# An Empirical Model for Predicting the First Symptoms of Sooty Blotch and Flyspeck of Apples

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**ABSTRACT**

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Measures of leaf wetness duration were related to the appearance of symptoms of sooty blotch (caused by *Peltaster fructicola, Leptodontium elatius,* and other fungi) and flyspeck (caused by *Zygophiala jamaicensis*) on apple (*Malus* × *domestica*) during the 1987 through 1994 growing seasons. Hours of leaf wetness of 4 h duration or greater accumulated from the first rain that occurred 10 days after petal fall provided the best measure of the time of symptom appearance. Over the 8 years of the study, symptoms appeared after an average of 273 h of leaf wetting (range 209 to 310 h). No consistent temperature effects on the time of first symptom appearance were found. A threshold value of 200 to 250 h of leaf wetting is suggested to initiate fungicide applications for the control of sooty blotch and flyspeck.

Sooty blotch (SB) of apples, a disease complex caused by *Peltaster fructicola* Johnson, Sutton & Hodges, *Leptodontium elatius* (G. Mangenot) De Hoog, *Geastrumia polystigmatis* Batista & M. L. Farr and other fungi (9,10) and flyspeck (FS) caused by *Schizothyrium pomi* (Mont. & Fr.) Arx. (anamorph: *Zygophiala jamaicensis* E. Mason) are the most common summer diseases of apple (*Malus* × *domestica* Borkh.) in the southeastern United States. Sooty blotch was believed until recently to be caused by *Goeodes pomigena* (Schwein.) Colby; however, Johnson (9) and Johnson et al. (10) were unable to find *G. pomigena* on apples collected throughout the eastern United States and presented evidence that sooty blotch is a disease complex composed of the fungi listed above. Infections by the fungi that cause these diseases occur soon after petal fall (late April to early May) in North Carolina, but symptoms can develop anywhere from early June to mid July (2). In areas with warm humid summers, SB and FS require a 10 to 14 day protectant fungicide program throughout the summer for control.

The incidence and severity of SB and FS are dependent on moisture and temperature conditions. Sharp (18) correlated accumulated hours of relative humidity (RH) >95% beginning 3 weeks after the last fungicide application with the incidence of SB and FS and found that 50 to 100 h of high humidity accumulated before SB symptoms appeared. The amount of SB in orchards in Pennsylvania in a given year was proportional to the amount of rainfall occurring in July and, to a lesser extent, in August and September (12). Hickey (6) reported that SB symptoms appeared in 8 to 12 days on inoculated mature fruit in a moist chamber but appeared only after 20 to 24 days in the field. Johnson (9) found that conidia of *P. fructicola* germinated at lower RH than *L. elatius* but conidia of neither fungus germinated at RH <95%.

Optimal growth of *P. fructicola* and *S. pomi* occurs at 16 to 24°C with no growth at 30°C (10,15); optimal growth of *L. elatius* occurs at 24 to 28°C. Temperatures >32°C are lethal to *P. fructicola* but not to *L. elatius* (9). Baines and Gardner (1) believed the development of SB was arrested during hot, dry weather in the summer but favored by lower temperatures and higher humidity during August. They observed symptoms of SB 2 to 3 weeks after inoculation of fruit in the laboratory, but 1 to 2 months after inoculation in the orchard. The average daily temperatures in the mountain apple-growing areas of North Carolina from petal fall to harvest rarely fall outside the optimum range for the SB and FS fungi. Consequently, symptom development of SB and FS in North Carolina is most likely dependent on the frequency of moisture and, to a lesser extent, on temperature.

