Weather and Epidemics of Septoria Leaf Blotch of Wheat

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Purdue University Agricultural Experimental Station Journal Paper No. 5950.

Accepted for publication 8 January 1976.

ABSTRACT

SHANER, G., and R. E. FINNEY. 1976. Weather and epidemics of Septoria leaf blotch of wheat. Phytopathology 66: 781-785

Weather records were compared with severity of Septoria leaf blotch of wheat over a 20-year period at Lafayette, Indiana. In 3 years of "very severe" epidemics, in which all leaves of susceptible cultivars were killed prematurely, there were at least 40 days of rain from 1 April - 17 June, 8 days above average. A "severe" epidemic occurred when there were 34 days of rain if there was no excess of 2-day periods with minimum temperatures of 7 C or lower (34 such periods compared to an average of 26). It may be possible to forecast a "very severe" epidemic at the time flag leaves emerge by examining weather data from the previous 40 days (1 April - 10 May) and predicting weather for the next 35 days. A severe epidemic is likely to develop if past weather has been favorable, if the pathogen is well-established, and if the 30-day outlook is for much above-normal precipitation (17 or more days of rain from 11 May - 14 June).

Additional key words: Septoria tritici, Triticum aestivum, epidemiology, temperature, moisture.

Septoria leaf blotch of wheat, caused by *Septoria tritici* Rob. ex Desm., is an important disease in many parts of the world (14). Recent reports suggest that the disease is becoming more serious (10, 12). Indiana farmers annually plant 6-7 $\times 10^5$ hectares (ha) of wheat and Septoria leaf blotch is now one of the major hazards to producing a successful crop. Although a resistant cultivar is now available (12), most of the wheat in the state is very susceptible to the disease.

Leaf blotch evidently is serious only in wet weather, but there is little specific information on the relation of weather to epidemics of the disease. In an early study, abundant warm rains with foggy or cloudy conditions were considered to favor spread in Wisconsin (15). Mackie (7) reported that similar conditions in California favored the disease. To induce the disease artificially, inoculated plants in the field or greenhouse are kept in a moist chamber for 2-4 days to obtain satisfactory infection (5, 6, 8).

In the field a 15-hour period of leaf wetness was the minimum for infection (9). Water on leaves for 35 hours followed by 48 hours of high relative humidity favored heavy infection. In the laboratory, spores germinated on wet leaves within 12 hours and penetrated after 24 hours (5). High relative humidity also favors lesion growth (8), pycnidium formation (9), and oozing of conidia from ostioles of pycnidia (3). In one study, leaves were never sprayed with water, but inoculated plants were maintained at 100% RH in polyethylene bags while they were transferred between 4 C and 23 C diurnal temperature regimes during infection and lesion formation (1). Thus, evidence indicates that moisture is important in all stages of the infection cycle, from inoculum production through liberation, dispersal, penetration, and lesion development, but it is unclear how much moisture is needed in the field or for how long, for an epidemic to develop.

In breeding for resistance to this disease it has been our experience that if leaf blotch fails to develop naturally on uninoculated wheat, it also develops poorly on inoculated wheat regardless of the frequency and timing of inoculations. Development of the disease is similar on both uninoculated and inoculated wheat. Compared to the climate of the wheat growing areas of the Great Plains or Pacific Northwest, most of Indiana's wheat seasons may be considered wet. Nevertheless, leaf blotch is a serious problem only in years that seem abnormally wet.

There also is little useful information in the literature concerning temperature and leaf blotch. Many references suggest 20-24 C as the optimum range for disease (14), but data on comparative rates of pathogen development over the range of temperatures that occur during the wheat growing season are lacking. Renfro and Young (9) observed that two consecutive days with a minimum temperature of 7 C or less inhibited infection.

Because information in the literature does not define precisely the weather conditions conducive to leaf blotch epidemics, we attempted to discern some relation among rainfall, temperature, and leaf blotch severity on winter wheat at Lafayette, Indiana.

