The Distribution of the Mycelial Types of *Gloeodes pomigena* on Apples in North Carolina and Their Relationship to Environmental Conditions

ABBEY L. SUTTON, Former Graduate Research Assistant, and T. B. SUTTON, Professor, Department of Plant Pathology, North Carolina State University, Raleigh 27695-7616

ABSTRACT

Sutton, A. L., and Sutton, T. B. 1994. The distribution of the mycelial types of *Gloeodes pomigena* on apples in North Carolina and their relationship to environmental conditions. Plant Dis. 78:668-673.

The distribution of the four mycelial types of *Gloeodes pomigena* was determined by monitoring their incidence and severity in eight locations throughout North Carolina in 1986 and 1987. Temperature, rainfall, and relative humidity were monitored at four sites in 1986 and seven sites in 1987 throughout the growing seasons. The incidence of sooty blotch approached 100% at all locations by the end of each growing season. Severity of the disease was highest at locations with cooler temperatures and longer periods of dew (western Mountains) or higher humidities (eastern Coastal Plain). The punctate mycelial type was most common overall and was most prevalent in areas where disease severity was greatest. The incidence and severity of the punctate type increased with increasing hours of high relative humidity; severity decreased with increasing temperature. The incidence and severity of the ramose mycelial type increased with increasing temperature and increasing amount of rainfall. This type was most abundant in the Coastal Plain region. There were no significant correlations between any environmental factors and the fuliginous mycelial type. The incidence and severity of the rimate type was correlated positively, although weakly, to measures of relative humidity.

Gloeodes pomigena (Schwein.) Colby, causal agent of sooty blotch of apple (*Malus domestica* Borkh.), was first reported and described in 1832 in Pennsylvania on Newtown Pippin (as cited by Colby [2]). This disease affects apples in a wide geographic region and has been reported throughout the apple-producing regions of Great Britain, France, Zaire, South Africa, and North America (5). In the southeastern United States, sooty blotch is an important economic problem for the apple industry. In North Carolina, 5–10% of the commercial crop is affected annually in spite of the use of fungicide control programs. Although sooty blotch does not cause a yield loss, it leaves surface blemishes which affect the appearance of the fruit and therefore decrease their value.

Sooty blotch is characterized by surface spots or blotches on the cuticle of the fruit. The blotches are frequently irregular in outline but have a general circular shape resulting from mycelial threads which radiate from a common center. Early researchers believed that the fungus did not cause any cellular injury or malformation, existing only superficially on the cuticle of the apple (1,2). Penetration of the cuticle was subsequently observed (3) and is believed to accelerate the loss of moisture from the affected areas of the fruit during storage.

G. pomigena produces a variety of colony types, both in culture and on the fruit surface. These growth types were divided by Colby (2) into three groups based on the microscopic observation of thallus appearance on the apple cuticle: fernlike, honeycomb, and reticulate. Based on work conducted in Virginia, these groups were later divided into four mycelial types by Groves (3). Thalli which appear as smoky or sooty smudges are termed fuliginous. This group contains colonies without well-defined margins, often extending over a wide area of the fruit surface, and colonies which are more restricted in extent with well-defined margins. Under microscopic examination, fuliginous colonies have few if any arborescent characteristics and have a reticulate appearance. Colby's reticulate and honeycomb groups were placed in this mycelial type. Thalli which are arborescent, rugose radiate, frondose, or fernlike were placed in the ramose mycelial type. Plectenchymal bodies may or may not be present and, if present, are not abundant. The punctate group contains thalli with large, conspicuous plectenchymal bodies. Variation in the heaviness of the thallus, prominence of the connecting mycelium between plectenchymal bodies, and the size and abundance of the bodies characterize this type. All thalli which penetrate the host cuticle are placed in the rimate type without regard to other morphological characteristics.

Groves (3) found that thalli of the ramose group were the most abundant, comprising approximately 80% of all thalli observed; 5% of the thalli were of the fuliginous type, and 5–10% were of the punctate type.

Groves (3) reasoned that because more than one mycelial type may appear on a single fruit, the occurrence of the mycelial types was not a response to local environmental conditions. Colby (2) reported that *G. pomigena* was extremely sensitive to unfavorable environmental conditions. He found that disease severity was reduced in orchards that had good air flow and water drainage; however, it was practically impossible to exclude disease from sites which did not (2). *G. pomigena* primarily grows superficially on the host; therefore, atmospheric humidity directly affects the growth of the fungus (1). Cool, wet conditions favor the development of sooty blotch colonies, and high humidity is necessary for maximum growth (1). Hickey (5) found that the amount of rainfall in any given year played a predominant role in the amount of sooty blotch occurring in that year. After examining 25 yr of meteorological records, Kirby (6) found that the amount of sooty blotch present on fruit in unsprayed orchards was proportional to the amount of rainfall oc-

