Threshold Leaf Levels of Zinc that Influence Nut Yield and Vegetative Growth in Pecan

Darrell Sparks

Department of Horticulture, University of Georgia, Athens, GA 30602-7273

Additional index words. *Carya illinoensis*, critical level, leaf deficiency symptoms, plant tissue analysis

Abstract. The modified Mitscherlich plant growth model was used to quantify the threshold leaf Zn level influencing nut yield and vegetative growth, on an orchard basis, for pecan [*Carya illinoensis* (Wangenh.) C. Koch]. Four indices of tree performance, including percentage of trees without deficiency symptoms, vegetative growth, nut yield, and trees without deficiency symptoms plus nut yield, were analyzed with regard to leaf Zn concentration. Data available from published and unpublished sources on any single performance index were combined for mathematical modeling. The threshold value for leaf Zn was determined to be $\approx 50 \mu\text{g}\cdot\text{g}^{-1}$ for these tree performance indices. Thus, nut yield and vegetative growth in an orchard will be reduced with a leaf Zn concentration below $\approx 50 \mu\text{g}\cdot\text{g}^{-1}$, but will not be affected above this value.

Rosette, a disorder in pecan resulting from inhibition of shoot elongation, has been recognized as a major cultural problem since the early part of this century (Orton and Rand, 1914). By 1932 the disorder was discovered to be caused by Zn deficiency (Alben et al., 1932), but threatened to destroy commercial pecan production during the interim (Sparks, 1987). Symptoms of Zn deficiency may be more, or less, severe than rosette and follow a sequence of interveinal chlorosis, yellow leaflets, wavy leaflet margins, rosette, and shoot dieback. The influence of Zn in relation to these leaf deficiency symptoms, as well as proposed threshold leaf values, soil content, soil availability, plant uptake, and correction methods, have been reviewed from a historical perspective (Sparks, 1976). Other aspects of the fate of pecan trees in relation to Zn nutrition, as well as research not covered in the review, include methods of prevention and correction of Zn deficiency and influence on vegetative growth and nut yields (Banin et al., 1980; Brooks, 1964; Hunter, 1965; Kilby, 1985; Smith and Storey, 1982; Sparks, 1976; Worley et al., 1972, 1981), reproductive growth (Hu and Sparks, 1990), leaf morphology and anatomy (Rand, 1922), and leaf chlorophyll and photosynthesis (Hu and Sparks, 1991).

On a shoot basis, the threshold value of leaf Zn has been established so that leaf deficiencies and decreases in either leaf photosynthesis or fruit growth will be prevented. Leaf deficiency symptoms, as judged by rosette, are not apparent until leaf Zn is $6 \mu\text{g}\cdot\text{g}^{-1}$ (dry-weight basis) (Finch, 1936; Finch and Kinnison, 1934; Hu and Sparks, 1990). Changes in leaf photosynthesis and fruit growth

can be detected at higher leaf Zn. Maximum leaf photosynthesis and fruit growth require that the leaves on the supporting shoot have Zn at $\approx 14 \mu\text{g}\cdot\text{g}^{-1}$ (Hu and Sparks, 1990, 1991).

On an orchard basis, the threshold value of leaf Zn that prevents leaf Zn deficiencies is much higher, i.e., $\approx 43 \mu\text{g}\cdot\text{g}^{-1}$ (Sparks and Payne, 1982), than that on a shoot basis. The differences in the values on a shoot and orchard basis are explained by variability of deficiency among and within pecan trees. During leaf sampling, leaflets are taken from normal and Zn-deficient branches or trees. Within a tree, only one small branch may show deficiency. Symptoms often appear first and/or are more severe in the upper portion of the canopy. One tree may have leaf deficiency symptoms, but an adjacent tree in the same orchard will be normal (Sparks and Payne, 1982), as reflected in concomitant variability in the concentration of leaf Zn between trees in the same orchard (Sparks and Payne, 1982; Worley et al., 1972). Leaflet samples typically are taken from the lower canopy and, in practice, are composite samples of leaflets from normal and Zn-deficient branches and/or trees. As a result of the masking effect of the composite sample and the sampling position, the threshold Zn value for a shoot is much less than on an orchard or tree basis. The net result is that the leaf Zn concentration required to prevent leaf deficiency symptoms on an orchard basis is much higher than on a shoot basis.

