Manure and Soil Zinc Application to ‘Wichita’ Pecan Trees Growing Under Alkaline Conditions

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Abstract. The effect of cattle manure or combined manure and zinc (Zn) application on Zn uptake, mineral composition, and yield and nut quality in pecan trees [Carya illinoinsensis (Wangenh.) C. Koch] was evaluated. In 2006, treatments evaluated were: manure (12 ton/ha; M), manure plus Zn (12 ton/ha plus 129 kg Zn/ha as ZnSO4; MZ), and an untreated control. During 2007, two more treatments were added with doubled manure and Zn rates. New treatments were manure = 2x (24 ton/ha; MZ) and manure = 2x plus Zn = 2x (24 ton/ha plus 258 kg Zn as ZnSO4; M2Z2). Manure was broadcast on the soil in a 2.5-m wide band 2 m from the trunk. Zinc sulfate was broadcast over the manure, and then manure and Zn were disked into the top 10 cm of soil. In 2008, in five of nine sampling dates, significant treatment effects were detected on leaf Zn concentrations. On all of the dates, M2Z2 had the highest foliar Zn levels. During the Summer 2008 (17 July) follar Zn in M2Z2, treatment reached 66 µg g⁻¹; the control treatment level was 45 µg g⁻¹. Nut yields were higher in treatments receiving manure, with or without Zn in the first year, and highest in the untreated control the second year. No differences were observed in trunk growth, leaf area, leaf weight, or nut growth. Kernel percentages were over 61.4 in the 3 years of study in all treatments. Largest differences among treatments in nut size were found in 2007; nut weight in the control treatment was 7.5 g per nut and in M was 8.0 g per nut. Nut weight was smaller during 2008 when nut yield was high, and the untreated control nuts were smaller than those from treated trees. The manure and manure plus Zn treatments increased follar Zn levels in pecan trees after 3 years of annual applications. In 2008, significant differences in leaflet Zn concentration among treatments were detected with M2Z2 having the highest concentrations.

Increased use of animal manure in pecan orchards has recently accompanied a shift toward “organic” production. The purpose of the manure applications is primarily to supply nitrogen in this production system. The relatively large quantities of manure used for this purpose (~5 to 12 Mt ha⁻¹) might reasonably be expected to have an impact on levels of soil organic matter and metal solubility and bioavailability. Manure fortified with supplemental Zn might provide additional available Zn for trees growing in calcareous soils.

Zinc uptake and pecan tree performance were studied after the application of manure alone or in combination with Zn sulfate. The purpose of this study was to determine the effect of the addition of manure on Zn uptake, growth, yield, and nut quality of pecan trees growing under alkaline and calcareous conditions and to ascertain whether these effects can be enhanced by providing extra Zn with applied manure.

Materials and Methods

A field study was conducted in a commercial pecan orchard in southeast Arizona (lat. 31°55’01.25” N, long. 110°57’27.56”, elev. 844 m) on ‘Wichita’ pecan trees (7 years old) from May 2005 to Dec. 2008. The alluvial soil in the orchard is a calcareous Pima clay loam with a soil pH of 7.6 (fine silty, mixed, thermic Typic Torrifuvents). This site is semiarid with a mean annual soil temperature from 15 to 22 °C and the area has a mean annual precipitation between 25 and 40 cm (Hendricks, 1985). Table 1 presents general soil characteristics of the orchard site at 0- to 30-cm depth. The soil is typical of many southwestern U.S. soils and therefore many regional pecan orchards. Trees are planted in a square design and the space between trees is 9.15 m. Mowing was used to keep the soil clean of weeds during growing seasons. Trees were flood-irrigated twice each month from April to October. A total of 1.50 m of water depth was applied each year. Standard chemical methods were initially used to control aphids, but in 2007, the orchard was converted to “organic” production and pest control methods were changed accordingly. During the winter of

Received for publication 14 May 2009. Accepted for publication 22 July 2009.