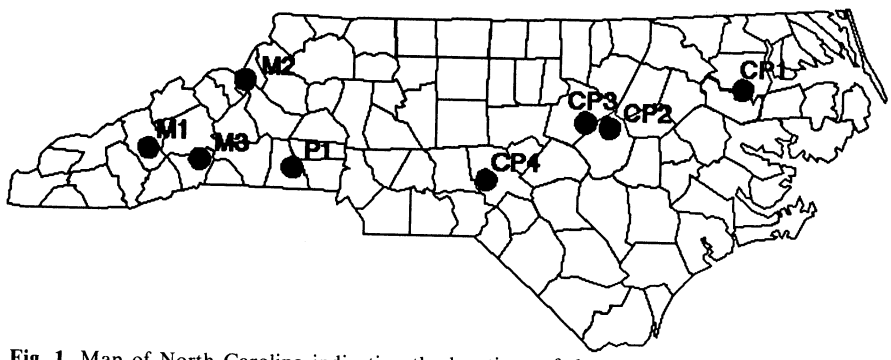

Fig. 1. Map of North Carolina indicating the locations of the sample sites used in 1986 and 1987. CP = Coastal Plain, P = Piedmont, and M = Mountains.

The use of trade names in this publication does not imply endorsement by the North Carolina Agricultural Research Service nor criticism of similar ones not mentioned.

Accepted for publication 21 March 1994.

curring in July and, to a lesser extent, in August and September.

The purpose of this study was to determine how the mycelial types of *G. pomigena* are distributed geographically across North Carolina and the relationship of the incidence and severity of each mycelial type to various environmental variables.

MATERIALS AND METHODS

Site location. Eight orchards located in three geographical areas of North Carolina were used in the study (Fig. 1). The three regions represented in this study are the Coastal Plain, the Piedmont, and Mountains. The Isaac Rascoe Orchard (CP1) in Bertie County, located in the eastern Coastal Plain, is approximately 8 m above sea level. The Central Crops Research Station (CP2) in Johnston County, University Farm No. 2 (CP3) in Wake County, and the Sandhills Research Station (CP4) in Moore County are located in the western Coastal Plain. These sites are situated approximately 90, 90, and 60 m above sea level, respectively. The Piedmont

