Zinc Nutrition of Fruit Trees by Foliar Sprays

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Abstract

Effective methods of supplying Zn to fruit trees are needed to combat widespread deficiency of this element all over the world. Soil applications are not very effective because the roots of fruit crops occupy deep soil layers and zinc does not easily move in the soil. Although foliar sprays are more effective, foliar-absorbed Zn is not easily translocated in plants, which necessitates repeated spray applications and diminishes the ability of foliar sprays to alleviate Zn deficiency in all plant parts. Conditions under which fruit trees are most likely to respond to corrective Zn treatments in terms of growth, yield, and fruit quality are not completely understood. In citrus and apples, the occurrence of severe deficiency symptoms appears to be a prerequisite for tree responses. Zinc foliar sprays applied before anthesis may be most beneficial in terms of fruit yield in citrus and grapes. More research is needed to better define the critical periods for Zn supply to assure optimal fruit set, fruit growth, and high external and internal fruit quality.

INTRODUCTION

Foliar sprays with Zn are widely practiced by fruit growers because: (1) the metal is an essential element for normal plant development; (2) large areas of agricultural soils are deficient in this element; and (3) soil applications are generally ineffective in correcting Zn deficiency in fruit crops (Swietlik 1999). Although the subject has been studied for a long time, we still need to develop a better understanding of the factors limiting the effectiveness of Zn foliar sprays such as: (1) the rate of absorption of Zn by the aboveground plant parts; (2) translocation of the absorbed Zn into specific organ(s) to elicit the desired physiological effect(s); (3) the critical timing for Zn foliar sprays; and (4) the critical Zn nutritional level below which the corrective treatments would be expected to improve growth, yield, or fruit quality.

ABSORPTION AND TRANSLOCATION OF FOLIAR-ABSORBED ZN

Mineral nutrients enter into leaves in three steps involving: (1) penetration through the cuticle and epidermal walls; (2) adsorption on the surface of the plasmalemma, and (3) passage through the plasmalemma into the cytoplasm (Swietlik and Faust, 1984). The cuticle is covered by epicuticular waxes, which constitute the most hydrophobic component of the leaf surface. Discontinuities and cracks in these waxes, however, open a pathway for penetration of leaf-applied nutrients (Swietlik and Faust, 1984). The underlying cutin is much more hydrophilic because its building blocks, polyesterified hydroxy fatty acids, contain polar groups. Schonherr and Bukovac (1970) demonstrated the existence of polar pathways in the cuticle and Schonherr (1976) proposed the existence of transculticular canals lined with carboxyl groups serving as polar pathways for penetration. Due to its pectin and polar nature, the epidermal cell wall is much less of a barrier to nutrient diffusion than is the cuticle (Schonherr and Bukovac, 1970).

Our knowledge of absorption pathways for Zn following cuticular penetration is still very limited. Some of the possible pathways are depicted in Fig. 1. After passing through the cuticle, Zn may diffuse through the free space (apoplast) of cell walls to vascular tissue where, after loading into phloem, it may be transported out of the leaf. Alternatively, after lateral and inward diffusion, Zn may get adsorbed on negatively charged sites and remain in the apoplast of leaf mesophyll tissue. Another pathway of foliar Zn absorption may involve transport across the plasmalemma and the cytosol of

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leaf mesophyll (symplast) to the vascular tissue.

In studies conducted by Zhang and Brown (1999b) and Ferrandon and Chamel (1988), approximately 89-95 % of Zn recovered after foliar application to pistachio and pea (*Pisum sativum*) was found in the treated leaf after 10 and 1 day, respectively (Table 1). This shows very poor translocation of foliar-applied Zn and indicates that only a very small proportion of Zn recovered in plants was actually transported across the cell membranes into the symplast. Furthermore, there was a linear relationship between the concentration of foliar-applied Zn and the amount of Zn recovered in plants (Zhang and Brown, 1999a). This kind of kinetics strongly indicates the involvement of physical processes in Zn uptake such as diffusion and binding to the cuticle and cell walls, rather than enzymatically-dependent Zn transport across the cell membranes. Indeed, Zhang and Brown (1999a) showed metabolic inhibitors and light had no effect on leaf Zn absorption by pistachio and walnut leaves whereas temperature had only a weak effect (Q_{10}= 1.2-1.4).

