Research Update

A Climatic Approach to Pecan Scab Control

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Additional index words, *Cladosporium caryigenum,* Orbit, SuperTin, fungicide, leaf wetness, temperature

Summary. Pecan (*Carya illinoinensis)* scab was evaluated following unusually extended rains in 1994. Strengths and weaknesses of a variety of scab management practices were studied in five orchards, Scab control was more effective on trees with adequate sunlight exposure than in dense orchards or with fungicide applied after rain than by preset intervals. Triphenyl tin hydroxide, a nonsystemic fungicide, was most effective when applied within 24 h after rain; but, the systemic fungicide, propiconazole, was effective when applied within 6 days after rain. Fungicides must be applied consistently after rain for maximum scab control.

Cladosporium caryigenum (Ell. et Lang, Gottwald), the fungus causing scab disease on pecan leaves and fruit, has been recognized as a major crop-production problem in humid climates since early in the century (Nolen, 1926), Scab incidence varies among growing seasons and was especially high in the early 1990s compared to the 1980s. The upsurge in scab has been due mainly to climate changes from dry in most of the 1980s to wet beginning in 1989, Severe rains during Summer 1994 caused flooding of such magnitude that the southern half of Georgia was declared a national disaster area, These environmental conditions provided a unique opportunity to evaluate scab development in different orchards under a variety of scab management practices, The objective of this study was to analyze variations in scab control programs among and within orchards, with regard to scab incidence, as bases for developing a better scab control strategy,

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Background

Tissue age vs. scab susceptibility. Pecan leaves are susceptible to scab when young or immature, but not when mature (Gottwald, 1985). The leaf is mature once expansion is completed, about 6 weeks after budbreak for an individual leaf (Davis and Sparks, 1974) and about 2 weeks later for the shoot as a whole. Foliar scab is often limited to the more terminal leaves, which develop during the last half of the leaf-expansion period. Two reasons may account for the increased incidence of scab on these leaves, First, increasing spring temperatures create more favorable environmental conditions for scab growth, Second (and more likely), the rapid expansion in leaf surface makes fungicide coverage of new leaf tissue difficult.

Shucks, in contrast to leaves, continue to expand and remain immature during fruit development (Sparks, 1986). Because of the prolonged immaturity, the shuck remains susceptible to scab during most of its growth cycle (Gottwald and Bertrand, 1983), However, damage decreases with fruit development. Scab infection of small fruit in June causes total fruit loss, but fruit approaching maximum volume in late August have only cosmetic shuck damage, Fruit infection is most likely to occur in the southeastern United States during rapid expansion, usually July until early August, for three reasons: 1)July is the wettest month of the growing season; 2) rapid fruit expansion exposes new, unprotected tissue daily; and, 3) foliage surface area has maximized, causing difficulty in penetrating the canopy with fungicide to cover the fruit,

Role of temperature and humidity in scab infection. Optimum temperature for scab infection is 20 to 25C (Gottwald, 1985). Scab infection decreases outside this range regardless of leaf wetness, especially at <20C as in early Spring 1993, when the average daily temperature was <15C. In contrast, high temperature and frequent rains in Spring 1991 created ideal conditions for scab development.

Moisture has a role in two phases of scab infection: spore release and spore germination (Gottwald, 1985; Latham, 1982). Spores are re-

