Influence of Environment on Conidial Concentration of *Alternaria porri* in Air and on Purple Blotch Incidence on Onion

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ABSTRACT

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A study was conducted to determine the influence of weather variables on conidial concentration of *Alternaria porri* in air above an onion field in Michigan. Temperature, humidity, leaf wetness, rainfall, solar radiation, wind speed, and concentration of airborne conidia were monitored at the Michigan State University Muck Experimental Farm in 1985 and 1987. Weather instruments and spore trap were placed in the center of an unsprayed 15- × 30-m plot of field seeded Spartan Banner onions. In both years, the natural logarithm of numbers of airborne conidia sampled during the current day (D) was positively correlated with 1) the maximum hourly vapor pressure deficit (VPD) (= saturation-ambient vapor pressure) on D, and 2) the logarithm of the conidial concentration sampled on D-1. A regression equation was developed to predict relative conidial concentration on day D in 1987 that explained 59% of the variability. Purple blotch lesions were counted weekly at the same site in 1986 and 1987. In 1987, counts of lesions were also made on onion trap plants placed in the field plot at weekly intervals. Large concentrations of conidia of *A. porri* did not always precede increases in lesions.

Additional keywords: disease prediction, quantitative epidemiology.

Purple blotch of onion (*Allium cepa* L.) caused by *Alternaria porri* Ell. is an important disease of onions throughout the United States. Under favorable environmental conditions purple blotch can spread rapidly and yield losses can exceed 30% (14).

The first event in the spread of disease is the formation and release of conidia, which are then transported by air currents to susceptible hosts. The influence of environment on concentration of airborne conidia of several *Alternaria* spp. has been studied (1–5,13). Hirst (5) found that the lowest conidial concentrations in air of unidentified *Alternaria* spp. occurred in the early morning hours when wind velocities were usually low and relative humidities were high. Maximum concentrations occurred in the afternoon when wind velocities were higher and relative humidities were lower. Conidial numbers of *A. solani* (Ell. & G. Martin) and *A. alternata* were lowest at night, began increasing by 0900 hours, peaked by 1100 hours, then decreased sharply (13). This pattern of conidial concentration coincided with a decrease in relative humidity and an increase in wind velocity.

Relatively little work has been published concerning concentration of airborne conidia of *A. porri*. Meredith (8) monitored conidia of *A. porri* over an onion plot in Nebraska to determine periodicity and influence of weather on relative conidial density. Peak concentrations of conidia occurred between 0800 and 1400 hours, which corresponded to times when wind velocity and temperatures were rising or high, and relative humidities were decreasing or low. The lowest conidial concentrations occurred daily between the hours of 2000 and 0600, but when wind gusts occurred during this period, an increased number of conidia were caught. Air turbulence caused by pesticide spraying greatly increased conidial concentrations in the air. Meredith (8) also noticed that during calm weather only mature conidia were trapped; in stormy weather, mature and immature conidia, mycelial fragments, and conidiophores were also trapped. Smaller numbers of conidia were trapped while rain was falling; however, airborne conidial concentration increased following rain or irrigation. Decreasing humidity seemed to weaken the conidial attachment to conidiophores (8) but did not cause active conidial release.

In a study of the relationships between environmental conditions, airborne conidia of *A. porri*, and purple blotch incidence, Miller (9) found a positive correlation between the occurrence of at least 11 hr of leaf wetness or 14 or more hours of relative humidity (RH) above 90% and the trapping of five or more conidia of *A. porri* in an unspecified volume of air during the following day. In Texas, leaf wetness duration recorded at four locations has been used to issue advisories for the presence of high concentrations of conidia for spray advisories (12). Temperature was not used in this predictive model.

The objective of this study was to examine the progress of purple blotch disease in the field, the relationship between airborne conidia and lesion number, and the relationships of weather variables to concentration of airborne conidia of *A. porri*. Although laboratory and field studies had identified high relative humidity, high temperatures, prolonged dew periods, and high wind speed as factors that favored conidial formation and release (8,9), the relationship between the magnitude and duration of these weather variables and the numbers of conidia that formed as a result was not known.

