Dispersal of Conidia of *Zygophiala jamaicensis* in Apple Orchards

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ABSTRACT

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Conidia of *Zygophiala jamaicensis*, the causal agent of flyspeck, were trapped in apple (*Malus domestica*) orchards or near reservoir inoculum sources from late May or early June through harvest (mid-September). Hourly spore concentrations were positively correlated with temperature and windspeed and negatively correlated with relative humidity and leaf wetness. Conidia concentration in the air was characterized by a distinct diurnal periodicity; most conidia were trapped between 0700 and 1300 hours. Fruit infections were usually observed about 1 mo after the first conidia were trapped. Management practices for flyspeck in apple orchards need to account for the presence and abundance of reservoir hosts, environmental conditions, orchard management strategies, and fungicide choice and timing.

Flyspeck (caused by *Zygophiala jamaicensis* Mason; teleomorph, *Schizothyrium pomi* [Mont. & Fr.] Arx), is one of the most important diseases of apples (*Malus domestica* Borkh.) in the southeastern United States. *Z. jamaicensis* overwinters on apple twigs and on numerous reservoir hosts (2,9). Ascospores mature in late spring and initiate primary infections on apples and reservoir hosts. Conidia, produced from primary infections, initiate secondary cycles throughout the growing season. Numerous reservoir hosts are sources of inoculum. *Rubus* spp. are the most abundant reservoir hosts in North Carolina, however, at least 37 additional hosts have been identified (9).

Control of flyspeck is based on the application of protectant fungicides applied at 10- to 14-day intervals. Not all fungicides registered for flyspeck control are equally effective against *Z. jamaicensis*. For instance, the ethylenebis[dithiocarbamate] (EBDC) fungicides are much more effective than captan (1); however, captan is often preferred because it provides better fruit finish early in the season and is more active against white rot (caused by *Botryosphaeria dothidea* [Moug. ex Fr.] Ces. & De Not.) and black rot (caused by *Botryosphaeria obtusa* [Schwein.] Shoemaker). Consequently, growers are often faced with the problem of knowing in what periods the likelihood of infection are greatest and deciding when to initiate a program for control of flyspeck. Knowledge of periods of inoculum availability would help growers decide when to be most concerned about the possibility of infection. Thus, the objective of this study was to determine periods of spore production and release and to investigate the environmental variables favoring spore release.

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MATERIALS AND METHODS

Spore trapping studies. Airborne conidia of *Z. jamaicensis* were monitored with Burkard volumetric spore traps (Burkard Scientific Sales, Ltd., Rickmansworth, Hertfordshire, England) at five locations in North Carolina: at the edge of a patch of blackberry (*Rubus argutus* Link) (Pope82) from 1 May to 3 September 1982; at the edge of a patch of blackberry adjacent to a commercial orchard (Laughter81) from 2 June to 29 September 1981 and MHCRS82 from 15 May to 15 September 1982; and in the edge of a research orchard (CCRS81) from 27 May to 5 October 1981 and Nesbitt84 from 16 May to 31 August 1984. Each site was located approximately 10 m from blackberries and other (9) reservoir hosts. CCRS and MHCRS refer to the Central Crops Research Station in Clayton and the Mountain Horticultural Crops Research Station in Fletcher, respectively. Pope82 and CCRS81 are located in Wake County, MHCRS82 and Laughter81 in Henderson County, and Nesbitt84 in Haywood County.

Traps were placed on the ground with their orifices approximately 40 cm above the ground except for the trap at CCRS81, which was placed in the canopy of a tree about 2 m above the ground. Traps were adjusted to sample 10 L of air per minute. Tapes from the trap were cut into 48-mm sections, mounted on a glass slide, and spores were stained with cotton blue in lactophenol and counted at ×250 by making one traverse (0.70 mm field diameter) through the center of each hourly exposure.

Temperature and relative humidity (RH) were monitored at each location with a hygrothermograph located in a standard weather shelter. Rainfall was measured with a top-weighing, recording rain gauge. Leaf wetness at CCRS81, MHCRS82, and Pope82 was measured with a DeWit wetness meter (Valley Streams Farm, Orano, Ontario). Windspeed was measured at MHCRS with an automatic weather system (10) located approximately 0.5 km from the orchard site.

