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CORRECTION OF IRON DEFICIENCY IN ORANGE AND GRAPEFRUIT TREES IN HIGH pH SOILS

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Abstract. **In some areas of flatwoods citrus production regions along the east coast and in south Florida, soils are highly calcareous and the trees exhibit iron (Fe) chlorosis symptoms. Currently, Fe-EDDHA (ethylenediiminobis-2-hydroxyphenyl acetic acid) chelate is the most effective source of Fe for high pH soils; however, it is an expensive source. Iron humate, a less expensive by-product of the drinking water decolorization process, was compared with Fe-EDDHA for Fe deficiency correction. Non-bearing 'Ambersweet' orange and 'Ruby Red' grapefruit (*Citrus paradisi* Macf.) and bearing 'Hamlin' orange (*Citrus sinensis* (L.) Osb.) and 'Flame' grapefruit trees, all on Swingle citrumelo rootstock, planted in high pH (> 7.6) soils, were used in this study. Iron humate was applied under the tree canopy in spring at rates from 0.07 to 7.0 oz Fe, for the non-bearing trees, or 0.75 to 12.0 oz Fe, for the bearing trees, per tree per year. Application of Fe humate at 0.75 oz Fe/tree/yr significantly increased the Fe concentration in the leaves as well as the fruit yield of both 'Hamlin' orange and 'Flame' grapefruit trees as compared to that of the trees in unamended soil. The fruit yield increase with application of Fe humate was generally very close to that with application of Fe-EDDHA at a similar Fe rate per tree. Modification of the Fe humate with addition of urea or ammonium nitrate did not increase Fe availability. Application of the Fe amendments regardless of rate or sources did not significantly affect the fruit quality. Application of Fe humate to non-bearing trees decreased twig dieback rating and increased flush growth, flush color rating, tree size, and leaf Fe concentration. This study demonstrated significant improvements in growth and Fe availability to non-bearing trees and Fe availability and fruit yield of bearing trees in high pH soils with application of Fe humate as compared to the unamended treatment.**

Iron (Fe) deficiency is a widespread problem in calcareous soils (Alva, 1992; Korcak, 1987). Soil application of organic Fe chelates is more effective than foliar application due to poor translocation of leaf-absorbed Fe (Anderson, 1982; Mortvedt, 1982). The effectiveness of Fe chelates depends strongly on the soil pH (Norvell, 1991). In highly calcareous soil with pH above 7, the only stable Fe chelate is EDDHA (as an example commercially available product is Sequestrene 138-Fe). The EDTA chelated Fe is stable only at pH < 6.5. Although the most effective source of Fe for high pH soils (pH > 6.5) is EDDHA chelated Fe, the high cost of this product is a major limitation for its use, particularly during the years of low net economic returns for a given production system. Therefore, it was necessary to explore an alternate low-cost Fe amendment which can be effective in high pH soils.

By-product materials from mining and industrial operations have been used to alleviate Fe chlorosis in various crop plants (Martens and Westermann, 1991; Parkpian and Anderson, 1986). Most agricultural industries are cautious about the use of industrial by-products as agricultural soil amendments. Therefore, it is important to conduct a thorough investigation on the by-product quality, crop response, and long-term effects on environmental quality. The by-product evaluated in this study came from a drinking water treat-

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ment plant, as a part of decoloration (of river water) process using ferric sulfate. The decoloration is mainly a process of removal of organic fractions by way of complexation with Fe, which settles at the bottom of the decoloration pond. The clear water is transferred for other pretreatment prior to delivery into the drinking water system. The by-product which is settled is predominantly Fe complexed with humic and fulvic acid fractions from the river water, generally referred to as Fe humate. Since this by-product comes from drinking water treatment plant, unlike waste water or other industrial sources, it is most likely free from toxic elements. Therefore, use of this by-product as a soil amendment will have minimal risk of heavy metal contamination. The objective of this study was to evaluate the effects of Fe humate applications to high pH soils on the growth and leaf Fe concentrations of non-bearing trees, and fruit yield and quality of oranges and grapefruit. This paper is a condensed version of the full paper published elsewhere (Alva and Obreza, 1997).

