EVALUATION OF SYSTEMIC FUNGICIDES AND DORMANT SPRAY APPLICATIONS IN PECANS AND IMPLICATIONS FOR DISEASE MANAGEMENT

by

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(Under the Direction of Timothy Brenneman)

ABSTRACT

Pecan scab, caused by the fungal pathogen *Fusicladium effusum*, is the most severe disease of pecan in the southeastern United States. Fungicides are an essential tool to reduce losses, and the movement of systemic fungicides, as well as benefits of dormant sprays was investigated. Field experiments demonstrated the systemicity of azoxystrobin, tebuconazole, and phosphorous acid. All systemic treatments translocated at least two leaves above where fungicide was applied in the field, and azoxystrobin and phosphorous acid resulted in greater inhibition seven days after fungicide application compared to earlier samples. In studies of basipetal movement, the first unsprayed leaf below the treated foliage showed a small reduction in lesion development from TPTH at day 4, perhaps from redistribution with moisture, but none thereafter. In contrast, the phosphorous acid greatly reduced lesion development at most sampling dates on both the first and second leaf below the treated foliage for up to 14 days after application. Dormant sprays applied just prior to budbreak were evaluated to reduce inoculum from over wintering lesions, and thus primary infections. Elast most consistently reduced in sporulation from stem lesions, but reductions in disease were relatively small. Other products like chlorothalonil, Sulforix, Lime sulfur, copper, and combinations of these also reduced
sporulation in the lab, but had little if any effect on disease development when applied in the field. When applied mid-season after leaves formed but before fruit development, Sulforix and Lime sulfur both sometimes reduced nut scab, but not nearly as much as commercial covers sprays. Results from this study will contribute to managing *F. effusum* more efficiently with fungicides, especially during the early part of the growing season.

INDEX WORDS: *Fusicladium*, pecan scab, triazole, strobilurin, phosphite, TPTH, systemic fungicide, dormant spray, lime sulfur
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CHAPTER 1
INTRODUCTION AND LITERATURE REVIEW

Introduction

Pecan (*Carya illinoinensis*) is an important nut crop in the United States, but is subject to several diseases, especially in the more humid production areas like Georgia. Approximately 40% of pecan production in the United States is in the state of Georgia. In 2013, pecan acreage was estimated to be 145,769 acres in Georgia with a total farm gate value of $315,570,610 (12). Pecans are affected by several fungal diseases such as scab (*Fusicladium effusum* G. Winter), anthracnose (*Colletotrichum gloeosporioides*), downy spot (*Mycosphaerella caryigena*), zonate leaf spot (*Cristulariella moricola*), and powdery mildew (*Microsphaera ulni*) (4). Pecan scab is the most economically important pecan disease (31). In Georgia, annual economic losses to pecan scab are estimated to be 20-50 million dollars, including direct crop loss and the costs of chemical control (10,11,12). Fungicides are a critical part of pecan production programs. It is imperative that they consistently provide effective control, especially considering the short life cycle and polycyclic nature of the pathogen that can lead to explosive epidemics when weather is favorable. Fungicide applications for pecan scab are recommended at approximately 14-day intervals on susceptible cultivars. However, abnormally wet spring weather, as seen in 2013 and 2014 triggered epidemics of scab earlier in the season, and forced some growers to adopt 7-10 day intervals based on disease history and cultivar. In 2013 and 2014, some susceptible cultivars such as Desirable also exhibited severe disease and even defoliation by *F. effusum* as early as
June. While leaf health is very important, these early season foliar lesions are also thought to be an important source of inoculum for later season infection of the fruit (21). In an attempt to better manage pecan scab, it is imperative to prevent the early stages of disease epidemics by fungicide application to protect young developing tissue. Considering the rapid growth of pecan foliage at this time of year, and the extreme susceptibility of this young expanding foliage, this can be difficult based on current spray recommendations if only protectant fungicides are used (21). Fortunately several classes of systemic fungicides are labeled for use on pecans, including demethylation inhibitors, quinone outside inhibitors, and most recently the phosphites. However, the degree of movement of these products in pecan foliage is largely unknown.

Another approach that has been used to manage disease in some perennial crops is the application of dormant sprays to reduce initial inoculum from overwintering structures (7). Pecan scab overwinters as stromata on diseased tissues, with lesions on the young stems thought to be particularly significant source of conidia for initiating new epidemics. Caustic materials such as lime-sulfur have been shown to be efficacious in managing diseases in other fruit crops where the primary inoculum has a direct impact on the epidemics (7). Current protectant fungicides used in pecan production such as dodine have consistently provided in-season control of pecan scab since the 1960s. Furthermore, dodine has been found to suppress sporulation of \textit{F. effusum}, which merits a deeper investigation into the potential dormant use of dodine in pecans (48,49). Dodine severely affects the metabolism of fungal cells, thus inhibiting growth and respiration (16). However, the degree of control provided by products such as dodine and lime-sulfur applied to pecans in the dormant stage remains unknown.
The overall goal of this research project was to improve management of pecan scab by better understanding the mobility of the current systemic fungicides used in pecan production, and to evaluate dormant fungicide applications for the reduction of overwintering inoculum.

Literature Review

Pecan (C. illinoinsis) is a species of hickory in the Juglandaceae family; it is native to the Mississippi river valley in the southern regions of the United States, but is not native to Georgia. In the United States, pecans are grown commercially for their nuts, with 40% of that production in the state of Georgia. In 2012 commercial pecan production was reported in 14 states, and overall the United States produced more than 80 percent of the world’s pecans (27). The Georgia Farm Gate report placed the value of pecan production in Georgia at $319 million in 2011, $249 million in 2012, and $315 million in 2013.

Disease Development and Biology

Pecan scab, caused by Fusicladium effusum is a hemi-biotrophic fungus in the family Venturiaceae. Scab is the most devastating disease of pecan (C. illinoinsis), and is the major target of disease control efforts in the southeast (4). The pathogen survives the dormant period of pecan as stromata formed on shucks, twigs, bud scales, leaf rachises, and petioles (21,23). In the spring, under conditions of high relative humidity or free moisture, the stromata produce conidia that are the primary inoculum for new epidemics. These stromata can survive extended periods of nutrient depletion, cold weather, or other periods of stress by remaining dormant in the late-season shoot infections, shucks, and leaves from previous seasons (21, 23, 33, 46). Environmental conditions are usually favorable for sporulation of F. effusum at the time of bud break, and disease management recommendations suggest that the first fungicide application be applied at this time. Stromata in the previous season’s lesions continue to produce inoculum
well into the growing season, making *F. effusum* difficult to manage during favorable disease development conditions, especially in the early spring due to the continuous and prolonged susceptibility of young foliar tissue. *Fusicladium effusum* has been reported to survive the winter in mid- to late-season shoot infections and to produce inoculum much more frequently at these sites compared with new shoot infection initiated in the spring (4). The overwintering of inoculum remains poorly understood in pecans but has obvious implications for the pathogen’s life cycle. The disease is characterized by olivaceous to black lesions, with a velvety or rough appearance when active (4). When conditions become favorable conidia are released from the conidiophores within the lesions; this is brought about by surface drying and abrupt drop in relative humidity (31,32). Once liberated, conidia are dispersed by wind, rain splash and wash off (46). Moisture in the form of rain, fog or dew is essential for infection (32,33). Forty-eight hours of continuous leaf wetness is optimum for infection and less than 9 hours can result in a low rate infection (32). Conidial release peaks in the morning as dew dries, however secondary releases may occur after daytime rain showers (4). Thus, scab epidemics are most severe in years with above average rainfall. Free moisture is required for germination and infection. Infection occurs at 10-35 °C, with an optimum range of 15-25 °C (4). Infection requires as little as two hours of wetness at 20 °C, but the combined effects of wetness period duration and temperature are not fully understood (4). Secondary cycles of infection occur throughout leaf and fruit development, and these secondary cycles can have a direct impact on the crop value (39, 61). Symptoms of pecan scab infection include reduction of healthy foliar and fruit surface area and premature nut and leaf drop (4). Premature nut drop occurs as a result of early season infection, especially on susceptible cultivars.
The pecan is most vulnerable to scab from the onset of fruit development until the shell hardening period, thus making fungicide application a crucial management practice over a long period of fruit development.

**Disease Management**

Many of the pecan cultivars in production are susceptible to scab, and historically there are several examples of relatively resistant cultivars becoming susceptible after some years of cultivation (29). Considering the potential for serious yield loss and lack of other control options, growers rely heavily on fungicide applications to manage scab in commercial orchards (8, 13, 22). Establishing an orchard with resistant cultivars is the ideal control method; however differences in nut quality between susceptible and resistant cultivars is an economic constraint for commercial production. With the increased international export of pecans, growers often prefer susceptible cultivars that exhibit large nut size and percent kernel because of their high market demand. Infection by *F. effusum* is highly cultivar specific; fungal isolates from one cultivar are often unable to infect other cultivars (19). However, over time new biotypes of *F. effusum* have been observed on previously resistant cultivars (4,48,67). For example, the cultivar Stuart was introduced as resistant to pecan scab during the 1950s, but is now considered susceptible (4,45,62,69).

The commercial production of high quality pecans, especially those of susceptible cultivars, depends on multiple fungicide applications per season. Fungicides with different modes of action have been deployed in spray programs to control pecan scab (38). Fungicide applications can be scheduled with either a calendar based program, or a weather-driven program such as the Au-Pecan model (6). In calendar based spray programs, fungicides are typically applied every 10-14 days during the pre- pollination period and 10-21 days in the post-
pollination period. The secondary method for timing fungicide application is AU-Pecan, which was adapted at the University of Georgia from the AU-Pnut system developed by Auburn University for peanut leaf spot. The system is based on occurrence of rain or heavy fog and the average probability of rain over the next five days (9). Field tests with Au-Pecan have provided similar control of pecan scab with an average of 2 or fewer fungicide applications per growing season (9,38).

**Fungicide Classes**

Fungicides registered for use for pecan scab control belong to different groups with different MOAs including guanidines, organotins, methyl benzimidazole carbamates (MBCs), demethylation inhibitors (DMIs), quinone outside inhibitors (QoIs), and phosphorus acid (38).

**Guanidines.** Dodine is a member of the guanidines chemical group (FRAC Code U12), and was registered for pecan scab control in 1963 (48). Guanidines are broad spectrum multisite fungicides. The mode of action for guanidines is unknown, but is thought to involve the disruption of cell membranes. Guanidines such as dodine can target the mitochondrial membrane of fungal cells, as well as certain enzymes involved in oxidative phosphorylation (16,52). Dodine, currently labeled as Elast (Aceto Agricultural Chemical Corp., Port Washington, NY), has been used as a protectant with minimal systemic activity (48). Dodine is a surface protectant compound with a strong diffusing capability in the leaf cuticle or in surface lipids (37). There is a medium to low risk for fungicide resistance to dodine, however fungicide resistance has been reported in the apple scab pathogen, *Venturia inaequalis*, which is a close relative of the pecan scab fungus (40).

**Organotins.** Fentin hydroxide (or triphenyltin hydroxide, TPTH) is a member of the organotins chemical group (FRAC Code 30). The mode of action of organotins on fungi is not
well described, but is thought to inhibit the mitochondria (1). TPTH is applied to pecan foliage and fruit tissue throughout the growing season as a protectant; however it is most effective in providing control for nut scab epidemics. Organotins inhibit spore germination and growth, thus preventing infection. Because organotins such as TPTH having multiple sites of action, it is uncommon for fungi to evolve resistance to them. However, resistance to the organotin fentin hydroxide has been reported in pecan scab isolates from several counties in Georgia and in other plant pathogens (64,66).

**Methyl Benzimidazole Carbamates (MBCs).** Thiophanate-methyl, a member of the methyl benzimidazole carbamates group (MBC) (Frac Code 1), is marketed on pecans as Topsin-M (United Phosphorus Inc, King of Prussia, PA). Thiophanates are broad spectrum systemic fungicides that target β-tubulin assembly. Thiophanate-methyl is xylem mobile and is translocated through the plants transpiration stream (15). The MBC fungicides have a high risk for fungicide resistance due to their site-specific mode of action. Because MBC’s suppress the activity of β-tubulin, thiophanates can interfere with mitosis, and inhibit spore germination and hyphal growth (57). Fungicide resistance to benomyl and thiophanate-methyl have been reported in many plant pathogens, including the pecan scab pathogen (48,66).