MATERIALS AND METHODS

Effect of weather conditions on concentrations of airborne conidia. Weather conditions were monitored hourly in a 15- × 30-m onion plot at the Michigan State University Muck Experimental Farm during 1985 and 1987. The field consisted of 19 1.6-m beds each with three rows of Spartan Banner onions spaced 0.46-m apart. The plot was fertilized according to soil tests and insect and weed control was applied according to state extension recommendations. Temperature and relative humidity were monitored using a Weathermeasure (Sacramento, CA) model H311 or Weathertronics (West Sacramento, CA) model 5021 hygrothermograph; rainfall using a Weathermeasure model P501 remote recording rain gauge; leaf wetness using a Dewitt leaf wetness recorder (Valley Stream Farms, Orono, Ontaria, Canada); and intensity of direct and indirect solar radiation using a Weathermeasure model 3010-01 mechanical pyranograph. Vapor pressure deficit (VPD) values were derived with the method of Lacy and Pontius (6). In 1987, wind speed and direction were measured with a Weathermeasure model W123 recording three-cup anemometer and airfoil vane placed 5 m above the soil surface. Numbers of conidia present hourly in 1 m^3 of air were sampled in a Burkard (Rickmansworth, Herts., England) 7-day recording volumetric spore trap with the sampling orifice 42 cm above the soil surface. Count data were transformed by adding one to each daily total (so that no values of zero were present in the data) and taking the natural logarithm $[\ln(Y + 1)]$ of each number. Logarithmic transformations were necessary because variances in the data were high (14). Simple correlations between the weather data and concentration of conidia sampled daily between 0700 the previous day (D-1) and 0600 the current day (D) were determined with the MSTAT statistical package (Department of Crop and Soil Sciences, Michigan State University). Multiple regression analysis for the relationship between conidial concentration sampled daily from 0700 on D-1 and 0600 on D and the weather variables were also performed. Regression equations were considered acceptable for describing the relationship between the number of airborne conidia sampled and weather variables when the probability of obtaining a greater F-value was less than 0.01. The proportion of variation in airborne conidia sampled that is explained by each equation is estimated by the adjusted coefficient of multiple determination (R^2). Autocorrelation was accounted for by inclusion, when necessary, of a dummy variable that represented plant growth stage and allowed for linear time trends. Weather variables that most influenced conidial formation and release were thus identified.

Disease progression in the field. Numbers of purple blotch lesions present on onions in the same 15- × 30-m unsprayed plot of Spartan Banner onions described above were monitored from 10 July to 15 August 1986 and from 23 July to 13 August 1987. In 1986, numbers of lesions present on 10 plants each in five randomly selected rows, and in 1987 numbers of lesions present on 2.75-m sections of six randomly selected rows were counted weekly. Only lesions on nonsenescent leaves were counted since nonpathogenic or weakly pathogenic *Alternaria* and *Stemphylium* spp. commonly colonize senescent onion leaf tissues, and colonized areas are difficult to distinguish from lesions caused by *A. porri*.

Occurrence of lesions on trap plants. Ten 4-wk-old Spartan Banner onion plants were placed in the field at weekly intervals in 1987 so that fresh, noninfected onion plants would be in the field each week. These plants were grown from dormant bulbs in a disease-free environment in the greenhouse for 5 wk, placed in the same 15- × 30-m unsprayed onion plot at the Muck Farm for 1 wk, then returned to the mist chamber in the greenhouse for 24 hr to enable any spores produced and deposited during that week to infect and form lesions. Lesions were counted 3 days later when individual lesions were easily visible, but still discrete so that numbers of lesions produced in a given week could be correlated with numbers of conidia present in the atmosphere (as measured by a spore trap in the same plot) that same week.

