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Comparison of ZnO and $ZnSO_4$ for Correcting Severe Foliar Zinc Deficiency in Pecan

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Abstract. **Ground applications of ZnO to large mature pecan [*Carya illinoinensis* (Wangenh.) K. Koch] trees in orchards possessing an acidic soil, but with a culturally induced slightly alkaline soil surface zone, were at least as effective as was $ZnSO_4$ for rapidly correcting severe foliar Zn deficiency, improving in-shell nut production, and maintaining kernel quality. Under such soil conditions, light disking of Zn applied at 160 kg·ha^{-1} from ZnO elevated foliar Zn above the sufficiency level by the second growing season after application; whereas an absence of disking delayed substantial uptake from ZnO until the fourth growing season. ZnO, usually a lower priced Zn source, was as effective as was $ZnSO_4$ for correcting Zn deficiencies via broadcast ground application; however, same season correction of Zn deficiency was best accomplished by the standard practice of using foliar sprays of $ZnSO_4$ rather than by heavy soil applications of either Zn source.**

Crop sensitivity to low soil availability of Zn is a common problem in the southeastern United States, especially on sandy well-drained acid soils and on soils developed from phosphatic rocks (Kubota and Allaway, 1972). Pecan is particularly sensitive to low Zn; thus, deficiency has been a major and common problem throughout much of the southeastern U.S. Pecan Belt (Sparks, 1987; Storey et al., 1971, 1979) since pecan's introduction to the region during the late 19th century (Wood et al., 1990). Zinc deficiency has a major influence on economic returns due to its effect on leaf efficiency, flowering, fruit size, nut yield (Worley et al., 1972), and quality (Hu and Sparks, 1990, 1991). Severe deficiencies are not uncommon and are frequently associated with rosetting of shoots and eventual shoot death (Alben, 1955; Alben et al., 1932; Orton and Rand, 1914).

Zinc problems within the region are controlled by either foliar (predominately for a short-term correction) or soil applications (for long-term correction) of Zn via a variety of sources; however, $ZnSO_4$ (O'Barr, 1989) has been the traditional source. $ZnSO_4$ is usually preferred to ZnO because of its high water solubility (≈865 g·L^{-1} H_2O)—and, therefore, perceived rapid availability to trees (Worley et al., 1972)—and ease of use; ZnO is a generally more economical source per unit of Zn but has low water solubility (≈$1.6 \cdot 10^{-3}$ g·L^{-1} H_2O). The solubility differential is, however, of little practical significance, since much of the ground-applied $ZnSO_4$ is rapidly converted to an oxide (Viets, 1962), thus limiting its availability to the tree and neutralizing a perceived disadvantage over the use of ZnO. An additional potential disadvantage of $ZnSO_4$ is that it acidifies soils and can be a problem in the southeastern United States because soil acidity there is typically undesirably low (pH 5.5 to 6.5 in "A" horizon). A disadvantage of relatively pure ZnO is that it is difficult to evenly spread due to its fine powder-like texture. Studies with a wide variety of Zn-sensitive agronomic and horticultural crops conclude that ZnO is at least as good as $ZnSO_4$ in correcting deficiencies (Murphy and Walsh, 1972). Worley et al. (1972) came to the same conclusion for pecan after comparing the ability of several Zn sources for correcting foliar deficiencies. However, after more than 2 decades, $ZnSO_4$ remains the overwhelmingly used source by the southeastern pecan industry.

The time required to elevate Zn levels after ground application is a problem for pecan growers insofar that [depending upon climate, soil type and pH, method, amount applied, and Zn interactions with other nutrient elements (Lucas and Knezek, 1972; Olsen, 1972)] 3 to 8 years may be required before foliar levels are sufficient (Hunter, 1965; O'Barr, 1989; Payne and Sparks, 1982; Worley et al., 1972). This slow response presents practical problems if mature orchards suddenly exhibit substantial Zn deficiencies, such as feeder roots being killed by winter cold or a decline in uptake due to excessive addition of P or lime (Murphy and Walsh, 1972). Excessive liming can occur in southeastern orchards where growers annually lime without adequate regard to that which is accumulating near the soil surface, hence, elevating pH of the soil surface zone enough to retard Zn uptake. Under these, or other circumstances where Zn uptake is low, it becomes economically important to correct the problem rapidly and prudently.