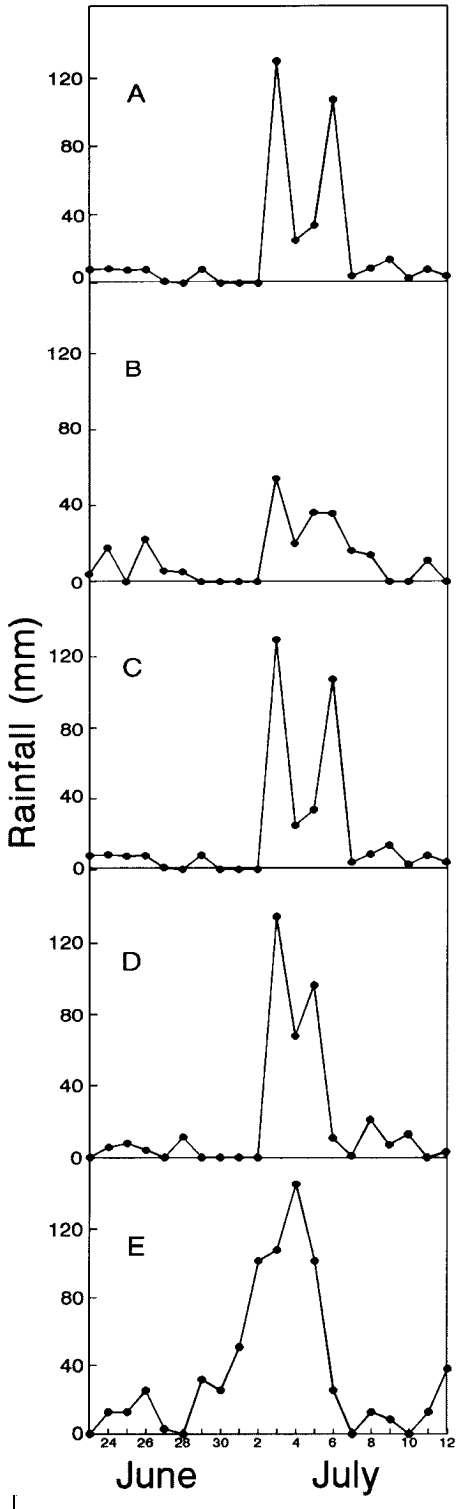

Fig. 1. *Rainfall in orchards A, B, C, D, and E in late June and early July 1994. Rainfall was recorded in individual orchards. Orchards A and C are situated in close proximity. Rain was recorded for orchard C and assumed to be the same for orchard A.*

leased from overwintering lesions or from lesions formed during the current season, followed by spore germination under suitable temperature and moisture. Spore release and germination have different humidity requirements. Spore release will not occur on a wet substrate, Additionally, spore release is minimal and of minor consequence at 40% to 100% relative humidify (Gottwald, 1982), Once spores are released, free water is essential for germination. Germination rate increases in free water and is near maximum after 12 h of continuous wetness (Latham and Rushing, 1988), Germinating spores begin limited leaf penetration after about 12 h, but most activity occurs after 24 h. Scab lesions occur within 7 to 9 days, although the lesions are not visible microscopically at this time (Gottwald, 1985; Latham, 1982; Latham and Rushing, 1988).

Spores require 12 h of continuous wetness for substantial germination and an additional 12 h for leaf penetration, Thus, about 24 h of specific conditions are required for leaf infection by the scab fungus. Nonsystemic fungicides must be applied before the fungus penetrates the leaf to be effective, i.e., within 24h of the onset of rain. On the other hand, systemic fungicides can be applied even after the fungus penetrates the leaf,

Air circulation. Multiple observations indicate that air circulation promotes the drying of fruit and foliage and is a dominant factor in scab control, Scab control is easier on windy hills or ridge tops than in depressed areas or sites with a flat topography surrounded by woods, lakes, or ponds. A dense orchard will have more severe scab than an open orchard, regardless of topography. Trees are too dense if the grass on the orchard floor is dying or already has died from lack of sunlight,

Inoculum source. Presence of overwintering lesions (primary inoculum) is regarded as a dominant factor in subsequent control of leaf scab. In addition, leaf lesions are assumed to increase the difficulty of controlling fruit scab. Neither of these have been proven, but both are supported by lesion biology. Spores are released from lesions for weeks, thus furnishing a continuous spore source for new infections (Reynolds, 1994).

Fungicides: SuperTin vs. Orbit. The two major pecan fungicides are SuperTin (triphenyl tin hydroxide) and Orbit (propiconazole). SuperTin is nonsystemic and, to be effective, must be applied before the germinating spore enters the leaf. SuperTin, as indicated by experiments and grower experience, will control scab at an acceptable level in seasons of moderate scab pressure. However, the fungicide is susceptible to partial wash-off during rain (Reynolds, 1992). Efficacy is unknown for residual SuperTin left on the leaf, but the claim is that>13mm of rain does not impair efficacy, The problem with SuperTin apparently occurs after heavy rains. Presumably, heavy or prolonged rains wash off the fungicide to the point that the concentration is insufficient to control scab, The scab disease organism apparently has not developed resistance to SuperTin even after wide use for many years, Orbit, in contrast to SuperTin, is systemic and is effective after the fungus enters the leaf, Orbit is not translocated from one leaf to another (Latham and Hammond, 1983), so leaves developing after Orbit application are not protected. A major concern is that the organism causing scab may develop resistance to Orbit (Bertrand and Brenneman, 1995).

