Early Blight of Celery: Analysis of Disease Spread in Florida

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ABSTRACT

Disease incidence and weather during periods of spore formation and release influenced the number of *Cercospora apii* spores trapped. Daytime cloudiness and rain reduced the numbers of spores trapped. Light rain in late afternoon or early morning lengthened the leaf wetness period and increased spore numbers. Wind did not figure prominently in spore detachment. Celery harvesting over-rode the aforementioned factors, with unusually high spore counts occurring during this period. Blight-infected transplants resulted in higher daily spore counts, higher disease incidence throughout the growing season, required more time to reach harvest maturity, and yields lower than those produced by blight-free transplants. The number of spores trapped each day could be used to predict disease increase and thus, could be extrapolated for spray application recommendations.

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Early blight of celery (*Apium graveolens* L. var. *dulce* DC.), incited by *Cercospora apii* Fres., is the most important fungus disease of celery in Florida (6). Growers spray celery 25-40 times during the growing season to control early blight. The effect of temperature on sporulation, the diurnal periodicity of spore release, and the influence of duration of high relative humidity periods on sporulation of *C. apii* have been reported (1, 2). A forecasting method which permitted growers to successfully reduce the number of fungicide applications was recently described (1, 2). This paper reports on disease spread in commercial celery fields and a method of predicting disease increase.

MATERIALS AND METHODS.—Data were obtained in commercial muck soil celery fields 60.7-243 hectares (150-600 acres) in the Everglades farming area of Florida. Meteorological data were monitored with a recording anemometer, tipping-bucket rain gauge, and maximum-minimum thermometers located in a central field area. Hygrothermographs in instrument shelters at crop level were placed in three locations to record ambient field conditions. The usual culture is to plant celery seedlings successively over several months. The crop canopy and leaf microclimate will vary considerably from one side of the field to the other depending upon the age and height of the crop. Air spora were monitored by four continuously sampling traps (5) located in the celery fields. Each trap sampled approximately 8.75 liters/min (15 cubic ft/hr). The spore trap slides were collected daily and examined with a light microscope (×200).

Actual leaf and lesion measurements, as described previously (3), were used to determine disease incidence at less than 3% disease. These calculations were supplemented by the Horsfall-Barratt scale (8) to estimate disease at higher incidences.

RESULTS.—*Effect of blight-favorable weather on numbers of spores trapped.*—Blight-favorable hours (BFH) were hours with relative humidity near 100% and temperatures ranging 15-30 C (2). Spore monitoring in large acreages of Florida celery for over 1,250 "trap-days" showed that significant spore releases occurred when BFH exceeded 10 hr per day (Fig. 1).

Fig. 1. Influence of blight-favorable hours/day (BFH) on numbers of trapped *Cercospora apii* spores. Data selected from 1,250 "trap-days" with no allowance for micro-climatic effects. 400 Obs. = number of days with 0-10 spores/day at 0-4 BFH. BFH = blight-favorable hours. R.H. = relative humidity.

Rain.—The time of occurrence and the amount for each occasion of precipitation greatly affected the number of spores trapped (Tables 1, 2). Light rain at night generally had no detectable influence on the number of spores trapped the following day. If precipitation occurred in early morning or late afternoon, there was an increase in the number of BFH, and spore counts were usually higher during the subsequent spore release period. Heavy, beating rain at any time decreased the numbers of spores trapped. Microscopic observation of diseased tissue the day after a heavy rain showed that exposed lesion surfaces were devoid of external fungal fruiting structures. Lesions in protected locations (leaf undersurfaces and lower sites in the plant canopy) often had ruptured conidiophores.

Rain during the middle of the day (1000-1500 hr) greatly reduced spore numbers (Table 2). When leaf drying followed midday rains, secondary peaks of spore numbers were observed.

Cercospora apii spores were found in rain droplets on leaf surfaces confirming splash dispersal as reported also by Carlson (4) for *C. beticola* Sacc.

