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Management of Pecan Fruit and Foliar Diseases with Fungicides

Pecan (*Carya illinoensis* [Wang.] K. Koch) is indigenous along several rivers in Texas and along the Mississippi River system as far north as central Illinois. The United States is the world's major pecan-producing country, with annual production exceeding 90 million kg; Mexico, Israel, South Africa, and Australia also produce pecans. The two distinct production areas in the United States are the coastal plain of the southeast, including portions of North and South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, and eastern Texas, and the arid southwest, involving western Texas, New Mexico, and Arizona

The suppression of fruit and foliar diseases is as essential for economic production of pecans in the southeast as irrigation water is in the arid southwest. Since pecan cultivation began in the 1900s diseases have been important limiting factors in production. The annual use of fungicides on more than 3 million trees in the coastal plain production area places pecan as the third largest market for fungicides in the United States, following peanuts and deciduous fruits.

Pecan scab (*Fusicladium effusum* Wint.) (Fig. 1A) is by far the most important disease. Others of concern to growers are downy spot (*Mycosphaerella caryigena* Demaree and Cole) (Fig. 1B), zonate leaf spot (*Cristulariella pyramidalis* Waterman and Marshall) (Fig. 1C), and powdery mildew (*Microsphaera alni* Wint.) (Fig. 1D). Several foliar diseases are of minor economic importance, including liver spot (*Gnomonia caryae* Wolf), leaf blotch (*Mycosphaerella dendroides* Demaree and Cole), Gnomonia leaf spot (*Gnomonia dispora* Demaree and Cole), and fungal leaf scorch (causal agent unknown) (16). Effective use of fungicides in disease management requires understanding the survival mechanism, source of primary inoculum and secondary spread of the target pathogen. The need to control scab, because of its overwhelming importance, determines the pecan fungicide program.

Scab

The scab fungus survives the dormant period of pecan as stromata formed on shucks, twigs, bud scales, leaf rachises, and petioles (Fig. 2). In the spring, under conditions of high relative humidity or free moisture, the stromata produce the conidia that provide the primary inoculum (Fig. 3). The conditions favorable for sporulation on stromata usually exist at bud break, and the currently recommended fungicide program calls for the first spray to be applied at this time.

Foliage or developing fruit may be infected within 4–6 hours if moisture is sufficient and temperature is above 10 C. Symptoms develop 5–21 days after infection.

Stromata continue to provide inoculum well into the growing season. Secondary inoculum develops on leaves and fruit and increases the difficulty of controlling scab with protective fungicides. Foliage becomes more resistant with age, but fruit remains susceptible throughout the nearly 6-month growing season. New growth may occur during the growing season and increase the amount of susceptible tissue. A protective fungicide must be on foliage and fruit throughout the entire growing season. The standard scab prevention program in Georgia calls for fungicide applications at 14-day intervals during the period of rapid foliar growth, from bud break until pollination, and at 21-day intervals from pollination through August. Most growers modify this program somewhat to meet their individual needs.

Downy Spot

The downy spot fungus survives the fall and winter in lesions on fallen leaves (9). The sexual stage develops in the spring

Table 1. Loss of resistance of pecan cultivars to *Fusicladium effusum* between 1910 and 1956[a]

Cultivar	1910	1920	1931	1940	1954	1956
Georgia Giant	S	S	S	S	S	S
San Saba	S	S	S	S	S	S
Delmas	R	S	S	S	S	S
Van Deman	R	S	S	S	S	S
Schley	R	S	S	S	S	S
Pabst	R	S	S	S	S	S
Alley	R	R	S	S	S	S
Mobile	R	R	S	S	S	S
Moore	R	R	S	S	S	S
Success	VR	R	S	S	S	S
Teche	VR	VR	R	S	S	S
Frotcher	VR	VR	R	S	S	S
Money Maker	VR	VR	R	R	S	S
Curtis	VR	VR	VR	VR	S	S
Stuart	VR	VR	VR	VR	VR	S

[a] S = Susceptible; heavy losses from pecan scab common in some locations. R = Resistant; occasional light losses from pecan scab in a few locations. VR = Very resistant; losses from pecan scab very rare.