Orbit controls scab on the leaf for 11 days: 5 days before application (back action or curative control) and 6 days after application (forward action or protestant activity). Applications 6 and 8 days after fungal infection arrest scab disease, although the site of initial leaf infection will be marked by a small black fleck. Some flecks produce viable spores, but in limited quantities. Thus, Orbit provides 6 days of protestant activity, 5 days of curative activity, and 2 additional days of reduced, but probably acceptable, curative action. The protestant activity of Orbit on the fruit is likewise significant, but begins to deteriorate at least after 15 days (Latham and Hammond, 1983).

Apprehension has developed regarding the effect of Orbit in controlling scab disease on leaves and fruit and retarding pecan leaf development, One misgiving is that Orbit is ineffective on leaf or fruit scab at recommended dosages—0.28 and 0.40 kg·ha^{-1}, respectively, However, multiple investigations have provided data that these concentrations of Orbit control leaf and fruit scab as effectively as SuperTin (Latham and McDaniel, 1980; Reynolds and Bertrand, 1993). Side-effects of Orbit became a concern after a report of retarded leaf expansion after four weekly applications at 0.28 kg·ha^{-1} (He and Wetzstein, 1994). However, weekly applications are unlikely in commercial orchards. Nut growth was not retarded by three Orbit applications at 0.4 kg·ha^{-1} at 20-and 27-day intervals during early fruit growth (Reynolds and Bertrand, 1993). Similarly, 0.56-kg applications at about 20-day intervals during rapid fruit expansion were not phytotoxic (Latham and McDaniel, 1982), Nevertheless, Orbit should be used with caution until more definitive data are available.

Preset vs. climatic-based sprays. The Georgia Cooperative Extension Service spray guide for scab control schedules fungicide applications at preset time intervals during the growing season based on calendar days without regard to environmental conditions (Ellis et al., 1991). Fungicide applications are recommended every 2 weeks until pollination and then every 3 weeks ending in August. The preset schedule maximizes early control of leaf scab but minimizes late control of leaf scab and control of fruit scab during fruit development. Spray intervals are close during early leaf susceptibility but far apart during the rest of the scab-susceptibility period, Consequently, during rainy seasons, the recommended program is not sufficiently effective,

A Georgia grower observed that scab devel-

oped only after rain in his orchards, and he devised a strategy to spray immediately after rains Good to excellent scab control was obtained for 3 consecutive years by applying SuperTin to a small block of 'Desirable' trees only after rain. Later, this approach was extended to a larger orchard. With this regime, scab control was acceptable when SuperTin was applied within 24 h after onset of rain. The fungicide was beneficial applied up to 36 h after a rain, but less effective than within 24 h. SuperTin applied 48 h after a rain had little, if any, benefit, and at 72 h did not control scab. These results correlate with the physiology of the fungal spore causing scab. Applications within 24 h after a rain were effective because this amount of time is required for peak spore germination, but leaf penetration is minimal. SuperTin applied up to 36 h after a rain gave some control, because spore germination continues to some extent and the fungicide will kill late-germinating spores that have not penetrated the leaf.

Observations in another orchard in Georgia also support the importance of spraying immediately after rain, In 1992, scab was much more severe on fruit in blocks sprayed with SuperTin either 1 or 3 days before a 41-mm rain than in a block sprayed immediately after the rain.

Timing the first spray. The Georgia Cooperative Extension Service preset schedule recommends applying the first fungicide at budbreak. Considering the dynamics of temperature and leaf surface growth in early spring, spraying at budbreak is of questionable value for two reasons: 1) the temperature may be too low in some years for scab infection and 2) little or no foliage has developed to be sprayed. Recently, some growers delayed the first fungicide spray until leaves developed to the parachute stage (stage VII of bud and leaf development) (Wetzstein and Sparks, 1983) or beyond. Scab control on the foliage has been acceptable in that scab lesions have been sparse, resulting in leaves' being neither distorted nor abscised.

