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# Foliar iron-fertilisation of fruit trees: present knowledge and future perspectives – a review

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SUMMARY
Iron (Fe)-deficiency is a common physiological disorder affecting fruit crops in many areas of the World. Foliar Fe-fertilisation is a common agricultural strategy to control Fe-deficiency under field conditions. However, variable responses to Fe sprays have often been described and foliar Fe-fertilisation cannot yet be considered a reliable strategy to control plant Fe-deficiency. The lack of understanding of some factors relating to the penetration, distribution, and bio-activity of leaf-applied, Fe-containing solutions hinders the development of effective Fe formulations for foliar treatment. The current state-of-the-art and future perspectives for foliar Fe-fertilisation, as a strategy to control Fe-deficiency in fruit crops, is discussed.

Iron (Fe)-deficiency chlorosis is a widespread physiological disorder affecting many fruit crops and is a limiting factor for production, especially under high pH, calcareous soil conditions, such as those prevailing in many agricultural areas with a Mediterranean climate. Typical symptoms of Fe-deficiency include the development of interveinal chlorosis, starting from the apical leaves, reduction of shoot growth, defoliation during the growing season and, ultimately, tree death (Rombolà and Tagliavini, 2006). Iron chlorosis has deleterious effects on fruit production, reducing the number of fruits per tree, fruit size, total yield, and affecting fruit quality parameters such as colour, firmness, or acidity (Álvarez-Fernández *et al.*, 2003; 2006).

There is scientific evidence that Fe-fertilisation increases fruit quality and yield in many crops (Álvarez-Fernández *et al.*, 2006). Iron-fertilisation is a standard agricultural practice in fruit production areas that suffer from plant Fe-deficiency. Strategies to alleviate Fe-chlorosis in fruit crops include: (i) the use of rootstocks tolerant to soil conditions that induce the development of the disorder and with improved Fe-uptake mechanisms; (ii) modifying soil characteristics; and/or (iii) treatment with Fe-substances *via* root, trunk, or canopy application(s) (Abadía *et al.*, 2004; Lucena, 2006). Iron-fertilisation of roots is the most reliable and widely-used technique to control Fe-deficiency, and commercial Fe(III)-EDDHA-based products are the most effective fertilisers used to correct Fe-chlorosis under severe soil conditions (Lucena, 2006). However, such chemicals are expensive and may perform differently according to the particular Fe(III)-EDDHA formulation (Cerdán *et al.*, 2007).

Foliar Fe-fertilisation could be a cheaper and more targeted strategy to correct plant Fe-chlorosis (Abadía *et al.*, 2002; Álvarez-Fernández *et al.*, 2004; Fernández *et al.*, 2008a), but the response to Fe sprays has been shown to vary according to many plant-related, environmental, and physico-chemical factors (Fernández and Ebert, 2005). Problems of reproducibility and interpretation of results from foliar and cuticular Fe-application studies have been described (Fernández and Ebert, 2005). Our current limited understanding of the factors involved in the penetration, translocation, and bio-availability of leaf-applied Fe fertilisers makes it difficult to develop effective spray formulations for agricultural purposes. At present, foliar nutrition is only considered to be a valuable complement to the application of nutrients *via* the root system (Weinbaum, 1996).

In general, the penetration of Fe-containing solutions will be influenced by plant factors, environmental conditions, the nature of the spray solution, and the method of application (Currier and Dybing, 1959). Similarly, the roles of active and passive processes involved in the penetration and subsequent physiological effects of foliar-applied nutrient solutions remain controversial (Jyung and Wittwer, 1964; Zhang and Brown, 1999).

The effectiveness of leaf-applied, Fe-containing solutions is normally assessed on the basis of their re-greening capacity, tissue Fe-absorption rate, and Fe-translocation from the site of treatment (Fernández, 2004; Fernández *et al.*, 2006; 2008a). Therefore, in response to foliar treatment with a Fe-containing solution, at least three distinct key processes can be distinguished, in theory, although they are difficult to separate from one another: (i) the penetration of foliar-applied Fe through the leaf surface; (ii) the distribution of Fe from the site of application; and (iii) the active involvement of exogenous Fe in physiological processes.

An account of the state-of-the-art concerning foliar Fe-fertilisation of fruit trees and the key factors to be considered for the development of more effective Fe-containing formulations is provided in the following sections.

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