Analysis of Factors Affecting Dispersal of *Podosphaera leucotricha* Conidia

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ABSTRACT

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Dispersal of conidia of *Podosphaera leucotricha* was monitored in the summers of 1973 and 1974 with a Burkard recording volumetric spore trap or a Kramer-Collins spore sampler. Dispersal was diurnal with peak concentration in early afternoon and a distinct subsidiary peak after dark. The concentration of conidia in the air was associated positively with wind velocity, temperature, and solar radiation and negatively with relative humidity and leaf wetness. Three general patterns of spore dispersal were observed: spore dispersal highly correlated with environmental variables, spore dispersal with little or no correlation with the environmental variables, and dispersal during rainfall.

Additional key words: apple powdery mildew, epidemiology.

Powdery mildew, caused by *Podosphaera leucotricha* (Ell. and Ev.) Salm., is a serious disease of apples in the Northeast and North Central United States. In the spring, airborne conidia produced by overwintered mycelium in infected buds initiate infections. Secondary infections occur through the summer until vegetative growth stops.

Factors that affect dispersal of conidia have been studied in England (1–6), Czechoslovakia (11), Poland (7), and New Zealand (9). Spore release generally is diurnal, with a secondary peak after dark (1,7,11,12). Relative humidity, wind, and rainfall have the greatest influence on spore dispersal. High relative humidity favors sporulation but not spore release. Release of conidia increases linearly with wind speeds of 1.7–5.0 mph, and rainfall is generally unfavorable for dispersal (1,4,7,11). The relationship to temperature has not been well characterized but temperatures greater than 20 C are thought to favor release of conidia (11).

This study was done to confirm in Michigan previous findings on the relationship between certain environmental conditions and the dispersal of *P. leucotricha* conidia and to characterize the relationships through multiple regression and correlation analyses.

MATERIALS AND METHODS

Airborne conidia of *P. leucotricha* were trapped from 10 May to 24 August 1973 in a commercial orchard of 25 yr old Jonathan apple trees in southwest Michigan and from 22 June to 5 October in a block of 21 yr old Jonathan trees at the Graham Experiment Station in Grand Rapids, MI. At the southwest site, a Kramer-Collins spore sampler (G. R. Manufacturing Co., Manhattan, KS) was placed just outside the drip line of a heavily infected tree. The trap was 2 m above ground level; the trap intake was fitted with a copper extension tube directed toward a group of infected shoots about 0.5 m away. The trap was adjusted to sample 22.5 L of air per minute for five of every 15 min. Temperature, relative humidity, and wind speed levels were obtained from a weather station 14 km away at the Donald C. Cook Nuclear Plant Environmental Impact Network. Leaf wetness was determined with a deWit 7-day recording leaf wetness meter placed 1.5 m above ground level in the drip line of the tree.

In 1973 at the Grand Rapids site, conidia dispersal was monitored from 26 July to 30 August with a Burkard 7-day recording volumetric spore trap (Burkard Scientific Sales Limited, Rickmansworth, Hertfordshire, England) that was about 2 m above ground level in the crown of an unsprayed tree. Temperature and relative humidity were measured with a 7-day recording hygrothermograph 1.5 m above ground level in a standard instrument shelter. Leaf wetness was measured with a deWit leaf wetness recorder placed 2 m above ground level in the drip line of an apple tree. The instruments were about 400 m from the trap. Wind velocity data were from the Grand Rapids Airport, about 16 km away.

In 1974 conidia were trapped at Grand Rapids from 15 May to 28 June with a Kramer-Collins spore sampler and from 29 June to 30 August with a Burkard trap. The traps were in the same area of the orchard in 1973 and 1974. In 1974 the Kramer-Collins sampler was fitted with a rotary-vane intake adapter (G. R. Manufacturing Co., Manhattan, KS) to direct the intake toward the wind. Temperature and relative humidity at 1.5 m above ground level, rainfall at ground level, and wind run in the midcanopy region of the apple trees were measured by an automatic weather station about 400 m from the trapping site. A mechanical pyranograph measured solar radiation.

Spore counts from the Kramer-Collins samplers were made by counting all conidia in each hourly band. Hourly counts of conidia caught by the Burkard trap were made by treating the Milinex tape from the trap with Meltzers reagent (13) and traversing the tape at 2-mm intervals. Counts from the Burkard traps were corrected to compensate for the area sampled, and counts from the Kramer-Collins traps were corrected for the length of the sampling period. Counts were recorded as the number of conidia per cubic meter of air sampled per hour.