Efforts to rapidly correct Zn deficiencies in mature southeastern orchards by Payne and Sparks (1982) demonstrated that broadcast ground applications of relatively large amounts (160 kg·ha^{-1}) of $ZnSO_4$ increase foliar Zn levels beyond the sufficiency level (≈50 mg·kg^{-1}) within 1 year of application, whereas lower rates (80 kg·ha^{-1} or less) required 4 or more years. Because ZnO is a more economical source than $ZnSO_4$ and does not possess the acidifying sulfate component, its relative effectiveness for rapidly correcting severe Zn deficiency problems in mature pecan orchards merits investigation. This study assesses the efficacy of correcting severe foliar Zn deficiencies of large pecan trees growing on acidic orchard soils, possessing a slightly alkaline surface zone, by soil application of ZnO or $ZnSO_4$.

Materials and Methods

Efficacy of ZnO and $ZnSO_4$ on acidic soils with an alkaline surface zone. The efficacy of surface broadcast applications of either ZnO or $ZnSO_4$ to rapidly correct severe Zn deficiency in mature pecan trees was evaluated using ≈75-year-old 'Stuart' trees growing under nonirrigated conditions at a 19.5 × 19.5-m spacing on a Faceville fine sandy loam. The genotype of the rootstock is unknown. The orchard possessed a grass sod floor. The pH of the upper 2.5 cm of soil was ≈7.3, a result of excessive liming in previous years, whereas the zone 2.5 to 5 cm in depth was at ≈6.2. Fertilizer (N, P, and K) was added annually, during the study period, as needed, based on Georgia Cooperative Extension Service recommendations, as determined by leaf analysis. Lime was withheld to avoid interference with Zn uptake and because pH was already excessively high in the feeder root zone. It was noted in 1986, the year before study initiation, that most trees in the study orchard exhibited severe Zn deficiency with many displaying dead shoots at the top of the crown. Foliar analysis indicated Zn levels from 4 to 22 mg·kg^{-1} (average of 12 mg·kg^{-1}) in ≈85% of the trees and only 4% with Zn above the 50-mg·kg^{-1} sufficiency level (O'Barr, 1989; Worley and Mullinix, 1993).

The design was a randomized complete block (17 blocks with trees blocked by degree of Zn deficiency) and three Zn treatments (N = 51 trees). Equivalent amounts of elemental Zn from $ZnSO_4$ and ZnO, plus a nontreated control, served as the treatments. Zinc was applied 3 Mar. 1987 at 160 kg·ha^{-1} and was uniformly deposited to the orchard floor beneath the canopy of each tree (≈334 m^2) without cross-contamination of adjacent plots. No Zn was applied in subsequent years. The root system of each tree was effectively enclosed in a square just before Zn application by multiple right angle subsoilings (45 cm deep) midway between trees to minimize cross-feeding by root systems and movement of Zn into adjacent plots. Measured variables for the next 8 years were foliar Zn levels (taken in late July to mid-August), in-shell nut mass, and kernel percentage. Foliar Zn was determined by oven-drying leaflets 72 h at 70 °C; they then were

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ground and analyzed for Zn by DCP (ARI Spectraspan V; Beckman Instruments, Fullerton, Calif.). Data were statistically analyzed by SAS-PC (SAS Institute, 1988). Trees received standard pesticide applications (Crocker, 1986; Ellis et al., 1994) for disease and insect problems throughout the study period.

Methods to accelerate correction of foliar Zn deficiency. The influence of tillage, or disking, on the uptake of Zn from ground-applied ZnO and its comparison with the standard foliar sprays of $ZnSO_4$ was evaluated using Zn-deficient (foliar levels of 10 to 15 mg•kg^{-1}) 75-year-old 'Schley' pecan trees growing under spacing, soil, and management conditions identical to the above study. Fertilization and soil characteristics were also as described above.

The design was a randomized complete block (four blocks with trees blocked by degree of Zn deficiency) with four Zn treatments (N = 16 trees). Treatments were equivalent amounts of Zn from ZnO: 1) plus either light disking, 2) no disking, 3) Zn corrected by foliar applications of $ZnSO_4$ (at 2.2 kg•ha^{-1} plus 4.5 kg•ha^{-1} feed grade urea; four sprays at 3-week intervals, with foliar sprays applied annually) (Ellis et al., 1994), and 4) a nontreated control. Plots were managed, and Zn applied, as described above, on 3 Mar. 1987 at 160 kg•ha^{-1} and lightly disked a few days later. Foliar Zn concentrations in subsequent years were determined as described above.