Scab evaluations

Procedures and assumptions The 1994 growing season in Georgia was ideal for assessing fruit scab, considering the minimal spring rains creating unfavorable conditions for foliar scab and record June and July rains creating favorable conditions for fruit scab (Fig. 1). Heavy rains during late June and early July caused extensive floods in south Georgia. Thus, scab was expected to become a problem only after the extended rains in late June and early July (Fig. 1). Observations of fruit during late June and early July or examination of scouting reports supported the expectation.

Scab severity was assessed just before nut maturity by visually estimating the percentage crop lost from 'Schley', a cultivar highly susceptible to scab (Sparks, 1992). Scab estimates within a block were limited, when possible, to fruit on

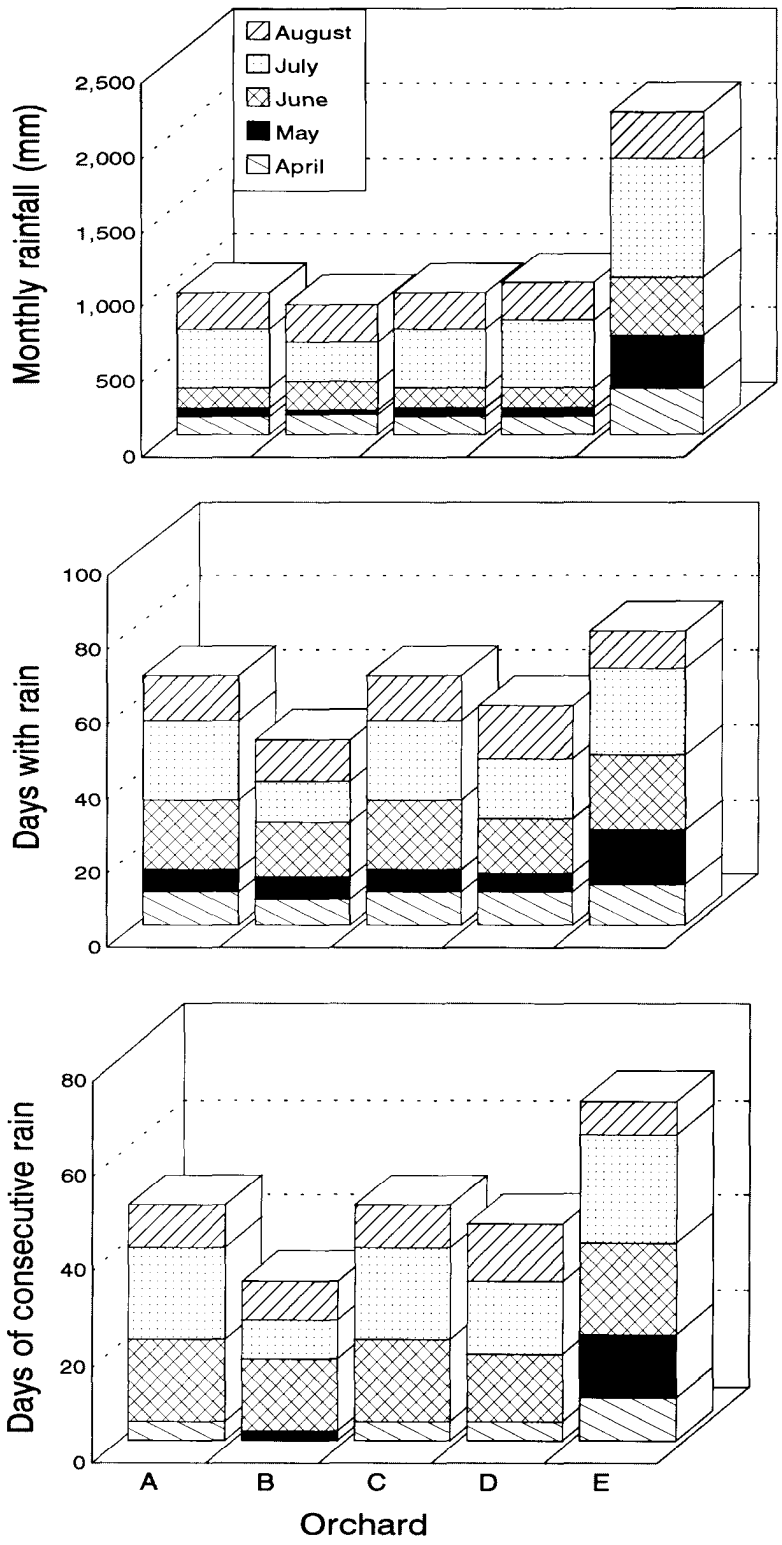

Fig. 2. *Monthly rainfall, days with rain, and days of consecutive rains in orchards A, B, C, D, and E, 1994. Orchards A and C are situated in close proximity Rain was recorded for orchard C and assumed to be the same for orchard A. Days of consecutive rain = days with 2 or more consecutive days of rain.*

