THE UNIVERSITY OF ARIZONA
Cooperative Extension

az1789 January 2019

Zinc Management in Arid Region Pecan Orchards

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Figure 1. Zinc deficiency symptoms: (a) Rosetting caused by shortened internodes and (b) interveinal chlorosis and necrosis of young leaves.

Introduction

Ever since the earliest pecan orchards were commercially planted in the southeastern US in the 19th century, various abnormal growth patterns called "rosette" and "little leaf" have been observed in the trees. Affected trees exhibited shortening of the shoot internodes, which gave shoots a "rosette"-type appearance. Leaf shape, size, and color were also noticeably affected: leaflets were much narrower and smaller in surface area, had wavy edges on the leaf margins, and exhibited a pale yellowish, or chlorotic color especially between the leaf veins. In more severe cases, leaflets showed dark necrotic blotches between the veins and eventually shoot terminal dieback (Alben et al., 1932; Heerema, 2013)(Figure 1).

The cause of these unusual symptoms remained a mystery for decades, but in the early 1930's, a USDA soil scientist in Louisiana named Arthur O. Alben began to suspect that the symptoms were due to iron deficiency. In the course of his experiments, he noticed something surprising: iron fertilizers alleviated the symptoms, but only if the fertilizer solutions were mixed in a certain kind of container - a galvanized container! Galvanized metals are coated with zinc (Zn) and the containers had contaminated the iron fertilizer solutions with zinc, accounting for the surprising results. This led to additional studies that confirmed that the observed symptoms actually resulted from zinc deficiency and could be successfully treated with zinc fertilizers which alleviated these symptoms. Growers should continually examine trees and blocks for zinc deficiency symptoms.

Effect of soil conditions on zinc availability

Pecan trees are adapted to the soil conditions of the lower Mississippi River valley where they are native. The soils in native pecan forests are deep, well-drained alluvial river bottom soils - loamy, rich in organic matter, and moderately acidic[1]. Over the past several decades, the US pecan industry has expanded rapidly into areas outside the trees' native range, particularly into desert areas to the west. The dry weather, intense sunlight, and low pest pressure of the southwestern states afford many advantages for growing pecan orchards, but the majority of soils in this region are alkaline and calcareous (high pH; containing lime, or calcium carbonate), which presents some serious challenges for managing zinc nutrition. Zinc is not very available in these soils because solubility of zinc decreases 100-fold with each 1-unit increase in soil pH. To make matters worse, soil carbonates can bind zinc ions, further reducing the availability of zinc to plant roots. Therefore, plant available zinc is severely limited in alkaline desert soils containing carbonates.

Zinc is not the only nutrient that can be tied up due to soil lime and alkaline pH. Most of the other micronutrients (i.e. iron, copper, manganese, nickel), and phosphorus (a macronutrient), are also poorly available to plants under these soil conditions. Deficiencies for these other nutrients also regularly occur in the southwest, but pecan trees are particularly sensitive to zinc deficiency.

Zinc management strategies

Foliar zinc application

Application of nutrients directly to leaf surfaces is an effective method for satisfying the zinc requirement of newly expanding leaves. This has long been the standard method for managing zinc in arid-region pecan orchards because it allows growers to avoid the zinc binding with alkaline, calcareous soils and becoming biologically unavailable.

However, there are some challenges in the Southwest associated with supplying all of a pecan orchard's zinc requirements with foliar sprays, primarily because foliar applied zinc is immobile in the plant (see Figure 2). In other words, when zinc from a spray droplet is absorbed by leaf tissues, it is not transported through the vascular system to other parts of the plant that also need zinc. Thus, each foliar zinc spray is like a "snapshot in time". Only young leaves that are actively expanding when the spray contacts them absorb the zinc that they need. Unfortunately, it is too late to alleviate zinc deficiency on older leaves that are already fully expanded (foliar zinc sprays do not "undo" zinc deficiency that is already evident on mature leaves). Additionally, the tree does not have the ability to store up and later move foliar-applied zinc to leaves that were not yet present when the foliar zinc spray was applied. This is why it is important to make frequent, repeated foliar zinc applications during the active growing season. The immobility of foliar applied zinc also highlights the necessity for excellent spray coverage of the tree canopy— any immature leaves in the canopy that are not directly contacted by the zinc sprays are at risk of developing zinc deficiency symptoms. Difficulties with attaining adequate canopy spray coverage may result from spraying in windy conditions, driving the sprayer too fast through the orchard, or by poorly managing tree height.