**Demethylation Inhibitors (DMIs).** Triazoles, the largest group of the DMI fungicides, are single-site systemic fungicides with translaminar movement in plant tissue. The ability of fungicides such as triazoles to penetrate the xylem apoplast is related to their lipophilicity (42). Fungicide lipophilicity is defined as the partition coefficient between a plant membrane and an aqueous environment, and is measured by determining its octanol-water coefficient ($K_{ow}$). The DMI fungicides generally have intermediate log $K_{ow}$ values allowing for rapid permeation through the cuticle. Sterol demethylation inhibitors (DMIs) have been used in pecan fungal
disease control since 1988 (4). DMI fungicides registered for use on pecan include fenbuconazole, propiconazole, tebuconazole, and metconazole, marketed under the trade names, Enable 2F (DOW AgroSciences, Indianapolis, IN), Orbit/Propimax (Syngenta Crop Protection, Inc, Greensboro, NC), Orius 3.6F (Makhteshim Agan of North America, Inc, Raleigh, NC), and Quash (Valent U.S.A. Corp. Walnut Creek, CA), respectively (38). Additionally, products sold under the trade names Quadris Top (Syngenta Crop Protection, Inc., Greensboro, NC), Quilt (Syngenta Crop Protection, Inc., Greensboro, NC), Stratego (Bayer CropScience LP, Research Triangle Park, NC), Absolute (Bayer CropScience LP, Research Triangle Park, NC), and Custodia (Adama Australia Pty. Ltd, St Leonards NSW, Australia) are mixtures of DMI and QoI fungicides (38). The DMI fungicides hinder the production of ergosterol in fungal cells by inhibiting C-14 demethylase (45). New DMIs continue to be developed due to their desirable qualities of broad-spectrum activity and single-site mode of action (44, 59).

Quinone Outside Inhibitors (QoIs). The QoIs (FRAC Code 11) sometimes referred to as strobilurins, are single-site, systemic fungicides that exhibit limited xylem mobility in the host plant (27, 78). All QoI fungicides move into the plant and are locally systemic (translaminar) (78). However, differences in systemic movement have been observed with the various QoI products (27). For example, pyraclostrobin is a locally systemic QoI fungicide that is taken up by the plant, but doesn’t move far beyond the site of uptake (27,78). Whereas, azoxystrobin is taken up by the plant and is also systemic to a limited extent beyond the site of uptake (27). These unique characteristics help compensate for incomplete spray coverage which can be a critical factor in disease management in many crops, especially pecans. The target site of all QoI fungicides is the cytochrome b complex in the respiratory chain complex III, located in the
mitochondria. QoI fungicides bind at the Qo-center on cytochrome b and block electron transfer between cytochrome b and cytochrome bc1, preventing the mitochondria from producing ATP (54). The QoIs currently registered for pecan fungal disease control are azoxystrobin, pyraclostrobin, kresoxim-methyl, and trifloxystrobin, marketed under the trade names Abound (Syngenta Crop Protection, Inc., Greensboro, NC) or Quilt (Syngenta Crop Protection, Inc., Greensboro, NC), Headline (BASF Corp., Research Triangle Park, NC), Sovran (BASF Corp., Research Triangle Park, NC), and Stratego (Bayer CropScience LP, Research Triangle Park, NC), respectively (38).

**Phosphorus Acid.** Phosphorus acid fungicides (FRAC Code 33), commonly referred to as phosphites, were originally developed for use on oomycete pathogens. However, they have been shown to be efficacious on fungal pathogens of various genera, including the pecan scab pathogen (5). Phosphorous acid is a simple molecule and has low environmental toxicity (5). The mode of action of phosphite is not fully understood, although it may operate at two different levels. First, there may be a direct mode of action (5). Second, it appears that phosphites can increase resistance to pathogens by stimulating the plant defense system on plants treated with phosphite, therefore minimizing or preventing infection (5,36). Phosphites such as Prophyt (Helena Chemical Company, Collierville, TN) and K-Phite (Plant Food Systems, Inc., Zellwood, FL) are labeled to control pecan scab, particularly on the leaves, but are sometimes less effective in controlling fruit scab (5). One reason for this difference may involve differences in uptake and systemicity in leaves versus fruit. As a group, the phosphites are highly systemic with the ability to translocate in both the xylem and the phloem (55). In the phloem, phosphite is trapped and is translocated through the plant in association with photo-assimilates in a source-sink relationship (56,60). Phosphite treatment also induces
a rapid defense response in the challenged plant (35). This defense response aids in stopping pathogen spread in a great number of hosts. Although the mode of action of phosphites is largely unknown, it offers several advantages by acting directly on the pathogen and indirectly in stimulating host defense responses that ultimately inhibit pathogen growth (36).

The value of preventative fungicides for pecan scab control was clearly demonstrated as early as 1930 (48). The fungicide of choice prior to 1960 was Bordeaux mixture. Improved levels of control in the 1960s were achieved following the registration of dodine, triphenyltin hydroxide, and benomyl for management of pecan foliar diseases. Dodine represented a major breakthrough in effective scab control in 1960. Dodine has been found to suppress sporulation of *F. effusum* (49). In order to take advantage of such effects, most of the small amounts of dodine that were used were applied during the prepollination period when phytotoxicity is minimal (48). However, dodine was relatively expensive, and the previous wettable formulation was not as desirable to growers. As other fungicide options became available, overall use declined. Price reductions and a relatively recent change to a superior flowable formulation (Elast) created renewed interest in dodine, and it is now one of the most widely used fungicides on pecans. Benomyl was also found to be highly effective in controlling all fruit and foliar diseases of pecans. In the early 1970’s, benomyl was the most popular fungicide being used by pecan growers, but due to its widespread use (or overuse) resistance to benomyl rapidly built up in *F. effusum* (47). Because of the problems associated with the use of dodine and benomyl, triphenyltin hydroxide became the major pecan fungicide, and has given consistently excellent control of scab since its introduction in 1965.
Since the introduction of fungicides for the management of pecan scab they have gradually evolved from contact materials such as dodine, Bordeaux mixture, and TPT to newer chemistries that have the ability to translocate through plant tissue. With the abundance of rainfall and rapid leaf growth of pecans in the southeastern United States, there is a need for systemic fungicides that will be less prone to wash-off, and also move within tissue to help protect new growth. Some fungicides used on pecans are known to move systemically in other plants, but little is known about this phenomenon in pecan tissues. The newer modes of action such as the DMIs, QoIs, and the phosphites are of greatest importance in pecan production in this regard.

Systemic uptake and movement in pecans has obvious implications for disease management in terms of application coverage considerations, protection of developing tissues between sprays, and protection from wash-off due to frequent rainfall events. Systemic fungicides can be absorbed in the plant tissue and may offer post-infection activity (53). There are three different types of systemic fungicides, categorized based on their mobility in plants: translaminar, xylem mobile, and amphimobile.

Translaminar fungicides are active in plant tissue by moving through the leaf from the upper surface to the lower surface (and vice versa) (51). When these translaminar fungicides are applied, most of the initial ingredient is held on or within the waxy cuticle of the plant surface (78). Some translaminar fungicides can move all the way through the lamina and rebind to the cuticle on the opposite side of the leaf blade, thus allowing the fungicide to be present on both leaf surfaces when only one was treated (78). Azoxystrobin and kresoxim methyl are among two of the top translaminar fungicides used in pecan production (38). However, azoxystrobin can translocate both translaminarly and systemically through the plant’s vascular system (2,78).
Kresoxim methyl moves as a gas in the still air acting as a boundary layer on the surface of the leaf. Some QoI fungicides can rebind to (or in) the cuticle as they move in the vapor phase and are thus considered surface systemics (78). In practical significance, systemic movement and translaminar movement can compensate for incomplete spray coverage and allow for some redistribution of fungicides in the plant tissue.

Xylem-mobile fungicides move more extensively compared to translaminar systemic fungicides due to their ability to move through the xylem tissue. When xylem mobile fungicides are applied to the root zone the fungicides can be absorbed into the roots and move upward through the plant with the transpiration stream, and can thus be categorized as xylem-mobile systemic (51). Xylem-mobile systemic fungicides are also effective when they are applied to the foliage. Upon application, the xylem-mobile fungicides move upward through the leaf where it was applied, but cannot be redistributed out of that leaf (51). In contrast to leaf deposition of xylem-mobile fungicides, stem application can result in the upward movement of the fungicide into the younger leaves above the point of application (51). QoI and DMI fungicides both have xylem-mobile properties that can be used to inhibit the development of fungal diseases in the host. QoI application is important in the pre-infection period allowing for residual control to prevent new infections. Triazole fungicides allow for post-infection treatment with multiple applications preventing sporulation from developing infections (51). The application of xylem mobile systemic fungicides can help protect plants from a broad spectrum of diseases by having the capability of moving upward and outward in the plants water transport system.
Amphimobile fungicides are rare, but are of great interest with their ability to be mobile in both the xylem and phloem of the host plant. Amphimobile, also known as phloem-mobile systemics, could have potential for excellent disease management exhibiting bi-directional mobility (51). Fungicides exhibiting characteristics such as bi-directional mobility allow material to move in the phloem out of the leaf where deposited upwards to other leaves and downwards to the root zone (51). However, these systemics cannot move again after translocation (2,51). Phosphite fungicides are classified in this group of amphimobile fungicide class with their ability to move in the plant either through the xylem or phloem (55,68). Phosphite fungicides could become a major chemistry relied upon in management of pecan scab, due to the recently evolved resistance to other classes of fungicides used in pecan production (65,66,67).

Amphimobile fungicides generally are excellent in their mobility properties within the plant tissue, but their capabilities to move in pecans is not known.

Because pecan tissues are most susceptible to scab while they are still growing, protecting developing foliage from the time of bud break until leaf expansion is complete is crucial in managing the disease throughout the growing season. During rainy and humid environmental conditions for infection by *F. effusum* are ideal and scab can become severe if foliage and fruit are not properly protected through fungicide application. The application of systemic fungicides should be a good option for protecting developing, highly susceptible foliage early in the growing season before the waxy cuticle has formed on the leaves.

Although the mobility of the different types of systemic fungicides is important in protecting plants from infection, there is also an increased risk of resistance with these fungicides because they are all single-site modes of action. In spite of the risk, systemic
fungicides have been a valuable tool for pecan growers for many years. One key benefit is that systemic fungicides are rain fast within a few hours of application and may require less thorough application coverage to be effective (20). Also many systemic fungicides inhibit fungal growth and sporulation when applied after the early stages of infection (20).

The aim of this study is to determine the movement of different classes of fungicides in pecan tissues with different MOAs, and develop application strategies that could help growers benefit from using fungicides with systemic characteristics during the growing season. We will also evaluate the efficacy of fungicide applications for the reduction of inoculum early in the season so as to aid growers in managing the disease, especially at the time of disease onset. Little is known about the movement of systemic fungicides and dormant spray applications in pecans, thus the need for this project to optimize efficacy of these fungicides for management of pecan scab.
Objectives

1. Evaluate systemic fungicide mobility in pecan tissue to develop improved fungicide application strategies to manage disease more efficiently in young susceptible tissue.

2. Evaluate fungicides applied to pecan tissues during dormant and mid-season timings for effects that fungicides have on sporulation and subsequent epidemic development of scab in pecan trees.

