Citrus Fertilizer Management on Calcareous Soils[1]

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INTRODUCTION

Soils in the south Florida flatwoods are underlain by calcium carbonate ($CaCO_3$) that has accumulated through marine deposition over thousands of years. In most flatwoods, the $CaCO_3$ lies below the profile and the overlying surface soil is usually acidic. However, $CaCO_3$ also can occur at the surface, either naturally or as a result of earth-moving operations that have mixed the soil. The resultant soil is called calcareous. Soils also can become calcareous through long-term irrigation with water from the Floridian aquifer. This water contains small amounts of dissolved $CaCO_3$ that can accumulate with time.

Florida calcareous soils are alkaline (have pH values greater than 7) because of the presence of calcium carbonate ($CaCO_3$), which dominates their chemistries. These soils can contain from about 3% to more than 25% $CaCO_3$ by weight, with pH values in the range of 7.6 to 8.3. Usually, the pH is not in excess of 8.3 regardless of $CaCO_3$ concentration, unless a significant quantity of sodium (Na) is present.

Many Florida flatwoods soils contain one or more calcareous horizons, or layers (see Table 1). A typical characteristic is an alkaline, loamy horizon less than 40 inches deep, which can be brought to the surface during land preparation for citrus planting. These soils are important for citrus production in the Indian River area (east coast) and, to a lesser extent, in the Gulf region (southwest Florida). Increased nutritional management often is required to grow citrus successfully on calcareous soils. Some sites (e.g., ditchbanks) are composed of soils with extremely high levels of lime rock or shell. Planting these sites may not be economically justifiable, considering the management problems and costs involved.

Citrus fertilizer management on calcareous soils differs from that on noncalcareous soils because of the effect of soil pH on soil nutrient availability and chemical reactions that affect the loss or fixation of some nutrients. The presence of $CaCO_3$ directly or indirectly affects the chemistry and availability of nitrogen (N), phosphorus (P), magnesium (Mg), potassium (K), manganese (Mn), zinc (Zn), and iron (Fe). The availability of soil copper (Cu) is also affected; however, since the citrus Cu requirement is normally satisfied through foliar sprays of Cu fungicides, it is not discussed in this fact sheet.

THE EFFECT OF $CaCO_3$ ON NITROGEN TRANSFORMATIONS

Soil pH affects the rates of several reactions involving N and can influence the efficiency of N use by plants. Nitrification, or the conversion of ammonium (NH_4^+) to nitrate (NO_3^-) by soil bacteria, is most rapid in soils with pH values between 7 and 8. Nitrification approaches zero below pH

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5. Ammonium-N fertilizers applied to calcareous soils are converted within a few days to nitrate, which moves freely with soil water. The acidity produced during nitrification is quickly neutralized in highly calcareous soils but may lower the pH value in soils containing low levels of $CaCO_3$.

Ammonia volatilization is the loss of N to the atmosphere through conversion of the ammonium ion to ammonia gas (NH_3). Volatilization of ammoniacal-N fertilizer is significant only if the soil surface pH value is greater than 7 where the fertilizer is applied. This condition occurs in calcareous soils, or where the breakdown of the N fertilizer produces alkaline conditions (e.g., urea decomposition). Nitrogen loss through ammonia volatilization on calcareous soils is a concern when ammoniacal N is applied to the grove floor and remains there without moving into the soil. Following an application of dry fertilizer containing ammoniacal N, the fertilizer should be moved into the root zone through irrigation or mechanical incorporation if rainfall is not imminent. Since urea breakdown creates alkaline conditions near the fertilizer particle, surface application of urea can cause N loss if the urea is not incorporated or irrigated into the soil, regardless of initial soil pH.

THE EFFECT OF $CaCO_3$ ON MAGNESIUM AND POTASSIUM

Although low concentrations of Mg and K in citrus leaves are not uncommon in groves planted on calcareous soils, there is not necessarily a concurrent reduction in fruit yield or quality. If a low concentration of leaf K or Mg is found in a grove that produces satisfactory yield and quality, attempts to increase leaf levels with fertilizer are not necessary. However, if a detrimental condition such as low yield, small fruit, or creasing is observed, an attempt to raise the leaf K or Mg concentration with fertilizer is justified.

