Soil-applied ZnEDTA: Vegetative Growth, Nut Production, and Nutrient Acquisition of Immature Pecan Trees Grown in an Alkaline, Calcareous Soil

James L. Walworth¹, Scott A. White, and Mary J. Comeau
Department of Soil, Water and Environmental Science, University of Arizona, 1177 East 4th Street, Tucson, AZ 85721

Richard J. Heerema
New Mexico State University, Extension Plant Sciences, MSC 3AE Box 30003, Las Cruces, NM 88003

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Abstract. A field study was conducted to evaluate efficacy of soil-applied zinc (Zn) fertilizer on young pecan [Carya illinoinensis (Wangenh.) K. Koch] trees growing in alkaline, calcareous soils. Chelated Zn ethylenediaminetetraacetic acid (ZnEDTA) was applied at rates of 0, 2.2, or 4.4 kg·ha⁻¹ of Zn via injection into irrigation water (fertilization) in microsprinkler irrigated ‘Western’ and ‘Wichita’ trees. Over the 5-year duration of the study, leaf Zn levels were increased from 22 to 35 μg·g⁻¹ in the highest rate of ZnEDTA treatment compared with 7 to 14 μg·g⁻¹ in unfertilized trees. Zn concentrations in shoot and root tissues were also elevated in Zn-treated trees. Zn treatments largely eliminated visible Zn deficiency symptoms, and increased trunk diameter growth compared with untreated trees. Nut yield (in the third through fifth seasons) were also increased as a result of Zn fertilization. No additional benefit in terms of trunk diameter growth or nut yield was observed by adding a higher rate of Zn (4.4 kg·ha⁻¹) vs. the lower rate (2.2 kg·ha⁻¹). ‘Western’ and ‘Wichita’ trees responded similarly to Zn fertilization.

Pecan (C. illinoinensis) is the major tree nut crop grown in the desert southwestern states of Arizona, New Mexico, and Texas. Growing conditions vary throughout this region; however, the soils are generally calcareous, with pH levels of 8.0 or above. Pecan trees growing in these soils are prone to Zn deficiency due to limited soil Zn availability (Alloway, 2008; Malstrom and Fenn, 1981; Smith et al., 1980). Fenn et al. (1990) reported that water extractable Zn in a South Texas soil decreased from 394 to 12 μg·g⁻¹ as soil pH increased from pH 4 to 8. Muhammad et al. (2006) found that the majority of Zn in calcareous soils is sorbed to calcium (Ca) carbonate.

Rosetting, a characteristic visual symptom of Zn-deficient pecan trees, occurs when leaf and internode size are reduced. Severe deficiency symptoms also include interveinal chlorosis, eventually developing into necrosis. Terminal growth dieback can occur in severe cases. Zn deficiency can reduce catkin length, number of fruits per shoot, fruit development, and when severe, it can inhibit production of inflorescences (Hu and Sparks, 1990, 1991). Published literature suggests that pecan leaf Zn concentrations should be greater than 40 to 50 μg·g⁻¹ to avoid deficiency (Payne and Sparks, 1982; Pond et al., 2006; Reuters and Robinson, 1997; Sparks, 1993, 1994). Foliar application of Zn solutions directly onto tree foliage is the standard method for supplying this nutrient to pecan trees. Foliar Zn sprays can reliably increase leaf Zn levels over threshold levels of 50 μg·g⁻¹, but this method has several disadvantages. Foliar application is time consuming, requires investment in expensive equipment which requires fuel, and spray schedules may conflict with other management practices in the orchard (mainly with irrigation). Achieving adequate coverage via foliar application is difficult and only leaves actually contacted by spray are affected by foliar treatments (Wadsworth, 1970). Storey et al. (1971) noted that only 0.2% and 1.0% of applied Zn was absorbed by mature and young leaves, respectively. Additionally, repeated applications are required during the growing season as a result of low mobility of sprayed Zn within the tree (Grauke et al., 1982; Wadsworth, 1970). For these reasons, there is considerable interest among pecan producers in the potential of soil-applied Zn.