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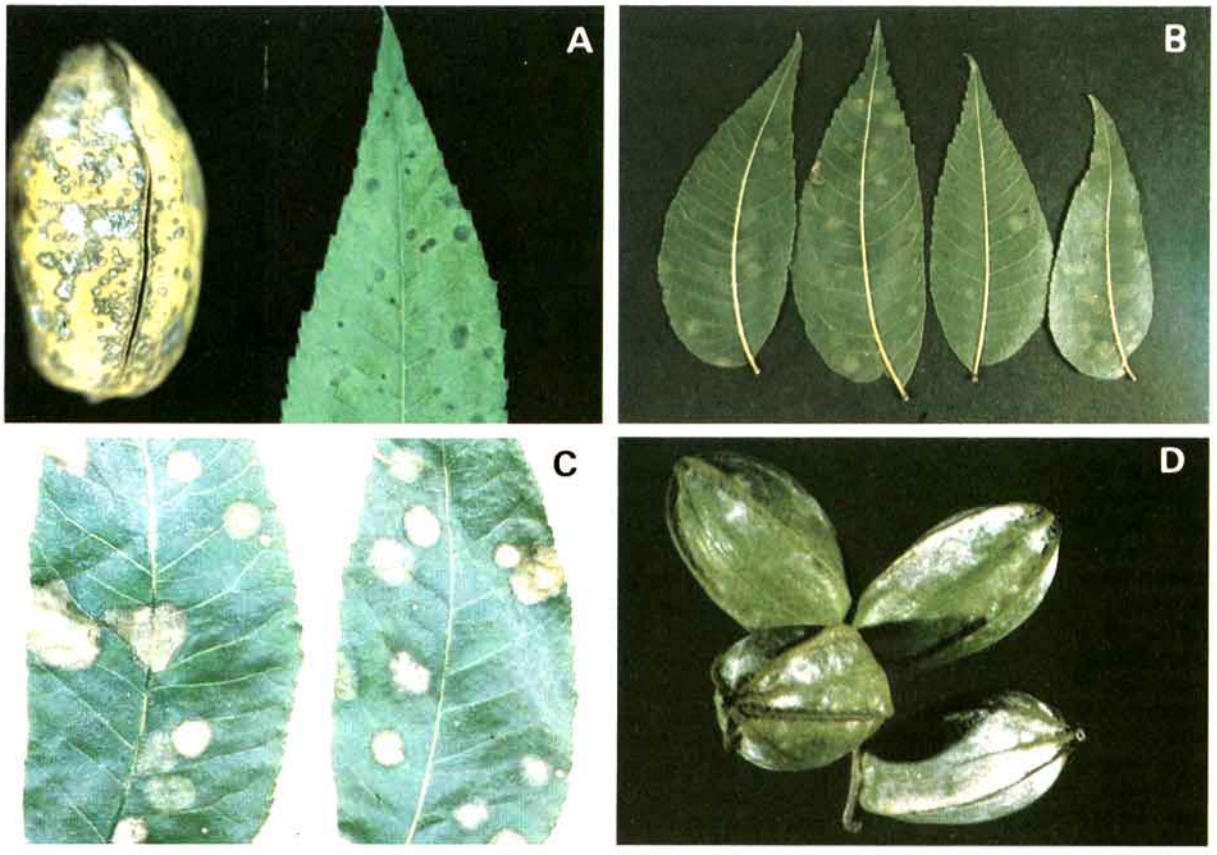


Fig. 1. Diseases of pecan: (A) scab on fruit and leaflet; (B) downy spot; (C) zonate leaf spot; and (D) powdery mildew.

