Relation of Weather Variables and Periodicities of Airborne Spores of Alternaria dauci

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ABSTRACT

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Trends in weather variables, leaf blight, and numbers of airborne spores of *Alternaria dauci* were monitored in carrot field-plots during two growing seasons. Weather factors during July frequently favored spore production, liberation, and dispersal, but low numbers of airborne spores were detected because there was a scarcity of spore-bearing carrot leaves. The numerous airborne spores which occurred during August coincided with periods favorable for spore production and release and increased blighting of carrot leaves. In September, low numbers of airborne spores frequently were observed, usually after nights when temperatures were too low for abundant sporulation during the period of leaf wetness. Numbers of airborne spores showed a characteristic circadian periodicity. Few spores were dispersed at night when host leaves were wet, the relative humidity (RH) high, the temperatures cool, and the wind speeds low. Numbers of spores increased after 0800 hours when the leaves dried, the RH decreased, and the temperature and wind speed increased. Peak populations occurred at about 1300 hr. Prolonged high winds, periods of rain or persistent leaf wetness, and cool temperatures during dew periods resulted in atypical periodicities and few airborne spores. Limited amounts of blighted leaves, low temperatures, and short dew periods were the major factors restricting spore production.

Additional key words: epidemiology, Alternaria leaf blight of carrot.

Leaf blight produced by *Alternaria dauci* (Kühn) Groves and Skolko is the major foliar disease of carrots *(Daucus carota* L. var. *sativa* DC.) in the Holland-Bradford Marsh, an area of intensive carrot production in Ontario. The disease is controlled by six to 10 fungicide applications to the foliage in the period from late July to late September when most blight occurs. Development of a scheme for improved timing of fungicide applications (6) depended upon definition of the effects of weather on the development and dispersal of airborne spores of *A. dauci*.

Even though airborne spores (conidia) are the means of spread of the pathogen and thus are important in development of carrot leaf-blight epiphytotics, the relationships of *A. dauci* spore production, liberation, and dispersal to weather have not been described previously. However, the effects of weather factors on spore production and dispersal of *A. solani* Sorauer, *A. porri* (Ellis) Cif., and *A. alternata* were studied by Rotem (11), Meredith (8), and Pearson and Hall (10), respectively.

In the work presented here correlative field studies of trends in weather variables, blight development, and numbers of airborne spores provided a means for examining the interrelationships of certain weather variables that limit or promote *A. dauci* spore production, liberation, and dispersal at various times during the season.

MATERIALS AND METHODS

Plots of carrot cultivar Spartan Sweet, which is highly susceptible to Alternaria blight, were established at the Muck Research Station, at Kettleby, Ontario, in 1973 and 1974. The Station is located near the center of the Holland-Bradford Marsh. The plots were arranged in a randomized-block design, and separated by strips of non-cropped soil about 0.86 m in width. Each plot comprised seven rows of carrots 3.1 m in length and spaced 0.43 m apart. Some plots in each block received fungicide sprays (6), but blight assessments reported here were made in five replicate plots that were not sprayed. The carrots were sown on 21 May 1973, and on 24 May 1974, and grown according to Ontario carrot production recommendations (9).

Numbers of airborne spores, blight severity, and various weather parameters were monitored continuously from 25 June to 4 October in 1973, and from 21 June to 4 October in 1974.

The incidence of airborne spores of *A. dauci* above the carrot plots was measured with volumetric spore traps. In

1973, spores were collected with a Hirst automatic volumetric spore trap (C. F. Casella and Co. Ltd., London, England) which was placed with the intake orifice 5 m above ground level. In 1974, spores were trapped with a Burkard volumetric trap (Burkard Scientific Sales Ltd., Rickmansworth, England) located 0.5 m above the ground.

Alternaria dauci spores recovered in traps were identified according to the criteria of Ellis (1), counted, and the numbers of spores per cubic meter of air were estimated according to Hirst (3). Because no corrections were made for variation in trapping efficiency associated with wind speed, the spore concentrations recorded are under-estimates of true values. *Alternaria dauci* spores are morphologically similar to those of *A. solani* Sorauer and *A. porri* (Ellis) Cif. which also occur in Ontario. During 1973 and 1974, however, there were few hosts of *A. solani* within 40 kilometers of the traps, and no purple blotch disease produced by *A. porri* was found or reported in onions grown in the Holland-Bradford Marsh. Thus, it was assumed that few conidia of *A. solani* or *A. porri* were present that could have been trapped and confused with those of *A. dauci*.

