1. Introduction and scope

Foliar fertilization is an important tool for the sustainable and productive management of crops. However, current understanding of the factors that influence the ultimate efficacy of foliar applications remains incomplete. This book provides an integrated analysis of the principles, both physico-chemical and biological, known to influence foliar absorption and utilization by the plant, and reviews the available laboratory and field experimental results to provide insights into the factors that ultimately determine the efficacy of foliar applications. Advances in this field will require a sound understanding of the physical, chemical, biological and environmental principles that govern the absorption and utilization of foliar applied nutrients. The aim of this book is to describe in detail the state of knowledge on the mechanisms of uptake by plant organs (leaves and fruits) of surface-applied nutrient solutions, and to describe the environmental and biological factors and interactions that are key to understanding these processes. Empirical information gathered from foliar nutrient spray trials and field practices will be merged with physical, chemical and biological principles to arrive at a greater understanding of this technology, its potential, its weaknesses and its unknowns. The authors will also strive to illustrate the challenges facing this technology and the research and development required for its advancement. The goal of this book is to provide the reader with this understanding.

1.1. A brief history of foliar fertilization

The ability of plant leaves to absorb water and nutrients was recognized approximately three centuries ago (Fernández and Eichert, 2009). The application of nutrient solutions to the foliage of plants as an alternative means to fertilize crops such as grapevine agriculture was noted in the early 19th century (Gris, 1843). Following this, research efforts were applied to try and characterize the chemical and physical nature of the plant foliar cuticle, the cellular physiology and structure of plant leaves as well as focusing on potential mechanisms of penetration by foliar sprays. With the advent of firstly fluorescent and then radio-labelling techniques in the first half of the 20th century it became possible to develop more accurate methods to investigate the mechanisms of leaf cuticular penetration and translocation within the plant following foliar application of nutrient solutions (Fernandez and Eichert, 2009; Fernandez *et al.*, 2009; Kannan, 2010).

The role of stomata in the process of foliar uptake has been a matter of interest since the beginning of the 20th century. However in 1972 it was postulated that pure water may not spontaneously infiltrate stomata unless a surface-active agent to lower surface tension below 30 mN m^{-1} is applied with the solution (Schönherr and Bukovac, 1972).

As a consequence of this, most investigations were subsequently carried out on cuticular membranes isolated from adaxial (upper) leaf surfaces of species in which enzymatic isolation procedures could be conducted, e.g. from poplar or pear leaves. Utilizing this system it was found that cuticles are permeable to water and ions as well as to polar compounds (Kerstiens, 2010). Furthermore the occurrence of two distinct penetration pathways in the cuticle, one for hydrophilic and another for lipophilic substances, has been suggested (Schönherr, 2006; Schreiber and Schönherr, 2009).

The proposition that stomata could also contribute to the foliar penetration process was re-assessed by Eichert and co-workers at the end of the 1990's and subsequently validated (Eichert and Burkhardt, 2001; Eichert and Goldbach, 2008; Eichert *et al.*, 1998; Fernandez and Eichert, 2009). At present the quantitative significance of this pathway and the contribution of other surface structures such as lenticels to the uptake of foliar applied solutions remain unclear.

Since its first recorded use in the early 19th century (Gris, 1843), foliar fertilization has been the subject of considerable controlled environment and field research and has become widely adopted as a standard practice for many crops. The rationales for the use of foliar fertilizers include: 1) when soil conditions limit availability of soil applied nutrients; 2) in conditions when high loss rates of soil applied nutrients may occur; 3) when the stage of plant growth, the internal plant demand and the environment conditions interact to limit delivery of nutrients to critical plant organs. In each of these conditions, the decision to apply foliar fertilizers is determined by the magnitude of the financial risk associated with the failure to correct a deficiency of a nutrient and the perceived likelihood of the efficacy of the foliar fertilization.

Furthermore foliar fertilization is theoretically more environmentally friendly, immediate and target-oriented than soil fertilization since nutrients can be directly delivered to plant tissues during critical stages of plant growth. However while the need to correct a deficiency may be well defined, determining the efficacy of the foliar fertilization can be much more uncertain.