Table 1. ***Spray dates, fungicide used, and pecan fruit loss from scab, orchard E, 1994.***[z]

Block	Spray date: After 22 June rains	Spray date: After 6 July rains	Fungiclde	Fruit loss (%)
1	26 June	6 July	Orbit	5
2	26 June	6 July	Orbit	5
3	Not sprayed		80	

[z]*Application was 04 kg·ha*$^{-1}$

noncrowded trees exposed to sunlight, In addition, within a block or orchard with crowded and noncrowded trees, fruit scab on shaded vs. sun-exposed trees was evaluated to assess sunlight exposure on scab incidence. Evaluations were made in five orchards. Four orchards (A, B, C, and D) are located west of Albany, Ga., and within about a 16-km radius of each other. The fifth orchard (E) is located east of Perry, Ga., and about 130 km north of the other orchards. Orchard A consists of 97 ha divided into 5 blocks; B, 215 ha with 10 blocks; C, 210 ha with 13 blocks; D, 356 ha with 21 blocks; and E, 45 ha with 3 blocks. Portions of orchard B were sprayed by the preset schedule; the rest was sprayed only after 13 mm rain. SuperTin was used except for one application of Orbit in April. Orchards A, C, and D were sprayed with SuperTin by the preset schedule; however, Orbit was substituted for one application after the extended rains in early July, Orbit was the only fungicide applied in orchard E. Both fungicides were applied at doses recommended in the preset schedule (Ellis et al., 1991). Sprayer speed varied from 2.4 to 3.2 km·h^{-1} among the orchards, All orchards had some blocks with severe scab damage due to insufficient time to spray the entire orchards within the range of fungicide effectiveness, crowded orchard conditions, surrounding woods or wet areas, or a combination of these factors.

The fact that scab severity was visually estimated raises the question of possible bias and repeatability. However, the data collection methodology was validated by statistical analyses. Estimates of scab severity for orchards A and C made by myself and the farm manager were highly correlated (r^2 = 0.93).

Scab ratings were grouped by orchards and orchard blocks, type and timing of fungicide sprays, and the degree of tree exposure to sunlight. Factors regarding the timing of fungicide applications were examined and included 1) spraying by the preset schedule vs. spraying only after rain, 2) spraying after the extended rains in late June or early July, and 3) time elapsed after rains before fungicide application, The critical application time for SuperTin and Orbit was set at 24 h and 6 days, respectively, after rain, Results were analyzed by chi square (Li, 1959).

Overall scab rating by orchard. Fruit loss from scab varied widely among the five orchards, Fruit loss was 85%, 72%, 46%, 40%, and 5% in orchards A, B, C, D, and E, respectively. Variation among orchards cannot be explained by differences in total or frequency of rainfall (Fig. 2). In fact, the orchard with the best scab control, E, had the highest rainfall, the most rainy days, and the most consecutive days of rain.

Sunlight exposure vs. scab. 'Schley' trees with adequate sunlight had about one-half the fruit loss to scab as trees that were shaded by adjacent trees; 39% and 76% fruit loss for sun-exposed and shaded, respectively. Means are significantly different ($P < 0.05$). The pronounced effect of shade on scab incidence was universal in all orchards, regardless of spray intervals or fungicide used. Scab was more severe in crowded orchards because of inadequate spray coverage from blockage of spray by overlapping branches and lack of sunlight and air circulation, which created an ideal environment for scab development. The data indicate that an open orchard is an absolute requirement for scab control.

