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Ethephon and NAA Facilitate Early Harvesting of Pecans

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Abstract. **In an attempt to solve the problems of nonuniform and delayed shuck dehiscense of pecan [*Carya illinoensis* (Wangenh.) C. Koch], ethephon and NAA were evaluated for their efficacy as harvest-aid treatments. A 3-year study under commercial-like orchard conditions using 75-year-old 'Stuart' trees resulted in a spray mixture of 9 mM ethephon and 1.5 or 3.0 mM NAA, or just 9 mM ethephon alone, accelerating shuck dehiscence by 1 to 2 weeks relative to that of the nontreated control. While all three treatments induced some degree of leaflet abscission, the two treatments employing the NAA and ethephon combination induced only about one-fourth (21% vs. 75%) as much leaflet abscission as when ethephon was used alone. However, this level of leaflet abscission (21%), plus an associated 50% drop in net photosynthesis for several days post-treatment, was sufficient to reduce in-shell nut yields in subsequent years. This appears to preclude commercial acceptability of such treatments for pecan. Chemical names used: (2-chloroethyl)phosphonic acid (ethephon), 1-napthaleneacetic acid (NAA).**

Technology allowing once-over or early harvesting would be of major benefit to the pecan industry. Such practices would be desirable because of the higher prices generally paid for the first fresh nuts on the market, higher quality of early season nuts, and reduced harvesting cost. It would also be of benefit to pecan growers in the southwestern United States, where the occurrence of late-season shuck dehiscence often results in freeze-damaged shucks that become a major obstacle to harvesting. Chemicals that produce ethylene or induce endogenous ethylene have proven beneficial to harvest-associated problems of several crops (Ben-Tal, 1987; Olien and Bukovac, 1978; Stein et al., 1986, 1987). Ethephon is one such chemical that exhibits potential as a harvest-aid for pecan (Stein et al., 1986, 1987; Wood, 1986). Involucre (shuck) dehiscence at nut ripening appears to be triggered by the evolution of ethylene from the kernel (Lipe and Morgan, 1970 and 1972) and can be accelerated by exposure to exogenous ethylene (Kays et al., 1975). Exposure of ripe fruit to ethephon accelerates shuck dehiscence and therefore exhibits potential as a commercial early harvest aid (Kays et al., 1975; Wood, 1986). Its use is currently deemed unacceptable because of its concurrent induction of leaf abscission and subsequent accentuation of alternate bearing due to stress imposed on assimilate reserves of the tree (Sparks, 1983; Sparks and Brack, 1972; Wood, 1987; Worley, 1979a, 1979b). Previous research based on limb treatments has shown that this adverse effect can be mitigated when NAA is used in conjunction with ethephon (Wood, 1985, 1986). Shucks are therefore induced to dehisce 3 to 5 weeks earlier than normal without the undesirable premature loss of leaves. This is partially attributed to a continued supply of auxin to the abscission zone, thus offsetting the decline in transported auxin that appears to be blocked by ethephon (Wood, 1985, 1986). Previous research using major limbs indicated that the combined use of ethephon and NAA as a harvest-aid appears promising (Wood, 1985, 1986); however, it had to be evaluated on a whole-tree basis in the orchard environment before its utility could become discernible. The objective of this study was to ascertain the effectiveness of ethephon and NAA as a commercially acceptable early harvest-aid of pecan.

Materials and methods

Plant material. The trees used in the various phases of this study were in a commercial-like orchard of 75-year-old 'Stuart' pecan trees growing at a 18.3 × 18.3 m spacing on an uniform soil (Norfolk loamy fine sand, siliceous, thermic Typic Paleudult) without supplemental irrigation and in accordance with Georgia Cooperative Extension Service recommendations for pest control and fertilization practices (Crocker, 1986).

Determination of kernel independence (Expt. 1). The time of completion of kernel filling and its independence from the tree was estimated using radiotracer methods. Terminal shoots with five to 10 leaves and supporting from one to three nuts were exposed to ^{14}C at roughly weekly intervals during the latter portion of the filling period and subsequently analyzed for ^{14}C imported into the kernel. Labeling was accomplished by sealing two to three terminal shoots supporting developing fruit in a large plastic bag containing a vial with 10 nCi of ^{14}C as $NaH^{14}CO_3$ (56 mC·mmol^{-1}, s.a.) The phloem of the terminal shoot was severed by ringing immediately after bagging to prevent the export of the radiolabel to other portions of the tree. $^{14}CO_2$ was then released by adding 1 ml of 1 M HCl and leaves were allowed to assimilate the label for 12 hr. Exposed nuts were collected after 2 days and stored at −20C until analysis. The level of radiolabel in the kernel was determined by extracting the kernel with petroleum ether and an aliquot mixed with 14 ml of Beckman non-aqueous liquid scintillation cocktail (Beckman Instruments, Fullerton, Calif.), cpm were determined using a Beckman LS-1800 liquid scintillation spectrophotometer.