It is often difficult to increase leaf Mg and K levels with fertilizer applied directly to calcareous soils, which contain tremendous quantities of both exchangeable and nonexchangeable Ca. Leaf Mg and K concentrations are strongly influenced by soil conditions that control leaf Ca concentration, including high soil Ca levels. High Ca levels suppress Mg and K uptake by citrus trees in part, presumably, through the competition of Ca^{2+}, Mg^{2+}, and K^{+}. Citrus growing on soils high in Ca often requires above normal levels of Mg and K fertilizer for satisfactory tree nutrition. In cases where soil-applied fertilizer is ineffective, the only means of increasing leaf Mg or K concentration may be through foliar application of water-soluble fertilizers, such as magnesium nitrate [$Mg(NO_3)_2$] or potassium nitrate (KNO_3).

THE EFFECT OF $CaCO_3$ ON PHOSPHORUS

Phosphorus availability in calcareous soils is almost always limited. The P concentration in the soil solution is the factor most closely related to P availability to plants. The sustainable concentration is related to the solid forms of P that dissolve to replenish soil solution P following its depletion by crop uptake. Many different solid forms of phosphorus exist in combination with Ca in calcareous soils. After P fertilizer is added to a calcareous soil, it undergoes a series of chemical reactions with Ca that decrease its solubility with time (a process referred to as **P fixation).** Consequently, the long-term availability of P to plants is controlled by the application rate of soluble P and the dissolution of fixed P. Applied P is available to replenish the soil solution for only a relatively short time before it converts to less soluble forms of P.

TESTING CALCAREOUS SOILS FOR P

Accumulation and loss of soil P can be evaluated through soil testing, but more information is required to make a fertilizer recommendation based on this method. The amount of extractable P must be related to crop yield or quality. An ideal P-extracting solution should remove from soils only those forms of P that are available to plants. This is difficult to achieve with the extracting solutions that are currently used.

The major extractants used by southeastern U. S. soil testing laboratories to measure soil P include Mehlich 1 (double acid), Bray P1 and P2, and sodium bicarbonate. Mehlich 1 is not appropriate for use on calcareous soils because its extracting ability is weakened by exposure to $CaCO_3$. While Bray and sodium bicarbonate have been consistently correlated to P uptake by plants growing on calcareous soils in other parts of the United States, these extractants have not been calibrated with citrus leaf P concentration or yield on Florida calcareous soils. Mehlich 3, a newer extractant with promising ability for Florida conditions, is not yet widely used and also will require calibration. Currently, no suitable extractant for soil P has an established, calibrated sufficiency level for use with citrus grown on Florida calcareous soils.

THE EFFECT OF $CaCO_3$ ON ZINC AND MANGANESE

Soil pH is the most important factor regulating Zn and Mn supply in alkaline soils. At alkaline (high) pH values, Zn and Mn form precipitous compounds with low water solubility, markedly decreasing their availability to plants. A soil pH value of less than 7 is preferred to ensure that Zn and Mn are available to plants in sufficient amounts. The soil around a plant root (the rhizosphere) tends to be acidic due to root exudation of H^+ ions. Therefore, soils that are slightly alkaline may not necessarily be deficient in Zn or Mn. In addition, Zn and Mn can be chelated by natural organic compounds in the soil, a process that aids the movement of these nutrients to the plant root. On highly alkaline soils, however, Zn and Mn deficiencies are not uncommon. Soil applications of Zn and Mn fertilizers are generally ineffective in these situations, but deficiencies can be corrected through the use of foliar sprays.

THE EFFECT OF $CaCO_3$ ON IRON

Calcareous soils may contain high levels of total Fe, but in forms unavailable to plants. Visible Fe deficiency, or Fe chlorosis, is common in citrus. The term **chlorosis** signifies a yellowing of plant foliage, whereas Fe **deficiency** implies that leaf Fe concentration is low. Owing to the nature and causes of Fe chlorosis, however, Fe concentration is not necessarily related to degree of chlorosis. In chlorotic plants, Fe concentrations can be higher than, equal to, or lower than those in normal plants. Thus, this disorder on calcareous soils is not always attributable to Fe deficiency. It may be a condition known as **lime-induced Fe chlorosis.** Iron is considerably less soluble than Zn or Mn in soils with a pH value of 8. Thus, inorganic Fe contributes relatively little to the Fe nutrition of plants in calcareous soils. Most of the soluble Fe in the soil is complexed by natural organic compounds. (Fe nutrition in plants has improved in response to the application of sewage sludge, which contains organically complexed Fe.) The primary factor associated with Fe chlorosis under calcareous conditions appears to be the effect of the bicarbonate ion (HCO_3) on Fe uptake and/or translocation in the plant. The result is Fe inactivation or immobilization in plant tissue.

