No Adverse Effect of Early Season Fungicide and Zinc Sprays on Leaf Area, Fruit Set, and Nut Quality of Pecan

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Abstract. Propiconazole, a fungicide, suppressed leaf area of a wide variety of young pecan [*Carya illinoensis* (Wangenh.) K. Koch] seedling genotypes but did not reduce leaf area of orchard trees. Leaf area declined linearly as dosage increased from 0.16 to 1.25 mL·L⁻¹. Suppression of leaf area by propiconazole was inversely proportional to leaf age. No reduction of leaf area was detected in orchards where 'Cheyenne', 'Desirable', and 'Pawnee' were treated with three applications (14-day intervals) of fungicide (either propiconazole, fentin hydroxide, or fenbuconazole) from budbreak to early May. Spring application of the three fungicides alone or in combination with zinc sulfate did not influence fruit set. Control of pecan scab [*Cladosporium caryigenum* (Ell. et Lang) Gottwald] was achieved with either fentin hydroxide or fenbuconazole for the full season, or with early season use of dodine, then propiconazole, and then followed by fentin hydroxide for late-season disease control. Fungicide treatments had no effect on nut weight. These data indicate that fungicides applied to pecan during pollination at commercially recommended dosages and intervals, with or without zinc sulfate, do not adversely influence leaf area or fruit set of orchard trees. Chemical names used: n-dodecylguanidine acetate (dodine); triphenyltin hydroxide (fentin hydroxide); 1-[[2-(2,4-dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl] methyl]-1H-1,2,4-triazole (propiconazole); α -[2-(4-chlorophenyl)ethyl]- α -phenyl-1H-1,2,4-triazole-1-propanenitrile (fenbuconazole).

Fentin hydroxide (SuperTin), and more recently propiconazole (Orbit) and fenbuconazole (Enable), are the primary fungicides used for early season pecan disease control. These fungicides are applied at 14-day intervals in the humid southeastern United States. Applications from budbreak ($\approx$ 1 Apr.) through pollination (early to mid-May) are primarily to protect young expanding foliage from pecan scab, as well as from minor diseases that may occur during this period (Ellis et al., 1994). The chemistry and mode of action of propiconazole and fenbuconazole are similar but markedly different from fentin hydroxide. The two new fungicides were recently introduced for pecan disease control, and the magnitude of their effects on horticulturally important factors, such as leaf development and pollination, has not been adequately assessed. Several foliar applications of zinc sulfate are also commonly applied during the spring to correct foliar deficiencies (O'Barr, 1989); hence, applications of fungicides and zinc are often combined. The application of these tank mixes often occur during pollen dispersal and

stigma receptivity and could adversely influence fruit set.

The influence of these chemicals on pecan physiology and biology is not fully understood and may be adverse. For example, fentin hydroxide inhibited flower receptivity and pollen germination of pecan at recommended commercial rates for disease control (He and Wetzstein, 1994; Wetzstein, 1989, 1990; Wetzstein and Sparks, 1983). Additionally, even a single application of fentin hydroxide reduced net photosynthesis of mature leaves on greenhouse-grown 'Curtis' pecan seedlings (Wood et al., 1984), and on mature leaves in an orchard, a 20% reduction persisted for up to 5 days (Wood et al., 1985). Fentin hydroxide, when applied during the previous season, is beneficial to fruit set of pecan and did not reduce fruit set when applied during pollination (Goff, 1990; Worley and Harmon, 1969). Additionally, propiconazole can inhibit shoot and leaf expansion of pecan under certain conditions (He and Wetzstein, 1991). Potential reductions in the area and photosynthetic efficiency of the foliage are of special significance in pecan because production and quality of the nut crop, during both current and subsequent crop seasons, are easily influenced by such factors (Monselise and Goldschmidt, 1982).

This study reports the effects of the primary pecan fungicides (fentin hydroxide, propiconazole, and fenbuconazole), singly or in combination with zinc sulfate, on leaf area, fruit set, and nut quality. It also evaluates the relative effectiveness of these fungicides for control of pecan scab.