Materials and Methods

Details of four field experiments and some selected soil properties are shown in Table 1. In the 'Hamlin' and 'Flame' grapefruit experiments, application of Fe as Fe-EDDHA or Fe humate was compared to an unamended control. Dewatered and dried Fe humate (18% Fe) was used either without any modifications or with addition of 100 lbs/ton of either urea or ammonium nitrate to evaluate the effects of these amendments on the Fe availability. The recommended rate of Fe application using Fe-EDDHA for correction of Fe deficiency is about 0.65 oz elemental Fe/tree (Tucker et al., 1995). In this study Fe-EDDHA was applied at 0.75 and 1.5 oz Fe/tree/yr, and Fe humate was applied at 0.75, 1.5, and 3.0 oz Fe/tree/yr. An additional rate of 12 oz Fe/tree as Fe humate was included to examine the effects of 16-fold increase in recommended Fe rate on the tree response as well as the soil properties. The Fe amendment was applied in early spring on the soil surface within the canopy area without incorporation. The subsequent irrigation resulted in dissolution of the product and downward movement into the soil which facilitated root uptake. The experiment was conducted with five trees per plot and five replications using a randomized complete block design, and repeated over 3 yr. The citrus groves were managed according to the usual cultural practices (Tucker et al., 1995).

Leaves from 5-mo-old spring growth were sampled annually from the middle two trees (40 to 50 leaves) of each plot in August. The leaves were washed in a mild detergent solution by rubbing both sides with cheesecloth, followed by a rinse in distilled water, a 20 sec rinse in 5% HCl, and several rinses in distilled water. The leaves were dried at 158°F for 48 hr and ground to pass a 40-mesh screen. A 0.5-g subsample of ground leaf tissue was ashed in a muffle furnace at 930°F for 5 hr, the ash was dissolved in 20 mL of 1 M HCl, and Fe concentration was determined using inductively coupled plasma emission spectroscopy (ICPES, Plasma 40, Perkin Elmer Inc., Norwalk, Conn.).

At fruit maturity, 30 fruits were sampled from the middle two trees of each plot to determine percentage of juice, brix, acid, and soluble solids. For the grapefruit experiment, on-tree fruit yield was estimated by using fruit counts per tree and mean weight per fruit. For the 'Hamlin' oranges, fruit from the middle two trees in the plot were harvested and the yield measured using the conventional field boxes.

In the case of the 'Ambersweet' and 'Ruby Red' grapefruit experiments, the treatments included three rates of Fe humate (0.07, 0.35, and 3.5 oz Fe/tree/yr for 'Ambersweet', and 2× rates of the above for 'Ruby Red' grapefruit), two rates of Fe-EDDHA (0.035 and 0.07 oz Fe/tree/yr for 'Ambersweet' and 2× rates of the above for 'Ruby Red' grapefruit), and one untreated control. Initial applications were made in May, with six replications of each treatment. The Fe humate was surface-applied and lightly mixed with the top soil to prevent rain from eroding it from the sloped bed. The Fe-EDDHA was dissolved in 1 gal of water and applied to a trench approximately 2 inches deep around the dripline of each tree.

Table 1. Details of field experiments and selected soil properties.

Sites	Soil series	Scion	Rootstock	Tree age	Spacing (ft)	Trees/acre	Soil pH	Extractable elements[z] (lb/acre) P	K	Ca	Mg	Fe
Arcadia	Wabasso sand	'Hamlin'	Swingle citrumelo	9 yr	25 × 15	116	7.6	48	120	2710	366	44
Fort Pierce	Oldsmar fine sand	'Flame' grapefruit	Swingle citrumelo	7 yr	25 × 15	116	7.8	140	280	17000	340	200
Fort Pierce	Winder sand	'Ambersweet'	Swingle citrumelo	5 mo	25 × 10	174	7.4	6	126	3956	126	24
Fort Pierce	Hallandale sand	'Ruby Red' grapefruit	Swingle citrumelo	3 yr	25 × 10	174	8.0	8	470	13478	162	16

[z]Soil samples from the first two sites were extracted with Mehlich 3 solution for all elements; and those from the last two sites were extracted with Mehlich 3 solution for P, K, Ca, and Mg, and ammonium-bicarbonate/DTPA solution for Fe.

