Effects of an Abbreviated Pecan Disease Control Program on Pecan Scab Disease Increase and Crop Yield

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ABSTRACT

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Disease intensity of pecan scab on foliage fluctuated with cultivar and the prevalence of new growth, whereas disease intensity on fruit increased most during those periods when fruit expanded most rapidly. Cumulative fruit drop was independent of disease control strategy. The amount of drop associated with early-season disease was later offset by natural midseason and late-season fruit abortion. Yield and percentage of kernel associated with different abbreviated disease control strategies demonstrated that fungicide applications after the nut and nut shuck were fully expanded had little effect on end-of-season disease severity and no significant effect on crop yield or nut quality. End-of-season disease appeared to be largely cosmetic and not significant to crop value. This demonstrated the possibility for an abbreviated scab disease control program, depending on cultivar.

Pecan scab is the most commercially important and prevalent disease of pecan (*Carya illinoensis* Koch) throughout the commercial pecan production areas of the southeastern United States (2,14). The causal organism, *Cladosporium caryigenum* (Ell. et Lang.) Gottwald (=*Fusicladium effusum* Wint.), causes a serious fruit and foliar disease. The pathogen overwinters in twig, leaf rachis, and nut-shuck (involucre) lesions (5). Inoculum is disseminated by rain splash of conidia over short distances and by aerial conidial release triggered by fluctuations in relative humidity, light intensity, and temperature (6,8,14). Warm weather combined with free moisture promotes disease development (1,2,7,14–16), which has been implicated in reduction of both crop yield and quality and in decreased photosynthetic potential of foliage and involucre tissues (9,10). Decreased phytosynthetic activity may contribute to alternate bearing by decreasing stored carbohydrate reserves used during the succeeding season.

Pecan scab increase over time has been measured previously (4,8,9); however, attempts to correlate disease severity with yield loss have been complicated by alternate bearing, lack of adequate acreage for proper replication, site variability, lack of cultivar uniformity, and planting patterns. Use of nut quality parameters and nut drop, as well as the recent development of pecan yield estimation techniques, has presented alternative approaches for demonstrating the effects of pecan scab epidemics on

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crop production (9,18). Inoculating nut clusters with *C. caryigenum* conidia at various times throughout the season and correlating the resulting epidemics with kernel size, weight, and quality demonstrated that scab infections after midseason have progressively less effect on yield and quality until later in the season, when new infections become nearly cosmetic (9).

The purpose of this study was 1) to compare disease increase in natural epidemics where chemical disease management was curtailed at various times during the season, 2) to examine the effects of each epidemic on crop yield and quality, and 3) to identify a more efficient alternative disease control strategy that would reduce fungicide applications while maintaining crop yield and quality.

MATERIALS AND METHODS

This study was conducted in two orchards over a 3-yr period, spring 1982 to fall 1984. The first orchard, known as the Schley Block (SCH), was located at the USDA, ARS, Southeastern Fruit and Tree Nut Research Laboratory at Byron, Peach County, Georgia, and consisted of about 10 ha of 55-yr-old cultivar Schley pecan planted with about 18.6 trees per hectare. A second planting, designated the Magnolia grove (MAG), consisted of about 2 ha of 10-yr-old pecan cultivar Wichita planted with about 118.6 trees per hectare and was located on the Magnolia Plantation about 24 km west of Albany in Calhoun County, Georgia.

Experimental design. The experimental design in SCH consisted of a randomized block that remained the same throughout all three seasons. Treatments were relative to the Georgia recommended spray program (GRSP) for fungicides, i.e., first spray at budbreak and every 2 wk thereafter until pollination, then every 3 wk for the remainder of the season until harvest. Treatments consisted of 1) full-season fungicide spray program according to GRSP, 2) termination of the GRSP 10 wk after nut set, which presumably occurred after fertilization and was determined by stigmas turning from green to brown, 3) termination of GRSP 6 wk after nut set, and 4) no fungicide sprays (check). Sprays of a recommended fungicide were applied by air-blast sprayer to individual rows. Each treatment was replicated three times by tree rows. Five trees of cultivar Schley within each row were designated for sampling.