3. Evaluate the effects that fungicides have on overwintering stromata on pecan shoots infected the previous year to determine anti-sporulant advantages that some products may have.
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CHAPTER 2

EVALUATION OF FUNGICIDE SYSTEMICITY IN PECAN AND IMPLICATIONS FOR DISEASE MANAGEMENT

Abstract

Scab (*Fusicladium effusum*) is a common disease of pecans and frequent fungicide sprays are needed to prevent serious losses, especially during wet years. Some fungicides used on pecans are known to move systemically in other plants, but little is known about fungicide mobility in pecan tissues. Experiments were conducted under field conditions to evaluate the acropetal movement of foliar-applied azoxystrobin, tebuconazole, and phosphorous acid compared to a reference standard application of the protectant fungicide triphenyltin hydroxide. Movement from lower to upper leaves on a stem was quantified with a bioassay using *Sclerotium rolfsii* at 1, 3, 5 and 7 days after application. In a separate experiment, the basipetal movement of phosphorous acid (7.027 L/ha) from upper to lower leaves was evaluated and compared to a nontreated check and treatment with triphenyltin hydroxide. Tebuconazole, azoxystrobin, and phosphorous acid all reduced the diseased area compared to the protectant (triphenyltin hydroxide) in juvenile expanding foliage. Phosphorous acid provided the best control 1 day after spray application, whereas azoxystrobin had better control at 7 days in unsprayed existing foliage. Phosphorous acid exhibited the greatest basipetal movement 4, 10, and 14 days after fungicide application two and three leaves below sprayed foliage compared to the contact, triphenyltin hydroxide and the nontreated control. The benefits of such movement is likely more local affecting adjacent tissues. Results of experiments on whole trees with naturally occurring pecan scab demonstrated little difference between phosphorous acid and the protectant fungicide in their ability to control scab in the tops of trees, even in the vigorous young vegetative growth following hedge-pruning. Overall results indicate that systemic fungicides can help protect pecan foliage where the fungicide is not uniformly applied, and even protect new leaves not present at the time of application.
Introduction

Pecan (Carya illinoensis) is a major crop in Georgia, but the humid climate is conducive to a number of diseases, most notably scab caused by Fusicladium effusum. Pecan scab caused an average annual loss in yield valued at $44.3 million dollars from 2011-2013, and a further annual cost of $25.2 million for control in Georgia (Georgia Plant Disease Loss Estimate, www.caes.uga.edu/Publications). The onset of epidemics normally occurs during the beginning of the growing season when young leaves are first emerging. This foliage is extremely susceptible to infection by F. effusum since a waxy cuticle has not yet been formed. Hence, fungicide applications are usually initiated soon after bud break and reapplied at various intervals throughout the season depending on specific products and rates used. These sprays are usually effective, but in years with frequent rains, such as 2013 and 2014, pecan scab can cause tremendous losses. The degree of systemicity of several pecan fungicides was evaluated as a basis to help improve protection of young developing tissue during this critical period of leaf expansion.

Chemical control plays an important role in the management of pecan scab, especially in the Southeastern United States, and numerous fungicides with different modes of action are readily available to growers. Guanidines, demethylation-inhibitors (DMIs), quinone outside inhibitors (QoIs), organometallics, methyl benzimidazole carbamates (MBCs), and phosphonates (phosphorus acid based products) products) are recommended for control of pecan scab in Georgia (6,7,8). Typically rotations or mixtures of different product classes are recommended to lower the risk of fungal pathogens developing resistance, however products vary in their effectiveness on different tissues.
For example, dodine and triphenyltin hydroxide, have been particularly effective for nut scab control after pollination; however they are also sometimes utilized to protect the expanding leaves after bud break. Pecan shoots grow very rapidly after bud break, and even a relatively short 12-14 day spray interval leaves some leaves unprotected in the days prior to the next application. The systemic attributes of the DMIs, QoIs, and the newly introduced phosphorous acids are of great interest in pecan production as tools to potentially improve protection of these very vulnerable tissues. They could also potentially improve the distribution and uniformity of fungicide coverage throughout the pecan canopy, which can be very difficult to protect uniformly due to their large size (3). However, the degree of movement of these products in pecan tissues has not been characterized. Research is needed to evaluate the mobility of these fungicides in pecan tissues and determine how they can best be used to manage pecan scab, especially during periods of rapid vegetative growth. Such periods can occur in the spring as the leaves develop on the terminals, or throughout the growing season on trees that have been hedged pruned to reduce tree height (42). This practice is gaining popularity in Georgia, and hedged trees produce abundant new shoots continuously throughout the season.

The majority of systemic fungicides currently used in pecan production are considered xylem-mobile, being transported upward in the plant through the xylem apoplast. The one exception are the phosphonates which exhibit both xylem mobility and basipetal movement via the phloem sap of the symplast sieve tubes (11,12,30). Once the fungicide is applied it must diffuse through the leaf cuticle and penetrate the xylem apoplast and symplast membrane before moving into the sieve tubes (24,25). This is a rare trait that very few fungicides share making the phosphonates of great interest in pecans due to spray coverage issues.
The ability of fungicides to penetrate the xylem apoplast is related to their lipophilicity. Fungicide lipophilicity can be quantified based on the octanol-water coefficient \( (K_{ow}) \). Lipophilic fungicides usually have log \( K_{ow} \) values of -7.5 to <2 (1, 16, 44).

Fungicide concentrations in the phloem can fluctuate as they move between the symplast membranes and xylem apoplast (24). Fungicides that have the least efflux back into the xylem apoplast will ultimately move greater distances in the phloem. While lipophilicity determines a fungicides apoplastic systemicity, basipetal systemicity is associated with acid strength of the compound (1, 9, 15, 18, 29, 32). Acid strength is measured as the negative logarithm, \( pK_a \), of the acid dissociation constant \( K_a \) (32). The xylem apoplast has an acidic to neutral pH (approximately 6) while the phloem symplast is slightly alkaline (approximately 8) (9, 17). Most weak acidic pesticides of intermediate lipophilicity are reported to have phloem mobility because they are retained longer within the phloem sieve tubes (10, 44).

Understanding the movement of systemic fungicides in developing pecan foliage should result in more consistent disease management, and encourage the use of these products earlier in the season when their systemicity is most needed. Thus, the efficacy and systemicity of the fungicides in different classes discussed above need to be compared with standard protectant fungicides such as triphenyltin hydroxide to determine the relative degree of control that these products could provide during and after leaf expansion. The objective of the study was to evaluate the systemic movement of azoxystrobin, tebuconazole, and phosphorous acid in developing and fully expanded leaves on pecan shoots. Additionally, foliar application of phosphorous acid was evaluated for its ability to control scab both in leaves of the lower canopy shoots, as well as in upper canopy shoots of mature trees and regrowth shoots in the top of the trees following hedge pruning.
Materials and Methods

Systemic Movement of Fungicides within Existing Foliage

*Plant preparation.* Experiments were conducted on trees of cultivar “Excel” in a research orchard at the University of Georgia Ponder Farm, Tifton, GA in 2014. Individual non-flowering terminals with fully expanded, mature leaves were flagged with a piece of yarn to separate sprayed and non-sprayed foliage. The “Excel” cultivar is highly resistant to scab, and the trees had received no fungicides prior to the initiation of the experiment. Six individual terminals were used per treatment on separate trees with each terminal being one replication, and the treatments being replicated on each of six trees in each experiment. Fungicide applications were made on June 30, 2014.

*Fungicide applications.* Before fungicide was applied, four compound leaves above the flagged section of yarn were covered with a plastic poultry bag (60 cm × 30 cm) to prevent exposure to fungicide. Fungicide was applied as a foliar spray to run-off with a handheld pump sprayer (Project Source 1.50-Liter Plastic Tank Sprayer). Products were mixed in water at a dilution equivalent to a lower volume currently applied by pecan growers in commercial orchards using air-blast sprayers (703 L/ha).
Azoxytrobin (Abound 2.08, Syngenta Crop Protection, Inc., Greensboro, NC) was applied at 0.22 kg a.i./ha + Alkyl Aryl Polyoxylkane ethers, alkanolamides, dimethyl siloxane, and free fatty acids (Induce, Helena Chemical Company, Collierville, TN) was applied at 0.06 % v/v, tebuconazole (Orius 3.6F, Makhteshim Agan of North America, Inc., Raleigh, NC) was applied at 0.25 kg a.i./ha + Alkyl Aryl Polyoxylkane ethers, alkanolamides, dimethyl siloxane, and free fatty acids (Induce, Helena Chemical Company, Collierville, TN) was applied at 0.06 % v/v, triphenyltin hydroxide (Super Tin 4L, United Phosphorus, Inc., King of Prussia, PA) was applied at 0.42 kg a.i./ha, mono- and dipotassium salts of phosphorus acid (Rampart, Loveland Products, Inc., Greeley, CO) was applied at 0.42 kg a.i./ha.

**Detached tissue sampling and bioassay.** The systemic activity of the applied fungicides was determined using a bioassay technique 1, 3, 5, and 7 days after application. A middle leaflet was taken from each compound leaf on each sample day, at four leaf positions per terminal: 1st leaf position (1st sprayed compound leaf below flagged yarn), 2nd leaf position (1st unsprayed compound leaf above sprayed foliage), 3rd leaf position (2nd unsprayed compound leaf above sprayed foliage), and 4th leaf position (3rd unsprayed compound leaf above sprayed foliage). Detached leaflets were placed in resealable plastic freezer bags and cooled for transport back to the laboratory.

Plastic containers (59/cm × 43/cm × 15/cm) layered at the bottom with moist paper towels were used as humidity chambers. Detached leaflets were placed directly on moist paper towels, which was shown in preliminary studies to improve uniformity of colonization (data not shown). Cultures of *S. rolfsii* (isolate SR-18, originally from peanut) were incubated on potato dextrose agar at 25°C in the light for two days and were used for all inoculations. All leaflets were inoculated with a 4-mm diameter agar plug from the margin of an actively growing culture.
of *S. rolfsii* by placing the mycelial side of the agar plug down on the center of the leaflet surface. Containers were incubated in the laboratory at 24°C for 48 hours. A randomized complete block design was used where each humidity chamber was one block for a total of six blocks per treatment. After incubation, length and width of lesions caused by *S. rolfsii* were measured to compare fungicidal activity. Measurements were taken on each leaflet sample at 48, 72, and 96 hours post inoculation to obtain information on lesion area for each treatment at different times. The experiment was repeated.

*Statistical Analyses.* Data were analyzed using Proc GLIMMIX in SAS (SAS Version 9.3, SAS Institute, Cary, NC) to examine treatment effects. Means were compared using pairwise t-tests least squares means to identify significant differences among treatments (α = 0.05).

**Systemic Movement of Fungicides into Emerging Foliage**

*Plant Preparation and Fungicide Applications.* Experiments were conducted in the field on the same trees and with the same application procedure described above. However, in this experiment individual terminals were monitored for juvenile expanding tissue in the younger leaves of the terminal. Yarn was tied under the youngest expanding leaf to separate older expanded leaves from newly expanding leaf. The juvenile foliage in early stages of development were covered with a clear plastic bag (60 cm x 30 cm) to prevent exposure to fungicides. Older, more expanded foliage in the lower section of the terminal was treated with fungicide to subsequently explore movement into expanding foliage. Fungicide was applied on May 6, 2015.

*Detached tissue sampling and bioassay.* The systemic activity of applied fungicides was determined using the bioassay technique described above, with samples collected 4, 7, 10 and 14 days after fungicide application. One leaflet sample was taken from the middle of each
compound leaf at each leaf position. Leaflets were removed from leaves at three leaf positions on each terminal: 1\textsuperscript{st} leaf position (1\textsuperscript{st} sprayed compound leaf below flagged yarn), 2\textsuperscript{nd} leaf position (1\textsuperscript{st} unsprayed emerging compound leaf above sprayed foliage), and 3\textsuperscript{rd} leaf position (2\textsuperscript{nd} unsprayed emerging compound leaf above sprayed foliage). Detached leaflets were placed in plastic freezer bags for transport back to the laboratory. Protocol using \textit{S. rolfsii} was the same as described in the previous experiment.

\textit{Statistical Analyses.} Data were analyzed using Proc GLIMMIX in SAS (SAS Version 9.3, SAS Institute, Cary, NC) to examine treatment effects. Means were compared using pairwise t-tests least squares means to identify significant differences among treatments (α = 0.05).

\textbf{Basipetal Movement of Phosphites within Existing Foliage:}

\textit{Plant preparation.} Experiments were conducted in a pecan orchard in Cairo, GA in 2015. Terminals on tress of the scab-resistant cultivar “Elliot” were flagged using yarn to separate sprayed and non-sprayed foliage as already described. Six individual terminals on six individual trees were used per treatment with each terminal being one replication in each experiment.

\textit{Fungicide applications.} Treatments were assigned to terminals using a randomized complete block design with six replications. Before fungicides were applied compound leaves below the flagged section of yarn were covered with a clear plastic bag to prevent exposure to fungicide. Fungicides were diluted in water equal to 703 L/ha and were sprayed to run-off with a handheld pump sprayer (Project Source 1.50-Liter Plastic Tank Sprayer).
Treatments included a nontreated control, triphenyltin hydroxide (Super Tin 4L, United Phosphorus, Inc., King of Prussia, PA) applied at 0.42 kg a.i. kg/ha, and mono- and dipotassium salts of phosphorous acid (Rampart, Loveland Products, Inc., Greeley, CO) were applied at 0.42 kg a.i./ha.

