Special Report

Factors Associated with Global Occurrences of Septoria nodorum Blotch and Septoria tritici Blotch of Wheat

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ABSTRACT

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Changes in incidence and severity of Septoria nodorum blotch (SNB) and Septoria tritici blotch (STB) have been noted in recent years in several wheat-growing areas of the world. A questionnaire was designed to identify factors associated with occurrence and development of these diseases. The questionnaire was sent to Septoria workers worldwide, and 71 responses were received and analyzed. The most important factors found relating to disease occurrence were: 1) latitude, 2) non-growing season precipitation, 3) growing season precipitation, 4) application of phosphorus, and 5) frequency of minimum or reduced tillage. Latitude effects were in agreement with general observations of SNB and STB occurrence. Also, growing season precipitation was important with regard to occurrence and severity of these diseases. Influential factors that were not expected were non-growing season precipitation and application of phosphorus fertilizer. Additionally, reduced or minimum tillage was shown to be negatively associated with disease levels, an effect opposite to that reported for other pathosystems under long-term controlled conditions. The study demonstrated the need for further investigation by a multidisciplinary team of scientists under long-term controlled conditions in order to understand the unexpected results of our survey.

Additional keywords: cereals, *Leptosphaeria (Septoria) nodorum*, *Mycosphaerella graminicola*

The Septoria diseases of cereals are pervasive, damaging maladies caused by the fungus pathogens *Phaeosphaeria nodorum* (E. Müller) Hedjaroude = *Leptosphaeria nodorum* E. Müller, anamorph: *Stagonospora nodorum* (Berk.) Castellani & E.G. Germano = *Septoria nodorum* (Berk.) Berk. in Berk. & Broome, and *Mycosphaerella graminicola* (Fuckel) J. Schröt. in Cohn, anamorph: *Septoria tritici* Roberge in Desmaz. For the purposes of this report, the diseases will be called Septoria nodorum blotch (SNB) and Septoria tritici blotch (STB). The causal organisms will be called by their classical names, *Septoria nodorum* and *S. tritici*.

SNB and STB occur in many parts of the world (Fig. 1), causing yield reductions of 50% or more when conditions are favorable for disease development (3). Damage to wheat crops can be considerable in terms of both quality and quantity of grain produced (5). Historically, relationships between yield and SNB or STB have been unclear. Similarly, occurrence and severity of these diseases have been inconsistent within and across wheat-growing regions. Recently, Scharen et al (6) showed that location and year significantly affect kernel weight in the presence of SNB. Kernel weight is the component of yield most often affected by SNB. This work clearly demonstrated the complex relationship between SNB, yield, and environmental variation.

In recent years, scientists have noticed apparent changes in the incidence of SNB and STB when compared with historic records of the two diseases in several wheat-producing regions of the world (A. L. Scharen, *personal observation*). For many years, researchers also had difficulty in clearly explaining why SNB and STB occur in some regions but do not occur or occur infrequently in other similar locations. These observations were discussed in detail at the Third International Workshop on Septoria Diseases of Cereals held in Zurich, Switzerland, in July 1989. As a result of those discussions, we decided to determine the relationship between disease presence and severity and various cultural and climatic factors. This paper reports the results of these efforts.

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MATERIALS AND METHODS

A survey questionnaire (Fig. 2) was mailed in April 1990 to 125 individuals with current or past experience working on Septoria blotch diseases of cereals in principal wheat-growing areas of the world. The list was compiled primarily from those who attended or were invited to the Third International Workshop on Septoria Diseases of Cereals held in Zurich in 1989 and from individuals who participated in the USDA-ARS International Septoria Nursery program coordinated by A. L. Scharen. Six additional researchers were identified and sent questionnaires.

Responses were received from 30 countries representing all six continents on which wheat is grown (Fig. 3). Approximately 80 individuals returned survey forms, yielding a response rate of 64%. Failure to answer some questions and inconsistency of responses reduced the data set to the 71 used in our analysis.

