Overcoming Iron Chlorosis in Olive and Peach Trees Using a Low-pressure Trunk-injection Method

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Abstract. Chlorotic 'Manzanillo' olive (*Olea europaea* L.) trees and 'Maycrest' peach [*Prunus persica* (L.) Batsch] trees were injected with Fe solutions using an apparatus that consisted of a plastic injector and a pressurized latex tube containing the solution to be injected. Injections were made on various dates from Sept. 1987 to July 1988. All treatments increased chlorophyll content compared to that of the control. Ferrous sulfate was the most effective Fe compound in alleviating chlorosis; its effect lasted for two seasons in peach and for at least three seasons in olive. Also, ferrous sulfate increased vegetative growth and affected cropping the year following injections. Ferrous sulfate at 0.5% to 1% is recommended to reduce the risk of foliar burning. The injection method effectively introduced Fe compounds into olive and peach trees.

Iron chlorosis is a major nutritional problem of fruit trees growing in alkaline, calcareous soils. Iron chlorosis results in crop losses, and, in severe cases, trees become unproductive and may die. Much research has been conducted to determine the most effective and economical methods of correcting Fe chlorosis. The proceedings of the six international symposia on Fe nutrition (Barton and Johnson, 1988; Chen and Hadar, 1991; Clark et al., 1986; James et al., 1984; Miller et al., unpublished; Nelson et al., 1982) and the review by Korcak (1987) provide information on plant Fe nutrition and control. Developing more Fe-efficient cultivars or rootstocks seems to be the best method of controlling Fe (Mortvedt, 1991). For established trees, injecting Fe compounds into trunks has alleviated chlorosis for at least two growing seasons in various deciduous fruit trees (Barney et al., 1985; Hurley et al., 1986; Raese and Parish, 1984; Raese et al., 1986; Reil et al., 1978; Yoshikawa, 1988; Yoshikawa et al., 1982). Of the various chemicals tested, ferrous sulfate gave the best results at the lowest cost.

The high-pressure trunk-injection system described by Reil and Beutel (1976) was used in the experiments noted. However, commercial use of this method is limited because special equipment is needed, labor costs are high, and the high pressure may injure some trees. Recently, Navarro et al. (1992) described a low-pressure trunk-injection method that is easy to use, economical, and does not require special equipment. The objective of the present study was to evaluate the effectiveness of this

method in alleviating Fe chlorosis in olive and peach trees.

Olive. Two distinct experiments were carried out in a commercial olive orchard located in the Seville province in southern Spain. Drip-irrigated, 12-year-old 'Manzanillo' trees growing on a calcareous soil and showing clear symptoms of Fe chlorosis were selected for the experiments. In Expt. 1, a split-plot design was used with four blocks; injection date was the whole-plot factor and the concentration of ferrous sulfate was the subplot factor. Each subplot consisted of one tree. The subtreatments were a nontreated control and injections of 0.5%, 1%, or 2% ferrous sulfate solutions. Ferrous sulfate was injected in Sept. and Dec. 1987, and Mar. and June 1988. One selected scaffold of 80- to 120-cm² cross-sectional area per tree received one 250-ml injection. This scaffold served as the experimental unit. Chlorophyll content was determined in July and Nov. 1988, 1989, and 1990 from the second fully expanded leaf of 10 shoots from each scaffold. After extraction with methanol, chlorophyll content was determined (Harborne, 1973). Chlorosis development was also evaluated from Mar. 1988 to May 1991 using a scale of 0 to 3, where 0 = no chlorosis and 3 = very strong chlorosis. Vegetative growth was determined at the end of each growing season by measuring shoot length

on 10 tagged shoots per scaffold and by measuring leaf area on the same leaves used to determine chlorophyll content. The leaf area of each sample was determined with an area meter (model 3100; LI-COR, Lincoln, Neb.). The effect of Fe trunk injections on cropping was evaluated by measuring yield and fruit size at harvest.

The objective of Expt. 2 for olive was to evaluate the effectiveness of Fe sources in alleviating Fe chlorosis. A randomized block design was used with four blocks and seven treatments. Each plot consisted of one tree. The treatments were a nontreated control and injections of 0.5 g Fe in the following compounds: ferrous sulfate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, 20% Fe), ferric citrate ($\text{FeC}_6\text{H}_5\text{O}_7 \cdot \text{H}_2\text{O}$, 19% Fe), Sequestrene (Ciba-Geigy, Switzerland) [6% ferric ethylenediamine di (o-hydroxyphenylacetate) (Fe-EDDHA)], Flavex-Hierro (ERT, Spain) (9.6% Fe, 7% S), Ferriplus (ABM Chemicals, England) [6% ferric methyl-ethylenediamine di (o-hydroxyphenylacetate) (Fe-EDDHMA)], and Welgro Hierro (Massó Spain) (5% Fe heptagluconate). Trunk injections were made on July 1988. Experimental details were similar to those described for Expt. 1. To avoid problems caused by poor solubility, we increased the injection volume of Sequestrene, Ferriplus, and Flavex-Hierro to 400 ml. Chlorophyll content was determined on Nov. 1988 and 1989 and July 1989. Chlorosis development was recorded from July 1988, just before treatments, to July 1990.