Susceptibility to Fe chlorosis depends on a plant's response to Fe deficiency stress, which is controlled genetically. Citrus rootstocks vary widely in their ability to overcome low Fe stress (see Table 2). The easiest way to avoid lime-induced Fe chlorosis in citrus trees to be planted on calcareous soils is to use tolerant rootstocks. Existing Fe chlorosis can be corrected by using organic chelates, a method discussed in detail in a later section.

FERTILIZER MANAGEMENT ON CALCAREOUS SOILS

Nitrogen. Regardless of the initial form applied, essentially all N fertilizer ultimately exists as NO_3 because nitrification proceeds uninhibited in calcareous soils. Rather than attempt to slow this process, citrus grove management practices should emphasize irrigation and fertilizer application scheduling strategies that decrease N leaching. These include irrigating based on tensiometer readings or evapotranspiration measurements and using split applications of N fertilizer. Applying a portion of the required N fertilizer with irrigation water (i.e., through fertigation) and scheduling irrigations to maintain the N in the root zone is a sound method to prevent large N leaching losses. Using controlled-release N also can increase N fertilizer efficiency.

Management of N fertilizer also should involve practices that minimize its loss through ammonia volatilization. Following an application of ammoniacal-N to the surface of a calcareous soil, the fertilizer should be moved into the soil profile with irrigation water if rainfall is not likely. Urea applied to the surface of any soil, regardless of its pH value, should be moved into the soil via rainfall or irrigation. Fertigation using either of these N sources is a suitable application method, provided that there is ample time to flush the fertilizer out of the lines and into the soil.

Phosphorus. To maintain P availability to citrus on calcareous soils, water-soluble P fertilizer should be applied on a regular, but not necessarily frequent, basis. Since P accumulates in the soil, it is at least partially available as it converts to less soluble compounds with time. Phosphorus deficiency has never been found in citrus grown on Florida calcareous soils where P fertilizer has been applied regularly.

Phosphorus fertilizer should be applied each year in newly planted groves, at a rate based on the recommended rate for young trees, until the groves begin to bear fruit. As the trees approach maturity, P applications can be limited to once every few years. Diagnostic information from leaf and soil testing can help determine whether P fertilization is necessary. Citrus yields have not been correlated with the results of soil tests measuring P levels in calcareous soils; however, soil testing with Mehlich 3, sodium bicarbonate, or another suitable extractant still can be useful in estimating the magnitude of accumulated P. An increased level of P measured by soil tests following periodic fertilization would indicate an increase in available P above the native soil level.

Leaf tissue testing can be used to determine whether soil P is available to citrus trees. For best results, the leaf P concentration of 4- to 6-month-old spring flush leaves from mature trees should be evaluated. The optimum range for leaf P in mature citrus leaves is from 0.12% to 0.16% on a dry weight basis. A decline in leaf P concentration from optimum to low over several years indicates declining soil P availability and justifies a P fertilizer application.

Potassium. For citrus on noncalcareous soils, nitrogen and potassium fertilizer applications with a 1:1 ratio of N to K_2O are recommended. If leaf testing on calcareous soils reveals that high levels of soil Ca may be limiting K uptake, the K_2O rate should be increased by about 25%. This approach may not work in all situations, however. Another way to increase leaf K concentration is through foliar application of KNO_3. A solution of 20 lbs KNO_3 per 100 gallons of water, sprayed to the point of foliar runoff, has been shown to raise leaf K, especially if applied several times during the year. Concentrations greater than 20 lbs KNO_3 per 100 gallons of water should be avoided, since high salt levels promote leaf burn. The availability of N applied through foliar spray equals that of N applied in regular ground fertilizer programs. Therefore, the amount of N applied as KNO_3 should be considered when determining annual N fertilization plans for citrus groves.