Nevertheless, when canopy spray coverage is complete and not too much time elapses between zinc applications, well-timed foliar zinc sprays are effective in preventing development of visible zinc deficiency symptoms in pecan. Beginning at bud-break (mid-April for most pecan orchards), and continuing for 2-3 months or until vegetative growth has subsided, pecan producers in semi-arid production areas typically need to make multiple foliar spray applications to maintain adequate zinc in trees. Young, rapidly growing trees may be sprayed every week, resulting in 12 or more sprays during the active growing season. For mature trees, a total of 3 to 5 sprays per season are typically applied at two-week intervals.

In mature orchards, zinc fertilizer solutions should be applied with an air-blast sprayer at a rate of 100 gallons per acre. The most commonly used source of zinc for foliar spray applications is zinc sulfate monohydrate ($ZnSO_4$; approximately 36% zinc by weight). If using a dry powder form, 2 to 3 pounds zinc sulfate fertilizer are mixed with 100 gallons water. Zinc sulfate is not very soluble and should be premixed or added to sprayer with good agitation. Various liquid zinc sulfate fertilizer formulations are available that may be more convenient for some farm operations to handle than dry zinc sulfate (these will require calculations to apply equivalent rates of elemental zinc per acre; be sure to follow product labels). Zinc nitrate [$Zn(NO_3)_2$] is also an effective foliar spray and is available as a liquid material. When applied at identical rates, it results in greater foliar absorption than $ZnSO_4$, however the difference between the two materials is much less when UAN32 (urea ammonium nitrate) is added as an adjuvant to zinc sulfate sprays (Smith and Storey, 1979). Kilby (1985) noted that $ZnSO_4$ in combination with UAN32 was as effective as $Zn(NO_3)_2$ sprayed alone. Thus when using $ZnSO_4$ it is recommended that 3 pints UAN32 per 100 gallons be mixed in the spray tank to enhance foliar absorption of zinc. Zinc oxide (ZnO) may be applied foliarly, but is less effective than $ZnSO_4$ (Storey et al. 1971). Zinc chelates are effective when applied

[1] pH 7.0 is neutral (neither acidic nor alkaline). The pH of acidic soils is less than 7.0 and that of alkaline soils is greater than 7.0. The pH of soils in the semi-arid southwestern US typically ranges from 7.8 to 8.4.

foliarly, however they are more expensive. Ojeda-Barros et al. (2014) found that foliar-applied ZnEDTA was no more effective than $ZnSO_4$. Total annual foliar zinc application in mature orchard is usually about 4 to 6 pounds per acre of zinc.

Weather conditions greatly impact the efficacy of foliar zinc applications. Wind negatively affects the ability of a grower to get adequate canopy spray coverage. Ideally, foliar sprays should be applied when wind speeds are less than 7 mph, and spray operations are not recommended with wind speeds in excess of 15 mph. Foliar fertilizer nutrients are absorbed from solution, so the absorption process is enhanced by high ambient humidity that slows evaporation. High temperatures increase the rate of nutrient absorption, but also accelerate droplet evaporation, so the net effect of temperature on spray efficacy is variable. Because winds are lower and relative humidity higher at night, many pecan producers make their zinc sprays at night or during the early morning hours.