The experimental design in MAG during 1982 also was a randomized complete block. The treatments were the same as used in SCH, except they were applied to cultivar Wichita. Each block was a row and contained all four treatments, with 12 trees per treatment, and treatment placement was randomized within each row. Treatments were replicated once in each of four rows. Five trees within each treatment were designated sample trees in each row. Experimental designs between the two orchards differed because of necessary spraying and harvesting patterns, orchard layout, and cultivar and soil uniformity. During the 1983 and 1984 seasons, because of the potential deleterious effect of pecan scab on yield and quality in this commercial grove and the economic loss this represented, the number of treatments in the MAG plot was reduced. Only treatments 1 and 2 were examined during these years. During these years, each treatment was replicated four times. Each replicate was a row (48–58 trees), and 12 trees were designated sample trees within each row. The full-season GRSP acted as a control with which the abbreviated treatment 2 was compared.

Disease determinations. Disease determinations were made about every 2–3 wk in each plot. Foliar disease determinations were taken in SCH and MAG in 1982 and in SCH in 1983 and 1984. Nut-shuck (involucre) disease determinations were made in all plots in all years. To facilitate the collection of numerous disease severity readings, a disease rating scale was used. Both foliar

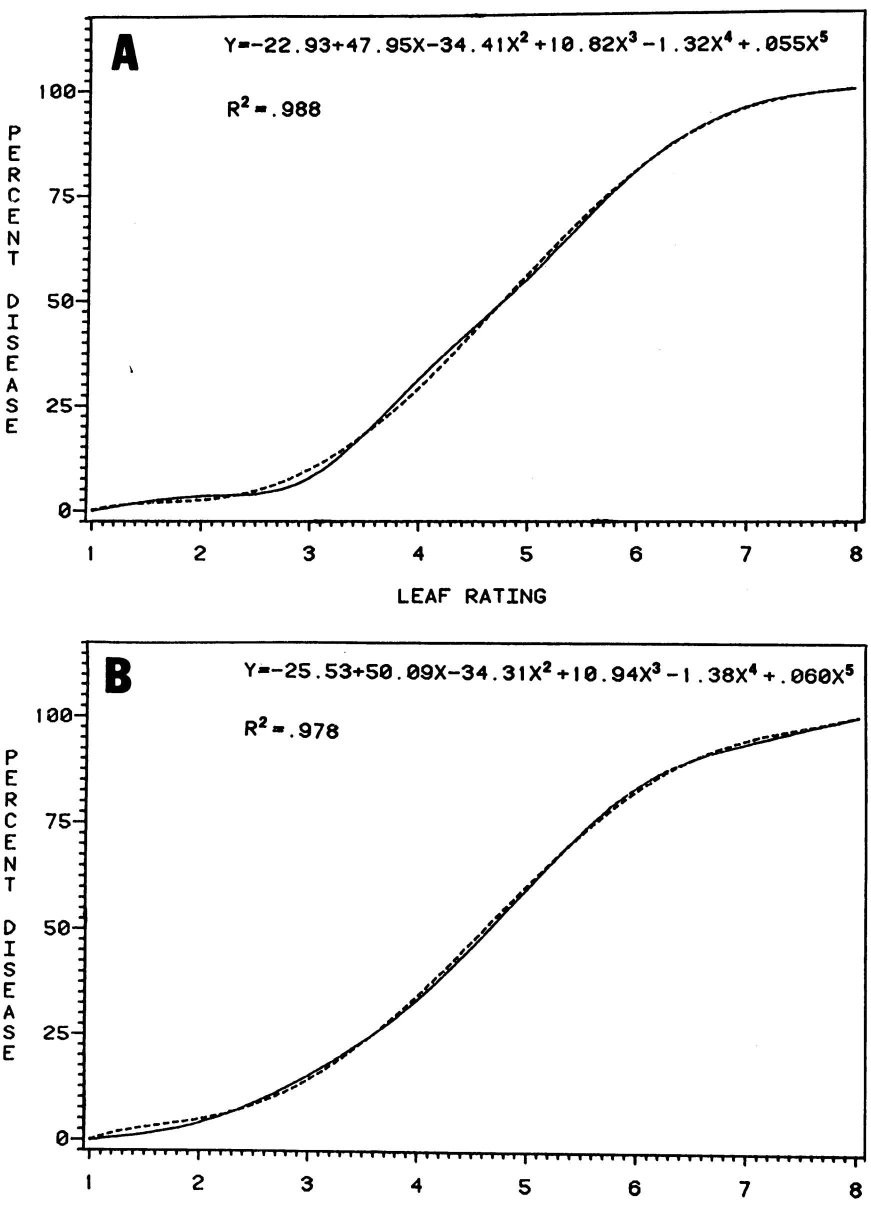

Fig. 1. Equations to convert foliar (**A**) and nut-shuck (**B**) pecan scab disease ratings to percentage of disease. One hundred leaves and 100 nuts were collected for each of the eight disease rating categories. Each leaf or nut rating was then paired with visual percentage of the disease estimation. Solid lines represent the relationship between independent disease rating/percentage of disease estimation pairs. Broken lines represent fifth-power polynomial approximations of the disease rating to percentage of disease conversion.