Zinc and manganese. The most common inorganic Zn and Mn fertilizers are the sulfates ($ZnSO_4$, $MnSO_4$) and the oxides (ZnO, MnO). Broadcast application of these compounds to correct Zn or Mn deficiencies in calcareous soils is not recommended, since the alkaline pH renders the Zn and Mn unavailable almost immediately. Zinc is also available in chelated forms, including Zn-EDTA and Zn-HEDTA. A **chelate** is a large organic molecule that "wraps around" a micronutrient ion such as Zn^{2+}, sequestering it from soil reactions that make it unavailable. Chelated Zn is sometimes, but not always, superior to inorganic Zn sources. Soil applications of chelated Zn are rarely economical, however. Manganese chelates have limited effectiveness in calcareous soils and are not normally used.

The least expensive way to apply Zn and Mn to citrus is through foliar sprays. In addition to the forms listed above, a number of other Zn and Mn formulations are available for foliar spraying, including nitrates and organically chelated forms using lignin sulfonate, glucoheptonate, or alpha-keto acids. Research data indicate little difference in magnitude of foliar uptake, regardless of the form of carrier or chelate applied. Similarly, foliar applications of low rates of Mn or Zn (e.g., 0.5 to 1.0 lb elemental per acre) are not adequate to correct moderate to severe deficiencies often found in soils with high pH values.

Iron. It is not easy to remedy iron chlorosis of citrus trees on susceptible rootstocks planted on calcareous soils. Iron fertilizer formulations are available that can correct chlorosis; however, the required application rate and frequency make the treatment expensive. Inorganic sources of Fe such as ferrous sulfate ($FeSO_4$) or ferric sulfate [$Fe_2(SO_4)_3$] are not effective unless applied at extremely high rates; these sources should not be used on calcareous soils. Iron chlorosis should be addressed through soil application of Fe chelates. Chelates are superior sources of Fe for plants because they supply sufficient Fe at lower rates than are required with inorganic Fe sources. The most popular synthetic organically chelated forms of Fe include Fe-EDTA, Fe-HEDTA, Fe-DTPA, and Fe-EDDHA. The effectiveness of these fertilizers varies greatly, depending on soil pH (see Table 3). Fe-DTPA may be used on mildly alkaline soils (with pH values of 7.5 or less), whereas Fe-EDDHA is the chelate of choice for use on highly calcareous soils (with a pH value greater than 7.5).

Natural, organically complexed Fe exists in organic waste products such as sewage sludge, but at lower concentrations than in chelated Fe fertilizers. On calcareous soils in the western United States, sludge applied at 15 tons per treated acre was an effective Fe source for field crops severely deficient in Fe. The efficacy of sludge as an Fe fertilizer for citrus grown on Florida calcareous soils has not been investigated. Sludge is potentially useful since it contains readily soluble forms of Fe that may remain in soil solution through organic complexation.

Foliar application of $FeSO_4$ or Fe chelates has not proven satisfactory on citrus trees because of poor translocation within the leaf. The use of foliar sprays also increases the possibility of fruit and/or leaf burn. For these reasons, foliar application of Fe is not recommended to correct Fe chlorosis of citrus.

SULFUR PRODUCTS USED AS SOIL AMENDMENTS

Although little work has been done in Florida on the use of sulfur (S) products **(soil acidulents)** for citrus grown on calcareous soils, application of these products may be beneficial under certain circumstances. This section, drawn from the results of research conducted in other regions of the United States, discusses the potential benefits of sulfur products.

Soil acidulents can improve nutrient availability in calcareous soils by decreasing soil pH. The rates of soil acidulents required to cause a plant response depend on the amount of $CaCO_3$ in the soil. Soils with visible lime rock or shell in the root zone would require repeated applications of a high rate of acidulent, and a lengthy interval would be needed to observe results. Because plant response to broadcast application of an acidulent is unlikely in this instance, such applications are not recommended. In contrast, soils containing little $CaCO_3$, or those that have become alkaline from irrigation water with high levels of bicarbonate, require less acidulation and respond faster. It is feasible to acidify in this situation.

Wide variability in soil types precludes a standard recommendation for acidification. If soil acidulents are used, a comprehensive program of soil pH measurement should be undertaken. Portable soil pH meters that can be taken into the field are readily available. Soil pH should be measured prior to, and periodically after, application of an acidulent to monitor its effect. Decisions regarding the rate and frequency of subsequent applications of acidulent can be based on desired changes in soil pH and visible plant response.