THE IMMOBILITY OF FOLIAR APPLIED ZINC IN PECAN

Grady Wadsworth (1970) applied ^{65}Zn (a synthetic radioactive isotope of zinc) onto pecan leaves to create autoradiographs that show subsequent zinc distribution (Figure 2). The figure on the left shows very limited zinc distribution following application of a $ZnSO_4$ droplet directly on the leaf, whereas the right-hand figure shows a much more even distribution resulting from root-supplied zinc. Movement of zinc from foliar droplets was primarily towards the leaf tip, indicating little flow towards other plant parts. In contrast, zinc absorbed through the roots was distributed throughout the plant, including leaves, stems, and roots. Wadsworth (1970) also noted that mature pecan leaves are much less efficient zinc absorbers than immature leaves and that there was little difference between absorption from upper and lower leaf surfaces. All sprays were relatively inefficient, with upper or lower leaf surfaces or mid-ribs absorbing approximately 1% of applied zinc, whereas droplets placed directly on the leaf axil absorbed approximately 8% of applied zinc.

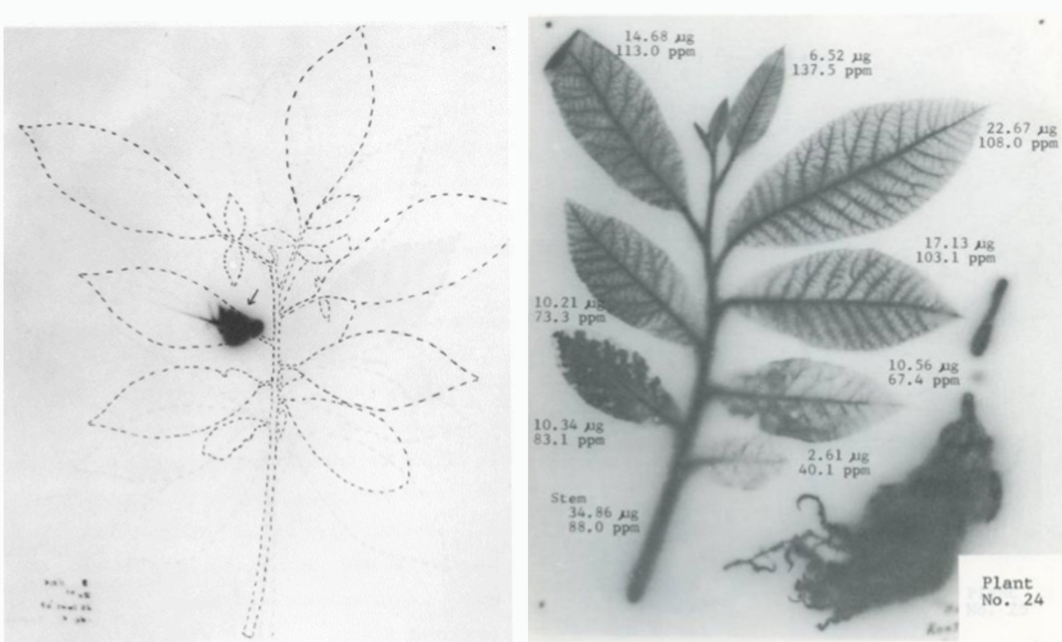

Figure 2. Zinc distribution in pecan seedlings: (left) leaf zinc distribution following application of a single droplet of ^{65}Zn and (right) zinc distribution in a pecan seedling grown in a hydroponic solution fertilized with ^{65}Zn.

