Response of 'Desirable' and 'Kiowa' Pecan to a Late-spring Freeze

M. Lenny Wells[1]

ADDITIONAL INDEX WORDS. *Carya illinoinensis*, freeze damage, chlorophyll, flowering

SUMMARY. This study was established to assess the effects of a severe late spring freeze on flowering, shoot growth, leaf nutrient status, and the retention of fruit developing from secondary buds of pecan [*Carya illinoinensis* (Wangenh.) K.Koch]. Freeze damage appears to have a significant influence on pecan physiology and fruit retention. 'Desirable' produced a crop of pistillate flowers from secondary buds after the freeze; however, many of these flowers were abnormal in appearance. Freeze-damaged 'Desirable' trees exhibited shorter shoots, reduced flower and fruit retention, a lower chlorophyll index, and decreased leaf nitrogen concentration compared with nondamaged trees. Leaf zinc concentration was higher in freeze-injured 'Desirable' trees than in nondamaged trees. Freeze-damaged 'Kiowa' trees had longer shoots and failed to produce a crop of pistillate flowers from secondary buds on most shoots. Freeze damage led to the appearance of mouse-ear leaf symptoms and reduced leaf chlorophyll index, leaf nitrogen, and leaf magnesium concentrations in 'Kiowa'. Leaf phosphorous and leaf potassium concentrations were higher in freeze-injured 'Kiowa' trees than in nondamaged trees. These observations provide insight into the potential response of bearing orchard trees injured by a late spring freeze.

Pecan trees and orchards occasionally suffer damage as a result of cold or freezing temperatures. In the southeastern United States, this is most likely to occur in the autumn before trees have become acclimated to cold temperatures (Madden, 1978; Smith et al., 1993; Sparks et al., 1976) or in the spring after growth has been initiated (Madden, 1980; Maelstrom et al., 1982). Cold injury may be expressed through a number of symptoms, including longitudinal bark splitting, separation of bark from wood, sunken areas on limbs and shoots, death and browning of the cambium, inner bark and phloem, sporadic death of small shoots, delayed budbreak, sparse canopy, and resprouting (Wood and Reilly, 2001). A variety of factors influence the susceptibility of pecan trees to freeze injury. These include dormancy, insect and disease injury, air drainage, cultivar, tree health, tree size, and seedling versus cultivar trunk (Sparks and Payne, 1978).

Sparks and Payne (1978) suggests that late spring freezes appear to be the most common way in which pecans are damaged by freezing temperatures. This is related to the stage of tree dormancy at the time of exposure to freezing temperatures. Damage by late-spring freezes are most likely to occur when a sudden freeze is preceded by an extended period of warm early spring temperatures. In such scenarios, cultivars that break bud early are more susceptible than those that break bud late.

Although many authors have examined the effects of cold injury on pecan trees, there is little information available on the effects of late spring freezes on subsequent flowering and fruit set. Early-spring mechanical removal of various combinations of buds from 1-year-old branches of 'Desirable' pecan was shown to increase the number of lateral shoots, indicating the potential for development of pistillate and staminate flowers, and fruit from primary, secondary, and tertiary buds (Wood and Payne, 1983). The production of pistillate flowers from secondary buds after a late spring freeze has been previously observed (Cole and Hunter, 1965; Hagler, 1956; Sparks, 1992). Under normal conditions, pistillate flowers are borne terminally on current season shoots that arise from primary compound buds on 1-year-old branches. Staminate flowers develop from primary compound buds on 1-year-old branches. Typically, all primary buds initiate growth, but shoots abort on all but the distal one to three buds, and catkins persist along the entire length of the shoot.

Woodroof and Woodroof (1929) suggested that an "abnormal flowering" of pecan can occur as a result of genetic instability. The described abnormal flowering resulted in two types of "perfect flower clusters" (those with staminate and pistillate parts). They described one or more staminate inflorescences borne at the terminus of the pistillate flower cluster, whereas the other type had staminate inflorescences at the base of the pistillate cluster. Such abnormal flowering was later attributed to abnormal physiology of lateral buds resulting from unseasonably low temperatures rather than genetic instability (Cole and Hunter, 1965; Sparks, 1992). Although the abnormal appearance of these flowers has been reported previously, no data are available in the literature regarding the fate of flowers developing from secondary buds after a late spring freeze or on season-long response of the tree to freeze-induced stress.