Blight was assessed according to the criteria of Horsfall and Barratt (5) at intervals of 7 to 10 days from early August until harvest time. At each time of assessment, 20 randomly selected plants in the three center rows of each plot were examined. On each plant, blight symptoms were

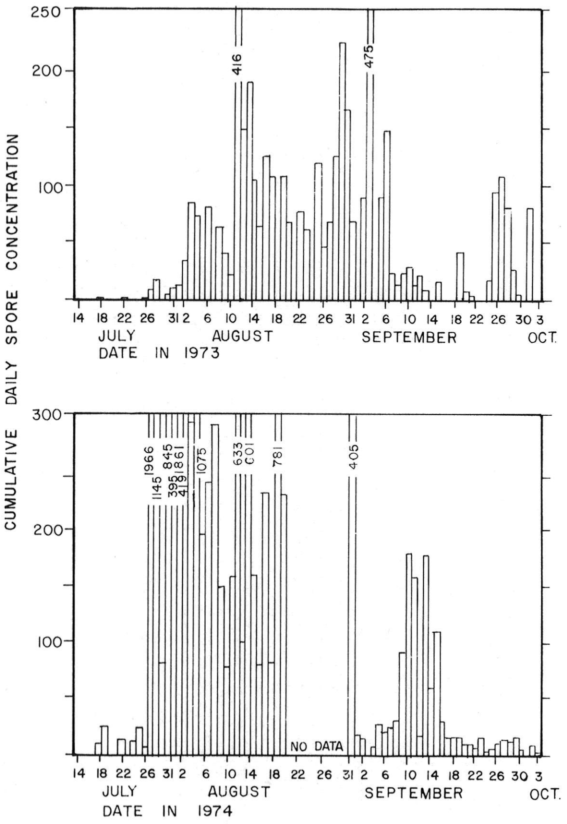

Fig. 1. Cummulative daily concentrations of airborne *Alternaria dauci* spores from mid-July to October in 1973 and 1974. The cumulative daily spore concentration equals the hourly numbers of spores recovered per cubic meter of air arithmetically summed during the respective 24-hr period.

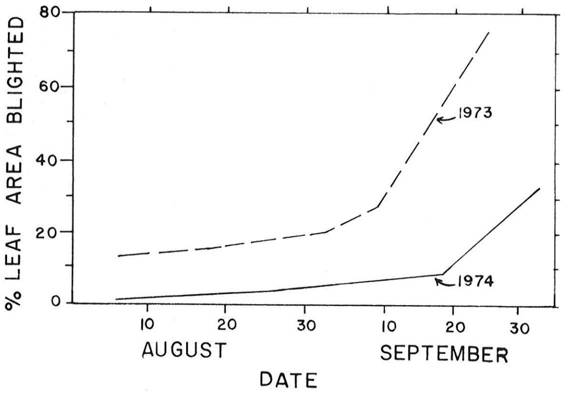

Fig. 2. Development of Alternaria blight in field plots of nonsprayed carrots in 1973 and 1974.