Peach. A block of chlorotic 7-year-old 'Maycrest' peach trees growing in a commercial orchard in the Guadalquivir Valley in southern Spain was chosen for peach experiments. A split-plot design with four blocks was used; injection date was the whole-plot factor and the concentration of ferrous sulfate was the subplot factor. Each subplot consisted of a single tree. The treatments were a nontreated control and injections of 0.5% or 1% ferrous sulfate solutions. Injections were made in Apr., May, June, or July 1988. Each experimental tree received two simultaneous 250-ml injections. Chlorophyll content was determined on July 1988 and Apr. and June 1989. The current season's shoot length and leaf area, and fruit yield the year following injections were determined as described in the olive experiments.

We used the injection method described by Navarro et al. (1992). In brief, Fe solutions were placed under pressure in a latex tube that was closed at both ends. After removing one of the ties, the pressurized tube was connected to

Table 1. Leaf chlorophyll content at various dates in 'Manzanillo' olive trees injected with ferrous sulfate (FeSO_4) or not injected.

FeSO_4 concn (%)	Chlorophyll content ² (mg·g ⁻¹ fresh wt)					
	July 1988	Nov. 1988	July 1989	Nov. 1989	July 1990	Dec. 1990
0	0.93	1.07	0.90	0.88	0.87	0.91
0.5	1.27	1.57	1.04	1.06	0.97	0.87
1	1.22	1.80	1.14	1.09	1.01	0.90
2	1.33	1.92	1.23	1.29	1.13	1.15
Significance	L***	L***	L***	L***	L***	L**

²Each datum is the average of values from four injection dates.

****Significant at $P = 0.01$ or 0.001 , respectively; L = linear.

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compound for alleviating Fe chlorosis. Although Fe solution uptake was not quantified, we observed differences in absorption rate among the Fe solutions. The ferrous sulfate and ferric citrate solutions were absorbed in a few minutes, whereas absorption of Fe-EDDHA, Fe lignosulfonate, Fe-EDDHMA, and Fe heptagluconate solutions took several hours.

The injection method used in the present work alleviated Fe chlorosis in olive and peach trees with the same efficiency of other injection methods. Chlorophyll content in treated trees remained higher than in the control for at least three seasons in olive trees and for two seasons in peach trees. The species differences may be related to Fe losses associated with leaf fall in peach. In our experiment, each peach tree received two 250-ml injections of ferrous sulfate. We hypothesize that increasing the number of injections per tree may result in a longer-lasting effect; however, Yoshikawa (1988) reported that 1-liter ferrous sulfate injections twice the volume applied in our experiment also remained effective for only two seasons in peach trees. Iron injections reduced chlorosis for 3 or 4 years in apple (*Malus domestica* Borkh.) and pear (*Pyrus communis* L.) trees only when fall and spring injections were made (Raese et al., 1986). We also observed that increasing the number of

injections per tree distributed Fe solution more uniformly throughout the tree, particularly in trees with short trunks (data not shown).

Although all Fe compounds tested rapidly corrected Fe chlorosis, only ferrous sulfate and Fe-EDDHMA had a prolonged effect. Solubility plays an important role in the uptake of Fe solutions from trunk injections and, thus, may play a significant role in their effectiveness. Other factors related to the chemical nature of the Fe compounds may affect their efficiency in controlling Fe chlorosis to a larger extent than does uptake rate. For example, ferric citrate was absorbed in a few minutes but was the least effective Fe compound in alleviating chlorosis. Similar results were reported by Barney et al. (1985) for apple trees. Ferrous sulfate gave the best overall results; it was taken up rapidly and had a more prolonged effect.

The main problem with trunk injection is phytotoxicity. Foliar burning is related to Fe concentration. At the concentrations we used, phytotoxicity was slight. We recommend injecting ferrous sulfate at concentrations $\leq 1\%$ to reduce the risk of foliar burning. We also observed more damage on foliage when Fe was injected in spring, during the new flux of vegetative growth. These observations suggest that the number and the age of the leaves must be considered when determining the proper injection time.