Quite a different picture emerges from the studies on Zn absorption by sugarcane leaf discs (Bowen, 1969). The relationship between Zn absorption and the concentration of applied Zn followed Michaelis-Menten kinetics as the rate of Zn absorption reached saturation at elevated Zn concentrations. The rate of absorption was reduced by a number of metabolic inhibitors and it also showed stronger dependence on temperature (Q_{10}= 1.8) than in Zhang and Brown's (1999a) study. Light, however, still had no effect on Zn absorption.

The discrepancy between Zhang and Brown's (1999a) and Bowen's (1969) studies could be due to different plant species and concentrations of foliar-applied Zn. Most likely, however, various experimental procedures were responsible for the observed differences. Bowen (1969) employed leaf discs whose edges with exposed mesophyll cells had a direct contact with the Zn treatment solution. Zhang and Brown (1999a) used intact leaves therefore the cuticle and the underlying cell walls could adsorb Zn on negatively charged sites as the metal diffused into the leaf interior.

The difficulty of separating adsorption from absorption is one of the reasons there is controversy in the literature as to whether Zn absorption by plants is an active or passive process (Swietlik, 1999). The lack of a rigorous definition for an active uptake process is a further contributing factor. In this paper, active uptake is defined as transport against an electrical potential gradient (Kochian, 1991). Thus, a mere dependence of uptake on metabolic processes does not prove the existence of active uptake across cell membranes. In fact, a cell membrane potential of –120mV to –180 mV generated by a proton pump is believed to be large enough to drive passive uptake of Zn (Kochian, 1991). This process is illustrated in Fig. 2. One must keep in mind, that the proton pump, whose functioning depends on metabolic processes, generates the voltage potential. That is why, Zn uptake across cell membranes, although passive is dependent on metabolic processes (Bowen, 1969).

Hacisalihoglu et al. (2001) reported that Zn transport across root-cell membranes followed Michaelis-Menten kinetics because it had a saturable component, suggesting the involvement of a protein-mediated transport system. Three Zn transport genes have been identified in *Arabidopsis thaliana* and one in the Zn hyper-accumulator species, *Thlaspi caerulescens* (Kochian, 2000). Since the rate of absorption and mobility of foliar-applied Zn is low (Zhang and Brown, 1999a b), one may speculate that leaf cell membranes may be lacking an efficient Zn transporter(s).

Poor mobility of foliar-absorbed Zn reported by Zhang and Brown (1999b) and Ferrandon and Chamel (1988) was also found in other studies (Swietlik, 1996). It is also reflected by the inability of foliar sprays with Zn to eliminate Zn deficiency in roots as measured by growth and Zn tissue concentrations (Swietlik and Zhang, 1994) (Table 2). The foliar treatments reported in Table 2, however, alleviated the deficiency in the aboveground plant parts.

ZINC FERTILIZERS

Zinc oxide, ZnS, and $ZnCO_3$ were equally effective on citrus (Parker, 1937a) but in pecan and citrus Zn $(NO_3)_2$ alone and in combination with urea and ammonium nitrate raised leaf Zn level more than Zn SO_4 (Smith and Storey 1979; Embleton et al., 1988). There was no difference in the effectiveness of Zn compounds for foliar sprays applied to apples (Neilsen and Neilsen 1994) but Zn $(NO_3)_2$ alone or in combination with other compounds was not tested. Dithane M-45 and Zineb fungicides contain Zn and were successfully used as foliar Zn fertilizers (Beyers and Terblanche, 1971).