Evaluation of ethephon and NAA as a harvest-aid (Expt. 2). The effectiveness of the conjunctive use of ethephon and NAA as a commercial-type harvest-aid technique for large trees was evaluated over 3 years. Effectiveness was determined by monitoring leaf abcission, shuck dehiscence, in-shell nut yield, and nut quality. Treatments were based on successful treatments used in a previous study involving applications to major limbs

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(Wood, 1987); they were as follows: a) unsprayed control; b) 9 mM ethephon (formulated as Ethrel; Rhone-Poulenc, Research Triangle Park, N.C.) plus 0.25% Surfel (nonionic spreader); c) 9 mM ethephon plus 1.5 or 3.0 mM NAA plus 0.25% Surfel. Dates of treatment application varied from 24 to 28 Sept., depending on the year. This corresponded to about 1 week before the period at which the earliest shuck dehiscence is visible on about 1% of the fruit. NAA was applied as the commercial NAA-800 formulation [potassium salt of napthaleneacetic acid (Rhone-Poulenc, Research Triangle Park, N.C.)]. The study was a randomized complete block with three blocks of four treatments with four trees per experimental unit. Sprays were applied at 6.4 $km\cdot hr^{-1}$ using a Bean Model 9100 (FMC Corp., Ocoee, Fla.) air-blast sprayer fitted with nozzle sizes of four to eight and calibrated to spray 45 liters/tree. Leaf retention and shuck dehiscence were determined about 9 days after treatment and in-shell nut yield determined in late October for each of the three treatment years. The pH of the treatment solutions were about 3.0 for the growth regulators and 6.8 for the water used for the sprays. Treatments were sprayed onto the trees within about 45 min of being mixed and were applied after air temperatures exceeded 24C.

Influence of ethephon and NAA on net photosynthesis (Expt. 3). Leaf net photosynthesis (Pn) was measured with a LI-600 (LI-COR) portable photosynthetic system equipped with a 1-liter leaf chamber. Measurements were made in the field on intact leaflets between 0900 and 1300 HR (solar time) at a near-saturating light level of 1000+ $\mu mol\cdot s^{-1}\cdot m^{-2}$ photosynthetic photon flux (Crews et al., 1980) and at ambient CO_2 levels. Leaf temperature generally ranged between 24 and 32C and typically increased about 0.2C during the measurement period, while leaf chamber relative humidity and CO_2 levels increased <2% and dropped about 30 ppm, respectively, during the 90-sec measurement period.

The influence of ethephon and ethephon–NAA on leaf Pn was determined by spraying major limbs to run-off with a hand sprayer and comparing Pn at 1, 2, 3, and 5 days post-treatment to pretreatment rates. The experiment was a randomized complete block design with nine blocks on three different trees. In addition to a water control, treatments consisted of the three ethephon and NAA treatments described in the above harvest-aid experiment plus ethephon (and 0.25% Surfel) at 3, 6, 12, and 24 mM levels.

Results

Nut independence study. The incorporation of ^{14}C into 'Stuart' pecan kernel tissues dropped rapidly between 6 and 15 Sept., with very little accumulation after the 22 Sept. (Table 1). Shuck dehiscence was first observed on a few nuts about 7 Oct., with there being little radiolabel accumulated thereafter. It is not clear whether this post-dehiscence accumulation was by importation or by absorption of $^{14}CO_2$ by the kernel oils via diffusion through the shell. In either case, kernel filling had nearly ceased 1 to 2 weeks before the earliest signs of shuck dehiscence.

Harvest-aid study. Spraying large orchard trees with ethephon and NAA at the first signs of shuck dehiscence accelerated dehiscence in each of the 3 years of treatment (Table 2). Dehiscence appeared to be advanced by 2 to 3 weeks over the check, with trees treated with all three harvest-aid treatments being harvestable by 9 days after treatment. Such treatments increased the percentage of dehiscent nuts by 2- to 3-fold by the end of this 9-day period. Shuck dehiscence during the third year was not as high as that of the preceeding 2 years. This may have

Table 1. Accumulation of ^{14}C in developing kernel tissues of 'Stuart' pecan as a result of exposing associated foliage to $^{14}CO_2$ at different dates during the filling period.