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Pecan trees growing in alkaline and calcareous soils are prone to zinc (Zn) deficiency (Malstrom and Fenn, 1981; Smith et al., 1980). Soluble Zn compounds such as Zn sulfate applied to alkaline soil react with hydroxides and carbonates and are converted to compounds unavailable to plants (Essington, 2003; Lindsay, 1972; Sadiq, 1991; Udo et al., 1970). Acidification using large quantities of strong acids such as sulfuric acid can increase Zn uptake by pecan (Fenn et al., 1990). Acid-forming compounds such as sulfur (S) and organic matter can increase Zn availability (Essington, 2003). Humic acids can also complex metals, including Zn, increasing mobility and solubility in calcareous soil (Bunluesin et al., 2006; Chien et al., 2006; Ozkutlu et al., 2006). Addition of manure, S, and Zn can increase Zn availability (Essington, 2003).
2006–2007, trees in the buffer rows between experimental plot rows were mechanically hedge-pruned. In the winter of 2007–2008, trees in treatment rows were also hedged. Trees were hedged 3 m from each side of the trunk and 9 m high. Lateral hedge-pruning had an inclination of 5° from the vertical toward the trunk with the top pruned at an angle of 160°.

In 2006, treatments evaluated were: manure (a blend of cattle and horse manure at 12 ton/ha) (M1), manure plus Zn (12 ton/ha of manure plus 129 kg of Zn/ha as ZnSO₄) (M1Z1), and an untreated control. The manure application rate is that used commercially to supply nitrogen in this orchard. None of the plots were sprayed with Zn during the study. Two additional treatments were to have received a urea application instead of manure, but were left untreated in 2006 because the block was converted to organic production. Instead, these plots were used to evaluate two more treatments with doubled rates of manure and manure plus Zn in 2007: 24 ton/ha of manure (M2) and 24 ton manure/ha plus 258 kg Zn/ha as ZnSO₄ (M2Z2).

Manure was broadcast on the soil in a 2.5-m wide band beginning 2 m from the trunk. Zinc sulfate was broadcast over the manure. All plots were disked to mix the top 10 cm of soil. Manure had a pH of 7.8 and an electrical conductivity of 4.0 and contained ≈0.84% nitrogen, 0.18% P₂O₅, and 1.19% K₂O. Treatments were replicated four times in a randomized complete block design. Each experimental plot consisted of one row containing 15 trees (n = 12 in 2006; n = 20 in subsequent years). Leaf samples and growth measurements were collected from the 11 central trees in each plot row. Experimental plot rows were each separated by one buffer row.

Data were analyzed using analysis of variance with mean separation using Tukey’s test (SAS Version 9.1; SAS Institute, Cary, NC).

Twenty-four middle leaflet pairs located in the middle of the current year’s shoot growth were collected every 2 or 3 weeks from May to October for Zn analysis. These samples were collected from the branches on the lower part of the trees that could be reached from the ground. Leaflet samples collected in late July were used for complete elemental analysis. Leaves were washed using the following routine: washed in phosphate-free soap, rinsed in tap water, rinsed in distilled water, and rinsed three times in deionized water. Leaf samples were dried at 70°C, weighed, and then ground in a mortar.

During 2008, a rinse with hydrochloric acid was added to the following routine: washed in phosphate-free soap, rinsed in tap water, rinsed in deionized water, and rinsed three times in deionized water. Leaf samples were dried at 70°C, weighed, and then ground in a mortar.

Trees were hedged 3 m from each side of the trunk and 9 m high. Lateral hedge-pruning had an inclination of 5° from the vertical toward the trunk with the top pruned at an angle of 160°.

Trunk circumference was measured at 20 cm above the ground in Feb. 2007 and Feb. 2008. Trunk cross-sectional area was calculated from these measurements. Leaflet growth and chlorophyll index were determined on a sample of 60 leaflets collected in late July or early August. Chlorophyll index was obtained using a Konica Minolta SPAD 502 m (Konica Minolta Sensing America Inc., Ramsey, NJ) by optical density difference at two wavelengths (650 and 940 nm). Chlorophyll readings were conducted on the middle part of the leaflet. Leaflets were scanned on a flatbed scanner and leaflet area obtained using Scion Image software (Scion Corp., Frederick, MD).

During late July or early August, 20 middle pairs of leaflets were collected from the top half of the trees as described previously for the bottom part of the tree to determine if leaf Zn, leaf area, and leaf weight in the upper half of trees were affected by treatments.

During 2006 and 2007, nut yield and quality were determined. Yield was calculated by mechanically harvesting the complete experimental row. Alternate bearing intensity (I) was determined by the ratio between the absolute difference in yield with the sum of the yields of successive years (Pearce and Dobbersek-Urbanc, 1967) according to the formula:

\[
I = \frac{1}{n-1} \times \left( \frac{Y_1 - Y_3}{Y_1 + Y_3} \right) + \frac{1}{n-1} \times \left( \frac{Y_2 - Y_4}{Y_2 + Y_4} \right) + \cdots + \frac{1}{n-1} \times \left( \frac{Y_{n-2} - Y_n}{Y_{n-2} + Y_n} \right)
\]

where I = alternate bearing intensity, n = total years, and Y = year. Values are absolute numbers.