Models based on measures of moisture (leaf wetness, rainfall, or RH) and temperature (4,11) have been developed for a number of diseases to warn that infection has occurred. However, there are fewer models that predict the onset of symptoms. One of the first models for predicting symptom initiation was developed by Mills and LaPlante (13). Their model predicted the time when the first symptoms of apple scab would appear following infection and was based on temperature during the incubation period. Recently, Steiner and Lightner (19) developed a model for fire blight (MARYBLYT) that predicts first symptoms following infection based on degree day accumulation (base 12.7°C). These models generally have less utility in a disease management program because of the lack of suitable eradicant fungicides and the short incubation/latent period of many pathogens.

A forecast of when SB and FS symptoms will appear in the orchard could be a valuable tool in the control of these diseases. Current control strategies in the southeastern United States utilize benzimidazole fungicides that are included in the summer spray program beginning in late May or early June (21). Although benzimidazole fungicides have some eradicant activity against SB and FS (2,5,7,16,17), they usually are applied on a preventative basis and do not take into account yearly variation in environmental conditions favoring infection and symptom expression. The objective of this study was to develop a model that can predict when symptoms of SB and FS first appear in the orchard and serve as a guide for initiating fungicide applications to control these diseases.

## MATERIALS AND METHODS

**Location.** Tests were conducted from 1987 through 1994 at the Mountain Horticultural Crops Research Station (MH CRS), Fletcher, N.C., and the Marlowe and Hillcrest orchards, Edneyville, N.C., in 1992. The MHCRS orchard is a block of 120 standard Golden Delicious trees planted in 1972 and spaced 3 m apart in rows 9 m apart. The orchard is bordered on one side by woods and has a history of extensive SB and FS infections. The Marlowe orchard is a block of 100 spur Golden Delicious trees planted in 1980 and spaced 4.5 m apart in rows 8.5 m apart. The orchard is bordered on two sides by woods and has a history of moderate SB and FS infections. The Hillcrest orchard is composed of 400 standard Golden Delicious trees planted in 1988 and spaced 3 m apart in rows 6 m apart. The orchard has a history of low to moderate SB and FS infections. All trees in the

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three orchards were pruned annually to a central leader and had generally open canopies. Each orchard was sprayed with fenarimol (Rubigan 1E) at 2.8 mg a.i. per liter from green tip through petal fall for apple scab control. Fenarimol has little or no activity on SB or FS. Each orchard was sprayed with a standard insecticide program (20).

**Data collection.** Hours of leaf wetness were recorded by using a deWit leaf wetness meter (Instrumentenfabrick IFG de Wit, Rhoden, The Netherlands) that uses a hemp string as a sensing element. Changes in the length of string in response to wetting are recorded on a revolving 7-day chart (15). One instrument was placed in each orchard on the north side of a tree under the drip line, approximately 1.5 m above the ground. An hour was considered wet when there was a 50% or greater deflection in the recording pen from the dry to wet position. Wetting periods from rainfall were characterized by a deflection in the pen toward complete leaf wetness. Wetting periods from dew, mist or fog were characterized by a gradual deflection in the pen. Temperature data were obtained from the National Oceanic and Atmospheric Administration (NOAA) station at the Asheville Regional Airport, located approximately 1.6 km from MHCRS.

**Relationship of leaf wetness and temperature to disease appearance.** Hours of leaf wetness were recorded beginning with the first rain that occurred 10 days after petal fall. This criterion was used because previous studies showed that infection of *G. pomigena* and *S. pomi* occurs 10 to 21 days after petal fall in North Carolina (2). Hours were accumulated until first SB and FS symptoms were observed in the orchard. The following moisture parameters were investigated: (i) all hours of leaf wetness; (ii) hours of leaf wetness following a rain (>0.25 mm); and (iii) hours of leaf wetness of 4 h duration or greater. Models were evaluated by visual examination of plots of the data and comparison of the coefficients of variation (CV) of the moisture parameters.

The leaf wetness meter at MHCRS sporadically malfunctioned in 1989, 1990, and 1991. Hours of RH >95% recorded at the NOAA station at the Asheville airport were utilized as an indication of leaf wetness for the missing days. This threshold was used because optimal growth of *G. pomigena* was observed by Baines and Gardner (1) and Johnson (*P. fructicola*, 9) at ≥95% RH and *Z. jamaicensis* conidia germinate at RH >97% (14).

