UF UNIVERSITY of FLORIDA
IFAS Extension

HS1208

Understanding and Applying Chelated Fertilizers Effectively Based on Soil pH[1]

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Plant nutrients are one of the environmental factors essential for crop growth and development. Nutrient management is crucial for optimal productivity in commercial crop production. Those nutrients in concentrations of ≤ 100 parts per million (ppm) in plant tissues are described as micronutrients and include iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), boron (B), chlorine (Cl), molybdenum (Mo), and nickel (Ni). Micronutrients such as Fe, Mn, Zn, and Cu are easily oxidized or precipitated in soil, and their utilization is, therefore, not very efficient. Chelated fertilizers have been developed to increase micronutrient utilization efficiency. This publication provides an overview of chelated fertilizers and considerations for their use to county Extension faculty, growers, and students who are interested in commercial crop production.

What is chelated fertilizer?

The word *chelate* is derived from the Greek word *chelé*, which refers to a lobster's claw. Hence, chelate refers to the pincer-like manner in which a metal nutrient ion is encircled by the larger organic molecule (the claw), usually called a ligand or chelator. Table 1 lists common natural or chemical synthetic ligands (Havlin et al. 2005; Sekhon 2003). Each of the listed ligands, when combined with a micronutrient, can form a chelated fertilizer. Chelated micronutrients are protected from oxidation, precipitation, and immobilization in certain conditions because the organic molecule (the ligand) can combine and form a ring encircling the micronutrient. The pincer-like manner in which the micronutrient is bonded to the ligand changes the micronutrient's surface property and favors the uptake efficiency of foliarly applied micronutrients.

Why is chelated fertilizer needed?

Because soil is heterogeneous and complex, traditional micronutrients are readily oxidized. Chelation keeps a micronutrient from undesirable reactions in solution and soil. The chelated fertilizer improves the bioavailability of micronutrients such as Fe, Cu, Mn, and Zn, and in turn contributes to the productivity and profitability of commercial crop production. Chelated fertilizers have a greater potential to increase commercial yield than regular micronutrients if the crop is grown in low-micronutrient stress or soils with a pH greater than 6.5. In order to grow a good crop, crop nutrient requirements (CNRs), including micronutrients, have to be satisfied first from the soil. If the soil cannot meet the CNR, chelated sources need to be used. This approach benefits the plant without increasing the risk of eutrophication.

Several factors reduce the bioavailability of iron, including high soil pH, high bicarbonate content, plant species (grass species are usually more efficient than other species because they can excrete effective ligands), and abiotic stresses. Plants typically utilize iron as ferrous iron (Fe^{2+}). Ferrous iron can be readily oxidized to the plant-unavailable ferric form (Fe^{3+}) when soil pH is greater than 5.3 (Morgan and Lahav 2007). Iron deficiency often occurs if soil pH is

1. This document is HS1208, one of a series of the Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Original publication date November 2012. Visit the EDIS website at http://edis.ifas.ufl.edu.

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greater than 7.4. Chelated iron can prevent this conversion from Fe^{2+} to Fe^{3+}.

Applying nutrients such as Fe, Mn, Zn, and Cu directly to the soil is inefficient because in soil solution they are present as positively charged metal ions and will readily react with oxygen and/or negatively charged hydroxide ions (OH^-). If they react with oxygen or hydroxide ions, they form new compounds that are not bioavailable to plants. Both oxygen and hydroxide ions are abundant in soil and soilless growth media. The ligand can protect the micronutrient from oxidization or precipitation. Figure 1 shows examples of the typical iron deficiency symptoms of lychee grown in Homestead, Florida, in which the lychee trees have yellow leaves and small, abnormal fruits. Applying chelated fertilizers is an easy and practical correction method to avoid this nutrient disorder. For example, the oxidized form of iron is ferric (Fe^{3+}), which is not bioavailable to plants and usually forms brown ferric hydroxide precipitation ($Fe(OH)_3$). Ferrous sulfate is often used as the iron source. Its solution should be green. If the solution turns brown, this indicates that the bioavailable form of iron is oxidized and therefore unavailable to plants.

In the soil, plant roots can release exudates that contain natural chelates. The nonprotein amino acid, mugineic acid, is one such natural chelate produced by graminaceous (grassy) plants grown in low-iron stress conditions. The exuded chelate works as a vehicle, helping plants absorb nutrients in the root-solution-soil system (Lindsay 1974). A plant-excreted chelate forms a metal complex (i.e., a coordination compound) with a micronutrient ion in soil solution and approaches a root hair. In turn, the chelated micronutrient near the root hair releases the nutrient to the root hair. The chelate is then free and becomes ready to complex with another micronutrient ion in the adjacent soil solution, restarting the cycle. The process works like this:

A chelate is exuded from a root to the soil solution.