and shuck disease ratings were made based on percentage of surface area diseased: 1 = no disease, 2 = trace to 6%, 3 = 7–25%, 4 = 26–50%, 5 = 51–75%, 6 = 76–94%, 7 = 95–99%, and 8 = 100%. This grading system is similar to the one proposed by Horsfall and Barratt (11) and is based on visual acuity. This scale differs from that proposed for pecan scab by Hunter and Roberts (12) by having three additional grades for accurate grading of high disease incidence often associated with cultivar Wichita. Twenty leaves and five nut clusters per sample tree were used to calculate foliar and nut-shuck disease ratings and percentage of fruit drop over time. Because the disease rating scale used was nonparametric, a simple conversion was used to convert ratings to percentage of disease before analysis. One hundred leaves and 100 nut shucks were given a disease rating and also assessed for percentage of disease to the nearest 5% by different evaluators to prevent bias. The resulting paired scores (disease rating = percentage of surface area diseased) were used to develop fifth-power polynomial approximations, which resulted in foliar and nut-shuck "disease rating" to "percentage of diseased surface area" conversions.

Yield determinations. Yield determinations during the 1982 and 1983 seasons were made by harvesting individual trees by mechanical shaker and harvester in SCH and by mechanical harvesting of each treatment row segment in MAG. In 1984, yields were determined by a newly proposed segment method (18), which has been shown to be as accurate in determining yield as mechanical harvesting.

Statistics. Data from all plots and all years were subjected to analysis of variance by the general-linear-models program, and differences among treatment means were tested for by Duncan's multiple range test. The general-linear-models analysis and graphics were