Growth regulator effects on seedling foliage. The fungicides evaluated were commercial formulations at labeled recommended dosage and twice the recommended dosage (in mL·L⁻¹ of water): fentin hydroxide (SuperTin 4L; Griffin Corp., Valdosta, Ga.) at 0.94 and 1.88; propiconazole (Orbit; Ciba-Geigy Corp., Greensboro, N.C.) at 0.47 and 0.94; and fenbuconazole (Enable; Rohm and Haas Co., Philadelphia) at 0.63 and 1.26. These values are based on a use rate of 935 L of spray mixture per hectare. A dose response curve was developed in a second experiment for propiconazole using 0, 0.16, 0.31, 0.47, 0.63, 0.94, and 1.26 mL·L⁻¹. A third experiment compared the influence of propiconazole at 0.47 mL·L⁻¹ on diverse genotypes by using open-pollinated seedlings of 13 cultivars.

Treatments for all three experiments were applied to the leaves of greenhouse-grown pecan seedlings at the four-leaf stage with a hand-held sprayer. Each treatment was applied to all leaf surfaces until liquid runoff. Leaf areas were determined after 10 days by measuring the three youngest leaves of each plant using a LI-3100 area meter (LI-COR, Lincoln, Neb.). The design was a randomized block (10 blocks) comprised of single-tree experimental units reflecting the above chemicals and dosages.

Growth regulator effects on foliage of orchard trees. The growth regulator effects of fentin hydroxide, propiconazole, and fenbuconazole on trees in the field were determined during the 1992 or 1995 growing seasons on three cultivars growing in separate commercial-like orchards. The first study was on 7-year-old 'Pawnee' trees spaced at 9.1 $\times$ 9.1 m. This study, conducted in 1995, was structured as a randomized complete block (four blocks, consisting of four treatments per block, 10 trees per treatment; n = 160 trees). Five terminals per tree were sampled 25 days after the last application of fungicide by measuring the area of the fourth leaf from the bottom (mature) and the fifth leaf from the tip of the terminal (juvenile). Treatments were applied at 2-week intervals three times beginning at budbreak and included a nonsprayed control and (in mL·ha⁻¹) fentin hydroxide, 877; propiconazole, 483; and fenbuconazole, 584.

The second study, conducted in 1992, was on 14-year-old 'Desirable' trees spaced at 9.1 $\times$ 18.3 m and was comprised of five blocks consisting of four treatments per block with two trees per treatment (n = 40 trees). The treatments were nonsprayed control and (in mL·ha⁻¹) fentin hydroxide at 877 and propiconazole at 483, and were applied three times: first at budbreak, then at 2-week intervals. Leaves were sampled 21 days after the last fungicide application by collecting the fourth leaf from the bottom of the terminal of 25 random terminals of each tree.

The third study, conducted in 1992, was with 11-year-old 'Cheyenne' spaced at 9.1 $\times$ 9.1 m. This study was composed of six blocks

Received for publication 26 Oct. 1995. Accepted for publication 26 Mar. 1996. Chemical names are necessary to report factually on available data; however, the U.S. Dept. of Agriculture (USDA) neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable. 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.

with two treatments per block and four trees per treatment ($n = 48$ trees). This orchard was treated at budbreak and twice thereafter at 14-day intervals with (in $\text{mL}\cdot\text{ha}^{-1}$) fentin hydroxide at 877 and propiconazole at 483, and was sampled by collecting 10 leaves from each of the east and west sides of each tree by taking the fourth leaf from the bottom of randomly selected terminals.

All treatments were applied with a Savage 500 air-blast sprayer (Savage Equipment Co., Madill, Okla.) delivering $1262 \text{ L}\cdot\text{ha}^{-1}$. Leaf area of compound leaves was measured with a LI-3100 area meter.