The chelate complexes a micronutrient (e.g., iron) from the soil solution.

The chelated micronutrient is carried to a root hair, where it is released.

The chelate goes back to the soil solution and starts another cycle.

Figure 1. Typical iron deficiency symptoms of lychee (*Litchi chinensis,* the soapberry family)
Credits: Yuncong Li

Chemical reactions between micronutrient chelates and soil can be avoided by using a foliar application. Chelated nutrients also facilitate nutrient uptake efficiency for foliar application because crop leaves are naturally coated with wax that repels water and charged substances, such as ferrous ions. The organic ligand around the chelated micronutrient can penetrate the wax layer, thus increasing iron uptake (Figure 2). Compared to traditional iron fertilization, chelated iron fertilization is significantly more effective and efficient (Figure 3).

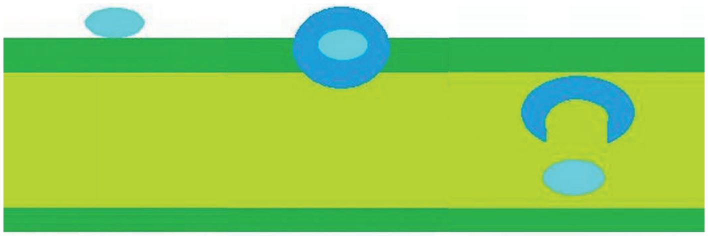

Figure 2. Schematic diagram of chelated fertilizers facilitating nutrient uptake for foliar application. Without chelation (aqua), micronutrients stay on the leaf surface. With chelation (aqua surrounded by blue), micronutrients first move into the mesophyll and then release micronutrients. Color key: aqua = a micronutrient ion; blue = organic ligand; dark green = wax layer on leaves; light green = mesophyll. (*Source:* Fullerton 2004)

Figure 3. Comparison of foliar applications of chelated Fe, regular iron fertilizers, and no iron fertilization on correcting iron deficiency of lychee (*Litchi chinensis,* the soapberry family).
Credits: Yuncong Li

Therefore, chelated fertilizaton can improve micronutrient use efficiency and make micronutrient fertilization more cost effective. The images in Figure 3 show the difference in three treatments with lychee: chelated Fe(II) is greener than $FeSO_4$ plus sulfuric acid, and $FeSO_4$ plus sulfuric acid is greener than no iron fertilization (Schaffer et al. 2011).

Which crops often need chelated fertilizers?

Vegetable and fruit crop susceptibility to micronutrients differs significantly (Table 2). For those in the highly or moderately susceptible categories, chelated fertilizers are often needed. For those with low susceptibility, generally speaking, no chelated fertilizers are needed unless the soil is low in micronutrient bioavailability, as demonstrated by a soil test. Soil pH is a major factor influencing micronutrient bioavailability; therefore, if soil pH is greater than 6.5, then the soil may have limited micronutrient bioavailability (Poh et al. 2009), and chelated fertilizers may be needed.

Which chelated fertilizer should be used?

Each of the ligands (Table 1) can form a chelated fertilizer with one or more micronutrients. The effectiveness and efficiency of a particular chelated fertilizer depends on the pH of the plant growth medium.

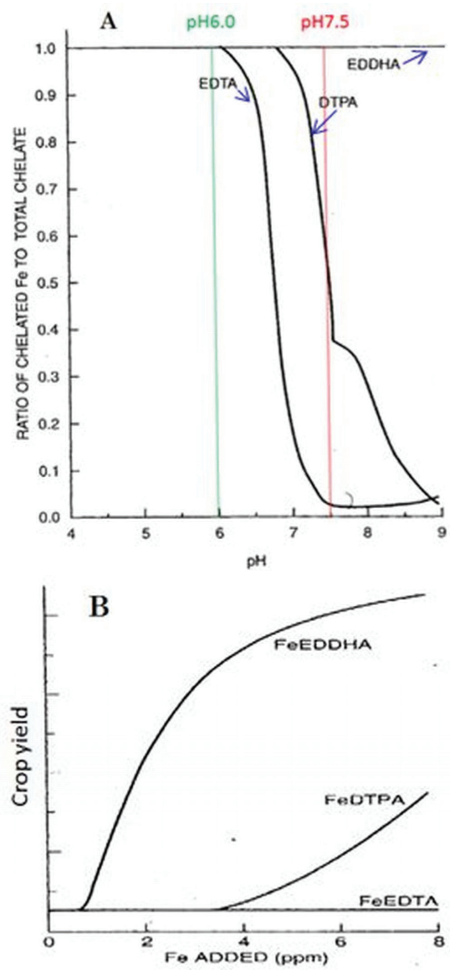

Figure 4. Effects of pH and chelate species, including EDTA, OTPA, and EDDHA, on chelated iron stability (A) (*Source*: Havlin et al. 2005; Norvell 1972) and on crop yield (B) (*Source*: Havlin et al. 2005; Lindsay 1974).