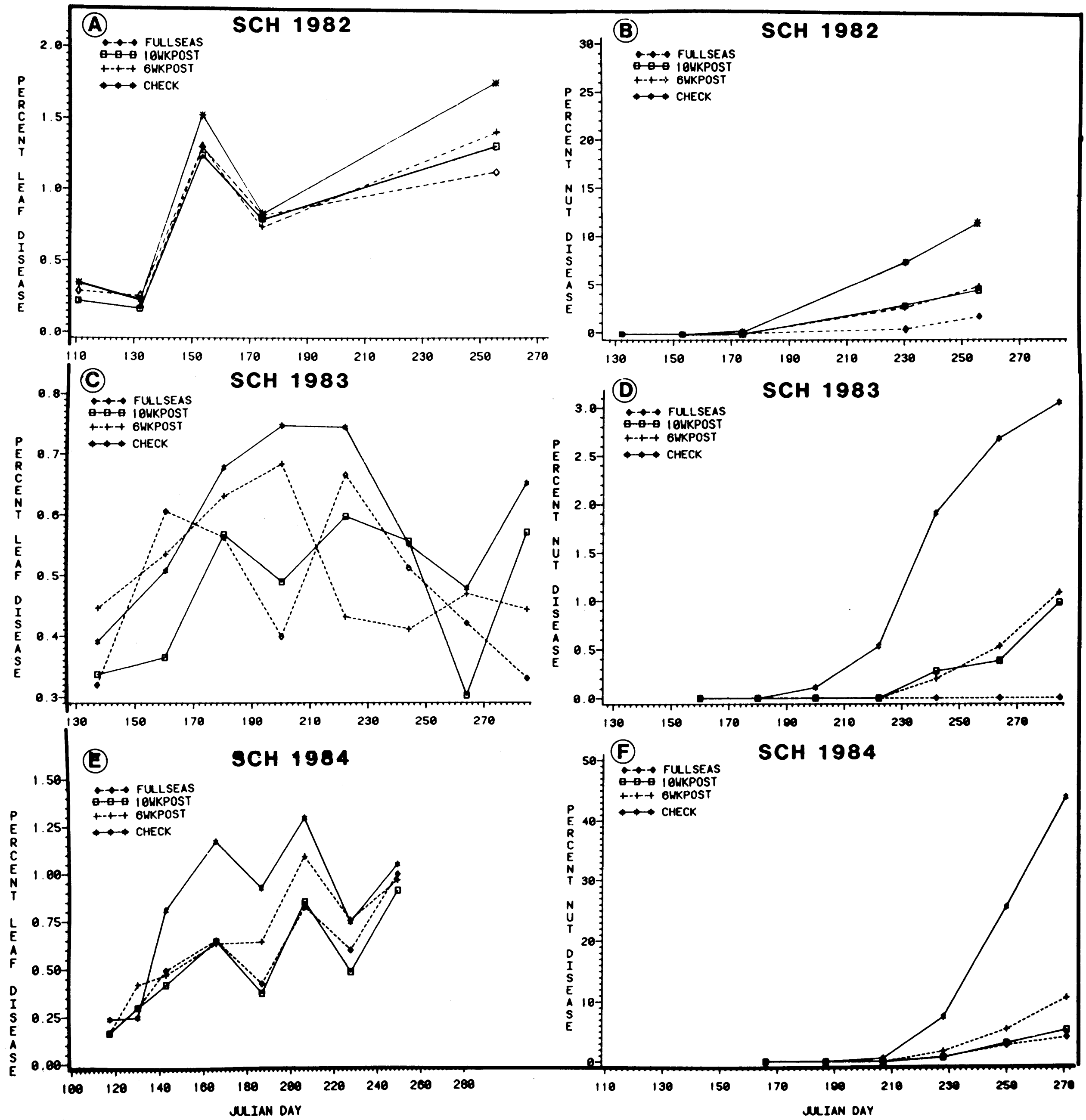

Fig. 2. Foliar and nut-shuck disease progress curves of four pecan scab disease control strategies in a 10-ha planting of cultivar Schley pecan. Treatments were 1) Fullseas = full-season fungicide application according to the Georgia recommended spray program, 2) 10wkpost = fungicide application terminated 10 wk after nut set, 3) 6wkpost = fungicide applications terminated 6 wk after nut set, and 4) check = no fungicide application throughout the entire season.

performed with SAS and SAS-Graphics, respectively (Statistical Analysis System, SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Conversions of foliar and nut-shuck disease ratings to percentage of diseased surface area by polynomial approximations were quite accurate as demonstrated by coefficients $r^2 = 0.988$ and $r^2 = 0.978$ for foliar and nut-shuck disease conversions, respectively (Fig. 1).