*Detached tissue sampling and bioassay.* Systemic activity was determined using a bioassay technique 4, 7, 10, and 14 days after fungicide application. Individual leaflet samples were taken from the middle of compound leaves. Leaflets were removed from leaves at three positions on each terminal: 1<sup>st</sup> leaf position (1<sup>st</sup> sprayed compound leaf above flagged yarn), 2<sup>nd</sup> leaf position (1<sup>st</sup> unsprayed compound leaf below sprayed foliage), and 3<sup>rd</sup> leaf position (2<sup>nd</sup> unsprayed compound leaf below sprayed foliage). Detached leaflets were placed in plastic freezer bags for transport back to the laboratory. Bioassay and inoculation techniques were the same as those described above for the previous experiments.

*Statistical Analyses.* Data were analyzed using Proc GLIMMIX in SAS (SAS Version 9.3, SAS Institute, Cary, NC) to examine treatment effects. Means were compared using pairwise t-tests least squares means to identify significant differences among treatments (α = 0.05).

**Whole Tree Systemicity Evaluation:**

Field experiments were conducted in a research orchard at the University of Georgia Ponder Farm, Tift Co., GA in 2014 and 2015. Pecan trees (cultivar Desirable) planted in 1988 were used for the experiment after being hedged-pruned to a height of approximately 7.6 m in the spring of 2014. The experimental design was a randomized complete block including three treatments with five replications. Fungicides were applied to the foliage with a Durand-Wayland air-blast sprayer calibrated to deliver 937 L/ha. Every four weeks beginning April 9, 2014 and April 10, 2015, trees received a total of five applications of Rampart (phosphite
treatment) (Loveland Products, Inc., Greeley, CO) or Super Tin 4L (positive control) (United Phosphorus, Inc., King of Prussia, PA) + Elast 400F (Aceto Agricultural Chemicals Corporation, Port Washington, NY) applied at 7.027 L/ha or 0.45 L/ha + 1.83 L/ha, respectively. In addition, all trees except the nontreated controls also received five sprays of Super Tin 4L + Elast 400F applied at 0.45 L/ha + 1.83 L/ha on a four-week schedule alternating with the Rampart or Super Tin 4L + Elast 400F applications beginning 16 April, 2014 and 17 April, 2015. Each treated tree received a total of 10 applications per season.

Triphenyltin hydroxide (Super Tin 4L, United Phosphorus, Inc., King of Prussia, PA) was applied at 0.45 L/ha, Mono- and dipotassium salts of phosphorous acid (Rampart, Loveland Products, Inc., Greeley, CO) was applied at 7.027 L/ha.

Disease Assessment. Six arbitrarily selected individual terminals were evaluated per tree in both the upper and lower canopy for incidence and severity of leaf and nut scab. Disease was also assessed on leaves of shoots that had regrown in the upper portion of the tree canopy following hedge pruning the previous spring. These included leaf scab incidence and severity, and the number of lesions on the middle 3 cm of stem on the current year’s wood. Disease was assessed on 12 September in 2014 and 27 July in 2015.

Statistical Analyses. Leaf and nut scab incidence and severity, leaf scab incidence and severity on regrowth, and number of lesions on the current year’s wood were analyzed using Proc GLIMMIX (SAS version 9.3, Cary, NC) to examine treatment effects. Means were compared using pairwise t-tests least squares means to identify significant differences among treatments (α = 0.05). Data are combined for trials in 2014 and 2015 because no significant year×treatment interactions were observed.
Results

Results of the statistical analysis of all dependent variables indicated significant trial-treatment interactions for experiments conducted on the systemic movement in existing foliage and basipetal movement of fungicides, whereas there was no significant trial×treatment interactions observed for experiments conducted on systemic movement during leaf expansion. Therefore, data were not combined for experiments conducted on movement between existing foliage and basipetal movement, but were combined for experiments conducted during leaf expansion. Results are displayed separately in five tables that are grouped by experiment type.

Systemic movement within existing foliage. The leaf in position 1 was sprayed so the inhibition of lesions by all four fungicides was due to the direct activity of the deposited residues on S. rolfsii. All fungicides tested clearly reduced lesion development, but TPTH started losing efficacy by day seven after treatment in both trials (Table 2.1).

Inhibition of lesions on leaf 2, the first one above the sprayed leaves, was consistent with all fungicides except TPTH for days one and three, and generally so for the other products except at day five in 2014 when no treatments were effective (Tables 2.1 and 2.2). Azoxystrobin and phosphorous acid tended to provide a higher level of suppression than tebuconazole and triphenyltin hydroxide, but differences were not consistently significant across all sampling times.

Inhibition of lesions on leaf three, the second one above the sprayed leaves, was less consistent (Tables 2.1 and 2.2). All fungicides except TPTH reduced lesion development at days one and three in both trials. By day 7, there were few differences between the treated and nontreated leaves. The results for leaf four were generally similar to those of leaf three but with even fewer significant differences between treated and nontreated leaves.
Systemic movement of fungicides into emerging foliage. The leaf in position 1 was sprayed, so the inhibition of lesions by all four fungicides was due to the direct activity of the deposited residues on *S. rolfsii* (Table 2.3). All the fungicides clearly reduced lesion development on this leaf up 14 days after application. Leaf two was the first emerging leaf, and was not directly sprayed with fungicide. Again all four fungicides significantly inhibited lesion development on this leaf, but TPTH was significantly less effective than the other fungicides. All other fungicides (azoxystrobin, tebuconazole, and phosphorous acid) maintained a high level of inhibition of *S. rolfsii* on this leaf up to 14 days after application. A very similar pattern was repeated on the second leaf to emerge above the treated tissue, although there were some minor differences among the three systemic products with regard to degree of inhibition.

Basipetal movement of phosphorous acid within existing foliage. The leaf in position 1 one was sprayed, so the inhibition of lesions by both fungicides was due to the direct activity of the deposited residues on *S. rolfsii* (Tables 2.4) Both fungicides clearly reduced lesion development on this leaf up to 14 days after treatment in both trials. In leaf two, the first unsprayed leaf below the treated leaf, there was a small reduction in lesion development from TPTH at day 4, but none thereafter. In contrast, the phosphorous acid greatly reduced lesion development at up to 14 days after treatment in both trials. The same pattern was observed for the second leaf below the treated foliage, except for day 7 in one trial where the diseased area was not significantly less compared to the nontreated control.

Whole tree systemicity evaluation. Phosphorous acid significantly reduced leaf scab incidence in the upper canopy compared to the nontreated trees, whereas TPTH did not (Table 2.5). Both phosphorous acid and TPTH significantly reduced leaf scab incidence in the lower canopy, with phosphorous acid resulting in significantly less disease in the lower canopy.
compared to TPTH. A similar pattern was observed for severity of leaf scab in the lower canopy; however, there were no significant differences in leaf scab severity observed among any of the treatments in the upper canopy (Table 2.5). In the shoots at the very top of the tree that had grown after hedging, applications of TPTH resulted in a small reduction in incidence of leaf scab, whereas application of phosphorous acid had no effect. Neither fungicide treatment reduced the severity of leaf scab in the shoots compared to the nontreated control. There was a small, but significant reduction in the number of lesions on the stems at the top of trees treated with fungicide compared to the nontreated (Table 2.6).

Both phosphorous acid and triphenyltin hydroxide reduced severity of nut scab significantly in the upper and lower canopy; however there was considerably less control in the upper canopy (Figure 2.2). Only phosphorous acid significantly reduced incidence of nut scab in the tops of the trees, but the reduction was very small. Reductions in incidence of nut scab by fungicide treatments were greatest in the lower canopy, but only significant for TPTH. There was a small, but significant reduction in the number of lesions on the stems at the top of the trees due to both fungicides.

**Discussion**

This is the first report of a bioassay test using *S. rolfsii* to quantify movement of fungicides in pecans, or any other tree crop. The technique was first used on peanut (1), a common host for *S. rolfsii*, but the ability of the fungus to grow saprophytically on many different tissues makes it a good candidate for this type of assay, as long as it is sensitive to the fungicide of interest. The procedure was used successfully in this research to demonstrate the mobility of azoxystrobin, tebuconazole, and phosphorous acid within pecan tissue. These fungicides are known to move acropetally in other crops, and in pecan acropetal movement was particularly evident during the period of leaf expansion compared to triphenyltin hydroxide and
the nontreated control. However, a slight reduction in lesion area was observed on leaflets from the shoots treated with triphenyltin hydroxide compared to the nontreated control in existing foliage. This may have been due to redistribution of surface fungicide residues from the treated to the nontreated leaves by rain. After fungicide applications were made on 21 June, 2014 rain in the amounts of 3.2, 0.1, 3.3, and 0.3 centimeters was recorded on 22, 23, 24, and 25 June, respectively (www.georgiaweather.net). Although it was hypothesized that azoxystrobin, tebuconazole, and phosphorous acid would exhibit greater translocation, the increased movement shown by azoxystrobin and tebuconazole could have been aided by the addition of a penetrating surfactant added to each treatment. The acropetal movement of the systemic materials was most evident in the young leaves that were not emerged at the time of fungicide application. This represents a significant advantage for these products in the spring when foliage is rapidly expanding, and multiple new leaves are formed during the interval between fungicide applications.

Based on the results from these experiments, applications of azoxystrobin, tebuconazole, and phosphorous acid will likely provide some compensation for incomplete spray coverage against pecan scab in the field, especially early in the season during leaf expansion. While such data are not presented here, this advantage has been observed, and these fungicides are used more extensively during the early part of the season for leaf scab. The ability of phosphorous acid to move down as well as up in the tree makes it even more likely to result in more uniform disease control. This study provided evidence that phosphorous acid was translocated at least two full leaves below the area of application, but phosphorous acid has been shown to be even more extensively phloem-mobile in other crops (26,32,36,44).

Based on the results from the whole-tree phosphorous acid systemicity evaluation studies, whole tree translocation upward was apparently not achieved. Such movement would
have huge scab control benefits due to the practical challenges of ensuring adequate spray coverage higher up in the canopy of tall pecan trees. However, the systemic properties of phosphorous acid offer more benefits to growers in terms of partial compensation for incomplete spray coverage, in contrast to standard protectants such as triphenyltin hydroxide. Recent studies of use of phosphorous acid fungicides in pecans raise concern about the efficacy on nut scab control (4), however results of the present study indicate that although triphenyltin hydroxide is effective in reducing nut scab, phosphorous acid is capable of achieving similarly efficacious results. The degree of systemic fungicide movement in nut shucks is not clear. Efforts were made to evaluate this with a similar bioassay method, but the results were not consistent and are therefore not reported.

This research demonstrates that several fungicides in different classes offer the advantages of being translocated in pecan shoots and foliage, and this is likely significant for disease management in pecans. Azoxyrstobin, tebuconazole, and phosphorous acid consistently provided the highest levels of mobility compared to triphenyltin hydroxide and the nontreated control during leaf expansion.

In conclusion, these results support the use of systemic fungicide applications during leaf expansion to maximize efficacy and to partially compensate for incomplete coverage of the product on pecan foliage. The application of systemic fungicides would likely be most critical in years with very wet weather and frequent infection periods as seen in the 2013 and 2014 growing seasons in Georgia.
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20. Hardy, G. S. J., Barrett, S., & Shearer, B. L. 2001. The future of phosphite as a fungicide to control the soilborne plant pathogen *Phytophthora cinnamomi* in natural ecosystems. *Australasian Plant Pathology, 30*(2), 133-139.


Table 2.1. Systemic movement of fungicide between fully expanded leaves in pecan (Trial 1).