Influence of fungicides and zinc on pollination. A 14-year-old 'Desirable' orchard was used for the pollination study in 1994 and 1995. The design was a randomized complete block consisting of six blocks with two trees per block for each treatment. All treatments were applied with a Savage 500 air-blast sprayer delivering $1262 \text{ L}\cdot\text{ha}^{-1}$. Treatments in 1994 were (in $\text{mL}\cdot\text{ha}^{-1}$) fentin hydroxide at 877; propiconazole at 438; zinc sulfate (36% Zn) (Fruit Industries, Ozark, Ala.) at $2.24 \text{ kg}\cdot\text{ha}^{-1}$ [plus urea (Tri State Plant Food, Dothan, Ala.) at $4.48 \text{ kg}\cdot\text{ha}^{-1}$]; fentin hydroxide at 877 plus zinc sulfate at $2.24 \text{ kg}\cdot\text{ha}^{-1}$ plus urea at $4.48 \text{ kg}\cdot\text{ha}^{-1}$; propiconazole at 438 plus zinc sulfate at $2.24 \text{ kg}\cdot\text{ha}^{-1}$ plus urea at $4.48 \text{ kg}\cdot\text{ha}^{-1}$; and a nontreated control. Applications were 5 days before stigma receptivity, during the early stages of receptivity, and 5 days after receptivity. Treatments for the 1995 season remained the same as in 1994, except fenbuconazole at $584 \text{ mL}\cdot\text{ha}^{-1}$ was substituted for propiconazole and applied either 5 days before or during the early stages of stigma receptivity. Influence on fruit set was determined for each tree by marking 25 nut clusters, each having four nuts per cluster, 2 days after the last treatments were applied, then remaining fruits were counted 5 weeks later.

Disease control. The efficacy of the fungicides for disease control and the resulting influence on nut quality were assessed using 'Desirable'. Fungicides were applied beginning at budbreak with a Savage air-blast sprayer during the 1991 and 1992 seasons. The first three sprays were at 14-day intervals with the next six applications at 21-day intervals. Six replications (randomized complete block) with two trees per replication were used for each treatment. Treatments were (in $\text{mL}\cdot\text{ha}^{-1}$) 1) fentin hydroxide, 877, for the full season; 2) dodine, $2.24 \text{ kg}\cdot\text{ha}^{-1}$ at budbreak, followed with propiconazole, 438, for the second and third applications, and then fentin hydroxide, 877, for the remainder of the season; 3) fenbuconazole, 584, for the full season; and 4) nontreated control. Twenty-five nut clusters per tree were tagged before nut elongation and rated at biweekly intervals for pecan scab severity. At harvest, the nuts were collected by replication and nut quality was determined using nut weight as the criterion. Data from the above studies were analyzed using SAS's analysis of variance procedure and means were separated with Duncan's multiple range test (SAS Inst., Cary, N.C.).

Results

Growth regulator effects. Commercial rates of fentin hydroxide and fenbuconazole did not reduce leaf area of greenhouse-grown 'Curtis' seedlings as compared to nontreated plants, whereas propiconazole caused a significant reduction in two of three tests (Table 1). Neither the recommended rate nor twice that rate of fentin hydroxide influenced leaf area. Fenbuconazole reduced leaf area only when applied at twice the recommended rate. This reduction occurred in only one of the three tests. Propiconazole reduced leaf area by about one-half at both rates in all three tests (Table 1). There was no difference between the $1\times$ and $2\times$ rates. A single treatment of propiconazole suppressed leaf area of 'Curtis' seedlings, with suppression increasing linearly with increasing concentration from 0.16 to $1.25 \text{ mL}\cdot\text{L}^{-1}$ of water (Fig. 1). This inhibitory influence of propiconazole on leaves of seedlings also was expressed by 13 other cultivars. Ex-

pansion of the youngest leaf of 'Cape Fear', 'Cheyenne', 'Curtis', 'Elliott', 'Mahan', 'Moneymaker', 'Moore', 'Pawnee', 'Schley', 'Stuart', and 'Success' was reduced ($\alpha \leq 0.05$ by F test), whereas 'Desirable' and 'Summer' were unaffected. The leaf area of older, more developed leaves was unaffected, except for 'Curtis', 'Elliott', 'Moneymaker', 'Moore', and 'Schley'. Leaf expansion in these cultivars was reduced in the second youngest leaf. Older (third) leaves were unaffected in 12 of the cultivars, with 'Moore' being the exception.