Soil application of Zn has been successful in the acidic soils of the southeastern United States (Sparks, 1976; Wood, 2007), but is much less likely to be effective in alkaline, and particularly, calcareous soils. Storey et al. (1971) found that a soil application of 126 kg/tree of zinc sulfate (ZnSO₄) was needed to provide adequate nutrition to mature pecans growing in a calcareous Texas soil. Soluble Zn compounds such as ZnSO₄ applied to alkaline soil react with hydroxyls and carbonates in alkaline and calcareous soils forming compounds of low solubility, limiting its plant availability (Agbenin, 2003; Essington, 2003; Lindsay, 1972, 1979; Sadiq, 1991; Udo et al., 1970). Smith (1934) reported that to correct rosette symptoms on pecan in an “aluvial silt loam soil high in lime” in Uvalde, Texas, a ZnSO₄ rate of 1.8 to 2.3 kg/tree (applied in a trench 60 to 75 cm from the trunk) was necessary. An application of 91 kg/tree of ZnSO₄ failed to bring soil Zn content to a critical level in a study by Lott (1938) because the Zn was converted to insoluble Zn carbonate.

Using Zn in combination with sulfuric acid (H₂SO₄) to fertilize pecans growing in alkaline soils was evaluated by acidifying a shallow trench making up less than 1% of the effective root zone of mature Texas pecan trees and applying a mixture of 9 kg ZnSO₄ and 113 L of 36% H₂SO₄ per tree (Fenn et al., 1990). Leaf Zn did not change in the first 3 years, but 4 years after application, leaves of treated trees contained 54 μg·g⁻¹ Zn vs. 39 μg·g⁻¹ in the untreated control. After 9 years, leaf Zn levels were 58 and 45 μg·g⁻¹ for treated and untreated trees, respectively, and 56 μg·g⁻¹ in trees receiving ZnSO₄ alone. Soil pH was decreased to a depth of 60 cm; however, roots did not grow into the acidified soil, proliferating instead at the interface of the acidified and calcareous soil.

Chelated Zn fertilizers, such as those made with EDTA, can alter the soil mobility of Zn and more effectively increase levels of bioavailable Zn compared with inorganic Zn fertilizers (Alvarez, 1997). Chelated Zn is less subject to soil fixation reactions (Norvell, 1991). Naik and Das (2010) showed that ZnEDTA was more effective than ZnSO₄ at keeping Zn in solution and Alvarez et al. (1997) found that compared with unamended soil, amendment with ZnEDTA increased soil Zn bioavailability to plants. In an alkaline, calcareous Arizona soil Núñez-Moreno et al. (2009) found that soil-banded application of ZnEDTA (19 kg·ha⁻¹ of Zn) resulted in significant pecan leaflet Zn concentration differences 1, 3, 4, 18, and 30 months after application, but that banded ZnSO₄ (74 kg·ha⁻¹ of Zn) did not.

In a field demonstration study in Texas in 1974, ZnEDTA was applied to pecans through a drip irrigation system at annual rates of 0.8, 1.6, and 2.5 kg·ha⁻¹ of Zn (Lindsey and Condra, unpublished data). Resulting leaf Zn levels were 39, 53, and 68 μg·g⁻¹, respectively. In 1975, the corresponding leaf Zn levels were 49, 54, and 70 μg·g⁻¹, respectively. These data suggest that drip irrigation-applied ZnEDTA increased leaf Zn concentrations; however, no unfertilized controls were included, treatments were not replicated, and the data were not statistically analyzed.
Zn fertilizer placement is also critical. Zinc oxide (ZnO) and ZnSO₄ were broadcast on a limed Georgia soil with a pH of 7.3 in the top 2.5 cm and 6.2 in the 2.5 cm below (Wood and Payne, 1997). A single application of 160 kg·ha⁻¹ of Zn supplied by either ZnO or ZnSO₄ increased leaf tissue Zn above 50 µg·g⁻¹ in the 2nd year after application if the Zn was disked into the soil and in the 4th year if it was not incorporated.