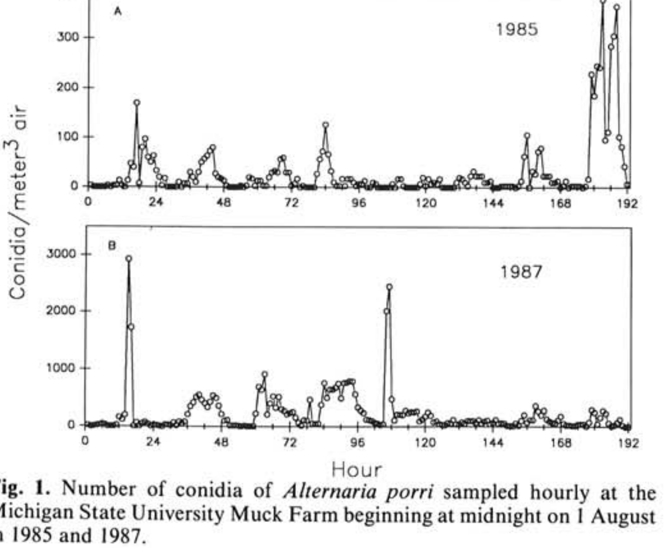

Fig. 1. Number of conidia of *Alternaria porri* sampled hourly at the Michigan State University Muck Farm beginning at midnight on 1 August in 1985 and 1987.

RESULTS

Effects of weather conditions on concentration of airborne conidia. In 1985, conidial concentration was sampled and weather conditions were monitored for 68 consecutive days (28 June to 3 September). In 1987 conidial concentration and weather conditions were monitored during 48 consecutive days (13 July to 31 August) (conidial concentration data for 1986 were lost due to technical difficulties). Airborne conidial concentration had a well-defined diurnal periodicity (Fig. 1A and B). Generally, few conidia were sampled between 0100 and 0800 hours. The number of conidia sampled began to increase after 0800 and stayed high throughout the afternoon and evening (1200–2200 hours). Because of the diurnal periodicity, cumulative spore catches were tabulated from 0700 on the current day to 0600 hours the following day. Spore catches varied from 0 to 5,420 and from 137 to 10,433/24 m^3 of air per day in 1985 and 1987, respectively.

Hourly weather data were summed and averaged over 24-, 12-, 6-, or 4-hr periods where appropriate, or over other time periods based on observations of weather and conidial density relationships. For example, hourly temperatures for the 12-hr period 0700–1900 were summed and averaged, as well as temperatures during hours of leaf wetness or low (<1.0 mb) VPD (6). In other cases, a single hourly value was identified as significant (for example, highest hourly VPD on the current day). After weather variables were compiled as described above, they were graphed against logarithm of conidia sampled between 0700 on the previous day (D-1) and 0600 on the current day (D). Graphs were examined for the presence of visual relationships. Examples of typical graphical data are shown (Fig. 2). Average temperature during hours of leaf wetness or low (<1.0 mb) VPD appeared to be related to the logarithm of the conidia sampled; however, no other obvious relationships were observed.

The number of hours during which VPD was <1.0 mb on D-1, the single highest VPD on day D, and the logarithm of the number of conidia sampled on D-1 were significantly and positively cor-