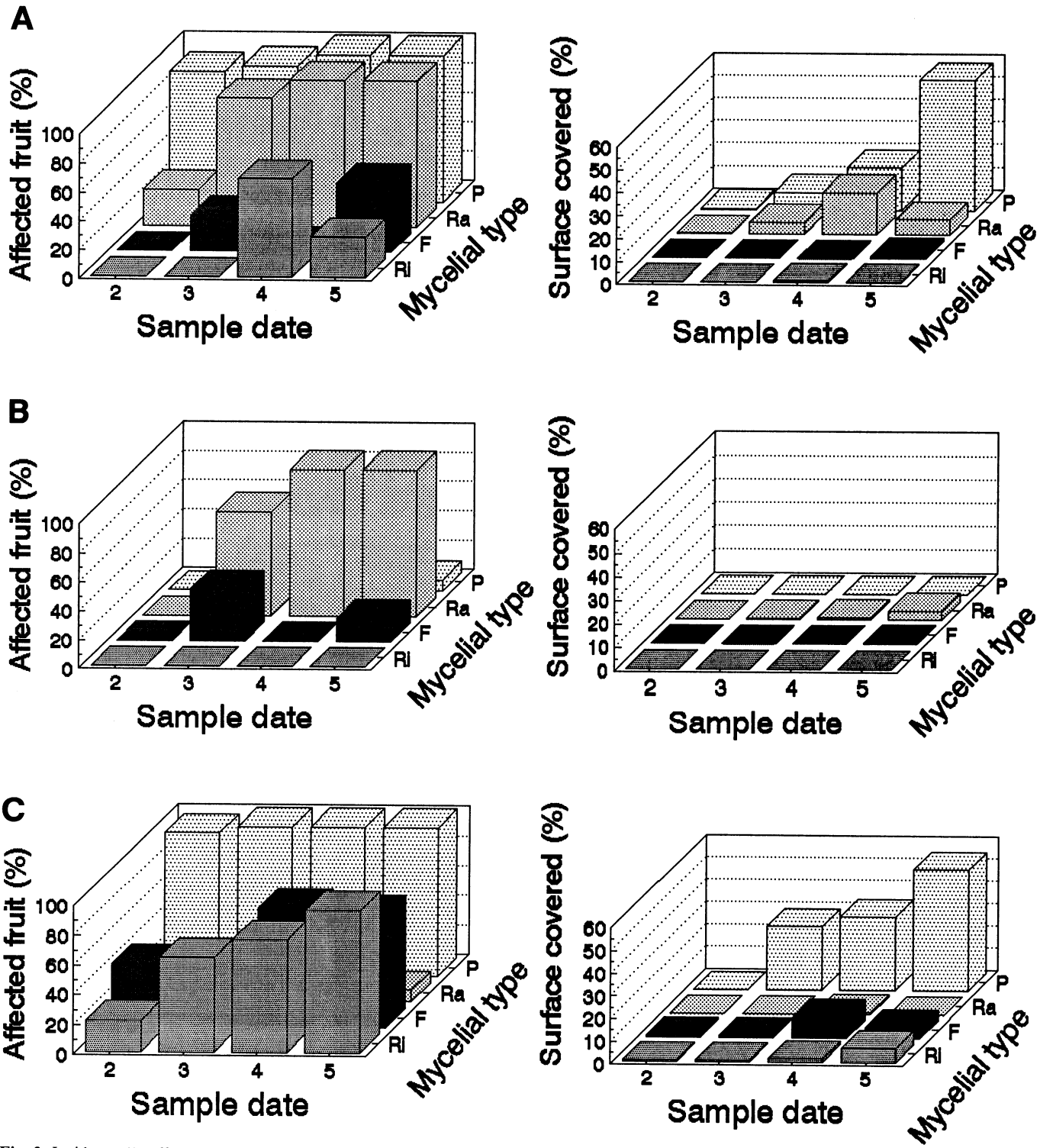

Fig. 2. Incidence (% affected fruit) and severity (% surface area covered) of punctate (P), ramose (Ra), fuliginous (F), and rimate (Ri) mycelial types at: **(A)** Isaac Rascoe Orchard (CP1), **(B)** Central Crops Research Station (CP2), and **(C)** Mountain Horticultural Crops Research Station (M3) in 1987. No infected fruit were found at the sites on the first sample date. Values for the percent fruit affected for the punctate type for the Central Crops Research Station are 0, 7, 0, and 8% for sample dates 1–4, respectively. For the Mountain Horticultural Crops Research Station, 40% of the fruit were affected with the fuliginous mycelial type on sample date 2; and 17, 20, 20, and 8% were affected with the ramose type on sample dates 1–4.

area is represented by the Cline Orchard (P1) in Cleveland County (260 m above sea level). Orchards located in the Mountain region include: Sutton Orchard (M1) in Haywood County at 1,100 m above sea level, Massie Orchard (M2) in Avery County at 1,100 m above sea level, and Mountain Horticultural Crops Research Station in Henderson County (M3) at 650 m above sea level. Orchards in the Piedmont and Mountains are within the primary apple-growing regions of North Carolina.

Four sites (CP2, CP3, CP4, and M3) were located at research stations. Plots for epidemiological evaluation at site CP2 were located within a 20-yr-old, 2-ha orchard and were composed of groups of two Delicious and two Golden Delicious trees. Plots at site CP3 were composed of four rows of three trees each within a 25-yr-old, 4-ha orchard. At site CP4, plots were composed of 38-tree rows within a 12-yr-old, 2-ha orchard. The orchard at site M3 was approximately 20 yr old and had not been sprayed with fungicides for 4 yr. The orchard was composed of Delicious, with Golden Delicious planted as every third tree within the row.

The remaining sites (CP1, P1, M1, and M2) were abandoned private orchards. Site CP1 had never been sprayed. Site M1 was unsprayed for a minimum of 10 yr, and sites P1 and M2 were unsprayed for at least 5 yr. Plots located at research stations were treated with standard insecticide and miticide sprays (7).

Survey methods. All data on the disease were obtained from Golden Delicious apples, for ease of mycelial type identification. Fruit were obtained from four trees selected arbitrarily per location. To estimate overall disease incidence, on each sample date 25 fruit per tree were arbitrarily chosen to represent the upper, lower, inside, and outside of the tree canopy. All affected fruit from each tree were combined, and 25 fruit were selected arbitrarily to determine overall sooty blotch severity and the incidence and severity of each of the four mycelial types. Each of these 25 fruit was considered a replication in subsequent data analyses. The percentage of the apple surface area covered by each mycelial type was estimated utilizing a 40× dissecting microscope. Samples were taken at 3-wk intervals during the growing season for a total of five sample dates per year in 1986 and 1987. We attempted to visit all sites within a 3-day period. Sites were sampled on the following dates in 1986: 14–17 June, 6–8 July, 26–30 July, 17–19 August, and 5–11 September. In 1987, samples were taken on 22–27 June, 1 July (CP2 and CP4 only), 13–18 July, 22 July (CP2 and CP4 only), 27–28 July, 8 August (CP1 only), 12 August (CP2 and CP4 only), 17–21 August, 29 August–2 September, and 9 September. Site CP3 was not used in 1987 due to freeze injury which significantly reduced the crop.

Table 1. The severity of *Gloeodes pomigena* at eight locations in North Carolina in 1986 and 1987

Location[w]	Severity[x] 1986	1987
CP1	50 b[y]	65 a[y]
CP2	5 e	4 d
CP3	4 e	...[z]
CP4	3 e	42 b
P1	19 d	41 b
M1	33 c	67 a
M2	6 e	22 c
M3	73 a	62 a

[w] CP1 = Isaac Rascoe Orchard, CP2 = Central Crops Research Station, CP3 = University Farm No. 2, CP4 = Sandhills Research Station, P1 = Cline Orchard, M1 = Sutton Orchard, M2 = Massie Orchard, and M3 = Mountain Horticultural Crops Research Station.

[x] Severity of disease as the perentage of apple surface area covered at the last sample date.