The purpose of this study was to evaluate the efficacy of applying ZnEDTA dissolved in irrigation water to immature pecan trees growing in an alkaline calcareous soil. This study reports on Zn uptake and plant growth response to fertigated ZnEDTA.

Materials and Methods

Study site and Zn treatments. A field study was conducted in a commercial pecan orchard in San Simon, AZ (32°15′20.2″N; 109°10′29.8″W; elevation 1118 m). The climate is semiarid with an average of <300-mm precipitation annually. The soil in the orchard is a Guest silty clay loam (fine, mixed, superactive, calcareous, and thermic Ustert Torrifluvents), with pH of 8.1; soil test values at initiation of the study are shown in Table 1.

The main cultivar in orchard block used for this study was ‘Wichita’ budded onto an open-pollinated seedling ‘Ideal’ (syn. ‘Bradley’) rootstock with 25% ‘Western’ (syn. ‘Western Schley’) pollenizers, also on ‘Ideal’ rootstock with 25% ‘Western’ (syn. ‘Western Schley’). This orchard had been fertilized with a 16N-3.5P-2.5K-4S fertilizer injected into the irrigation system (247, 247, 493, 740, and 1232 kg·ha⁻¹ over 3 years, 2011, 2012, 2013, 2014, and 2015, respectively).

Beginning in 2011 when trees were planted, treatments of ZnEDTA fertilizer (Sequestar 9% Zn Chelate; Monterey Ag Resources, Fresno, CA) were applied by injection through the orchard microsprinkler irrigation system at one of three rates: 0 (control), 2.2, or 4.4 kg·ha⁻¹·yr⁻¹ of actual Zn. Applications were split among irrigation dates (Table 2). No foliar Zn applications were made. The study was randomized complete block design with four blocks and main plots split into two varieties (‘Wichita’ and ‘Western’).

Soil and leaf analysis. Soil cores were collected on 25 June 2013 and separated into 0 to 30 cm, 30 to 60 cm, and 60 to 90-cm depth fractions from the 4.4 kg·ha⁻¹ treatment only. Cores were located 60, 120, and 240 cm from the trunks of four trees. Zn, copper (Cu), iron (Fe), manganese (Mn), and nickel (Ni) were extracted with diethylenetriaminepentaacetic acid-triethanolamine (DTPA-TEA) (Lindsay and Norvell, 1978) and analyzed with a ThermoFisher iCAP 7000 ICP-OES (Thermo Fisher Scientific Inc., Waltham, MA). In 2011, leaves from ‘Western’ and ‘Wichita’ were combined to represent a representative foliage sample from the newly transplanted young trees. In subsequent years trees were large enough to sample leaves of cultivars separately. Each year at least 40 leaflets were collected per treatment according to the methods recommended by the University of Arizona and New Mexico State University Extension Services (Heerema, 2013; Walworth and Pond, 2006). First year (2011) sampling was delayed until the end of the growing season (24 Sept.) to avoid damage to the young trees. Other sampling dates were 14 Aug. 2012, 11 July 2013, 24 July 2014, and 3 Aug. 2015.

Leaflet samples were first washed in a water bath with a phosphorus (P)-free detergent (0.05% detergent), followed by two rinses in deionized water and a rinse in dilute hydrochloric acid (1% HCl), and finally one additional rinse with ultrapure water. Leaflets were spun to remove excess water, then dried in an oven for 3 d at 65 °C, and mechanically ground to a 20-mesh particle size.

Root and dormant shoot tissues were collected on 21 Jan. 2015 and 15 Jan. 2016. One to four root sections and six shoot segments (previous-season growth only), each ≈1 cm in diameter were collected from each of four ‘Wichita’ trees in each plot. These were handled and analyzed for Zn concentration using the procedure for leaflet samples. Tissue samples were dry ashed in a muffle furnace by placing 0.5 g aliquots into 30-mL porcelain crucibles, ramping the temperature to 500 °C over 3.5 h, and maintaining the temperature for 5.5 h. Cooled ash was dissolved in 10 mL of 2.0 N HCl, allowed to sit for several hours, diluted to 50 mL with H₂O and allowed to sit overnight (Jones and Case, 1990).