Scab control by preset schedule vs. climatic based. Spraying after rain was more effective than adhering to the preset schedule. Fruit loss entrees sprayed after rain was 60% vs. 95%. fruit loss on trees sprayed on the preset schedule. Means are significantly different ($P < 0.05$). These results confirm observations that fungicides applied at preset intervals without regard to environmental conditions will not control scab in a high-pressure season. In spite of improved control by spraying after rain, fruit loss to scab was still unacceptable. Unsatisfactory control resulted because time for spraying the whole orchard extended beyond 24 h after onset of rains, SuperTin was the fungicide used for all sprays after April and, under this program, would have had to have been applied within 24 h after rain for maximum effectiveness. Scab disease probably was amplified by spraying SuperTin only after rains >13 mm.

Orchard E, scab control evaluation. Scab control was excellent in blocks 1 and 2, sprayed on 26 June and on 6 July, but not in the nonsprayed block 3 (Table 1). Orbit application on 26 June gave ideal control, as spraying was preceded by 6 days of rain over 7 days and followed by 8 consecutive days of rain, Thus, Orbit's back-action controlled spores released at intermittent drying periods before application, and the forward or protectant action controlled scab infection during the rains after application, Fruit examined on 5 July in blocks 1 and 2 had no scab lesions. Except for excessively crowded spots, damaging scab did not occur following the 6 July Orbit application. The efficacy of these treatments (Table 1) validate previous experimental data that Orbit controls fruit scab (Latham and Hammond, 1983; Latham and McDaniel, 1980, 1982; Reynolds and Bertrand, 1993), contrary to general opinion, The sequence of events described above support the back-action or curative property of Orbit (Latham and Hammond, 1983). That is, rain fell for 6 of 7 days, trees were sprayed afterwards on 26 June, and fruit examined on 5 July did not have any scab lesions. The rainy week before spraying on 26 June created ideal environmental conditions for scab disease development. Regardless, spraying the trees with Orbit curtailed any fungal growth that had been initiated during that period.

Orchards A, B, C, and D, scab control evaluations. SuperTin and Orbit control scab acceptably when applied within their effective range of disease control after rain (Table 2). Both fungicides controlled scab poorly when applied outside their effective range, Furthermore, these results confirm the hypothesis, based on scab biology (Latham and Rushing, 1988), that a nonsystemic fungicide must be applied within 24 h after rain onset; that is, before the germinating spore penetrates the leaf. The fruit loss of only 15% from trees sprayed with Orbit within 6 days after the early July rains substantiates data in Table 1 that Orbit has a substantial back-action as shown experimentally (Latham and Hammond, 1983). Applying fungicide after both rains provided more effective scab control than spraying only after the late June or the early July rain (Table 3). Thus, fungicides must be applied consistently after each rain for maximum scab control, Fruit losses resulting from spraying only after June rains compared to after July rains indicate that 1994 fruit scab became a problem

Table 2. ***Fungicide and timing effect on pecan fruit lost from scab, orchards B, C, and D.***

June rain: Fungicide	June rain: Time	July rain: Fungicide	July rain: Time[z]	Fruit loss (%)[y]
SuperTin	<24 h	SuperTin	<24 h	15
SuperTin	>24 h	SuperTin	>24 h	78
SuperTin	<24 h	Orbit	<6 days	15
SuperTin	>24 h	Orbit	>6 days	50

[z]*(<) Fungicide applied within noted time, (>) fungicide applied after noted time.*
[y]*Within vs. after means are significantly different, P < 0.05.*

mainly in late June and early July as assumed earlier.

A proposed climatic based scab control program

The climatic scab control program is based on the hypothesis that rain triggers the development of the organism causing pecan scab and that Orbit is a more versatile fungicide than SuperTin after rain. Advantages of Orbit over SuperTin are that Orbit is systemic vs. nonsystemic, has 5 days of after-infection and 6 days of protestant control vs. 24 h of protestant control, and, presumably, is less subject to wash-off. However, the scab fungus may more likely develop resistance to Orbit than SuperTin (Bertrand and Brenneman, 1995), The probability that scab will develop resistance to Orbit is a calculated risk. The advantages of systemic over nonsystemic fungicides are paramount and emphasize the need for continual development of new systemic fungicides.