Leaf and twig flush growth ratings were taken 4, 12, 18, and 24 mo after the initial Fe application for the 'Ambersweet' trees, and 4 mo after initial application for the 'Ruby Red' grapefruit trees. The rating method was 1 = no new flush to 10 = numerous new twigs. Leaf flush color ratings were also taken using the rating method with 1 = very chlorotic (pale yellow) to 10 = dark green. Twig dieback ratings were taken using a rating scheme with 1 = 10% of new twigs had dieback from the tip, 2 = 20% of new twigs had dieback, to 10 = 100% dieback. Trunk cross-sectional area, canopy diameter, and tree height measurements were taken at 12 and 24 mo for 'Ambersweet' trees and at 4, 12, and 24 mo for 'Ruby Red' trees. Concentration of Fe in 5-mo-old leaves was measured following the procedure as described for the bearing trees.

Results and Discussion

Bearing tree response. Modification of Fe humate by addition of either urea or ammonium nitrate had little effect on the tree response as compared to that with application of unmodified Fe humate. Increased rate of Fe application over the base rate of 0.75 oz Fe/tree/yr did not show significant effects in terms of the tree response. Therefore, only base rate data with unmodified Fe humate is discussed in relation to the similar rate of Fe-EDDHA or unamended control treatment.

Fruit yield of 'Hamlin' orange trees showed negligible increase regardless of source of Fe during the first year, but increased by 69 to 72 boxes/acre for the treatments which received Fe amendment as either Fe humate or Fe-EDDHA (Fig. 1). The yield increase with Fe amendment during the third year varied from 25 to 61 boxes/acre. Fruit yield data for the 'Flame' grapefruit experiment, was not available for the first year. Fruit yield increased by 15 to 29, and 11 to 35 boxes per acre with Fe amendment as compared to the unamended treatment during the second and third year, respectively. This study showed that significant increase in fruit yield was obtained with application of Fe amendment to both 'Hamlin' orange and 'Flame' grapefruit trees in high pH soils. In most cases, the magnitude of fruit yield response was very similar with use of Fe humate or Fe-EDDHA. Therefore, Fe humate is an effective source for supplying available Fe to the trees in high pH soils. Although both the experiments showed significant yield responses to Fe amendment, the fruit quality was not affected by the treatments (Data not presented).

Application of Fe amendments increased leaf Fe concentration significantly during all 3 yr in the 'Hamlin' orange and 'Flame' grapefruit trees (Fig. 2). Leaf Fe concentration of 'Hamlin' orange trees that received Fe-EDDHA was greater than that of the trees which received Fe humate. Leaf Fe concentrations of 'Flame' grapefruit trees receiving Fe-EDDHA were greater then those of the trees which received Fe humate in only 1 of 3 yr. Leaf Fe concentrations of 'Hamlin' orange and 'Flame' grapefruit trees with no Fe amendment were in the deficient range for the bearing trees (< 35 ppm; Tuckeret al., 1995) all 3 yr. Application of Fe amendments even at the low rate (0.75 oz/tree/yr) increased leaf Fe levels. However, these concentrations were in the low to optimum range (35 to 60 ppm) throughout the study. Leaf Fe concentration did not show any further increase with increased rates of Fe as either source.