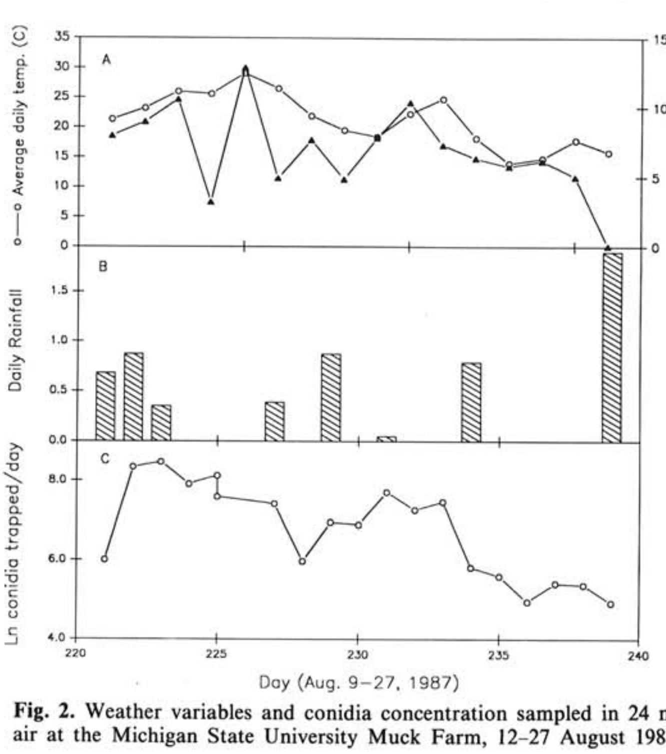

Fig. 2. Weather variables and conidia concentration sampled in 24 m^3 air at the Michigan State University Muck Farm, 12–27 August 1987.

related with the logarithm of the number of conidia sampled on day D in 1985 (Table 1). In 1987, unlike 1985, the number of hours the VPD was <1.0 mb on D-1 was negatively correlated with the logarithm of the number of conidia sampled on day D (Table 1). The average temperature during periods of low VPD (<1.0 mb) on D-1, maximum hourly VPD on day D, average VPD on D-1, average temperature during hours of leaf wetness on D-1, and the logarithm of the conidia sampled on D-1 were positively correlated with the logarithm of the conidia sampled day D in 1987.

Multiple regressions were performed on weather and conidial concentration data from 1985 and 1987 to determine the best equation to predict airborne conidial concentration. Conidial concentration in 1987 was most accurately predicted ($R^2 = 0.59$) based on the natural logarithm of the number of conidia sampled the previous day (X_1), average temperatures during those hours when the VPD was <1.0 mb on D-1 (X_2), and the sum of the numbers of hours during which rainfall occurred on day D (X_3) (Fig. 3A).

$$Y = 2.72 + 0.442X_1 + 0.094X_2 - 0.107X_3 \quad (1)$$

Because it would be impractical to determine the logarithm of the number of conidia sampled yesterday (D-1) during a growing season (because of the large amount of time necessary to retrieve, mount, and stain spore trap tapes and to count conidia) for purposes of making a conidial concentration prediction, regressions were also performed to determine the best predictive equation that could be constructed without this factor. Disregarding this variable, the parameter most highly correlated with the logarithm of conidia sampled each day in 1987 was average temperature during periods of low (<1.0 mb) VPD on day D-1 (Table 1, Fig. 4). The regression equation that best predicted the number of conidia sampled on a given day when the number of conidia sampled the previous day was unknown, (1987 data) was

$$Y = 2.03 + 0.092X_1 + 0.024X_2 + 0.423X_3 \quad (2)$$

in which Y = estimated number of conidia sampled on day D, X_1 = the average temperature during periods of low (<1.0 mb) VPD on D-1, X_2 = the maximum hourly VPD on day D, and X_3 = the prediction of the logarithm of the number of conidia sampled during the previous day. The X_3 term was derived with the equation

$$X_3 = 4.583 + 0.092X_1 + 0.055X_2 \quad (3)$$

in which the X_1 and X_2 terms are the same as in equation 2.

TABLE 1. Environmental variables in 1985 and 1987 which were significantly correlated with the logarithm of the conidia of *Alternaria porri* sampled during the current day (D)

Variable	Simple correlation coefficient (r), Year 1985[a]	1987[b]
Hours of low vapor pressure deficit (VPD) (<1.0 mb) on the previous day (D-1)	0.290*[c]	−0.326*
Average temperature during periods of low VPD (<1.0 mb) on D-1	0.132[d]	0.483**
Maximum hourly VPD on day D	0.263*	0.466**
Average VPD on D-1	0.132[d]	0.329*
Logarithm of conidia sampled on D-1	0.535**	0.701**
Average temperature during hours of leaf wetness on D-1	0.117[d]	0.468**
Hours rain 0800–2400 on day D	0.148[d]	−0.286*

[a] Number of days sampled = 67.
[b] Number of days sampled = 48.
[c] Significance: * = 0.05; ** = $P = 0.01$.
[d] Not significant in 1985.