MATERIALS AND METHODS

Disease observations were made at the Purdue University Agronomy Farm near West Lafayette, Indiana. This farm is also the site of a weather station of the National Oceanic and Atmospheric Administration (NOAA) network. The station is at 40°28' North latitude, 87°00' longitude, 215.6 m elevation, and within 0.25 km of the plots in which disease assessments were made. Temperature and rainfall data from this station are published by the National Climatic Center of the National Oceanic and Atmospheric Administration.

Research on Septoria leaf blotch and development of resistant cultivars began at Purdue about 1955 under the direction of R. M. Caldwell (8). Since that time, observations have been made each year on disease development at the Agronomy farm. The favorability of weather for leaf blotch epidemics each year was taken from the description of disease severity on the highly susceptible cultivar 'Monon' and related genotypes. In 1973 we began keeping records of disease development in large (30 × 1.6 m) plots which are part of our standard cultivar-testing program. Severity was recorded several times each season. Leaf blotch severity also was recorded in commercial fields throughout the state during 1973. In each field approximately 20 culms at about 5-meter intervals were rated for severity. From these data an average severity for the field was calculated. Data from several fields in adjacent counties were averaged to obtain the severity for a larger area.

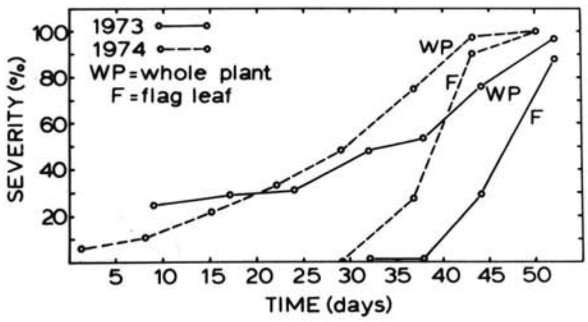

Fig. 1. Progress of Septoria leaf blotch on 'Monon' wheat at Lafayette, Indiana. Day 1 is 6 May. Wheat headed on 24 May in 1973 and 21 May in 1974.

RESULTS

We ranked the years 1955-1975 according to the severity of leaf blotch at the Agronomy Farm (Table 1). Some years may not be ranked correctly because severity data were not quantitative; however, we feel that the years are classified accurately within the broader categories 'Very severe', 'severe', 'moderate', and 'light'. 'Very severe' means that all leaves of susceptible cultivars were killed prematurely by *S. tritici* (Fig. 1). In these years leaf rust and powdery mildew were negligible. In 1970, when disease was 'severe', the lower leaves of susceptible cultivars were killed, but the flag leaf was only lightly infected.

To relate disease severity to weather, we examined weather data for 1 April - 14 June, the period of active spring growth and grain development of fall-sown wheat. Much fall-produced foliage dies back in winter. Regrowth begins in mid- to late-March, depending on temperature, and by late April stems are elongating. By 14 June flag leaves are senescing naturally, if not already killed by disease, the penultimate leaf is nearly dead, and grain is in the soft dough stage. Wheat is ripe for harvest (14% moisture) by about 7 July. Thus infections after 14 June are not likely to contribute to yield loss.

We compared the number of days on which rain fell and also total rainfall, during the period 1 April - 14 June, with leaf blotch severity. Both our experience and the literature suggest that duration of leaf wetness is critical for spread of *S. tritici*. We expected that rainfall frequency, more than its total, would reflect this, and therefore would correlate better with disease severity. Rainfall total is related to the number of days with rain,

TABLE 1. Weather parameters related to the severity of Septoria leaf blotch of wheat at Lafayette, Indiana