Wind.—Daily or hourly fluctuations in numbers of trapped spores could not be attributed to variations in wind velocities (Tables 1, 2). High spore counts were recorded during hours with a very light breeze 1.6-8 km/hr (1-5 mph). Spore counts were not significantly greater during hours of light wind 8-16.1 km/hr (5-10 mph) or moderate wind 16.1-32.2 km/hr (10-20 mph with gusts of greater velocity). Several high spore counts were recorded at times of little wind less than 1.6 km/hr (1 mph). Low numbers of spores were trapped on mornings with slow drying conditions regardless of wind velocities. On days when wind speeds remained relatively constant over the morning hours, the spore counts varied greatly depending upon the rapidity of relative humidity depression and cloud cover. Winds at night usually resulted in few spores trapped the next day because of the reduction in BFH on such nights. Few *C. apii* spores were trapped at night, even during storms.

Clouds and fog.—Overcast skies in the morning always significantly reduced the numbers of trapped spores despite the presence of abundant mature conidia on lesions from the previous night's spore-forming period. If the skies cleared in the afternoon, the spore count increased slightly during that part of the day but never reached the level equivalent to the counts observed on bright, sunny mornings. Morning fog increased the number of BFH but few spores were trapped before the fog dissipated. The dissipation of fog followed by a bright, sunny period resulted in high spore numbers when the relative humidity decreased.

Relative humidity.—A rapidly decreasing relative humidity during the morning (0800-1000 hr) resulted in the commonly recorded peaks in numbers of spores trapped. Peaks of spore numbers at other times of the day were also associated with decreasing relative humidity. The increase of relative humidity during the day because of rain showers or heavy cloud cover resulted in fewer spores trapped (Table 2). Few spores were trapped when the relative humidity was 90% or higher. Less than 1% of all

TABLE 1. Influence of blight-favorable hours (BFH), rain, and wind on daily catch of *Cercospora apii* spores in a celery field with 10-15% blighted foliage during November 1969

Date	BFH[a]	Rain (mm)	Time of rain	Wind[b]	Number spores/day
1 Nov	18	2.50	0500-0800	257	1,100
2	15			241	1,000
3	16			179	725
4	14	0.25	2100	354	750
5	4			229	20
6	0			164	0
7	0			113	2
8	0			119	10
9	10	4.75	1240-1300	113	150
10	15	0.25	0400	116	1,800
11	0			84	10
12	1			124	15
13	12			269	500
14	24	49.50	0200-2000	360	0

[a] Blight favorable hours (BFH) are hours of relative humidity near 100% at temperatures 15-30 C.

[b] Kilometers passage (0800-0800 hr).

TABLE 2. Selected 1969 spore trap records illustrating hourly weather influences on *Cercospora apii* spore catch in celery field with 10-15% blighted foliage

Time	20 Sept		21 Sept		24 Sept[c]		29 Sept		1 Oct		8 Oct		18 Nov[a]	
0800-0900	100[a]	(14)[b]	120[a]	(14)[b]	5[a]	(8)[b]	31[a]	(11)[b]	0[a,f]	(11)[b]	85[a]	(13)[b]	5[a]	(8)[b]
0900-1000	150	(16)	150	(16)	75	(6)	130	(6)	5[f]	(14)	400	(14)	215	(18)
1000-1100	90	(19)	70[c]	(14)	35	(5)	145	(10)	160	(18)	1,100	(13)	150	(19)
1100-1200	15	(19)	25(4.0)[d]	(11)	50	(5)	65[c]	(14)	230	(19)	20[c,d]	(18)	100	(23)
1200-1300	15	(21)	132[e]	(16)	80	(6)	25[c]	(14)	140	(23)	30(0.5)[d]	(19)	50	(21)
1300-1400	15	(21)	10	(16)	0(25.5)[d]	(23)	3(trace)[d]	(13)	70	(26)	75[e]	(21)	25	(21)
1400-1500	10	(19)	1	(21)	0	(6)	50[e]	(14)	90	(21)	10	(21)	10	(18)
1500-1600	5	(23)	0	(19)	0	(8)	55[e]	(14)	60	(21)	20	(23)	5	(18)
1600-1700	5	(21)	0	(21)	0	(11)	0	(8)	15	(13)	5	(14)	5	(14)
1700-1800	0	(21)	0	(13)	0	(10)	0	(8)	10	(11)	0	(8)	2	(8)
1800-1900	0	(13)	0	(6)	0	(6)	0	(5)	0	(5)	0	(5)	0	(6)