Equation 2 described about 43% ($R_2 = 0.43$) of the variation in sampled conidial concentration in 1987. There was generally good coincidence between numbers of conidia predicted and those actually sampled; however, the equation somewhat overpredicted low conidial concentration and underpredicted high conidial concentration (Fig. 3A and B).

Conidial concentration in 1985 was most accurately predicted ($R^2 = 0.35$) based on the natural logarithm of the number of conidia sampled on the previous day (X_1), and the maximum hourly VPD on day D (X_2).

$$Y = 1.195 + 0.551X_1 + 0.085X_2 \quad (4)$$

Correlations between temperatures during periods of low VPD on D-1 and conidial concentration on day D were not significant in 1985, in part because there were many days during 1985 when the VPD was never <1.0 mb. On those days, X_1 (the temperature during hours of VPD <1.0 mb on D-1) would have been a missing value. Correlations between temperatures during hours when the VPD was <2.0, 3.0, 4.0, and 5.0 mb on D-1 and conidial concentration on day D were also examined and found not to be

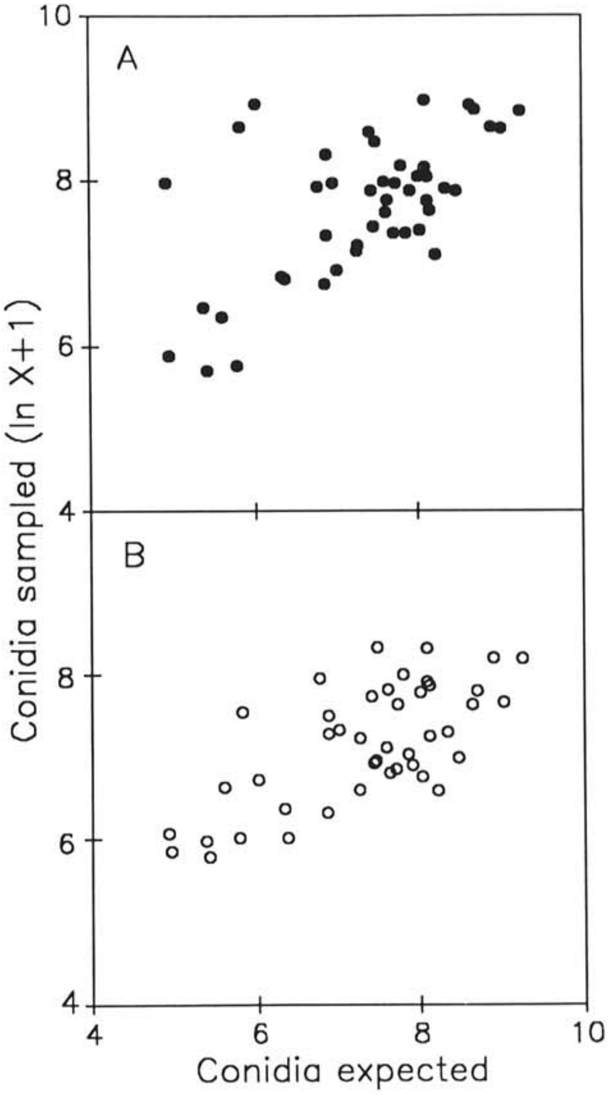

Fig. 3. Comparison of predicted and observed concentrations of airborne conidia (natural logarithm [ln] of the number of conidia sampled + 1) at the Michigan State University Muck Farm in 1987. **A,** Prediction was based on the ln of the number of conidia sampled the previous day (D-1), the temperature during hours when vapor pressure deficit (VPD) was <1.0 mb on D-1 and the total number of hours rain occurred on day D (eq. 1). **B,** Prediction was based on the temperature during hours of VPD <1.0 mb on D-1, the maximum VPD on day D, and the prediction of the ln of the number of conidia sampled on D-1 (eq. 2).

significant. Correlations between wind speed and airborne conidial concentration were examined in 1987 and found not to be significant ($r = 0.053$; $P = 0.81$).