Table 1. Soil test levels before field study initiation.

| Soil test | Method | Result | Rating |
|-----------|--------|--------|--------|
| pH | 1:1 soil:water | 8.1 | High |
| EC | 0.49 dS·m⁻¹ | Low |
| Calcium | NH₄NO₃ (pH 8.5) | 3200 mg·kg⁻¹ | Very high |
| Magnesium | NH₄NO₃ (pH 8.5) | 140 mg·kg⁻¹ | High |
| Sodium | NH₄NO₃ (pH 8.5) | 66 mg·kg⁻¹ | Medium |
| Zinc | DTPA | 380 mg·kg⁻¹ | High |
| Iron | DTPA | 0.39 mg·kg⁻¹ | Low |
| Manganese | DTPA | 11 mg·kg⁻¹ | High |
| Copper | DTPA | 0.83 mg·kg⁻¹ | High |
| Nickel | DTPA | 0.14 mg·kg⁻¹ | No standards available |
| Nitrate-N | Cd reduction | 23 mg·kg⁻¹ | Medium |
| Phosphate-P | Olsen | 7.9 mg·kg⁻¹ | Low |
| Sulfate-S | Hot water | 18 mg·kg⁻¹ | High |
| Boron | Hot water | 0.37 mg·kg⁻¹ | Medium |
| Free lime | Acid test | High |
| ESP | Calculated | 1.6% |
| CEC | Calculated | 18.4 cmol, kg⁻¹ |

Zn concentration was analyzed with a PerkinElmer 3100 Atomic Absorption Spectrophotometer (PerkinElmer, Waltham, MA) at a wavelength of 213.86 nm. Complete nutrient analyses were conducted on leaflets collected on 14 Aug. 2012, 11 July 2013, 23 July 2014, and 3 Aug. 2015. Samples were analyzed for N by combustion using a Leco® TruSpec (Leco Corp., Saint Joseph, MI). Following digestion with nitric acid/hydrogen peroxide, samples were analyzed for potassium, P, Ca, Mg, sulfur, boron, Cu, Mn, Ni, and Zn using a ThermoFisher iCAP 7000 ICP-OES (Thermo Fisher Scientific Inc.).

Trunk diameters were measured with a caliper at 45 cm above the ground in both northsouth and eastwest directions. The two directions were averaged to obtain trunk diameters. Measurements were made on 11 May 2011, 26 Sept. 2011, 9 Oct. 2012, 28 Sept. 2013, 11 Jan. 2015, and 4 Dec. 2015. Differences between measurements were used to estimate annual tree growth.

Visual ratings of severity of Zn deficiency symptoms were made using a scale of one to five, where five represented trees with no visible symptoms, and one represented trees with severe symptoms including limb dieback.
Visual ratings were conducted on 21 Aug. 2012, 19 July 2013, and 24 July 2014.

Nuts were harvested manually on 21 Nov. 2013, 24 Nov. 2014, and 19 Nov. 2015. Nuts were graded to determine percentages of nuts with vivipary, and shelled to determine relative weights of kernels and shells. Kernel Zn concentration was determined using the methods described above for leaf tissue.

Analyses of variance were conducted using a split-plot analysis where Zn treatments were the main plots and variety the split plots, except where data were collected from just one variety (e.g., stem and root samples) or from both varieties combined (leaf samples in 2011). In those cases, data were analyzed as a randomized complete block. Means were separated using least significant difference (LSD, $\alpha = 0.05$).

Results

Soil samples collected from the 4.4 kg·ha$^{-1}$ treatment in 2013, during the third season of ZnEDTA fertigation, show that available Zn levels were above background levels (indicated by samples collected 240 cm from the tree trunks, located well outside the fertigated zone; Table 3). Surface (0 to 30 cm) soil nearest the tree contained 5.65 μg·g$^{-1}$ of Zn.