Measurements of disease incidence and severity. The percentage of fruit infected with *Z. jamaicensis* and the number of colonies on infected fruit were determined in unsprayed portions of the orchards at CCRS and MHCRS. At

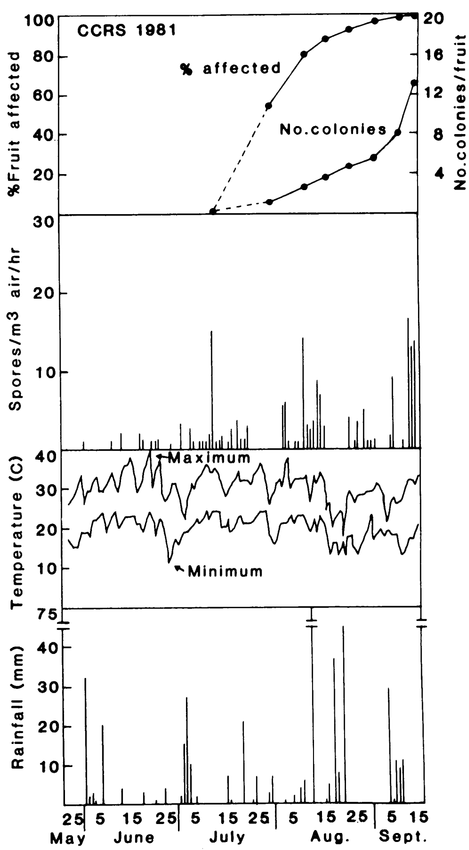

Fig. 1. Percent of fruit infected with *Zygophiala jamaicensis*, the number of colonies per fruit, concentration of airborne conidia, and temperature and rainfall for CCRS81 from 27 May to 15 September 1981. Spore trap data for 30-31 August are missing.

CCRS in 1981, 25 fruit on each of four trees were chosen arbitrarily to represent the various locations within the tree, tagged, and observed weekly for disease. At MHCRS in 1982, 25 fruit were chosen arbitrarily, tagged on each of four trees, and examined every 2–3 wk. The orchards Nesbitt84 and Laughter81 received standard fungicide sprays. There was no orchard near Pope82.

Data analysis. The relationship among the hourly environmental variables and conidia catch was examined by linear correlation analysis with the Statistical Analysis System (8). Analyses were performed on days with complete data for the period of 30 June to 17 August at Laughter81, 16 June to 15 September at MHCRS82, and for the 10 days with the greatest spore catch at Laughter81, MHCRS82, and Pope82.

RESULTS

The first conidia of *Z. jamaicensis* were trapped in late May to early June at all locations (Figs. 1–5). There was a general increase in density of airborne conidia through the growing season at CCRS81 and Nesbitt84; at Pope82 there was a slight decline through the season. There was no seasonal trend at Laughter81 or MHCRS82. Greatest conidial concentrations were found at Laughter81 where hourly concentrations averaged almost 300 conidia per m^3 of air sampled on 26 July. Conidia were generally trapped throughout the season although numbers were often lower during periods without rainfall. For instance, conidial concentrations were low in June 1981 at CCRS (Fig. 1), in late August 1981 at Laughter (Fig. 2), and in June 1984 at Nesbitt (Fig. 5). However, conidial concentrations were not greatly diminished at MHCRS in 1982 during dry weather in late August and early September (Fig. 3).

Peak conidial catch occurred between 0700 and 1300 hours; few spore were trapped between 1500 and 0400 hours (Fig. 6).

Correlations between meteorological variables and conidial concentrations were greatest when the natural log transformation of conidial concentration was used. The hourly conidia concentration was positively correlated ($P = 0.05$) with hourly temperature and windspeed and negatively correlated ($P = 0.05$) with relative humidity and leaf wetness (Table 1). There was no significant correlation with rainfall. The correlation coefficients increased when data from the 10 days of highest conidial concentration were used in the analysis; however, the general relationships between the spore concentration and the meteorological variables measured were similar to those obtained for the complete data set (Table 1).