The following temperature variables also were examined: daily maximum, minimum, and average temperature on days leaf wetness was recorded and temperature only during the time it was wet. Each temperature variable was regressed against the cumulated hours of wetting obtained until first symptoms were observed.

**Table 1.** Accumulated hours of leaf wetting using three criteria, beginning 10 days after petal fall and continuing until first sooty blotch and flyspeck symptoms were observed at Mountain Horticultural Crops Research Station, N.C., from 1987 through 1994

| | Date | | | Accumulated hours of wetting | | |
|---|---|---|---|---|---|---|
| Year | Petal fall | Beginning date | Symptoms observed | After rain | All periods | 4 h duration |
| 1987 | 27 April | 5 May | 15 June | 162 | 284 | 265 |
| 1988 | 28 April | 11 May | 26 July | 183 | 347 | 304 |
| 1989 | 26 April | 9 May | 23 June | 254 | 280 | 276 |
| 1990 | 25 April | 6 May | 16 July | 239 | 308 | 289 |
| 1991 | 25 April | 6 May | 4 June | 207 | 268 | 267 |
| 1992 | 1 May | 13 May | 15 June | 265 | 345 | 310 |
| 1993 | 7 May | 17 May | 6 July | 103 | 234 | 209 |
| 1994 | 29 April | 14 May | 21 June | 191 | 281 | 242 |
| Mean | | | | 200.5 | 293.4 | 270.3 |
| Coefficient of variation | | | | 53.4 | 38.4 | 33.1 |

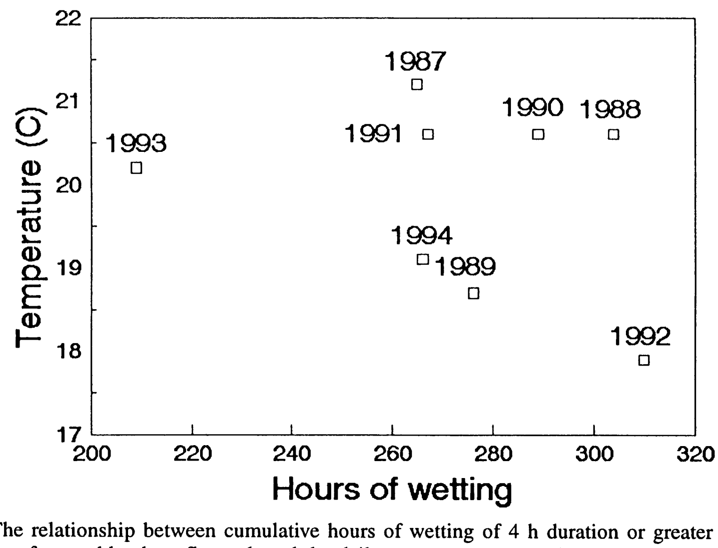


**Fig. 1.** The relationship between cumulative hours of wetting of 4 h duration or greater until first symptoms of sooty blotch or flyspeck and the daily mean temperature during the same period from 1987 through 1994 at the Mountain Horticultural Crops Research Station, Fletcher, N.C.

**Fungicide treatments.** Fungicide treatments were applied to the orchard of Golden Delicious trees at MHCRS to determine if benzimidazole fungicides applied at a specific leaf wetness threshold were effective in reducing the incidence and severity of SB and FS. The orchard is composed of 24 groups of five trees planted in three rows; groups are spaced 9 m apart. In 1993 and 1994 each treatment was applied to three groups of trees in a randomized complete block design. The orchard was sprayed both years with fenarimol at 2.8 mg a.i. per liter from green tip through petal fall for apple scab control and with a standard insecticide program (20).