Results and Discussion

Efficacy of ZnO and $ZnSO_4$ on acidic soils with an alkaline surface zone. Zinc uptake, based on foliar analysis, from either Zn source exhibited a roughly sigmoidal pattern with little uptake until the fourth growing season after application (Fig. 1A). Uptake was evident by the third growing season but averaged only 29 to 37 kg•mg^{-1} in Zn treatments; thus, leaflet Zn levels remained below the usually recommended 50-kg•mg^{-1} sufficiency level until the fourth growing season after application. This delayed response is typical of that observed by others (Alben, 1955; Hunter, 1965; Payne and Sparks, 1982; Worley et al., 1972) and emphasizes the likely need for conjunctive foliar applications of Zn during the year of ground application plus its continued annual application until there is sufficient uptake from the soil. The rate of uptake was very rapid between the third and fourth seasons after application (from ≈33 to ≈142 mg•kg^{-1}) and continued to increase for at least the next 4 years. There was no difference in accumulation between the sulfate and oxide sources. This equivalent uptake from either oxide or sulfate sources is in general agreement with that observed on many agronomic crops (Murphy and Walsh, 1972). There was a slight (≈9 to 22 mg•kg^{-1}) but gradual increase in Zn in the nontreated control, which we assume to have been due to a slight influx of Zn from adjacent treated plots or due to cross-feeding by roots; thus, the cross-ripping of the orchard to retard Zn movement or cross-feeding was largely successful. This observation of little or no cross-feeding is in general agreement with observations of other researchers for Zn and B (Brooks, 1964; Sharpe and Windsor, 1951; Worley et al., 1972).

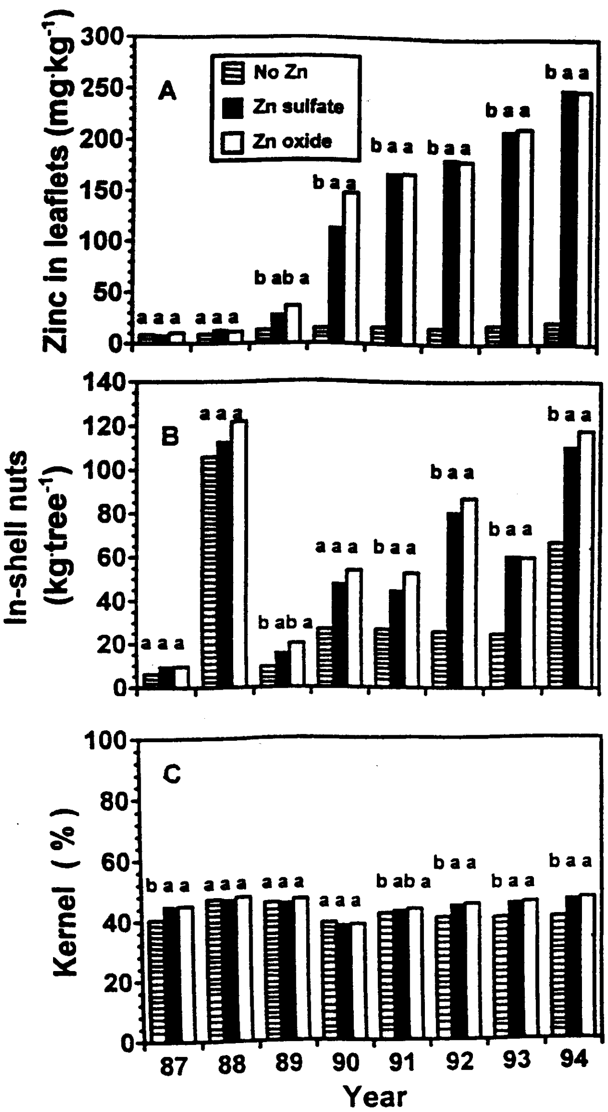

Fig. 1. Efficacy of applying ZnO and $ZnSO_4$ on leaflet Zn concentrations (**A**), in-shell nut production (**B**), and kernel percentage (**C**) of 75-year-old 'Stuart' pecan trees exhibiting severe Zn deficiencies and growing in an acidic soil possessing a slightly alkaline surface zone. Zinc at the rate of 160 kg•ha^{-1} was uniformly broadcast without incorporation to the orchard surface in Mar. 1987. Mean separation within year at $\alpha < 0.05$ level by Duncan's multiple range test.