Year	Severity of leaf blotch	No. of days with rain 1 April-14 June	No. of days with rain 11 May-14 June	Frequency of 1-day rainfree periods (%)	Total rainfall 1 April-14 June (mm)	Temperature 1 April-14 June Mean (C)	Temperature Max. (C)	Temperature Min. (C)	No. of 2-day periods with min. temp. ≤ 7 C 1 April-14 June	No. of 2-day periods with min. temp. ≤ 7 C 11 May-14 June
1974	very severe	44	24	53	295	14.2	19.6	8.8	22	0
1973	very severe	41	17	42	268	14.2	19.6	8.8	29	5
1957	very severe	40	19	56	421	14.4	19.3	9.4	20	0
1970	severe	34	13	50	334	15.5	21.4	9.6	28	0
1958	mod. severe	30	12	38	370	14.1	20.4	7.8	23	1
1964	mod. severe	32	14	35	233	15.7	22.7	8.8	18	3
1955	mod. severe	33	19	33	344	15.4	20.9	9.9	13	0
1962	mod. severe	30	14	44	179	15.6	21.7	9.4	23	0
1960	mod. severe	29	14	29	226	14.4	19.7	9.0	22	3
1972	moderate	32	11	23	343	14.4	20.6	8.2	27	2
1971	moderate	26	12	15	107	14.0	20.7	7.3	30	5
1956	moderate	30	13	21	182	13.7	19.8	7.6	34	3
1968	moderate	31	18	56	323	13.9	19.7	8.2	26	5
1961	light	34	13	35	214	12.3	18.1	6.4	34	5
1963	light	27	14	41	193	14.7	21.2	8.2	25	4
1965	light	26	12	29	234	15.6	21.8	8.8	25	2
1966	light	31	14	47	217	12.4	18.7	6.2	36	8
1967	light	37	13	53	199	14.0	19.8	8.2	36	10
1969	light	32	15	38	272	14.1	20.3	7.8	24	6
1959	very light	27	13	31	294	15.5	21.2	9.9	21	3
mean		32.3	14.7	38.4	262	14.4	20.4	8.4	25.5	3.25
standard error of the mean		1.1	0.7	2.6	17	0.2	0.2	0.2	1.4	0.6

but the correlation for the 75-day period is low ($r = 0.414$) for the 20 years. A few heavy thundershowers may contribute to a high total rainfall yet add little to rainfall frequency.

The data in Table 1 confirm that rainfall frequency bears more relation to leaf blotch severity than does rainfall total. Rainfall frequency was clearly higher in the three 'very severe' years, but in 1973 and 1974 the totals were near average. Among the remaining years disease tended to be more severe with more frequent rainy days. Within each broad category of severity we must take the lowest frequency of rainy days as a sufficient number for that level of disease. Thus, 34 days can be sufficient for a 'severe' epidemic, 29 days for a 'moderately severe' epidemic, etc. The ranges in rainfall frequency within these broad categories overlap, except in the case of 'very severe'. Something other than the number of rainy days must account for the overlap.

Because daily minimum temperatures of 7 C or less on two consecutive days were reported to prevent infection (9), we calculated the number of such periods for 1 April - 14 June. We used a running method in these calculations; i.e., three such consecutive days counted as two periods, four such days counted as three periods, etc. The total number of these cold periods for the 75-day period ranged from 18 to 36 (Table 1). Evidently 29 cold periods are not detrimental to an epidemic (see 1973 in Table 1). This number of cold periods was exceeded in five years: 1956, 1961, 1966, 1967, and 1971. There were enough rainy days in 1961 and 1967 that we would have expected a 'severe' epidemic. Thus, we hypothesize that 34 or more cold periods will prevent an epidemic regardless of rainfall frequency.

The rainfall and cold period criteria described above seem to account for disease development in all years except 1969 and 1972. By these criteria more leaf blotch would have been expected in those years. But in 1972 its incidence may have been reduced by other diseases. The fall of 1971 was exceptionally warm and wheat at the Agronomy Farm became heavily infested with aphids. The wheat also grew excessively in the fall. During the winter this foliage was destroyed by snowmold (caused by *Typhula itoana* Imai). In the spring, plants were weak and deficient in nitrogen and many showed severe symptoms of barley yellow dwarf virus infection. The premature death of leaves and generally weakened condition of plants may have destroyed inoculum and also retarded growth of *S. tritici* in infected leaves.