**Table 1. Orchard soil characteristics at the beginning of the study.**

| Soil test                        | Method          | Units | Value |
|----------------------------------|-----------------|-------|-------|
| pH                               | Saturated paste | SU    | 7.5   |
| Electrical conductivity          | Saturated paste | dS m⁻¹| 0.44  |
| Calcium                          | NH₄OAc (pH 8.5) | mg kg⁻¹| 4000  |
| Magnesium                        | NH₄OAc (pH 8.5) | mg kg⁻¹| 310   |
| Potassium                        | NH₄OAc (pH 8.5) | mg kg⁻¹| 510   |
| Zinc                             | DTPA            | mg kg⁻¹| 3.2   |
| Iron                             | DTPA            | mg kg⁻¹| 5.1   |
| Manganese                        | DTPA            | mg kg⁻¹| 9.4   |
| Copper                           | DTPA            | mg kg⁻¹| 2.4   |
| Nickel                           | DTPA            | mg kg⁻¹| 0.12  |
| NO₃-N                            | Cd reduction    | mg kg⁻¹| 8.8   |
| PO₄-P                            | Olsen           | mg kg⁻¹| 9.0   |
| SO₄-S                            | Hot water       | mg kg⁻¹| 22    |
| Effervescence                    | High            |       |       |
| Exchangeable sodium percent      | Calculated      | %     | 1.8   |
| Cation exchange capacity         | Calculated      | cmol kg⁻¹| 24.3 |

**Table 2. Effect of manure and zinc (Zn) application on foliar Zn concentration during the growing season in ‘Wichita’ pecan trees (μg g⁻¹ dry weight).**

| Zn (μg g⁻¹ dry wt) | 2006 | 2007 | 2008 |
|--------------------|------|------|------|
| Treatment          | 1 Nov | 1 Dec | 1 Jan |
| M1                 | 42    | 36   | 36   |
| M1Z1               | 40    | 34   | 34   |
| Control            | 44    | 39   | 39   |
| Pr > F             | NS    | NS   | NS   |

**Table 3. Effect of manure and zinc (Zn) application on foliar Zn concentration during the growing season in ‘Wichita’ pecan trees (μg g⁻¹ dry weight).**

| Zn (μg g⁻¹ dry wt) | 2006 | 2007 | 2008 |
|--------------------|------|------|------|
| Treatment          | 1 Nov | 1 Dec | 1 Jan |
| M1                 | 58    | 57   | 57   |
| M1Z1               | 61    | 55   | 55   |
| Control            | 48    | 48   | 48   |
| Pr > F             | NS    | NS   | NS   |

**Means followed by different letters are different at P = 0.05 through analysis of variance testing.**

M1 = manure 12 ton/ha; M2 = manure 24 ton/ha; Z1 = 129 kg Zn as ZnSO₄; Z2 = 258 kg Zn as ZnSO₄ (manure had a pH of 7.8 and an electrical conductivity of 4.0 and contained ≈0.84% N, 0.18% P₂O₅, and 1.19% K₂O).
A sample of harvested nuts was used to
determine kernel percent, yield, percent of
good nuts, pre-germinated nuts (viviparous),
and “stick-tight” nuts. “Stick-tights” are those
fruit with shucks that do not separate from the
shell at maturity; the shuck remains stuck to
the shell after harvest and cannot be separated
completely. Yield efficiency was calculated as
yield/cm² of TCSA. Kernel percent was deter-
mined by cracking 10 nuts from each experi-
mental plot and separately weighing shell and
kernel. Weight per nut was calculated from the
number of nuts in a 1-kg sample.

**Results**

Leaflet Zn concentration was unaffected
during the first year of study in 2006 (Table
2). Significant differences were found in July
2007 with the control having the highest
folicar Zn level. In 2008, in eight of the nine
leaf sampling dates, significant effects were
detected. On all of these sampling dates, trees
in the M2Z2 treatment had the highest follicar
Zn levels. During the summer of 2008 (17
July), in this treatment, follicar Zn reached 66
mg kg⁻¹, whereas the control treatment had
45 mg kg⁻¹. Only the M2 treatment had lower
folicar Zn levels than the control. In 2007, no
significant differences were found in follicar
Zn between the bottom and top sections of the
trees, but in 2008, leaflets from the top had
significantly lower values than the bottom
leaflets.