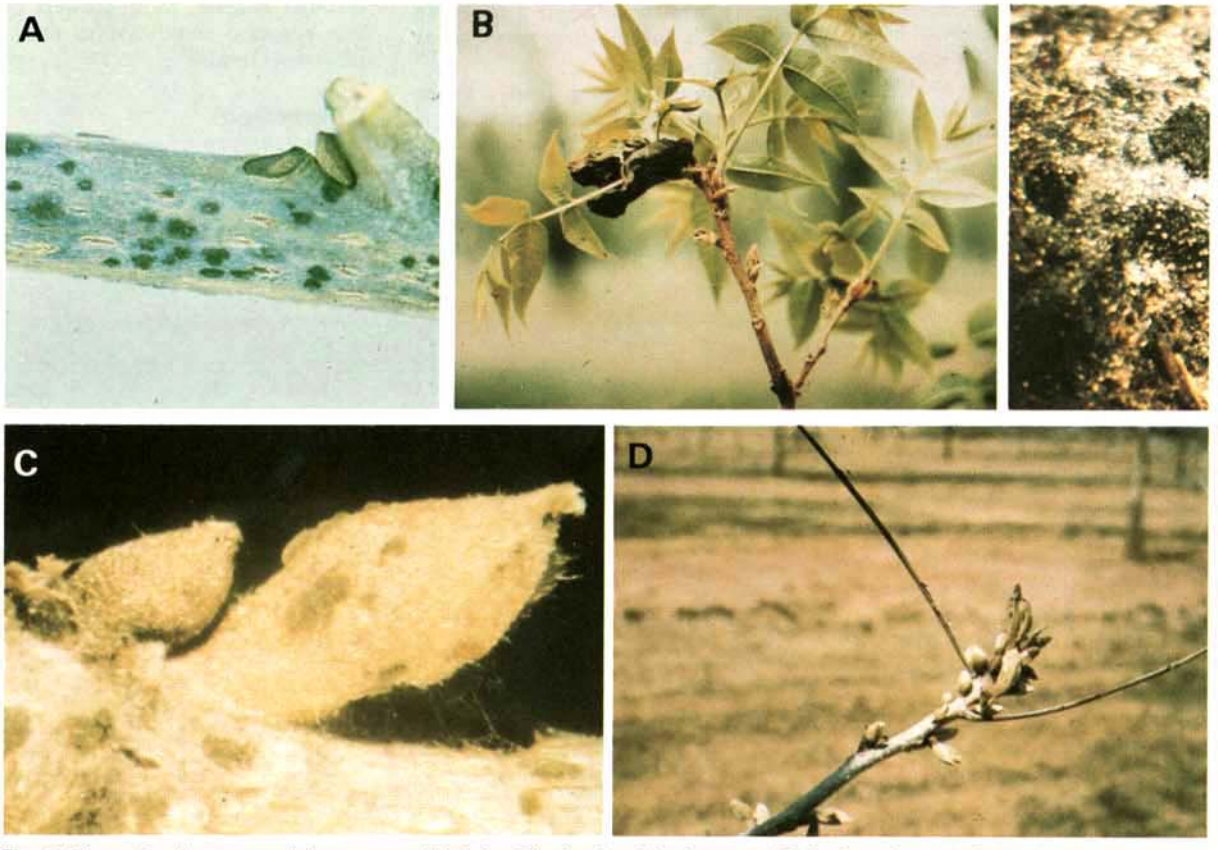


Fig. 2. Stromata of pecan scab fungus on: (A) twig; (B) shuck, with close-up; (C) bud scale; and (D) leaf rachis.