A preliminary analysis based on correlation coefficients and linear regression analyses suggested that we concentrate attention upon six (dependent) variables: NB, NA, NH, TB, TA, and TH, measuring SNB and STB occurrence where the first three relate to disease caused by *S. nodorum* and the last three to disease caused by *S. tritici*. These and other variables are listed and explained in Table 1. The principal criterion for retention was a correlation of 0.23 or higher with at least one of the six variables measuring occurrence of SNB and STB. A threshold of 0.23 corresponds to correlations with statistical significance at $P < 0.05$ for a sample of size $n = 71$. Table 2 shows the means, minima, maxima, and correlations among the final set of variables used in model development.

Initial regression analyses suggested the 12 potential explanatory variables could be reduced to a set of five having consistent explanatory capability for all six dependent variables. Explanatory capability, as determined by R^2, was notably higher for NA, NH, TA, and TH than for NB and TB. The latter two variables relate to estimates by the respondent of the "severity levels normally encountered for years with below average severity." Explanatory capability was marginally greater for NH and TH than for NA and TA. The encountered severity for NH and TH is relative to years having higher than average severity levels, while that for NA and TA is relative to years having average severity levels.

In order to reduce the potentially strong influence of a few extremes in occurrence of Septoria diseases, the analysis utilized the dependent variables both in their original scale and after transforming to logarithms. A numeric value "one" was added before transforming to overcome the problem of logarithms becoming undefined in the few cases for which occurrence was given a rating of zero. Approximately the same conclusions were reached when both scales were used, even though the logarithmic data appeared to meet more fully the statistical assumptions required for valid regression analysis. The values for R^2 were marginally higher when logarithmic values were used.

Results from the initial regression analysis suggested that all further analyses be conducted upon the means of the logarithmic values for NA and NH and for TA and TH, assigning these the abbreviations TAHLOG and NAHLOG, respectively. However, practically the same results would have been obtained by utilizing either the "average year" or "high year" mean values independently.

Multiple regression analysis using TAHLOG and NAHLOG produced the coefficients for models presented in Table 3. While the four explanatory variables for NAHLOG and three for TAHLOG were the first to enter during stepwise processing across the 12 potential explanatory variables, they were also the only ones remaining statistically significant near the levels cited.

RESULTS

Table 3 depicts a linear increase in the occurrence of SNB (as measured by NAHLOG) associated with increases in both distance from the equator (LT) and growing season precipitation (GP). An increase in occurrence of SNB is associated with increasing levels of applied phosphorus (P). Occurrence was found to decrease relatively in areas for which "no-tillage or minimum tillage is used on a substantial percentage of wheat acreage." These four variables explain 38% ($R^2 = 0.38$) of the natural worldwide variation in occurrence of *S. nodorum* ($P < 0.001$).

To the contrary, Table 3 depicts occurrence of STB (measured by TAHLOG) as decreasing linearly with an increasing distance from the equator (LT) and with increasing non-growing season average precipitation (FP) and as increasing linearly when moving from areas having low levels of applied phosphorus (P) to those having higher levels applied. While the regression suggested a possible decrease in occurrence of STB in areas for which "no-tillage or minimum tillage is used on a substantial percentage of wheat acreage" as was claimed for SNB, a specific coefficient has been excluded from Table 3 because it could not be deemed statistically significant at near $P = 0.05$. The three variables reported for STB explain 34% ($R^2 = 0.34$) of the natural worldwide variation in occurrence ($P < 0.001$).

