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Zinc Deficiency Inhibits Reproductive Development in 'Stuart' Pecan

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Abstract. **The effect of Zn deficiency on reproductive growth of 'Stuart' pecan *[Carya illinoensis* (Wangenh.) C. Koch] was studied. At the most severe Zn-deficiency level, shoots were rosetted and produced neither. staminate nor pistillate inflorescences. At less severe Zn-deficiency levels, catkin length and weight decreased as Zn concentration in the leaf decreased. The number of fruits produced per shoot was reduced by Zn deficiency. Even though fruit abortion was not affected by Zn status of the shoot, fruit death and drying in situ increased with increasing Zn deficiency. Zinc deficiency dramatically suppressed fruit development and resulted in delayed and staggered shuck dehiscence.**

Zinc deficiency is common in pecan, especially on trees grown in alkaline soils. Description of Zn deficiency symptoms in pecan, factors affecting Zn availability and its uptake, yield effects, proposed critical leaf values, and methods of correction have been reviewed (Sparks, 1976a, 1976b). Much research has been devoted to the methods of prevention and correction of Zn deficiency and to determining effects on pecan nut yields (Brooks, 1964; Hunter, 1965; Malstrom et al., 1984; Payne and Sparks, 1982; Sparks, 1976b; Worley et al., 1972, 1981). Nut yield obviously depends on the efficiency of reproductive development; however, the effect of Zn deficiency on the development and maturation of pecan reproductive structures has not been reported. The purpose of this study was to analyze the effect of Zn deficiency on catkin development, fruit set, and fruit characteristics of pecan.

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The study was conducted in a pecan orchard located on the USDA, Agricultural Research Service, Southeastern Fruit and Tree Nut Laboratory, Byron, Ga., with ≈60-year-old 'Stuart' trees. In the year before the study, eight trees exhibiting normal to varying degrees of deficiency were selected. Their relative Zn ranking remained unchanged during the course of the study. Both Zn-deficient and normal shoots often and usually do occur on the same branch or tree. For this reason, the study was conducted on a shoot rather than on a branch or tree basis to better define

Table 1. Effect of Zn deficiency on staminate flower development of 'Stuart' pecan.[z]

Severity of Zn deficiency	Leaf Zn ($\mu g \cdot g^{-1}$)	Catkin length[y,x] (cm)	Fresh wt/ catkin[y,x] (g)
Rosette	3.8 d	---	---
Very severe	4.4 cd	4.9 b	0.51 c
Severe	4.9 c	7.1 a	0.86 b
Moderate	6.1 b	7.7 a	1.01 a
None	14.3 a	---	---

[z]Means separation within columns at $P = 0.05$.
[y]Means for severe and moderate Zn deficiency consisted of 90 measurements; means for very severe deficiency consisted of 30 measurements.
[x]By the time severity of Zn deficiencies could be identified, most of the normal catkins had shed their pollen and, as a result, measurements were not made.

Table 2. The effect of Zn deficiency on pecan fruit characteristics.[z,y]

Severity of Zn deficiency	Shuck wt/nut (g)	Shell wt (g)	Kernel wt (g)	Nut wt (g)	Kernel[x] (%)	Volume/nut (ml)	Nut density ($g \cdot ml^{-1}$)	Nut length (mm)	Nut width (mm)	Nut length to width ratio	Shell thickness (mm)
Rosette	---	---	---	---	---	---	---	---	---	---	---
Very severe	0.42 d	0.51 d	0.01 d	0.52 d	1.5 d	1.1 d	0.44 d	18 d	11 d	1.6 a	0.58 c
Severe	0.99 c	1.52 c	0.36 c	1.87 c	19.0 c	3.1 c	0.58 c	25 c	16 c	1.6 a	0.65 b
Moderate	1.72 b	3.09 b	1.64 b	4.73 b	34.7 b	6.2 b	0.70 b	31 b	19 b	1.6 a	0.69 b
None	2.03 a	3.34 a	3.07 a	6.41 a	47.9 a	8.2 a	0.79 a	35 a	21 a	1.7 a	0.74 a

[z]All values are means of 90 measurements, except those from very severe deficiency, which consists of nine measurements.
[y]Means separation within columns at $P = 0.05$.
[x]Analysis of variance was on angular transformed data.