Non-bearing tree response. Application of Fe humate increased 'Ambersweet' tree size, flush growth, and flush color ratings, but decreased twig dieback rating compared with trees that received no Fe (Fig. 3). Tree growth response to Fe humate was clearly expressed in terms of trunk cross-sectional area (Fig. 4). 'Ambersweet' tree height and trunk cross-sectional area were also increased with application of Fe-EDDHA, which also reduced twig dieback and increased twig growth and leaf color. In contrast, the

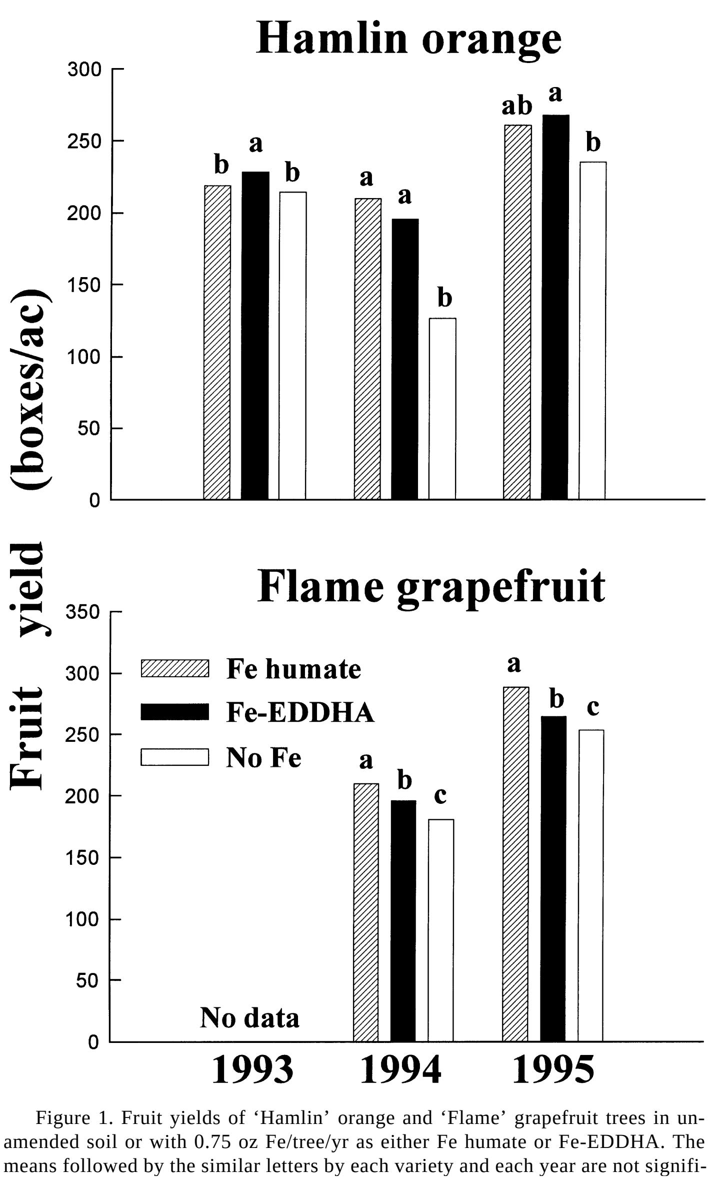

Figure 1. Fruit yields of 'Hamlin' orange and 'Flame' grapefruit trees in unamended soil or with 0.75 oz Fe/tree/yr as either Fe humate or Fe-EDDHA. The means followed by the similar letters by each variety and each year are not significantly different at P = 0.05.