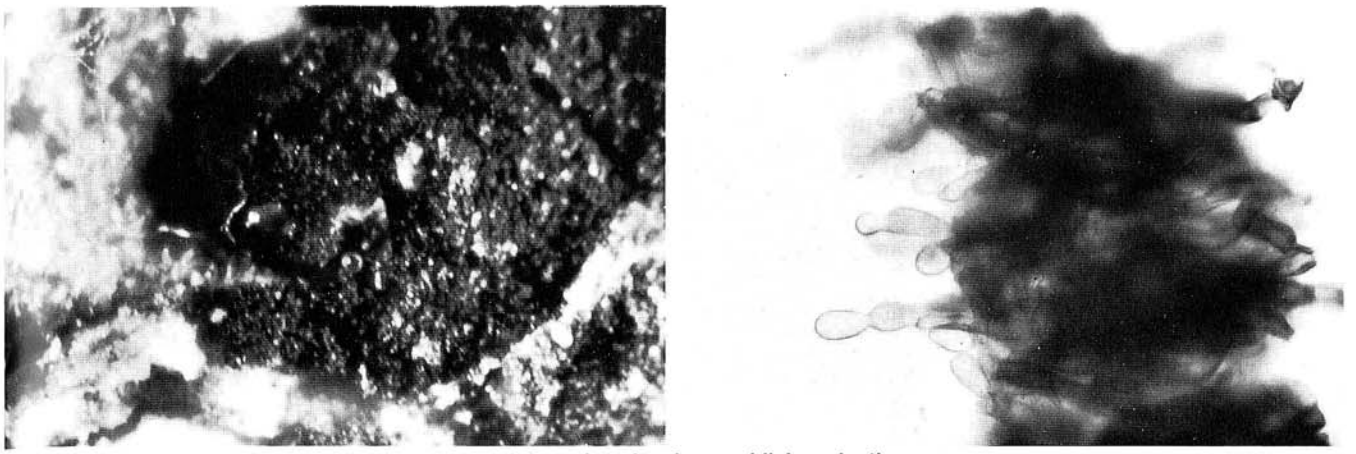


Fig. 3. (Left) Stroma of pecan scab fungus and (right) section showing conidial production.

and produces ascospores that are carried by wind currents to developing foliage. Symptoms appear 6–8 weeks after infection. The first signs of disease are more or less circular whitish spots, due to conidia production, on the undersurface of leaflets. Heavy rains may wash the conidia away, leaving only a faint discoloration. Lesions turn yellow as infection develops, and premature defoliation may occur late in the season. Even though symptoms are relatively mild, photosynthetic efficiency may be reduced as much as 40% (15). All fungicides recommended on pecan will effectively suppress downy spot if applied before initial infection. If treatment is delayed, however, downy spot will increase and become very difficult to manage.

Zonate Leaf Spot

Zonate leaf spot is characterized by concentric ring lesions on the foliage and causes rapid, severe defoliation. Several days of wet weather favor development of zonate leaf spot. The disease occurs most frequently in areas of poor air drainage and in orchards situated near river bottoms or adjacent to wooded areas.

The fungus has an extremely wide host range and is known to attack at least five species of maple, poison oak, hackberry, sassafras, and Virginia creeper (12). The disease may occur on a specific pecan tree year after year or on a group of trees within a large orchard. During periods of continuous rain and high humidity, the disease may spread over large acreages. How the fungus survives from year to year is not understood, but sporophores (Fig. 4) are known to be infective units.

The only effective fungicide treatment for control of zonate leaf spot is benomyl. Commercial growers who usually have zonate leaf spot apply benomyl, mostly in 1% superior oil, during June before symptoms develop. Once the disease has appeared, control is very difficult.

Chronicle of Scab Management

The earliest researchers recognized that pecan disease control meant pecan scab control. Scab is the only disease of the pecan fruit and foliage that can cause complete crop failure.

The first investigation of pecan scab control was conducted by M. B. Waite during 1909–1910. He found that Bordeaux mixture would control pecan scab (18). Because of the difficulties involved in spraying large trees and the apparent scab resistance of many pecan cultivars, he recommended "top working the more susceptible varieties to resistant sorts rather than attempting to prevent the disease by spraying" (18). By the early 1920s several cultivars previously believed to be scab resistant were highly susceptible (7,18). This unfortunate trend continued until all the old popular cultivars had lost scab resistance (Table 1).

Loss of scab resistance from many cultivars and improved gasoline-powered hydraulic orchard sprayers, newly available in the 1920s, renewed interest in pecan spraying. Bordeaux mixture was again found to be the most effective fungicide but was also found to be phytotoxic to young unfolding leaves and occasionally to other tissues as well (7,18). Growers were advised to make the first application of Bordeaux mixture after the pollination period, but there was no idea what a standard spray schedule should be (7).

