Effects of Leaf and Glume Blotch Caused by *Leptosphaeria nodorum* on Yield and Yield Components of Soft Red Winter Wheat in Pennsylvania

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ABSTRACT

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Epidemics of Septoria nodorum blotch were established in field plots of the soft red winter wheat cultivars Hart and Tyler. A range of disease severity was generated by manipulating irrigation, inoculum pressure, and fungicide treatment in two seasons. Yields were most consistently correlated with the disease severity of the leaf below the flag leaf at the Feekes growth stage 11.1. Estimated slopes of disease-yield relationships for the two cultivars were not equal and indicate differences in tolerance to disease. Yield was correlated with kernel weight in both cultivars and with the number of kernels per spike in the cultivar Tyler. For certain cultivars, the optimum time for fungicide application may be earlier in the epidemic or at an earlier growth stage than previously thought.

Septoria nodorum leaf and glume blotch of wheat (*Triticum aestivum* L.) is induced by the ascomyceteous fungus *Leptosphaeria nodorum* E. Müller (anamorph: *Septoria nodorum* Berk.). The disease is most severe in moist, temperate areas and where intensive crop management practices are used (8,11,26). Yield losses have been reported to exceed 50% under severe conditions (26). Annual losses caused by *Septoria* diseases in the United States have been estimated at 1% (1). In Pennsylvania, losses have been estimated at 5% (1) and are believed to be exceeded only by those induced by powdery mildew (*Erysiphe graminis* DC. f. sp. *tritici* E. Marchal) (1).

In Western Europe, yield reductions are associated primarily with reduced kernel weight (4,6,12,13,18,25,26,31,32). Yield losses have been statistically related to disease severity on the upper leaves at times between flowering and the milky ripe stage (12,13,22,31) through the use of critical-point models (16). This is consistent with studies indicating that most of the photosynthate available for grain filling is produced in the upper leaves late in the growing season (3,29). Yield losses also have been associated with a reduced number of kernels per spike (16,32), but effects of disease on this yield component have not been thoroughly investigated.

A major impediment in the evaluation of control programs for *L. nodorum* is a lack of quantitative information regarding relationships between disease severity and yield loss. The objective of this study was to investigate relationships between disease severity, yield, and yield components in the northeastern United States. Portions of this work have been reported previously (28).

MATERIALS AND METHODS

Field experiments were conducted in the 1984 and 1985 growing seasons at the Pennsylvania State University Agricultural Research Center, located near Pine Grove Mills in Centre County. A range of disease severity was generated in the soft red winter wheat (*T. aestivum*) cultivars Hart and Tyler by manipulating sprinkler irrigation schedules, inoculum pressure, and fungicide treatment.

Field plots were estimated using cultural practices recommended for central Pennsylvania (2). Plot areas were planted previously with oats and had not been planted with wheat for at least 2 yr. Field plots were 2.4 × 3.7 m and were separated by 1.5 m of barley (*Hordeum vulgare* 'Pennrad') that was periodically cut to near ground level. Plot areas that received different irrigation treatments were separated by 6 m of barley.

Field plots were seeded at a rate of 168 kg/ha to a depth of about 3.8 cm with commercial grain drills, giving a row spacing of 17.5 cm. Planting dates were 20 September 1983 and 18 September 1984. Fertilization consisted of 90.7 kg/ha of 10-10-10 (NPK) applied at planting and 67 kg/ha of N applied as ammonium nitrate in April of each year. The herbicide MCPA (Weedar) (0.58 L a.i./ha) was applied at the Feekes growth stage (GS) 4–5 (14).

Powdery mildew (*E. graminis* f. sp. *tritici*) and leaf rust (*Puccinia recondita* Rob. ex Desm. f. sp. *tritici*) were controlled by foliar applications of triadimefon fungicide (Bayleton 50WP). Fungicide (35 g a.i./ha) was applied to all plots twice in the 1984 growing season and three times in 1985 with a tractor-mounted, nitrogen-powered boom sprayer calibrated to deliver 280 L/ha (30 gal/A) of material at 1.2 atm. Low rates of triadimefon (<70 g a.i./ha) did not affect *L. nodorum* in field trials (27).