The ligands EDTA, DTPA, and EDDHA are often used in chelated fertilizers (Table 4). Their effectiveness differs significantly. Generally speaking, EDDHA chelated Fe is most stable at soil pH greater than 7 (Figure 4, A and B). Chelated fertilizer stability is desired because it means the chelated micronutrient will remain in a bioavailable form for a much longer time period, thus increasing micronutrient use efficiency in vegetable and fruit production. The stability of three typical chelated Fe fertilizers varies at different pH conditions (Figure 4, A). The Y-axis represents the ratio of chelated Fe to total chelate and ranges from 0 to 1.0. A value of 1.0 means the chelate is stable. The X-axis represents soil pH. At 6.0, the ratios for all of the three chelated Fe fertilizers are 1.0 (stable), but at pH 7.5, only the ratio of EDDTA chelated Fe is 1.0. That of DTPA chelated Fe is only 0.5, and that of EDTA chelated Fe is only 0.025. So, in practice, EDDTA chelated Fe fertilizer is most effective when pH is greater than 7. Accordingly, crop yields of these three chelated fertilizers are in this order: FeEDDHA > FeDTPA > FeEDTA (Figure 4, B). See *Micronutrient Deficiencies in Citrus: Iron, Zinc, and Manganese* (http://edis.ifas.ufl.edu/ss423) for effective pH ranges of iron chelates. Table 3 shows the relationship between soil pH and chelated fertilizer requirement.

Correction of Fe deficiency depends on individual crop response and many other factors. For instance, for vegetables, the rate is usually 0.4–1 lb. chelated Fe in 100 gal. of water per acre. Deciduous fruits need 0.1–0.2 lb. chelated Fe in 25 gal. of water per acre (Table 5). Foliar application is more effective than soil application. For foliar application, either inorganic or chelated Fe is effective, but for fertigation, chelated Fe should be used. In high pH soil, crops are also vulnerable to Cu deficiency stresses. Chelated Cu is significantly more effective than inorganic Cu. A commonly used copper chelate is $Na_2CuEDTA$, which contains 13% Cu. Natural organic materials have approximately 0.5% Cu (Table 5).

In addition to soil pH, Mn is also influenced by aeration, moisture, and organic matter content. Chelated Mn can improve Mn bioavailability. Mn deficiency occurs more often in high pH and dry soil. Similar to other micronutrients, foliar spray is much more effective than soil application. For commercial vegetable production, 0.2–0.5 lb. MnEDTA in 200 gal. of water per acre can effectively correct Mn deficiency (Table 5). Zinc is another micronutrient whose bioavailability is closely associated with soil pH. Crops may be susceptible to Zn deficiency in soil with pH > 7.3. Spraying 0.10–0.14 lb. chelated Zn in 100 gal. of water per acre is effective (Poh et al. 2009). Animal waste and municipal waste also contain Cu, Mn, and Zn micronutrients (Table 5). For more information about micronutrient deficiency in crops, see *Plant Tissue Analysis and Interpretation for Vegetable Crops in Florida* (http://edis.ifas.ufl.edu/ep081), *Micronutrient Deficiencies in Citrus: Iron, Zinc, and Manganese* (http://edis.ifas.ufl.edu/ss423), and *Iron (Fe) Nutrition of Plants* (http://edis.ifas.ufl.edu/ss555).

Practical take-home message

- High pH soil (pH > 6.5) often has low bioavailability in micronutrients such as Fe, Mn, Zn, and Cu, and micronutrient fertilizers are needed for commercial crop production.
- Crop susceptibility to the above micronutrients depends on the species and cultivar. Commercial crops can be categorized into three susceptibility groups: high, medium, and low. The first two groups often need chelated fertilizers.
- Inorganic water-soluble micronutrient application to the soil is often ineffective for correcting micronutrient disorders.
- Chelated fertilizers are less reactive to soil conditions and can significantly enhance nutrient uptake and utilization efficiencies.
- Chelate fertilization rates range from 0.2 to 1 lb. micronutrient per acre for vegetable production and 0.1–0.5 lb. micronutrient per acre for fruit production.
- Foliar application of chelated fertilizers is often more effective than soil application.