Zinc-treated trees responded to Zn application to produce more in-shell nuts by the third growing season and produced about twice as much during each of the remaining 5 years of the study (Fig. 1B). There was, however, no evidence that the sulfate source of Zn influenced production any differently than did the oxide source. The yield response of 'Stuart' trees to elevated foliar Zn levels confirms earlier reports (Brooks, 1964; Hu and Sparks, 1990; Worley et al., 1972) that low Zn depresses yields. The percentage of kernel in ripened nuts was not influenced by applied Zn until the fifth growing season after application (Fig. 1C). Average kernel percentage was enhanced (4 to 5 percentage points) by Zn fertilization from the fifth to eighth year, thus substantially influencing economic returns by elevating the amount of kernel per nut and confirming previous observations by Hu and Sparks (1990) that Zn deficiency can suppress kernel mass. Nut volume was not detectably affected by Zn treatments within the period of the study (data not presented).

Movement of Zn into the soil profile was minimal, even after 8 years posttreatment (Fig. 2). Soil Zn levels were greatly increased in the 0- to 2.5-cm zone by fertilization with some increase also occurring in the 2.5- to 5-cm zone; however, there was little or no movement of Zn below 5 cm. This response is typical of that reported for Zn movement in a variety of soils (Murphy and Walsh, 1972).

Methods to accelerate correction of foliar Zn deficiency. Zinc deficiency of 'Schley' pecan trees was corrected by the second growing season after ground application of a large amount of ZnO when the orchard surface was lightly disked, whereas ZnO not disked did not correct the foliar deficiency until the fourth year after application (Fig. 3). Foliar Zn in the

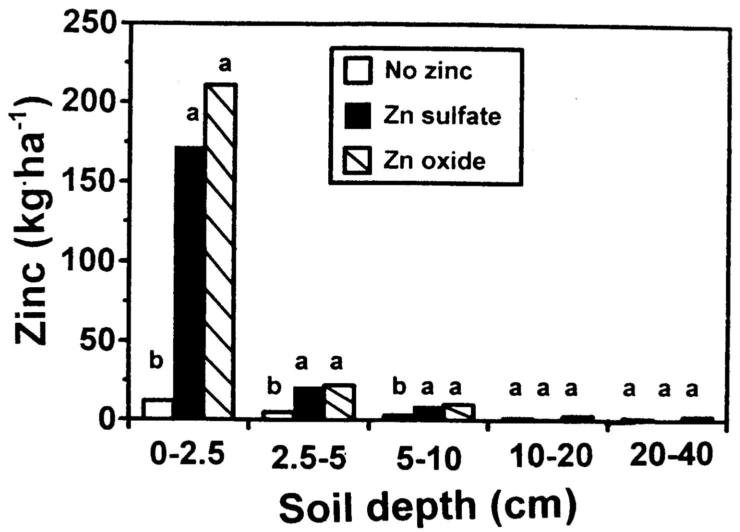

Fig. 2. Distribution of Zn from oxide and sulfate sources through soil profile at 8 years after application. Mean separation within year at $\alpha < 0.05$ level by Duncan's multiple range test.