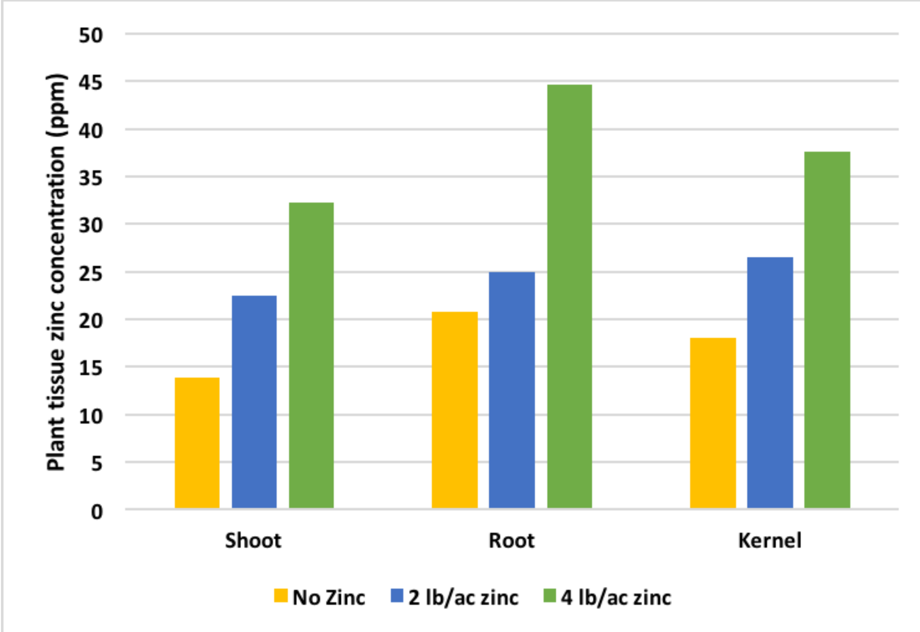

Figure 3. Zinc concentrations (2 year average) in pecan tree tissues resulting from fertigated ZnEDTA treatments.

Soil zinc application

As discussed earlier, zinc solubility is greatly reduced in high pH calcareous soils, and inorganic zinc fertilizers (ZnO, $ZnSO_4$ etc.) can be rapidly tied up by the soil. Accordingly, application of inorganic zinc materials to arid and semi-arid region soils generally has not been effective. Chelates[2], such as EDTA (ethylenediaminetetraacetic acid), can be synthesized to pair with zinc ions to reduce soil zinc fixation and maintain elevated plant-available zinc levels in the root zone. Zinc taken up by pecan roots, unlike that applied directly to the foliage, is translocated throughout the plant (Figure 2). Recent studies with fertigated Zn-EDTA (fertilizer injected into irrigation water) in a microsprinkler irrigated orchard resulted in elevated zinc levels in roots, stems, leaves, and fruit, demonstrating the efficacy of soil-applied chelated zinc in supplying zinc throughout the tree (Figure 3; Walworth et al., 2017). Other methods of Zn-EDTA application to the soil, such as banding or spraying onto the soil surface with a boom sprayer, have not been adequately tested at this time.

At planting

A one-time application of zinc fertilizer at planting can supply zinc for newly planted trees over an extended time. Research conducted in a newly planted pecan orchard evaluated the effectiveness of either 35 or 70 milliliters (ml) per tree Zn-EDTA (liquid formulation containing 9% zinc) placed directly in the planting hole on the planting date (Table 1). These trees did not receive foliar zinc applications. The one-time application of 70 ml ZnEDTA elevated leaf zinc levels and largely eliminated zinc deficiency symptoms for three seasons after the planting date. This method of fertilization provided adequate zinc nutrition for early tree growth and is recommended for planting in calcareous soils, particularly

Table 1. Leaf Zn concentrations (ppm) and Zn deficiency symptom ratings (1 = severe deficiency; 5 = no deficiency symptoms) in young 'Wichita' pecan trees following application of ZnEDTA at the time of planting on January 3, 2009. Numbers within each row are statistically different if followed by different letters.

	Date	Untreated Control	35 ml/tree ZnEDTA	70 ml/tree ZnEDTA
Leaf Zn concentration	9/24/2009	26.7 b	33.0 b	56.3 a
	7/29/2010	14.7 b	23.8 ab	28.7 a
	8/1/2011	20.5	23.5	22.9
Zn deficiency symptoms	7/29/2010	3.4 b	4.5 ab	5.0 a
	8/1/2011	2.7 c	3.6 b	4.5 a

[2] A chelate is a claw-shaped molecule of either natural or synthetic origin that binds to a metal ion and can protect it from reacting with its environment.

with cultivars susceptible to zinc deficiency. Caution is advised with application rates higher than those tested, as EDTA can have phytotoxic effects at high levels.