Table 3. DTPA-TEA extractable soil zinc (Zn) (μg·g$^{-1}$) on 25 June 2013 in plots fertigated with 4.4 kg·ha$^{-1}$ of Zn.

| Soil depth | Distance from tree trunk | 60 cm | 120 cm | 240 cm |
|------------|--------------------------|-------|--------|--------|
| 0–30 cm    | 5.65                     | 2.06  | 0.70   |
| 30–60 cm   | 4.53                     | 1.32  | 0.44   |
| 60–90 cm   | 3.95                     | 1.23  | 0.42   |
| LSD$_{0.05}$ |                          | 2.03  |        |

LSD = least significant difference.

Fig. 1. Average leaf zinc (Zn) concentration of ‘Wichita’ and ‘Western’ pecan trees fertigated with varying levels of Zn. Mean totals with a common letter within each year are not different ($\alpha = 0.05$) by analyses of variance least significant difference.

In contrast to foliar Zn concentrations, Zn deficiency symptoms were significantly more severe in untreated ‘Wichita’ than untreated ‘Western’ in both 2012 and 2013 (Table 4). In 2014, the cultivar × Zn treatment was not significant. By 2013, the second season of the study, Zn fertigation nearly eliminated visible deficiency symptoms (only some slight symptoms remained) in both ‘Western’ and ‘Wichita’, although even the highest treatment level did not result in leaf Zn concentrations above suggested minimum sufficiency levels of 40 to 50 μg·g$^{-1}$. By 2014, differences in Zn deficiency symptom severity between varieties were no longer apparent. Application of either 2.2 or 4.4 kg·ha$^{-1}$ eliminated most deficiency symptoms (Tables 4 and 5).

Shoot, root, and kernel Zn concentrations, measured only on ‘Wichita’ trees, closely mirrored leaf Zn concentrations (Table 6). Shoot, root, and kernel Zn concentrations in untreated trees were 14.92, 16.99, and 25.96 μg·g$^{-1}$, respectively, in 2014 and 12.95, 24.53, and 10.09 μg·g$^{-1}$ in 2015. In trees treated with 4.4 kg·ha$^{-1}$ of Zn the corresponding levels were 35.08, 44.01, and 43.40 μg·g$^{-1}$ in 2014 and 29.57, 45.26, and 31.91 μg·g$^{-1}$ in 2015. In contrast to foliar application where tissue Zn is elevated only in close proximity to Zn solution droplets (Wadsworth, 1970), fertigation with chelated Zn increased Zn concentrations in all plant parts tested.

Leaf concentrations of nutrients other than Zn were generally inconsistent, and few effects of Zn application or pecan variety were observed over all years in which complete leaf analyses were conducted (data not shown). There were, however, two notable exceptions. In 2012, 2013, 2014, and 2015,
Fertilization with ZnEDTA reduced foliar Ca and Mg concentrations (Table 7). The leaf Ca concentrations were within or above the adequate concentration range for pecans (Heerema, 2013). Magnesium concentrations; however, fell below the adequate concentration range of 3.0 to 6.0 mg·g⁻¹ in the trees fertilized with the higher rate of ZnEDTA, although no visible symptoms of Mg deficiency were observed. In 3 of the 4 years, foliar Ni levels also declined in trees fertilized with ZnEDTA.

Table 7. Foliar calcium (g·kg⁻¹), magnesium (g·kg⁻¹), and nickel (µg·g⁻¹) concentrations in ‘Western’ and ‘Wichita’ pecans combined resulting from various levels of fertigation with zinc (Zn) ethylenediaminetetraacetic acid.

| Zn treatment level | Ca  | Mg  | Ni  |
|--------------------|-----|-----|-----|
| 0 kg·ha⁻¹         | 22.0| 3.5 | 3.0 |
| 2.2 kg·ha⁻¹       | 21.8| 3.1 | 3.0 |
| 4.4 kg·ha⁻¹       | 22.8| 3.5 | 1.91|
| LSD0.05            | 1.6 | 0.5 | NS  |