On an orchard basis, a leaf Zn threshold value below which Zn is limiting and above which Zn is not limiting to either nut yield or vegetative growth has not been determined. Many reports propose leaf Zn levels to maximize nut yield (Amling, 1965; Brookshire, 1989; Jones, 1972; Storey, 1989; Storey et al., 1975). However, these proposed values vary greatly, from 35 (Brookshire, 1989) to $80 \mu\text{g}\cdot\text{g}^{-1}$ (Storey, 1989). Lack of an established threshold value of leaf Zn for optimum pecan vegetative growth and nut yield on an orchard

basis is due to investigators failing either to induce deficiency or to examine intermediate Zn levels between severely limiting and nonlimiting leaf Zn concentration. For example, in Georgia, nut yield was reduced by 7090 at $19 \mu\text{g}\cdot\text{g}^{-1}$ relative to the maximum leaf Zn at $45 \mu\text{g}\cdot\text{g}^{-1}$, but leaf Zn concentrations that would cause nut yield reduction between 0% and 70% were not investigated (Brooks, 1965; Lane et al., 1965). Similarly, Smith and Storey (1979) determined that nut yield was reduced by 45% at $29 \mu\text{g}\cdot\text{g}^{-1}$ and not affected at $200 \mu\text{g}\cdot\text{g}^{-1}$, but they did not establish Zn levels between the extremes of 45% and 0% reduction in nut yield. From these and other investigations, the conclusion can be drawn that nut yields and vegetative growth will be limited by low leaf Zn, but are unaffected at high leaf Zn. However, no single study has established the leaf concentrations at which Zn becomes limiting. This study was designed to use mathematical modeling to combine data from published and unpublished sources. The objective was to establish the threshold concentration of leaf Zn on an orchard basis at which Zn begins to limit pecan vegetative growth and nut yield as compared with the value for leaf deficiency symptoms.

Materials and Methods

Four indices of tree performance were examined in relation to leaf Zn concentration, from a low of $19 \mu\text{g}\cdot\text{g}^{-1}$ to a high of $250 \mu\text{g}\cdot\text{g}^{-1}$, by mathematical modeling using a modification of Mitscherlich's plant growth equation of $Y = \beta [1 - e^{-\alpha(X-p)}]$ (Ware et al., 1982), where Y is the tree performance index analyzed and X is Zn concentration in the leaf, β = the upper asymptotic value that Y approaches for large values of X; α = parameter associated with the rate of change; X_p = the value of X where Y approaches $(1 - p)\beta$; and e = exponential function. Thus, the Mitscherlich equation was used to calculate the threshold Zn deficiency level for four growth indices by setting $p = 0.02$, which provides the leaf Zn concentration (X_p) associated with 98% maximum response. The 98% maximum was selected because X_p projects into infinity for maximum response (β).

The four performance indices were percentage of trees without deficiency symptoms, vegetative growth, nut yield, and the combination of leaf deficiency symptoms and nut yield. The maximum value reported for a particular index in any single study was set at 100%, and all other values were calculated relative to that value. In all cases, the maximum value was nonlimiting with respect to leaf Zn concentration. For all equations, the r^2 values were calculated as 1.0 minus the ratio of the residual sum of squares to the corrected total sum of squares (Ware et al., 1982).

Leaf and trunk growth data were combined to derive a mathematical expression for vegetative growth. Combining these data is valid because pecan leaf and trunk growth are highly correlated with total tree growth, $r^2 = 0.931$ and 0.996, respectively (Sparks and Baker, 1975). Measurements for leaf growth vs. Zn

Received for publication 8 Mar. 1993. Accepted for publication 19 July 1993. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

are from studies conducted on basic soils in western Texas (Malstrom et al., 1984), central Texas (Smith and Storey, 1979), and Arizona (Kilby, 1985). Leaf growth was analyzed following Zn uptake from the soil in each of the three studies, as well as from foliar-applied ZnSO_4 in the latter two studies. Zinc sulfate, the commonly used Zn source, was applied at the commercial dosage of 129 and 86 g of Zn/100 liters of water in the Arizona and central Texas studies, respectively. I took trunk growth data from trees growing on an acid soil near Waycross, Ga. Growth was determined for controls and treatments 5 years after one soil application of Zn in an experiment replicated six times with two trees per experimental unit.