This study reports the effects of a late spring freeze on flowering, shoot growth, leaf nutrient status, and the retention of fruit developing from secondary buds after a late spring freeze.

Materials and methods

Data were collected in a commercial pecan orchard in Lee County, Georgia. The orchard soil type was uniformly Greenville sandy loam throughout the study area. Eight 'Desirable' and eight 'Kiowa' pecan trees were selected and blocked by

Units

To convert U.S. to SI, multiply by	U.S unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
1	ppm	$mg\cdot kg^{-1}$	1
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

Department of Horticulture, University of Georgia, Tifton, GA 31793

[1]Corresponding author. E-mail: lwells@uga.edu.

cultivar. 'Desirable' trees were planted in 1983 and were spaced 60 × 60 ft. 'Kiowa' trees were planted in 1999 and were spaced 30 ft within the row and 60 ft between rows. All trees were irrigated by underground drip irrigation and were managed according to University of Georgia Extension recommendations.

Four trees of each cultivar were assigned one of two damage levels, "none" (0%) or "severe" (80%–100%) injury, after a late spring freeze occurring on 8 Apr. 2007. Test trees were selected based on visual signs of frost damage. Trees receiving a 0% injury rating had no visible damage to shoot, leaf, or flower tissue observed 7 d after the freeze (DAF) and throughout the study. Trees receiving an 80% to 100% damage rating exhibited visible necrosis of shoot, leaf, and flower tissue over 80% to 100% of the tree 7 DAF. Trees of each damage level were paired by size from among two adjacent rows. Although no direct measurements of temperature were made in the orchard at the time the freeze occurred, a low temperature of –0.11 °C was recorded at a University of Georgia weather station about 6.0 miles from the study site on 8 Apr. 2007.

Budbreak occurred ≈21 d before exposure to freezing temperatures. Shoots were elongating, and pistillate and staminate flowers were present at the time the freeze occurred. Nondamaged 'Desirable' trees were located at an average elevation of 277 ft above sea level, whereas damaged 'Desirable' trees were at an average elevation of 261 ft. Average elevation of 'Kiowa' trees was 275 and 270 ft for damaged and nondamaged trees, respectively.

Ten exterior terminal branches per tree were flagged on 15 Apr. 2007 at ≈9 ft above the ground, and the following data were collected at 32, 47, 91, and 147 DAF: shoot length, number of terminals bearing pistillate flowers or fruit, and cluster size (number of pistillate flowers or fruit per fruiting terminal). Shoot length was measured from the base to the distal end of the terminal current season shoot. The percentage of flowering or fruiting terminals per tree was determined by dividing the number of flowering or fruiting terminals by the total number of terminals sampled. A leaf chlorophyll index was measured at each of the above dates using a chlorophyll meter (SPAD-502; Minolta, Ramsey, NJ). Measurement leaves were fully expanded and selected from one pair of middle leaflets of 10 tagged terminal branches per tree. The number of abnormal flower clusters per tagged branch was counted at 32 DAF. Flower clusters with one or more staminate inflorescences borne at the terminus or at the base of the pistillate flower cluster as described by Woodroof and Woodroof (1929) were considered abnormal. The percentage of abnormal flowering clusters was determined by dividing the number of abnormal flower clusters by the total number of flower clusters counted. The percentage of mouse-ear symptomatic shoots was determined by dividing the number of shoots exhibiting mouse-ear symptoms by the total number of shoots counted. Mouse-ear symptomatic shoots consisted of small, rounded, or blunt leaflet tips as described by Wood et al. (2004a).

Leaf samples, consisting of 30 middle leaflet pairs of the middle leaf of sun-exposed terminals, were collected on 12 July 2007. Samples were kept separate by tree. Leaf samples were washed in a dilute phosphate-free detergent solution (0.1% detergent), followed by rinsing with deionized water. Leaves were then dried to a constant weight at 80 °C and ground to pass a 20-mesh screen. Leaves for nitrogen (N) analysis were also ground with mortar and pestle. Samples were analyzed for N by combustion using a Leco FP528 (St. Joseph, MI), whereas remaining nutrients [calcium (Ca), magnesium (Mg), potassium (K), phosphorous (P), sulfur (S), boron (B), zinc (Zn), iron (Fe), manganese (Mn), nickel (Ni), and copper (Cu)] were measured by an inductive coupled plasma spectrophotometer coupled to a Digiblock 3000 (SCP Science, Baie D'Urfé, Quebec, Canada).