Rainfall frequency and number of cold periods (two consecutive days with minimum temperature $\leqslant$ 7 C) were similar in 1958 and 1969. There was a 'moderately severe' epidemic in 1958 but very little leaf blotch in 1969. Thus, some factor not accounted for by these two criteria must have retarded disease development in 1969. Although the number of cold periods that year was only 27, the mean minimum temperature was 0.6 C cooler than average and at least 1 C cooler than the three 'very severe' years. Moreover, six of the cold periods were in the latter part of the season (11 May - 14 June), whereas in 1958 there was only one cold period during this time. The cool nights in 1969 coupled with a low rainfall total may have been sufficient to retard spread of *S. tritici*.

Disregarding 1956, 1961, 1966, 1967, and 1972, because they were too cold or otherwise unfavorable, the following association between rainfall frequency and the five broad classes of leaf blotch severity occurred in the remaining years: very severe - at least 40 days, severe - 34 days, moderately severe - 29-33 days, moderate - 26-31 days, and light - 26-32 days. Assuming there was another limiting factor in 1969, then the range for "light" is 26-27 days.

In addition to having high rainfall frequencies, the three 'very severe' years had similar mean temperatures (Table 1). Mean daily temperatures were near the 20-year average, but the mean maximum temperatures were lower and the mean minimum temperatures were higher than normal. Apparently moderate temperatures, accompanied by frequent rainfall, favor an epidemic.

These relationships between weather and leaf blotch were developed from 20 years of observations at one location because adequate disease observations were made elsewhere only in 1973. In 1973 the disease was most severe in southwest Indiana, and least severe in two

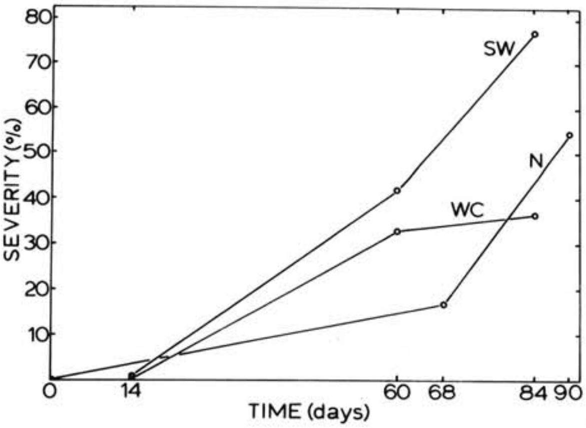

Fig. 2. Progress of Septoria leaf blotch in wheat fields in three areas of Indiana in 1973. At each date, several (usually five) fields were inspected in the northern third (N), the southwest corner (SW), and two counties in the west-central (WC) part of Indiana. Day 0 is 8 March. Wheat heads about 9 days earlier and about 5 days later in the SW and N, respectively, than at Lafayette (WC).

TABLE 2. Weather parameters that affect Septoria leaf blotch development on wheat from three areas of Indiana

	Number of days with rain		Number of 2-day periods with minimum temperature $\leqslant$ 7 C	
	1973	1974	1973	1974
Southwest[a]	47	34	24	25
West-central[b]	40	39	24	22
Northern[c]	43	44	27	23

[a]Data from stations at Edwardsport, Johnson, Mt. Vernon, and Vincennes, Indiana, for the period 23 March through 5 June.

[b]Data from stations at Terre Haute, Rockville, and Spencer, Indiana, for the period 28 March through 10 June.

[c]Data from stations at Ft. Wayne, Goshen, Rochester, South Bend, and Wheatfield, Indiana, for the period 5 April through 18 June.

counties of west-central Indiana 110 km south of Lafayette (Fig. 2). In summarizing weather data for these areas, the inclusive dates were adjusted to reflect differences in maturity of the wheat (Table 2). Disease severity in each area reflected the number of rainy days. A detailed disease survey was not made in 1974, but there were indications that disease was less severe in the southern half of Indiana, but as severe in the northern half, as in 1973 (*unpublished data* of extension pathologist D. Scott). The rainfall frequency data accord with this.