Length of time of leaf wetness, not amount of rain, regulates the infection process. Even 0.8 mm rain apparently provides adequate moisture for minimal infection if the leaf remains wet for 12 h, Scab incidence increases beyond 12 h of leaf wetness (Latham, 1982) as shown experimentally (Gottwald, 1985). Scab infection does not occur during extended periods without rain, even with 100% relative humidity for up to 11 h/day (Latham, 1982)

Proper timing of the first spray is critical to the progressional, seasonal development of scab disease. Suppressing the overwintering scab lesions reduces leaf infection and, subsequently, inoculum for the fruit. Apply Orbit as the first fungicide spray at the parachute stage of leaf development unless necessitated by environmental conditions. Orbit application cannot be delayed until the parachute stage if buds have broken when a rain occurs with a concomitant>14C average day temperature (average of minimum and maximum temperature for 24 h). If the average day temperature is <14C before the parachute stage and rain occurs, do not spray. Regardless of fungicide and time in the growing season, do not spray if the leaf wetness period after the rain does not exceed 8 h. Leaf wetness period is defined as the time from the beginning of rain to the time the leaf dries. The 8-h rule may result in some scab, but damage should be minor and of doubtful economical significance.

Gauge Orbit applications for the rest of leaf and fruit scab susceptibility by environmental conditions, recognizing Orbit's back-action and forward action of 5 and 6 days, respectively, Thus, spray no later than 5 days (120h)after a rain. Once environmental conditions conducive for scab disease occur after the day 6(1 44 h) forward-action window, another spraying will be necessary. Orbit should be sprayed before a predicted prolonged rain if spray equipment is insufficient to cover the orchard within the required 5 days after the rains.

Table 3 ***Effect of fungicide application after rain on pecan fruit loss from scabs, orchards A, B, C, and D.***

Spray action	Fruit loss (%)[z]
Sprayed only after June rains[y]	62
Sprayed only after July rains[x]	41
Sprayed after June and July rains[x]	15
Control[w]	69

[z]Sprayed June and July vs. control, sprayed after June rains, and sprayed after July rains is significantly different, P < 0.05.
[y]SuperTin was applied within 24 h following the rain.
[x]Fungicides SuperTin, Orbit, or both were applied within 24 h (SuperTin) and within 6 days (Orbit) after the rains.
[w]Either not sprayed or SuperTin, Orbit, or both were applied outside the effective tlme.

Detailed spray records by blocks are necessary because most pecan orchards cannot be sprayed in 1 day. Consequently, when a rains occurs, some blocks may be inside and others outside the 6 days depending on when the individual blocks were sprayed.

Applying Orbit during the parachute stage will provide 6 days of protection only for foliage that has developed by this stage. It will not protect foliage that develops during the 6 days after Orbit application, This problem can be minimized by applying one-sided sprays that are staggered in time, One side of the tree is sprayed followed by a spray applied to the other side 3 to 4 days later. The later spray will cover most of the new foliage that develops from the time of the first spray. Near 100% coverage can be obtained from a one-sided spray because the foliage is very sparse at this stage of leaf development.

This climatic-based spray program has some risks because of the possibility that the scab organism will become resistant to Orbit and because the program lacks validation by experimental testing, Thus, program implementation must be the decision and risk of the individual manager and should not applied on a wide basis until validated by testing.

The risk of the scab-causing organism's developing resistance to Orbit can be minimized by using SuperTin when possible. SuperTin can be used within the first 24h after a rain. Countdown begins with the beginning of the rain, If the rain continues for 12h, SuperTin can be applied within the next 12 h. If rains continues for 24 h or more, SuperTin cannot be effectively used, Thus, except for small acreages, respraying with SuperTin after rain has very little value. SuperTin must be applied before a rain to be of maximum value, i.e., on a preset schedule. Few orchards can be sprayed within the limited time SuperTin is effective, and rains cannot be predicted with certainty, Consequently, SuperTin, as such, is not very adaptable to a climatic-based spray schedule. Combinations of SuperTin and Orbit should be tested to determine the balance, if any, that will control scab when applied according to a climatic-based spray schedule.

In summary, the success of a climatic-based spray regime depends on precise fungicide application relative to rain and long-term effectiveness of Orbit, Scab development early in the growing season will increase the difficulty of control in the rest of the season. Results of this program will be modulated substantially by exposure to sunlight and overall air circulation within the orchard. Good scab control by a climatic-based spray regime would be unrealistic in an orchard with a dense tree stand or surrounded by woods or by low or wet areas. However, scab control based on seasonal climatic conditions in an orchard with proper air circulation and sunlight penetration should enhance environmental safety and provide financial profits to the grower.

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