Table 4. Visual rating of zinc (Zn) deficiency symptoms (5 = no symptoms; 1 = severe symptoms) of ‘Western’ and ‘Wichita’ pecan trees fertigated with various rates of Zn ethylenediaminetetraacetic acid.

| Yr   | Zn treatment level | Western | Wichita |
|------|--------------------|---------|---------|
| 2012 | 0 kg·ha⁻¹          | 4.10    | 3.65    |
| 2013 | 2.2 kg·ha⁻¹        | 4.40    | 4.38    |
| 2014 | 4.4 kg·ha⁻¹        | 4.30    | 4.35    |
| LSD0.05 |                 | 0.24    | 0.17    |

Table 5. Average visual rating of zinc (Zn) deficiency symptoms (5 = no symptoms; 1 = severe symptoms) of ‘Western’ and ‘Wichita’ pecan trees fertigated with various rates of Zn ethylenediaminetetraacetic acid.

| Yr   | Zn treatment level | Western | Wichita |
|------|--------------------|---------|---------|
| 2012 | 0 kg·ha⁻¹          | 3.88    | 3.65    |
| 2013 | 2.2 kg·ha⁻¹        | 4.39    | 4.33    |
| 2014 | 4.4 kg·ha⁻¹        | 4.35    | 4.33    |
| LSD0.05 |                 | 0.17    | 0.21    |

Table 6. Zinc (Zn) concentrations (µg·g⁻¹) of ‘Wichita’ shoots, roots sampled in the dormant season, and harvested nut kernels in trees fertigated with ZnEDTA.

| Zn treatment level | Plant part       | 2012 | 2013 | 2014 | 2015 |
|--------------------|------------------|------|------|------|------|
| 0 kg·ha⁻¹          | Shoot            | 14.92| 16.99| 25.96|      |
| 2.2 kg·ha⁻¹        | Root             | 25.32| 24.71| 37.73|      |
| 4.4 kg·ha⁻¹        | Kernel           | 35.08| 44.01| 43.40|      |
| LSD0.05            |                  | 10.70| 10.81| 11.07|      |

Discussion

In pecan orchards irrigated with pressurized irrigation systems, nutrient application via fertigation is being adopted. The industry standard for treating Zn deficiency in pecans growing in calcareous soils has been through the use of foliar sprays; however, the research described here shows that chelated Zn fertigation can be effective for young trees. Fertilization of 4.4 kg·ha⁻¹ of Zn in the form of ZnEDTA raised levels of available soil Zn from a low to an adequate range, while increasing leaf, stem, root, and nut kernel Zn concentrations. Plant responses were already measurable and significant in the first year of Zn application. Leaf tissue Zn concentrations were not raised to the 40 or 50 µg·g⁻¹ frequently cited as a minimum sufficiency level, but reached 22 to 35 µg·g⁻¹ with the higher Zn application rate tested (4.4 kg·ha⁻¹) and eliminated most visible deficiency symptoms. In 2015, leaf tissue Zn levels declined from those observed in 2014, even though application rates were not decreased, perhaps suggesting that tree Zn was diluted in a larger biomass as the trees grew larger or that the tree crop load was beginning to compete for Zn with the foliage. In contrast to leaf tissue Zn applications, fertigated ZnEDTA elevated Zn levels of all plant tissues, suggesting that this application method could positively impact root growth and function; however, this was not measured in the current study.

