Rainfall, Irrigation Water, and Temperatures Associated with First Occurrences of Tobacco Blue Mold in Leaf Production Area of North Florida from 1979 to 1984

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ABSTRACT

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Blue mold of tobacco occurred in north Florida in transplant beds or fields each year from 1979 to 1984. Average daily minimum temperatures for 10, 20, and 30 days prior to first disease occurrences at different sites varied considerably. Days achieving 30 C or greater or 7.8 C or less, both temperatures reported to have deleterious effects on the pathogen, were as high as 23 and 21, respectively, for 30 days prior to the appearance of the disease. For 10 days prior to occurrence of disease, days achieving these same temperatures were as high as 8 and 9, respectively. Of 18 sites studied, 14 sites had rainfall amounts in excess, some by a factor of two or three, of the normal for the 30 days prior to disease occurrence. Three of the remaining four sites also had excessive moisture when overhead irrigation was considered. One of these three sites had three adjacent tobacco fields with different blue mold severities that corresponded to the irrigation amounts and numbers. One of these fields, which was between the other two, had no blue mold and it received the least amount of irrigation. Because of the apparent wide temperature regimes and high rainfall or irrigation amounts associated with first blue mold appearances, moisture appears to be the stronger of the two variables in relation to blue mold occurrence in north Florida.

Additional key words: *Nicotiana tabacum*, *Peronospora tabacina*

Blue mold, caused by the obligate parasite *Peronospora tabacina* Adam, has been a sporadically occurring disease on tobacco (*Nicotiana tabacum* L.). Blue mold was first observed in 1921 in the United States and has occurred in Florida during at least 38 of the last 64 yr (inclusive of 1984) according to records of the Bureau of Plant Pathology (Division of Plant Industry, Department of Agriculture and Consumer Services, Gainesville), the Florida Plant Disease Clinic (Plant Pathology Department, University of Florida, Gainesville), and select literature (1,2,10,11,13–15,18,19). Included in these occurrences were the presence of blue mold in 9 of 10 yr in central Florida transplant beds between 1960 and 1969, occasional occurrences in the north Florida leaf production area during the 1970s, and one occurrence in the Vero Beach area in 1978.

On 9 May 1979, a severe blue mold epidemic began within the leaf production area of north Florida in Alachua County (26). As the season progressed, blue mold became epidemic on transplanted tobacco throughout the tobacco-growing regions in the United States and Canada (26). This first occurrence in Florida was associated with 20.8 cm of rainfall during April, which was the highest on record for that month in 25 yr. The last known epidemic in north Florida was sometime during March 1959 on plants in a transplant bed at the University of Florida, Gainesville (E. B. Whitty, *personal communication*). Interestingly, the 1959 epidemic was associated with 26.6 cm of rain, the highest amount recorded for March, April, or May from 1954 to 1984.

Except for an axiomatic realization that moisture is necessary for blue mold development, the relative importance of moisture compared with temperature effects on blue mold has attracted minimal study with conflicting interpretations. Cruickshank (6) deduced that because of the wide temperature range for spore germination, moisture relations may be the most important variable regulating blue mold development in Australia. Clayton and Gaines (3) stated that heavy rains tend to check blue mold development. Miller (20) concluded that rainfall and other moisture-related variables were not as important as January temperatures for blue mold occurrences on plants in the plant bed. Csinos and Arnett (7) mentioned that the initiation of the epiphytotic of blue mold in Georgia in 1980 was associated with 48.5 cm of rain.

From 1979 to 1984, many blue mold occurrences in Florida were associated with temperature and rainfall regimes that would normally be expected to be adverse for pathogen development and disease expression (4–6,9,16,18,20,21,23). Also, during the 6-yr period, average maximum and minimum temperatures in January were either below normal (1979, 1981, and 1983), mostly below normal

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(1982), or near normal (1980) for reporting NOAA-affiliated stations, which does not conform to the relationship of above-normal January temperatures and subsequent blue mold development (20). The purpose of this paper is to describe the wide variation in temperatures and the influences of rainfall and overhead irrigation events associated with first occurrences of blue mold in Florida.