The relationship of specific environmental factors to spore concentrations was determined by visual inspection of plots of the data and by correlation and multiple regression analyses. Correlation and multiple regression analyses were used to relate hourly spore concentrations to the environmental variables monitored for June 1973 at southwest Michigan, July 1973 at Grand Rapids, and June and July 1974 at Grand Rapids. Correlations were also analyzed on individual days with complete data during June and July 1974 at Grand Rapids, and stepwise

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regression (8) was used to evaluate the effect of possible two-factor interactions of the environmental variables on spore concentrations.

RESULTS

In 1973 at the southwest Michigan site, the concentration of powdery mildew conidia increased rapidly during the latter part of May and remained relatively high through June (Fig. 1). At the Grand Rapids site in 1973, the highest concentrations of conidia occurred from early July to mid-August (Fig. 1). The greatest concentration occurred on 24 July when 375 conidia per cubic meter of air per hour were recorded.

During the 1974 season at Grand Rapids, spore concentrations in the air increased through June and remained high during July (Fig. 1). The highest concentrations of conidia occurred during the first week in July.

In 1973 at both trapping sites, daily spore catch was mostly diurnal (Fig. 2). At the southwest Michigan site, peak catch occurred at 1400–1500 hours with a distinct subsidiary peak at 2000–2100 hours. At the Grand Rapids site, peak catch occurred at 1800 hours, although conidia were equally abundant from 1300 to 1700 hours. In 1974 at Grand Rapids, the diurnal periodicity was not as distinct and peak catch occurred at 2300 hours.

The natural log of hourly spore concentrations was correlated positively with temperature, wind, and solar radiation (July 1974 only) and correlated negatively with relative humidity, leaf wetness from rain, and leaf wetness from fog, dew, or rain at the three locations (Table 1). The relationship of $\log_e$ spore concentration to the rainfall amount was negative and insignificant.

Visual inspection of daily plots of spore concentration and environmental factors and correlation analyses of daily data demonstrated three general patterns or types of spore dispersal. Type 1 dispersal is represented in Fig. 3., with spore concentrations generally diurnal, increasing in the morning after the leaves dried and remaining high until 2000–2200 hours. Temperature, wind speed, and solar radiation usually were highest and relative humidity lowest during midday. The $\log_e$ of the spore concentration usually was correlated with three to six of the