Because the two cultivars were of different ages and located in different blocks within the orchard, no direct statistical comparisons are made between cultivars. All data were analyzed by *t* test to compare differences between measured parameters of damaged and nondamaged trees within each cultivar.

Results

The shoot length of 'Desirable' was significantly reduced on trees exhibiting severe freeze damage at 32, 47, 91, and 147 DAF (Table 1). The shoot length of damaged trees was less than half that of nondamaged trees on the first two sampling dates. By 147 DAF, the shoot length of damaged trees was only 64% of that for nondamaged trees (Table 1). In contrast, 'Kiowa' shoot length was significantly greater on trees suffering

Table 1. Shoot length, percentage of pistillate shoots, number of flowers or fruit/terminal, percentage of abnormal flowers, and leaf chlorophyll index of 'Desirable' pecan at 32, 47, 91, and 147 d after a late spring freeze.

DAF (d)	Damage	Shoot length [mean ± SD (cm)][z]	Shoots with pistillate flowers [mean ± SD (%)]	Flowers or fruit per fruiting terminal [mean ± SD (no.)]	Abnormal flowers [mean ± SD (%)]	Chlorophyll index [mean ± SD]
32	None	13 ± 4	95 ± 22	3.3 ± 1.0	0 ± 0	—
	Severe	6 ± 3*	65 ± 48*	2.0 ± 1.6*	50 ± 51*	—
47	None	13 ± 4	95 ± 22	2.8 ± 1.0	—	40 ± 3
	Severe	6 ± 3*	38 ± 49*	0.8 ± 1.2*	—	30 ± 4*
91	None	13 ± 4	53 ± 51	0.9 ± 1.1	—	45 ± 3
	Severe	8 ± 5*	15 ± 36*	0.3 ± 0.8*	—	42 ± 3
147	None	14 ± 5	53 ± 51	0.7 ± 0.8	—	45 ± 3
	Severe	9 ± 7*	10 ± 30*	0.1 ± 0.4*	—	43 ± 5

[z]1 cm = 0.3937 inch.
*Significantly different within columns and DAF by the *t* test at $P \leq 0.05$.

severe freeze damage than on nondamaged trees at 91, and 147 DAF (Table 2). The shoot length of damaged 'Kiowa' trees was not measured at 32 DAF because secondary budbreak was just beginning and shoots had not elongated to the point that they could be easily measured. By 147 DAF, the shoot length of damaged 'Kiowa' trees was 43% longer than that of nondamaged trees (Table 2).

The percentage of flowering or fruiting terminals was significantly lower on freeze-damaged 'Desirable' and 'Kiowa' trees than on nondamaged trees (Tables 1 and 2). At 32 and 47 DAF, 95% of the terminals of nondamaged 'Desirable' trees bore pistillate flowers. 'Desirable' trees with severe freeze damage bore pistillate flowers on 65% of terminals at 32 DAF and about 38% of terminals by 47 DAF. The percentage of fruit bearing terminals was reduced by 55% on damaged trees and by 42% on nondamaged trees between 32 and 147 DAF (Table 1). Only 5% of freeze-damaged 'Kiowa' terminals developed flowers or fruit throughout the study, whereas 95% of nondamaged 'Kiowa' terminals bore pistillate flowers at 32 and 47 DAF. Between 32 and 147 DAF, the percentage of fruiting terminals on nondamaged trees were reduced by only 12% (Table 2).

Cluster size was significantly smaller for freeze-damaged trees than for nondamaged trees on both cultivars throughout the study (Tables 1 and 2). The initial cluster size of freeze-damaged 'Desirable' was 2.0 flowers per cluster, decreasing to 0.1 fruit per cluster by 147 DAF (Table 1). The cluster size of nondamaged 'Desirable' 32 DAF was 3.3 flowers per cluster, decreasing to 0.7 fruit per cluster by 147 DAF. Freeze-damaged 'Kiowa' trees had a cluster size of only 0.2 47 DAF. This was reduced by only 0.1 fruit per cluster by 147 DAF. The cluster size for nondamaged 'Kiowa' trees dropped from 3.6 to 2.0 fruit per cluster over the course of the study (Table 2).