Zinc treatments did not affect TCSA, leaflet size and weight, and chlorophyll index
(Table 3). Neither TCSA nor its increase in 2
consecutive years was affected by treatments.

Heavy rains during 2006 prevented the
use of the hydraulic lift needed to sample the
top part of the trees. In 2007 and 2008, specific leaflet areas from the top and bottom
parts of the trees were unaffected by manure
or Zn applications. Chlorophyll index varied
from 46.5 to 47.3 in 2007 and from 46.8 to
45.4 in 2008. Manure treatments had the
highest values, but differences were not
significant.

Yield of whole nuts and kernel were
affected by applied treatments (Table 4). In
2006, both treatments receiving manure out-
yielded the control treatment, but differences
were not significant. In contrast, in 2007, the
highest yield of nuts was obtained in the
control treatment (3852 kg ha⁻¹), whereas
other treatments had yields between 2891 and
3010 kg ha⁻¹. In 2008, the control treatment
had the lowest yield, and it was signif-
ically lower than M2Z2, which had the
highest yield. Kernel yields and yield effi-
ciency reflected overall yields. Differences in
cumulative yields and cumulative efficiency
were not significantly different, although
control plots ranked highest in both. Alter-
ate bearing intensity ranged from 0.15 to
0.7. The control treatment had the highest
alternate bearing intensity, but differences
were not significant.

Nut filling and nut weight were unaffected
by treatments (Table 5). Nut fill was excellent
both years, over 61% in 2006 and over 62%
in 2007 and 2008. Nut weight was larger
in 2006–2007 2007–2008

| Treatment | Trunk cross-sectional area (cm²·ha⁻¹) | Increase (2007–2008) |
|-----------|----------------------------------------|----------------------|
| M1        | 387.4                                  | 58.3                 |
| M1Z1      | 393.7                                  | 64.6                 |
| M2        | 417.1                                  | 63.6                 |
| M2Z2      | 403.3                                  | 73.2                 |
| Control   | 354.6                                  | 76.5                 |

| Pr > F    | NS          | **          |
|-----------|-------------|-------------|

Leaflet area bottom (cm²)

| Treatment | Leaflet area bottom (cm²) | Pr > F |
|-----------|--------------------------|--------|
| M1        | 23.2                     |        |
| M1Z1      | 23.7                     |        |
| M2        | 29.9                     |        |
| M2Z2      | 30.0                     |        |
| Control   | 22.4                     |        |

| Pr > F    | NS          | NS          |

Leaflet area top (cm²)

| Treatment | Leaflet area top (cm²) | Pr > F |
|-----------|------------------------|--------|
| M1        | 23.0                    |        |
| M1Z1      | 23.7                    |        |
| M2        | 21.9                    |        |
| M2Z2      | 21.4                    |        |
| Control   | 20.7                    |        |

| Pr > F    | 0.895                   | 0.44   |

Leaflet weight bottom (g)

| Treatment | Leaflet weight bottom (g) | Pr > F |
|-----------|--------------------------|--------|
| M1        | 0.253                    |        |
| M1Z1      | 0.275                    |        |
| M2        | 0.247                    |        |
| M2Z2      | 0.235                    |        |
| Control   | 0.265                    |        |

| Pr > F    | 0.224                   | 0.223  |

Leaflet weight top (g)

| Treatment | Leaflet weight top (g) | Pr > F |
|-----------|------------------------|--------|
| M1        | 0.221                   |        |
| M1Z1      | 0.217                   |        |
| M2        | 0.217                   |        |
| M2Z2      | 0.217                   |        |
| Control   | 0.193                   |        |

| Pr > F    | 0.193                   | 0.195  |

Chlorophyll index (SPADs)

| Treatment | Chlorophyll index (SPADs) | Pr > F |
|-----------|--------------------------|--------|
| M1x       | 46.5                     |        |
| M1Z1      | 46.5                     |        |
| M2        | 47.1                     |        |
| M2 Z2     | 47.3                     |        |
| Control   | 46.5                     |        |

| Pr > F    | 583                     | 747    |

Means followed by different letters are different at
P = 0.05 through analysis of variance testing.