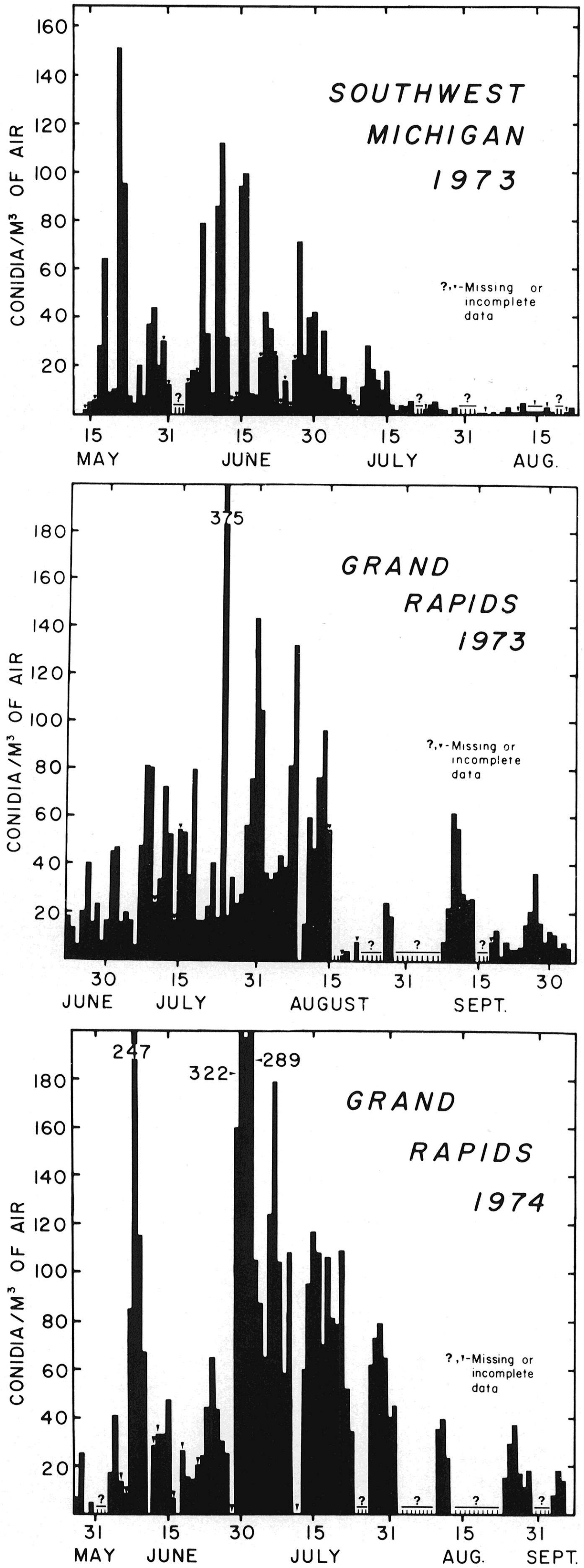

Fig. 1. Mean hourly counts (per cubic meter of air per hr) of conidia of *Podosphaera leucotricha* for 10 May to 24 August 1973 in southwest Michigan (top), 22 June to 5 October 1973 (middle), and 26 May to 30 August 1974 (bottom) at Grand Rapids, MI.

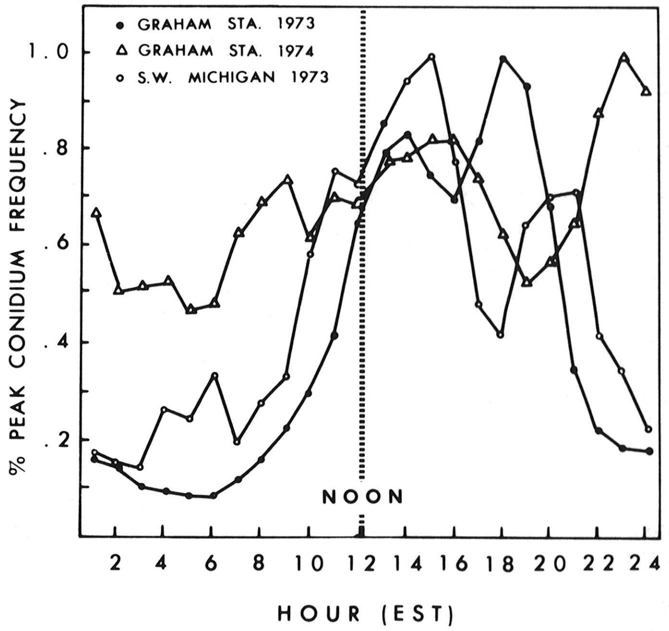

Fig. 2. Mean hourly concentrations of airborne conidia of *Podosphaera leucotricha*. Conidium frequency is expressed as a percentage of the peak arithmetic mean frequency for the periods: 10 May to 24 August 1973 in southwest Michigan, 22 June to 5 October 1973, and 26 May to 30 August 1974 at the Graham Station in Grand Rapids, MI.

environmental variables (17–21 July, Table 2). This type of day occurred about 55% of the time.

Type 2 dispersal is represented in Fig. 4. On these days the environmental conditions were similar to those during type 1 days, but spores were abundant throughout the day with no discernable periodicity. Correlations with the environmental variables were generally not significant (15 and 16 July, Table 2). These days occurred about 35% of the time.

In many type 1 and type 2 days, stepwise regression identified one or more of the two-factor interactions of the environmental variables that significantly correlated with $\log_e$ spore concentration. Specific interactions that were significant varied greatly from day to day, however, and no consistent interactions that influence spore concentration could be identified.

Type 3 release was associated with rainfall. When rainfall began, spore concentration in the air usually increased significantly but, with continuing rain, declined rapidly and remained low. For example, spore concentrations per cubic meter of air in the hours before, during, and after the rain began on 8 June 1974 at Grand Rapids were 159, 7, 114, and 373, respectively.

DISCUSSION

These results in Michigan confirm many of the findings on dispersal of apple powdery mildew conidia in other countries. As previously reported (4,5), high relative humidity was unfavorable and increasing wind speed was favorable for conidia dispersal. The relationship to rainfall was similar to that noted by others (1,7,11). The puff or splash dispersal at onset on rain that we observed with *P. leucotricha* conidia was characteristic of many dry air spores (10), as was the subsequent washing or scrubbing effect with continued rainfall. We confirmed Molnar's (11) findings that warm temperatures were more favorable than low temperatures for spore dispersal. In all three trapping locations, temperature was significantly correlated positively with $\log_e$ spore concentration. During July 1974 at Grand Rapids, solar radiation also had a positive influence on spore concentration. Because the effects of temperature, solar radiation, and relative humidity were often confounded, the relationship of spore concentration to temperature and solar radiation may not be significant. In fact, sunshine might have a greater influence on spore production (2). In this study, leaf wetness from fog, dew, or rain reduced spore concentrations; the reduction from leaf wetness from rain was greater than that from light dew or fog.