Treatment date[z]	Level of radiolabel in kernels (cpm)
September	
6	51,723 ± 15,031
15	3,098 ± 1,529
22	1,056 ± 589
October	
7[y]	122 ± 43
14	131 ± 55
21	99 ± 37

[z]$^{14}CO_2$ supplied to leaves associated with nut cluster for 12 hr and cpm determined 2 additional days after treatment.
[y]Early shuck dehiscence beginning at this time.

been due to the fact that pecans generally ripened later that year than in the previous two seasons and that the trees were under severe water stress the third season. The use of NAA in combination with ethephon resulted in the same level of shuck dehiscence as with ethephon alone.

Leaflet abscission was also influenced by the various harvest-aid treatments. All treatments increased leaflet abscission relative to the control for each of the three treatment years (Table 2). Ethephon alone induced from 50% to 92% leaflet abscission by 9 days after treatment. The loss was especially apparent when trees were mechanically shaken to release the nuts, resulting in a shower of leaves that interfered with harvesting efforts. Pecan foliage has two abscission zones, one at the base of leaflets and the other at the base of the compound leaf. The abscission mechanism of pecan is such that the leaflet abscission zone was more sensitive to ethephon than was the compound leaf zone. The 9-mM ethephon treatment resulted in foliar abscission at both zones, while the 9-mM ethephon plus 1.5- or 3.0-mM NAA treatments induced abscission only at the leaflet zones. The ethephon–NAA combination resulted in much more leaflet abscission than in the control, but only 25% of that of ethephon alone. There was no significant difference in leaflet abscission between the 1.5- and 3.0-mM rates; however, the 3.0-mM rate had a tendency to induce less abscission.

Harvest-aid treatments had no impact on nut production the first year, but did in subsequent years (Table 2). Trees sprayed with ethephon alone in 1985 had an in-shell nut yield reduction of 65% in 1986 and 95% in 1987. The two ethephon plus NAA treatments reduced in-shell yields in 1986 and 1987 ($\approx$30% and 40%, respectively).

Kernel quality, as judged by percent kernel shell-out, was not adversely influenced by any harvest-aid treatment during the 3-year study period (Table 2). Subjective evaluation of kernel color, also a quality factor, indicated a tendency for lighter-colored kernels from the harvest-aid treatment. This observation was based on kernel evaluations at the time of shuck dehiscence for each treatment.

Net photosynthesis. Leaves treated with ethephon exhibited with ethephon concentration (Table 3). Leaf Pn rates were suppressed in a linear manner when measured 1 day after ethephon treatment and in a curvilinear manner the 2nd and 3rd days post-treatment. The curvilinear effect was due to recovery of Pn rates by the 3-mM treatment and an encroachment of the saturation point at the highest ethephon levels (Table 3). Ethephon levels of 6 mM or higher had a substantial and long-lasting suppression of Pn. Pn of leaves treated with the ethephon–NAA treatments also was suppressed, with the NAA having no influence on Pn.

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Table 2. Shuck dehiscence, leaf abscission, in-shell nut yield, and kernel shell-out following treatment of 75-year-old 'Stuart' pecan trees with ethephon and NAA sprays.[z]

	Shuck dehisence (%)[x]			Leaflet abscission (%)[w]			In-shell nuts (kg/tree)			Kernel shell-out (%)		
Treatment[y]	1985	1986	1987	1985	1986	1987	1985	1986	1987	1985	1986	1987
Control	32 a	37 a	28 a	2 a	2 a	3 a	46 a	76 c	21 c	50.2 a	48.7 a	49.3 a
Ethephon, 9 mM	96 b	92 b	78 b	50 c	84 c	92 c	52 a	34 a	1 a	49.8 a	47.5 a	48.4 a
Ethephon, 9 mM + 1.5 mM NAA	93 b	94 b	73 b	23 b	21 b	26 b	42 a	54 b	9 b	50.4 a	46.4 a	50.0 a
Ethephon, 9 mM + 3.0 mM NAA	89 b	98 b	89 b	17 b	18 b	22 b	43 a	47 b	9 b	49.3 a	46.9 a	49.2 a

[z]Means followed by different letters are statistically different at the $P < 0.05$ level using the Waller–Duncan test.
[y]Treatments applied at first detection of natural shuck dehiscence, generally occurring around 25 Sept.
[w]Leaflet abscission determined 9 days after treatment by applying moderate pressure to leaflet base.
[x]Determined 9 days after treatment, suture split upon squeezing the shuck was regarded as shuck dehiscence.

Table 3. Influence of ethephon and/or NAA sprays on net photosynthesis of pecan leaves.