| Treatment | Yield of nut (kg ha⁻¹) | Nut yield efficiency (g·cm⁻²) | Yield of kernel (kg ha⁻¹) | Alternate bearing intensity (%) |
|-----------|------------------------|-----------------------------|-------------------------|-------------------------------|
| M1        | 863                    | 56.1                        | 19.0                    | 51.6                          |
| M1Z1      | 850                    | 54.1                        | 18.0                    | 51.9                          |
| M2        | 3,086                  | 62.3                        | 20.2                    | 52.3                          |
| M2Z2      | 2,910                  | 61.1                        | 19.0                    | 51.9                          |
| Control   | 597                    | 60.6                        | 14.0                    | 49.3                          |

| Pr > F    | NS                     | *                           | NS                      | *                             |

| Least significant difference (0.05) | 583                     | 747                        |

Means followed by different letters are different at
P = 0.05 through analysis of variance testing.

| Treatment | Yeild of nut (kg ha⁻¹) | Nut yield efficiency (g·cm⁻²) | Yield of kernel (kg ha⁻¹) | Alternate bearing intensity (%) |
|-----------|------------------------|-----------------------------|-------------------------|-------------------------------|
| M1        | 467                    | 1,904                       | 1,904                   | 1,904                          |
| M1Z1      | 448                    | 1,794                       | 1,794                   | 1,794                          |
| M2        | 1,960                  | 1,843                       | 1,843                   | 1,843                          |
| M2Z2      | 863                    | 863                         | 863                     | 863                            |
| Control   | 322                    | 2,417                       | 2,417                   | 2,417                          |

| Pr > F    | NS                     | *                           | NS                      | *                             |

| Least significant difference (0.05) | 583                     | 747                        |

Means followed by different letters are different at
P = 0.05 through analysis of variance testing.
during 2006, when nut harvest was small. In 2007, nuts from the control treatments were lighter than nuts from other treatments, but differences were not significant.

The percentage of nuts exhibiting vivipary and the percentage of stick-tights were unaffected by manure or Zn applications in the first year of study but was affected during 2007 and 2008 (Table 5). In 2007, leaflet potassium levels were higher in the control and M1Z1 treatments. In 2008, 2 years after the start of the study, significant differences were found in foliar calcium (Ca) and magnesium (Mg) concentrations, which were highest in manure and manure plus Zn treatments. The control treatment had foliar Ca and Mg concentrations of 21.8 g kg⁻¹ and 1.9 g kg⁻¹, respectively, compared with 25.8 g kg⁻¹ and 4.9 g kg⁻¹ in the M1Z1 treatment.

### Table 5. Effect of manure and zinc (Zn) application on nut quality of adult ‘Wichita’ pecan trees

| Treatment | 2006     | 2007     | 2008     |
|-----------|----------|----------|----------|
| Zn         | Nut filling (kernel %) | Nut weight (g) | Vivipary (%) | Stick tights (%) |
| M1        | 61.9     | 63.6     | 62.7     | 8.7       | 8.0       | 7.3 |
| M1Z1      | 61.4     | 62.2     | 62.2     | 8.2       | 7.4       | 7.0 |
| M2        | 63.3     | 62.8     | 62.8     | 7.7       | 7.7       | 7.0 |
| M2Z2      | 63.3     | 63.3     | 63.3     | 7.9       | 7.9       | 7.2 |
| Control   | 61.6     | 62.8     | 63.5     | 8.6       | 7.5       | 7.2 |
| Pr > F    | NS       | NS       | NS       | NS        | NS        | NS |

### Table 6. Effect of manure and zinc (Zn) application on mineral composition of pecan ‘Wichita’ trees

| Treatment | 2006     | 2007     | 2008     |
|-----------|----------|----------|----------|
| Zn         | Nitrogen | Phosphorus | Potassium | Calcium | Magnesium | Sulfur |
| M1        | 27.2     | 1.0      | 12.2     | 21.5    | 4.2       | 2.5    |
| M1Z1      | 27.0     | 0.9      | 11.5     | 20.5    | 4.0       | 2.4    |
| Control   | 27.0     | 1.0      | 12.0     | 19.0    | 3.6       | 2.4    |
| Pr > F    | NS       | NS       | NS       | NS       | NS       | NS    |

Discussion

The relatively low concentrations of foliar Zn during 2006 and 2007 did not cause visible deficiency symptoms in ‘Wichita’ pecan trees. Foliar Zn concentration ranged from 20 to 24, 33 to 44, and 46 to 62 ppm during 2006, 2007, and 2008, respectively. Leaflet Zn concentrations generally were below the widely accepted critical level for the southeast conditions of 50 μg g⁻¹ (Sparks, 1993; 1994; Wood, 2007) during the first 2 years of the study. These low levels of Zn apparently did not affect fruit set, yield, or quality of pecans in 2007 because a large crop with very high quality was produced.