Measurements for nut yield vs. leaf Zn are from studies of Brooks (1964), Lane et al. (1965), Malstrom et al. (1984), Smith and Storey (1979), and Worley et al. (1972). Investigations by Malstrom et al. and Smith and Storey were conducted in Texas on basic soils, and all others in Georgia on acid soils. Yield response was determined following soil-applied ZnSO_4 in all studies except that of Smith and Storey, which was for the control compared to foliar treatment of ZnSO_4 at 86.3 g Zn/100 liters of water. The relationship of visible Zn deficiency symptoms to leaf Zn was from a study (Sparks and Payne, 1982) with large mature trees growing in Georgia on acid soils. Measurements for this study were restricted to those obtained after broadcast treatments of Zn. The leaf-deficiency symptoms were expressed as the percentage of trees per treatment without visible Zn deficiency symptoms. The leaf Zn concentration in all studies and for all performance indices is comparable because the leaves were taken within a comparable sampling interval, as prescribed (Sparks, 1970).

Results and Discussion

The relationship of Zn deficiency symptoms (Fig. 1), vegetative growth (Fig. 2), and nut yield (Fig. 3) to leaf Zn followed the modified Mitscherlich's plant growth model. All tree performance indices are characteristic

Fig. 1. Pecan trees without deficiency symptoms vs. leaf Zn concentration of pecan (derived from Sparks and Payne, 1982). The relationship of deficiency symptoms vs. Zn follows Mitscherlich's plant growth model: $Y = 100.2125 [1 - 0.1e^{-0.1059(x-48.513)}]$, $r^2 = 0.790$, $P \leq 0.05$. The broken line indicates the threshold value (X_p) of Zn for 98% maximum response (β).

Fig. 2. Relative vegetative growth vs. leaf Zn concentration of pecan. The relationship of vegetative growth vs. Zn follows Mitscherlich's plant growth model: $Y = 98.2347 [1 - 0.1e^{-0.07925(x-49.0380)}]$, $r^2 = 0.504$, $P \leq 0.05$. The broken line indicates the threshold value (X_p) of Zn for 98% maximum response (β).

Fig. 3. Relative nut yield vs. leaf Zn concentration of pecan. The relationship of nut yield vs. Zn follows Mitscherlich's plant growth model: $Y = 97.0594 [1 - 0.1e^{-0.1147(x-50.3876)}]$, $r^2 = 0.852$, $P \leq 0.05$. The broken line indicates the threshold value (X_p) of Zn for 98% maximum response (β).

of a typical micronutrient response (Ware et al., 1982). Thus, the intermediate range of Zn concentrations is narrow between eliciting severe to no effect on the performance indices. The leaf Zn concentration associated with 98% maximum response was 48, 49, and 50 $\mu\text{g} \cdot \text{g}^{-1}$ for leaf deficiency symptoms, vegeta-

tive growth, and nut yield, respectively. Leaf deficiency symptoms and nut yield have similar slopes and follow a common curve (Fig. 4), but their slope is greater than that for vegetative growth. However, the leaf Zn concentration for maximum responses is similar for all performance indices. Thus, the threshold leaf concentration of Zn for pecan on an orchard basis is $\approx 50 \mu\text{g} \cdot \text{g}^{-1}$.

The curves for vegetative growth (Fig. 2) and nut yield (Fig. 3) indicate that a leaf Zn concentration of ≈ 250 and $200 \mu\text{g} \cdot \text{g}^{-1}$ is not toxic to vegetative growth and yield, respectively. Both values are from foliar-applied Zn. Results from soil-applied Zn likewise demonstrate that a leaf Zn concentration of at least $200 \mu\text{g} \cdot \text{g}^{-1}$ is not toxic to tree growth (Sparks and Payne, 1982).

Historically, Zn deficiency in pecan has been more of a problem in non-native than in native areas (Sparks, 1987). Cultivation induces and/or enhances Zn deficiency (Allen et al., 1932; Demaree, 1933; Rosborough et al., 1946). Native groves generally are not cultivated; hence, the low prevalence of Zn deficiency. At present, deficient Zn is a potential factor in reduced tree performance mainly when Zn is supplied only via acid soils, as may exist in Georgia at some locations. In regions

Fig. 4. Relative response of pecan trees based on combining values of leaf deficiency symptoms (Fig. 1) plus nut yield (Fig. 3) in relation to leaf Zn concentration of pecan. The relationship of relative response to Zn follows Mitscherlich's plant growth model: $Y = 98.0988 [1 - 0.1e^{-0.1053(x-49.0058)}]$, $r^2 = 0.818$, $P \leq 0.05$. The broken line indicates the threshold value (X_p) of Zn for 98% maximum response (B).