[a] Column of figures gives typical, representative daily spore catch for the hours indicated.
[b] Column of figures gives typical wind passage (km passage/hr) for the hours indicated.
[c] Cloudy, overcast skies for hour and date as indicated.
[d] Rain (mm) for hour indicated.
[e] Catch as foliage dried following midday rain.
[f] Catch delayed by light early morning rain (3.0 mm at 0645 hr).

spores were trapped during the humid nighttime hours (2000-0800 hr).

Relation of number of trapped spores to disease incidence.—When conditions favorable for spore formation and release were not limiting, the actual number of trapped spores was largely determined by the amount of disease in the field. Numerous zero daily spore counts were obtained when no disease was observed in the field despite seemingly favorable blight conditions. Low spore counts (1-25 spores/day) were also obtained when no disease was observed in the field. As disease incidence in the field increased, numbers of trapped spores progressively increased (Table 3).

Spore numbers and plant size.—Spore counts of 75-250 spores/day were recorded in young celery with 10% disease in blight-favorable weather. Spore counts of 750-2,500 spores/day were commonly recorded in mature celery with 10% disease. Recently transplanted celery had only a very small total leaf area (ca. 65 cm^2) compared to nearly mature celery (ca. 6,500 cm^2). Thus, mature celery had the sporulation potential approximately 100 X greater than young celery at the same disease incidence.

Spore detachment by man and machines.—The natural diurnal spore release of *C. apii* in celery fields was supplemented by high numbers of spores detached during several common field operations. A spore count of five spores/min was recorded for 1015-1018 hr on 27 October 1969 in a field of nearly mature celery with estimated 10% blighted foliage. When a field worker walked through the celery 7 m upwind of the trap at 1018-1021 hr, the spore count rose to 50 spores/min. The spore numbers dropped to 5-8 spores/min at 1021-1030 hr. At 1600-1603 hr on the same day, the background spore count had dropped to an average of 1.5 spores/min. The count rose to 16 spores/min at 1604-1607 hr when a worker again walked through the blighted foliage 5 m upwind of the trap.

The highest numbers of spores trapped in observations made over several seasons occurred during harvesting operations. Harvesting occurred when total foliage was greatest and usually when disease was maximal. Numerous occasions were observed where high numbers of trapped spores were traced to their detachment by harvest operations even though weather conditions were seemingly unfavorable for natural spore release (Table 4).

On 30 December 1969, harvest in a celery field with estimated 3-5% blight resulted in an unseasonably high count of 200 spores/day recorded by a spore trap operating in blight-free younger celery 150 m downwind. Infection from that solitary peak of spore numbers was detected 12 days later. Infection was most severe in plants closest to the harvested area 30 m away (15 lesions/leaf) and blight tapered off downwind to 10 lesions/leaf at the trap. Only occasional lesions were observed at the furthest field area, 1 km downwind from the harvested field.

Relation of lesion numbers to daily spore

TABLE 3. The daily numbers of trapped spores in relation to disease incidence[a]

% Disease	Spores trapped/day
0.0001 - 0.1	0 - 25
0.1 - 1.0	10 - 100
1.0 - 3.0	50 - 500
3.0 - 5.0	100 - 1,000
5.0 - 7.5	200 - 1,250
7.5 - 10.0	300 - 1,500
10.0 - 15.0	800 - 4,000
over 15.0	over 1,000

[a] Data taken from 1,000 "trap-days" in nearly mature celery assuming at least minimum conditions for sporulation with no allowance made for long distance "blow-in" or mechanical detachment. Traps operated at 8.75 liters/min (15 cubic ft/hr).