Colonies of *Z. jamaicensis* were usually observed on fruit approximately 1 mo after the first conidia were trapped. Fruit infections at CCRS81 were observed first in mid-July, and incidence increased to about 90% by mid-August

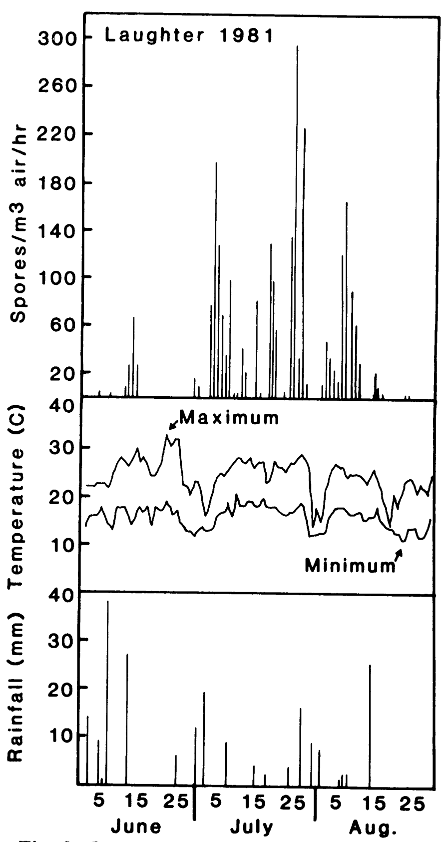

Fig. 2. Concentration of airborne conidia of *Zygophiala jamaicensis* and temperature and rainfall for Laughter81 from 2 June to 30 August 1981. Spore trap data for 1 June and 15–22 June are missing.

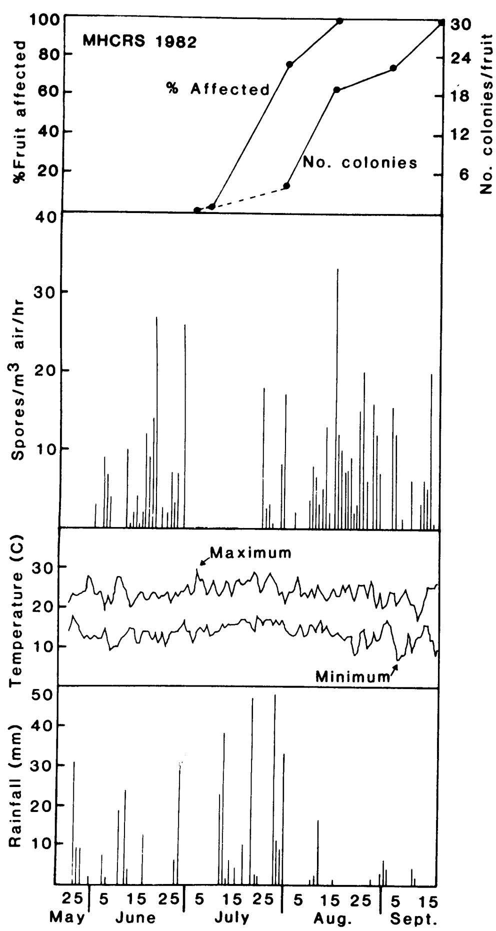

Fig. 3. Percentage of fruit infected with *Zygophiala jamaicensis*, number of colonies per fruit, concentration of airborne conidia, and temperature and rainfall for MHCRS82 from 20 May to 15 September 1982. Spore trap data for 28 June–13 July and 21–22 July are missing.

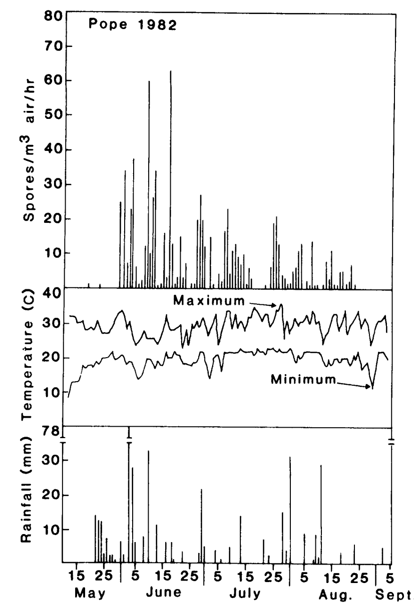

Fig. 4. Concentration of airborne conidia of *Zygophiala jamaicensis* and temperature and rainfall for Pope82 from 10 May to 3 September 1982. Spore trap data for 23–29 May are missing.