Irrigation was applied with an overhead sprinkler system designed to minimize output (2 mm/hr) but maintain leaf wetness. In 1984, irrigation was controlled manually and was applied from 1930 to 2000 hours four times between GS 6 and 10 in one plot area; the second plot area was not irrigated. In 1985, the irrigation system was automatically controlled. One plot area was irrigated for 15 min each hour from 1800 to 1200 hours the following day. Irrigation was applied to a second plot area for 15 min each hour from 1800 to 0300 hours the following day. A third plot area was not irrigated. All irrigation treatments in 1985 were applied daily (except during prolonged periods of rainfall) from GS 8 to 11.2.

Within each irrigation treatment, eight additional treatments were assigned to plots arranged in four randomized, complete blocks. The treatments consisted of a factorial arrangement of three factors: cultivar (Hart/Tyler), fungicide treatment (+/−), and artificial inoculation (+/−).

Fungicide treatment for control of *L. nodorum* consisted of a single application of propiconazole fungicide (Tilt 3.6EC) at a concentration of 0.125 kg a.i./ha applied at GS 8.

In 1984 plants in designated plots were inoculated at GS 6 by a method similar to that described by Cooke and Jones (7). A pycnidiospore suspension of five isolates of *L. nodorum* was prepared and adjusted to a concentration of 1×10^6 spores per milliliter. About 1 L of suspension was applied to each designated plot with a hand-held sprayer. Because only small differences in disease severity occurred between inoculated and uninoculated plots in 1984, the inoculation method was altered in 1985. Plants in designated plots were inoculated by spreading about 2 kg of infested wheat straw (cultivar Roland) at the three-leaf stage (November 1984). An equal weight of oat straw was applied to uninoculated plots.

Disease severity was assessed with a standard diagram (4) at 5- to 12-day intervals, depending on weather conditions, disease development, and host phenology. Ten primary tillers were identified randomly within each plot, and disease severities of the four uppermost fully expanded leaves of each tiller were estimated. Assessments began at about GS 8 and ended at GS 11.1. Glume blotch was estimated on 10 spikes per plot at GS 11.2 with a standard diagram (5). The area under the disease progress curve (AUDPC) (30) was calculated for each plot.

In 1984, 1 m of row was removed from each field plot for yield component analysis. In 1985, two such samples were collected from each plot. Samples were air-dried for 6 wk, threshed individually, and the number of spikes per linear meter (spikes/m), the number of kernels per spike (k/spike), and thousand-kernel weight (TKW) were determined. Yield per hectare was determined, based on a calculated value of 85,976.5 linear meters of row per hectare.

Analyses of main effects were performed for each year using the Statistical Analysis System (version 2) (SAS Institute, Cary, NC). The data were analyzed as a nested factorial design (19) according to the following model:

$$Y = E + B(E) + C + I + F + CI + CF + IF + CIF + EC + EI + EF + ECI + ECF + EIF + ECIF + u, \qquad (1)$$

where Y represents the following response variables: AUDPC, percent severity of the upper four leaves at GS 11.1 denoted by (%GS 11.1), percent disease severity of the flag leaf at GS 11.1 (%FL), percent severity of the leaf below the flag leaf at GS 11.1 (%FL-1), percent glume blotch severity at GS 11.2 (%GB), yield (kg/ha, YLD), spikes/m, k/spike, and TKW. E = effects of irrigation, $B(E)$ = effects of blocks within irrigation, C = effects of cultivar, I = effects of inoculation, F = effects of fungicide treatment, and u = a random error term.

Relationships between yield, yield components, and disease parameters were investigated by linear regression and correlation analysis. Analyses were performed on treatment means of data with Minitab statistical software for the IBM-PC (Minitab Data Analysis Software, State College, PA).

RESULTS

In 1984, average severities of Septoria nodorum leaf blotch on the four uppermost leaves at GS 11.1 ranged from 39 to 65%. In 1985, severities ranged from 5 to 88%. Leaf rust developed to noticeable levels in the nonirrigated area in 1985. Rust developed after GS 10.5.4 and was presumed to have little effect on yield.