Literature Cited

- Barney, D.L., R.H. Walser, T.D. Davis, and C.F. Williams. 1985. Trunk injection of iron compounds as a treatment for overcoming iron chlorosis in apple tree. *HortScience* 20:236-238.
- Barton, L.L. and G.V. Johnson (eds.). 1988. Proceedings of the fourth international symposium on iron nutrition and interactions in plants. *J. Plant Nutr.* 11:605-1621.
- Chen, Y. and Y. Hadar (eds.). 1991. Iron nutrition and interactions in plants. Kluwer Academic Publishers, The Netherlands.
- Clark, R.B., J.W. Maranville, R.A. Wiese, N.M. Ross, D. Knudsen, D.P. Coyne, and L.C. Lane. 1986. Proceedings of the third international symposium on iron nutrition and interaction in plants. *J. Plant Nutr.* 9:165-1066.
- Harborne, J.B. 1973. *Phytochemical methods*. Chapman and Hall, London.
- Hurley, A.K., R.H. Walser, T.D. Davis, and D.L. Barney. 1986. Net photosynthesis, chlorophyll, and foliar iron in apple trees after injection with ferrous sulfate. *HortScience* 21:1029-1031.
- James, D.W., J.C. Brown, V.D. Jolley, G.W. Miller, S.D. Nelson, F. Stewart, D.R. Walker, and A. Wallace. 1984. Proceedings of the second international symposium on iron nutrition and interactions in plants. *J. Plant Nutr.* 7:1-864.
- Korcak, R.F. 1987. Iron deficiency chlorosis. *Hort. Rev.* 9:133-186.
- Mortvedt, J.J. 1991. Correcting iron deficiencies in annual and perennial plants: Present technologies and future prospects, p. 315-321. In: Y. Chen and Y. Hadar (eds.). Iron nutrition and interactions in plants. Kluwer Academic Publishers, The Netherlands.
- Navarro, C., R. Fernandez-Escobar, and M. Benlloch. 1992. A low-pressure, trunk injection method for introducing chemical formulations into olive trees. *J. Amer. Soc. Hort. Sci.* 117:357-360.
- Nelson, S.D., A. Wallace, J.C. Brown, G.W. Miller, W.L. Lindsay, and V.D. Jolley. 1982. Proceedings of the first international symposium on iron nutrition and interactions in plants. *J. Plant Nutr.* 5:229-1002.
- Raese, J.T. and C.L. Parish. 1984. Mineral analysis and performance of chlorotic pear trees sprayed or injected with iron. *J. Plant Nutr.* 7:243-249.
- Raese, J.T., C.L. Parish, and D.C. Staiff. 1986. Nutrition of apple and pear trees with foliar sprays, trunk injections or soil applications of iron compounds. *J. Plant Nutr.* 9:987-999.
- Reil, W.O. and J.A. Beutel. 1976. A pressure machine for injecting trees. *Calif. Agr.* 30:4-5.
- Reil, W.O., J.A. Beutel, C.L. Hemstreet, and W.S. Seymen. 1978. Trunk injection corrects iron and zinc deficiency in pear trees. *Calif. Agr.* 32:22-23.
- Yoshikawa, F.T. 1988. Correcting iron deficiency of peach trees. *J. Plant Nutr.* 11:1387-1396.
- Yoshikawa, F.T., W.O. Reil, and L.K. Stromberg. 1982. Trunk injection corrects iron deficiency in plum trees. *Calif. Agr.* 36:13.

Table 5. Effect of ferrous sulfate (FeSO₄) injections on yield and fruit size in 'Manzanillo' olives.¹

FeSO ₄ concn (%)	Yield (kg/scaffold)		Avg fruit wt (g)	
	1989	1990	1989	1990
0	4.69	7.27	3.10	3.24
0.5	8.25	7.41	2.92	3.73
1	11.50	8.22	2.68	3.53
2	8.87	8.47	3.03	3.59
Significance	L*, Q**	NS	NS	NS

¹Each datum is the average of values from four injection dates.

NS, **Nonsignificant or significant at $P = 0.01$, respectively; L = linear, Q = quadratic.

Table 6. Chlorosis ratings and leaf chlorophyll content over 2 years in 'Manzanillo' olive trees injected with various Fe compounds.¹

Treatment ²	Sampling date							
	July 1988		Nov. 1988		July 1989		Nov. 1989	
	Chlorosis rating ³		Chlorosis rating	Chlorophyll (mg·g ⁻¹)	Chlorosis rating	Chlorophyll (mg·g ⁻¹)	Chlorosis rating	Chlorophyll (mg·g ⁻¹)
Control	2.2		2.5	0.62 a	2.5	0.60 a	2.4	0.33 a
Ferrous sulfate	2.2		0	1.52 b-d	0.1	1.25 b	0.2	0.94 b
Fe-EDDHA	2.1		0.1	1.71 bc	1.4	1.04 ab	1.0	0.80 ab
Fe lignosulfonate	2.0		1.0	1.14 d	1.7	0.66 a	1.1	0.60 ab
Fe-EDDHMA	2.0		0.1	1.86 b	0.2	1.32 b	0.6	0.85 b
Ferric citrate	2.2		1.0	1.33 cd	1.9	0.62 a	1.9	0.60 ab
Fe heptagluconate	2.2		0.2	1.67 bc	1.2	1.06 ab	0.6	0.80 ab

¹Mean separation within chlorophyll columns by Duncan's multiple range test, $P = 0.05$.

²Each treatment contained 0.5 g Fe, except the control.

³Rating scale: 0 = no chlorosis; 3 = very strong chlorosis.