TABLE 4. Selected spore-trap records illustrating *Cercospora apii* spore catch from harvest release[a]

Time	3 Dec 69[b]	4 Dec 69	27 April 70[b]	28 April 70
0800-0900	0	1	0	0
0900-1000	0	125[c]	30	40
1000-1100	0	10	30	65
1100-1200	5	5	20	25
1200-1300	1	20	20	500[c]
1300-1400	1	0	10	100[c]
1400-1500	0	0	5	25
1500-1600	0	0	5	25
1600-1700	0	0	5	25
1700-1800	0	0	5	10

[a] Estimated blight was 10% for 3 and 4 Dec 69; 3% for 27 and 28 April 70. Blight-favorable hours were 0 for 3 and 4 Dec 69; 10 for 27 April 70; and 11 for 28 April 70.

[b] Typical daily spore catch.

[c] Spore catch from harvest release.

counts.—The number of spores trapped daily gave a valid prognosis of the disease incidence likely to be observed after the incubation period elapsed. Zero to 25 spores trapped per day generally resulted in little detectable increase in lesion numbers. Twenty-five to 100 spores/day resulted in light infection; 1 to 10 lesions often developed on unprotected leaves of mature plants in the monitored area. Moderate blight (5 to 20 lesions/leaf) developed from counts of 100 to 300 spores/day. When spore counts were above 300 spores/day unprotected leaves became severely blighted. Some daily infection was observed, regardless of customary spray coverage, when spore counts were very high (800 to 10,000 spores/day).

Sporulation on refuse.—The plant material remaining in the field following harvesting from the leaf-stripping and plant culling and topping operations, if blighted, resulted in a suitable substrate for *C. apii* sporulation. This refuse was covered with fruiting structures of the fungus in favorable weather and winds often carried those spores to younger celery (as detected by trapping).

Delay of log increase of disease with blight-free transplants.—The effect on disease incidence of planting blight-free celery transplants was compared to that obtained with slightly and severely infected

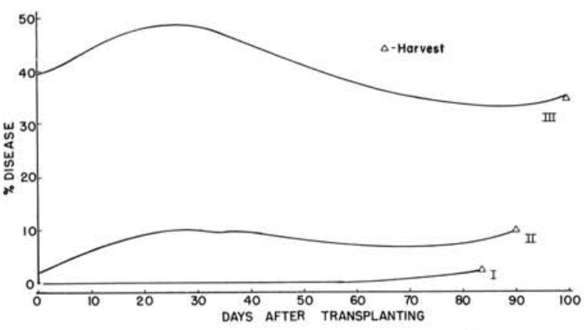

Fig. 2. Disease (early blight) progress and harvest dates of celery with three levels of blighted foliage at transplanting.

transplants. Crop culture, fungicide programs, and weather varied between locations; consequently direct comparisons were not precise although the data showed certain tendencies. The amount of blight on the transplants appeared to provide an over-riding influence on the course of disease at the three locations, particularly in delaying the logarithmic phase of disease progress (< 5.0%) (12).

Blight-free transplants were set in 122 hectares (300 acres) at location I. The epidemic was delayed so that less than 2% blighted foliage was present at harvest, 12 weeks from setting (Fig. 2); regular fungicide treatments were applied throughout the season. The plants remained blight-free for about 8 weeks, at which time infected transplants were introduced into a nearby field which provided an inordinate amount of spore "blow-in". The excellent blight control achieved through setting blight-free plants and routine spraying advanced harvest 7 to 10 days earlier than projected and yields were considerably above average.

Plants with less than 5% blighted foliage were set in 243 hectares (600 acres) at location II. The epidemic reached the 10% disease level in 4 weeks, and only intensive spraying maintained satisfactory disease control where daily new growth equalled or exceeded that percentage affected by disease. Harvest occurred near the projected date and yields were average.