More research is needed to elucidate the effectiveness of various sources of Zn as foliar fertilizers and to determine the effect of accompanying compounds and adjuvants on the rate of Zn uptake and translocation within the plant.

EFFECT ON VEGETATIVE GROWTH

Severely Zn deficient citrus trees responded to a single Zn foliar spray with greatly enhanced tree vigor (Parker 1937 a b) but when the expression of Zn deficiency was mild or absent, despite low Zn leaf levels, no growth responses were noted (Swietlik and LaDuke, 1991; Wutsher and Obreza, 1987).

In nutrient culture studies with sour orange (*Citrus aurantium*), Swietlik and Zhang (1994) demonstrated foliar sprays were less effective than Zn application to the roots in terms of stimulating the growth of leaves, stems, and roots (Table 2). They also showed that various growth variables have different sensitivity to Zn deficiency, i.e., (least to most sensitive) root dry weight<leaf number = white root dry weight <stem dry weight <leaf dry weight <shoot elongation = leaf area.

Zinc deficient 'McIntosh' apple seedlings doubled the amount of shoot growth when foliar sprayed with $ZnSO_4$ or a Zn chelate (Neilsen and Hogue, 1983). Both forms of Zn were equally effective. Due to increased growth and the associated dilution effect, Zn tissue concentrations remained the same in the treated and control plants.

Based on a limited number of published reports, it appears that foliar sprays are effective in stimulating vegetative growth on fruit trees suffering from severe Zn deficiencies.

EFFECT ON YIELD

Significant yield increases of apple trees were reported by Stiles (1966) and Stover et al. (1999) following foliar sprays with Zn. These experiments involved trees with Zn leaf concentrations of 2.8-7.4 mg kg^{-1} d.w. that showed severe deficiency symptoms and trees with leaf Zn of 16 mg kg^{-1} d.w. whose expression of Zn deficiency was not provided, respectively. The positive yield responses are in sharp contrast with another experiment on apples reported by Stover at al. (1999) in which leaf Zn concentration was only 11 mg kg^{-1} d.w., yet Zn foliar sprays did not affect yield. Factors responsible for these different responses were not apparent. Similarly, no yield responses were noted on apple trees with leaf Zn concentrations considered to be deficient (12-13 mg kg^{-1} d.w.) but showing no deficiency symptoms (Yogaratnam and Greenham, 1982).

Yield of grapefruit trees doubled when severely deficient trees with approximately 60% of their foliage affected by Zn chlorosis in winter months were Zn foliar sprayed one and two months before anthesis (Swietlik, 1996). This resulted from the increased fruit set and not fruit size. Yield also tended to increase following foliar sprays applied just after the bloom and again 3 months later but the response was not statistically significant. The severity of Zn deficiency symptoms in this study greatly diminished in spring and summer months which could reduce the latter sprays' effectiveness. It is also possible that applying sprays after anthesis might be too late to affect fruit set.

Grapefruit trees are likely to respond to Zn foliar sprays only when more than 15-20% of the canopy foliage is affected by Zn deficiency symptoms (Swietlik, 1996). No yield responses were noted on grapefruit and orange trees with low leaf Zn but mild Zn deficiency symptoms, i.e., only 1-2% of the canopy foliage expressed Zn deficiency patterns (Swietlik and LaDuke, 1991).

When Zn foliar sprays were applied to grapes that were moderately to severely affected by Zn deficiency in terms of leaf Zn concentration and the expression of deficiency symptoms, the number of berries per cm of cluster increased most consistently when sprays were performed 1-2 weeks before bloom (Christensen, 1980). No increases were noted when sprays were applied in the fall.

We do not know all the factors that affect yield responses to Zn foliar sprays. In apple, citrus, and grape, an essential prerequisite for such response appears to be the presence of severe Zn deficiency symptoms. In citrus and grape applying foliar Zn before anthesis also demonstrates increases in fruit set.