The diurnal periodicity of conidia concentration reported previously (3,7,11,12) also was characteristic of our data, as was the secondary peak described by Burchill (3).

Although our study and others show that certain meteorologic factors have a definite influence on spore concentrations in the air, the influence of type 2 days described in this study indicates that some factors affecting spores release and dispersal still are not clearly understood. Perhaps we are not measuring certain important factors or are not correctly measuring others. For instance, wind speed or wind run give little indication of gustiness or turbulence, both of which could be important in spore release directly or indirectly through shearing associated with leaf abrasion. We interpret the wide variation from day to day in the significance of the two-factor interaction terms in the stepwise regression analyses to mean that, although specific environmental effects are important, their interaction in various combinations may often have the greatest influence on spore dispersal.

TABLE 1. Correlation of $\log_e$ (*Podosphaera leucotricha* conidia concentration +1) with meterologic factors for southwest Michigan in 1973 and for Grand Rapids in 1973 and 1974

	Simple correlation coefficients[a]			
	Southwest MI	Grand Rapids	Grand Rapids	
Meterologic factors	June 1973	July 1973	June 1974[b]	July 1974
Temperature (C)	0.3317**	0.3249**	0.1247**	0.2763**
Relative humidity (%)	−0.2602**	−0.3245**	−0.1680**	−0.3650**
Wind velocity (km/hr)	0.2719**	0.1516**	0.1703**	0.2334**
Rainfall amount (mm)	...	...	−0.0431	−0.0530
Solar radiation[c]	...	...	0.0285	0.2451**
Leaf wetness from rain	−0.2162**	−0.1289**	−0.1182**	−0.2408**
Leaf wetness from rain, fog, or dew	−0.2239**	−0.2458**	−0.1325**	−0.2627**

[a] Asterisks indicate significant correlation coefficients at $P = 0.01$ (**)

[b] An unusually large release at the onset of rain on 8 June at 2300 hours was omitted from this analysis.

[c] gm-cal/cm^2/minute.

TABLE 2. Correlation of $\log_e$ (*Podosphaera leucotricha* conidia concentration + 1) with meterologic factors for 15 July through 21 July 1974 at the Graham Experiment Station. July 15 and 16 are characteristic of type 2 days and July 17 through July 21 of type 1 days

	Simple Correlation Coefficients[a]						
Meterologic factors	July 15	July 16	July 17	July 18	July 19	July 20	July 21
Temperature (C)	0.1069	0.4123*	0.7738**	0.7768**	0.4420*	0.6151**	0.6022**
Relative humidity (%)	−0.1250	−0.3469	−0.7937**	−0.3194	−0.4624*	−0.7303**	−0.4490*
Wind velocity (km/hr)	0.0905	0.3623	0.6989**	0.7563**	0.3796	0.2451	−0.7126**
Rainfall amount (mm)	...	...	...	...	0.1370	...	...
Solar radiation[b]	0.2776	0.1590	0.5817*	0.7562**	0.3809	0.4057*	0.3553
Leaf wetness from rain	...	...	...	...	−0.6456**	...	...
Leaf wetness from rain, fog, or dew	0.0144	−0.1414	−0.6245**	−0.4003*	−0.4863*	−0.7767**	−0.0086

[a] Asterisks indicate significant correlation coefficients at $P = 0.01$ (**) or $P = 0.05$ (*).

[b] gm-cal/cm^2/minute.

