Micronutrients—Iron

In the January 1997 issue, we completed our discussion of secondary nutrients, so with this issue we will start with the seven micronutrients (Table 2). Eric van Steenis of the British Columbia Ministry of Forests assisted with the writing of this article, and his help is gratefully acknowledged.

Iron (Fe) is one of the most common metallic elements on earth but its content and availability in soils is extremely variable. In good agricultural soils, adequate amounts of iron are released by the weathering of minerals and so supplemental fertilization is not needed. Many iron deficiency problems that require treatment can be found on alkaline or calcareous soils which are most common in semi-arid and arid climates. However, problems also have occurred on calcareous chalk soils which are found even in humid climates like England. Container growers need to be more aware of the availability of iron because levels are naturally low in artificial growing media, like those composed of peat moss and vermiculite.

Role in Plant Nutrition

In historical terminology, the "Iron Age" began about 1000 years B.C. but our understanding of the roles of iron in plant growth are relatively recent, dating back to the late 19th century. Plants are the ultimate energy transducers, converting light energy to chemical energy, and iron is absolutely critical in both the manufacture of the chlorophyll molecule and the physiological functioning of the photosynthetic process. Thus, even though iron is thought of as a micro-nutrient (Table 2), its role is of macro-importance in seedling nutrition.

A fascinating aspect of the energy transfer system in plants are ring structures known as porphyrins, which can be found in several molecules that are critically important to life as we know it. Porphyrins form metal chelates with a variety of metal ions; in chlorophyll, the center atom is magnesium, whereas in plant cytochrome and mammalian blood hemoglobin the center atom is iron **(Figure 6).**

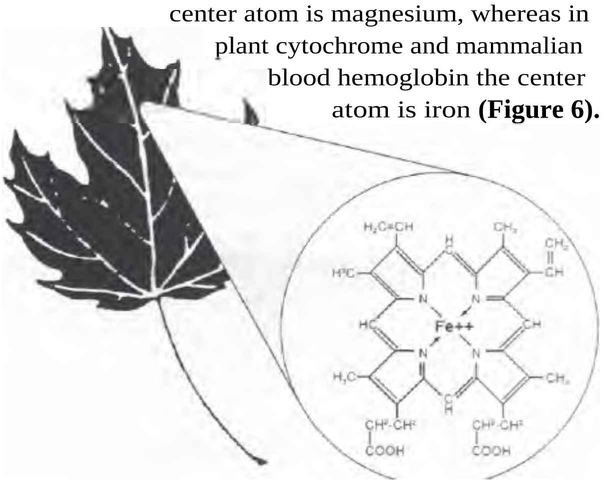


Figure 6. Iron can be found in the "heme" structure of cytochrome molecules, which are critical for formation and function of chlorophyll in leaves.

Table 2. The seven essential micronutrients and their typical concentrations in seedling tissue.

Element	Symbol	Average Concentration in Plant Tissue (%)	Adequate Range in Seedling Tissue (ppm) Bareroot	Container
Iron	Fe	0.01	50 to 100	40 to 200
Manganese	Mn	0.005	100 to 5.000	100 to 250
Zinc	Zn	0.002	10 to 125	30 to 150
Copper	Cu	0.0006	4 to 12	4 to 20
Molybdenum	Mo	0.00001	0.05 to 0.25	0.25 to 5.0
Boron	B	0.002	10 to 100	20 to 100
Chloride	Cl	0.01	10 to 3,000	

Of course, you already knew that because you remembered the similarity between the structure of chlorophyll (see "Secondary Nutrients—Magnesium" in the July, 1996 issue of FNN) and hemoglobin (see "Carbon Monoxide—the Silent Killer" in the January, 1997 issue). This presence of iron explains why blood can be used for iron fertilizer and why poisons that destroy the energy/oxygen carrying capacity of the cytochrome system are so deadly, *e.g.* cyanide and carbon monoxide.

The porphyrin structure is known as "heme" when iron is the central metal ion. Heme serves as a catalyst in various enzymes systems, directly influencing the synthesis of certain compounds, one of which is chlorophyll. Without iron, even if other building blocks are present, chlorophyll synthesis is seriously impaired or just will not occur. Combine this with the fact that iron is highly immobile in plants and you begin to understand why iron deficiency decreases the level of chlorophyll in newly forming tissues. In fact, "iron chlorosis" is the universal symptom for iron deficiency in plants.

Iron is also intimately involved in the energy transfer and capturing process. Note that this is *after* chlorophyll has been synthesized so iron actually has a hand in determining the efficiency of photosynthesis as well. As a constituent of cytochrome molecules, iron helps facilitate the transfer/elevation of electrons to "excited" states and is part of the final receiving protein molecule, ferredoxin, which plays an important role in nitrate and sulphate metabolism within plants. And, as a carrier of oxygen, iron is also an activator of respiration and aids in symbiotic nitrogen fixation.