Examples of S-containing acidulents include elemental S, sulfuric acid (H_2SO_4), and ammonium and potassium thiosulfate [$(NH_4)_2S_2O_3$, $K_2S_2O_3$]. These compounds act to neutralize $CaCO_3$ with acid (see Table 4); this, in turn, may lead to a lowering of soil pH. Ammonium sulfate [$(NH_4)_2SO_4$] acidifies the soil by converting NH_4^+ to NO_3 during nitrification. The sulfate ion (SO_4^2) alone possesses no acidifying power.

Pound for pound, elemental S is the most effective soil acidulent. Although not an acidic material itself, finely ground elemental S is converted quickly to sulfuric acid in the soil through microbial action. This material can be difficult to work with because it creates dust and fire hazards. Larger particles or flakes are easier to apply but react more slowly, owing to their smaller surface area. Sulfur has been formulated into porous, irregular granules to overcome this difficulty.

In theory, 6.4 tons per acre of elemental S = the equivalent of 2,720 gallons per acre of concentrated (66° Baume) sulfuric acid -- is required to neutralize each 1% of $CaCO_3$ in the soil to a depth of 12 inches. Broadcast application of S over the entire root zone is not practical because a large amount of S is required for acidification. It has been demonstrated in field crops, however, that only a small fraction of the root system is needed to absorb adequate Fe. Thus, it may be possible to improve Fe nutrition in trees by increasing Fe solubility in a small volume of root zone. A high rate of S, or sulfuric acid, concentrated in a small volume of calcareous soil creates an acidic zone and increases the availability of phosphorus and micronutrients to roots growing in, and adjacent to, the acidic zone. In one study, citrus on calcareous soil in Florida completely recovered from lime-induced chlorosis after 4.5 lbs (0.3 gallons) of concentrated sulfuric acid was distributed equally into 6 holes dug within a tree's root zone; however, this occurred only if Fe-EDTA was concurrently applied to the holes at a rate of 2 oz of Fe per tree.

Sulfuric acid reacts more quickly than any other material, but it is hazardous to work with and can damage plants if too much is applied at one time. Dilute concentrations of sulfuric acid can be applied safely with irrigation water and used to prevent Ca and Mg precipitates from forming in microirrigation lines (see Bulletin 258, Causes and Prevention of Emitter Plugging in Microirrigation Systems). Levels of $CaCO_3$ in the soil and of bicarbonate in the irrigation water determine the proper rate and frequency for injecting sulfuric acid (see Notes in Soil Science No. 18, February 1985). Repeated applications of sulfuric acid with irrigation water will tend to lower soil pH within the wetted pattern of the emitter.

Ammonium thiosulfate and potassium thiosulfate are clear liquid fertilizers (12-0-0-26S and 0-0-25-17S) containing sulfur in the $S_2O_3^2$ form. They can be blended with N, P, and K solutions to form a wide variety of N-P-K-S formulations. Thiosulfates are noncorrosive and nonhazardous to handle. They also are well adapted to the methods used to apply fertilizer solutions. When applied to the soil, half of the $S_2O_3^2$ converts to elemental S, the other half to SO_4^2. The elemental S further converts to sulfuric acid, which gives the thiosulfate its acidifying power. The NH_4^+ in ammonium thiosulfate also contributes to the acidification reaction.

Thiosulfate is also a good reducing agent. Iron is normally found in well aerated soils in the oxidized (Fe^{3+}) form. Before Fe can be taken up by plants, however, it must be reduced to Fe^{2+} at the root surface. Thus, thiosulfate possesses the power to increase Fe availability in calcareous soils to a greater degree than simple soil acidification. It has been demonstrated that soil levels of extractable Fe increase when ammonium thiosulfate is applied to calcareous soils.

Thiosulfate fertilizers can be applied under the tree canopy with a herbicide boom, but this method probably does not concentrate the material in a small enough zone to be effective. Injecting thiosulfates into a microirrigation system, as with sulfuric acid, would be easier and would allow more concentrated application. For example, if microirrigation were used to apply 100 lbs of N per acre, in the form of ammonium thiosulfate, to a grove containing 150 trees per acre, each tree would receive the acidifying power of 1.1 lbs of elemental S. If each tree were irrigated with a single microsprinkler with a wetted pattern diameter of 12 ft, the equivalent S application rate would be 1.0 lbs per 100 square ft, an amount that might be sufficient to correct a mild alkalinity problem. In the same example, if the wetted pattern diameter were 3 ft, as with young tree emitters, the S application rate would increase to 15.7 lbs per 100 square ft. Very likely, this rate of acidification would damage or kill the tree. Therefore, it is important to consider the amount of surface area wetted when applying acidifying materials through an irrigation system. The rate of S should be limited to 1.1 lbs per 100 square ft in any single application.