DISCUSSION

The strong influence of latitude, positively for SNB and negatively for STB, does not conflict with the world map of occurrence (Fig. 1). Average annual precipitation (AP) has a strong influence (*data not shown*), which is not entirely explained by growing season precipitation and non-growing season precipitation in the two models. *Septoria* spp. are known to be absent from most low precipitation areas; for example, it does not occur naturally at Bozeman, Montana, where annual precipitation averages 450 mm. The five questionnaire respondents reporting the lowest yearly average precipitation also reported no or negligible occurrence of SNB and STB. In the southeastern United States, where SNB is an important and continuing problem, high non-growing season precipitation may be influencing disease occurrence and severity, as our data show for STB. However, the effect of non-growing season precipitation on SNB was not evident in other regions. Relative humidity did not appear in the analysis as a significant influence on disease development. This result was not wholly expected because of the great influence of relative humidity on the etiology of SNB and STB. However, this may be due to the importance of adequate relative humidity levels for shorter periods of time. Studies have shown that the wetting period required for STB and SNB development varied between diseases and cultivars, but in all cases, 24 hr were adequate for disease development (2,4). Work by Eyal et al (2) showed high levels of SNB after a 96-hr wetting period. Wetting periods of these durations could occur in regions with low mean seasonal RH. Similarly, temperature variables never explained significant amounts of the variation in the data despite their association with latitude, and data were not available to study the effects of temperature in shorter intervals.

The positive relationship between soil phosphorus and SNB may be explained by the work of Cunfer et al (1). They

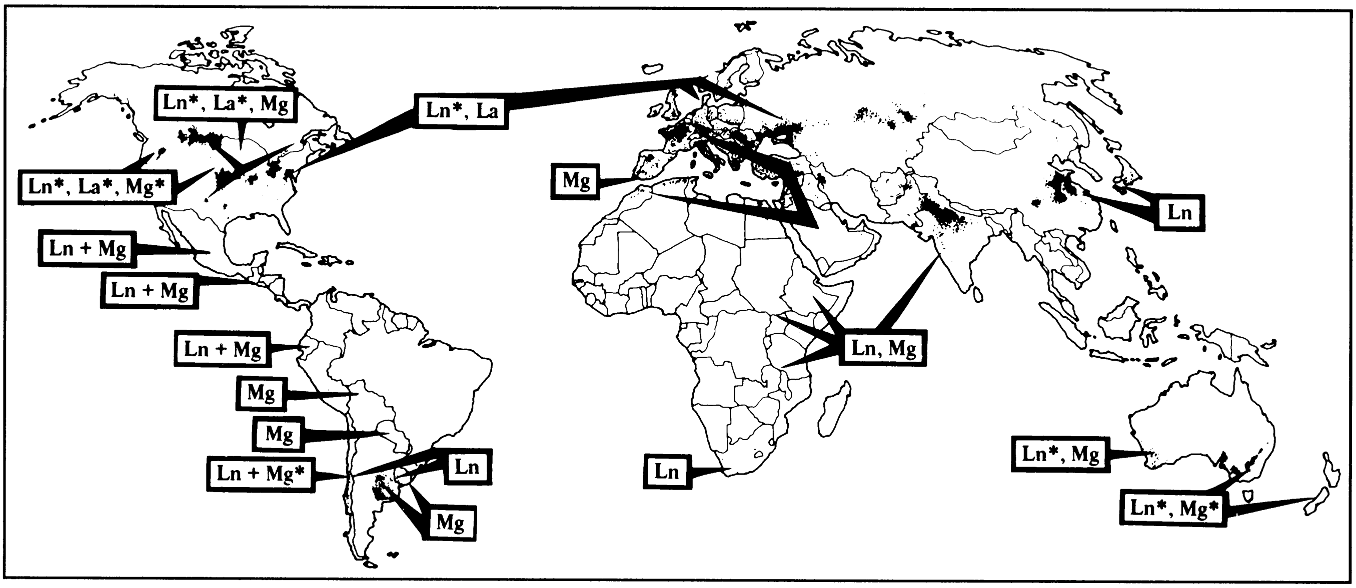

Fig. 1. Distribution of *Septoria* spp. on wheat (each dot represents 50,000 t). *Leptosphaeria nodorum* (Ln), *L. avenaria* (La), and *Mycosphaerella graminicola* (Mg) designate locations of the pathogens; asterisks indicate locations where the sexual state (pseudothecia and ascospores) has been reported.

