension. Since as much as 80 percent of the turfgrass root structure is replaced annually, inappropriately timed nitrogen applications can have a decidedly negative effect of root volume. This can result in less drought tolerance, reduced nutrient uptake and greater susceptibility to several diseases.

On athletic fields, high nitrogen turf is more vulnerable to injury and tends not to repair as rapidly. While these negative consequences of high nitrogen fertility are generally recognized, the desire for attractive deep-green turf makes many managers push the upper limit of appropriate nitrogen use.

If iron can promote good color with less nitrogen, will it also promote greater root growth? This was investigated by Snyder and Schmidt (1974) on creeping bentgrass putting green turf in Blacksburg, VA. While the emphasis of their study was extending turf quality during the winter and spring months by applying nitrogen and iron, they collected sufficient data to evaluate the fertility effects of iron on grass growth. In general, they noted greater root growth, improved turf quality and greater recovery from drought when frequent iron applications supplemented nitrogen applications. Differences were often less than dramatic, but consistently showed a positive impact of iron when applied with nitrogen.

A chelated form of iron was more effective than ferrous sulfate (FeSO_4) in pro-

moting root growth. While definitive data are hard to find, most published research indicates that the application of iron tends to suppress the nitrogen-induced reduction in root mass, but this is particularly true if nitrogen rates are lowered as a concession to the greening effect of iron.

Because root responses to iron deficiency demand energy and a turf growing under high nitrogen fertility will have less energy available in its roots, the iron deficiency strategy may be poorly or slowly implemented. Thus, when growing on an iron poor site, high nitrogen turf may be less able to induce its corrective strategy. Foliar applications of iron will meet the plants needs directly, stimulate increased chlorophyll synthesis and more efficient photosynthesis and make more energy available for translocation to the roots.

If an iron deficiency signal is perceived by the roots (accumulated phenolic compounds due to depressed lignin biosynthesis), the influx of additional photosynthate should promote the iron recovery strategy (phytosiderophore synthesis and membrane transporter induction) and increase the iron supply to the plant. This might explain the prolonged positive response from a single foliar iron application.

If a foliar iron application to a nitrogen saturated turf, promotes only shoot growth with little if any additional energy transported to the roots, the overall iron status of the turf may not be improved and the effect will be short lived. This is most likely to occur if clippings are collected and much of the applied iron is removed from site. This scenario argues for reducing nitrogen when correcting an iron deficiency in turf.

Iron Toxicity and Effects

It has been commonly noted that turf can become very dark green or even black, following a foliar application of iron (Carrow et al. 1988; Lee et al. 1996). This toxic response can be induced at relatively low iron application rates and tends to occur more readily at high temperatures. Carrow et al. (1988) observed that centipedegrass could tolerate a foliar iron application of 1.8 lb./acre on a warm day (70-91°F) without injury but only 0.7 lb/acre on a hot day (82-

100°F). This sensitivity to iron injury was increased when even moderate rates of nitrogen (.25 lb/msf) were applied with the iron. Iron phytotoxicity normally was short-lived with turf recovering completely within a week or two. An early September application of either ferrous sulfate or an iron chelate applied at 64 lb Fe/acre caused dramatic blackening of the turf as soon as one day after treatment. However, the injury was reduced to 10 percent within seven days (Yust et al. 1984). At the cellular level, toxic applications of iron to Kentucky bluegrass turf promoted a rapid 21 percent increase in total leaf chlorophyll and a 23 percent increase in the volume density of chloroplast membranes (Lee et al. 1996).

Generally a moderate toxic response to iron applications is not viewed as bad, because it is a dark green leaf color and it generally causes no lasting injury. If a turf is suffering from an incipient iron deficiency and abundant iron and nitrogen are suddenly made available, all constraints to chlorophyll and chloroplast protein synthesis are removed and rapid excessive greening occurs. If very high rates of iron are applied to turf, fundamental nutrient imbalances will occur and lasting injury may result.

Black Layer on Greens

A common problem for turf grown on sand-based media is the formation of an anaerobic layer that takes on a dark color referred to as black layer. Turf roots do not grow well in such black layers which occur just below the surface and can be anywhere from less than an inch to more than six inches thick. Because turf on putting greens frequently declines when associated with black layer formation, black layer is viewed as a very serious problem (Waddington 1992).