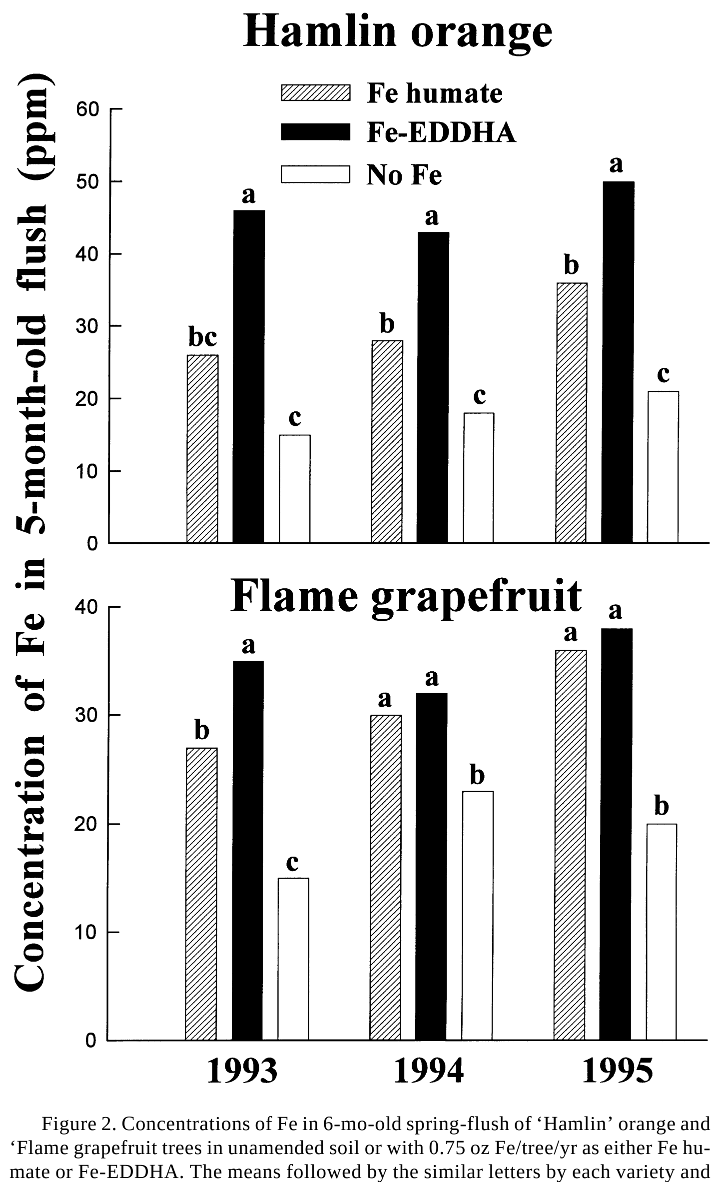

Figure 2. Concentrations of Fe in 6-mo-old spring-flush of 'Hamlin' orange and 'Flame grapefruit trees in unamended soil or with 0.75 oz Fe/tree/yr as either Fe humate or Fe-EDDHA. The means followed by the similar letters by each variety and each year are not significantly different at P = 0.05.

Ruby Red grapefruit trees did not respond to Fe application of any kind.

In summary, this study showed that the Fe humate was a effective source for correcting Fe chlorosis in orange and grapefruit trees in high pH soils. Applying high rates of Fe humate to citrus trees did not result in negative effects on the tree growth or fruit production, or on the soil chemical properties. Due to the high cost of Fe-EDDHA, this product needs to be applied on an individual tree basis, therefore, requires hand application which is very labor intensive. Fe humate can be broadcast using commercial fertilizer spreaders. Therefore, the cost of the product as well as application costs are greater for Fe-EDDHA than for Fe humate. This study clearly demonstrated the effectiveness of Fe humate for correction of Fe deficiency in citrus.