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<th>Year</th>
<th>Leaf Position&lt;sup&gt;w&lt;/sup&gt;</th>
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<th>Diseased Area (cm&lt;sup&gt;2&lt;/sup&gt;)</th>
<th>Day 1&lt;sup&gt;y&lt;/sup&gt;</th>
<th>Day 3&lt;sup&gt;y&lt;/sup&gt;</th>
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<td>4.57 bc</td>
<td>4.27 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tebuconazole</td>
<td>2.11 c</td>
<td>3.11 c</td>
<td>3.15 c</td>
<td>3.92 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phosphorus Acid</td>
<td>1.63 c</td>
<td>4.45 cb</td>
<td>5.94 ba</td>
<td>4.99 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TPTH</td>
<td>3.65 ba</td>
<td>5.24 b</td>
<td>6.07 ba</td>
<td>5.97 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nontreated</td>
<td>4.95 ba</td>
<td>7.62 a</td>
<td>7.70 a</td>
<td>8.50 a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Azoxystrobin</td>
<td>3.00 cb</td>
<td>3.58 b</td>
<td>4.09 b</td>
<td>4.31 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tebuconazole</td>
<td>3.89 b</td>
<td>4.82 b</td>
<td>7.93 a</td>
<td>5.30 ba</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phosphorus Acid</td>
<td>2.25 c</td>
<td>3.08 b</td>
<td>6.06 ba</td>
<td>4.40 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TPTH</td>
<td>3.13 cb</td>
<td>3.65 b</td>
<td>6.12 ba</td>
<td>4.74 ba</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nontreated</td>
<td>5.88 a</td>
<td>9.79 a</td>
<td>7.45 a</td>
<td>6.63 a</td>
<td></td>
</tr>
</tbody>
</table>

<sup>w</sup> Leaf position samples were as follows: 1 = first sprayed compound leaf, 2 = first unsprayed compound leaf above sprayed leaf, 3 = second unsprayed compound leaf above sprayed leaf, 4 = third unsprayed compound leaf above sprayed leaf.

<sup>x</sup> Treatments and fungicide rates were as follows: azoxystrobin (0.878 L/ha), tebuconazole (0.586 L/ha), triphenyltin hydroxide (0.878 L/ha), phosphorous acid (7.027 L/ha).

<sup>y</sup> Sample Days after fungicide application.

<sup>z</sup> Means followed by the same letter(s) do not differ significantly according to least squares means (α = 0.05).
### Table 2.2. Systemic movement of fungicide between existing leaves in pecan (Trial 2).

<table>
<thead>
<tr>
<th>Year</th>
<th>Leaf Position</th>
<th>Treatment</th>
<th>Diseased Area (cm²)</th>
<th>Day 1</th>
<th>Day 3</th>
<th>Day 5</th>
<th>Day 7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Day 1</td>
<td>Day 3</td>
<td>Day 5</td>
<td>Day 7</td>
</tr>
<tr>
<td>2014</td>
<td>1</td>
<td>Azoxystrobin</td>
<td>0.75 b z</td>
<td>1.34 b</td>
<td>3.04 c</td>
<td>2.52 c</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tebuconazole</td>
<td>0.10 b</td>
<td>2.25 b</td>
<td>2.25 c</td>
<td>2.75 c</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phosphorus Acid</td>
<td>0.57 b</td>
<td>1.20 b</td>
<td>1.92 c</td>
<td>1.50 c</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TPTH</td>
<td>0.75 b</td>
<td>7.50 a</td>
<td>9.06 b</td>
<td>6.44 b</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Nontreated</td>
<td>5.79 a</td>
<td>8.01 a</td>
<td>12.3 a</td>
<td>8.76 a</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Azoxystrobin</td>
<td>2.67 d</td>
<td>3.69 c</td>
<td>8.90 a</td>
<td>6.67 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tebuconazole</td>
<td>4.48 bc</td>
<td>7.83 b</td>
<td>9.25 a</td>
<td>8.21 ba</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phosphorus Acid</td>
<td>3.41 dc</td>
<td>5.88 cb</td>
<td>8.60 a</td>
<td>6.45 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TPTH</td>
<td>5.56 ba</td>
<td>7.50 b</td>
<td>9.91 a</td>
<td>6.79 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nontreated</td>
<td>6.47 a</td>
<td>10.1 a</td>
<td>11.3 a</td>
<td>9.09 a</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Azoxystrobin</td>
<td>2.46 c</td>
<td>4.26 c</td>
<td>8.47 a</td>
<td>6.21 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tebuconazole</td>
<td>3.94 cb</td>
<td>6.63 b</td>
<td>10.7 a</td>
<td>8.29 a</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phosphorus Acid</td>
<td>2.68 c</td>
<td>6.92 b</td>
<td>9.44 a</td>
<td>5.65 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TPTH</td>
<td>4.92 b</td>
<td>7.73 ba</td>
<td>10.2 a</td>
<td>7.42 ba</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nontreated</td>
<td>7.40 a</td>
<td>9.85 a</td>
<td>9.02 a</td>
<td>8.94 a</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Azoxystrobin</td>
<td>2.86 b</td>
<td>5.92 b</td>
<td>9.07 a</td>
<td>6.38 a</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tebuconazole</td>
<td>4.47 b</td>
<td>7.85 ba</td>
<td>9.20 a</td>
<td>6.40 a</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phosphorus Acid</td>
<td>3.65 b</td>
<td>8.14 ba</td>
<td>9.93 a</td>
<td>8.16 a</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TPTH</td>
<td>6.42 a</td>
<td>8.78 a</td>
<td>10.9 a</td>
<td>8.50 a</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nontreated</td>
<td>6.76 a</td>
<td>8.45 a</td>
<td>8.83 a</td>
<td>7.99 a</td>
<td></td>
</tr>
</tbody>
</table>

**w** Leaf position samples were as follows: 1 = first sprayed compound leaf, 2 = first unsprayed compound leaf above sprayed foliage, 3 = second unsprayed compound leaf above sprayed foliage, 4 = third unsprayed compound leaf above sprayed foliage.

**x** Treatments and fungicide rates were as follows: azoxystrobin (0.878 L/ha), tebuconazole (0.586 L/ha), triphenyltin hydroxide (0.878 L/ha), phosphorus acid (7.027 L/ha).

**y** Sample Days after fungicide application.

**z** Means followed by the same letter(s) do not differ significantly according to least squares means (α = 0.05).
Table 2.3. Systemic movement of fungicide into newly emerging leaf tissue in pecan.

(Combined results of 2 years)

<table>
<thead>
<tr>
<th>Year</th>
<th>Leaf Position</th>
<th>Treatment</th>
<th>Diseased Area (cm$^2$)</th>
<th>Day 4$^x$</th>
<th>Day 7</th>
<th>Day 10</th>
<th>Day 14</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>1</td>
<td>Azoxystrobin</td>
<td>0.358 b</td>
<td>0.071 b</td>
<td>0.306 b</td>
<td>0.201 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tebuconazole</td>
<td>0.164 b</td>
<td>0.052 b</td>
<td>0.169 b</td>
<td>0.021 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phosphorus Acid</td>
<td>0.999 b</td>
<td>0.026 b</td>
<td>1.031 b</td>
<td>0.070 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Triphenyltin Hydroxide</td>
<td>0.654 b</td>
<td>0.141 b</td>
<td>0.310 b</td>
<td>0.075 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nontreated</td>
<td>8.346 a</td>
<td>7.759 a</td>
<td>16.36 b</td>
<td>15.91 b</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Azoxystrobin</td>
<td>0.272 c</td>
<td>0.318 c</td>
<td>1.215 d</td>
<td>1.195 dc</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tebuconazole</td>
<td>0.205 c</td>
<td>0.297 c</td>
<td>0.880 d</td>
<td>0.378 d</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phosphorus Acid</td>
<td>0.520 c</td>
<td>0.826 c</td>
<td>3.031 c</td>
<td>1.504 c</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Triphenyltin Hydroxide</td>
<td>4.937 b</td>
<td>5.886 b</td>
<td>8.598 b</td>
<td>8.606 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nontreated</td>
<td>8.548 a</td>
<td>7.926 a</td>
<td>15.82 a</td>
<td>16.32 a</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Azoxystrobin</td>
<td>0.553 d</td>
<td>0.659 c</td>
<td>1.535 d</td>
<td>1.770 c</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tebuconazole</td>
<td>0.653 d</td>
<td>0.318 c</td>
<td>1.461 d</td>
<td>1.780 c</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phosphorus Acid</td>
<td>2.060 c</td>
<td>0.510 c</td>
<td>5.728 c</td>
<td>3.128 c</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Triphenyltin Hydroxide</td>
<td>5.662 b</td>
<td>6.358 b</td>
<td>9.195 b</td>
<td>9.667 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nontreated</td>
<td>8.025 a</td>
<td>7.963 a</td>
<td>16.85 a</td>
<td>17.06 a</td>
<td></td>
</tr>
</tbody>
</table>

$^x$ Leaf position samples were as follows: 1 = first sprayed compound leaf, 2 = first unsprayed emerged compound leaf above sprayed foliage, 3 = second unsprayed emerged compound leaf above sprayed foliage.

$^y$ Treatments and fungicide rates were as follows: azoxystrobin (0.878 L/ha), tebuconazole (0.586 L/ha), triphenyltin hydroxide (0.878 L/ha), phosphorus acid (7.027 L/ha).

$^{xy}$ Sample days after fungicide application.

$^z$ Means followed by the same letter(s) do not differ significantly according to least squares means ($\alpha = 0.05$).
Table 2.4. Basipetal movement of phosphorus acid between fully expanded leaves in pecan (Trial 1 and Trial 2).

<table>
<thead>
<tr>
<th>Year</th>
<th>Trial</th>
<th>Leaf Position</th>
<th>Treatment</th>
<th>Diseased Area (cm²)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Day 4^y</td>
<td>Day 7^y</td>
<td>Day 10^y</td>
<td>Day 14^y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>1</td>
<td>1</td>
<td>Phosphorus Acid</td>
<td>2.99 b^z</td>
<td>6.04 b</td>
<td>3.52 b</td>
<td>4.72 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TPTH</td>
<td>0.64 c</td>
<td>2.63 c</td>
<td>1.61 b</td>
<td>1.96 c</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nontreated</td>
<td>5.80 a</td>
<td>9.16 a</td>
<td>9.00 a</td>
<td>9.57 a</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>2</td>
<td>Phosphorus Acid</td>
<td>3.66 c</td>
<td>7.04 b</td>
<td>3.93 b</td>
<td>4.09 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TPTH</td>
<td>4.75 b</td>
<td>8.58 ba</td>
<td>6.59 ba</td>
<td>7.52 a</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nontreated</td>
<td>6.47 a</td>
<td>10.53 a</td>
<td>8.76 a</td>
<td>9.59 a</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>3</td>
<td>Phosphorus Acid</td>
<td>4.73 c</td>
<td>6.19 b</td>
<td>3.46 b</td>
<td>4.15 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TPTH</td>
<td>5.68 b</td>
<td>9.89 a</td>
<td>7.88 a</td>
<td>8.56 a</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nontreated</td>
<td>7.00 a</td>
<td>11.20 a</td>
<td>9.26 a</td>
<td>9.35 a</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>2</td>
<td>1</td>
<td>Phosphorus Acid</td>
<td>3.10 b</td>
<td>8.91 b</td>
<td>3.52 b</td>
<td>4.41 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TPTH</td>
<td>0.74 c</td>
<td>4.13 c</td>
<td>1.61 b</td>
<td>2.27 c</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nontreated</td>
<td>6.10 a</td>
<td>12.41 a</td>
<td>9.00 a</td>
<td>9.65 a</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>2</td>
<td>Phosphorus Acid</td>
<td>3.99 c</td>
<td>8.99 b</td>
<td>3.83 b</td>
<td>4.12 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TPTH</td>
<td>5.19 b</td>
<td>11.57 ba</td>
<td>6.55 ba</td>
<td>7.50 a</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nontreated</td>
<td>6.77 a</td>
<td>13.06 a</td>
<td>8.86 a</td>
<td>10.04 a</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>3</td>
<td>Phosphorus Acid</td>
<td>4.84 c</td>
<td>9.69 a</td>
<td>3.42 b</td>
<td>3.90 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TPTH</td>
<td>6.09 b</td>
<td>11.18 a</td>
<td>7.79 a</td>
<td>8.97 a</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nontreated</td>
<td>7.29 a</td>
<td>13.03 a</td>
<td>9.47 a</td>
<td>10.15 a</td>
<td></td>
</tr>
</tbody>
</table>

^w Leaf position samples were as follows: 1 = first sprayed compound leaf, 2 = first unsprayed compound leaf below sprayed foliage, 3 = second unsprayed compound leaf below sprayed foliage.

^x Treatments and fungicide rates were as follows: phosphorus acid (7.027 L/ha), triphenyltin hydroxide (0.878 L/ha).

^y Sample Days after fungicide application.