TABLE 1. Correlation coefficients for yield and yield components and for yield and disease parameters

		Yield parameter[a]			Disease parameter[b]				
Cultivar	Year	TKW	K/spike	Spikes/m	AUDPC	%GS 11.1	%FL	%FL-1	%GB
Hart	1985	0.777*[c]	0.255	−0.197	−0.761*	−0.765*	−0.333	−0.788*	−0.473
Tyler	1985	0.825*	0.882*	−0.346	−0.881*	−0.812*	−0.808*	−0.850*	−0.594*
Hart	1984	0.584	0.040	0.826*	−0.678	−0.550	−0.671	−0.789*	−0.435
Tyler	1984	−0.176	0.960*	−0.534	−0.687	−0.760	0.128	−0.808*	−0.702

[a] Yield parameters include thousand-kernel weight in grams (TKW), number of kernels per spike (k/spike), and number of spikes per linear meter of row (spikes/m).

[b] Disease parameters include area under the disease progress curve (AUDPC), average percent disease severity of the upper four leaves at growth stage 11.1 (%GS 11.1), percent disease severity of the flag leaf at GS 11.1 (%FL), percent disease severity of the leaf below the flag leaf at GS 11.1 (%FL-1), and percent glume blotch severity at GS 11.2 (%GB).

[c] Coefficient of linear correlation, between yield and the indicated parameter, with 10 degrees of freedom (1985 data) and 6 degrees of freedom (1984 data) (* = significance at $P \leqslant 0.05$). Values were calculated using the means of four replicated field plots.

TABLE 2. Regression parameters, *t*-ratios, error mean squares (EMS), and coefficients of determination (adjusted for degrees of freedom) (r^2) for regression models predicting yield from three disease parameters in 1985

	Disease parameter[a]					
	AUDPC		%GS 11.1		%FL-1	
Regression parameter[b]	r^2	*t*-ratio[c]	r^2	*t*-ratio	r^2	*t*-ratio
b_0	4,797.000	19.64*	4,679.70	19.16*	4,417.90	33.95*
b_1	−1.008	−2.96*	−10.06	−2.57*	−6.51	−2.89*
b_2	764.500	2.55*	786.60	2.53*	563.60	3.42*
b_3	−1.617	−3.16*	−11.72	−2.09*	−9.34	−2.75*
EMS	50,359		68,055		56,946	
r^2	0.764		0.681		0.733	

[a] Disease parameters include area under the disease progress curve (AUDPC), average percent severity of the upper four leaves at growth stage 11.1 (%GS 11.1), and percent severity of the leaf below the flag leaf at GS 11.1 (%FL-1). Analyses were performed on the means of four replicated field plots.

[b] Regression parameters for b_0 (intercept), b_1 (disease parameter), b_2 (cultivar), and b_3 (disease parameter × cultivar).

[c] Values followed by an asterisk are significant at $P \leqslant 0.05$. A significant value for b_1 indicates a significant relationship between yield and the indicated disease parameter, a significant value for b_2 indicates a significant effect of cultivar on the intercept, and a significant value for b_3 indicates a significant effect of cultivar on the slope.

Analyses of variance indicated that irrigation, cultivar, and fungicide treatment had great effects on disease and yield parameters. The cultivar Hart was more susceptible than Tyler. Fungicide-treated plots sustained less disease and produced higher yields than untreated plots. Irrigation enhanced disease severity in 1985 but not in 1984.

In 1985, yield of the cultivar Hart was correlated with TKW and with the disease parameters AUDPC, %GS 11.1, and %FL-1 (Table 1). Yield of Tyler was correlated with TKW, k/spike, and with all five disease parameters.

Correlations among yield, yield components, and disease parameters were generally lower in 1984 than in 1985. In 1984, yield of Hart was correlated with spikes/m and with the disease parameter %FL-1. For the cultivar Tyler, yield was correlated with k/spike and with the disease parameters %GS 11.1 and %FL-1.