Disease intensity was moderate each year during the 3 yr of the test, except during the 1983 season, when drought in central Georgia resulted in lower than normal disease intensities in the SCH plot (Fig. 2C,D). Foliar disease progress curves for 1983 demonstrate the extremely low percentage of foliar disease. However, unsprayed trees still showed the highest level of disease, especially during midseason. Foliar disease is especially important early in the season before nut set; it represents the reservoir for disease that provides for the eventual infection of developing nuts (8). On some cultivars, leaf scab intensity appeared to fluctuate throughout the season. The cultivar Schley showed this trend (Fig. 2A,C,E). Schley normally has one major and one or two subsequent less vigorous growth flushes per year. Scab attacks only young, expanding tissues, which it quickly colonizes and on which it sporulates, but as the foliage matures, it becomes resistant to infection and old lesions often begin to dry and crack (7,8,13,17). As subsequent flushes appeared, the percentage of diseased foliage was reduced until new scab lesions formed on the new flush. Thus, we noted a cyclic increase in disease intensity following each flush by a 7- to 14-day latent period (8). Slightly higher than normal scab disease was seen throughout southern Georgia in 1982 and was apparent in unsprayed control plots in MAG (Fig. 3A,B). In MAG, cultivar Wichita, unlike cultivar Schley, tended to have numerous foliar flushes each season. These flushes provided a nearly continuous supply of susceptible tissue for infection and subsequent colonization, and, therefore, a steady foliar disease increase resulted (Fig. 3A).

Pecan nut shucks are only moderately susceptible for the first 2–3 wk after nut set (9). As soon as the nuts enter a rapid expansion stage, susceptibility increases. Thus, rates of disease increase appear to accelerate in response to the increased susceptibility of the tissues (Figs. 2B,D,F and 3B–D). Apparently, during midseason to late season, nut-shuck tissues again decrease in susceptibility as nuts cease to expand and start to fill (9). Apparent disease increase during late season is probably the result of continued expansion of lesions over a predetermined surface area.

Fluctuation in disease increase on foliage is associated with some cultivars and not with others. Therefore, no predictive equation would be of general value to estimate foliar disease increase over time. Nut disease progress was followed on only two of the many commercial pecan cultivars; therefore, no predictive equations for nut disease increase over time were attempted either.

As previously described, the percentage of nut drop does not necessarily reflect what would be expected with higher