From the above discussion, it's easy to see why the internal iron status of plants determines their level of photosynthetic efficiency.

Availability and Uptake

Like all the mineral nutrients, plants take iron up from the soil where it occurs in two ionic forms: ferrous (Fe^{2+}) and ferric (Fe^{3+}). Although both ions can be absorbed by roots, the Fe^{2+} form is the most physiologically important. Compounds containing Fe^{3+} are usually of low solubility which limits their availability and, when Fe^{3+} ions are taken up by the plant, they have to be reduced to Fe^{2+} ions before they can be used. Iron availability and uptake are greatly influenced by the presence of other ions both in the root zone and in the plant. Iron and manganese together form a redox system, meaning they react with each other to induce valence changes in each other (*ie.* $Mn^{3+} + Fe^{2+}$ <<==>> + Fe^{3+}). Since Fe^{3+} is generally unavailable for plant use, excess manganese in the soil can induce iron deficiency. In horticulture, therefore, the Fe/Mn ratio in the fertilizer solution and in foliar analysis are important factors to consider when diagnosing a deficiency and prescribing a remedy. As mentioned earlier, excess calcium ions also can reduce the availability of iron for plant uptake. In fact, the most common soil condition associated with iron deficiency is the presence of calcium carbonate.

The pH of the soil is critical to iron availability since under alkaline conditions iron combines readily with phosphates, carbonates and hydroxyl ions. Phosphates can actually combine with iron inside the plant as well to form insoluble precipitates, rendering both elements unavailable. Another concept to keep in mind is that of ionic balance in general. This is critical when considering competition from calcium, magnesium, potassium, copper, and zinc for uptake by the roots. Ion competition can continue within the plant as both copper and zinc can interfere with iron function. This has particular application when copper-treated containers are used. The rate of iron application should be increased by several ppm to offset the copper competition effect and reduce the possibility of copper-induced iron deficiency. In bareroot nurseries with alkaline or calcareous soils or water, iron chelates should be used. (See Iron Management section for more specifics).

New, fine roots are the most efficient at taking up iron hence it is imperative that the plant has a healthy, actively growing root system. Anything that impairs root growth and function will impair iron uptake including extremes in temperature, moisture content, and salinity as well as low root zone oxygen levels and root disease. For example, under conditions of waterlogging, redox values are reduced along with pH and oxygen levels which favor the ferrous form of iron. However, the low oxygen availability is most critical because it virtually disables the root system, preventing it from taking up any available iron. A classic case of starvation in the midst of plenty. In this case, although iron deficiency is the symptom, applying iron fertilizer will not solve the problem. The real cure is proper irrigation and climate management to encourage transpiration and promote active root growth.

The form of nitrogen fertilizer also warrants attention. When nitrate (NO_3-) ions are taken up by the roots, hydroxyl (OH-) ions are released to balance the internal charge. This not only raises soil pH but the hydroxyl ions can tie up iron in the rhizosphere. On the other hand, when ammonium (NH_4^+) ions are absorbed, a hydrogen (H+) is released which acidifies the soil in the root zone and thereby increases the availability of the desirable ferrous form of iron. Nitrate fertilizers are often preferred in container nurseries during cloudy weather and with winter crops, especially with sensitive species or ecotypes *e.g.* coastal Douglas-fir. However, excessive use -of nitrate-nitrogen causes a slow increase in pH in the rhizosphere ultimately leading to an induced iron deficiency.

Diagnosis of Deficiencies and Toxicities

Because of its importance in the manufacture of chlorophyll and its functioning, the first symptom of iron deficiency is chlorosis. Remember that this symptom is the same for many other nutrient deficiencies, however, including nitrogen, magnesium, and sulfur. The diagnostic characteristic of iron deficiency is that it typically shows first in new foliage because iron is immobile in the plant. Note that this is different from a mobile nutrient, such as nitrogen, where the chlorosis shows first in older foliage. The possibility of iron deficiency can also be deduced from climatic and soil conditions. Iron chlorosis is a common disorder in arid or semi-arid climates, which often have alkaline soils and water, and in calcareous soils.

Deficiency symptoms — In young conifer seedlings, chlorosis of actively growing tops is the first evidence of iron deficiency. In severe cases, the affected foliage will turn white and may eventually die. If newly flushed shoots display the symptoms, the grower should be alerted to a change in conditions in the root zone. The primary symptom of iron deficiency in broadleaved seedlings is interveinal chlorosis of young leaves which can progress into marginal necrosis in severe cases.