Top working was still considered to be an important means of long-range control of scab in young orchards in the early 1920s (7,18). In 1924, sanitation, a concept that remained central to the scab control program for many years, was introduced. Demaree (7) pointed out that the scab fungus overwintered on shucks and leaves and recommended their destruction by deep plowing or raking and burning as a means to control primary scab infection.

In 1929, Demaree and Cole (8,11) presented evidence for host cultivar specificity in *F. effusum* and used this evidence to explain why individual pecan cultivars varied from very susceptible to very resistant in different locations with similar climates. Also about this time, top working ceased to be a recommended means of scab control.

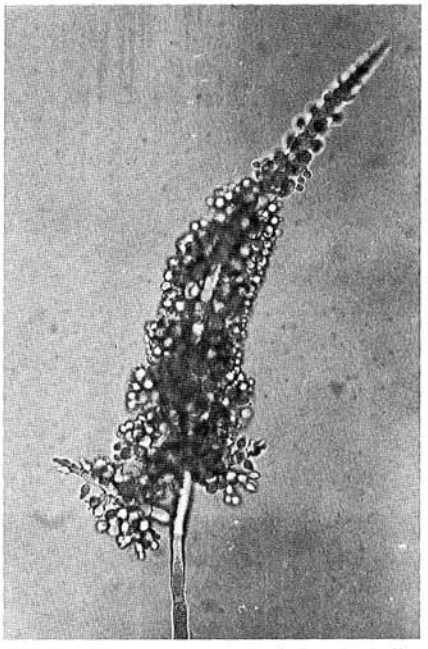


Fig. 4. Sporophore of *Cristulariella pyramidalis*, causal agent of zonate leaf spot. (Courtesy A. J. Latham, Department of Botany and Plant Pathology, Auburn University)

Bordeaux mixture remained the only effective fungicide for pecan scab control through the early 1930s. The standard program called for an initial treatment as soon as pollination was completed and subsequent treatments every 28 days for 3 or 4 months (Table 2). Despite cost, labor, periodic losses due to phytotoxicity, and occasional failure of the program in years with very wet springs, the practice of spraying to control disease gradually increased as orchard sprayers and most other management practices improved.

A major breakthrough came in 1940 when Cole and Large reported that "low-lime" Bordeaux mixture would give effective and, best of all, safe control of pecan scab (6). The nonphytotoxic nature

Table 2. Changes in fungicide usage for pecans in Georgia

Year	Fungicide and dosage	Instructions and remarks
1918	Bordeaux 6-6-100[a]	Apply every 3–4 weeks beginning as soon as pollination has occurred and young nuts are present.
1920	Bordeaux 8-8-100	As above.
1938	Bordeaux 4-1-100 then Bordeaux 6-2-100	Apply prepollination when leaves are one-half to two-thirds grown. Begin 3 weeks after prepollination spray and continue at 3-week intervals through season.
1963	dodine (Cyprex 65W), 2.24 kg/ha or zineb, 4.48 kg/ha or Bordeaux 4-1-100	Apply two prepollination sprays, one at bud break and one 14 days later. Treat every 3 weeks after pollination. If Bordeaux is used, increase strength to 6-2-100 in postpollination sprays.
1967	dodine (Cyprex 65W), 2.24 kg/ha or triphenyltin hydroxide (Du-Ter 47.5W), 0.9 kg/ha	Apply two prepollination sprays, one at bud break and one 14 days later. When scab is not a problem, use Bordeaux 4-1-100 or zineb 65W at 4.48 kg/ha. Treat every 14–21 days after pollination.
1974	dodine (Cyprex 65W), 2.24 kg/ha or triphenyltin hydroxide (Du-Ter 47.5W), 0.9 kg/ha or benomyl (Benlate 50W), 0.9 kg/ha	Apply at bud break and 14 days later. Apply every 14–21 days after pollination. When powdery mildew is a problem, use benomyl at 1.12 kg/ha.

[a] Bordeaux formulation strength expressed as pounds of copper sulfate–pounds of lime–100 gallons of water. Bordeaux should be applied for complete coverage, or about 2,338–3,274 L/ha.