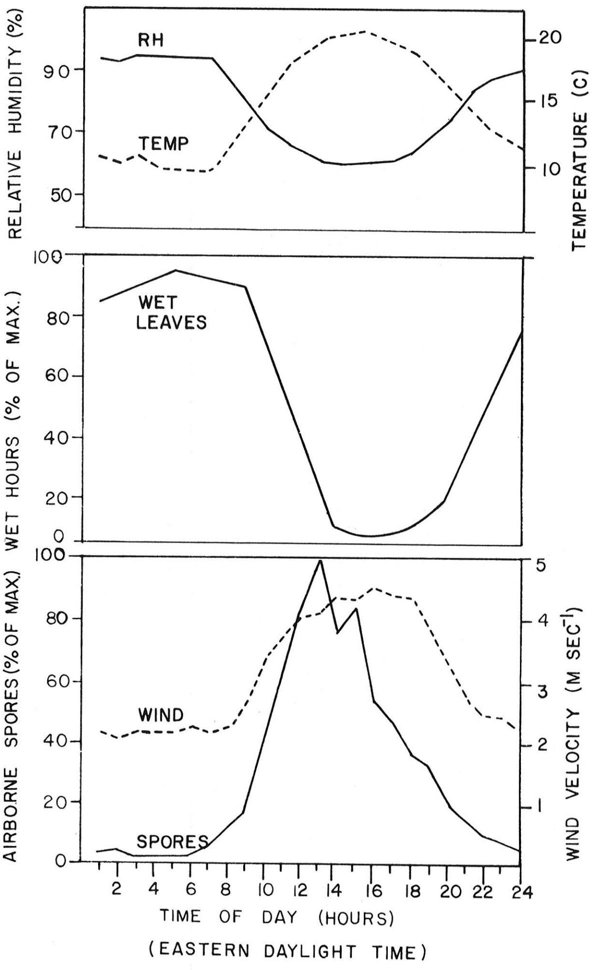

Fig. 3. Mean circadian trends of airborne *Alternaria dauci* spores, air temperature, relative humidity (RH), occurrence of leaf wetness, and wind speed for 18 July to 3 October 1974.

estimated in four expanded leaves, one each from the bottom, lower-center, upper-center, and top of the canopy.

Temperatures and relative humidities (RH) in the carrot plots were measured with a hygrothermograph (Lambrecht, Göttingen, Germany) located in a Stevenson Screen (instrument shelter) at 0.5 m above ground level in the carrot plot and 10 m from the spore trap.

Wind speed was monitored with a cup anemometer (Casella, London, England) mounted 5 m above ground level and 100 m from the spore trap.

The duration of leaf wetness was recorded with a DeWit leaf-wetness recorder (DeWit, Hengelo, The Netherlands) placed 0.5 m above ground level at 5 m from the spore trap.

Sunshine was monitored with a 7-day pyranograph (Weathermeasure, Sacramento, CA 95841. Solar energy data, as recorded by the pyranograph, were expressed as the precent of each hour with "bright sunshine" using a conversion factor determined by simultaneous comparison with a Campbell-Stokes recorder (Casella, London, England) during a few selected days.

Precipitation was measured with a standard Atmospheric Environment Service of Canada rain gauge.

RESULTS AND DISCUSSION

Seasonal trends in numbers of airborne spores of Alternaria dauci.—Estimated numbers of *A. dauci* spores in the air over the carrot plots were expressed as the cumulative daily spore concentration (CDSC), which equals the hourly numbers of spores per cubic meter of air arithmetically summed during each 24-hr period.

In 1973, the mean CDSC was low (six spores) in the period from 1 July (when the first *A. dauci* spore was trapped) to 2 August, moderate (52 spores) 3-10 August, and high (140 spores) 11 August to 15 September. Peak CDSC values were 416 and 475 on 11 August and 15 September, respectively (Fig. 1).

In 1974, greater numbers of spores were trapped than in 1973, but the trap was located closer to the carrot canopy. A single *A. dauci* spore was trapped on 21 June. The mean CDSC was low (10 spores) until 27 July, then increased sharply, and remained high (516 spores) until 19 August. In September, spores were scarce (17, 15, and 9 spores) during the 1st, 3rd, and 4th wk, respectively, but were more numerous (103 spores) throughout the 2nd wk (Fig. 1).

The seasonal trends in populations of airborne *A. dauci* spores were correlated with weather variables and blight severity. Conditions favorable for sporulation of *A. dauci* are darkness, a leaf wetness duration of at least 10 hr, and temperatures ranging from 11 to 23 C (6). A rough indication of the amount of spore-bearing tissue is given by the percentage of leaf area blighted (Fig. 2).