^z Means followed by the same letter(s) do not differ significantly according to least squares means (α = 0.05).
Table 2.5. Whole-tree systemicity evaluation of phosphorous acid from the lower to upper canopy in pecan to control leaf scab. (Combined results of 2 years).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Upper Canopy Leaf Scab Inc.</th>
<th>Lower Canopy Leaf Scab Inc.</th>
<th>Upper Canopy Leaf Scab Severity</th>
<th>Lower Canopy Leaf Scab Severity</th>
<th>Hedged Leaf Scab Incidence</th>
<th>Hedged Leaf Scab Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorous Acid</td>
<td>62.4 b</td>
<td>40.1 c</td>
<td>5.7 a</td>
<td>2.6 c</td>
<td>76.4 ba</td>
<td>8.1 a</td>
</tr>
<tr>
<td>TPTH + Dodine</td>
<td>69.7 ba</td>
<td>56.9 b</td>
<td>5.6 a</td>
<td>5.1 b</td>
<td>73.9 b</td>
<td>8.7 a</td>
</tr>
<tr>
<td>Nontreated</td>
<td>75.4 a</td>
<td>92.1 a</td>
<td>6.8 a</td>
<td>30.1 a</td>
<td>83.8 a</td>
<td>9.9 a</td>
</tr>
</tbody>
</table>

w Incidence was estimated by the following calculation: (# leaflets with scab/# leaflets) * 100. Severity ratings were taken by a percent of 0-100% area covered with scab.

x Treatments and fungicide rates were as follows: phosphorous acid (7.027 L/ha) and triphenyltin hydroxide (0.45 L/ha).

y Scab intensity was evaluated on 10 Sept, 12 Sept, in 2014 and 27 July in 2015.

z Means followed by the same letter(s) do not differ significantly according to least squares means (α = 0.05).
Table 2.6. Whole-tree systemicity evaluation of phosphorous acid from the lower to upper canopy in pecan to control fruit scab.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Upper Canopy Fruit Inc.</th>
<th>Lower Canopy Fruit Inc.</th>
<th>Upper Canopy Scab Severity</th>
<th>Lower Canopy Scab Severity</th>
<th># Lesions&lt;sup&gt;xy&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorous Acid</td>
<td>95.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>62.5&lt;sup&gt;ba&lt;/sup&gt;</td>
<td>31.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.8&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>TPTH + Dodine</td>
<td>97.6&lt;sup&gt;ba&lt;/sup&gt;</td>
<td>54.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>31.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9.8&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Nontreated</td>
<td>100&lt;sup&gt;a&lt;/sup&gt;</td>
<td>100&lt;sup&gt;a&lt;/sup&gt;</td>
<td>53.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>64.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.8&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>W</sup> Incidence was estimated by the following calculation: (# fruit with scab/# fruit) × 100. Severity ratings were taken by a percent of 0-100% area covered with scab.

<sup>x</sup> Treatments and fungicide rates were as follows: phosphorous acid (7.027 L/ha) and triphenyltin hydroxide (0.45 L/ha).

<sup>y</sup> Scab intensity was evaluated on 10 Sept, 12 Sept, in 2014 and 27 July in 2015.

<sup>xy</sup> Number of overwintering stromata on middle 7.6 cm section of current years shoots.

<sup>z</sup> Means followed by the same letter(s) do not differ significantly according to least squares means (α = 0.05).
CHAPTER 3
EVALUATION OF DORMANT AND MID-SEASON FUNGICIDE APPLICATIONS FOR THE REDUCTION OF PECAN SCAB INOCULUM

Brown, K., and Brenneman, T. 2015. To be submitted to Crop Protection.
Abstract

The efficacy of fungicides applied during the dormant season or mid-season after leaf expansion but prior to fruit expansion was investigated for reducing sporulation and thus potential control of pecan scab, caused by *Fusicladium effusum*. Field experiments were conducted during the 2014 and 2015 growing seasons in Georgia. Fungicides were applied to dormant pecan trees prior to bud break in early spring. Treatments included: calcium polysulfide, dodine, calcium polysulfide + dodine, and a nontreated control. All trees received a standard fungicide program after bud break. In another experiment, fungicides were applied in early June (mid-season). Specific treatments included: lime-sulfur (2.7 kg a.i./ha) + Pentra-Bark (2.3 L/ha), Sulforix (2.6 kg a.i./ha) or nontreated. No fungicides were applied prior to initiation of the experiment, allowing scab to develop on the leaves. Subsequently, paired trees were either coversprayed with a standard commercial program for the remainder of the season, or left nontreated. The incidence and severity of scab on leaves and nuts was rated in all trials, and stem lesions on the current year’s shoots were counted in the true dormant season spray trials. True dormant sprays of Elast alone or with Sulforix showed some reductions in leaf scab, nut scab, and stem lesions on the current year’s shoots, but reductions were relatively small. Both sulforix and lime-sulfur reduced nut scab when applied mid-season, but not as much as cover sprays which reduced scab to 35% severity, versus 61% in the nontreated trees. In addition to the field trials, effects of dormant-period applications on sporulation of *F. effusum* were determined by examining the number of conidia produced on treated and nontreated infected shoot sections in the lab. There was a significantly lower number of conidia produced per stem lesion from shoot treated with all dormant fungicides, however the greatest reduction in sporulation inhibition was observed following applications of chlorothalonil, chlorothalonil + dormant oil, or dodine. However, chlorothalonil + oil applied as a dormant spray did not reduce
early-season scab in field trials. Overall, dormant sprays of dodine provided the most consistent
disease reductions, but the benefits were not enough to justify replacement of commercial cover
spray applications. Early season use may provide additional disease control due to reductions in
overwintering inoculum. To avoid an additional spray, applications could be made after bud
break to capitalize on the known protectant activity of the product. The use of spore- reducing
sprays mid-season may provide additional disease control in years when potential inoculum is
unusually high due to severe early season leaf scab.

Introduction

Pecan scab, caused by the fungus Fusicladium effusum, is considered the most serious
disease of pecan (Carya illinoinensis) in Georgia (4). The majority of pecan cultivars that are
currently grown commercially have been selected for their desirable nut quality
characteristics, but they are generally susceptible to pecan scab (24).

The olivaceous to black spots typical of symptoms due to infection by F. effusum are
often visible on the foliage and fruit throughout the growing season and are a diagnostic sign of
the disease (4). The disease normally appears in the field soon after bud break when favorable
environmental conditions occur, stimulating the release of conidia from overwintering
inoculum sites. Frequent spring and summer rains in some recent years have been favorable for
early outbreaks of pecan scab and have significantly increased crop losses in Georgia. Once
infection occurs, the resulting lesions serve as sources of secondary inoculum that can increase
disease incidence and severity throughout the growing season (16).

From 2011 to 2013, economic losses due to pecan scab were estimated at approximately
$44 million including the cost of chemical control and an average 6% yield loss in Georgia
alone (Georgia Plant Disease Loss Estimate, www.caes.uga.edu/Publications).
*Fusicladium effusum* overwinters as stromata in lesions on pecan shoots, shucks, and leaf rachises infected the previous growing season, and all are sources of primary inoculum for epidemics (16,17). The stromata become active in the spring and produce conidia that serve as inoculum for pecan scab infection on the new foliage. Growers sometimes attempt to manage the overwintering inoculum with cultural practices such as pruning, but usually rely on frequent applications of fungicides during the growing season to protect the fruit and leaves as they develop. Currently fungicides applied during the dormant period of pecan aren’t recommended in pecan production practices, but severe scab epidemics in recent years have generated interest in their use to help combat the increased levels of overwintering inoculum and delay development. Close proximity between the source of inoculum within the canopy (infected shoots from previous season) and the susceptible tissues (new foliage) favors initial infection early in the growing season. Much of this inoculum is in the tops of the trees where there is more vegetative growth, as well as less good coverage with fungicide due to inaccessibility of the upper canopy (5).

The application of fungicides directly to the overwintering stromata on previously infected shoots during the dormant period has been tried on pecans with mixed results. In the late 1950s, studies conducted by Large (40) failed to show improved scab control using dormant fungicide applications. However, Converse (11) showed that using multiple applications of some contact fungicides during the dormant periods completely eliminated conidial production by overwintering stromata. Considering these mixed results in the past, new research is needed to evaluate newer fungicides for improved control of overwintering stromata. However, it should be evaluated in the field with significant inoculum potential on modern cultivars to determine if there are significant benefits. Similar applications of
fungicides during the dormant period are thought to reduce overall levels of inoculum in other fruit crops, hence further stimulating the interest in this disease management tool for pecans (9,20,35,48,49,50).

Lime sulfur is an older synthetic pesticide that has been shown to be efficacious in reducing overwintering inoculum in some fruit crops (33,34,38). A newer formulation of calcium polysulfide, Sulforix (Miller Chemical and Fertilizer Corp., Hanover, PA), has also been effective in blueberries at lower application rates compared to lime sulfur (9,49). It is an improved formulation of calcium polysulfide plus surfactants that is used at much lower rates. Although both products have the same active ingredient Sulforix has 27.5% versus Lime Sulfur having 29% active ingredient, respectively. Lime sulfur produces hydrogen sulfide, which can permeate fungal and plant cells (44,54,55). This explains its ability to suppress pecan scab infections already established in the plant. Lime sulfur affects the respiration complex of mitochondria by interfering with the electron transport in the respiratory chain, which results in multi-site toxicity and broad spectrum activity (2,3,37). Early reports from the 19th century until the mid-20th century indicate that lime sulfur was widely recommended for use in overwintering forms of diseases such as apple scab, powdery mildew, and brown rot of peach, before the introduction of more effective synthetic fungicides (35,42,53). However, dormant applications of lime sulfur or sulforix have not been studied for efficacy against F. effusum. The potential benefits of adding a surfactant to increase penetration of lime sulfur has also not been evaluated on pecans.

Dodine, which is a member of the guanidines chemical group, has been registered for in season pecan scab control since 1963 (41). Dodine has been particularly effective in controlling nut scab epidemics after pollination, however it is also used pre-pollination for
leaf scab. Guanidines like dodine target the mitochondrial membrane of fungal cells, as well as certain enzymes involved in oxidative phosphorylation (43). The anti-sporulant activity of dodine against *F. effusum*, along with the products history of excellent control of foliar and fruit infections, make a good case for evaluating the product as a dormant spray on pecans, particularly in light of the increased interest in dormant spray applications among pecan growers.

More recently chlorothalonil has been used as a dormant spray with excellent results in delaying epidemics of almond scab (*F. carpophilum*) (1). Although not currently labeled on pecans, similar activity on pecan scab would warrant pursuing a label for this use on pecan. Spray oils have also had some benefits on almond scab (1). Although chlorothalonil can sometimes be phytotoxic when used with oil, that should not be an issue on dormant tissue, so a combination of chlorothalonil plus oil might be particularly active (1). Copper is sometimes used as a dormant spray also, and the combined effects of copper plus chlorothalonil are very good for controlling leaf spot of peanut. This combination has not been evaluated on pecan scab as a dormant spray.

The objectives of this research were to evaluate the use of several fungicides as potential dormant applications for the reduction of inoculum of pecan scab prior to bud break. Mid- season applications during the scab epidemic on newly formed leaves, but prior to nut elongation, will also be evaluated to better understand the importance of application timing and effects of different sources of inoculum for management of pecan scab. The evaluation of fungicides to inhibit sporulation of *F. effusum* in laboratory experiments will also be evaluated to better understand the results seen in the field, and also for future products to be studied in pecans.
Materials and Methods

Field Experiments

*True dormant applications.* Field experiments in 2014 and 2015 were conducted to evaluate the effects of true dormant applications of Sulforix and/or Elast (dodine, Aceto Agricultural Chemicals Corp., Port Washington, NY) for the reduction of overwintering pecan scab inoculum. Experiments were conducted at the University of Georgia Ponder Farm in 2014 located in Ty Ty, GA, and commercial pecan farms in Albany, GA and in Baconton, GA in 2014 and 2015. Cultivars heavily infected with pecan scab the previous year were used at each location including: ~20-year-old cv. “Desirable” in Ty Ty, GA spaced 12×12 m, ~8-year-old cv. “Byrd” in Albany, GA spaced 12×12 m, and ~15-year-old cv. “Pawnee” in Baconton, GA spaced 9×9 m. Fungicides were applied with an air-blast sprayer (935 L/ha) approximately 2 weeks before bud break at each location. A randomized complete block design with 4 or 5 replications for each treatment was used at all locations. A total of twelve trees were sprayed with each fungicide treatment in each rep with four buffer rows in between treatments to prevent non-target fungicide exposure. Treatments included: Sulforix (14.0 L/ha), Elast (3.6 L/ha), Sulforix + Elast (14.0 + 3.6 L/ha), and nontreated. All trees received a standard fungicide program by the grower after bud break. Dormant sprays were applied in Tifton on 1 April 2014, and in Albany on 24 March in both 2014 and 2015. Dormant applications in Baconton were made on 22 March in 2014 and 24 March in 2015.