[y] Values with the same letter are not different from one another but are significantly different ($P = 0.01$) from all others based on the Waller-Duncan k-ratio t test.

[z] Data were not taken at site CP3 in 1987 due to an insufficient apple crop.

Environmental monitoring. Environmental data were taken from CP2, CP3, CP4, and M3 in 1986 and from all sites in 1987. In the abandoned orchards, rainfall was measured within the orchard using top weighing rain gauges (Belfort Instrument Co., Baltimore, MD), and hygrothermographs (Belfort Instrument Co.) were used to record humidity and temperature data at the sites. Hygrothermographs were located in standard instrument shelters. All instruments were calibrated prior to placement in the orchards and periodically throughout the study. At research station sites CP2, CP3, CP4, and M3, automated weather stations were used to obtain environmental data (9). Stations were located 100, 700, and 500 m from the plots at sites CP2, CP3, and CP4, respectively. At site M3, weather data from the Asheville, North Carolina airport, located approximately 2 km from the orchard, were utilized.

Statistical analysis. A general linear models procedure was used to test for significant differences in the amounts of disease and the distribution of types among locations (8). The mean incidence and severity of disease at each location and the means of the incidence and severity of each type by location were compared using the Waller-Duncan k-ratio t test, k-ratio = 100.

The relationship between the overall incidence and severity of disease, the incidence and severity of each of the mycelial types, and measures of temperature, rainfall, and relative humidity at the sites was examined using correlation analysis (8). Data on disease incidence and severity from all sample periods from 1986 at sites CP2, CP3, CP4, and M3, and all data from 1987 except sites CP2 and CP4 were pooled. Data from the automated weather stations at sites CP2 and CP4 in 1987 could not be used due to large data gaps caused by sensor malfunctions and lightning strikes. The following measures of disease incidence and severity were correlated to the environmental variables: IOVRL = the overall incidence of sooty blotch; SOVRL = the overall severity of the disease; (PI, FI, RAI, and RII) = the incidence of the punctate, fuliginous, ramose, and rimate mycelial types, respectively; and (PS, FS, RAS, and RIS) = the severity of disease caused by the four mycelial types. Severity was measured as the proportion of the affected area occupied by a particular mycelial type on a sample date. Environmental variables were mean daily minimum temperature (TMIN), mean daily maximum temperature (TMAX), days with rain (RN), amount of rain (AMT), hours of relative humidity ≥90% (RH90), hours of relative humidity ≥95% (RH95), and hours of relative humidity = 100% (RH100). Correlations were calculated between the measures of disease and the environmental conditions which occurred 21, 28, 35, and 42 days prior to each sample date (Lag21, Lag28, Lag35, and Lag42) using a lag function in SAS (8). Correlations were also calculated between the change in the incidence and severity of the mycelial types from sample date to sample date and the environmental variables for the same period, as well as Lag21, Lag28, Lag35, and Lag42.

RESULTS

Incidence and severity of disease. The data presented in Figure 2A–C for orchards CP1, CP2, and M3 in 1987 are representative of the distribution patterns of the mycelial types during the growing season at a site in the eastern Coastal Plain (P1), western Coastal Plain (P2), and Mountains (M3), respectively. The disease was typically observed earlier in the eastern Coastal Plain orchard (Fig. 2A) and in orchards in the Mountains (Fig. 2C) than in orchards in the western Coastal Plain (Fig. 2B) or Piedmont. The incidence of the punctate type was nearly 100% on the first sample date in orchards in which it predominated (Fig. 2A and C). The severity of symptoms of each mycelial type generally increased through the growing season. Data obtained in the final sample period were used to compare the geographical distribution of the mycelial types and each type's incidence and severity compared to the other types (Tables 1 and 2).

In 1986, *G. pomigena* was most severe at site M3, where a mean of 73% of the apple surface area was covered with the fungus on the final sample date, and least

severe in the Coastal Plain orchards CP2, CP3, and CP4 and the Mountain orchard M2 (Table 1). The severity of disease was greatest at sites CP1, M1, and M3 in 1987 (Table 1). No differences were seen in the incidence of disease in either year. The disease incidence was 100% at all sites except site CP2, which had a 95% incidence.

Incidence and severity of disease by mycelial type. In 1986, the incidence of the fuliginous mycelial type was highest at sites P1 and M1 and lowest at sites CP1, CP2, CP3, CP4, and M2 (Table 2). In 1987, site CP4 had the highest mean incidence at 96%, followed by site M3 at 76% (Table 3). Sites P1 and M1 had the greatest severity of the fuliginous type in 1986. The incidence and severity of the fuliginous type were greatest at site CP4 in 1987, although this site had a low severity for this mycelial type in 1986 (Tables 2 and 3).

Overall, the punctate mycelial type was the most prevalent, and its incidence ranged from 92 to 100% at sites CP1, P1, M1, and M3 in 1986 and 1987 (Tables 2 and 3). The incidence of this mycelial type was lowest at site CP4 in 1986 and sites CP2 and CP4 in 1987. Severity of the punctate type was highest at sites CP1, P1, M1, and M3 in 1986; site M3 had the highest severity of punctate type at 71.94% (Table 2).