In 1973 and 1974, the low numbers of airborne spores trapped during the early part of the growing season (before 2 August and 27 July, respectively) were associated with a scarcity of spore-bearing host tissues, but not with weather unfavorable for sporulation. In 1973, weather favorable for sporulation occurred on seven nights between 1 July and 2 August, and in 1974 there were four favorable periods between 18 July and 27 July. Amounts of blighted leaf tissues in the plots and nearby carrot fields were very low during these periods. The limited amount of blighted tissue was probably due to the scarcity of inoculum and substantial resistance of young carrots to lesion development (13).

The moderate-to-large numbers of spores trapped in the periods of 3 August to 15 September in 1973, and 27 July to 19 August and 8 to 15 September in 1974 coincided with frequent periods favorable for spore production and release and the presence of increasing amounts of blighted carrot tissues (Fig. 1 and 2).

Low numbers of airborne spores in September were observed on days following nights with temperatures too low for abundant sporulation during periods of leaf wetness. In 1973, night temperatures during 6 to 23 September fell below 11 C, except on 22 September. In 1974, night temperatures dropped below 11 C during the 1st week of September and ground frost occurred frequently after 15 September. There were few airborne spores on days following nights with low temperatures even though conditions favorable for spore release were frequent. Many spores were trapped on most days that followed nights with temperatures that favored spore production.

Mean circadian trends in numbers of airborne spores of Alternaria dauci and weather variables during 1974.—Mean circadian trends in airborne populations of

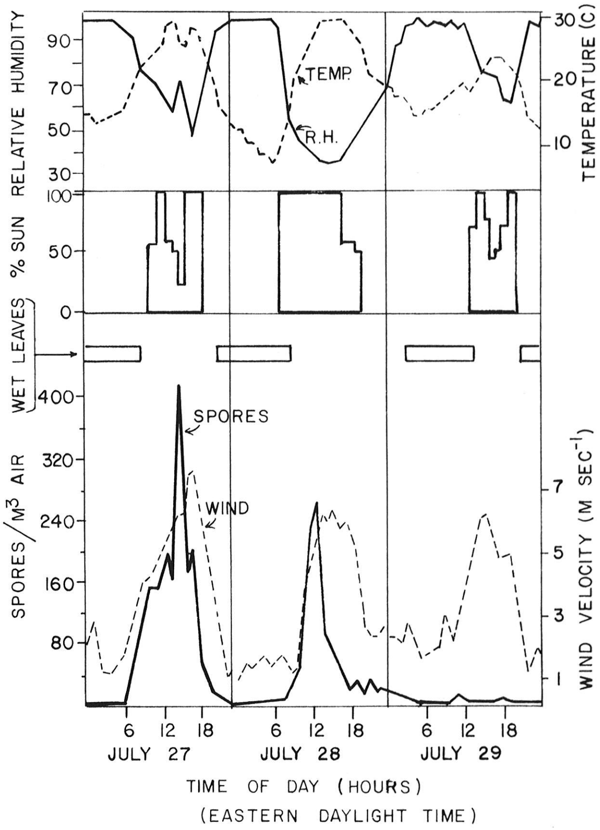

Fig. 4. Circadian periodicities in numbers of airborne spores of *Alternaria dauci* in relation to wind speed, leaf wetness duration, sunshine, air temperature, and relative humidity during 27 to 29 July 1974.

A. dauci spores and weather variables were determined for the 65-day period from 18 July to 3 October, exclusive of 20 to 30 August when no spore counts were made. For each day, hourly numbers of spores per cubic meter of air were normalized as a percentage of the maximum trapped during any hour of that day. Hourly values for temperature, wind speeds, RH, and occurrence of leaf wetness also were recorded. For each hour of the day, the normalized numbers of spores and the weather data were averaged over the 65-day period and represented by circadian periodic curves (Fig. 3).

Concentrations of airborne spores showed a marked circadian periodicity (Fig. 3). Numbers of spores were low from about 2200 hours to 0800 hours, then increased abruptly to maximum concentrations between 1300 and 1500 hours, and steadily declined thereafter. Similar circadian periodicities in airborne spore concentrations have been shown for *A. solani* and *A. tenuis* (11), for *A. porri* (8), and for *A. alternata* (10).