Three additional experiments were conducted in 2015 to evaluate the efficacy of Bravo + oil as a dormant spray. Experiments were conducted at the UGA Ponder farm and were similar to those just described for that site. Two experiments were conducted on cv. “Desirable” and one on cv. “Wichita”, both cultivars being extremely scab-susceptible.
The trees used were nontreated and had received no fungicides for several years, so potential inoculum levels were high on diseased tissues. A randomized complete block design with four replications was used for each treatment in all experiments.

*Mid-season applications.* In a separate experiment, mid-season fungicides were applied in early June on cultivars Wichita and Desirable at the University of Georgia Ponder Farm located in Ty Ty, GA. In both 2014 and 2015 the experiment had a 2 × 3 factorial design with four replications arranged in randomized complete blocks. Specific treatments included: Lime sulfur (37.3 L/ha) + Pentra-Bark (Quest Products Corp., Louisburg, KS) (2.4 L/ha), Sulforix (14.0 L/ha), or nontreated. No fungicides were applied prior to initiation of the experiment to allow scab to develop on the foliage. These treatments were then either followed by a standard cover spray program or not the remainder of the season for a total of six treatments. The cover sprays consisted of fungicides applied on a 14-day interval with alternating applications of Super Tin (United Phosphorus Inc., King of Prussia, PA) + Elast (Aceto Agricultural Chemicals Corporation, Port Washington, NY) 0.9 + 3.6 L/ha and Quadris Top (Syngenta Crop Protection, LLC, Greensboro, NC) 1.02 L/ha + Induce (Helena Chemical Company, Collierville, TN) 0.06% v/v for a total of six applications. The mid-season fungicide applications were made on 5 June in 2014 and 4 June 2015.

*Disease assessment.* Leaf scab incidence (% leaves with scab lesions) was evaluated approximately 2 months after dormant fungicide, but before mid-season applications, in all field trials in 2014 and 2015. Five arbitrarily selected terminals were selected from each of six trees per treatment. Disease was assessed on two compound leaves on each terminal: one leaf from the top third of the terminal and one leaf from the bottom third of the terminal. For each leaf, the total number of leaflets with scab symptoms was counted and disease incidence was
calculated by the following formula: INC = (number of leaflets with scab/ total number of leaflets on terminal) × 100%. Leaf scab severity was also assessed at the same time as leaf scab incidence by visually estimating the diseased leaf area (% area) on individual terminals on the top and bottom third compound leaves on each terminal ranging from 0-100%. The number of scab lesions on the current year’s stems was recorded at the time of leaf scab ratings by counting the number of lesions on the center 7.6-cm section of each terminal. % defoliation was also assessed by taking an arbitrary visual estimate of the percentage of foliage on the entire tree defoliated from scab on a scale ranging from 0-100%. Each treatment per rep was evaluated to obtain an average defoliation. These ratings were taken on 25 September 2014 and 16 November 2015.

Fruit scab incidence and severity was evaluated approximately 2 months after fungicide application in all field trials in 2014 and 2015 by examining six arbitrarily selected individual fruiting terminals on each tree. For each terminal, the number of fruit was counted along with the number of nuts with pecan scab symptoms, and the severity of scab was estimated for all nuts present on a terminal. Nut scab incidence and nut scab severity was calculated as described above.

Statistical analysis. Leaf and nut scab incidence and severity and number of lesions on the current years wood were analyzed using Proc GLIMMIX (SAS version 9.3, Cary, NC) to examine treatment effects. Means were compared using pairwise t-tests least squares means to identify significant differences among treatments (α = 0.05). Data are not combined for trials in 2014 and 2015 because significant year×treatment interactions were observed.
Laboratory Experiments

Effect of fungicides on reducing pecan scab sporulation. An experiment was conducted to evaluate the effects of fungicides on spore production from overwintering stem lesions on pecan shoots. In 2015 the current-year wood with active scab lesions was sampled from nonsprayed trees in an orchard at the University of Georgia Ponder Farm located in Ty Ty, GA. Stems were collected in June 2015 from cv. “Desirable” pecan trees. The experiment was a randomized complete block design with four replications and nine treatments, including the nontreated control. Shoots collected in the field were transported back to the laboratory and washed in deionized water amended with 0.1% Tween 20 to remove any existing conidia. Stems were air dried and cut into 2-cm sections and the number of scab lesions was recorded for each stem section. Stem segments were dipped in fungicide solutions calculated to equal a dilution of 935 L/ha spray volume. Treatments included 1) chlorothalonil (Syngenta Crop Protection, Greensboro, NC) at 4.685 L/ha, 2) chlorothalonil + petroleum oil (The Ortho Group, Columbus, OH), 3) cuprous oxide (Cu₂O) Nordox 75 WG, (Monterey Chemical Company, Fresno, CA) at 7297.9 g/ha, 4) chlorothalonil + cuprous oxide (Cu₂O) (Bravo Weather Stik, Syngenta Crop Protection, Inc., Greensboro, NC; Nordox 75 WG, Monterey Chemical Company, Fresno, CA) applied at 4.685 L/ha + 7297.9 g/ha, 5) calcium polysulfide + pentrabark applied at 46.78 L/ha + 2.34 L/ha, 6) calcium polysulfide at 14.05 L/ha, 7) dodine at 3.66 L/ha, 8) dodine + calcium polysulfide applied at 3.66 L/ha + 14.05 L/ha, and a water only control. After dipping in the fungicide suspension, the stem segments were placed in a petri dish suspended above moist filter paper with laboratory mixing rods and transferred to an incubator maintained at 15° C with continuous fluorescent light.
Four stems were treated per treatment. A preliminary study showed three days to be the optimum incubation period to obtain sporulation but minimize contaminants.

After three days, each section was washed individually in 2 ml deionized water containing 0.1% Tween 20, vortexed for 30s to dislodge spores, and the concentration of conidia in the wash water estimated with a hemacytometer. The total number of conidia per shoot section was calculated by multiplying the concentration of conidia by the total volume of the wash water. Production of conidia per lesion was estimated by the total number of conidia per shoot section ÷ by the number of lesions per section. The experiment was repeated.

Statistical analysis. Data were analyzed using Proc GLIMMIX in SAS (SAS Version 9.3, SAS Institute, Cary, NC) to examine treatment effects. Means were compared using pairwise t-tests least squares means to identify significant differences among treatments (α = 0.05).

Results

The statistical analysis of all dependent variables indicated significant trial × treatment interactions for true dormant and mid-season application experiments; therefore results of each individual trial are shown in separate figures due to independent analysis. There was no significant trial × treatment interaction for effects of fungicides on reducing pecan scab sporulation, therefore data from two trials are combined in the analysis.

True dormant applications. All dormant treatments reduced incidence and in some cases severity of leaf scab, but there were some treatments that resulted in an increase in scab (Tables 3.1, 3.2 & 3.3). In fact, for the leaves on the top third of the terminal there were as many fungicide treatments that increased scab intensity as there were fungicide treatments that decreased scab, relative to the nontreated control. Thus the leaves on the bottom third of the shoots had less scab than the nontreated control as a result of the dormant sprays. The Elast
treatment resulted in the most consistent decrease in scab intensity on the fruit and stems. Elast provided the most consistent reductions of scab on foliage in the bottom third of the terminal and on the current-year shoots in 2014 on cv. “Byrd” (Tables 3.1 & 3.2). Increased leaf scab was observed in the top third of the terminal with Elast treatments on cultivar Byrd in 2014, however significant reductions were observed in the bottom one-third of terminal and in the number of lesions on the current-year shoots with Elast (Tables 3.1 & 3.2). Elast also provided the most consistent reductions in nut scab severity on cultivar Byrd in 2014 compared to the nontreated control (Table 3.3). However, in 2015, stand-alone treatments of either Sulforix or Elast decreased disease levels on leaf scab on cultivar Byrd, but no significant differences were observed in nut scab incidence or severity compared to the nontreated control (Tables 3.1, 3.2 & 3.3). Treatments of Elast or Sulforix + Elast significantly reduced leaf scab on cultivar Pawnee in 2014 and 2015, especially on the bottom third of the terminal (Tables 3.1 & 3.2).

*Bravo dormant season experiments.* The fungicides evaluated were not effective in reducing pecan scab infection in the field in 2015. There were no significant differences among treatments on leaf scab incidence, nut scab incidence, or severity. However, there was a slight reduction in leaf scab severity with Bravo + Oil. The results from the experiments conducted in the lab suggest anti-sporulant activity of Bravo, therefore these trials need to be repeated to establish the effects of Bravo.

*Mid-season applications.* The intensity of scab at the time of mid-season applications was exceptionally high with leaf scab incidence being ~100% on cv. “Wichita” in 2014 and 2015 resulting in abundant in- season inoculum (Figure 3.1). Increased leaf scab severity and percent defoliation was greater in 2014 in trees treated with Sulforix, however an increase in leaf scab incidence and defoliation was observed in 2015 (Figure 3.2 and Figure 3.5). Lime
Sulfur + Pentra-Bark and Sulforix significantly reduced nut scab severity in 2014, but only Sulforix significantly reduced nut scab severity in 2015 (Figure 3.3 and 3.6). Of all the mid-season sprays evaluated, none provided significant differences when compared to standard cover sprays alone. Cover sprays reduced leaf scab severity by approximately 40%, nut scab severity by 35%, and defoliation by 40% respectively in 2014 (Figure 3.4). In 2015 cover sprays alone reduced leaf scab severity significantly, but also reduced nut scab severity by 30% compared to the nontreated trees (Figure 3.7).

Effect of fungicides in reducing pecan scab sporulation. All fungicides evaluated significantly reduced spore production per lesion compared to the nontreated control (Figure 3.8). Although all treatments reduced sporulation, the greatest reductions were observed following treatment with chlorothalonil, chlorothalonil + oil, and dodine (Figure 3.8). Elast and lime-sulfur are the only products tested currently registered for use in pecans, thus showing that there are various other products with the potential of reducing sporulation of *F. effusum*. These results confirm that these products applied to active stromata on pecan shoots offer some anti-sporulant advantage when compared to the nontreated control, and may ultimately provide more advantages in terms of scab management, especially when the inoculum potential is high.

Discussion

Both years of this study were abnormally wet during the growing season with conditions very favorable for scab epidemic development. The average rainfall from 1 April to 31 October is 55.2 cm from 2010-2012, but the actual rainfall was 106.9 cm, 90.9 cm, and 79.7 cm in 2013, 2014, and 2015 in the above months, respectively (www.Georgiaweather.net). The favorable conditions resulted in increased scab, particularly
early in the season, which provided an excellent opportunity to evaluate the efficacy of early season fungicide treatments. The procedures used to evaluate the efficacy of fungicides applied during the dormant and mid-season stages were very effective and successfully demonstrated alternative disease management considerations. Elast, and sometimes combinations of Sulforox and Elast, provided more effective control when applied as a dormant spray compared to nontreated trees. Efficacy of treatments in field trials in 2014 was significantly greater due to increased rain which led to severe scab epidemics. Increased disease intensity in 2014 likely resulted in more overwintering inoculum sites; however, less rainfall during the 2015 growing season, ultimately resulted in less disease in the orchard that year.

Based on the results, alternative disease management methods such as dormant and mid-season fungicide applications aimed at reducing inoculum appear to have some potential for improving scab management in pecans. It should be noted that lime-sulfur has been shown to have post-inoculation activity against apple scab caused by Venturia inaequalis in the orchard (42), so some of the control found in the mid-season applications may have been on latent infections. However, the degree of control observed in these preliminary studies was not sufficient to draw conclusions, and certainly any dormant season fungicide applications would have to be used in conjunction with currently recommended commercial fungicide applications. Although other factors such as timing and weather patterns have direct impact on the efficacy of these treatments, leaf and nut scab was more severe than anticipated in the 2014 growing season because of frequent spring and summer rains, and resulting favorable infection periods. The lack of a more significant response in these years of ideal conditions for early season scab development casts doubt on the utility of these sprays for routine scab management, especially considering their significant cost. Of the fungicides evaluated as dormant applications, Elast gave the most consistent control, but the benefits were relatively
small. Perhaps this result is due to the ability of *F. effusum* to rapidly build up an epidemic when conditions are ideal, given the short incubation period. Therefore early-season use may provide additional disease control due to reductions in overwintering inoculum. Applications could be made after bud break to capitalize on the known protectant activity of the product. Since fungicide sprays usually begin soon after bud-break, this would avoid adding an additional application to the program.