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Table 1. Common synthetic and natural chelate compounds (ligands)

Abbreviation	Name	Formula
CDTA	Cyclohexanediaminepentaacetic acid	$C_{14}H_{22}O_8N_2$
CIT	Citric acid	$C_6H_8O_7$
DTPA	Diethylenetriaminepentaacetic acid	$C_{14}H_{23}O_{10}N_3$
EDDHA	Ethylenediaminediaminedi-o-hydroxyphenylacetic acid	$C_{18}H_{20}O_6N_2$
EDTA	Ethylenediamintetraacetic acid	$C_{10}H_{16}O_6N_2$
EGTA	Ethylene glycol bis(2-aminoethyl ether) tetraacetic acid	$C_{14}H_{24}O_{10}N_2$
HEDTA	Hydroxyethylenediaminetriacetic acid	$C_{10}H_{18}O_7N_2$
NTA	Nitrilo-triacetic acid	$C_6H_9O_6N$
OX	Oxalic acid	$C_2H_2O_4$
PPA	Pyrophosphoric acid	$H_4P_2O_7$
TPA	Triphosphoric acid	$H_5P_3O_{10}$
(*Source*: Havlin et al. 2005; Sekhon 2003)		

Table 2. Selected vegetable and fruit crop species' relative susceptibility* to some micronutrient deficiencies

	Cu	Fe	Mn	Zn
Vegetable				
Asparagus		Medium		Low
Bean	Low	High	High	High
Broccoli	Medium	High	Medium	
Cabbage	Medium	Medium	Medium	Medium
Cauliflower	Medium	High	Medium	
Carrot	High		Medium	Low
Celery	Medium		Medium	
Cucumber	Medium		High	
Lettuce	High		High	Medium
Mustard/crucifers				Low
Onion	High		High	
Pea	Low/medium	Medium	High	Low
Potato	Low	Low	High	Medium
Radish	Medium		High	
Spinach	High	High	High	Medium
Sweet corn	Medium	Medium	Medium	High
Tomato	Medium	High	Medium	Medium
Turnip	Medium			
Fruit				
Apple	Medium		High	High
Deciduous	Medium	High	High	High
Citrus	High	High	High	High
Grape	Medium	High	High	High
Raspberry		High	High	
Strawberry	Medium	High	High	

*The high category needs micronutrient fertilization; the medium category probably needs it; the low category usually does not need it.
Note: Cultivars often respond differently to low soil micronutrient conditions. Check with your seed or transplant supplier about the attributes when selecting a cultivar source.
(*Source*: Alloway 2008; Havlin et al. 2005)

Table 3. Soil pH and chelated fertilizer requirements in commercial crop production

Soil pH < 5.3	Soil pH ranges from 5.3 to 6.5	Soil pH > 6.5
No chelated fertilizers are needed.	Chelated fertilizers may be needed.	Chelated fertilizers are needed.

At soil pH 5.3 or lower, soil can generally provide sufficient micronutrients. In the soil pH range from 5.3 to 6.5, highly susceptible crop species may need chelated fertilizers. At soil pH 6.5 or greater, most crops need chelated fertilizers.

Table 4. Chelated fertilizers, formula, and nutrient content (%)

Source	Formula	Nutrient (w/w, %)
Iron chelates	NaFeEDTA	5-14
	NaFeEDDHA	6
	NaFeDTPA	10
Copper chelates	$Na_2CuEDTA$	13 Cu
	$Na_2CuHEDTA$	9
Manganese chelates	$Na_2MnEDTA$	5-12 Mn
Zinc chelates	$Na_2ZnEDTA$	14 Zn
	$Na_2ZnHEDTA$	9-13 Zn
Natural organic materials	-	5-10 Fe,0.5 Cu, 0.2 Mn, 1-5 Zn

Table 5. Examples of chelated fertilization rates for selected commercial vegetable and fruit crops

Crop	Nutrient Rate	Source
Iron:		
Vegetables	0.5–1 lb./100 gal. water/A	Iron chelates
Deciduous fruits	0.1–0.2 lb./25 gal. water/A	Iron chelates
Citrus	0.03–0.05 lb./2–5 gal. water/tree	Iron chelates
Copper:		
Corn	0.8 lb./100gal. water/A	$Na_2CuEDTA$
Manganese:		
Vegetables	0.2–0.5 lb./200 gal. water/A	$Na_2MnEDTA$
Zinc:		
Pecan	0.3–0.5 lb. Zn/100 gal. water/A	$Na_2ZnEDTA$
(*Source*: Havlin et al. 2005)		