Black layers form following periods of waterlogged soils due to excess rain or irrigation coupled with poor subsurface drainage and the presence of an organic layer (often thatch buried by top-dressing material). Under these conditions, microorganisms that are decomposing the organic matter consume all the available oxygen and then reduce sulfate (SO_4^{2-}) to sulfide (S^{2-}), which can then form insoluble pre-

precipitates with several metal cations. At the same time, any ferric ions present within the anaerobic band will become reduced to ferrous and precipitate the sulfide. The resulting ferrous sulfide is intensely black and is the major contributor to the dark color of black layers. These sulfide salts and along with various algae and bacteria, that grow under these conditions, plug the soil capillary pores and further aggravate the existing poor drainage condition. Heavy use of fungicides, which can cause dramatic changes in microbial populations, is thought to also contribute to black layer formation (Adams et al. 1993).

It has been suggested that applications of iron to promote turf green-up could also contribute to black layer formation, because it ensures a ready supply of iron to precipitate as ferrous sulfide. However, research reported from Wales (Adams et al. 1993) questions this conclusion and suggests that poor drainage and soil pH are much more important. In that study, soil samples from under the turf at an intensively managed sports facilities were collected and incubated anaerobically for 22 days with a sulfate and organic source buffered at three pHs (4.4, 5.0 and 6.2). In the first six days virtually all of the extractable iron was in the Fe^{2+} form. However, over a 12-day period, no ferric sulfide (FeS) was present when the pH was less than 5. At pH 6.2, ferrous sulfide was detected after six days of incubation and it increased rapidly thereafter. The researchers concluded that black layer is unlikely to develop if the soil pH is maintained close to 5 and the addition of FeSO_4 will not contribute to this problem because it is an acidifying salt.

Humic Substances and Iron

The addition of humic substances (partially decomposed humus or soil organic matter) to sand-based greens has been reported to increase seed germination and seedling growth; increase water holding capacity; enhance nutrient uptake; and stimulate both microbial activity and the

vigor of established turf (Dorer and Peacock 1997). It has also been reported that the addition of humic substances increases the root mass and root depth on greens turf (Dorer and Peacock 1997; Cooper et al. 1998). However, macronutrient uptake was rarely enhanced by humate additions with the exception of the Cooper et al. study (1998) where the phosphorus content in grass clippings was increased. Micronutrient recovery was stimulated slightly by the addition of humic substances (Dorer and Peacock 1997), but Cooper et al (1998) observed increased iron uptake only from solution-cultured turf. Increased iron content in field-grown turf was not significantly greater in humate-treated turf than in control plots.

Much of the iron available to roots growing in a soil is in a chelated form even when iron supplies are sufficient and phytosiderophore release from roots is not induced. Therefore, it has been proposed that additions of organic matter to the root zone should produce more organic chelates and increase the availability of micronutrient cations, especially ferric. Sand based greens would seem to be excellent sites where such organic additions might increase iron absorption. Results, however, have been mixed and not especially dramatic, as noted above.

The reason for this marginal effect of humate additions on the iron nutrition of greens turf may result from the relatively small amounts of material incorporated into the sand medium and the questionable practice of applying soluble forms of iron as a foliar spray.

There also may be a more fundamental reason why such natural organics only marginally enhance iron absorption. The transport protein that carries iron-phytosiderophore complexes across the cell membrane is highly specific (Marschner 1995). It only poorly transports chelates of ions other than Fe^{3+} and it may not be very efficient in transporting Fe^{3+} chelated to molecules other than phytosiderophores. Most humate-based chelates are polyphe-nolic acids, while phytosiderophores are

complex amino acids. Thus, increasing the quantity of chelated iron in the rhizosphere will make more iron available for uptake but its absorption efficiency might not be very great. Based on this analysis, relatively small additions of humic substances, especially if they are not effectively introduced into the root zone, could have little or no impact on iron recovery by turfgrass.

Sources of Iron

The most commonly used inorganic iron source is ferrous sulfate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, 19 percent Fe). It can be applied directly to the soil or sprayed on the foliage. Because nitrogen is required for a full greening response from iron, ferrous ammonium sulfate [$\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$, 12 percent Fe and 8 percent N] is sometimes used because it contains nitrogen along with iron.

Soil applications of iron fertilizers can be problematic, however, because the soil conditions that lead to an iron deficiency also will immobilize iron applied as FeSO_4 . Ferrous (Fe^{2+}) salts are much more water soluble than ferric (Fe^{3+}) salts and for that reason they are the only practical inorganic iron sources used. However, in a well aerated soil, ferrous ions are rapidly oxidized to

ferric ions and these readily precipitate as hydroxides to a highly insoluble and unavailable form (Fig. 4). The net result is a very short-lived increase in available iron following a soil application of FeSO_4 .