Table 3. Georgia pecan disease control schedule, 1981[a]

Fungicide	Dosage	Instructions and remarks
Dodine Cyprex 65W or	 2.24 kg/ha	Do not use on cultivars Moore, Van Deman, Barton, and Shawnee.
Triphenyltin hydroxide (TPTH) Du-Ter 47.5W or Du-Ter 30F or Super-Tin 4L	 0.9 kg/ha 1.75 L/ha 0.88 L/ha	Where powdery mildew is observed or zonate leaf spot is expected, combine benomyl (Benlate 50W) at 1.12 kg/ha with a full dosage of TPTH.
Triphenyltin hydroxide (TPTH) Du-Ter 47.5W or Du-Ter 30F or Super-Tin 4L plus Benomyl Benlate 50W	 0.56 kg/ha 0.88 L/ha 0.44 L/ha 0.56 kg/ha	Use this combination only where pecan scab fungus is known *not* to be resistant to benomyl. To control zonate leaf spot or powdery mildew, increase benomyl dosage to 1.12 kg/ha.

[a] Fungicide applications should be made every 14 days from bud break to pollination and every 21–28 days from pollination through August. Spray suspensions are usually applied at 468–1,169 L/ha.

of low-lime Bordeaux mixture allowed growers to make prepollination treatments, the value of which was suspected long before they became possible. Cole and Large continued to recommend a sanitation program aimed at destroying primary inoculum (6). They noted that a good scab control program also controlled most of the minor foliar diseases. The low-lime Bordeaux mixture program was quickly adopted and used for many years (Table 2).

In 1948, Cole reported that the new air-blast speed sprayers were doing a good job in pecan scab control (1). That same year he also reported successful pecan scab control with ziram (2). Ziram and zineb both gained some popularity as postpollination fungicides during the 1950s.

In 1956, the cultivar Stuart was reported to be heavily damaged by scab in Mississippi (5). Scab had been known to occur in very minor amounts on Stuart for many years (8), but this was the first report of severe losses. Stuart was the last of the popular old cultivars to become susceptible. Stuart does not scab heavily in all areas of the Southeast, but some growers still suffer losses by assuming that Stuart is resistant. In 1957, Cole (3) discussed the cultivar situation and suggested that growers plant those cultivars that produce large quantities of high-quality nuts and expect to control disease with a good spray program.

Beginning in the 1950s and continuing through the 1960s, orchard plowing was gradually phased out in favor of a permanent sod orchard floor that facilitated mechanized harvest. This shift in practices also ended the destruction of primary inoculum as a major scab control measure.

All the fungicides currently used on pecans were tested and proved effective between 1959 and 1968. In 1960, Cole reported excellent scab control with dodine (4). Large achieved equally excellent results with triphenyltin hydroxide (TPTH) in 1965 (11). Excellent results with benomyl were reported in 1968 (20). Because of problems associated with the use of dodine (17) and benomyl (13), triphenyltin hydroxide in flowable and wettable powder formulations has become the major and nearly exclusive pecan fungicide.

Current Fungicide Situation

The three registered compounds available for management of pecan foliar diseases are dodine (Cyprex 65W),

benomyl (Benlate 50W), and TPTH (Du-Ter 47.5W, Du-Ter 30F, and Super-Tin 4L). All are subject to limitations.

Dodine. Dodine represented a major breakthrough in effective scab control in 1960 (4) but was phytotoxic to several cultivars. The cultivars Moore and Van Deman are especially sensitive to dodine injury, as are most selections derived from crosses with Moore. Moore and Van Deman are not major cultivars but are common enough in many older orchards to discourage widespread use of dodine. Damage from dodine appears more severe during the hot midsummer. Dodine has been found to suppress sporulation of *F. effusum* (14). In order to take advantage of this effect, most of the small amounts of dodine now used are applied during the prepollination period when phytotoxicity is minimal.