The incidence of the ramose mycelial type was highest at sites CP1, CP2, and CP4 in both years and site CP3 in 1986 (Tables 2 and 3). The severity of the ramose type was greatest at site CP1 in 1986; there were few detectable differences in ramose severity among the other sites (Table 2). In 1987, severity of the ramose type was significantly higher at sites CP1, CP2, and CP4 than at the other sites (Table 3).

The rimate type was the most prevalent overall at sites P1, M2, and M3 in 1986. There was little difference in the severity of the rimate type among sites. In 1987, disease incidence at site M3 was greater than at the other sites and reached 96% (Table 3). Sites M1 and M3 had the highest severities of that year, with values of 1.12 and 6.32%, respectively (Table 3).

Correlation of disease measures with environmental variables. The incidence of sooty blotch was positively correlated to the amount of rain which occurred in the 28-, 35-, or 42-day period prior to the sample date (Lag28, $P = 0.10$; Lag35, $P = 0.10$; Lag42, $P = 0.05$) (Table 4). RH90 for the 28-day period prior to sampling was also positively correlated to the incidence of disease (Table 4). The severity of sooty blotch generally decreased with increasing temperature; however, the correlation was significant only for the 21-day period prior to sampling ($P = 0.10$) (Table 5). RH90 was positively correlated to disease severity at all times tested (Table 5). Severity increased with RH95 in the 21- and 28-day periods prior to the sample date (Table 5).

A reduction in the incidence of the punctate mycelial type was weakly correlated with increasing temperature; correlation coefficients were significant only with TMAX for Lag21 (Table 4). The incidence of this type was positively correlated with RH90 and RH95 for all times tested (Table 4). The incidence of the punctate type was significantly and positively correlated with RH100 for Lag21 ($P = 0.01$) and Lag28 ($P = 0.05$) (Table 4). The severity of this mycelial type decreased with increasing TMIN and TMAX over all times tested (Table 5). Punctate severity was positively correlated with RH90 for all Lag periods. Severity was also positively correlated with RH95 and RH100 for Lag21 ($P = 0.05$ and $P = 0.10$, respectively) (Table 5).

The incidence of the ramose mycelial type was positively correlated with temperature for all time periods (Table 4). The correlation coefficient was significant between ramose incidence and AMT for Lag21 ($P = 0.10$) (Table 4). RH90 for Lag21 was negatively correlated, and for Lag35 was positively correlated, with ramose incidence (Table 4). As with ramose incidence, increasing severity was positively correlated with TMAX and TMIN for all time periods tested (Table 5). Ramose severity increased with rainfall at Lag35. RH90 was negatively correlated with ramose severity for all time periods tested except Lag35 (Table 5). Severity was also negatively correlated with both RH95 and RH100 for Lag21 (Table 5).

The incidence and severity of the fuliginous mycelial type were not significantly correlated with any of the environmental variables.

Rimate incidence generally was negatively correlated with temperature, but the correlation was significant only with

Table 2. The incidence and severity of the mycelial types of *Gloeodes pomigena* at eight locations in North Carolina in 1986

	Mycelial type[x]							
	Fuliginous		Punctate		Ramose		Rimate	
Location[w]	I[y]	S[z]	I	S	I	S	I	S
CP1	16 c	0.24 b	100 a	38.26 b	96 a	11.76 a	4 c	0.02 b
CP2	12 c	0.27 b	88 a	3.62 e	72 b	1.37 bc	4 c	0.04 b
CP3	4 c	0.01 b	60 b	2.03 e	76 b	1.52 bc	8 bc	0.08 b
CP4	8 c	0.10 b	8 c	0.16 e	92 ab	2.68 b	4 c	0.08 b
P1	68 a	4.51 a	92 a	13.26 d	28 c	1.07 bc	24 ab	0.40 ab
M1	56 a	6.43 a	100 a	26.43 c	20 c	0.24 c	4 c	0.06 b
M2	4 c	0.29 b	92 a	4.53 e	12 c	0.18 c	32 a	0.71 a
M3	36 b	0.46 b	100 a	71.94 a	20 c	0.64 c	32 a	0.24 b

[w] CP1 = Isaac Rascoe Orchard, CP2 = Central Crops Research Station, CP3 = University Farm No. 2, CP4 = Sandhills Research Station, P1 = Cline Orchard, M1 = Sutton Orchard, M2 = Massie Orchard, and M3 = Mountain Horticultural Crops Research Station.

[x] Values with the same letter within a mycelial type and disease measure are not different from one another but are significantly different ($P = 0.05$) from all others within that type and measure based on the Waller-Duncan k-ratio t test.

[y] Incidence of disease as the percentage of fruit infected with the mycelial type at the last sample date.

[z] Severity of disease as the percentage of apple surface area covered with the mycelial type at the last sample date.