EFFECT ON FRUIT QUALITY

On grapefruit trees with 100% of foliage affected by Zn deficiency symptoms, foliar sprays with Zn increased fruit size and juice content, eliminated resin formation in the albedo, reduced rind thickness, and eliminated abnormal fruit shape (Parker, 1937b). However, in another study on severely deficient grapefruit trees, foliar sprays did not affect fruit size, juice content, percent soluble solids (SS), percent total acid (TA), percent peel, and percent blush on the fruit surface (Swietlik, 1996).

Zinc sprays elevated apple fruit Ca and diminished the occurrence of bitter pit (Schmitz and Engel, 1973). Subsequent studies, however, showed that Zn foliar sprays did not affect bitter pit, internal breakdown, cracking, and red color (Yogaratnam and Johnson, 1982), even though some of the trees were judged deficient based on leaf Zn analysis (12-13 mg kg^{-1} d.w.). None of them, however, showed Zn deficiency symptoms.

CONCLUSIONS

Conditions under which fruit trees are most likely to respond to Zn foliar sprays in terms of growth, yield, and fruit quality are not completely understood. The occurrence of severe Zn deficiency symptoms appears to be a prerequisite to induce these responses. More research is needed to better define the critical periods for Zn supply to assure optimal fruit set, fruit growth, and high external and internal quality. Corrective Zn foliar sprays applied before anthesis may be most beneficial in terms of fruit yield in citrus and grapes.

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Tables

Table 1. The percent distribution of plant-recovered Zn following foliar application of ^{65}Zn to pistachio seedlings and pea plants.

Treatment	Plant	Tissue	Days after application 1	2	10	Reference
Zn SO4	Pistachio	Treated Leaf	---	99.1	94.6	Zhang &
7.5 mM		Stems & Leaves & Roots	---	0.7	5.4	Brown, 1999
Zn SO4	Pea	Treated Leaf	95	---	---	Ferrandon &
0.1 mM		Stems & Leaves & Roots	5	---	---	Chamel, 1988
Zn EDTA	Pea	Treated Leaf	89	---	---	Ferrandon &
0.1 mM		Stems & Leaves & Roots	11	---	---	Chamel, 1988

Table 2. Dry weight and tissue Zn concentrations in sour orange seedlings as affected by foliar and root Zn treatments. The seedlings grew in a nutrient solution for 3 months. Foliar sprays were applied at 5.2 mM ZnSO4 +0.1% Tween 20 at 2-week intervals (Swietlik and Zhang, 1994).

Treatment (mM Zn)	Dry Wt (g / plant)			Zn conc (mg·kg-1 d.w.)		
	Leaves	Stems	Roots	Leaves	Stems	Roots
5 (Control)	0.2	0.14	0.77	9.9	11.3	17.7
69	3.5	1.16	2.24	19.7	24.7	37.3
6x Zn SO4 Sprays	1.9	0.58	1.27	24.8	35.5	17.1