Fertigating young orchards

We evaluated the effectiveness of Zn-EDTA injected into irrigation water in a field study started on newly planted 'Wichita' and 'Western' trees. Our study compared annual applications of 0, 2, or 4 pounds per acre of zinc (0, 2, or 4 gallons per acre of 9% ZnEDTA) split among irrigation events during the early part of the growing season. These trees never received zinc spray applications. Both the 2 and 4 pound per acre zinc application significantly increased zinc concentration in the leaf, and eliminated most zinc deficiency symptoms (Table 2). Growth of trunk diameter was also greater in trees fertigated with Zn-EDTA than non-fertigated trees. Research to date suggests that fertigation timing is not critical, and that zinc-amended soil can provide a steady source of zinc between applications, although fertigation timing has not been investigated.

Fertigating mature trees

Fertigating mature pecan trees with Zn-EDTA has not been adequately studied to establish optimal rates or application timing recommendations. It is apparent that as tree demand increases, and irrigated wetting area is expanded, zinc application rate must be increased. We have applied as much as 16 lb/ac of zinc as Zn-EDTA without causing noticeable damage to trees. Currently, growers with 5 to 15 year old trees are achieving satisfactory results fertigating with Zn-EDTA at rates of 6 to 8 lb/ac of zinc split in multiple applications. The first application is made at bud break and subsequent

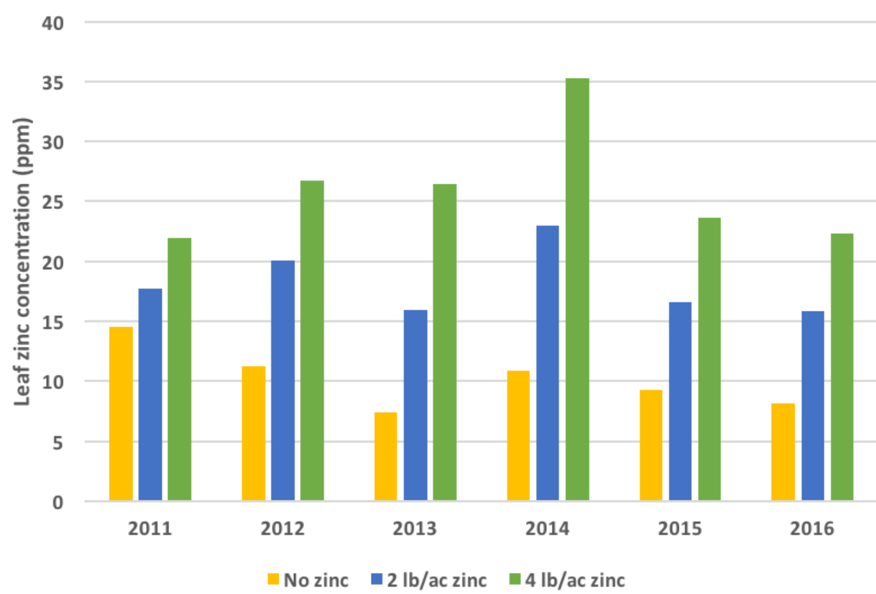

Figure 4. Leaf Zn concentrations (ppm) in young pecan trees ('Wichita' and 'Western Schley' trees combined) resulting from fertigation with 9% ZnEDTA at rates of 0, 2, or 4 lb/ac Zn.

Table 2. Zinc deficiency symptom ratings (1 = severe deficiency; 5 = no deficiency symptoms) in young pecan trees ('Wichita' and 'Western Schley' trees combined) in response to fertigated ZnEDTA. Numbers within each row are statistically different if followed by different letters.