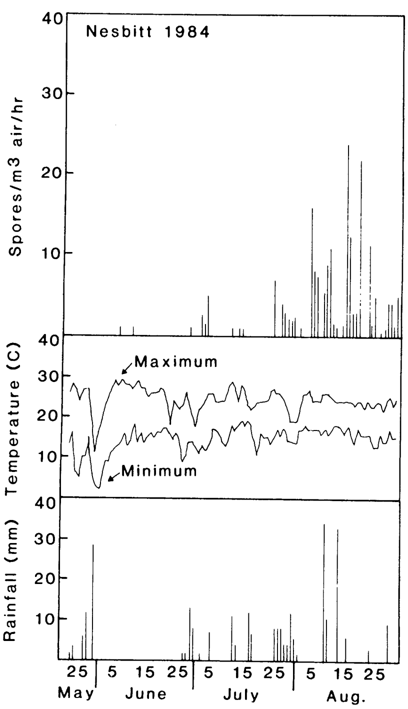

Fig. 5. Concentration of airborne conidia of *Zygophiala jamaicensis* and temperature and rainfall for Nesbitt84 from 20 May to 31 August 1984. Spore trap data for 24–29 May are missing.

(Fig. 1). Number of infections increased from a mean of approximately one per fruit in early August to almost six per fruit by the end of August. At MHCRS82 (Fig. 3), fruit infection was observed first on 7 July, and by mid-August 100% of the fruit were infected. The number of colonies per fruit increased from a mean of approximately three in early August to almost 30 by mid-September.

DISCUSSION

Environmental variables affecting dispersal of conidia of *Z. jamaicensis* in apple orchards were similar to those reported in a banana plantation (5). Airborne concentrations of conidia were reduced by free water (leaf wetness) and high relative humidity and were characterized by a distinct diurnal periodicity. Meredith (5) found that airborne conidia concentrations of *Z. jamaicensis* increased following rains; however, a similar trend was not observed in this study. Spore concentrations were lowest during prolonged periods without rain. The exception to this occurred at MHCRS82 where spores continued to be trapped during mid-August and early September when rainfall was light. Heavy fog is common at this location in the mornings in the late summer, and it is probable that sufficient moisture was present for production of conidia. Ocamb-Basu and Sutton (6) found that conidia were produced at relative humidities greater than 96%.

Conidia were not trapped until late May to early June, which is 4–6 wk after full bloom in North Carolina. Although the exact time of primary infection has never been determined, pseudothecia of *S. pomi* mature in North Carolina from early to mid-April to mid-May (T. B. Sutton and C. M. Ocamb-Basu, *unpublished*). Because colonies become visible within 10–12 days under optimum conditions, infections from ascospores in late April or early May could result in colonies capable of producing conidia in late May. Infections of *Z. jamaicensis* on apple fruit have been observed as early as mid-May (E. M. Brown and T. B. Sutton, *unpublished*). Secondary infections by conidia are probably much more important than primary infection by ascospores in disease development through the season. Ascospores are produced only in a distinct period during the spring, but abundant conidia are produced on lesions on reservoir hosts and apple fruit (C. M. Ocamb-Basu, *unpublished*, [3]) through the growing season. Consequently, control of secondary infection should be the focus of disease management programs for flyspeck.