Iron availability may be less of a problem for turf grown on a formulated medium, such as a sand-based green. Here iron may be lacking because it was never introduced in the original media formulation, not because it was immobilized. Under such conditions, applications of FeSO_4 to the growing medium may give prolonged benefits.

Because of the possible immobilization of soil-applied iron, foliar applications of iron can be more effective in relieving iron deficiency. The results can be disappointing, however, because this iron salt is reasonably soluble and will wash off the foliage during rain or irrigation. This may not be a serious problem because, as suggested earlier, shallow roots within the thatch layer may be able to absorb the Fe^{2+} ions before they are oxidized to Fe^{3+} . Also, the relative inability of iron to translocate out of mature leaves to growing regions of the plant, often limits the effective duration of foliar sprays.

Some of the problems associated with FeSO_4 use can be reduced by applying a chelated form of iron. The most common

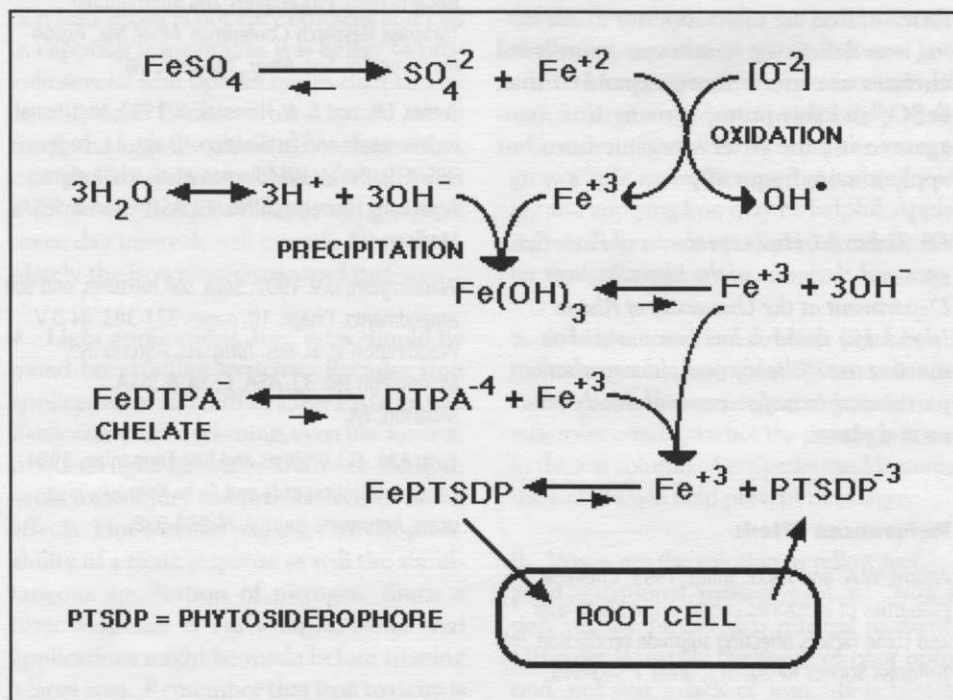


Figure 4. Dynamics of ferrous and ferric ion release in soil and ferric uptake by root cells.

form used on turf is NaFeDTPA (sodium ferric diethylenetriaminepentaacetate marketed as Sequestrene 330, 10 percent Fe) although other iron chelates are also available. Chelate iron is in the ferric form but most of the iron remains bound to the organic molecule and very little is in solution as free Fe^{3+} (Fig. 4). For this reason, there is little tendency for the iron to precipitate as hydroxides and most of it remains in solution as the Fe-chelate. It is likely that most iron from an Fe-chelate is absorbed by root as Fe-phytosiderophore (Fig. 3) or possibly as FeDTPA-, or some similar, chelate ion.

When applied to leaves, iron chelates can give more rapid and lasting results than FeSO_4 , although the differences are sometimes slight. Here entry into leaf cells probably occurs as the chelate ion since it is not clear if leaf cells excrete phytosiderophores. The chelate iron probably better solubilizes with the surface cuticle of leaves and thus is less likely to be removed during rain or irrigation. Also, its stability in and availability from thatch may be greater than FeSO_4 which would contribute to a greater and longer lasting response. While chelate forms of iron are often superior in alleviating iron deficiency symptoms, commercial chelates are much more expensive than FeSO_4 and this prompts many turf managers to use the latter inorganic form but apply it more frequently.

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.

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