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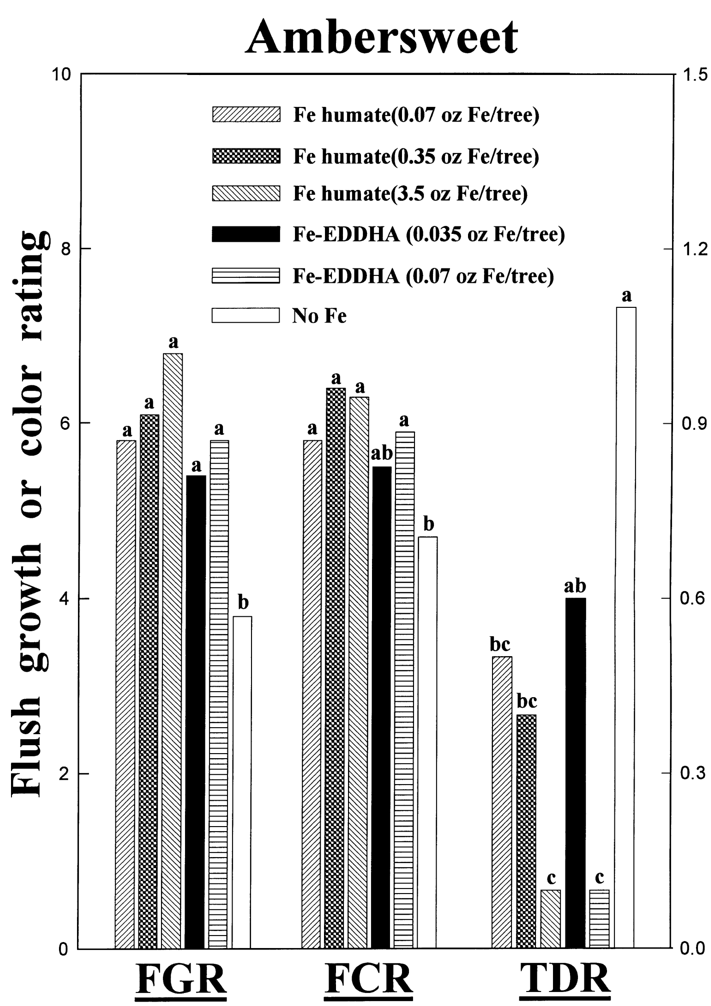

Figure 3. Effects of Fe amendments on flush growth (FGR) and color ratings (FCR), and twig dieback rating (TDR). Means followed by similar letters within each response parameter are not significantly different at P = 0.05.

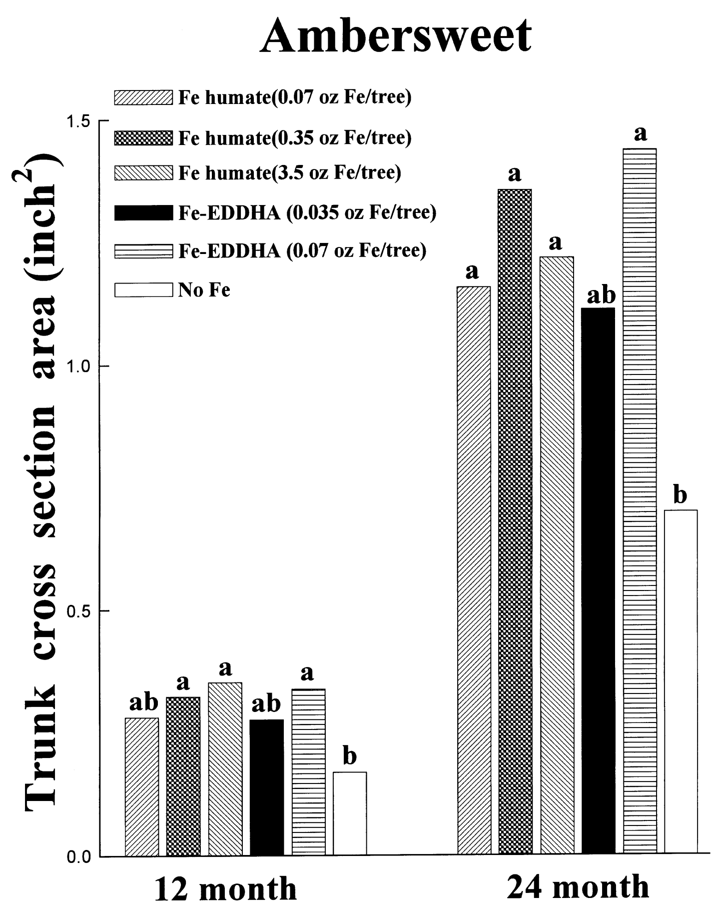

Figure 4. Trunk cross sectional area of 'Ambersweet' orange trees as influenced by Fe amendments in a high pH soil. Means followed by similar letters within each response parameter are not significantly different at P = 0.05