Field applications of the three fungicides, beginning at budbreak on 'Pawnee', did not affect ($\alpha \leq 0.05$) leaf area of either older (fourth from the bottom of the developing terminal) or younger (fifth from the tip of the developing terminal) leaves even though the terminals were exposed to three sprays of each fungicide. Similar results were obtained in 1992 when only propiconazole and fentin hydroxide were compared on 'Desirable' and

Table 1. Influence of fungicide sprays on leaflet area of 'Curtis' seedlings receiving a single foliar spray.

Fungicide concn ^y	Leaflet area (cm^2)		
	Test ^z		
	1	2	3
Nonsprayed control	58 a ^x	26 ab	44 a
Fentin hydroxide, $1\times$	47 a-c	27 ab	33 ab
$2\times$	42 ab	26 ab	40 a
Propiconazole, $1\times$	38 d	13 b	17 bc
$2\times$	33 d	10 b	9 c
Fenbuconazole, $1\times$	54 ab	38 a	33 ab
$2\times$	40 cd	28 ab	25 a-c

^xFor each fungicide concentration, 10 seedlings at the four-leaf stage were sprayed, and leaf area of the three youngest leaves was measured after 10 days. This test was repeated three times.

^yFungicide concentration (in $\text{mL}\cdot\text{L}^{-1}$ of water): fentin hydroxide at 0.94 and 1.88; propiconazole at 0.47 and 0.94; and fenbuconazole at 0.63 and 1.25.

^zMean separation within columns at $\alpha \leq 0.05$ by Tukey's HSD test.

Fig. 1. Dose response of propiconazole on leaf areas of 'Curtis' pecan seedlings. Propiconazole was applied to the foliage as a single application while seedlings were actively growing. Dosages were 0, 0.16, 0.31, 0.47, 0.63, 0.94, and $1.26 \text{ mL}\cdot\text{L}^{-1}$. Significant regression responses ($\alpha \leq 0.05$) were linear (L) and quadratic (Q). The regression model was leaf area (y) = $156.5 - 240.1x + 125.5x^2$, where x = propiconazole ($\text{mL}\cdot\text{L}^{-1}$) ($R^2 = 0.68$; $P \leq 0.0001$ for linear component and $P \leq 0.0002$ for quadratic component, and $n = 56$).

'Cheyenne'. Neither fungicide affected ($\alpha \leq 0.05$) the leaf area of 'Desirable'. This trend also was found in the 'Cheyenne' orchard where only fentin hydroxide and propiconazole were compared without a nonsprayed control.

Pollination response. Fruit set for 'Desirable' was determined after the end of the second fruit drop, which is associated with conditions that prevent ovule fertilization (Sparks and Madden, 1985). The average fruit drop for all treatments was 54% and 70% for 1994 and 1995, respectively—greater than that previously reported for open-pollinated 'Desirable' [usually $\approx 40\%$ (Sparks and Madden, 1985)]. There was no difference ($\alpha \leq 0.10$) in 1994 among fungicide, zinc sulfate, or fungicide plus zinc sulfate treatments during either prestigma receptivity, stigma receptivity, or poststigma receptivity when compared to a nonsprayed control. There also were no treatment effects ($\alpha \leq 0.10$) during 1995, when sprays were applied during either prestigma receptivity or stigma receptivity. Fenbuconazole, used in place of propiconazole in the 1995 test, has a similar chemistry to propiconazole and also had no effect on fruit set.