Disease progression in the field. Lesions appeared sooner (23 July) in 1987 than in 1986 (31 July) and onions in all rows observed had lesions on every observation date in 1987 (Table 2). Lesions per plant stayed at about the same level (0.4–0.6 lesions/plant) in 1986, but in 1987 increased from 0.28 to 1.48 lesions/plant in 1 wk during favorable weather. As in 1986, older susceptible leaves became senescent, lesions coalesced, and leaves died. Thus there appeared, at times, to be a decrease in lesion numbers/plant when lesions on dead leaves (counted the previous but not the current week) outnumbered new lesions.

Occurrence of lesions on trap plants. Lesion formation on trap plants placed in the field varied over the six sample periods in 1987 (Fig. 5). Weeks when larger numbers of lesions occurred were not correlated ($r = -0.57$; $P = 0.234$) with weeks when large conidial concentration occurred. However, on some dates, large conidial concentration preceded a high infection level. For example, the increase in lesions on trap plants removed from the field at noon on 1 September (day 243) probably resulted from large numbers of airborne conidia present from the afternoon of 30 August through noon 1 September.

DISCUSSION

In 1985, weather was generally less favorable for purple blotch development and fewer weather variables were correlated with the logarithm of conidia sampled than in 1987. The lack of correlation between weather variables and airborne conidial concentration occurred because there were fewer days when moderate to large conidial concentrations were sampled in 1985 than in 1987.

Surprisingly, there was a negative correlation between hours of low VPD (<1.0 mb) the previous day and conidial concentration on the current day in 1987 data that was not true for 1985 data. This may be a direct result of the overriding effect of temperature. Warm days tended to favor conidial formation more than cooler days even if the number of hours that VPD was low remained the same. This agrees with work on other *Alternaria* spp. Madden et al (7) developed a severity index (an indication of disease potential of early blight of tomatoes) for conidial formation in *A. solani* based on the interaction between temperature and wet periods. He assigned higher severity values to days that had higher temperatures than to days with cooler temperatures during the same length period of leaf wetness. Conidial production of *A. dauci* was also favored by high temperatures at night, when RH is usually high or leaf wetness is likely to occur (15).

In Texas, a prediction system for *A. porri* has been based solely on daily hours of leaf wetness (12), disregarding temperature. In Texas, unlike Michigan, temperature may be frequently favorable but moisture limiting. In Michigan, especially in humid muck areas, moisture is prevalent but temperature is generally relatively too cool to be optimum for conidial formation or infection of onions by *A. porri*. The difference between the weather variables that coincided with large conidial concentrations in air in Michigan and Texas, in addition to the large differences in airborne conidial concentration observed in the 2 yr of this study indicates that any predictive model containing an airborne conidial concentration component must be carefully studied to determine the geographical and temporal conditions in which it is valid.

We found that the logarithm of the number of conidia sampled on D-1 was significantly correlated with the logarithm of conidia sampled on day D. This may have occurred because weather is autocorrelated and lesion area is more similar on two consecutive days than two days separated in time. However, it probably occurred primarily because of incomplete liberation of conidia or the ability of partially formed conidia to survive and complete formation on a subsequent night. Bashi and Rotem (3) observed that a portion of conidia of *A. solani* that formed during the night were not released the following day despite exposure to dry, windy conditions, which were conducive to release. Also, more conidia were formed under discontinuous wet periods than continuous wet periods of the same total duration, and the number of conidia produced each successive night (up to six) increased.