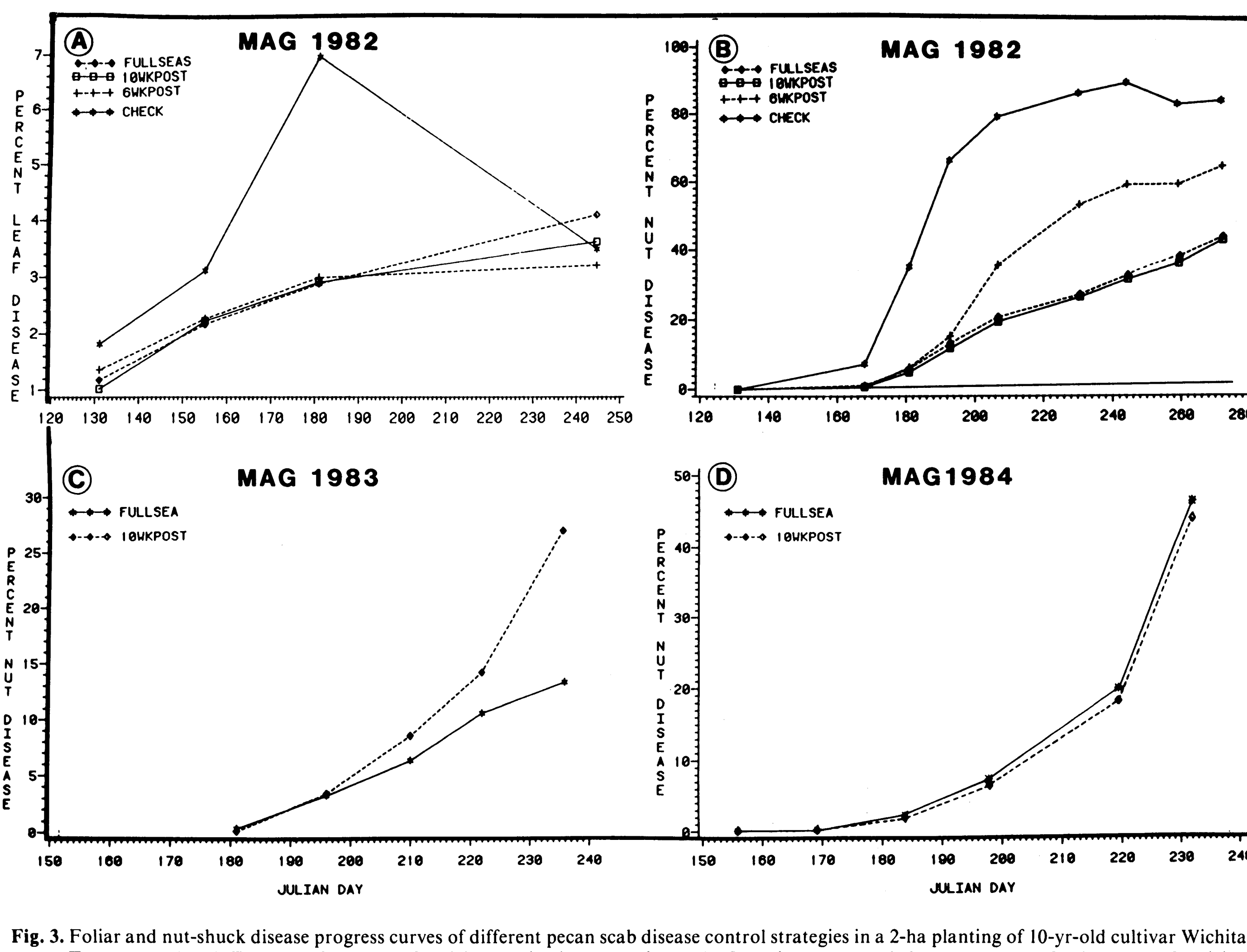

Fig. 3. Foliar and nut-shuck disease progress curves of different pecan scab disease control strategies in a 2-ha planting of 10-yr-old cultivar Wichita pecan. Treatments were 1) Fullseas = full-season fungicide application according to the Georgia recommended spray program, 2) 10wkpost = fungicide application terminated 10 wk after nut set, 3) 6wkpost = fungicide applications terminated 6 wk after nut set, and 4) check = no fungicide application throughout the entire season.

levels of disease (8). Nut drop is affected by cultivar, tree health, season, and insect infestation but is a natural phenomenon, sometimes ranging as high as 60%. When nuts are aborted early in the season, as sometimes occurs with an early-season scab infection, those remaining on the tree appear more likely to survive. Previous studies have demonstrated that the cumulative percentage of nut drop was often equivalent between treatments where trees were heavily or lightly diseased (9). This was evidenced in the present study also, where percentage of drop did not appear to decrease greatly or consistently with the more thorough disease control strategies (Tables 1–3).

"Percentage of kernel" is an estimate of weight of the edible kernel in relation to the total weight of the in-shell nut and is used by the industry as a means of comparing the quality of individual lots of nuts. The percentage of kernel decreased significantly only in nuts from unsprayed check trees. Differences were not observed in other treatments (Tables 1–3).

Yield data associated with pecan have long been difficult to obtain and of questionable significance because of the problems previously discussed. Alternate bearing alone can cause large yield fluctuations from year to year. As a result of these large fluctuations, differences between treatments within a single season may not be discernible, or even valid, and problems associated with alternate bearing may not be overcome even when large numbers of individual trees and treatment replicates are employed. Rather, yields should probably be looked at in terms of averages from plots where the same treatments are applied to the same trees during two or more successive seasons to help dampen these fluctuations. Yield fluctuations associated with alternate bearing can be seen in the present study by comparing yields related to treatments 1 and 2 (Tables 1–3). Note how the yield for SCH treatment 1 is less than that for SCH treatment 2 for 1982 (Table 1), then the two treatments appear to reverse in 1983 (Table 2) and again in 1984 (Table 3). The same reversal is seen in the yields from MAG during 1982 and 1983 (Tables 1 and 2).