We investigated two other methods of expressing the wetness of a season. In one, the mean length of the rainfree period was calculated. This ranged from 2.1 to 3.8 days. We also calculated the percentage of rainfree periods that lasted only 1 day. These ranged from 14 to 56%. Both of these parameters were related to the number of rainy days ($r = 0.665$ and $r = 0.608$, respectively), but did not relate to leaf blotch severity as closely as rainfall frequency. In 1973 the average rainfree period was 2.8 days. Ten other years in addition to 1957 and 1974 had an average rainfree period of 2.8 days or less. The percentage of rainfree periods that lasted only 1 day was a better indication of leaf blotch potential than mean length of rainfree period. In 1973, 42% of the rainfree periods lasted only 1 day. Five other years, in addition to 1957 and 1974, exceeded this figure. These included the cold years of 1966 and 1967. This measure of wetness suggests that 1962, 1968, and 1970 were more favorable for leaf blotch than was 1973, but they were less favorable. Rainfree periods are evidently not so important in the spread of *S. tritici* as is rainfall frequency.

The simple relation between rainfall frequency, cold weather, and leaf blotch has value as a disease forecast if these weather patterns can be predicted several weeks in advance. A forecast made 1 April for the next 75 days would probably not be sufficiently accurate, but a forecast made later, to predict the final stages of an epidemic, is feasible. For purposes of prognosis we can divide the growing season into two phases, separated by the date flag leaves emerge. At Lafayette this is about 10 May. Infections occur on lower leaves during the early phase and appear on the upper two leaves during the late phase (Fig. 1, 2). Significant yield reductions seem to occur only when all leaves are severely infected (6). The flag leaf is exposed to the pathogen only during the late phase, so weather during that time is critical in determining eventual yield reduction. A disease forecast based on disease severity on 10 May and weather predicted from 11 May - 14 June would indicate the chance of substantial yield reduction.

Rainfall frequency data and cold period data for the late phase appear in Table 1. The number of days with rain for the three 'very severe' years is well above average for this 35-day period. In 1970 there were 21 days with rain in the early phase compared to 20, 24, and 21 days in 1974, 1973, and 1957, respectively. We expect that *S. tritici* would have spread in the early phase in 1970 as rapidly as in these other 3 years, which was the case. But during the late phase in 1970 rainfall frequency was near normal, which may explain why infection did not become severe on flag leaves. Only in one of the 'moderately severe' years - 1955 - was rainfall in the late phase as frequent as it was in the 'very severe' years. During the early phase there were only 14 rainy days in 1955, and this may have sufficiently reduced infection on lower leaves that not enough inoculum was available for a severe epidemic on the upper leaves.

Cold periods are uncommon in the late phase. Evidently five periods will not halt an epidemic when the pathogen is well-established on lower leaves, as in 1973. But the effect of the colder weather in the late phase of 1973 compared to 1974 is evident in the disease progress curves (Fig. 1). Disease developed more slowly in 1973, especially on the flag leaf.

Comparison of the years in Table 1 suggest that for a 'very severe' epidemic there must be at least 17 rainy days from 11 May - 14 June with no more than five cold periods. Furthermore, these 17 rainy days must have been preceded by more than 14 days of rain from 1 April - 10 May (see 1955 and 1968). The rainfall frequency necessary during the early phase is probably nearer 20 days. There are insufficient data to be more precise than that. If a disease forecast is to be made on 11 May, the current state of the disease must be determined, both from weather records for 1 April - 10 May and from actual observations of disease in the field.

DISCUSSION

The relation between weather and Septoria leaf blotch epidemics that we have identified is a fairly simple one. It seems to identify adequately or predict 'very severe' epidemics on the basis of two parameters: rainfall frequency and the number of periods of two consecutive days of minimum temperature $\leqslant 7$ C. We cannot determine precisely the number of rainy days necessary for an epidemic in which all leaves are killed prematurely because of the large gap in number of rainy days between the years of very severe epidemics (1957, 1973, and 1974) and years of less severe epidemics. This number appears to be between 35 and 40 days. Although 20 years of data were available for this study, the conclusions must be regarded as tentative. The comparisons between weather and disease incidence were made for one location only. We did obtain some confirmation of our model by examining leaf blotch severity data from other parts of Indiana in 1973 and 1974.