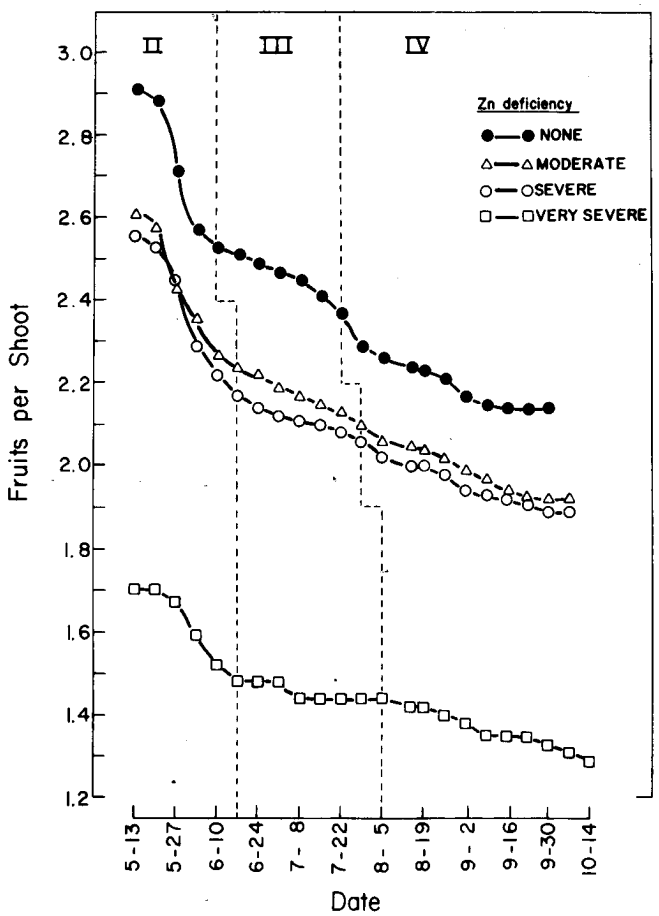

Fig. 1. Effect of Zn deficiency on fruit abortion in 'Stuart' pecan. The designation of the abortion periods are the same as used by Sparks and Madden (1985).

degree of deficiency and prevent confounding normal and deficient shoots. Individual shoots were tagged when the degree of Zn deficiency could be clearly distinguished (6 and 13 May). Shoots were divided into five groups according to rosette and extent of leaf crinkling: 1, rosette; 2, very severe crinkling but no rosette; 3, severe crinkling; 4, moderate crinkling limited to apical leaves only; and 5, no visible symptoms of deficiency. There were 150 shoots tagged for each of the latter three categories, 36 for the very severe and 39 for the rosette. The scarcity of shoots exhibiting characteristics of the two most severe Zn deficiency categories accounts for the reduced number analyzed in these classes. At the time of tagging, the first drop (Sparks and Madden, 1985), which consists of weak and underdeveloped pistillate flowers (Sparks, 1988), had occurred. Fruits were borne on all shoots, except those forming a rosette. Earlier observations (27 Apr.) showed that the latter did not produce distillate inflorescences.

Catkins were collected 6 May for length and fresh-weight measurements. The number of fruits per shoot was recorded weekly beginning 13 May and continuing through 14 Oct. After each observation, the tagged shoots were hand sprayed with *S* [(6-chloro-2-oxo-3(2 *H*) *-benzoxazolyl)methyl]O,O*diethyl phosphorodithioate (phosalone) to prevent fruit abortion from insect damage (Payne et al., 1979). This was in addition to normal pesticide sprays (French et al., 1983). Nut maturity, indicated as shuck (involucre) dehiscence, was also recorded at appropriate time intervals for each shoot.

The dehisced fruits were collected from the tagged shoots beginning 30 Sept. All fruits from normal shoots had dehisced and were collected by 14 Oct., while only about half were collected from shoots with moderate deficiency and none from shoots with severe and very severe deficiency, as they had not dehisced at that time. A week later (21 Oct.), the same number of undehisced fruits as those remaining on tagged shoots was collected from untagged shoots with moderate, severe, and very severe Zn deficiency. These samples and those collected earlier were analyzed for fruit characteristics, and the remaining undehisced fruits from tagged shoots were observed for shuck dehiscence.

The fruits were dried at room temperature until reaching a constant weight. The shucks of the undehisced fruits were scraped from the shell (ovary wall plus packing tissue) and dried under the same conditions. Nut volume was measured by water displacement. After determining nut length and width, the nuts were cracked. Shell thickness was measured and shell and kernel (seed coat, embryo, and remaining endosperm) weights were determined.