MATERIALS AND METHODS

Eighteen first occurrences of blue mold in Florida counties from 1979 to 1984 are presented. Each of these occurrences is given a site (case) letter (A–R). Each site where blue mold first occurred in the state in each of the 6 yr was observed by the author, as were those sites where irrigation was thought to have been involved with the appearance of blue mold. Of the 18 sites, F, N, O, and P were observed by county agents, who also submitted samples to the Florida Plant Disease Clinic for confirmation. The date of first appearance of blue mold and other pertinent information were not available for all first occurrences of blue mold for each county in each year, and therefore not all sites are included. No fungicides, except preplant fumigation chemicals, were used prior to the occurrence of blue mold at any of the sites.

Weather data were attained from *Climatological Data* (volumes 83–88), published by NOAA (National Climatic Center, Asheville, NC), or directly from those responsible for recording temperature and rainfall events for the pertinent NOAA weather stations. Temperature and rainfall data ascribed to a site were from the closest NOAA weather station. Except for Union County, where the closest reporting station was in Bradford County (Starke), all weather stations were located within the respective county where blue mold was found. Rainfall in this report was associated with frontal passages, except for three rainfalls totaling 1.3 cm associated with site R in mid-May 1984. These three rainfalls were probably from small convective-type clouds.

Accumulated total numbers of days achieving 30 C or higher and 7.8 C or lower were determined for each site because of reported effects of these temperatures on spore germination (5,16), symptom expression (23), and sporulation (4,6,9,23) in relation to blue mold.

Information on overhead irrigation frequencies and amounts (to the nearest 1.3 cm) were attained from growers during on-site visits. Actual dates of irrigation were not always available but could be confidently placed within a 30-day period prior to the appearance of blue mold. To reaffirm that the date when blue mold was first seen by the grower was likely to be near the time when blue mold first appeared, the grower was asked to describe disease distribution. At all sites, the author witnessed or the grower made reference to an infection focus or a few discrete foci, which should be indicative of an earlier aspect of the epidemic.

Blue mold severities were assessed at site R in Alachua County in 1984 for different portions of one field and two nearby fields. The grower used different irrigation regimes in each field. The cultivar Speight G-28 was used in all three fields, and fertilization for the three fields was identical (25).

RESULTS AND DISCUSSION

Overview of blue mold epidemics from 1979 to 1984. Blue mold occurred in north Florida each year from 1979 to 1984. Major epidemics throughout the north Florida area occurred in 1979, 1980, and 1983. The 1979 epidemic was confined to transplanted tobacco beginning on 9 May, more than 1 mo after transplanting for most fields. The 1980 epidemic occurred primarily in transplant beds but did occur on transplanted tobacco to a lesser degree. The 1983 epidemic occurred in transplant beds beginning on 7 March and continued through transplanting and into mid-June. Single occurrences of blue mold were found in 1981 and 1982, and three were found in 1984.

Minimum temperatures associated with blue mold appearance. First occurrences of blue mold were associated with as few as 0 and as many as 21 of the previous 30 days with temperatures of 7.8 C or lower (Table 1). At site I, which was the only known occurrence of blue mold in Florida in 1981, 9 of the 10 days prior to blue mold appearance had a temperature of 7.8 C or less. The average minimum temperature for the 30 days prior to blue mold appearance ranged from 3.9 (site C) to 16.8 C (site A) for the 18 sites (Table 1). The average minimum temperatures for these 30-day periods were near the 30-yr average for each site on that date. Considering the average minimum temperature for 10- and 20-day

Table 1. Select temperature measurements prior to first occurrences of blue mold of tobacco in Florida from 1979 to 1984[a]