with basic soils, as in most areas of Texas, Oklahoma, New Mexico, Arizona, and California, the standard practice is to apply Zn as a foliar spray because the chemistry of basic soils impedes plant uptake of soil-applied Zn (Alben and Hammar, 1944; Smith et al., 1980). Over the past decade, foliar Zn sprays have become the standard application method in most pecan orchards, regardless of soil type. Pecan trees supplied Zn through properly timed foliar sprays rarely exhibit limiting Zn because leaf absorption of Zn is extremely efficient. Foliar-applied $ZnSO_4$ can produce leaf Zn values far higher (Kilby, 1985; Smith and Storey, 1979; Storey et al., 1971) than the threshold value of $50 \mu g \cdot g^{-1}$ determined in this study.

Because foliar-applied Zn sprays usually result in leaf Zn values in excess of $50 \mu g \cdot g^{-1}$, the threshold value has limited usefulness in orchards in which foliar sprays are the only means of preventing Zn deficiency, mainly orchards in basic soils outside the native pecan range. In contrast, in orchards on acid soils, where Zn is supplied via soil application, and in native pecan groves, the threshold value has significance. An exact threshold value is especially significant in native groves.

Low-input management strategies must be employed to make a pecan grove an economically feasible operation because nut yields in pecan groves, unlike pecan orchards, are inherently low (Sparks, 1980). Any cost associated with culture of the trees in pecan groves, such as spraying Zn, has a greater impact on profit margin than in pecan orchards. Thus, to spray pecan trees in native orchards to increase leaf Zn above the threshold level of $50 \mu g \cdot g^{-1}$ is an unnecessary expense, especially if the spray is solely for Zn nutrition—i.e., when Zn application does not coincide with a pesticide spray. The current recommended threshold Zn values for the two major native pecan-producing states, Oklahoma and Texas, are 60 and $80 \mu g \cdot g^{-1}$ (Smith, 1991), respectively. The results of this study suggest that these values are too high and may cause growers managing

native groves to spray Zn unnecessarily. Furthermore, a need to spray Zn on pecan trees growing in groves should be rare, as indicated by evidence from this study together with the infrequency of deficiency symptoms in pecan groves under sod culture (M.W. Smith, personal observation). This investigation clearly documents that the Zn level required for maximum vegetative growth and nut yields coincides with the threshold value for visible leaf deficiency symptoms of Zn. Thus, trees without visible leaf deficiency symptoms do not require Zn sprays to be Zn-sufficient.