Fungicide treatments were applied dilute at 1,946 liters per ha (208 gal per acre) with a Swanson DA 500A airblast sprayer driven 67 m per min with a manifold pressure of 862 kPa (125 lb/in$^2$). All treatments were sprayed with captan at 1,200 mg a.i. per liter (2 lb Captan 50W per 100 gal) from first cover to harvest. The experiment was designed to make the first benzimidazole applications at 200 and 250 h of leaf wetting; however, due to the times wetting events occurred, application times exceeded these thresholds. The 200-h treatments were actually applied at 209 and 222 h of wetting in 1993 and 1994, respectively, and the 250-h treatments were applied at 270 and 260 h wetting in the respective years. In 1993, thiophanate methyl at 158 mg a.i. per liter (3.0 oz Topsin-M 70W per 100 gal) was included in cover sprays after 209 and 270 h. In 1994, benomyl at 75 mg a.i. per liter (2.0 oz Benlate 50W per 100 gal) was applied alone after 222 h of wetting and was included in all subsequent cover sprays in the 200-h treatment. In the 250-h treatment, benomyl at 75 mg a.i. per liter was included with captan in all cover sprays after 266 h of wetting. The standard used for comparison was captan (1,200 mg a.i. per liter) combined with either thiophanate methyl (105 mg a.i. per liter in 1993) or benomyl (75 mg a.i. per liter in 1994) applied every 2 weeks from first cover until approximately 2 weeks prior to harvest. SB and FS incidence and severity (percent surface area affected) were determined at harvest from an arbitrary sample of 100 fruit from each 5-tree group (replication). Treatments were subjected to an analysis of variance and means were separated using the Waller-Duncan *k*-ratio *t* test (SAS/STAT User's Guide, vers. 6.0, ed. 4, SAS Institute, Cary, N.C.).

**Observations of disease incidence.** One hundred nonsprayed fruit in each orchard were examined weekly beginning after approximately 150 h leaf wetting to determine when SB and FS symptoms developed. Fruit were selected arbitrarily from both the perimeter and inside the tree canopy.

## RESULTS AND DISCUSSION

The first symptoms of SB and FS were observed as early as 4 June (in 1991) and as late as 26 July (in 1988) (Table 1). The cumulative hours of leaf wetness using the three moisture parameters are presented in Table 1. Hours of leaf wetness following rainfall were the most variable and ranged from 103 to 265 h. This large variation suggests that other wetness parameters such as fog or dew may play a significant role in symptom development. Cumulative hours of leaf wetness from all wetting periods (rain, dew, or fog) ranged from 234 to 347 h whereas hours of leaf wetting of 4 h duration or greater had the narrowest range (209 to 310 h) and the lowest coefficient of variation (Table 1). The 4-h threshold may have been less variable than the cumulative hours from all wetting periods because it reflects our observations that the minimum time required for germination and/or mycelial growth of the pathogens upon wetting is 4 to 5 h. Ocamb-Basu and Sutton (14) showed that conidia of *Z. jamaicensis* required 5 h of wetting at optimum temperatures to achieve 80% germination.

In 1993, we observed symptoms with fewer hours of accumulated leaf wetting with all moisture parameters than in any other years (Table 1). We do not have a good explanation for this finding. We utilized a different deWit leaf wetness meter in 1993 than in previous years, but this should not have affected the hours of leaf wetting to a great extent. We also observed FS symptoms earlier than those of SB in 1993; in all other years we observed SB symptoms first. If the 1993 data are not used in the model development, then mean and CV for wetting periods of 4 h duration or greater are 282.4 h and 18.8%, respectively.

There was no clear relationship of hours of leaf wetting until first symptoms of SB and FS were observed to temperature. Coefficients of determination for regression models of temperature variables against the 4-h wetness variable ranged from 0.1 to 0.5. A plot of the daily average temperature and hours of wetting of 4 h duration or greater are representative of the relationship with temperature observed (Fig. 1). The lack of a relationship to temperature was not unexpected because temperatures in North Carolina during the summer period fall within the optimum range for *P. fructicola* and *Z. jamaicensis* (1,9,14). However, in environments where temperatures are cooler, such as in the northeastern and midwestern U.S., temperature may play a more significant role.