Case and place[b]	County	Date[c]	Av. min. temp. (C) for previous			30-Yr av.[d]	No. days 7.8 C or lower			No. days 30 C or higher		
			10 Days	20 Days	30 Days	(30 days)	10	20	30	10	20	30
AF	Alachua	9 May 1979	18.1	17.2	16.8	14.8	0	0	0	4	4	9
BF	Madison	25 May 1979	15.8	17.6	16.3	16.6	0	0	0	5	12	14
CB	Suwannee	29 Feb. 1980	8.2	7.6	3.9	NA	4	8	21	0	0	0
DB	Alachua	22 Mar. 1980	15.0	11.6	10.5	9.7	1	5	11	0	0	0
EB	Columbia	17 Mar. 1980	12.4	7.4	6.8	8.0	1	8	14	0	0	0
FB	Hamilton	18 Mar. 1980	11.7	9.6	7.2	6.8	2	11	14	0	0	0
GF	Madison	22 Apr. 1980	11.9	12.6	12.4	12.6	2	3	4	0	0	0
HF	Dixie	25 Apr. 1980	11.3	11.7	12.1	11.9	3	4	4	0	0	0
IB	Dixie	23 Mar. 1981	3.2	4.7	8.2	8.0	9	17	19	0	0	0
JF	Suwannee	15 Apr. 1982[e]	10.6	10.9	12.9	NA	2	6	6	0	2	8
KB	Alachua	7 Mar. 1983	10.2	9.2	6.6	8.1	4	9	17	0	0	0
LB	Columbia	6 Apr. 1983	8.1	8.1	8.6	10.2	4	8	13	0	0	0
MB	Suwannee	6 Apr. 1983	9.8	9.1	9.7	NA	4	9	13	0	0	0
NB	Union	7 Apr. 1983	7.0	7.5	8.9	NA	6	11	12	0	0	0
OF	Baker	21 Apr. 1983	7.4	9.9	9.7	11.3	7	7	12	0	1	1
PF	Jefferson	15 May 1983[f]	20.3	16.9	14.0	14.1	0	9	9	5	5	5
QF	Madison	1 May 1983[g]	10.9	9.9	10.9	13.6	1	5	7	0	0	0
RF	Alachua	22 May 1984	15.1	13.6	15.9	16.3	0	0	0	8	16	23

[a] Temperatures from *Climatological Data* volumes 83–87 and *Climatological Data for Gainesville* (both NOAA-affiliated).
[b] First letter (A–R) = case; second letter = B for transplant bed and F for field.
[c] Date of symptom appearance.
[d] Interpolated from monthly averages from NOAA records; NA = not available.
[e] Blue mold was halfway up plants on 5 May; the 15 April date is considered approximate time disease first appeared.
[f] Within 3 days of first appearance.
[g] Blue mold was two-thirds of way up plant on 25 May; the 1 May date is considered approximate time disease first appeared.

periods prior to blue mold appearance, respectively, the ranges were similar, 3.2 (site I) to 20.3 C (site P) and 4.7 (site I) to 17.6 C (site B).

Considering the variation between previous studies (3,4,6,9,23) on minimum temperatures that support pathogen and symptom development, the wide range of minimum temperatures associated with blue mold appearance in this study may be normal. Clayton and Gaines (4) found that the temperature for optimal spore germination varied from 1.6 to 26.1 C depending on the time of day spores were harvested. Cruickshank (6) determined that sporulation was greatly reduced, not eliminated, after 6-hr exposures to 7.8 C or lower. Clayton and Gaines (3) noted that blue mold was associated with minimum temperatures from 10 to 18 or 21 C. Dixon et al (9) associated minimum temperatures of 5.6–16.7 C from 0 to 9 days before first occurrences in North Carolina from 1931 to 1935. They also found that sporulation was abundant from 5.6 to 17.2 C and occurred from 2.2 to 20 C. Rotem and Cohen (23) attained trace amounts of sporulation at 5 C, with 15 C being optimal for sporulation. Clayton and Gaines (3) found that sporulation did not occur with constant temperatures from 4.4 to 24 C but did occur when infected plants were exposed to diurnal temperatures with the optimum minimum temperature being 16 C and a temperature of 10 C noticeably reducing sporulation. The 18 sites in this study are representative of the range of minimum-temperature effects found in previous studies.

Maximum temperatures associated with blue mold occurrences. Six of the 18 sites had incurred days of 30 C or higher for the 30 days prior to blue mold appearance (Table 1). Sites B and R, respectively, had 14 and 23 days with such temperatures. Also, sites B, P, and R incurred such temperatures for at least 5 of the 10 days prior to appearance of disease. Blue mold continued to increase on numerous farms in Florida during 1979 and 1983 after these initial finds and after numerous days that had reached 30 C or higher.

Although previous studies have demonstrated the adverse effects of 30 C on spore germination (5,16) and sporulation (4,6,9,23) of *P. tabacina* as well as symptom expression of blue mold (23), the occurrence of blue mold at six of the 18 sites indicated that this temperature cannot be relied on to thwart the initiation of blue mold. Furthermore, it has been shown that the adverse effects of 30 C on symptom development can be overcome by lengthening the time inoculated plants remain at 20 C during the early incubation period (23). Popular (21) also indicated that the presumed inhibitory effect of 30 C may not be a strong parameter because of the normal occurrence of blue mold in some localities after the accumulation of days with temperatures of 30 C or greater. High-temperature parameters associated with blue mold seem to vary considerably, as do the low-temperature parameters.