Management strategies for flyspeck need to take into account the presence and abundance of reservoir hosts, environmental conditions, orchard management, and fungicide choice and timing. The potential for disease occurrence is greater in orchards surrounded by reservoir hosts. The large number of spores trapped in proximity to reservoir hosts in this study is evidence of their importance. It may not always be possible to remove many tree species, but *Rubus* spp., which are the most widespread hosts, can be mowed in ditchbanks and orchard borders. Optimum conditions for disease development are temperatures ranging from 16 to 24 C and wet conditions or relative humidities of 96% or greater (6). Thus, the potential for disease development is greatest in orchards in warmer and wetter growing regions and in orchards on slow-drying sites or in valleys in which fog and dew persist in the morning (3). Cultural practices such as pruning can significantly reduce flyspeck incidence and severity in some seasons (4,7) and are an important component of a management program for flyspeck.

In this study, secondary inoculum was trapped at most sites by 4–6 wk after full bloom. This is additional evidence of the need to initiate a fungicide control program for flyspeck by second or third cover in North Carolina. A similar situation is likely to occur in other southeastern apple-growing regions of the United States. In eastern and midwestern apple-growing regions of the United States where temperatures and moisture conditions are less favorable for disease development, controls may not be necessary until mid- or late-season.

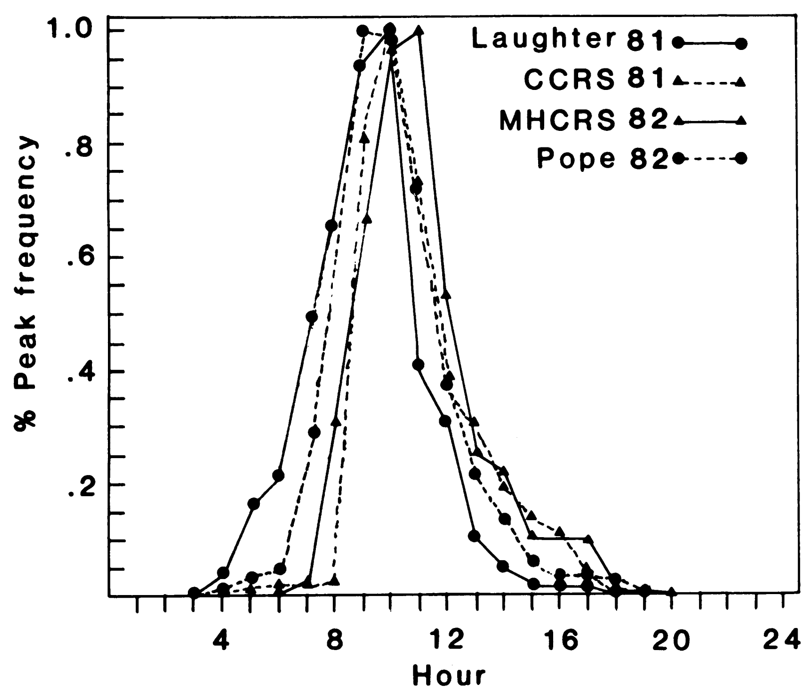

Fig. 6. Percentage peak frequency of airborne conidia trapped at Laughter81, CCRS81, MHCRS82, and Pope82. See text for dates conidia were trapped at each location.

Table 1. Correlation coefficients between weather variables and natural logarithm (number of airborne on conidia + 1) of *Zygophiala jamaicensis* per hour for the season[a] and the 10 days of peak spore trap catch at Laughter81 and MHCRS82, and for the 10 days of peak catch at Pope82

	Variables[b]				
Orchard	**Temp.**	**RH**	**Rainfall**	**LW**	**WS**
Laughter81					
Season	0.16	−0.22	0.02	···	···
(N = 804)	**[c]	**	NS		
10 days	0.35	−0.32	0.05	···	···
(N = 238)	**	**	NS		
MHCRS82					
Season	0.23	−0.12	−0.01	−0.27	0.27
(N = 1,212)	**	**	NS	**	**
10 days	0.46	−0.23	−0.05	−0.50	0.35
(N = 240)	**	**	NS	**	**
Pope82					
10 days	−0.02	−0.16	−0.08	−0.20	···
(N = 236)	NS	**	NS	**	

[a]See text for dates.
[b]Temp. = temperature (C), RH = relative humidity, Rainfall = rainfall in mm, LW = leaf wetness, WS = windspeed.
[c]NS = nonsignificant, ** = significant at $P = 0.01$, * = significant at $P = 0.05$.

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