We believe a model based on cumulated hours of wetting of 4 h duration or greater beginning with the first rain 10 days after petal fall can be used to predict when symptoms of SB and FS will occur in the orchard. When the mean number of hours of wetting of 4 h duration or greater (273 h) was selected as a threshold, symptoms were observed within 1 week of the threshold each year of our study (Fig. 2). Consequently, a lower threshold, 200 or 225 h, could be used to initiate scouting and/or a fungicide spray program. A threshold of 50 or 75 h less than the mean is necessary to account for the variation in the accumulated hours of wetting that we observed and to give sufficient warning and time to make a fungicide application. During a prolonged wet period, hours of wetting can accumulate rapidly over a 2- or 3-day period. For example, in 1989 204 h were recorded prior to 18 June. It rained periodically over the next 4 days and on the morning of 23 June, the first suitable time for spraying, 276 h had accumulated. Conditions were not favorable for spraying during the 4-day period.

Fungicide trials conducted in 1993 and 1994 support the use of a threshold of 200 to 225 h. In both years there was no significant difference in SB and FS incidence or severity among benomyl treatments applied at 209 (1993) and 222 h (1994) and the standard treatment (Tables 2 and 3). The 250-h treatments applied 22 (1994) to 61 (1993) h after first symptoms appeared were also efficacious and did not result in any significant increase in disease. This may reflect the eradicant activity of the benzimidazole fungicides. Use of the model resulted in savings of three and two benzimidazole sprays in 1993 and 1994, respectively, compared with the standard treatment. If a threshold of 200 to

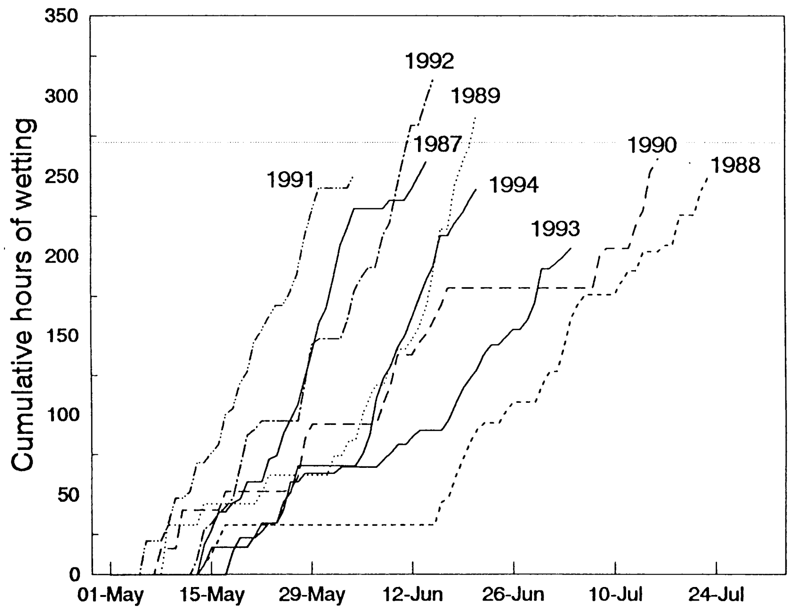


**Fig. 2.** Cumulative hours of wetting of 4 h duration or more beginning 10 days after petal fall until first symptoms of sooty blotch or flyspeck were observed at the Mountain Horticultural Crops Research Station, Fletcher, N.C., from 1987 through 1994. Horizontal line is mean for the 8-year period (273 h).