Table 3. The incidence and severity of the mycelial types of *Gloeodes pomigena* at eight locations in North Carolina in 1987

	Mycelial type[x]							
	Fuliginous		Punctate		Ramose		Rimate	
Location[w]	I[y]	S[z]	I	S	I	S	I	S
CP1	48 cd	0.94 d	100 a	57.50 a	96 a	6.65 b	28 c	0.35 c
CP2	16 e	0.79 d	8 c	0.04 c	100 a	3.68 c	0 e	0.00 c
CP4	96 a	26.57 a	12 c	1.17 c	100 a	17.45 a	12 de	0.05 c
P1	28 e	20.90 b	96 a	15.19 b	28 b	0.11 d	0 e	0.00 c
M1	60 bc	7.29 c	100 a	54.67 a	4 c	0.03 d	68 b	1.12 b
M2	32 de	0.62 d	68 b	5.31 c	0 c	0.00 d	16 cd	0.44 c
M3	76 ab	4.78 cd	100 a	51.04 a	8 c	0.06 d	96 a	6.32 a

[w] CP1 = Isaac Rascoe Orchard, CP2 = Central Crops Research Station, CP4 = Sandhills Research Station, P1 = Cline Orchard, M1 = Sutton Orchard, M2 = Massie Orchard, and M3 = Mountain Horticultural Crops Research Station.

[x] Values with the same letter within a mycelial type and disease measure are not different from one another but are significantly different ($P = 0.05$) from all others within that type and measure based on the Waller-Duncan k-ratio t test.

[y] Incidence of disease as the percentage of fruit infected with the mycelial type at the last sample date.

[z] Severity of disease as the percentage of apple surface area covered with the mycelial type at the last sample date.

Table 4. Correlation coefficients of the incidence of the mycelial types of *Gloeodes pomigena* with environmental variables at sites CP2, CP3, CP4, and M3 in 1986 and CP1, P1, M1, M2, and M3 in 1987

Environmental variable[v]	Incidence of mycelial type[w]				
	IOVRL[x]	P	RA	F	RI
TMIN					
Lag21[y]	−0.12	−0.31	0.77**[z]	−0.13	−0.27
Lag28	−0.18	−0.02	0.83**	−0.05	−0.29+
Lag35	−0.33	0.02	0.86**	−0.05	−0.31
Lag42	−0.28	−0.02	0.86**	−0.18	−0.38+
TMAX					
Lag21	−0.15	−0.35+	0.62**	−0.06	−0.23
Lag28	−0.44	−0.05	0.58*	0.01	−0.17
Lag35	−0.02	0.06	0.63*	0.03	−0.15
Lag42	−0.02	−0.06	0.72**	−0.05	−0.24
RN					
Lag21	0.20	−0.04	0.11	−0.05	−0.05
Lag28	0.30	−0.18	−0.03	−0.01	−0.11
Lag35	0.38	−0.45	−0.06	−0.01	−0.21
Lag42	0.39	−0.41	−0.16	0.02	−0.09
AMT					
Lag21	0.36	0.02	0.30+	−0.19	−0.08
Lag28	0.61+	0.01	0.22	−0.12	−0.14
Lag35	0.68+	−0.22	0.35	−0.20	−0.23
Lag42	0.76*	−0.24	0.15	−0.21	−0.23
RH100					
Lag21	−0.21	0.68**	−0.15	0.02	0.13
Lag28	0.28	0.62*	0.18	0.09	0.14
Lag35	−0.44	0.55	0.33	0.01	0.10
Lag42	−0.43	0.59	0.24	−0.03	0.10
RH95					
Lag21	−0.11	0.80**	−0.27	0.17	0.25
Lag28	0.47	0.85**	0.08	0.25	0.26
Lag35	−0.33	0.79**	0.36	0.13	0.20
Lag42	−0.31	0.82**	0.24	0.13	0.23+
RH90					
Lag21	0.05	0.84**	−0.36*	0.24	0.33+
Lag28	0.73*	0.90**	−0.03	0.28	0.32+
Lag35	−0.25	0.87**	0.37+	0.15	0.28
Lag42	−0.20	0.94**	0.23	0.25	0.36+

[v] TMIN = mean daily minimum temperature, TMAX = mean daily maximum temperature, RN = days with rain, AMT = amount of rain, RH100 = hours of relative humidity at 100%, RH95 = hours of relative humidity ≥ 95%, and RH90 = hours of relative humidity ≥90%.
[w] P = punctate, RA = ramose, F = fuliginous, and RI = rimate.
[x] Overall incidence of *G. pomigena*.
[y] Environmental data for the period 21, 28, 35, and 42 days prior to disease sample period.
[z] + = ($P = 0.10$), * = ($P = 0.05$), and ** = ($P = 0.01$).

TMIN for Lag28 and Lag42 (Table 4). The incidence of this type was significantly positively correlated to RH90 for Lag21, Lag35, and Lag42 (Table 4). The severity of the rimate mycelial type was weakly negatively correlated with temperature and measure of rainfall, and positively correlated with measures of relative humidity. The correlation was significant only for AMT for Lag35 ($P = 0.10$) (Table 5).