The soil within the wetted pattern of a microirrigation emitter often becomes alkaline when the water contains bicarbonate, while the surrounding soil may be neutral or acidic. To lower the soil pH in this situation, acid or acidifying fertilizer must be applied to the wetted pattern only. Applying acid or thiosulfate fertilizer through the irrigation system can be effective in treating this problem.

SUMMARY

1. Calcareous soils are alkaline because they contain $CaCO_3$. They are commonly found in south Florida citrus groves, especially in the Indian River area.

2. The availability of N, P, K, Mg, Mn, Zn, and Fe to citrus decreases when soil $CaCO_3$ concentration increases to more than about 3% by weight. These soils generally have a pH value in the range of 7.6 to 8.3.

3. To avoid ammonia volatilization, fertilizers containing ammonium-N or urea should be moved into the root zone with rainfall or irrigation, or be incorporated into the soil.

4. Phosphorus fertilizer applied to calcareous soils becomes fixed in sparingly soluble compounds over time. To maintain continuous P availability, P fertilizer should be applied on a regular, but not necessarily frequent, basis.

5. Soil testing is useful in determining the magnitude of extractable P. Differences in P soil tests over time indicate accumulation or loss of soil P availability.

6. Leaf testing can gauge the effectiveness of soil P as a supply for citrus uptake and should be used to assess the need for P fertilizer application.

7. Citrus planted on calcareous soils may require above normal levels of Mg or K fertilizer for satisfactory nutrition. Foliar sprays of $MgNO_3$ or KNO_3 may be effective where soil applications are not.

8. The least expensive and more efficient way to correct Zn and Mn deficiencies of citrus in calcareous soils is through foliar application of inorganic or organically chelated forms.

9. The easiest way to avoid lime-induced Fe chlorosis on calcareous soils is to plant trees budded on tolerant rootstocks.

10. The most effective remedy for lime-induced Fe chlorosis on nontolerant rootstocks involves the use of organically chelated Fe.

11. Sulfur products that act as soil acidulents can potentially improve nutrient availability in calcareous soils.

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Table 1. Potential Extent of Calcareous Soils in Major South Florida Citrus-Producing Counties.

County	Acres of Land Area	Percentage of Land Area That is Potentially Calcareous[a]	Acres of Land Area Used for Citrus Production (Rank in Florida)
St. Lucie	367,089	42	105,117 (1)
Hendry	772,903	21	87,396 (3)
Indian River	318,146	26	65,446 (4)
DeSoto	406,867	11	58,058 (6)
Martin	346,158	32	46,335 (8)
Collier	686,581[b]	37	34,167 (9)

[a] Includes these soil series: Pineda, Riviera, Winder, Boca, Hilolo, Pople, Tuscawilla, Pinellas, Bradenton, and Felda.[b] Includes only the portion of Collier County mapped in the USDA-SCS soil survey.

Table 2. Citrus rootstocks ranked according to susceptibility to Fe chlorosis.

Sour orange *(C. aurantium)*	lowest susceptibility
Rough lemon *(C. jambhiri)*	
Cleopatra mandarin *(C. reticulata)*	
C. macrophylla	
C. volkameriana	
Sweet orange *(C. sinensis)*	moderate susceptibility
Carrizo citrange *(C. sinesis x P. trifoliata)*	
Trifoliate orange *(P. trifoliata)*	highest susceptibility
Swingle citrumelo *(C. paradisi x P. trifoliata)*	

Table 3. Effective pH range of various Fe chelates.

Fe Chelate	**Effective pH Range**
Fe-EDTA, Fe-HEDTA	4 to 6.5
Fe-DTPA	4 to 7.5
Fe-EDDHA	4 to 9
Source: Norvell, 1991.	

Table 4. $CaCO_3$-neutralizing power of several S sources.

Sulfur Source	**Amount Needed to Neutralize 1,000 lbs $CaCO_3$**
Elemental S	320 lbs
Concentrated sulfuric acid (66° Baume)	68 gal
Ammonium thiosulfate 12-0-0-26S	1,600 lbs
Potassium thiosulfate 0-0-25-17S	3,800 lbs
Ammonium sulfate 21-0-0-24S	900 lbs