**Table 2.** Time of benzimidazole applications and incidence and severity of sooty blotch and flyspeck in fungicide trials at the Mountain Horticultural Crops Research Station, N.C., in 1993

| | Percent fruit affected[x] | | |
|---|---|---|---|
| **Time of benzimidazole application[w]** | **Sooty blotch** | **Flyspeck** | **Disease severity[y]** |
| Second cover (24 May) | 77.3 b[z] | 82.0 | 12.2 b |
| 209 h wetting (6 July) | 93.3 ab | 96.7 | 18.1 b |
| 270 h wetting (20 July) | 90.0 ab | 88.7 | 12.4 b |
| Check (no fungicide) | 100.0 a | 100.0<br>NS | 64.8 a |

[w] First through eighth cover sprays were made on 13 and 24 May, 7 and 22 June, 16 and 19 July, and 15 through 19 August.

[x] Based on 100 fruit selected arbitrarily from each of three 5-tree replications per treatment.

[y] Mean percent fruit surface covered with sooty blotch or flyspeck at harvest.

[z] Means within the same column followed by the same letter are not significantly different at $P$ = 0.05 as determined by the Waller-Duncan *k*-ratio *t* test.

**Table 3.** Time of benzimidazole applications and incidence and severity of sooty blotch and flyspeck in fungicide trials at the Mountain Horticultural Crops Research Station, N.C., in 1994

| | Percent fruit affected[x] | | |
|---|---|---|---|
| **Time of benzimidazole application[w]** | **Sooty blotch** | **Flyspeck** | **Disease severity[y]** |
| First cover (10 May) | 78.7 bc[z] | 77.3 bc | 4.7 b |
| 222 h wetting (15 June) | 70.0 c | 67.3 c | 4.1 b |
| 266 h wetting (22 June) | 88.7 ab | 82.7 abc | 5.3 b |
| Check (No fungicide) | 100.0 a | 100.0 a | 67.3 c |

[w] All treatments were sprayed with captan from petal fall through eighth cover. Petal fall through eighth cover sprays were made on 28 April (petal fall), 11 and 24 May, 9 and 22 June, 7 and 20 July, and 4 and 18 August.

[x] Based on 200 fruit selected arbitrarily from each of three 5-tree replications per treatment.

[z] Mean percent fruit surface covered with sooty blotch or flyspeck at harvest.

[z] Means within the same column followed by the same letter are not significantly different at $P$ = 0.05 as determined by the Waller-Duncan $k$-ratio $t$ test.

250 h had been used each year from 1987 through 1994, then the model would have resulted in a mean savings of two benzimidazole sprays yearly. In 1988, the driest year of the study, five benzimidazole sprays would have been saved compared with the standard treatment.

Variation in inoculum density from orchard to orchard should not affect the model threshold unless inoculum levels are very low. In 1992, at the Marlowe and Hillcrest orchards, we observed symptoms after 308 and 328 h respectively, compared with 310 h at MHCRS. However, in low inoculum situations, early infections will be more difficult to detect, and secondary spread on fruit will not occur as rapidly. The inoculum level at MHCRS is very high and often multiple colonies were present on fruit when symptoms were first observed. At harvest 50 to 70% of the fruit's surface was typically covered with multiple colonies in unsprayed orchards. Consequently, under low inoculum situations it may be possible to use a higher threshold for benzimidazole applications, because benzimidazole fungicides have some eradicant properties against SB and FS (2,7,16).

Our model is based on leaf wetness as detected by the deWit leaf wetness meter, which uses a hemp string as the sensing element. Other leaf wetness sensors are available and may detect moisture from rain, dew, and fog differently from the deWit instrument. Electronic sensors appear more variable than others (3,8). Consequently, the threshold that we have established with the deWit sensor may have to be modified if other sensors are used. Hartman (5) evaluated our model in Kentucky using an Envirocaster (Neogen Corp., Lansing, Mich.) with an electronic leaf wetness sensor and observed symptoms following only 182 h of wetting using the 4-h criterion.

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