Benomyl. Benomyl was found to be highly effective in controlling all the fruit and foliage diseases of pecans. For a time in the early 1970s, benomyl was the most popular pecan fungicide. Then in 1975, Littrell found that *F. effusum* had developed resistance to benomyl at several locations in Georgia (13); widespread dependence on benomyl ceased in 1976. A survey conducted in 1979 showed that resistant strains of the fungus persisted in orchards where they had been identified in 1975, indicating these resistant strains are capable of surviving. Despite this major limitation, benomyl remains a valuable pecan fungicide. It continues to be recommended as a supplement to the normal fungicide program for control of specific diseases, such as zonate leaf spot and powdery mildew (Table 3).

TPTH. Because of the problems associated with the use of dodine and benomyl, TPTH is now the major pecan fungicide. TPTH has given consistently excellent control of scab and downy spot since its introduction in 1965. TPTH is used strictly as a protectant. There is no evidence that TPTH has any systemic activity or capacity to suppress sporulation. This forces growers to adhere to a rather strict calendar spray schedule and allows only minimal flexibility for disease management schemes. For example, any attempt to time TPTH applications based on the occurrence of infection periods would be of very little value and very risky.

How long this compound can continue to enjoy such exclusive use before some tolerance develops in the target organism is not known. Giannopolitis (10) observed a marked drop in efficacy of TPTH in Greece where it had been used exclusively for control of Cercospora leaf spot on sugar beets. This drop in efficacy was due to increased tolerance of *Cercospora beticola* to TPTH. This was not a case of a shift to total resistance, as occurred with benomyl, but the increased tolerance to TPTH was definite and measurable. At present, there is no evidence for this phenomenon in pecan pathogens, but the potential must be recognized.

The Desirable Fungicide

The proper timing for fungicide treatment is critical in the management of diseases. With the current protective program (Table 3), treatment must begin at bud break and continue on a calendar schedule through August. Since cultivars differ in the time of bud break, growers must compromise timing of the first treatment. A fungicide that would cure infection as well as protect tissues would be of great benefit. For maximum practical value the curative action should be effective 96 hours or longer after the infection process is initiated. Such a fungicide could be more easily used in a disease forecasting system based on weather patterns or anticipation of infection periods. This in turn would lead to more efficient fungicide usage and offer a possibility for reducing the number of fungicide applications.

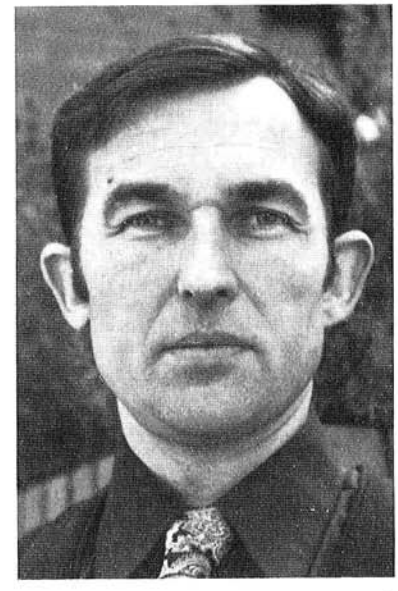
Regardless of what type of new fungicides are developed, the continued production of annual crops of high-quality pecans in the Southeast depends on availability of effective fungicides.

Accurate Disease Loss Evaluation

Plant pathologists, county extension agents, and farmers must keep in mind that the application of fungicide is to minimize disease losses and not to control disease per se. Significant improvement in disease control as measured by visual ratings with no corresponding decrease in disease losses was observed in pecan scab trials in Georgia in 1980. Results such as these should be familiar to all plant pathologists.

Pecan suffers both direct and indirect losses from disease. Pecan scab and, to a much lesser extent, powdery mildew cause direct losses by attacking the current season nut crop. These losses may be due to premature nut drop or incomplete kernel development. Losses of this nature are not difficult to measure with adequate sampling and accurate yield records.

The other foliar diseases present a more complex situation. All foliar diseases can cause indirect losses. The disease occurrence in one season results in crop losses the next season, because the



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damage done by foliar diseases results in premature leaf drop. It has been clearly demonstrated that premature leaf drop one season can greatly affect the quantity and quality of the crop the following season (19). Gauging losses of this nature is very complicated and requires tremendous amounts of sampling. Several common insect and mite pests (16) as well as adverse environmental conditions may interact with foliar disease to cause early leaf drop.