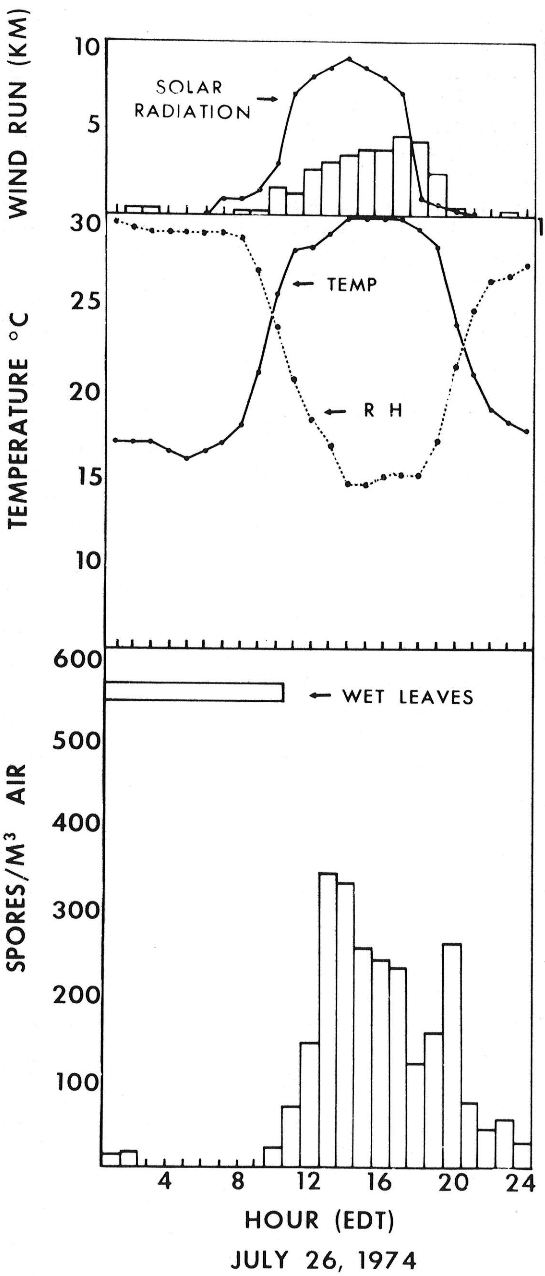

Fig. 3. Concentration of airborne conidia of *Podosphaera leucotricha* in relation to leaf wetness, air temperature, relative humidity, wind run, and solar radiation on 26 July 1974 but characteristic of dispersal (type 1) on about 55% of the days.

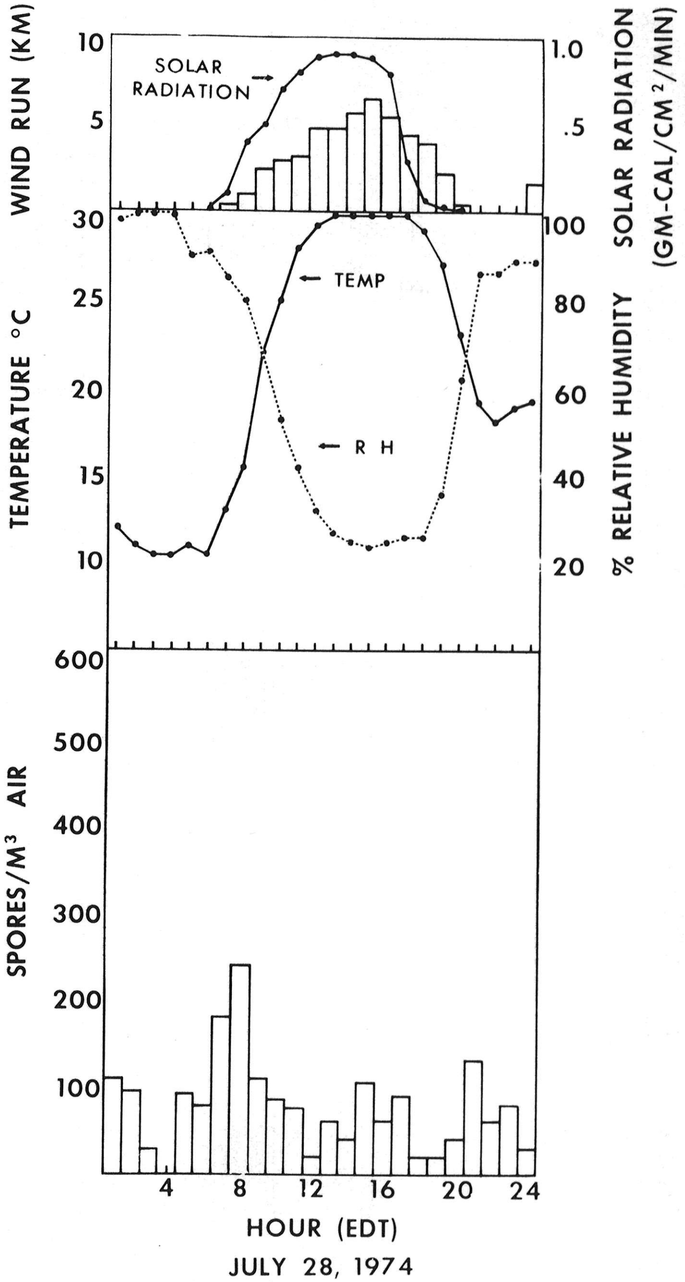

Fig. 4. Concentration of airborne conidia of *Podosphaera leucotricha* in relation to air temperature, relative humidity, wind run, and solar radiation on 28 July 1974 but characteristic of dispersal (type 2) on about 35% of the days.

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