1. a. Do your answers apply to spring wheat /___/ or winter wheat /___/?
   b. What percentage of your crop is: bread wheat ___ durum wheat ___ soft wheats ___

2. Area you are reporting for: Country ________ Province or State ________ Latitude ________ Longitude ________

3. a. What is your annual precipitation in mm? ________
   b. What is your precipitation during growing season? _____ mm

4. What is your average temperature at planting ________ heading ________ harvest ________

5. What is your elevation in meters? ________

6. What is your normal seeding time? ________

7. What is your normal harvest time? ________

8. a. How many kg/ha of nitrogen are applied to the crop? Fall ________ Spring ______
   b. What other fertilizers are applied to the crop? Kind ________ Amount ________

9. During the growing season, is the relative humidity generally _______ < 20 % _______ Between 20 and 40 % _______ > 40 %

10. What month are symptoms first observed? *S. tritici* ________ *S. nodorum* ________

11. What severity levels do you normally encounter for *S. tritici* in a year with below average severity _______, average severity ________, or high severity _________.

12. What severity levels do you normally encounter for *S. nodorum* in a year with below average severity _______, average severity ________, or high severity _________.

13. Is barley an important crop in the region? Yes ________ No ________

14. Are pycnidia readily visible on diseased tissue? Yes ______ No ________

15. Were any perithecia, asci, or ascospores found?
    Perithecia Yes _______ No _______ Uncertain ______
    Asci Yes _______ No _______ Uncertain ______
    Ascospores Yes _______ No _______ Uncertain ______
    Which is the earliest month that perithecia are usually observed? ________

16. Normally, how many years are there between wheat crops in a given field (do not count years when barley is planted)? None________ One__________ Two__________ Three or more________?

17. Is no-tillage or minimum tillage used on a substantial percentage of the wheat acreage? Yes ________ No _________

18. What percentage of your crop is usually sprayed with fungicides? _______

19. What were the principal chemicals used on wheat and/or in the last twenty years?
    1970 - 1980 ________ ________
    1980 - 1990 ________ ________

20. Is there another factor to which you attribute your levels of *S. nodorum* and *S. tritici*?

Fig. 2. Questionnaire sent to researchers worldwide to accumulate disease occurrence and related environmental data.

showed how high levels of phosphorus result in increased SNB in the southeastern United States as a direct result of application of phosphorus and through increased lodging. The lodging contributes to a microclimate that is conducive to *S. nodorum* growth and sporulation. Also, certain soil types that are low in available phosphorus may determine plant characteristics that either encourage or discourage disease development. Similarly, soils low in phosphorus may not be conducive to overseasoning of the pathogens because of phosphorus deficiency factors of the host plants or a lack of native weed alternative hosts endemic to these soils. In our analysis, these factors may have appeared as the strong influence of phosphorus fertilization.

The influence of reduced tillage in this study could not be readily inferred from related literature. Normally, the consensus among researchers is that reduced tillage increases the availability of pri-

Table 1. Abbreviations and descriptions of selected variables defined and based upon questionnaire responses

Abbreviated name	Description
LT	Latitude
WT	1 = spring wheat, 2 = winter wheat, 3 = both
AP	Average annual precipitation (mm)
GP	Growing season precipitation (mm)
FP	Non-growing season precipitation (mm) = AP − GP
RH	Relative humidity 10 < 20%, 30 = 20–40%, 70 > 40%
VT	Harvest time temperature (C)
EL	Elevation (m)
N	Applied nitrogen (kg/ha)
P	Applied phosphorus P_2O_5 (kg/ha)
K	Applied potassium K_2O (kg/ha)
MT	Substantial no-tillage or minimum tillage 0 = yes, 1 = no
TB	Below average year severity level *Septoria tritici* (%)
TA	Average year severity level *S. tritici* (%)
TH	High year severity level *S. tritici* (%)
NB	Below average year severity level *Septoria nodorum* (%)
NA	Average year severity level *S. nodorum* (%)
NH	High year severity level *S. nodorum* (%)
TAHLOG	$[\text{Log}_e(\text{TA} + 1) + \text{Log}_e(\text{TH} + 1)]/2$
NAHLOG	$[\text{Log}_e(\text{NA} + 1) + \text{Log}_e(\text{NH} + 1)]/2$