Pecan scab control. During 1991 and 1992, fentin hydroxide and fenbuconazole were compared as full-season fungicides for pecan scab control. Propiconazole was used primarily as a prepollination fungicide, preceded at budbreak with fentin hydroxide (1991) or dodine (1992). Nontreated nuts were more severely diseased during both seasons than those treated with fungicide treatments (Table 2). Fentin hydroxide gave better disease control than did full-season fenbuconazole, but there was no difference between propiconazole and the fenbuconazole treatments for each season (Table 2). When nuts per kilogram was used as criterion to measure effectiveness of disease control, nonsprayed nut counts were 191 and 150/kg for 1991 and 1992, respectively. Fungicide-treated nuts were larger ($\alpha \leq 0.05$) than nontreated nuts for 1991 (ranging from 112 to 123/kg) and 1992 (ranging from 108 to 112/kg). Nut size was not influenced ($\alpha \leq 0.05$) by any of the fungicide treatments for either year.

Discussion

Leaves of greenhouse-grown seedlings and of orchard-grown trees responded differently to propiconazole. Fungicide application to the seedling leaves until liquid runoff probably delivered a higher dose to leaf surfaces than is typically delivered by air-blast sprayers. This practice may partially explain why leaf area was reduced for seedlings but not orchard trees. A previous report that propiconazole reduced leaf area in orchard trees was based on

Table 2. Pecan nut scab as affected by the fungicides fentin hydroxide, propiconazole, dodine, or fenbuconazole on 'Desirable', 1991 and 1992.

Fungicides	Nut scab severity ²	
	1991 ³	1992
Nonsprayed control	6 a	7 a
Fentin hydroxide	3 c	2 d
Fentin hydroxide/propiconazole/fentin hydroxide	4 bc	---
Fenbuconazole	4 bc	4 bc
Dodine/propiconazole/fentin hydroxide	---	3 cd

²Nut scab severity ratings: 1 = no scab; 2 = trace to 6%; 3 = greater than 6% to 25%; 4 = greater than 25% to 50%; 5 = greater than 50% to 75%; 6 = greater than 75% to 94%; 7 = greater than 94% to 99%; 8 = 100%.

³Mean separation within years by Duncan's multiple range test at $\alpha \leq 0.05$.

spraying leaves until runoff, once or thrice weekly from budbreak through pollination (He and Wetzstein, 1991, 1994). Our studies demonstrated reduced leaf area of greenhouse-grown seedlings when propiconazole was applied once until runoff, but not on orchard leaves of mature trees treated with an air-blast sprayer. These data, therefore, indicate that a propiconazole-induced reduction of leaf area is unlikely in commercial orchards.

The influence of disease management practices during pollination and pistillate flower receptivity on fruit set is of concern. For example, fentin hydroxide reduced pollen germination and disfigured stigmas during the receptivity period (He and Wetzstein, 1994; Wetzstein, 1989, 1990). The inhibited pollen was derived from individually treated branches sprayed with the fungicide until runoff, once or thrice weekly, from budbreak through pollination. In contrast, neither fruit set nor nut quality were reduced under field conditions when fentin hydroxide was applied with an air-blast sprayer (Goff, 1990). Data from our study confirm the reported benign influence of fentin hydroxide on fruit set and, additionally, indicate a benign role for propiconazole and fenbuconazole under conditions of normal field use.

Fungicides and zinc sulfate are commonly applied to pecans during the time of rapid leaf expansion, hence, creating the possibility of an influence of zinc alone, or in combination with the fungicides, on fruit set. Our results demonstrated not only that fruit set was unaffected by fungicide sprays but also that combined fungicide and zinc sulfate sprays just before, during, or just after stigma receptivity are not likely to adversely influence fruit set in the commercial orchard environment.

Pecan scab control is usually essential to producing a quality crop in the southeastern United States. Fentin hydroxide and propiconazole have been the recommended primary early season fungicides until the recent introduction of fenbuconazole in 1995. Data obtained from this study indicate that all three of these fungicides can effectively control pecan

scab and have no detrimental effect on leaf area or fruit set under orchard conditions when used singly or in combination with zinc sulfate.

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