Leaflet samples for Zn analysis were taken on 29 July according to prescribed sampling procedures (Amling, 1965; Sparks, 1970). The air-dried leaflets were oven-dried for 72 hr at 70C, ground, redried, and analyzed by inductively coupled plasma spectroscopy (Isaac and Johnson, 1983).

Data were delineated either by analysis of variance and Duncan's multiple range test with Kramer's adjustment or by linear and curvilinear regression (Ezekiel and Fox, 1963; Milton and Toskos, 1983).

Severity of Zn deficiency was inversely related to Zn concentration in the leaf (Table 1). Zinc in leaves with moderate Zn deficiency was 6.1 $\mu g \cdot g^{-1}$, which is close to the critical value of 7 $\mu g \cdot g^{-1}$ reported for pecan by Finch (1936) and Finch and Kinnison (1933). Also, the value of 14.3 $\mu g \cdot g^{-1}$, associated with no Zn deficiency, is close to the values reported by these researchers for normal leaves.

Catkins from very severely affected shoots, which were low in Zn, were shorter than those from less severely affected shoots. Catkin fresh weight decreased with increasing Zn deficiency (Table 1). When the shoot was rosetted, catkins were not produced. In addition, observations showed that with very severe Zn deficiency, the number of catkins per bud was reduced compared with other

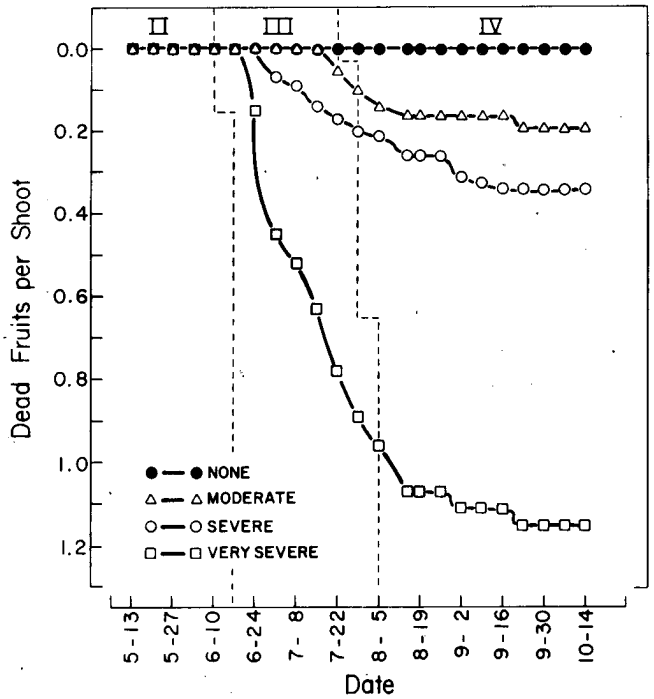

Fig. 2. Effect of severity of Zn deficiency on fruit death of 'Stuart' pecan.