Table 2. Simple correlations[a] between disease occurrence at different severity levels and important environmental and agronomic factors and means for selected variables

Variable[b]	TB	TA	TH	TAHLOG	NB	NA	NH	NAHLOG	LT	FP	GP	P	MT
LT	−0.21	−0.20	−0.11	0.04	0.01	0.01	0.14	0.35	1.00				
FP	−0.19	−0.29	−0.36	−0.51	−0.03	−0.04	−0.04	−0.22	−0.43	1.00			
GP	0.29	0.21	0.20	0.21	0.31	0.34	0.35	0.40	0.01	−0.29	1.00		
P	0.10	0.06	0.06	0.11	0.22	0.36	0.32	0.30	0.20	0.05	0.08	1.00	
MT	0.02	0.01	0.04	0.12	−0.24	−0.26	−0.31	−0.13	0.34	−0.13	−0.01	−0.01	1.00
Mean	11	22	41	2.7	10	23	45	2.9	39	358	513	61	0.76
Minimum	0	0	0	0	0	0	0	0	0	50	50	0	0
Maximum	60	80	100	4.5	70	85	100	4.5	58	1,750	1,200	300	1

[a] Correlations exceeding 0.23 differ significantly from zero at $P < 0.05$ for $n = 71$.
[b] See Table 1.

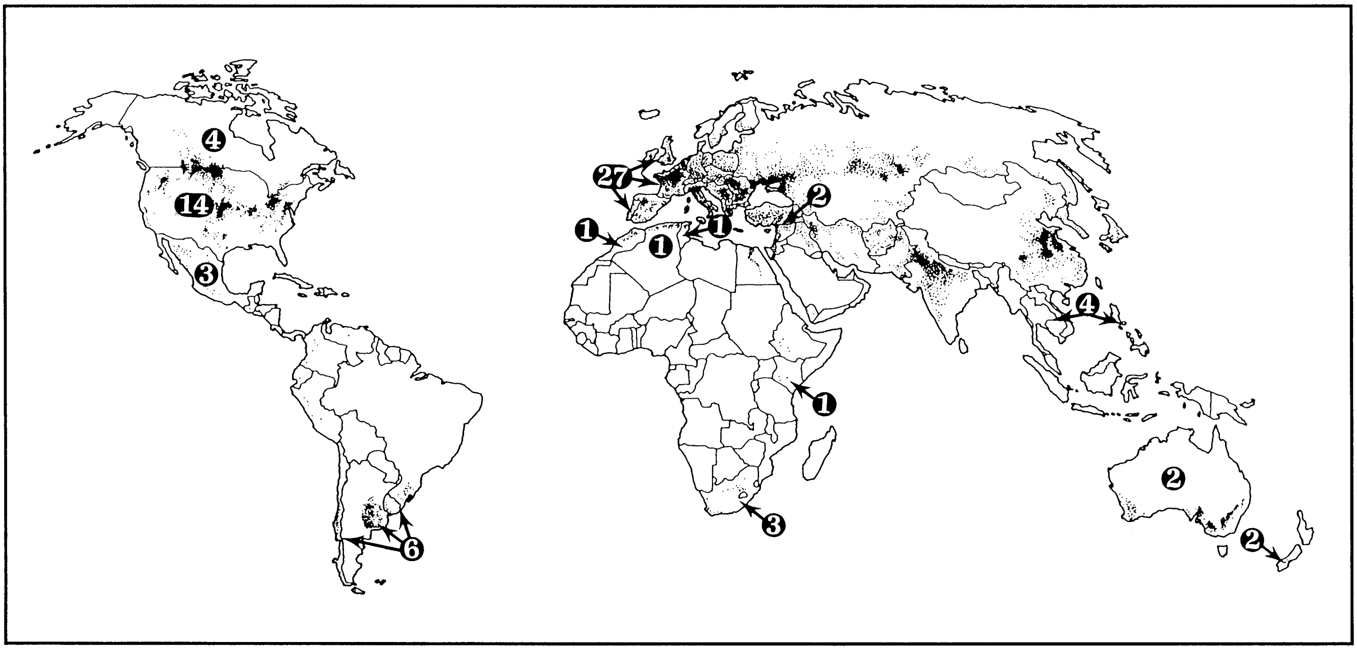

Fig. 3. Wheat-growing areas of the world (each dot represents 50,000 t) from where questionnaires were received. Numbers indicate how many questionnaires were returned from those countries.