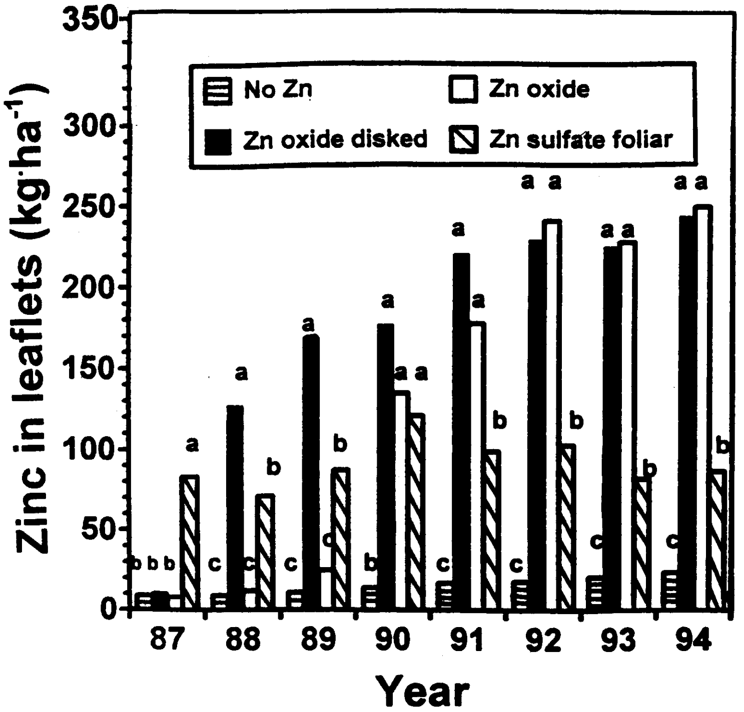

Fig. 3. Efficacy of correcting severe foliar Zn deficiency in mature (75-year-old) 'Schley' pecan trees in a sod-covered orchard possessing an acidic soil with a slightly alkaline surface zone. Trees received Zn via ZnO broadcast, ZnO broadcast plus disking, or $ZnSO_4$ as a foliar spray. Application was Mar. 1987. Mean separation within each year at $\alpha < 0.05$ by Duncan's multiple range test.

nontreated control remained low for the duration of the study, whereas repeated foliar sprays of $ZnSO_4$ corrected deficiencies the first year. While soil applications of Zn are considered the most common and generally successful method of application for many crops (Murphy and Walsh, 1972), these data indicate that if trees in old pecan orchards with well-trafficked, high-pH sod floors are to benefit from Zn fertilization, then light disking at about the time of application is likely necessary. The ability of large amounts of disk-incorporated Zn (160 kg•ha^{-1}), applied as $ZnSO_4$, to quickly correct severe Zn deficiencies of pecan was reported by Payne and Sparks (1982). Similarly, Worley et al. (1972) observed that foliage of mature pecan trees treated annually with Zn at 35 kg•ha^{-1} as either $ZnSO_4$ or ZnO, in conjunction with light disking, appeared to have elevated foliar Zn levels the first growing season after application. However, the concentration was not statistically higher than for the control until the third and fourth year after the initiation of the study. There was no mention of the pH status of the upper soil surface in either of these studies. Hunter (1965) reported that foliar Zn was not enhanced until the third growing season after disk incorporation of $ZnSO_4$ with Zn at 58 kg•ha^{-1}. Our data, therefore, expand upon this previous work to show that large amounts of ground-applied ZnO (160 kg•ha^{-1}) can also quickly correct Zn deficiencies and can do so under field conditions where the soil surface is alkaline, thus indicating ZnO as an alternative to $ZnSO_4$.

Conclusion

These data showed that Zn deficiency of pecan, even severe deficiencies for trees growing in orchards with acidic soils with a slightly alkaline surface zone, can be quickly and effectively corrected by substantial ground applications of ZnO if it is lightly disked into the orchard floor. Failure to incorporate apparently delays the correction of foliar Zn levels until 3 to 4 years after application, even at application rates as high as 160 kg•ha^{-1}. The similar response of Zn levels in trees from either the sulfate or oxide sources indicate that ZnO would be a preferred source over $ZnSO_4$ when price is considered. Cost is currently such that the oxide form is a little less than half as expensive as is the sulfate form [about $0.99 U.S. per kg (assuming 80% Zn but can be less depending on the purity of the source), whereas the sulfate form is $2.20 per kg (Worley, 1995)]. The substantial costs associated with the correction of Zn deficiencies with heavy application of either oxide or sulfate sources suggest that foliar application of $ZnSO_4$, coupled with perhaps relatively low amounts applied via soil incorporation (in the acidic soils of the southeastern United States), are likely to be most practical for the correction of Zn deficiencies. Our data also indicate that oxide or sulfate sources are likely to be equivalent in terms of correcting foliar levels in many soils (Worley, 1995), especially of acidic soils with slightly alkaline surface zones. The acidifying sulfur component of the $ZnSO_4$ had relatively little effect on reducing the pH of the alkaline soil surface zone (pH 7.1 after 8 years), hence, indicating little or no chemical advantage for the use of the sulfate form over the oxide form. We, therefore, conclude 1) the efficacy of using large amounts of ZnO (160 kg•ha^{-1}) as an alternative to equivalent elemental amounts of $ZnSO_4$ for rapidly correcting severe Zn deficiencies of large pecan trees in orchards with acidic soils possessing alkaline feeder root surface zones, 2) the necessity of using foliar-applied Zn (such as $ZnSO_4$) in conjunction with soil-applied Zn to adequately correct foliar deficiencies the first year after soil applications, and 3) the importance of lightly disking the orchard floor to achieve rapid Zn uptake after soil application.

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