In Georgia, high-yielding pecans (greater than 58 kg nuts per tree) had an average of 126 μg g⁻¹ Zn in leaves (Beverly and Worley, 1992), in Mexico 65 μg g⁻¹ (Medina, 2004), and in the southwest United States 174 μg g⁻¹ (Pond et al., 2006). Zinc critical levels have been established for pecans ranging from 20 to 60 μg g⁻¹, and several authors have noticed no difference in tree growth development within this range (Lane et al., 1965; Obarr et al., 1978; Sparks, 1976; Storey et al., 1971; Worley et al., 1972). Seedlings of ‘Curtis’ grown in nutrient solution without Zn had 24 to 37 μg g⁻¹ and seedlings showed mild Zn deficiency symptoms (Sparks, 1978). Pecans grown in sand culture under hydroponic conditions with a nutrient solution lacking Zn had interveinal necrosis in leaves with 7.2 μg g⁻¹, mottling at 9.8 μg g⁻¹, and no symptoms in leaves with 11.2 μg g⁻¹ (Kim et al., 2002).

Size of leaflets in this study were larger than those reported from ‘Choctaw’ pecan trees in spring flush shoots growing in Georgia, where leaflets had 18.5 cm²/leaflet (Andersen and Brodbeck, 1988).

Published data regarding chlorophyll indices of pecan leaves are uncommon, but it is known that leaf chlorophyll content, stomatal conductance, and net photosynthesis are all positively related to leaf Zn concentration (Hu and Sparks, 1991). Chlorophyll content rose from 0.5 to 3.0 mg g⁻¹ fresh leaflet in pecan as Zn leaflet concentration increased from 4 to 9 μg g⁻¹ dry matter (Hu and Sparks, 1991). The lack of chlorophyll in Zn-deficient leaves is related with the characteristic interveinal chlorosis in Zn-deficient pecan trees. Because the nut yield and quality from the trees in this study were relatively good, chlorophyll indices from these trees may be considered to represent acceptable readings for established ‘Wichita’ pecan trees in the irrigated southwestern United States. In several other crops, a SPAD index reading of 50 to 52 represented chlorophyll concentrations of 4 to 5 mg of total chlorophyll per gram of (fresh weight) leaf (Uddling et al., 2007). Thus, in our study, 1 g of fresh leaflet was estimated to have...
contained ≈4 to 5 mg of chlorophyll. For comparison, healthy fresh ‘Mohawk’ leaflet had 185 mg chlorophyll per leaflet (Andersen and Brodbeck, 1988). Hu and Sparks (1991) found that ‘Stuart’ fresh non-Zn-deficient leaflets contained 3.2 mg of chlorophyll/g fresh leaves and 10 µg Zn/g in dry leaflets. Yield was very low in 2006 but quite high in 2007. High nut yield coupled with low observed foliar Zn levels in 2007 suggests that the critical level of 50 µg g⁻¹ may be too high. The fact that the highest yield in 2007 was in the control treatment could be a result of the very low yield in this treatment the previous year. This is apparent from the alternate bearing intensity, which is very high for this treatment (although not significantly different from other treatments). In other studies, ‘Wichita’ pecans have had lower alternate bearing intensities than those we observed in the control plots (Conner and Worley, 2000; Nunez, 2001).

A higher incidence of vivipary in 2007 than in 2006 could be the result of stress caused by the high crop load in 2007. In previous studies conducted in Arizona and Texas, it was reported that ‘Wichita’ exhibited increased vivipary when large crop load was present (Kilby and Gibson, 2000; Sparks et al., 1995).

Manure and Zn affected foliar Zn levels in the plant. These results agree with research with other crops: rice (Battacharyya et al., 2006); sorghum (Pinto et al., 2004); basil, chard, dill, and peppermint (Zheligov and Warman, 2004). Additionally, foliar Zn concentrations have also been increasing in control treatment since the beginning of the study. Possible explanations for this may be related to conversion of this orchard to “organic” production and a change from a traditional tillage system for eliminating weeds to mowing. A reduction and a change from a traditional tillage to conversion of this orchard to “organic” production since the beginning of the study. Possible explanations for this may be related to conversion of this orchard to “organic” production and a change from a traditional tillage system for eliminating weeds to mowing. A reduction and a change from a traditional tillage to conversion of this orchard to “organic” production since the beginning of the study. 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