Average temperatures associated with and overall impact of temperature on blue mold occurrences. None of the 18 sites incurred both minimum and maximum temperatures, respectively, of 7.8 C or lower and 30 C or higher within 10 days of blue mold appearance (Table 1). However, such did occur at sites J, O, and P within 20 and 30 days of blue mold appearance. The average daily temperature for 30 days prior to appearance of blue mold ranged from 10.5 (site C) to 23.7 C (site R). This range is near the 16.7 C that McGrath and Miller (18) concluded was the overall optimum for blue mold development after composite analyses of numerous studies cited in their summary article that represented those events from spore germination and infection to symptom development and sporulation. The various temperature parameters associated with blue mold occurrences from 1979 to 1984 were not unusual for north Florida, and therefore, temperature by itself does not appear to account for the occurrences of blue mold for this 6-yr period.

Amounts of rainfall and irrigation associated with blue mold appearances. Fourteen of the 18 sites received rainfall amounts in excess of the 30-yr average for that date (Table 2) for the 30 days prior to blue mold appearance. Sites C, D, I, and R had less than average rainfall for the previous 30 days. Sites D, I, and R each received amounts of overhead irrigation that together with rainfall

Table 2. The amounts and frequency of rain and irrigation associated with first occurrences of tobacco blue mold (TBM) from 1979 to 1984 in Florida[a]

Case and place[b]	County	Date[c]	Amounts (cm) prior to TBM appearance				30-Yr av.[d]	Number prior to TBM appearance			
			Rain			Rain and irrigation		Rain			Rain and irrigation
			10 Days	20 Days	30 Days	(30 days)	(30 days)	10 Days	20 Days	30 Days	(30 days)
AF	Alachua	9 May 1979	6.9	13.2	16.0	16.0	8.4	5	8	11	11
BF	Madison	25 May 1979	0.2	12.4	15.0	15.0	9.9	3	9	13	13
CB	Suwannee	29 Feb. 1980	0.2	4.3	4.9	4.9[e]	9.7	2	4	6	6
DB	Alachua	22 Mar. 1980	0.7	4.7	8.0	23.2	9.8	2	7	10	16
EB	Columbia	17 Mar. 1980	28.4	29.3	36.8	36.8	10.4	5	7	10	10
FB	Hamilton	18 Mar. 1980	13.3	14.1	18.2	18.2	11.1	4	5	9	9
GF	Madison	22 Apr. 1980	4.1	10.3	15.2	15.2	10.4	4	8	12	12
HF	Dixie	25 Apr. 1980	0.1	7.8	21.6	21.6	8.0	1	6	9	9
IB	Dixie	23 Mar. 1981	2.6	5.9	5.9	16.1	10.0	4	6	6	14
JF	Suwannee	15 Apr. 1982[f]	10.4	12.2	18.5	18.5	10.5	4	7	11	11
KB	Alachua	7 Mar. 1983	0.9	3.2	10.7	10.7	9.8	2	6	11	11
LB	Columbia	6 Apr. 1983	1.8	11.6	18.3	18.3	10.4	2	7	10	10
MB	Suwannee	6 Apr. 1983	3.4	11.5	17.0	17.0	10.9	3	7	11	11
NB	Union	30 Mar. 1983	6.5	20.0	27.9	27.9	8.5	3	7	8	12
OF	Baker	26 Apr. 1983	2.8	11.8	13.0	13.0	8.8	3	7	9	9
PF	Jefferson	15 May 1983[g]	1.6	2.3	17.3	17.3	11.2	5	6	10	10
QF	Madison	1 May 1983[h]	4.9	9.7	21.5	21.5	9.8	1	2	7	7
RF	Alachua	22 May 1984	0.0	0.7	1.3	31.8	9.7	0	3	4	8

[a] Rainfall is from *Climatological Data* volumes 83–87 and *Climatological Data for Gainesville* (both NOAA-affiliated); irrigation is as reported by grower in increments of 1.3 cm.
[b] First letter A–R = case; second letter = B for transplant bed and F for field.
[c] Date of symptom appearance.
[d] Interpolated from monthly averages from NOAA records.
[e] Grower claimed no irrigation used.
[f] Blue mold was halfway up plants on 15 May; the 15 April date is considered approximate time disease first appeared.
[g] Within 3 days of first appearance.
[h] Blue mold was two-thirds of way up plant on 25 May; the 1 May date is considered approximate time disease first appeared.

exceeded the 30-yr average for that date. Site C may have received irrigation, but that cannot be confirmed.