Literature Cited

- Alben, A.O., J.R. Cole, and R.D. Lewis. 1932. New developments in treating pecan rosette with chemicals. *Phytopathology* 22:979-981.
- Alben, A.O. and H.E. Hammar. 1944. The effect on pecan rosette from application of zinc sulfate, manure, and sulfur on heavy-textured alkaline soils. *Proc. Amer. Soc. Hort. Sci.* 45:27-32.
- Amling, H.J. 1965. Alabama leaf analysis service. *Proc. Southeastern Pecan Growers Assn.* 58:25-32.
- Banin, A., J. Navrot, and Y. Ron. 1980. Tree implanted zinc-bentonite paste as a source of slow-release zinc for 'Delmas' pecan. *HortScience* 15:182-184.
- Brooks, O.L. 1964. Yield and growth response of Stuart pecan trees to zinc sulfate and nitrogen. *Univ. of Georgia Agr. Expt. Sta. Circ. N.S. 40*.
- Brookshire, K. 1989. Fertilizing with zinc through drip irrigation. *Western Pecan Conf. Proc.* 23:24-26.
- Demaree, J.B. 1933. Progress of pecan rosette control. *Proc. Ga.-Fla. Pecan Growers Assn.* 27:38-45.
- Finch, A.H. 1936. Zinc and other mineral constituents in relation to rosette disease of pecan trees. *J. Agr. Res.* 52:363-376.
- Finch, A.H. and A.F. Kinnison. 1934. Pecan rosette: Soil, chemical, and physiological studies. *Univ. of Arizona. Agr. Expt. Sta. Bul.* 47.
- Hu, H. and D. Sparks. 1990. Zinc deficiency inhibits reproductive development in 'Stuart' pecan. *HortScience* 25:1392-1396.
- Hu, H. and D. Sparks. 1991. Zinc deficiency inhibits chlorophyll synthesis and gas exchange in 'Stuart' pecan. *HortScience* 26:267-268.
- Hunter, J.H. 1965. Effect of lime and zinc on the pH of soil, yield of pecans, and zinc content of leaves. *Proc. Southeastern Pecan Growers Assn.* 58:6-11.
- Jones, J.B., Jr. 1972. General fertilizer recommendations for pecans. *Proc. Southeastern Pecan Growers Assn.* 65:101-112.
- Kilby, M.K. 1985. Zinc nutrition of pecan trees in Arizona. *Western Pecan Conf. Proc.* 19:9-19.
- Lane, R., H.F. Perkins, and F.E. Johnstone, Jr. 1965. Studies on the relationship of calcium, zinc and pH in pecan nutrition. *Proc. Southeastern Pecan Growers Assn.* 58:21-24.
- Malstrom, H.L., L.B. Fenn, and T.R. Riley. 1984. Methods of zinc fertilization. *Western Pecan Conf. Proc.* 18:18-25.
- Orton, W.A. and F.V. Rand. 1914. Pecan rosette. *J. Agr. Res.* 3:149-174.
- Rand, F.V. 1922. Pecan rosette: Its histology, cytology, and relation to other chlorotic diseases. *U.S. Dept. of Agr. Bul.* 1038.
- Rosborough, J.F., C.L. Smith, and L.D. Romberg. 1946. The pecan in Texas. *Texas Agr. Ext. Bul.* 120.
- Smith, M.W. 1991. Pecan nutrition, p. 152-158. In: B.W. Wood and J.A. Payne (eds.). *Pecan husbandry: Challenges and opportunities*. U.S. Dept. Agr./Agr. Res. Serv. 96.
- Smith, M.W. and J.B. Storey. 1979. Zinc concentration of pecan leaflets and yield as influenced by zinc source and adjuvants. *J. Amer. Soc. Hort. Sci.* 104:474-477.
- Smith, M.W., J.B. Storey, P.N. Westfall, and W.B. Anderson. 1980. Zinc and sulfur content in pecan leaflets as affected by application of sulfur and zinc to calcareous soils. *HortScience* 15:77-78.
- Sparks, D. 1970. The time to sample leaflets for foliar nutrient analysis of pecans. *Proc. Southeastern Pecan Growers Assn.* 63:113.
- Sparks, D. 1976. Zinc nutrition and the pecan-A review. *Pecan South* 3(2):304-334.
- Sparks, D. 1980. Energy requirements for pecan, *Carya illinoensis* (Wang.) K. Koch. *Handbook of energy utilization in agriculture*. CRC Press, Boca Raton, Fla.
- Sparks, D. 1987. Apparent effect of zinc treatment on the growth rate of pecan production and yield. *HortScience* 22:899-901.
- Sparks, D. and D.H. Baker. 1975. Growth and nutrient response of pecan seedlings, *Carya illinoensis* Koch, to nitrogen levels in sand culture. *J. Amer. Soc. Hort. Sci.* 100:392-399.
- Sparks, D. and J.A. Payne. 1982. Zinc concentration in pecan leaflets associated with zinc deficiency symptoms. *HortScience* 17:670-671.
- Storey, J.B. 1989. Principles of pecan zinc nutrition. *Western Pecan Conf. Proc.* 23:17-26.
- Storey, J.B., M. Smith, and P. Westfall. 1975. Recent advancements in zinc nutrition in pecans. *Proc. Southeastern Growers Assn.* 68:127-130.
- Storey, J.B., G. Wadsworth, M. Smith, P. Westfall, and J.D. Hanna. 1971. Pecan zinc nutrition. *Proc. Southeastern Pecan Growers Assn.* 64:87-91.
- Ware, G.O., K. Ohki, and L.C. Moon. 1982. The Mitscherlich plant growth model for determining critical nutrient deficiency levels. *Agron. J.* 74:88-91.
- Worley, R.E., S.A. Harmon, and R.L. Carter. 1972. Effect of zinc sources and methods of application on yield and leaf mineral concentration of pecan, *Carya illinoensis* Koch. *J. Amer. Soc. Hort. Sci.* 97:364-369.
- Worley, R.E., R.H. Litrell, and J.D. Dutcher. 1981. A comparison of zinc injection and zinc implantation for rapid connection of zinc deficiency. *Proc. Southeastern Pecan Growers Assn.* 74:69-71.