About 50% of the flower clusters on severely damaged 'Desirable' trees were abnormal compared with none of those from nondamaged trees at 32 DAF. Abnormal flower clusters were not observed on damaged or nondamaged 'Kiowa' trees throughout the study.

Leaf chlorophyll index was lower for freeze-damaged trees of both cultivars on the first sampling date (Tables 1 and 2). Leaf chlorophyll index continued to increase for damaged and nondamaged trees of both cultivars throughout the study (Tables 1 and 2).

Leaf N was lower in freeze-damaged trees than in nondamaged trees for both cultivars (Table 3). Leaf P and K were higher in freeze damaged 'Kiowa' trees than in nondamaged trees. Leaf Zn was also increased in freeze-damaged 'Desirable' (Table 3). Leaf Mg was significantly lower in freeze damaged 'Kiowa' trees.

The percentage of shoots bearing mouse-ear symptomatic leaves was higher on freeze-damaged 'Kiowa' trees than on nondamaged trees. Mouse ear symptoms were not observed on 'Desirable'.

Discussion

Although 'Desirable' trees produced pistillate flowers from secondary buds after damage by the late spring freeze, the percentage of

Table 2. Shoot length, percentage of pistillate shoots, number of flowers or fruit/terminal, percentage of abnormal flowers, leaf chlorophyll index, and percentage of mouse-ear symptomatic shoots of 'Kiowa' pecan at 32, 47, 91, and 147 d after a late spring freeze.

DAF (d)	Damage	Shoot length [mean ± SD (cm)][z]	Shoots with pistillate flowers [mean ± SD (%)]	Flowers or fruit per fruiting terminal [mean ± SD (no.)]	Abnormal flowers [mean ± SD (%)]	Chlorophyll index (mean ± SD)	Mouse-ear symptomatic shoots [mean ± SD (%)]
32	None	18 ± 9	95 ± 22	3.6 ± 15	0.00 ± 0.00	—	—
	Severe	—	—	—	0.00 ± 0.00	—	—
47	None	18 ± 9	95 ± 22	3.1 ± 1.5	—	38 ± 3	0 + 0
	Severe	21 ± 16	5 ± 22*	0.2 ± 0.7*	—	26 ± 4*	50 ± 51*
91	None	23 ± 18	85 ± 36	2.4 ± 1.4	—	43 ± 3	0 ± 0
	Severe	37 ± 30*	5 ± 22*	0.2 ± 07*	—	40 ± 4	50 ± 51*
147	None	23 ± 18	83 ± 38	2.0 ± 1.3	—	45 ± 3	0 ± 0
	Severe	40 ± 30*	5 ± 22*	0.1 ± 0.6*	—	42 ± 4	50 ± 51*

[Z]1 cm = 0.3937 inch.
* Significantly different within columns and DAF by the *t* test at $P \leq 0.05$.

Table 3. Leaf elemental concentration of freeze-damaged and nondamaged 'Desirable' and 'Kiowa' pecan.

		Leaf element concentration[z]											
Cultivar	Damage	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	S (%)	B (ppm)[y]	Zn (ppm)	Mn (ppm)	Fe (ppm)	Cu (ppm)	Ni (ppm)
Desirable	None	2.74	0.15	1.26	0.46	2.15	0.22	46	96	577	53	9.75	3.86
	Severe	2.57*	0.14	1.46	0.48	2.24	0.23	47	106*	568	52	10.0	2.35
Kiowa	None	2.76	0.15	1.43	0.56	1.96	0.24	55	128	388	55	9.75	3.20
	Severe	2.66*	0.17*	1.67*	0.52*	1.81	0.24	51	105	386	58	9.0	2.78

[z]Nitrogen (N), phosphorous (P), potassium (K), magnesium (Mg), calcium (Ca), sulfur (S), boron (B), zinc (Zn), manganese (Mn), iron (Fe), copper (Cu), and nickel (Ni).
[y]1 ppm = 1 $mg.kg^{-1}$.
*Significant difference within columns and cultivars by the *t* test at $P \leq 0.05$.