Disease severity-yield models were developed for each year by linear regression analyses. To determine if disease-yield relationships differed between the two cultivars, indicator variables were used to test for the effects of cultivar on intercepts and slopes (21).

Disease parameters for the 1985 data included the AUDPC, %GS 11.1, and %FL-1. For the 1984 data, only %FL-1 was used, because only this parameter was correlated with yield of both cultivars. The general form of the model was:

$$\text{Yield} = b_0 + b_1\,(\text{disease parameter}) + b_2\,(\text{cultivar}) + b_3\,(\text{cultivar} \times \text{disease parameter}) + u. \qquad (2)$$

Cultivar was denoted by an indicator variable (0 = Hart, 1 = Tyler); u = a random error term.

The significance of regression parameters was tested using t-ratios (Tables 2 and 3) (20). A significant t-ratio for b_1 indicated a significant relationship between yield and the specified disease parameter. A significant t-ratio for b_2 indicated a significant effect of cultivar on intercepts, and a significant t-ratio for b_3 indicated a significant effect of cultivar on slopes. Residual plots for all regressions displayed no departures from linearity.

For the 1985 data, regression analyses indicated that cultivar significantly ($P < 0.05$) affected both the intercept and slope of relationships between the three measures of disease severity and yield (Table 2). For the 1984 data, cultivar had no significant effect on the intercept and slope of the relationship between yield and %FL-1 (Table 3).

Multiple-regression analyses were also performed to determine if models for the 2 yr could be combined. Indicator variables were used to test for the effect of years on intercepts and slopes for functions for each of the two cultivars (21). The disease parameter %FL-1 was used, because this parameter was correlated to yield for both cultivars in both years. The model used was:

$$\text{Yield} = b_0 + b_1\,(\%\text{FL-1}) + b_2\,(\text{year}) + b_3\,(\text{year} \times \%\text{FL-1}) + u, \qquad (3)$$

where year was denoted by an indicator variable (0 = 1984, 1 = 1985) and u = a random error term. The significance of regression parameters was determined by t-ratios (Table 4).

Intercepts and slopes were not significantly affected by year for the cultivar Tyler. For the cultivar Hart, slopes were also constant over the 2 yr but intercepts were significantly different (Table 4).

DISCUSSION

Sprinkler irrigation, fungicide treatment, and artificial inoculation resulted in a range of disease severities and yield losses, particularly in 1985. Of the five disease parameters studied, %FL-1 was the most consistent predictor of yield. This parameter may be the most useful in quantifying the disease severity-yield relationship in the northeastern United States.

Most yield loss studies on Septoria nodorum blotch emphasize relationships between disease severity on the upper one to three leaves and yield (12,13,26). In this study, the severity of disease on the flag leaf was a poor predictor of yield. A wide range of disease severity is necessary to establish disease-yield loss relationships (9). In this study, severity values on the flag leaf were generally low (< 10%). It is interesting to note that most yield loss studies on this disease have been performed in Western Europe (4,6,10,13,18, 25,31,32), where the growing season, particularly the period of grain-fill (GS 10.5–11.2), is typically longer than in the northeastern United States (V. Morton, Ciba-Geigy Ltd., *personal communication*). This may allow more opportunity for infection and disease development on the flag leaf in Europe.

James and Teng (9), in a review of methods for studying yield loss, state that to achieve a gradient of disease severity, "Varieties with varying susceptibility to disease, but with similar yield potential in the absence of disease can be used, with the proviso that disease susceptibility is not highly correlated with potential yield." Several studies on the relationship between yield and the severity of Septoria nodorum blotch have used this technique without regard to differences in yield potential of different cultivars (20,25,31). In this study, the use of irrigation, artificial inoculation, and fungicide treatment permitted the comparison of disease-yield relationships of the two cultivars. Significant differences in the intercepts and slopes of these relationships were found in 1985 for the two cultivars. Differences in intercepts correspond to differences in yield potential. Differences in slopes may indicate differences in "tolerance" (15), as described by Schafer (24). Bronnimann (4,5) also described tolerance to this