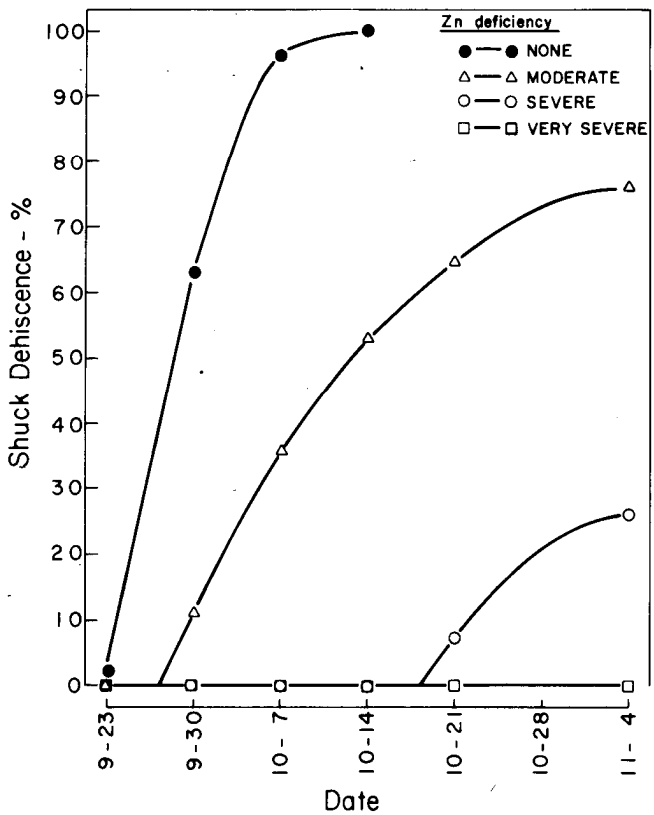

Fig. 3. Effect of severity of Zn deficiency on shuck dehiscence of 'Stuart' pecan fruit. Shuck dehiscence of fruits on shoots with no Zn deficiency and moderate deficiency increased curvilinearly with time (Log Y = 1.7234 + 0.0145X and Log Y = 1.1835 + 0.0223X, respectively); dehiscence of fruits on shoots with severe and very severe deficiency did not. Line drawn for severe deficiency is proposed relationship if additional sampling had been included. Statistical significance of regression coefficients were tested at $P = 0.05$.

categories. Often the catkin consisted of a single branch instead of the normal three-branch ament. Also, pollen shedding was observed to be progressively delayed as Zn deficiency increased.

On some shoots with Zn deficiency, all fruits in the cluster and its peduncle died and dried in situ. To separate fruit death from fruit abortion (Sparks and Madden, 1985), fruit lost was plotted as fruits remaining (Fig. 1) and as dead fruits (Fig. 2) per shoot with time. By 13 May, Zn deficiency had affected the number of fruits per shoot (Fig. 1). Rosetted shoots had no fruit and fruits per shoot decreased from 2.9 for normal shoots to 1.7 for shoots with very severe deficiency (Fig. 1). Because Zn deficiency is invariably more severe on the terminal portion of shoots and because the fruit is borne terminally, Zn deficiency would be expected to adversely affect the number of fruit produced. The fruit abortion curves paralleled each other, indicating that Zn has little effect on fruit abortion as such. Parallelism is supported by the high correlation of fruits per shoot over time for normal vs. deficiency shoots. The correlation *(r)* of mean fruit set by date on normal vs. moderate, severe, and very severe shoots was 0.993, 0.971, and 0.973, respectively. Lack of an effect of Zn deficiency on abortion is also evident in total abortion for the season in that it ranged from 24% to 27%, with no statistically significant difference with respect to Zn deficiency.

None of the fruits on normal shoots died (Fig. 2). Fruit death occurred first on shoots with very severe deficiency, followed 1 week later on shoots with severe deficiency, and 4 weeks later on shoots with moderate Zn deficiency. Fruit death increased with Zn deficiency and was 7.2%, 13%, and 67% for moderate, severe, and very severe, respectively. Fruit death began within the interval associated with the third drop, which coincides with the beginning of rapid fruit expansion, and had mostly ceased by the time the fruit entered the period of kernel development in September (Fig. 2). This pattern suggests that Zn is more critical for fruit survival during fruit expansion than during kernel development.

Time to initial shuck dehiscence was delayed and rate of dehiscence was dramatically decreased by increasing severity of Zn deficiency (Fig. 3). The effect of Zn deficiency on delaying shuck dehiscence was as observed previously by us (unpublished data) and by Brooks (1964). Because the kernel is the major ethylene-producing organ in the fruit (Lipe and Morgan, 1970, 1973), the effect of Zn deficiency on shuck dehiscence may possibly be indirect by its depressing effect of kernel development (Table 2) and reduced ethylene production. That kernel development and shuck dehiscence parallel each other (Fig. 4) tentatively supports this hypothesis.

Almost all indices of fruit development were more depressed as Zn deficiency symptoms became more evident (Table 2). The length : width ratio remained constant, which indicates that nut shape is not affected by Zn deficiency. In this study, fruit growth was at a maximum when leaves were normal, that is, when leaf Zn was $\approx 14\ \mu g \cdot g^{-1}$. Maximum fruit growth at 14 µg leaf Zn/g is supported by the leveling off of the fruit growth curves between 6 and 14 ppm (Fig. 5) and by the kernel percentage in the nut (Table 2). When leaf Zn of the supporting shoot was 14 $\mu g \cdot g^{-1}$,