The circadian periodicity in concentrations of airborne spores showed correlations with circadian trends in weather variables (Fig. 3). During the night and early morning, when numbers of airborne spores were quite low, the host leaves were wet, the atmospheric RH high, the temperatures cool, and the wind speeds low. The sharp increases in numbers of airborne spores after 0800 hour occurred when the leaves dried, the RH declined, and the temperature and wind speed increased. Thus, release of *A. dauci* spores was correlated with a warming trend, increased air circulation, and the consequential drying of leaf surfaces and decrease in RH of the ambient air. Peak populations of airborne spores occurred about 3 hr before the maximum wind speed, 2 hr before the highest temperature, and 1 hr before the lowest RH. The decline in numbers of airborne spores after 1500 hours did not coincide with changes in trends of weather parameters; thus it possibly was related to a progressive depletion of mature spores available for dispersal from the carrot leaves.

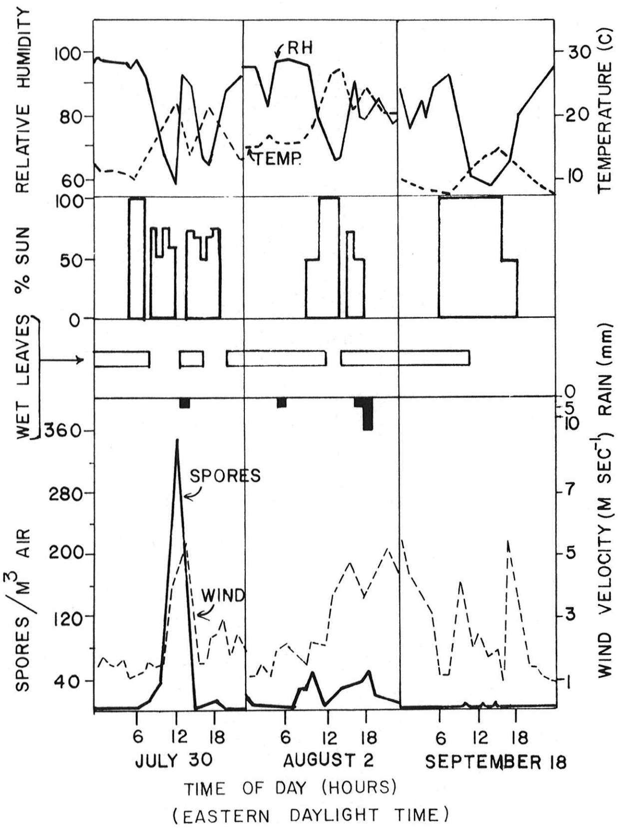

Fig. 5. Circadian periodicities in numbers of airborne spores of *Alternaria dauci* in relation to wind speed, leaf wetness duration, rain, sunshine, air temperature, and relative humidity on 30 July, 2 August, and 18 September 1974.

Depletion of spore supply by prolonged high wind speeds.—On the days of 27, 28, and 29 July 1974, moderate-to-strong winds (>5 m $\sec^{-1}$) occurred for periods of 7, 8, and 5 hr duration, respectively, but airborne spores were numerous for 10, 5, and 0 hr during these respective windy periods (Fig. 4).

On 28 July, concentrations of airborne spores increased sharply at 1000 hours, immediately after an increase in wind speed, but decreased sharply after 1300 hours, even though moderate-to-strong winds persisted until 1900 hours. During peak hours of spore dispersal and strong winds, mature and immature spores and conidiophore fragments were recovered in the spore trap. Evidently the source of spores on carrot leaves virtually was depleted at 1500 hours. Because the average temperature of 11.1 C observed during the dew period of 27-28 July was at the lower limit for abundant sporulation (6), even though temperatures during the previous night were 5 C warmer, spores available for dispersal on 28 July probably were fewer than on 27 July.

On 29 July, even though conditions favored spore formation and subsequent spore release, few spores were airborne which probably was related to a scarcity of mature spores on the carrot leaves. Conidiophore fragments trapped on 28 July indicated extensive destruction of conidiophores by strong winds which would necessitate conidiophore regeneration before spores could be formed. The length of time favorable for sporulation in the early hours of 29 July may have been insufficient for formation of both conidiophores and spores. This is substantiated by the occurrence of numerous airborne spores on 30 July, following another period favorable for sporulation.