In conclusion, dormant or mid-season applications of fungicides aimed at reducing inoculum are not currently recommended in commercial pecan production in Georgia. In the experiments conducted on the effects of fungicides on reducing pecan scab sporulation from overwintered lesions on stems, we have confirmed significant anti-sporulant activity of the products evaluated; however, the reduction in sporulation did not translate consistently into lower scab intensity. The application of fungicides such as Sulforix and Lime sulfur mid-season provided better scab control than they did as true dormant sprays. Further research may demonstrate how these products can be optimized to improve disease management, especially in high pressure disease years.
Literature Cited


43. Miller, L. 1960. Uptake and innate toxicity of dodine (n-dodecyl-guanidine acetate) to fungus conidia. Phytopathology 50(9).


Table 3.1 Effect of dormant applications of Sulforix, Elast, or Sulforix + Elast on leaf scab incidence and severity of pecan in five experimental trials conducted in 2014 and 2015.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Year</th>
<th>Sulforix</th>
<th>Elast</th>
<th>Sulforix + Elast</th>
<th>Nontreated</th>
<th>Sulforix</th>
<th>Elast</th>
<th>Sulforix + Elast</th>
<th>Nontreated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desirable</td>
<td>2014</td>
<td>10.9 a</td>
<td>6.8 a</td>
<td>15.6 a</td>
<td>12.3 a</td>
<td>1.1 a</td>
<td>0.7 a</td>
<td>1.3 a</td>
<td>1.1 a</td>
</tr>
<tr>
<td>Wichita</td>
<td>2014</td>
<td>51 a</td>
<td>49.5 a</td>
<td>44.8 a</td>
<td>51 a</td>
<td>5.8 a</td>
<td>2.7 a</td>
<td>2.8 a</td>
<td>5.3 a</td>
</tr>
<tr>
<td>Pawnee</td>
<td>2014</td>
<td>56.4 a</td>
<td>41.1 b</td>
<td>45.1 b</td>
<td>53.2 a</td>
<td>3.9 a</td>
<td>2.5 c</td>
<td>3.1 b</td>
<td>3.7 a</td>
</tr>
<tr>
<td>Byrd</td>
<td>2014</td>
<td>31.4 ba</td>
<td>36.9 a</td>
<td>32.1 ba</td>
<td>27.2 b</td>
<td>1.5 b</td>
<td>1.9 a</td>
<td>1.7 ba</td>
<td>1.5 b</td>
</tr>
<tr>
<td>Pawnee</td>
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<td>18.2 a</td>
<td>12.5 b</td>
<td>8.1 c</td>
<td>13.2 b</td>
<td>1.3 a</td>
<td>0.9 cb</td>
<td>0.7 c</td>
<td>1.1 b</td>
</tr>
<tr>
<td>Byrd</td>
<td>2015</td>
<td>14 b</td>
<td>24.1 a</td>
<td>24.1 a</td>
<td>16.1 b</td>
<td>1.1 b</td>
<td>1.2 b</td>
<td>1.7 a</td>
<td>1.3 b</td>
</tr>
</tbody>
</table>

x Top third leaf scab incidence. Based on 5 terminals per tree (% of leaflets on top third of terminal with any scab). Least squares means with the same letter(s) do not differ significantly according to pairwise t-test (α = 0.05).

y Top one-third leaf scab severity. Based on 5 terminals per tree (% of foliage on top one-third of terminal covered with scab 0-100%). Means with the same letter(s) do not differ significantly according to pairwise t-test (α = 0.05).

z Treatments were as follows: (1) Sulforix (4.27 kg a.i./ha), (2) Elast (0.24 kg a.i./ha), (3) Sulforix + Elast (4.27 kg a.i./ha + 0.24 kg a.i./ha) applied during the dormant period of pecan (~mid-March). All trees received a full-season fungicide program [10 applications] during the growing season.
Table 3.2 Effect of dormant applications of Sulforix, Elast, or Sulforix + Elast on leaf scab incidence and severity of pecan in five experimental trials conducted in 2014 and 2015.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Year</th>
<th>Bottom Leaf, Incidence&lt;sup&gt;x&lt;/sup&gt;</th>
<th>Bottom Leaf, Severity&lt;sup&gt;y&lt;/sup&gt;</th>
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<tr>
<td></td>
<td></td>
<td>Sulforix&lt;sup&gt;z&lt;/sup&gt;</td>
<td>Elast</td>
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<tr>
<td>Desirable</td>
<td>2014</td>
<td>32.7 b</td>
<td>37.3 ab</td>
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<td>Wichita</td>
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<td>68.9 a</td>
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<td>Pawnee</td>
<td>2014</td>
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<td>Byrd</td>
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<td>77.8 a</td>
<td>64.5 b</td>
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<tr>
<td>Pawnee</td>
<td>2015</td>
<td>20 a</td>
<td>11.7 c</td>
</tr>
<tr>
<td>Byrd</td>
<td>2015</td>
<td>30.2 b</td>
<td>30.3 b</td>
</tr>
</tbody>
</table>

<sup>x</sup> Bottom one-third leaf scab incidence. Based on 5 terminals per tree (% of leaflets on top one-third of terminal with any scab). Least squares means with the same letter(s) do not differ significantly according to pairwise t-test (α = 0.05).

<sup>y</sup> Bottom one-third leaf scab severity. Based on 5 terminals per tree (% of foliage on top one-third of terminal covered with scab (0-100%). Means with the same letter(s) do not differ significantly according to pairwise t-test (α = 0.05).

<sup>z</sup> Treatments were as follows: (1) Sulforix (4.27 kg a.i./ha), (2) Elast (0.24 kg a.i./ha), (3) Sulforix + Elast (4.27 kg a.i./ha + 0.24 kg a.i./ha) applied during the dormant period of pecan (~mid-March). All trees received a full-season fungicide program [10 applications] during the growing season.
Table 3.3 Effect of dormant applications of Sulforix, Elast, or Sulforix + Elast on nut scab incidence, severity, and number of lesions on current year’s wood of pecan in five experimental trials conducted in 2014 and 2015.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Year</th>
<th>Sulfurix</th>
<th>Elast</th>
<th>Sulfurix + Elast</th>
<th>Nontrtd</th>
<th>Sulfurix</th>
<th>Elast</th>
<th>Sulfurix + Elast</th>
<th>Nontrtd</th>
<th>Sulfurix</th>
<th>Elast</th>
<th>Sulfurix + Elast</th>
<th>Nontrtd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desirable</td>
<td>2014</td>
<td>27.6 a</td>
<td>32.3 a</td>
<td>29.9 a</td>
<td>37.7 a</td>
<td>1.3 a</td>
<td>2.0 a</td>
<td>1.5 a</td>
<td>0.4 a</td>
<td>8.8 a</td>
<td>8.1 a</td>
<td>9.3 a</td>
<td>10.3 a</td>
</tr>
<tr>
<td>Wichita</td>
<td>2014</td>
<td>88.4 a</td>
<td>84.9 a</td>
<td>86.7 a</td>
<td>77.9 a</td>
<td>5.2 a</td>
<td>5.4 a</td>
<td>6.8 a</td>
<td>7.1 a</td>
<td>4.5 a</td>
<td>4.6 a</td>
<td>5.8 a</td>
<td>5.4 a</td>
</tr>
<tr>
<td>Pawnee</td>
<td>2014</td>
<td>98.9 a</td>
<td>91.9 b</td>
<td>95.9 ba</td>
<td>97.1 a</td>
<td>7.2 a</td>
<td>4.7 b</td>
<td>5.2 b</td>
<td>5.4 b</td>
<td>0.5 a</td>
<td>0.1 b</td>
<td>0.1 b</td>
<td>0.5 a</td>
</tr>
<tr>
<td>Byrd</td>
<td>2014</td>
<td>95.8 ba</td>
<td>97.8 b</td>
<td>95.1 b</td>
<td>97.1 a</td>
<td>6.5 bc</td>
<td>5.8 c</td>
<td>7.9 ba</td>
<td>8.3 a</td>
<td>10.7 a</td>
<td>5.9 b</td>
<td>11.5 a</td>
<td>9.3 a</td>
</tr>
<tr>
<td>Pawnee</td>
<td>2015</td>
<td>98.4 a</td>
<td>91.8 b</td>
<td>96 ba</td>
<td>92.1 b</td>
<td>5.8 a</td>
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<td>0.1 a</td>
<td>0.1 a</td>
<td>0.1 a</td>
<td>0.1 a</td>
</tr>
<tr>
<td>Byrd</td>
<td>2015</td>
<td>23.1 a</td>
<td>22.9 a</td>
<td>25.5 a</td>
<td>17.6 a</td>
<td>1.2 a</td>
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<td>0.3 a</td>
<td>0.4 a</td>
<td>0.2 a</td>
<td>0.2 a</td>
</tr>
</tbody>
</table>

\[x\] Fruit scab incidence. Based on 5 terminals per tree (# fruit with scab/# fruit *100). Least square means with the same letter(s) do not differ significantly according to pairwise t-tests (\(\alpha = 0.05\)).

\[y\] Fruit scab severity. Based on 5 terminals per tree (% of fruit surface area covered with scab 0-100%). Least square means with the same letter(s) do not differ significantly according to pairwise t-tests (\(\alpha = 0.05\)).

\[xy\] Number of scab stromata on current year’s wood. Counts were taken on a 7.6-cm section in the middle of the current year’s wood.

\[z\] Treatments were as follows: (1) Sulfurix (4.27 kg a.i./ha), (2) Elast (0.24 kg a.i./ha), (3) Sulfurix + Elast (4.27 kg a.i./ha + 0.24 kg a.i./ha applied during the dormant period of pecan (~mid-March). All trees received a full-season fungicide program [10 applications] during the growing season.
Fig. 3.1 Scab intensity on current-year shoots of pecan trees at the time of mid-season fungicide applications in 2014 and 2015.
**Fig. 3.2** Effect of fungicide applications to reduce scab inoculum on leaf scab when applied mid-season (early June) in 2014. Scab ratings were taken on 22 July. Least squares means with the same letter(s) do not differ significantly according to pairwise t-tests ($\alpha = 0.05$).
Fig. 3.3 Effect of fungicide applications to reduce scab inoculum on nut scab when applied mid-season (early June) in 2014. Scab ratings were taken on 4 August. Least squares means with the same letter(s) do not differ significantly according to pairwise t-tests (α = 0.05).
Fig 3.4 Effect of cover sprays to reduce leaf scab, nut scab, and % defoliation when applied in conjunction with mid-season fungicide applications (June 2014). Scab ratings were taken on 4 August. Least squares means with the same letter(s) do not differ significantly according to pairwise t-tests ($\alpha = 0.05$).
**Fig 3.5** Effect of fungicide applications to reduce scab inoculum on leaf scab when applied mid-season (early June) in 2015. Scab ratings were taken on 22 July. Least squares means with the same letter(s) do not differ significantly according to pairwise t-tests ($\alpha =0.05$).
Fig. 3.6 Effect of fungicide applications to reduce scab inoculum on nut scab when applied mid-season (early June) in 2015. Scab ratings were taken on 4 August. Least squares means with the same letter(s) do not differ significantly according to pairwise t-tests ($\alpha=0.05$).
### Fig 3.7 Effect of cover sprays to reduce leaf scab, nut scab, and % defoliation when applied in conjunction with mid-season fungicide applications (early June) in 2015. Scab ratings were taken on 4 August. Least squares means with the same letter(s) do not differ significantly according to pairwise t-tests ($\alpha = 0.05$).
**Figure 3.8** The effects of fungicides treatment on sporulation of *Fusicladium effusum* from overwintering lesions on pecan shoot segments. Treatment rates were as follows: (1) Bravo (1.7 kg a.i./ha), (2) Oil (2.3 L/ha), (3) Nordox (7.3 kg a.i./ha), (4) Lime-sulfur (2.7 kg a.i./ha), (5) Sulforix (2.6 kg a.i./ha), (7) Elast (0.24 kg a.i./ha) Least squares means with the same letter(s) do not differ significantly according to pairwise t-tests ($\alpha = 0.05$).