Iron deficiencies can be difficult to diagnose with foliar symptoms, however, because the symptoms are often the result of an imbalance between several different micronutrients. One of the simplest tests for iron deficiency is to apply a dilute solution of ferrous sulfate (0.5 to 1.0 %) to the chlorotic foliage, which will turn green within a couple of weeks if iron is the problem.

Toxicity symptoms — Iron toxicity is rare under natural conditions but can occur with excessive foliar fertilizer applications. Be aware that moss control chemicals containing iron sulfate may result in iron toxicity, especially on young succulent tissue. The principal symptom is severe stunting, with some species showing chlorosis, browning, or necrotic spots.

Monitoring

The available iron status of nursery soils or growing media can be monitored by soil tests, irrigation water tests, or seedling nutrient analysis.

Chemical analyses of soils or growing media are relatively useless for determining iron availability. Many laboratories report total iron but active iron is more important, because total iron includes unavailable ferric iron. Measure root zone pH on a weekly basis and watch for any trends. An upward pH drift mayb be indicative of a developing problem. Rising root zone pH is often thought to be the cause of iron deficiency when it may actually be the symptom, rising concentrations of ions such as calcium and bicarbonate being the actual culprits.

Iron quickly becomes unavailable when alkaline water is used for irrigation. The water sources of good nursery sites typically is around neutral or slightly acidic, but it may exceed ph 7.0 when other dissolved salts are present, especially bicarbonate ions. Weakly buffered alkaline water may not need to be treated if the pH of the soil or growing medium is maintained in the proper range. It is relatively easy to lower water pH with acid injection because the excess hydrogen ions bond with the hydroxyl ions to form water. The need for acid injection and the amount of acid to use per volume of water must be determined with a laboratory titration.

Seedling nutrient analysis can be used to diagnose iron deficiency but interpretation can be difficult. Because of the variability that can exist, paired samples of normal and healthy plants should always be taken. Seedlings with iron chlorosis keep trying to take up more iron but cannot metabolize it, and so foliar analysis often shows that symptomatic seedlings have higher concentrations than healthy ones.

Iron Management

When iron chlorosis is diagnosed, growers need to remedy it in the short term, determine its cause, and adjust long term culture to prevent a future occurrence. Foliar fertilization will provide a quick remedy for an acute deficiency, but this will not solve the real problem and so some detective work is needed. Check the supply of iron first. If it is adequate, then check water and soil pH and complexing/competing ion concentrations of the fertilizer solution. Often, instead of requiring the addition of more iron fertilizer, one actually needs to make that iron which is present more available by reducing something else or just shifting the balances. Once active iron is available and the plant's root system has been encouraged to take it up, iron problems will disappear. Granted, this type of diagnosis and correction may be challenging but that's why growers make the big bucks!

There are basically two options for managing iron in nurseries: • *maintain slightly acid pH,* and *fertilize properly.*

pH maintenance — Hopefully, this should not be a problem if the nursery site was properly selected but there are still several nurseries with problems of high pH. In bareroot nurseries, either alkaline soil or irrigation water can be the culprit. Water is much easier to treat and acid injection is commonly recommended for container nurseries, but treating the water has not solved the problem in bareroot nurseries with alkaline or calcareous soils. In particular, calcareous soils are highly buffered and the excess calcium ions can still cause problems after the pH has been lowered. The pH of alkaline soils can be lowered with sulfur applications although this can take many years with calcareous soils. Leaching must be done at the same time to remove the excess ions from the acidification.

Fertilization — Iron can be supplied from inorganic fertilizer salts or organic compounds known as chelates, and both single nutrient and micronutrient mixes are available **(Table 3).** The most comprehensive list of the types of iron fertilizers and their US suppliers can be found in the Farm Chemicals Handbook. In Canada, Plant Products Co. Ltd. offers a wide variety of chelated iron fertilizers.

The effectiveness of iron fertilizers can be rated by solubility and resistance to chemical tic-up by other ions in the soil or water. The most soluble inorganic Fertilizer is ferrous sulfate which is ineffective as a soil application because it is rapidly oxidized to insoluble Ferric sulfate. Ferrous sulfate may be acceptable as a Foliar spray depending on water quality. Although they pan be attractive because of their low price, inorganic ron fertilizers cannot be widely recommended considering all the possible problems with availability.

Chelates are the most popular type of iron fertilizers and consist of organic compounds which contain a negatively charged "cavity" which holds a positively charged cation such as Fe++ **(Figure 7a).** In this enveloping structure. the iron is protected from other ions which normally render it unavailable to plant uptake. Not only does chelation keep iron available to plants under adverse soil conditions, it also protects against overfertilization because the iron is slowly released From the organic complex.