Table 3. Regression models relating the log of disease severity in an average year to five explanatory variables

Variable[a]	*Septoria tritici* using TAHLOG Partial R^2 [b]	β[c]	P[d]	*Septoria nodorum* using NAHLOG Partial R^2	β	P
LT	−0.29	−0.039	0.017	0.42	0.051	<0.001
FP	−0.58	−0.003	<0.001	...	...	...
GP	...	...	...	0.43	0.002	<0.001
P	0.24	0.005	0.054	0.22	0.004	0.067
MT	...	...	...	−0.31	−0.921	0.009
Model	$R^2 = 0.34$		<0.001	$R^2 = 0.38$		<0.001

[a] See Table 1.
[b] Partial correlation for specified variable with dependent adjusting for all other variables in model.
[c] Regression coefficient.
[d] Significance level for testing against zero value.

mary inoculum and therefore disease incidence. Our results do not support that consensus. One consideration was that reduced tillage only occurred into nonwheat stubble, thus confounding the effects of minimum tillage and rotation; since years between wheat crops ranged from 0 to 4 (mean = 1.7) in these locations, a rotation effect was possible. However, frequency of minimum tillage and years between crops were not strongly associated ($r = 0.14$, $P = 0.27$), nor was years between crops associated with STB severity in an average season ($r = 0.15$, $P = 0.26$). There was, however, a weak relationship between SNB severity in an average year and years between crops ($r = 0.22$, $P = 0.11$). The occurrence and possible competitive effects of other saprophytes in minimum tillage situations is an area for investigation that was not considered in this survey.

Our survey results suggest several areas where additional research is needed. One such area would be the relationship of growing season precipitation, non-growing season precipitation, and total annual precipitation and both their distribution patterns and their total amounts as they influence SNB and STB. Another area is the influence of fertilization rates and soil amendments on both diseases, particularly in those regions where available phosphorus is low. Yet another area that needs more study is the influence of reduced or minimum tillage on the incidence and severity of SNB and STB in a variety of different climates. The survival of other microorganisms in these situations and their potential antagonistic effects is an important area of biological control that can be studied. Ultimately, we may be able to indicate the use of reduced tillage in regions where SNB and STB can be expected to occur.

ACKNOWLEDGMENT

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LITERATURE CITED

1. Cunfer, B. M., Touchton, J. T., and Johnson, J. W. 1980. Effects of phosphorus and potassium fertilization on Septoria glume blotch of wheat. Phytopathology 70:1196-1199.
2. Eyal, Z., Brown, J. F., Krupinsky, J. M., and Scharen, A. L. 1977. The effect of postinoculation periods of leaf wetness on the response of wheat cultivars to infection by *Septoria nodorum*. Phytopathology 67:874-878.
3. Eyal, Z., Scharen, A. L., Prescott, J. M., and van Ginkel, M. 1987. The Septoria Diseases of Wheat: Concepts and Methods of Disease Management. CIMMYT, Mexico City.
4. Holmes, S. J. I., and Calhoun, J. 1974. Infection of wheat by *Septoria nodorum* and *S. tritici* in relation to plant age, air temperature and relative humidity. Trans. Br. Mycol. Soc. 63:329-338.
5. Karjalainen, R., Laitinen, A., and Juuti, T. 1983. Effects of *Septoria nodorum* Berk. on yield and yield components of spring wheat. J. Sci. Agric. Soc. Finl. 55:333-344.
6. Scharen, A. L., Lund, R. E., and Dietz-Holmes, M. E. 1991. Analysis of factors that influence kernel weight of wheat infected by *Septoria nodorum*. Plant Breed. 106:242-249.