fruiting terminals and cluster size were reduced by ≈27% and 60%, respectively by 47 DAF. Because of the delay incurred by the loss of initial tissue to the freeze and subsequent initiation of new tissue growth flush, pistillate flowers were probably underdeveloped by 32 and 47 DAF. The first drop of pecan flowers consists of weak or underdeveloped flowers borne on short shoots (Sparks and Heath, 1972; Sparks and Madden, 1985). This drop is inversely related to shoot vigor (Sparks and Heath, 1972). At 47 DAF, the average shoot length of damaged trees was 6 cm, whereas that of nondamaged trees was 13 cm. There was no reduction in the percentage of fruiting terminals on nondamaged trees during this period. The average cluster size of nondamaged trees was only reduced from 3.3 to 2.8 pistillate flowers per cluster, indicating that the first drop of nondamaged trees was likely very light. During the same period, the cluster size on damaged trees was reduced from 2.0 to 0.8 fruit per cluster. Thus, it appears that the flower drop associated with the reduction of pistillate flowers on freeze-damaged 'Desirable' trees occurring between 32 and 47 DAF is likely a result of weak flowers rather than inadequate pollination and egg fertilization. Heavier fruit drop associated with frost damage has also been documented with apple (*Malus* × *domestica* Borkh.; Hirst, 2002).

The percentage of fruiting terminals and cluster size on nondamaged 'Desirable' was reduced by 42% and 1.9 fruit per cluster, respectively, between 47 and 91 DAF, whereas that of freeze-damaged trees was reduced by 23% and 0.5 fruit per cluster during the same period. This reduction occurred after the pollination period for damaged and nondamaged trees based on fruit size and coloration of the stigma at 91 DAF. Stigmatic surfaces of pistillate pecan flowers macroscopically appear brown or blackened within 48 h after pollination (Wetzstein and Sparks, 1989). The second drop of pecan fruit, occurring between 14 and 45 d after pollination, has been shown to coincide with abscission of nonpollinated flowers and is from a lack of successful fertilization of the egg (Sparks and Madden, 1985). As a wind-pollinated, monoecious crop exhibiting heterodichogamy, main pecan cultivars require a pollenizer with suitable pollen-release phenology, located within ≈49 m from the main cultivar to achieve adequate cross-pollination (Wood, 1997). The lack of a suitable pollinizer in the solid 'Desirable' block in which the study was conducted indicates poor pollination potential for freeze-damaged and nondamaged trees. Personal observations by the author suggest that freeze-damaged pecan trees can retain more fruit than that observed in the current study when adequate pollen is available to pollinate the subsequent crop of pistillate flowers developing from secondary buds. Initial development of fruit from secondary buds of freeze-damaged trees appeared to be delayed compared with nondamaged fruit. Nondamaged 'Desirable' pecans were in the "gel-stage" of fruit development on 5 Sept. 2007, whereas those of freeze-damaged trees were still in the "water-stage," at least 14 d behind in development on that date. Because of the limited number of fruit on damaged trees at harvest, there were not enough nuts to generate a statistically comparable data set for fruit quality and size. Fruit from damaged and nondamaged trees were fully mature when harvested together on 26 Oct. 2007.

Abnormal flowering as described previously (Cole and Hunter, 1965; Sparks, 1992; Woodroof and Woodroof, 1929) was observed in this study on about half of the fruiting terminals of freeze-damaged 'Desirable' trees. Although 'Kiowa' trees developed few pistillate flowers on growth from secondary buds after the freeze, the flower clusters that developed on damaged 'Kiowa' trees appeared normal. Cole and Hunter (1965) observed abnormal flowering after the Mar. 1955 freeze damage of pecan in Georgia on 'Schley', 'Stuart', 'Desirable', 'Farley', 'Moneymaker', 'Success', 'Pabst', and 'Mahan', but not on 'Curtis', 'Teche', 'Moore', 'Van Deman', or 'Frotscher'. Therefore, it appears that certain cultivars are more likely to produce abnormal flowers after a spring freeze than are others. This may be influenced by the phenology of budbreak. Sparks (1992) suggests that 'Desirable' is especially sensitive to environmental conditions that cause abnormal flowering. Abnormal flowering has been shown to depend on a critical temperature between –1.7 and –2.2 °C, and a critical stage of pistillate flower bud development within the 8 to 10 d interval before budbreak (Sparks, 1992). It appears likely that abnormal flowering of 'Desirable' in the current study resulted from secondary buds being exposed to low temperatures at the critical stage before morphological development of pistillate flowers. Based on the developmental stage of growth from secondary buds on 'Desirable', secondary budbreak of this cultivar likely occurred within a relatively short period after the freeze. The delayed secondary budbreak of 'Kiowa' may have influenced the lack of production of abnormal flowers on this cultivar.