Three-year average yield from SCH demonstrates the statistical superiority of treatments 1 and 2 over treatments 3 and 4 (Table 3). Likewise, although yields were taken only for the first 2 yr of the study at MAG, the 2-yr average yield demonstrates that there was no statistical difference between treatments 1 and 2 (Table 3). As previously mentioned, the other two treatments, 3 and 4, were determined to be too damaging to the MAG commercial planting to be continued after the 1982 trials. Note the greatly reduced yields associated with these two treatments (Table 1) and the

Table 1. Effects of four pecan scab disease control strategies on disease intensity and yield of cultivars Schley and Wichita pecan in Georgia in 1982

Location[w]	Treatment[x]	End-of-season nut disease rating[y]	Yield (kg/ha)	Nut drop (%)	Kernel (%)
Schley (SCH)	1	1.00 a[z]	402.2 a	82.4 a	60.3 a
	2	1.45 a	516.4 a	76.0 a	59.5 a
	3	1.39 a	281.0 a	74.9 a	59.5 a
	4	2.42 b	279.3 a	77.4 a	57.0 b
Magnolia (MAG)	1	3.89 a	1,326.9 a	56.4 c	54.9 a
	2	3.84 a	1,309.2 a	51.2 c	53.8 a
	3	5.52 b	978.9 ab	69.7 b	54.6 a
	4	7.76 c	648.6 b	90.3 a	48.9 b

[w] Schley (SCH) = a mature pecan grove in Peach County, Georgia, consisting of 10 ha of 55-yr-old cultivar Schley pecan. Magnolia (MAG) = a pecan grove in Calhoun County, Georgia, consisting of 2 ha of 10-yr-old cultivar Wichita pecan.

[x] Treatments: 1 = biweekly fungicide applications until nut set, then triweekly applications until the end of the season; 2 = same as above but terminated 10 wk after nut set; 3 = same but terminated 6 wk after nut set; and 4 = check, no fungicide sprays for the entire season. The fungicide used was triphenyltin hydroxide (Supertin 4-L) at 0.355 L (0.75 pt) per acre per application.

[y] Rating based on percentage of surface area diseased: 1 = no disease, 2 = trace to 6%, 3 = 7–25%, 4 = 26–50%, 5 = 51–75%, 6 = 76–94%, 7 = 95–99%, and 8 = 100%.

[z] Means followed by the same letter (within block) are not significantly different at $P = 0.05$ according to Duncan's multiple range test.

Table 2. Effects of four pecan scab disease control strategies on disease intensity and yield of cultivars Schley and Wichita in Georgia in 1983

Location[w]	Treatment[x]	End-of-season nut disease rating[y]	Yield (kg/ha)	Nut drop (%)	Kernel (%)
Schley (SCH)	1	1.01 b[z]	977.6 a	66.7 ab	···
	2	1.17 b	691.3 b	59.0 b	···
	3	1.20 b	535.7 bc	70.7 a	···
	4	1.56 a	533.1 c	67.0 ab	···
Magnolia (MAG)	1	2.61 a	393.5 a	···	61.7 a
	2	3.33 b	468.1 a	···	61.5 a

[w] Schley (SCH) = a mature pecan grove in Peach County, Georgia, consisting of 10 ha of 55-yr-old cultivar Schley pecan. Magnolia (MAG) = a pecan grove in Calhoun County, Georgia, consisting of 2 ha of 10-yr-old cultivar Wichita pecan.

[x] Treatments: 1 = biweekly fungicide applications until nut set, then triweekly applications until the end of the season; 2 = same as above but terminated 10 wk after nut set; 3 = same but terminated 6 wk after nut set; and 4 = check, no fungicide sprays for the entire season. The fungicide used was triphenyltin hydroxide (Supertin 4-L) at 0.355 L (0.75 pt) per acre per application.

[y] Rating based on percentage of surface area diseased: 1 = no disease, 2 = trace to 6%, 3 = 7–25%, 4 = 26–50%, 5 = 51–75%, 6 = 76–94%, 7 = 95–99%, and 8 = 100%.

[z] Means followed by the same letter (within block) are not significantly different at $P = 0.05$ according to Duncan's multiple range test.