TABLE 3. Regression parameters, t-ratios, error mean squares (EMS), and coefficients of determination (adjusted for degree of freedom) (r^2) for regression models predicting yield from the percent disease severity of the leaf below the flag leaf at growth stage 11.1 (%FL-1) in 1984

Regression parameter[a]	%FL-1	
	r^2	t-ratio[b]
b_0	5,425.70	22.21*
b_1	−16.52	−3.34*
b_2	−75.30	−0.26
b_3	6.88	1.18
EMS	27,641	
r^2	0.649	

[a] Regression parameters for b_0 (intercept), b_1 (disease parameter), b_2 (cultivar), and b_3 (disease parameter × cultivar).

[b] Values followed by an asterisk are significant at $P \leqslant 0.05$. A significant value for b_1 indicates a significant relationship between yield and the indicated disease parameter, a significant value for b_2 indicates a significant effect of cultivar on the intercept, and a significant value for b_3 indicates a significant effect of cultivar on the slope.

TABLE 4. Regression parameters, t-ratios, error mean squares (EMS), and coefficients of determination (adjusted for degrees of freedom) (r^2) for regression models predicting yield from the percent disease severity of the leaf below the flag leaf at growth stage 11.1 (%FL-1) for two cultivars

Regression parameter[a]	Tyler		Hart	
	r^2	t-ratio[b]	r^2	t-ratio[b]
b_0	5,350.4	2.70*	5,425.7	21.41*
b_1	−9.6	−2.09*	−16.5	3.22*
b_2	−368.9	1.43	−1,007.8	3.73*
b_3	6.2	−1.17	10.0	1.86
EMS	62,162		29,751	
r^2	0.715		0.785	

[a] Regression parameters for b_0 (intercept), b_1 (disease parameter, %FL-1), b_2 (year), and b_3 (year × %FL-1).

[b] Values followed by an asterisk are significant at $P \leqslant 0.10$. A significant value for b_1 indicates a significant relationship between yield and the indicated disease parameter (%FL-1), a significant value for b_2 indicates a significant effect of year on the intercept, and a significant value for b_3 indicates a significant effect of year on the slope.

disease in other wheat cultivars. Differences in yield potential and the existence of tolerance to disease implies that use of different cultivars to produce disease severity gradients is inappropriate. In 1984, a more limited range of disease severity occurred, and differences in disease-yield relationships between the cultivars were not detected.

The slopes of relationships between yield and the disease parameter %FL-1 were constant over both years in both cultivars and may represent consistent relationships between disease severity and yield loss. For the cultivar Hart, intercepts for the relationship between disease severity and yield varied in the 2 yr of this study. This variation may be the result of differences in yield potential in the two years (15). King et al (13) also reported variation in intercepts of disease-yield relationships from data taken at different locations. Data were transformed to percentages of potential yield at each location to reduce between-site variability. MacKenzie and King (15), however, caution against the use of yield data transformed to percentages. When yield of rice was regressed against the severity of leaf blight (*Xanthomonas campestris* pv. *oryzae* (Ishiyama) Dye), slopes of relationships did not vary between 2 yr. When data were transformed to percentages of disease-free plots, however, intercepts varied between the 2 yr.

Variation in disease severity-yield models attributable to cultivar and environment have been demonstrated in this study. Estimates of crop loss derived from generalized disease-yield loss models made without regard to these factors may be misleading.

Yield was correlated with different yield components for the two cultivars and the two seasons. Cultivar differences may be attributed to small differences in crop development (23). Alternatively, the time of stresses, such as disease, may affect yield components differently in the two cultivars (17).

This study confirms the association between yield loss and kernel weight. The close associations between yield, disease parameters, and the number of kernels per spike for the cultivar Tyler, however, indicate that a reduction in this yield component may be an important consequence of epidemics of *L. nodorum* on certain cultivars in Pennsylvania. Control methods designed to reduce the impact of disease on this yield component should be evaluated and differences in cultivar responses to disease considered in the development of control tactics.

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