Suppression of airborne spore concentrations during periods of rain or persistent leaf wetness.—Numbers of airborne spores declined precipitously during a rain shower (2 mm) of 30 min duration on 30 July 1974 (Fig. 5). Spore numbers per cubic meter of air in the hours preceding, during, and following the hour within which the rain occurred were 350, 75, and 0, respectively. Recovery of *A. dauci* spores in the spore trap ceased abruptly just after the rain began.

On the night of 1 to 2 August 1974, conditions favored spore production, but there were few airborne spores the following day. On 2 August, warm and moderate winds developed. However, because of early morning cloudiness and afternoon rain showers, the leaves were dry for only 4 hr. Airborne spore populations declined abruptly after the heaviest afternoon shower.

In these examples it is likely that both the removal of airborne spores by rain and the restriction of spore liberation by moisture on leaves contributed to the observed decreases of spore concentrations.

Suppression of numbers of airborne spores on days following cool nights.—Wind and dry periods favorable for spore liberation and dispersal occurred on several days after 15 September, including 18 September (Fig. 5), but airborne conidia were scarce. However, temperatures on preceding nights were too low for abundant sporulation; thus, scarcity of fresh spores is presumed to have limited airborne spore concentrations.

Integrated effects of weather and host factors on concentrations of airborne spores.—Moisture regimes exerted a major influence on concentrations of airborne *A. dauci* conidia. Absence or scarcity of airborne spores when leaf surfaces were wet indicated that surface moisture prevented spore liberation. However, the amount of surface moisture required to prevent spore release is not known. The abrupt increases in airborne spore concentrations coincident with drying of the leaves demonstrated the importance of dry leaf surfaces for abundant liberation of spores. The liberation of spores as the RH declined indicated a possible effect of decreasing RH on the spore-release mechanism. Spore liberation in *A. dauci* may be triggered during normal weather by RH declining from near-saturation and may involve a violent-release mechanism similar to that reported by Leach (7) for *Alternaria tenuis* and other porosporous fungi, and by Meredith for *A. porri* (8).

Peak concentrations of airborne conidia of *A. dauci* occurred 6.5 hr after sunrise, but the peaks for *A. solani* in the Negev Desert of Israel were found by Rotem (11) to occur only 4.5 hr after sunrise. The earlier peak concentration for *A. solani* may be related to earlier and more rapid drying in the Negev than occurred at the Holland-Bradford Marsh. Rotem postulated that early drying hastens the peak hour of spore dispersal.

Wind is required for dispersion of spores (2), but its role in their detachment from conidiophores is not known. The liberation of both mature and immature spores and of conidiophore fragments during prolonged periods of strong winds indicated that wind may enhance spore liberation temporarily. However, decreasing numbers of airborne spores on successive days when strong winds occurred, and the frequent occurrence of peak numbers of airborne spores for several hours before a decline in wind speed (Fig. 4), indicated that strong winds may result in depletion of spores available for liberation from leaves, which was reported by Rotem (11). Gusts of wind reduce the thickness of the boundary layer of still air surrounding the leaf surface, thereby exposing more spores to the action of wind eddies. The increased movement and mutual abrasion of carrot leaves that occurs with increased wind speeds may encourage dislodgement of *A. dauci* spores into the turbulent air. Increases in numbers of airborne spores with accelerated wind speeds have been reported frequently (2, 4, 8, 11, 12).

Limited amounts of blighted leaves, low temperatures, and short dew periods were the major factors restricting production of *A. dauci* spores on carrot leaves, whereas numbers of airborne spores also were limited by rain or prolonged leaf wetness. Low numbers of airborne spores during July and September generally were associated with restricted sporulation attributable to scarcity of blighted leaves and low temperatures. On occasional days throughout the season, periods of leaf wetness were too short for spores to form. On certain days, however, prolonged or intermittent periods of leaf wetness restricted spore release. Rain probably decreased numbers of airborne spores both by prolonging leaf wetness and by direct removal of spores from the air.

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