Figures

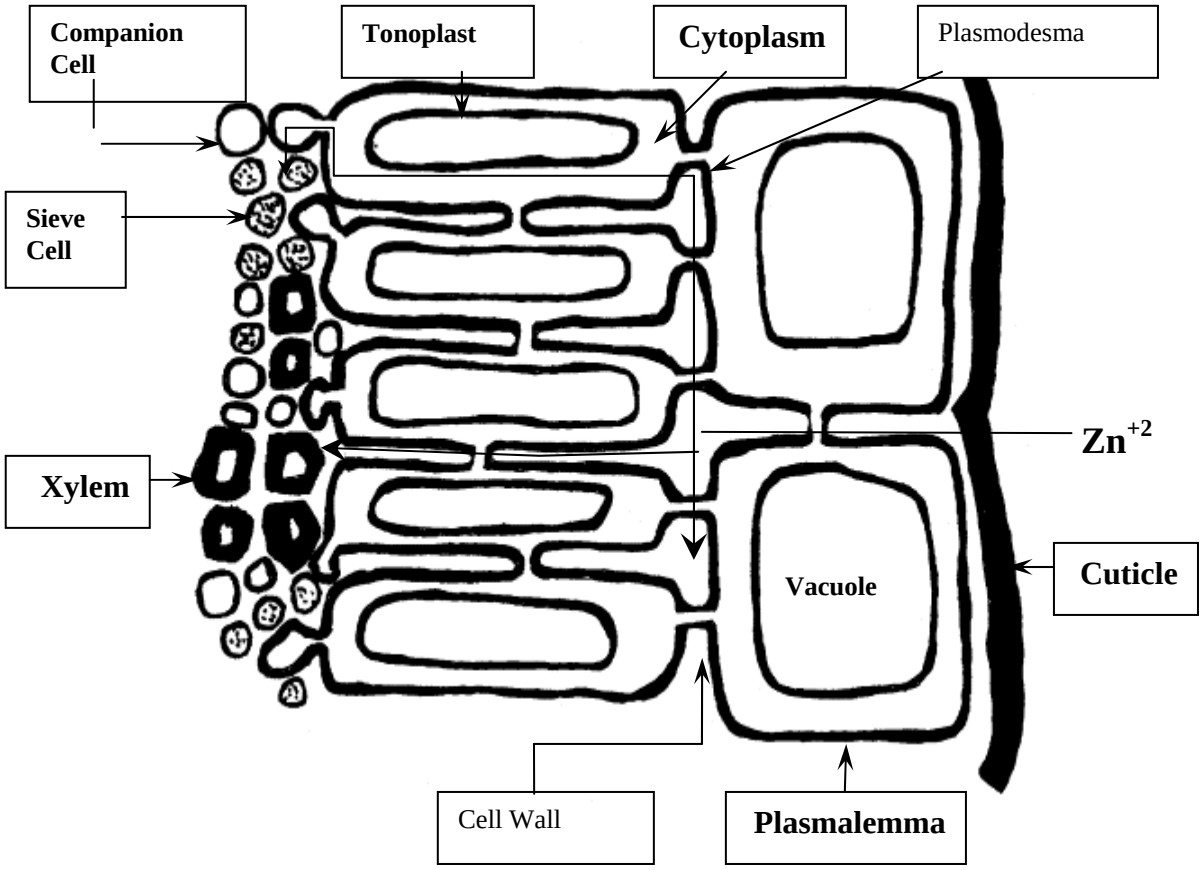

Fig. 1. Pathways of foliar Zn^{+2} penetration.

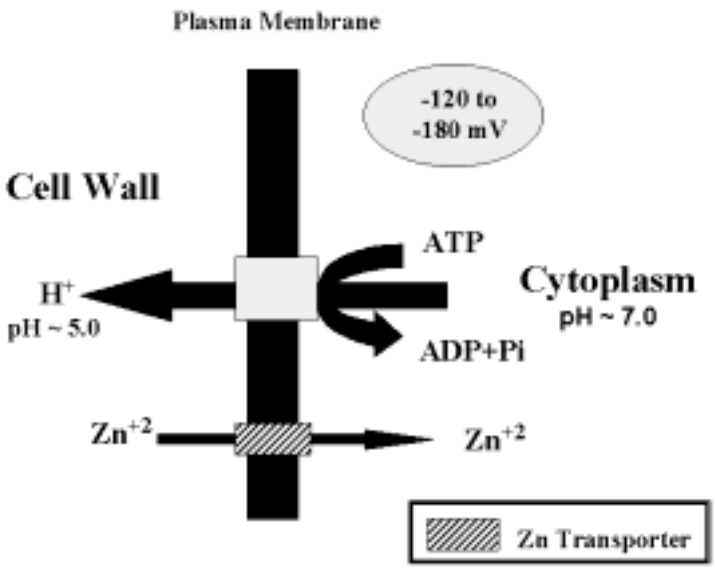

Fig. 2. Zn^{+2} transport through the plant plasma membrane.