The losses due to any specific foliar disease have never been reported but must occur. Foliage maintenance is a central part of a pecan production program. Accurate measurement of reductions in disease losses rather than simple percentage of control is essential to meaningful programs of product development and accurate formulation of cost-effective management strategies.

Literature Cited

1. Cole, J. R. 1948. Latest results on pecan scab control in the Southeast. Proc. Southeast. Pecan Grow. Assoc. 41:67-78.
2. Cole, J. R. 1948. Zinc dimethyldithiocarbamate (Zerlate or Karbam White), a promising fungicide for pecan scab control. Phytopathology 38:921-922.
3. Cole, J. R. 1957. Will scab eventually affect all varieties of pecans? Proc. Southeast. Pecan Grow. Assoc. 50:79-82.
4. Cole, J. R. 1960. Dodine, an outstanding fungicide for pecan scab control. Plant Dis. Rep. 44:251-252.
5. Cole, J. R., and Gossard, A. C. 1956. Stuart pecan found susceptible to scab in Mississippi. Plant Dis. Rep. 40:156.
6. Cole, J. R., and Large, J. R. 1940. Resume of five years of spraying pecans with low-lime Bordeaux and zinc sulfate to control scab, foliage and rosette diseases. Proc. Southeast. Pecan Grow. Assoc. 34:16-29.
7. Demaree, J. B. 1924. Pecan scab with special reference to sources of the early spring infections. J. Agric. Res. 28:321-331.
8. Demaree, J. B., and Cole, J. R. 1929. Behavior of *Cladosporium effusum* (Wint.) Demaree on some varieties of pecan. J. Agric. Res. 38:363-370.
9. Demaree, J. B., and Cole, J. R. 1932. The downy spot disease of pecans. J. Agric. Res. 44:139-146.
10. Giannopolitis, C. N. 1978. Occurrence of strains of *Cercospora beticola* resistant to triphenyltin fungicides in Greece. Plant Dis. Rep. 62:205-208.
11. Large, J. R. 1965. Results of two years spraying with Du-Ter (triphenyltin hydroxide) compared with other fungicides for the control of pecan scab. Proc. Southeast. Pecan Grow. Assoc. 58:55-59.
12. Latham, A. J. 1972. Some hosts of *Cristulariella pyramidalis* in pecan orchard hedgerows. Plant Dis. Rep. 56:176-177.
13. Littrell, R. H. 1976. Resistant pecan scab strains to Benlate and pecan fungicide management. Pecan South 3:335-337.
14. Littrell, R. H., and Hunter, R. E. 1979. Laboratory and field studies for suppression of primary inoculum of the pecan scab fungus. Proc. Southeast. Pecan Grow. Assoc. 72:71-76.
15. Loustalot, A. J., and Hamilton, J. 1941. Effects of downy spot on photosynthesis and transpiration of pecan leaves in the fall. Proc. Am. Soc. Hortic. Sci. 39:80-84.
16. Payne, J. A., Malstrom, H. L., and KenKnight, G. E. 1979. Insect pests and diseases of the pecan. U.S. Dep. Agric. Sci. Educ. Admin. Agric. Rev. Man. South. Ser. No. 5. 43 pp.
17. Payne, J. A., and Sparks, D. 1978. Pecan foliage susceptibility to dodine. Plant Dis. Rep. 62:996-998.
18. Waite, M. B. 1924. Comparison of orchard and nut diseases and their control by spraying with fungicides. Proc. Nat. Pecan Grow. Assoc. 23:48-58.
19. Worley, R. E. 1979. Pecan yield, quality, nutlet set, and spring growth as a response to time of fall defoliation. J. Am. Soc. Hortic. Sci. 104:192-194.
20. Worley, R. E., and Harmon, S. A. 1968. New fungicides for pecan scab control in Georgia. Plant Dis. Rep. 52:108-109.