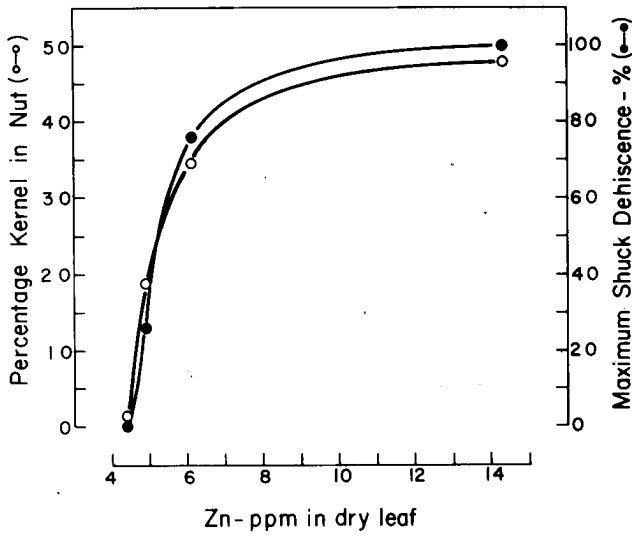

Fig. 4. Influence of Zn in leaves of the supporting shoot on kernel development and shuck dehiscence in 'Stuart' pecan. (ppm = $\mu g \cdot g^{-1}$)

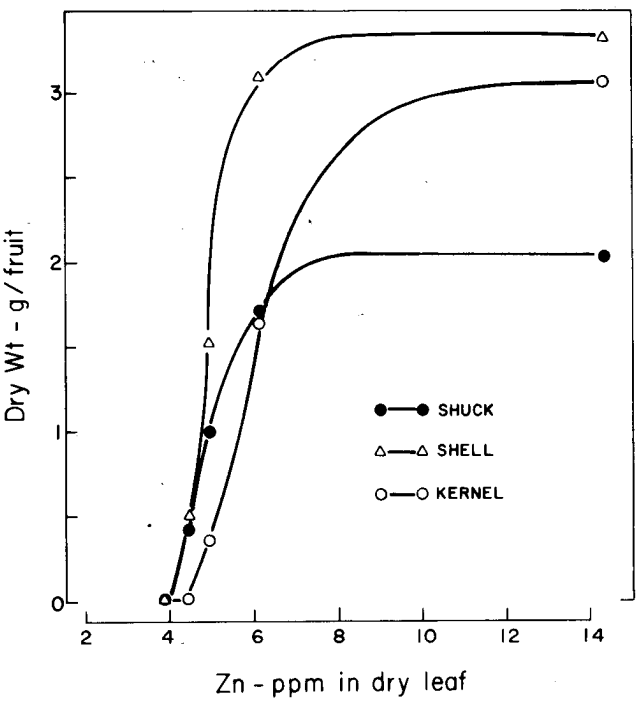

Fig. 5. Weight of the pecan shuck, shell, and kernel of 'Stuart' fruit as a function of leaf Zn. (ppm = $\mu g \cdot g^{-1}$)

kernel percentage was ≈48%, which is accepted by the industry as being a fully develaped 'Stuart' kernel. The suppressive effect of Zn deficiency on kernel percentage is commercially important because, within a cultivar, selling price is determined by kernel percentage. The kernel percentage of ≈35, associated with moderate Zn deficiency, is not a commercially acceptable 'Stuart' nut. Thus, commercially, delayed shuck dehiscence on Zn-deficient shoots (Fig. 3) is academic because the kernels are unacceptable (Table 2).

These data, as those of others (Finch, 1936; Finch and Kinnison, 1933), show that Zn deficiency symptoms occur when leaf Zn in affected shoots is near 6 $\mu g \cdot g^{-1}$. Our data also demonstrate that normal fruit development will not occur if leaf Zn of the supporting shoot is at some value less than or near to 14 $\mu g \cdot g^{-1}$. However, on a whole-tree basis or on an orchard basis, pecan will often respond to leaf diagnostic values >14 $\mu g \cdot g^{-1}$. This occurs because of the extreme variation in Zn deficiency within and among trees and because of the method of leaf sampling. Within a tree, only one branch may show deficiency. Symptoms often appear first or are more severe in the upper parts of the canopy. In an orchard, one tree may show deficiency symptoms while an adjacent tree is normal (Sparks and Payne, 1982), which is reflected in concomitant variability in leaf Zn (Sparks and Payne, 1982; Worley et al., 1972). Leaflet samples are normally taken from the lower canopy and, in practice, are composite samples of leaflets from both normal and Zn-deficient branches or trees. As a result of the masking effect of the composite sample, the leaf Zn needed to prevent deficiency symptoms on an orchard basis increases with variability in deficiency until a leaf Zn of 40 $\mu g \cdot g^{-1}$ is obtained (Sparks and Payne, 1982).

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