Chlorophyll index readings have been shown to correlate well with leaf N concentration and stress for a variety of crops (Olivier et al., 2006; Varvel et al., 1997; Vos and Bom, 1993). The leaf chlorophyll index was lower for freeze-damaged pecan trees of both cultivars than for nondamaged trees at 32 and 47 DAF. In addition, leaf N was lower in freeze-damaged trees of both cultivars compared with nondamaged trees. These data, along with the observed reduced shoot length of freeze-damaged 'Desirable' trees, indicate a significant resource drain on freeze-damaged trees. This likely results from the energy expenditures required to produce growth from secondary buds after the late-spring freeze. Therefore, it appears that freeze-damaged trees are likely to benefit from supplemental fertilizer N application after a freeze event.

Heavy fruiting of pecan suppresses leaf K (Sparks, 1977; Wells and Wood, 2007) and leaf P (Hunter and Hammar, 1957; Sparks, 1977) concentration. The higher leaf concentrations of P and K in freeze-damaged trees compared with nondamaged trees likely results from the light crop load on damaged trees. Crop load may also influence leaf Zn, which likely accounts for the elevated concentration of leaf Zn in freeze-damaged 'Desirable'; however, there was no statistical difference in leaf Zn concentration between freeze-damaged and nondamaged 'Kiowa' trees. Suppression of leaf Mg in freeze-damaged 'Kiowa' trees may have been a result of increased leaf K because Mg and K compete for uptake by the tree (Sparks, 1985).

Although mouse-ear symptoms were visible on 50% of freeze-damaged 'Kiowa' shoots (Table 2), there was no significant difference in leaf Ni concentrations for either cultivar (Table 3). Mouse-ear symptoms have been previously attributed to a virus, a Cu deficiency, and a Mn deficiency (Gammon and Sharpe, 1956). Recently, mouse-ear has been proven to be symptomatic of Ni deficiency (Wood et al., 2004a). Wood et al. (2004b) suggest that mouse-ear symptoms can result from a physiological deficiency of nickel at budbreak, and may be influenced by biotic and abiotic factors. It appears that stress induced by freeze damage likely resulted in mouse-ear symptomology in the current study. Mouse-ear of pecan after a late-spring freeze has also been observed by Wood and Reilly (2007).

In summary, late spring freeze damage appears to have a significant influence on pecan physiology and fruit retention. Cultivars may vary in their response to late spring freeze damage. Although 'Desirable' produced a crop of pistillate flowers from secondary buds after the freeze, many of these flowers were abnormal in appearance. Freeze-damaged 'Desirable' trees exhibited reduced shoot length, reduced flower and fruit retention, reduced leaf chlorophyll index, and reduced leaf N concentration compared with nondamaged trees. In contrast, leaf Zn concentrations were higher in freeze-damaged 'Desirable' trees than in nondamaged trees. 'Kiowa' trees damaged by the late spring freeze had longer shoot length and failed to produce pistillate flowers from secondary buds on most shoots. Abnormal flowers were not observed on 'Kiowa'. Freeze damage also led to the appearance of mouse-ear leaf symptoms and reduced leaf chlorophyll index, leaf N, and leaf Mg concentrations. Leaf P and leaf K concentrations were higher in freeze-damaged 'Kiowa' trees than in nondamaged trees. These observations provide valuable information regarding the response of pecan trees to late spring freezes.

Literature cited

Cole, J.R. and J.H. Hunter. 1965. Abnormal flowering of pecans following freeze damage in 1965. Plant Dis. Rpt. 49:146–147.