Correlation coefficients for correlation between the change in sooty blotch incidence and severity between sample dates and the environmental variables for the same periods and Lag21, Lag28, Lag35, and Lag42 were similar in size and level of significance to the results of the correlation analyses presented above, and therefore are not given. There were two exceptions. The severity of the ramose mycelial type was positively correlated to the three measures of relative humidity and significant for Lag21 ($P = 0.010$), Lag28 ($P = 0.01$), Lag35 ($P = 0.05$), and Lag42 ($P = 0.05$). The incidence of the punctate mycelial type was positively associated with AMT, but the correlation was significant only for Lag21 ($P = 0.10$).

DISCUSSION

The incidence of *G. pomigena* approached 100% in all orchards that were not treated with fungicides and which experienced sufficient rain and humidity for fungal development. The overall incidence of disease was correlated weakly with most environmental variables. Disease incidence was correlated with the amount of rainfall which occurred 28, 35, and 42 days prior to each sample date and the number of hours of humidity ≥90% that occurred 28 days prior to the sample date. Colby (2) reported that sooty blotch appeared during the latter part of the growing season except when rainfall was scarce during that period.

Baines and Gardner (1) found that *G. pomigena* grew slowly at temperatures above 27 C and humidities less than 90%. Disease development was best at 20 C and almost nonexistent at 30 C (1). Overall sooty blotch severity decreased with increasing temperature in our study, although the correlation was significant only for the 21-day period prior to the sample date. In addition, Baines and Gardner (1) found growth to be best at humidities of 95% and above, dropping off rapidly below 95%, with no growth at 85 and 86%. However, we found disease severity to be positively correlated with both the hours of humidity of 95% or greater (RH95) (21 and 28 days prior to sampling) and the hours of humidity of 90% and greater (RH90) at all times. The severity of *G. pomigena* was highest at site M3, a location which experiences frequent fog and dew. Severity of disease was also high at sites CP1 and M1 in both years. Humidity is consistently high at site CP1, and site M1 experiences conditions similar to those of site M3, although fog is not as abundant in this region of the North Carolina Mountains. The sites located in the western Coastal Plain and the site in the Piedmont consistently maintained the lowest severities of disease. These locations encounter less fog, lighter dews, and somewhat lower humidities.

Increasing temperature negatively affected the incidence and severity of the punctate mycelial type. The growth and development of this mycelial type was positively correlated with the hours of relative humidity at or above 90, 95, and 100%. The punctate type was most abundant and severe at sites CP1 and M3, which are characterized by high relative humidities and/or fog. Although temperatures were generally higher at site CP1 (A. L. Sutton, *unpublished*), their negative effect was apparently overcome by average humidities greater than those found at the majority of sites tested.

In contrast to the growth response of the punctate type, incidence and severity of the ramose type increased with increasing temperatures and generally decreased with increasing hours of high relative humidities. However, correlations with the actual change in severity among sample dates indicated a positive association with high humidities. The incidence and severity of the ramose mycelial type was greatest at locations in the Coastal Plain, as these sites have the highest temperatures, intermittent heavy rainfalls, and consistently high humidities.

The incidence and severity of the fuliginous mycelial type was not strongly associated with any of the environmental factors monitored, although there was a general positive association with temperature and a negative association with all wetness variables. There was no clear association of the incidence and severity of this mycelial type with any geographic region in North Carolina.

The rimate mycelial type was the least prevalent at all locations. The incidence

Table 5. Correlation coefficients of the severity of the mycelial types of *Gloeodes pomigena* with environmental variables at sites CP2, CP3, CP4, and M3 in 1986 and CP1, P1, M1, M2, and M3 in 1987

Environmental variable[v]	Severity of mycelial type[w]				
	SOVRL[x]	P	RA	F	RI
TMIN					
Lag21[y]	−0.30[+z]	−0.49**	0.59**	0.01	−0.23
Lag28	−0.30	−0.45*	0.57**	0.13	−0.21
Lag35	−0.27	−0.49**	0.61**	0.16	−0.25
Lag42	−0.27	−0.50**	0.65**	0.13	−0.28
TMAX					
Lag21	−0.29+	−0.45**	0.49**	0.09	−0.18
Lag28	−0.27	−0.37*	0.42*	0.18	−0.11
Lag35	−0.24	−0.39*	0.44*	0.21	−0.12
Lag42	−0.23	−0.46*	0.53**	0.21	−0.19
RN					
Lag21	−0.15	0.02	0.09	−0.10	−0.10
Lag28	−0.12	0.09	0.05	−0.07	−0.12
Lag35	−0.15	0.01	0.17	−0.08	−0.22
Lag42	−0.16	0.10	0.08	−0.11	−0.16
AMT					
Lag21	−0.10	−0.13	0.16	−0.10	−0.20
Lag28	−0.01	−0.03	0.14	−0.12	−0.24
Lag35	−0.05	−0.13	0.32+	−0.19	−0.32+
Lag42	−0.09	−0.03	0.25	−0.22	−0.32
RH100					
Lag21	0.16	0.22	−0.32+	0.01	0.21
Lag28	0.25	0.08	−0.19	−0.02	0.16
Lag35	0.19	0.01	−0.11	−0.10	0.14
Lag42	0.17	0.08	−0.17	−0.16	0.18
RH95					
Lag21	0.29+	0.41*	−0.50**	0.05	0.22
Lag28	0.37+	0.31	−0.39+	−0.01	0.15
Lag35	0.30	0.21	−0.27	−0.13	0.13
Lag42	0.30	0.29	−0.34	−0.18	0.17
RH90					
Lag21	0.39*	0.55**	−0.58**	−0.01	0.18
Lag28	0.44*	0.48*	−0.46*	−0.13	0.09
Lag35	0.38+	0.42*	−0.32	−0.32	0.06
Lag42	0.41+	0.51**	−0.44*	−0.31	0.12