While several workers correlated wind speed with concentration of airborne *Alternaria* spp. (8,13,16) we did not find the same pattern. Strandberg (16) estimated that a wind velocity above 2–3 m/sec was required for large numbers of conidia to become airborne. Our average wind velocity in 1987 ranged from 0.88 to 2.05 m/sec, which is very low in comparison. Our instrument was positioned 5 m above the ground, 1 m higher than Strandberg positioned his. This may not have accurately reflected the wind velocity in the onion plant canopy, or else wind gusts of short duration (combined with rising VPD) were adequate to liberate conidia.

The relationship between leaf age and susceptibility of onions to purple blotch has been documented by Miller (11). We also

TABLE 2. Mean numbers of purple blotch lesions per plant present on onions monitored in 1986 and 1987.

Date	1986	1987
10 July	0[a]	...
17	0	...
23	0	0.28[b] ± 0.05[c]
31	0.50 ± 0.12	1.48 ± 0.05
7 August	0.38 ± 0.16	0.94 ± 0.06
13	0.56 ± 0.24	...
15	...	1.26 ± 0.10

[a] Mean of five sample rows.
[b] Mean of six sample rows.
[c] Standard error.

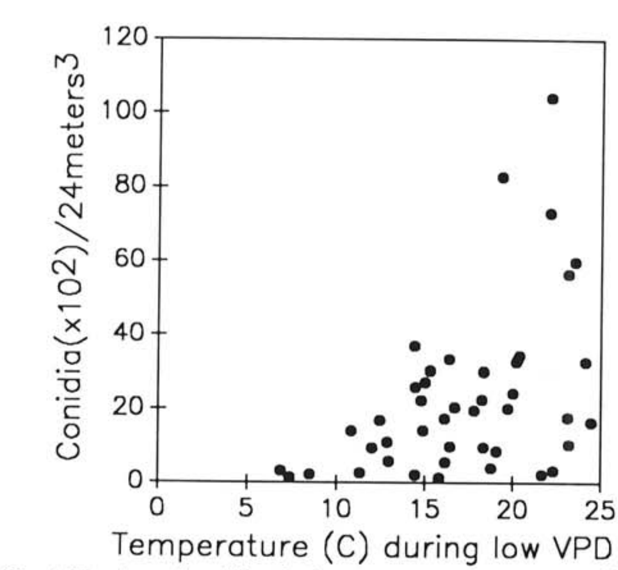

Fig. 4. Numbers of conidia of *Alternaria porri* sampled in 24 m³ of air in relation to temperatures during periods of low vapor pressure deficit (<1.0 mb) the previous day (D-1).

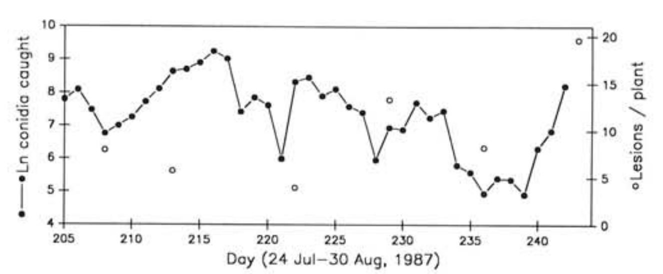

Fig. 5. Lesions per trap plant and the natural logarithm of conidia trapped daily during the time onion plants were in a field plot at the Michigan State University Muck Farm in 1987.

found that lesions appeared late in the growing season in 1986 and 1987, coinciding with both the physiological aging of onion plants and a buildup of blighted tissue where sporulation could occur. The increase in numbers of lesions on trap plants (which were uniform in age) may indicate that weather factors were also more favorable for spore deposition, infection, or lesion development late in the season. Because we found little correlation between conidial concentration in air and lesion number, and because of the relative importance of lesion size (10), factors which influence leaf infection and subsequent lesion expansion should be determined and included in a predictive model for the timing of fungicide sprays. However, weather variables identified here will be important in identifying weather patterns that favor large concentrations of airborne conidia of *A. porri* in onion-growing regions such as Michigan.

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