Date	0 lb/ac	2 lb/ac	4 lb/ac
2012	3.88 b	4.39 a	4.33 a
2013	3.28 b	4.90 a	4.95 a
2014	2.89 b	4.97 a	4.96 a

applications applied monthly, or with each irrigation, depending on grower preference. Both appear to provide adequate zinc nutrition.

Leaf sampling, analysis, and interpretation

It is highly recommended to annually collect leaf tissue for nutrient analyses. The recommended sampling procedure for pecans is to sample the middle pair of leaflets from the compound leaf in the middle of the current season's shoot (Figure 5) in late July or early August. Collect leaflets from all sides of the tree that are exposed to sunlight. If possible, avoid sampling leaflets with wind or insect damage, evidence of disease, or other abnormalities. For routine leaf sampling, collect leaflets from each 10-acre or smaller orchard block for analysis as a separate sample. Collect a minimum of 60 leaflets per block, sampling from representative trees over the entire area.

Spray residues on leaf surfaces caused by foliar fertilizer applications can give false nutrient concentration readings unless the leaves are thoroughly washed. If leaflets have been sprayed in the current season with foliar micronutrient fertilizers, external fertilizer residues should be removed by washing leaflets with 0.1% hydrochloric acid solution in distilled water, then rinsing three times with distilled water. In orchards where there have been no foliar micronutrient sprays in the current season, leaflets may be simply washed in tap water and a small amount of phosphate-free detergent and then rinsed three times with distilled water. Your analytical laboratory may prefer that you send them unwashed, fresh, undried leaves that they will wash and process. Before collecting leaf samples, consult with your analytical laboratory for their specific sample handling instructions.

If you are going to send dried leaf tissue to the laboratory, once the leaflets have been washed, blot them dry, place them in an open perforated paper bag (to allow air flow), and air-dry them at room temperature. Put the dry leaf samples in fully labeled (date, orchard name, sample number) paper bags, seal, ship to the analytical laboratory for nutrient analysis. See publication AZ1111 – *Laboratories Conducting Soil, Plant, Feed, or Water Testing* for a listing of local laboratories.

Although foliar zinc concentrations increased and zinc deficiency symptoms were largely eliminated in our Zn-EDTA fertigation studies, foliar zinc remained below frequently cited sufficiency levels of 40 to 50 ppm. Rates of photosynthesis, the process by which plants convert solar energy into sugars,