[v] TMIN = mean daily minimum temperature, TMAX = mean daily maximum temperature, RN = days with rain, AMT = amount of rain, RH100 = hours of relative humidity at 100%, RH95 = hours of relative humidity ≥ 95%, and RH90 = hours of relative humidity ≥90%.
[w] P = punctate, RA = ramose, F = fuliginous, and RI = rimate.
[x] Overall incidence of *G. pomigena*.
[y] Environmental data for the period 21, 28, 35, and 42 days prior to disease sample period.
[z] + = ($P = 0.10$), * = ($P = 0.05$), and ** = ($P = 0.01$).

and severity of this type were not strongly correlated to the environmental factors examined, although they were weakly negatively correlated to temperature and positively correlated to measures of relative humidity. Because the rimate mycelial type has been reported to penetrate the surface of the cuticle, it is possible that environmental conditions affect its severity less than the severity of the other mycelial types.

Groves (3) found that the ability of isolates of *G. pomigena* to grow at different temperatures varied only slightly among isolates, and that there was no correlation between these differences and the mycelial type of the isolate. In a laboratory study using one isolate per type, Hickey (5) found that the growth of the ramose, punctate, and fuliginous types responded similarly to different temperatures (5). In this study, we found that the punctate type decreased with increasing temperature, the ramose type increased, and there was no consistent effect of temperature on the fuliginous or rimate types. These seemingly conflicting results between laboratory studies and our study may be explained by the small sample size used in the laboratory studies, as isolates of *G. pomigena* exhibit wide variation in growth even within the same mycelial type. Alternatively, the significant correlations we obtained may reflect the confounding of temperature effects with other environmental variables.

In the study by Groves in 1933 (3), the ramose mycelial type was most abundant, comprising approximately 80% of all thalli observed. The most prevalent type seen in our study at the majority of sites was punctate, with the ramose type predominating only in some sites in the Coastal Plain (CP2 and CP4, 1986, and CP2, 1987). Due to the variation in the response of the mycelial types to environmental conditions, the abundance of the four types would be expected to differ depending on the geographical area under examination.

The different responses of the punctate, ramose, and fuliginous mycelial types to environmental conditions may be an indication that the types themselves possess distinct and fundamental differences. Laboratory studies are needed to confirm the differences in temperature and moisture requirements found in our study. Such distinct differences suggest that the mycelial types of *G. pomigena* may be distinct species. However, the rimate mycelial type is unlikely to receive such a designation, as it consists of any of the other types which penetrate the apple cuticle.

LITERATURE CITED

1. Baines, R. C., and Gardner, M. W. 1932. Pathogenicity and cultural characters of the apple sooty-blotch fungus. Phytopathology 22:937-952.
2. Colby, A. S. 1920. Sooty blotch of pomaceous fruits. Trans. Ill. State Acad. Sci. 13:139-175.
3. Groves, A. B. 1933. A study of the sooty blotch disease of apple and the causal fungus *Gloeodes pomigena*. Va. Agric. Exp. Stn. Bull. 50:1-43.
4. Hesler, L. R., and Whetzel, H. H. 1917. Sooty blotch and fly speck of apple. Pages 104-108 in: Manual of Fruit Diseases. MacMillan Co., NY.
5. Hickey, K. D. 1960. The sooty blotch and fly speck diseases of apple with emphasis on variation within *Gloeodes pomigena* (Schw.) Colby. Ph.D. thesis. Pennsylvania State University, College Park.
6. Kirby, R. S. 1954. Relation of rainfall to occurrence of apple scab and sooty blotch. (Abstr.) Phytopathology 44:495.
7. Rock, G. L., Sorensen, K. A., Skroch, W. A., Unrath, C. R., Ritchie, D. F., Sutton, T. B., Shelton, J. C., and San Julian, C. J. 1986. Agricultural Chemicals for North Carolina Apples. N.C. Ext. Serv. Circ. AG37.
8. SAS Institute. 1985. SAS User's Guide: Statistics. Version 5 ed. SAS Institute, Cary, NC.
9. Wiser, E. H., Young, J. H., and Harris, P. E. 1978. Microcomputer based data acquisition system. Pap. 78-5546, Am. Soc. Agric. Eng., St. Joseph, MI.