Severely infected transplants with about 40% blighted foliage were set in 81 hectares (200 acres) at a third location (III). Disease incidence fluctuated in the 35 to 50% range for the duration of the season. Fair blight control was achieved with very frequent fungicide applications. Yields were considerably reduced and harvest was delayed 2 weeks over standard because of the loss of foliage to blight.

DISCUSSION.—In analyzing the spread of *C. apii* in Florida celery, the disease in many respects fits very closely the theories of disease progress set forth by van der Plank (12). Accurate disease severity ratings over the course of several crop seasons often depicted celery blight as developing similar to the lower and middle portions of the sigmoid curve for epidemic progress. Van der Plank (12) did not consider in detail disease increases in a crop of indeterminate growth under circumstances where weather or control measures may halt disease increase, as occurred with celery infected by *C. apii*. Growth of new, noninfected tissue of celery diluted the amount of disease so that there was a decrease in disease incidence resulting in negative infection rates (12). Mechanical tillivation in usual celery culture may effect a removal of diseased tissue and this practice may cause a decrease in the total amount of disease.

It was of particular interest that the number of trapped spores monitored over several seasons closely reflected the respective disease progress curves. The trap monitoring gave a more valid estimate of daily blight pressure than meteorological data since spore releases brought about by mechanical disturbance of spore-bearing plant tissue could not be determined through examination of weather data.

Heavy, beating rain decreased the number of trapped spores because of the erosion of conidia and conidiophores from lesion surfaces. On several occasions following beating rains, spore numbers were negligible the first day and even somewhat reduced the second day. The time lag for the fungus to resume maximum sporulation following heavy rain was dependent on the time needed for the formation of new conidiophores from the denuded stromata (mostly the first day's blight-favorable period) and new conidia (the second and subsequent days).

The effect of crop canopy on spread of Cercospora blight of celery and other diseases needs to be examined. It is fairly well established that the leaf microclimate in a plant canopy could be considerably altered from the ambient field climate (7). The extent to which sporulating lesions within the canopy participate in disease spread has not been fully determined. Plant growth could act as a system that partially or totally removes lesions from further participation in the epidemic. Lesions on the upper, more fully exposed leaves may play the most significant role in disease spread. Spore counts from young and mature celery provided additional evidence that crop canopy influenced this aspect. Spore counts in mature celery were only 10X that recorded in young celery at the same disease incidence although there was a hundredfold difference in leaf area.

Occasionally, *C. apii* spores were trapped when no disease was observed in the monitored field. These spores evidently arose from a few undetected lesions in nearby field areas, or they were detected as "blow-in" from distant sources. Low numbers of spores (20 to 50/day) were trapped on several days when wind was from the direction of an abandoned 40.5 hectare (100 acre) field of severely blighted celery, 15.3 km from the trap.

Several high spore counts were recorded at times of little wind 1.6 km/hr (less than 1 mph) as also reported by Meredith (11) and others (4, 10) for *C. beticola*. Few *C. apii* spores were trapped at night, even during storms. which is in contrast to Lawrence & Meredith's (10) report on *C. beticola*.

Current disease simulators (9, 13) pay particular attention to meteorological conditions as affecting spore formation and discharge. With *C. apii*, many spores remain on lesion surfaces several days after they are formed. A disease simulator for celery blight must take into account the important spore dissemination peaks that occur at times other than those influenced by favorable weather conditions. Disease simulators for this and other diseases would likely be more accurate if spore monitoring data was included in the program.

Van der Plank (12) has adequately described the effect of sanitation on a compound-interest type disease. The results obtained by using blight-free, or nearly blight-free celery transplants supported van der Plank's thesis. However, the combination of blight-free transplants and routine fungicide sprays appeared to be much more effective in delaying the initial appearance and logarithmic phase of blight than was considered by that author.

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