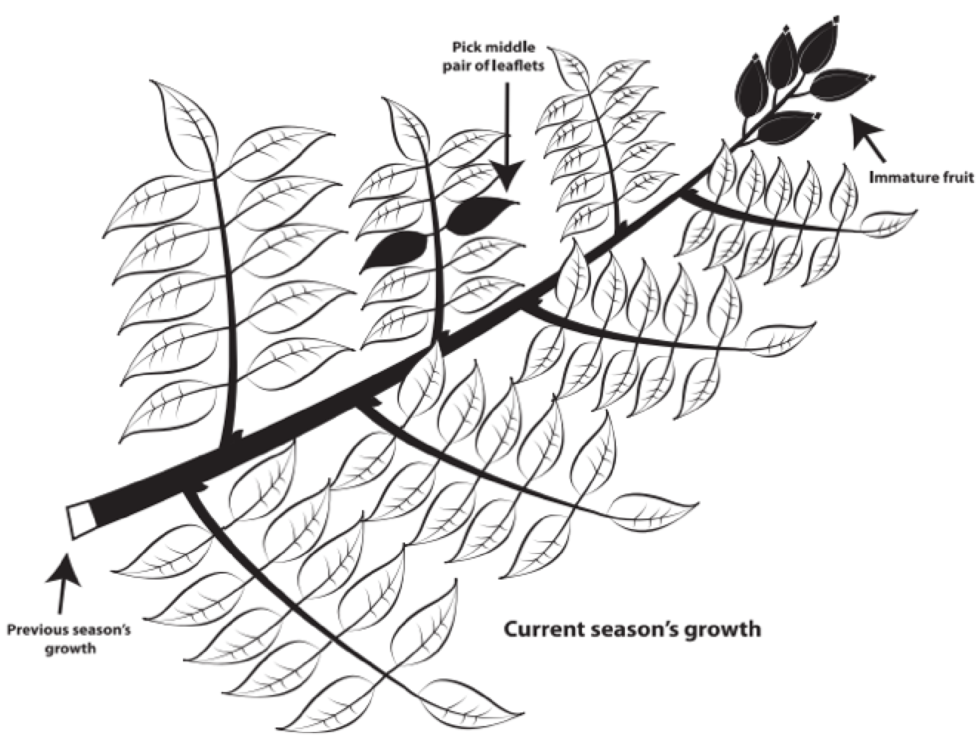

Figure 5. Recommended location to collect leaflet samples for tissue nutrient analysis (from Heerema, 2013).

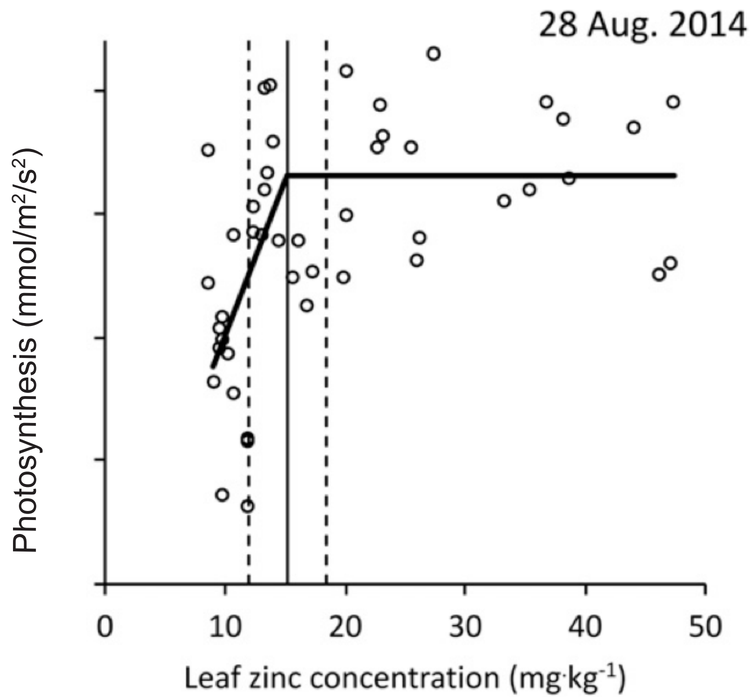

Figure 6. Photosynthesis rates of 'Wichita' pecan under varying levels of zinc deficiency stress.

Table 3. Interpretation for leaf zinc analyses.

	Deficient	Adequate	High
Leaf Zn concentration	< 30 ppm	30 to 100 ppm	> 100 ppm

starches, and other plant building blocks discussed earlier, were measured on individual trees that fertigated with varying rates Zn-EDTA.

Photosynthesis was reduced under zinc deficiency stress when leaf zinc concentrations were below 15 ppm (Figure 6; Heerema et al., 2017). The rate of photosynthesis increased along with leaf zinc concentration, reached a maximum when leaf zinc was approximately 15 ppm, and did not increase further at higher leaf zinc levels. This corresponds well with our observations of visual zinc deficiency symptoms and can be considered an acceptable minimum level for foliar zinc for a single tree. Because zinc levels vary from tree to tree within an orchard block, a higher minimum should be applied to whole orchard blocks. We believe that 30 ppm is a safe minimum 'orchard-level' leaf zinc concentration (Table 3). Although the 'adequate' range extends to 100 ppm, problems associated with foliar pecan zinc levels exceeding this have not been reported.

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