Concn (mM)[z]		Post-treatment net photosynthesis[y] Days after treatment			
Ethephon	NAA	1	2	3	5
		Experiment 1			
0	---	90	99	95	---
3	---	78	96	96	---
6	---	67	48	21	---
12	---	55	27	3	---
24	---	43	20	0	---
Significance[x]		0.96	0.93	0.89	
r^2[w]		L	LQ	LQ	
		Experiment 2			
0	0	72 b	103 b	---	79 b
9	0	63 a	48 a	---	32 a
9	1.5	59 a	39 a	---	39 a
9	3.0	61 a	41 a	---	40 a

[z]All sprays in both experiments, except checks, contained 0.25% Surfel.
[y]Net photosynthesis values are expressed as a percentage of the pretreatment check.
[x]Coefficient of determination (r^2) for best-fit model.
[w]L and Q represents significance of linear (L) or quadratic (Q) components at $P < 0.05$ level (N = 54), respectively.
[v]Means followed by different letters are statistically different at the $P < 0.05$ level by Waller–Duncan test.

Discussion

When viewed in the short-term, any of the three ethephon and ethephon–NAA harvest-aid treatments used in this study appear to be useable as a method to obtain early harvesting of pecan; however, the substantial loss of nut production in subsequent years precludes their long-term commercial utility. This production loss appears to be due to at least two factors—the suppression of net photosynthesis and the loss of leaf area. Both factors reduce tree assimilate reserves at a critical time of the year and subsequently contribute to reduced tree productivity and an accentuation of alternate bearing (Sparks, 1983; Sparks and Brack, 1972; Worley, 1979a, 1979b). The degree of leaf loss necessary to induce a yield loss is currently unknown, but it is clear from this study that a loss of 15% to 20% of the tree's foliage, accompanied by a 60% suppression of Pn for at least several days, is sufficient to reduce in-shell yields in 75-year-old trees by ≈35%. This reaffirms the importance of maintaining healthy foliage during autumn if consistent productivity is desired.

The interval between the application of the harvest-aid treatment and full development of shuck dehiscence was about 9 days the first and 3rd years of treatment and about 5 days the 2nd year. This variability appears to be temperature-related, since treatments were applied at about the same stage of shuck dehiscence each year. Since temperature influences the rate of ethylene evolution from ethephon-treated leaves (Olien and Bukovac, 1978) (there is a Q_{10} of ≈7.0 between 10 to 20C in sour cherry leaves), it would appear that the higher night and day temperatures (20/33C) in 1986 were enough to accelerate shuck dehiscence by several days in relation to the cooler night and day temperatures (≈13/29C) present during the 7 days following the ethephon treatments in 1985 and 1987. Post-treatment temperature is reported to be an important factor affecting field effectiveness of ethephon (Biddle et al., 1976; Olien and Bukovac, 1978; Wittenback and Bukovac, 1973), with temperatures between 16 and 29C being the optimum range for ethephon use (Biddle et al., 1976). Thus, it would appear that the effectiveness of ethephon on pecan would be highly temperature-dependent. Also, the energy of activation for ethephon degradation is relatively stable between pH 3 and 7 (Olien and Bukovac, 1978); it would be important to maintain the spray solution between these pH levels. The solution pH in this particular study was ≈3.0; this pH should have resulted in the ethylene-producing dianionic ethephon species to be less abundant than at a higher pH. The pH of the spray solution on the leaf surface was not determined, however, if it became much more acidic than pH 3.0, the rate of ethylene evolution would have rapidly diminished. Such a response could influence treatment effectiveness. An improvement on the method would likely have been to buffer the spray solution at a pH of 4 to 6 to assure optimum ethylene evolution.

It appeared, although no actual measurements were made, that there was little, if any, differential effect of ethephon on leaflet abscission or shuck dehiscence in relation to vegetative vs. reproductive growth or the number of fruit per cluster, as was reported for olive (Lavee and Martin, 1981a, 1981b).

Even the relatively low level of pecan leaflet abscission obtained with the use of NAA is still unacceptable for large trees. A much reduced level of drop is necessary if the method is to become commercially practical on trees with relatively low leaf to fruit ratios; however, the high ratio typical of younger trees may render the loss of leaf area and Pn efficiency negligible relative to the impact on nut yield. It is possible that leaf drop might be eliminated by inducing a rapid release of ethylene from ethephon over a shorter period of time, as has been observed in olive (Ben-Tal, 1987). Since ethylene evolution is much more

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rapid when the ethephon molecule is in the dianionic form at high pH, treatments may prove safe and effective if applied at pH 7 or higher.

This study supports the general observation that auxins can influence physiological processes thought to be regulated by ethylene (Ables, 1973) and that the conjunctive use of auxins (NAA) and ethylene (ethephon) can be used to partially control physiological processes such as shuck dehiscence and leaf abscission in pecan. Their use as a harvest-aid method for commercial pecan orchards is still questionable, but nevertheless encouraging, and merits much more research.

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