Gammon, N. and R.H. Sharpe. 1956. Mouse ear: A manganese deficiency of pecans. Proc. Amer. Soc. Hort. Sci. 68:195–200.

Hagler, T.H. 1956. Freeze injury to pecans in Alabama. Proc. Southeastern Pecan Growers Assn. 49:9.

Hirst, P.M. 2002. The apple fruitlet thinning response to carbaryl is unaffected by russet. HortTechnology 12:75–77.

Hunter, J.H. and H.E. Hammar. 1957. Variation in composition of pecan leaves. Better Crops Plant Food 41:18–25.

Madden, G. 1978. Effect of winter injury. Pecan Qrtly 12:17.

Madden, G. 1980. Late spring freeze in a pecan nursery as a function of variety. Pecan Qrtly 14:11.

Maelstrom, H.L., J.R. Jones, and T.D. Riley. 1982. Influence of freeze damage on fruitfulness of the pecan. Pecan Qrtly 16:13–17.

Olivier, M., J. Goffart, and J. Ledent. 2006. Threshold value of chlorophyll meter as a decision tool for nitrogen management of potato. Agron. J. 98: 496–506.

Smith, M.W., J.A. Anderson, and B.S. Parker. 1993. Cultivar and crop load influence cold damage of pecan. Fruit Var. J. 47:214–218.

Sparks, D. 1977. Effects of fruiting on scorch, premature defoliation, and nutrient status of 'Chickasaw' pecan leaves. J. Amer. Soc. Hort. Sci. 102: 669–673.

Sparks, D. 1985. Potassium nutrition of pecans, p. 1135–1152. In: R.D. Munson (ed.). Potassium in agriculture. ASA, CSA, SSSA, Madison, WI.

Sparks, D. 1992. Pecan cultivars: The orchard's foundation. Pecan Production Innovations, Watkinsville, GA.

Sparks, D. and J.L. Heath. 1972. Pistillate flower and fruit drop of pecan as a function of time and shoot length. HortScience 4:402–404.

Sparks, D. and G.D. Madden. 1985. Pistillate flower and fruit abortion as a function of cultivar, time, and pollination. J. Amer. Soc. Hort. Sci. 110:219–223.

Sparks, D. and J.A. Payne. 1978. Winter injury in pecans: A review. Pecan South 5:56–88.

Sparks, D., J.A. Payne, and B.D. Horton. 1976. Effect of subfreezing temperatures on budbreak of pecan. HortScience 11:415–416.

Varvel, G.E., J.S. Schepers, and D.D. Francis. 1997. Ability for in-season correction of nitrogen deficiency in corn using chlorophyll meters. Soil Sci. Soc. Amer. J. 61:1233–1239.

Vos, J. and M. Bom. 1993. Hand-held chlorophyll meter: A promising tool to assess the nitrogen status of potato foliage. Potato Res. 36:301–308.

Wells, M.L. and B.W. Wood. 2007. Relationships between leaflet nitrogen: Potassium ratio and yield of pecan. HortTechnology 17:473–479.

Wetzstein, H.Y. and D. Sparks. 1989. Stigma-pollen interactions in pecan. J. Amer. Soc. Hort. Sci. 114:355–359.

Wood, B.W. 1997. Source of pollen, distance from pollinizer, and time of pollination affect yields in block-type pecan orchards. HortScience 32:1182–1185.

Wood, B.W. and J.A. Payne. 1983. Flowering potential of pecan. HortScience 18:326–328.

Wood, B.W. and C.C. Reilly. 2001. Atypical symptoms of cold damage to pecan. HortScience 36:298–301.

Wood, B.W. and C.C. Reilly. 2007. Nickel: Impact on leaf morphology and growth. Pecan South 40:13–16.

Wood, B.W., C.C. Reilly, and A.P. Nyczepir. 2004a. Mouse ear of pecan: A nickel deficiency. HortScience 39:1238–1242.

Wood, B.W., C.C. Reilly, and A.P. Nyczepir. 2004b. Mouse ear of pecan: I. Symptomalogy and occurrence. HortScience 39:87–94.

Woodroof, J.G. and N.C. Woodroof. 1929. Abnormalities in pecan flowers. J. Hered. 21:39–44.