Number of rainfalls and irrigations associated with blue mold occurrences. Fifteen of the 18 sites had 9 days or more with rain or irrigation for the 30 days prior to the appearance of blue mold (Table 2). Sites Q and R had 7 and 8 days with rainfall or irrigation, respectively, but rainfall or irrigation amounts were more than twice and three times above normal for those dates, respectively. The number of days with rainfall within 10 days of blue mold appearance was quite low for some sites, even those where irrigation was not used. Sites H and Q, where irrigation was not used, had 1 day with rain within 10 days of blue mold appearance. The strong effects from rainfall or irrigation may have been 10–30 days prior to the finding of blue mold foci, which could be the period when incipient infections occurred. However, the chronological plotting of days with rain failed to reveal a common pattern among sites.

Specific on-farm irrigation practices that contributed to blue mold occurrences. Site R was the first, and one of three, where blue mold occurred in Florida in 1984. This site offered a unique situation to assess blue mold where different irrigation practices were employed. Three fields of tobacco were planted with the cultivar Speight G-28, and the fertilizer program was the same. Row direction was east to west for each field, with the north and south fields parallel to each other and 30 m apart. The northeast field was less than 60 m from the north field. No blue mold was observed anywhere in the north field, where rainfall and irrigation totaled 2.6 cm in amount and five in number. In contrast, blue mold occurred in the south and northeast fields, where application of irrigation water was higher in amount and number. The north field was exposed to blue mold inocula from the south and northeast. In the south field, blue mold severities were greatest along rows surrounding an alley near the center of the field. Noticeably, the amount of blue mold diminished from 10% to a trace amount as the distance increased from this alley. The grower indicated that the area where blue mold was most severe received eight irrigations totaling 30.5 cm of water compared with half of that in number and amount for the remainder of the field because of overlap from the irrigation gun that traveled along alleys on both the north and south sides of that zone. For the 30 days prior to blue mold appearance, the weather was hot and dry, as indicated by the occurrence of only 4 days with rain and 23 of the past 30 days with temperatures of 30 C or more (Table 1).

On 5 June 1984, blue mold appeared in another field in Alachua County. Disease was generally distributed and was associated with 32.2 cm of rain and irrigation. For 10 and 30 days prior to blue mold appearance, respectively, 7 and 21 of those days had temperatures of 30 C or higher. This site was being used by University of Florida agronomists to study the effects of maximum irrigation on reduction of plant stress. Of the 32.2 cm of water, 15.2 cm was from five irrigations of 3 cm each and 17 cm was from eight rainfalls varying from a trace to 6.9 cm. The grower decided when to irrigate according to soil tensiometer measurements, a technique with more frequent usage by growers of agronomic crops in Florida.

According to observations and informal reports from ASCS personnel, irrigation of tobacco has increased greatly in recent years. Main et al (17) used irrigation to extend leaf wetness periods for epidemiological studies on blue mold. They concluded that a temperature-tolerant strain might exist, because blue mold persisted in their test site after the occurrence of daytime temperatures of 30 C or higher. Several sites within this study were associated with daytime temperatures of 30 C or higher, but these occurrences may not be associated with a temperature-tolerant strain. First, moisture in the form of rainfall or overhead irrigation can influence canopy temperature in a complex way and can cool the canopy area (12; J. Bennett, *personal communication*). Specific information in this regard is not available for tobacco. However, temperatures within irrigated, mature peanut canopies have been measured to be 6.5–7.5 C lower than within water-stressed canopies (24). Second, the inducement of symptom expression at 30 and 40 C by manipulation of early incubation temperatures (23) disproved the occurrence of a thermophilic strain in Israel. Rotem and Aylor (22) found during the latter part of the tobacco season in Connecticut that *P. tabacina* continued to sporulate and cause disease when average minimum daily temperatures and the average air temperatures were suboptimal, marginal, or even submarginal as long as abundant inoculum was available and leaf moisture was adequate for sporulation and infection.

Davis et al (8) used a broad-scale meteorologic approach to interpret the general effects of weather on blue mold development and spread in the United States and Canada in 1980, but they cautioned that such an approach would "filter out" the effects of smaller scale meteorologic events on localized disease situations. Data herein support that conclusion, particularly when irrigation is considered.

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