In relating moisture to disease severity, we have not considered dew, although there is no reason to suppose that this form of moisture would not be conducive to disease development, provided it lasted long enough. However, 15 hours of leaf wetness was reported to be the minimum for infection (9) and 48-72 hours were necessary for heavy infection. During the spring at Lafayette, dew rarely persists more than 10 hours (official weather records, Purdue Agronomy Farm, *unpublished*). Moreover, dews of this length are associated with clear weather which means that daytime conditions would probably not favor penetration, pycnidial formation, or spore release and dispersal. Possibly dew duration data would help distinguish weather conditions conducive to light versus moderate epidemics, which are not clearly distinguished by rainfall frequency data. Ideally, a weather-disease relationship for Septoria leaf blotch would use hours of leaf wetness rather than simply the frequency of rainy days. Such data are not often taken and when they are, they are not published. Surface wetness data are being gathered now at the Purdue Agronomy Farm weather station and in the future can be used in studies of weather and plant disease.

The lack of information on the effect of light, temperature, and moisture on certain stages of the disease cycle also hinders attempts to relate weather to epidemics. Very little is known about spore dispersal. Nor is it known why leaf surface wetness seems to enhance formation of pycnidia within the leaf (9, 13). It is not known if penetration will occur only if the spore and germ tube are in a water droplet, or if, once a spore has germinated in water, penetration can proceed on a dry leaf if the relative humidity is high. The correlation that we and others (7, 15) have observed between rainy weather and leaf blotch epidemics may be due not only to long periods of leaf wetness, but to the effect of reduced light intensity on host and pathogen (1).

To forecast the disease, we divided the epidemic into two phases, separated by the date flag leaves emerge, which at Lafayette is about 10 May. If *S. tritici* is abundant on lower leaves by 10 May then the challenge to the forecaster is to predict weather for the next 35 days. Weather forecasters issue 30-day temperature and precipitation outlooks every 15 days. For the 35-day period in question there is a good correlation between a prediction of higher than normal rainfall and number of days with rain, especially if below-normal temperatures are predicted (W. L. Stirm, NOAA, *personal communication*). An outlook of 'above normal precipitation' suggests 3-4 days more than the normal 12 days of rain and an outlook of 'much above normal precipitation' suggests at least 5 days more than the normal. Thus an outlook of 'much above normal precipitation' could be taken as a warning that, provided the early phase has also been favorable for leaf blotch, a severe epidemic is likely and that farmers growing susceptible cultivars can expect substantially lower yields, from direct disease effects and from lodging.

In 1973 and 1974 lesions did not appear on the flag leaves until about 4 weeks after flag leaves emerged, at which time the severity on the penultimate leaf was about 20%. Latent periods of 12-21 days have been reported (4, 7, 11). This means farmers would have 1-2 weeks (11 May - 25 May) to decide whether to spray with a fungicide. Because application would have to be by aircraft this range in time of application is desirable because of limited availability of applicators.

Wheat cultivars currently grown in Indiana head about 22 May at Lafayette. Bissonnette et al. (2) found that two aerial applications of zineb on spring wheat, one at heading and the second 10 days later, gave sufficient control of foliar diseases, including leaf blotch, to raise yields 10-20%. Such a spray schedule could be carried out on winter wheat in Indiana and would provide protection for the upper two leaves before much infection could occur.

Even if farmers choose not to apply fungicides to control leaf blotch, a forecast has value. Farmers, elevator operators, millers, and others interested in wheat would find a forecast useful as a warning that yields will be less than possibly anticipated. Finally a retrospective look at weather would tell breeders what the potential was for an epidemic during a season in which they had selected for resistance. This could be especially valuable when working with 'greenleaf' resistance (12).

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