Growth of trees, measured by change in trunk diameter, was increased by application of fertigated ZnEDTA, as were nut yields of both ‘Western’ and ‘Wichita’ trees. Although leaf Zn concentrations were greater in trees fertilized with 4.4 kg·ha⁻¹ than in those receiving 2.2 kg·ha⁻¹ of Zn, neither trunk diameter growth nor nut yield increased along with the elevated leaf Zn concentrations. Trunk diameter growth and nut yield were actually numerically lower in trees receiving 4.4 kg·ha⁻¹ vs. 2.2 kg·ha⁻¹ of Zn, although differences were not statistically significant. Top growth and nut yields were associated with leaf Zn concentrations ranging from 16 to 23 µg·g⁻¹, suggesting that current sufficiency levels may be higher than necessary for immature pecan trees. However, ZnEDTA application reduced leaf Mg concentrations below the sufficiency levels for that nutrient and, although no Mg deficiency symptoms were noted, low Mg concentrations resulting from ZnEDTA application could adversely impact pecan growth and yield. No explanation is offered for this phenomenon. Nutrient dilution as a result of accelerated plant growth was not noted for nutrients other than Ca, Mg, and, perhaps Ni, so this is not a likely explanation. Neither Ca nor Mg form strong bonds with EDTA and, if they did, one would expect increased rather than decreased plant uptake. This interaction warrants additional investigation.

Our data show that soil application of ZnEDTA by fertigation may be a commercially acceptable alternative to foliar Zn spray applications in immature pecan orchards with alkaline and calcareous soils. Nevertheless, additional research is needed. Information about nut yield and quality effects of ZnEDTA application by fertigation.
Table 8. Annual and cumulative trunk diameter (mm) growth of ‘Western’ and ‘Wichita’ pecans.

| Variety | 2012 | 2013 | 2014 | 2015 | 2012–15 |
|---------|------|------|------|------|---------|
| ‘Western’ | 12.92 | 21.24 | 17.70 | 24.90 | 76.75 |
| ‘Wichita’ | 9.20 | 18.10 | 12.94 | 19.99 | 60.22 |

LSD0.05 = least significant difference.

Table 9. Average annual and cumulative trunk caliper growth (mm) of ‘Western’ and ‘Wichita’ pecans combined.

| Zinc treatment level | Yr(s) |
|----------------------|-------|
|                      | 2012  | 2013  | 2014  | 2015  | 2012–15 |
| 0 kg ha⁻¹            | 10.38 | 18.09 | 13.48 | 19.49 | 61.42   |
| 2.2 kg ha⁻¹          | 12.24 | 20.80 | 16.40 | 24.08 | 73.52   |
| 4.4 kg ha⁻¹          | 10.57 | 20.12 | 16.07 | 23.76 | 70.51   |
| LSD0.05              | 2.61  | 2.54  | 1.90  | 7.37  |

LSD = least significant difference.

Table 10. In-shell nut yield (kg ha⁻¹) of ‘Western’ and ‘Wichita’ pecans fertigated with zinc (Zn).

| Year | Zinc treatment level | Yr(s) |
|------|---------------------|-------|
|      | 2012 | 2013 | 2014  |
|      | Western |      |      |
| 0 kg ha⁻¹ | 0.0  | 68.3 | 155.9 |
| 2.2 kg ha⁻¹ | 0.0  | 96.5 | 554.1 |
| 4.4 kg ha⁻¹ | 0.0  | 67.7 | 338.7 |
| LSD      | 7.7  | NS   | NS    |

NS = not significant (α = 0.05).

Table 11. Combined average in-shell nut yield (kg ha⁻¹) of ‘Western’ and ‘Wichita’ pecans fertigated with zinc (Zn).

| Year | Zinc treatment level | Yr(s) |
|------|---------------------|-------|
|      | 2013 | 2014 | 2015 |
| 0 kg ha⁻¹ | 9.0  | 51.3 | 123.4 |
| 2.2 kg ha⁻¹ | 19.8 | 103.0 | 475.3 |
| 4.4 kg ha⁻¹ | 14.0 | 81.2 | 330.9 |
| LSD0.05 | 5.5  | 25.5 | 99.9 |

LSD = least significant difference.

in more mature pecan orchards with alkaline soils, especially, in comparison with the standard foliar Zn applications, is of particular interest. Furthermore, there remain several important unanswered questions regarding soil application of other Zn chelates, other soil-application techniques, and effects of timing and placement of soil-applied ZnEDTA fertilizers.

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