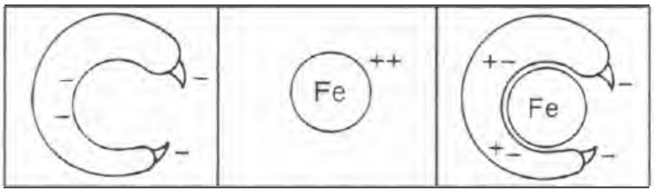
There are several types of chelates, which vary in the strength with which they hold the ferrous ion at different pH values and against competing ions in the soil or growing medium. Fe-EDTA is primarily used in more acidic conditions because the chelate is weak above pH 7 **(Figure 7c),** and it has a high affinity for calcium

Table 3. Some common fertilizers containing iron.

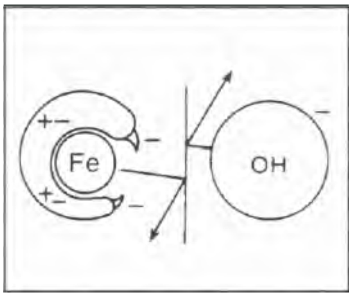
Fertilizer	*Chemical Notation*	*Iron (%)*	*Use in Nurseries*
	Single Nutrient Fertilizers		
Ferrous sulfate	$Fe SO_4 \cdot 7 H_2O$	19	Only for foliar applications
Iron Chelate	NaFeEDTA	5 to 14	Foliar or soil applications*
Iron Chelate	NaFeDTPA	7	Foliar or soil applications*
Iron Chelate	NaFeHEDTA	6	Foliar or soil applications*
Iron Chelate	NaFeEDDHA	10	Foliar or soil applications*
	Multinutrient Fertilizers		
STEP®	Iron as $Fe SO_4$	7.5	Incorporation in growing media
Micromax®	Iron as $Fe SO_4$	12	Incorporation in growing media
Chelated Micronutrient Mix®	Iron as EDTA and DTPA	7	Foliar or soil applications*

*Availability of iron chelates depends on pH—see Figure 7c.

A. What is a chelate?



B. How a chelate works.



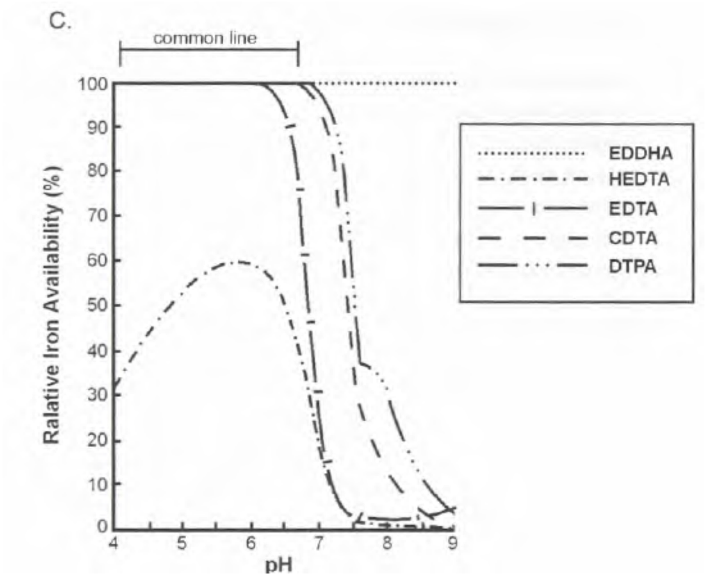


Figure 7. Chelates are composed of a negatively charged organic complex and a positively charged cation such as ferrous iron (A). Chelate fertilizers remain active under adverse conditions because they resist inactivation by ions such as hydroxyl (B). There are several types of chelate fertilizers available, but EDDHA chelates are the only ones that remain active across the full range of pH (A,B from Stoller chemical company; (C) modified from Norvell 1972).

ions which can displace the iron. Therefore, Fe-EDTA is often used for foliar applications but should not be used with high alkalinity/calcium water sources. FeDTPA is not as susceptible to calcium replacement hence is recommended for nutrient solutions. Above pH 7 the recommended chelate is FeEDDHA although this fertilizer is by far the most expensive. Iron chelates can be applied to the soil or to the foliage but bed width spray applications are a combination of both. Severe cases of chlorosis may require application every couple of weeks during the early part of the growing season. Even with the proper iron chelate fertilizer, treatment must begin in the early stages of the chlorosis or the seedlings may not respond.

In conclusion, iron is a critical micronutrient which must be carefully managed to make certain that it is supplied in a readily available form. This is usually not a problem in container nurseries or in bareroot nurseries with good quality soil and irrigation water. Iron chelates are recommended instead of ferrous sulfate because they are more available and there is little chance of overfertilization. The best chelate to use is a function of soil and water pH. The most serious availability problems occur in alkaline or calcareous soil and these will require special chelates and cultural procedures.

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