Table 3. Effects of four pecan scab disease control strategies on disease intensity and yield of cultivars Schley and Wichita pecan in Georgia in 1984

Location[v]	Treatment[w]	End-of-season nut disease rating[x]	Yield (kg/ha)	Nut drop (%)	Kernel (%)	Av. yield[y] (kg/ha)
Schley (SCH)	1	1.77 c[z]	786.3 b	71.4 a	57.7 a	720.0 a
	2	1.95 bc	1,101.7 a	64.3 a	56.6 a	769.8 a
	3	2.44 b	772.3 b	62.3 a	56.7 a	536.4 b
	4	4.29 a	852.2 ab	61.4 a	55.5 a	521.5 b
Magnolia (MAG)	1	4.50 a	···	12.8 a	58.1 a	860.2 a
	2	4.40 a	···	8.8 a	58.2 a	888.6 a

[v] Schley (SCH) = a mature pecan grove in Peach County, Georgia, consisting of 10 ha of 55-yr-old cultivar Schley pecan. Magnolia (MAG) = a pecan grove in Calhoun County, Georgia, consisting of 2 ha of 10-yr-old cultivar Wichita pecan.

[w] Treatments: 1 = biweekly fungicide applications until nut set, then triweekly applications until the end of the season; 2 = same as above but terminated 10 wk after nut set; 3 = same but terminated 6 wk after nut set; and 4 = check, no fungicide sprays for the entire season. The fungicide used was triphenyltin hydroxide (Supertin 4-L) at 0.355 L (0.75 pt) per acre per application.

[x] Rating based on percentage of surface area diseased: 1 = no disease, 2 = trace to 6%, 3 = 7–25%, 4 = 26–50%, 5 = 51–75%, 6 = 76–94%, 7 = 95–99%, and 8 = 100%.

[y] Three-year average for SCH and 2-yr average for MAG.

[z] Means followed by the same letter (within block) are not significantly different at $P = 0.05$ according to Duncan's multiple range test.

corresponding high percentage of nut disease (Fig. 3B). Nut disease progress curves for treatments 1 and 2 were very similar for all years in both plots (Figs. 2B,D,F and 3B–D). The curves were slightly divergent in both plots in 1983, when scab disease intensity was low to mild throughout the state (Figs. 2D and 3C). Such divergence was always toward the end of the season when, as previously noted, the occurrence of new lesions is low and disease increase, especially in treatment 2, was associated with lesion expansion largely because of a lack of inhibition by recently applied fungicide activity. Such late-season disease increase associated with lesion expansion, and to a much smaller extent new lesion development, had no significant effect on end-of-season nut disease rating (except for the 13–14% difference in MAG during 1983, the mild scab year), percentage of nut drop, percentage of kernel, or yield between the two treatments (Table 1). Apparently, such late-season disease increase on nuts was primarily cosmetic and had no quality or yield effect on the crop. Visual evaluations led us to believe, furthermore, that moderate scab epidemics have no effect on the next season's return bloom compared with plots with low scab intensity (P. F. Bertrand and T. R. Gottwald, *unpublished*).

Pecan cultivars are widely diverse in scab susceptibility, date of bloom, nut set, and maturation (3). No general rule can be applied to all cultivars; however, the present study indicates that an abbreviated disease control program for scab may be valid and, if properly timed, should have no adverse effect on yield or quality and only rarely on end-of-season disease intensity. In the present study, the most promising treatment, treatment 2, equaled the full-season fungicide applications and represented a savings of two or three fungicide applications in SCH and up to five in MAG. Treatment 3 resulted in slight damage to crop yield and quality. Further reduction in application beyond that achieved with treatment 2 may be possible. Also, a small amount of crop loss may be tolerable if offset by reduced fungicide costs. Perhaps, the termination of fungicide applications would be more practical if based on a calendar date for each cultivar rather than related to the physiological growth stage of the fruit, which better represents the susceptibility of the nut-shuck tissues but is more cumbersome in practice. Although beyond the scope of this study, further investigation is needed to better tailor a general reduced scab disease control program to most major pecan cultivars. It should be noted that the proposed abbreviated disease control program was for pecan scab only, but other foliar pecan diseases that were not encountered in this test should be adequately controlled by this program also. There is a chance, however, that they may also require end-of-season control in addition to that proposed.

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