Multiple Regression Accounting for Wheat Yield Reduction by Septoria nodorum and Other Pathogens

L. R. Nelson, M. R. Holmes, and B. M. Cunfer

Assistant Professors of Agronomy, Agricultural Economics, and Plant Pathology, respectively; University of Georgia College of Agriculture Experiment Stations, Experiment, GA 30212.

Accepted for publication 25 May 1976.

ABSTRACT

NELSON, L. R., M. R. HOLMES, and B. M. CUNFER. 1976. Multiple regression accounting for wheat yield reduction by Septoria nodorum and other pathogens. Phytopathology 66: 1375-1379.

During 1973-74 and 1974-75 severe natural infection of wheat by *Septoria nodorum* occurred in Georgia. Numerous cultivars were evaluated for disease severity and the effect of the pathogen on various yield components. A Septoria disease index (SDI) was derived from these data. The SDI correlated with yield, 1,000-kernel weight, test weight, and plant height. Multiple regression equations were utilized to predict yield from disease severity caused by *S. nodorum*, *Erysiphe graminis* f. sp. *tritici*, *Puccinia recondita* f. sp. *triticina*, and several agronomic factors. When 1,000-kernel weight was included in an equation with SDI and *E. graminis*, 81% of the yield variation could be explained. Correlation coefficients involving SDI and yield were improved when SDI was squared and/or divided by each cultivar's mean plant height.

Additional key words: glume blotch, leaf rust, powdery mildew, *Triticum aestivum*.

Septoria nodorum Berk., the incitant of glume blotch, causes significant economic losses of wheat (*Triticum aestivum* L.) in the U. S. and throughout many of the wheat-growing areas of the world (10). Frequent rain and high humidity with warm temperatures (normal in the southeastern U.S.), especially during the early heading stage, are ideal conditions for rapid buildup of the disease (2, 3, 5, 6, 13). Cultivars may appear to be resistant or susceptible on the basis of disease ratings; however, the actual effect of glume blotch on yield may be quite different (7, 11, 12). The disease reaction varies greatly from year to year and cultivars thought to be resistant or tolerant have failed to demonstrate this character under different environmental conditions. Other diseases may confound Septoria disease ratings since researchers have reported that prior infection by powdery mildew, *Erysiphe graminis* DC. f. sp. *tritici* predisposes the plant to attack by *Septoria tritici* Rob. ex Desm. (1). Also, there may be an interaction between *Puccinia recondita* Rob. ex Desm. f. sp. *triticina*, causal agent of leaf rust, and *S. nodorum* (14, 15). Therefore, when Septoria disease reactions are reported on wheat grown under field conditions, the incidence of all other diseases also must be noted. Disease severity ratings at several locations in Georgia have varied greatly (10).

During the winter wheat-growing seasons of 1973-74 and 1974-75 in Georgia, severe *S. nodorum* infection occurred. In 1973-74 there were natural infections of powdery mildew and leaf rust, whereas in 1974-75 the only serious pathogen was *S. nodorum*, which was accompanied by a very light infection of leaf rust. The purposes of this study are to report the relationships among these diseases, the effect of *S. nodorum* on yield and 1,000-kernel weight, and the relationship of the diseases to plant height and maturity of wheat under field conditions.

MATERIALS AND METHODS

The data reported in this study were recorded from a yield test that included 30 and 33 soft red winter wheat cultivars in 1973-74 and 1974-75, respectively. A plot consisted of four rows 2.5 m in length with a 30-cm row spacing. The wheat was planted in soil that had not been planted with wheat for 3 years. Wheat was planted about 1 November both years using a mechanical planter at a seeding rate of 8 g of seed per row. Fertilization included 28 kg N, 56 kg of P_2O_5, and 84 kg of K_2O per hectare (ha) applied prior to planting into conventionally-tilled Cecil clay loam soil (member of the clayey, kaolinitic, thermic family of the Typic Hapludults). Wheat was topdressed with 67 kg N/ha in February. Above-normal temperatures throughout most of the growing season in 1973-74 resulted in above-average vegetative growth during January and February. Powdery mildew was observed in January and disease severity was quite high until warmer weather occurred in May. Mildew ratings were taken on 26 March 1974. Leaf rust was observed throughout April and disease ratings were taken on 30 April 1974. Both mildew and leaf rust ratings were recorded as percentage of leaf area of entire plants affected by the disease. Glume blotch disease ratings were taken on two different dates. The first disease rating was taken on leaves only, on 26 April 1974. In this rating each plot was rated on a scale from one to nine in which one equaled no disease and nine represented all plants killed by *S. nodorum*. A rating of six indicated severe infection with all lower leaves dead and the upper leaves including the flag leaf approximately 50% covered with *S. nodorum* lesions. The second rating was taken on the heads on 20

May 1974. In this disease rating, a value of one indicated no disease symptoms and nine indicated that the head was dead with little or no seed in it. A Septoria disease index (SDI) was obtained by adding the leaf and head disease severity ratings. During both seasons 10 heads from each plot were collected at random and the grain was used to determine 1,000-kernel weight. This procedure was used to avoid the loss of shrunken kernels in any mechanical threshing process.

In 1974-75 the leaf ratings for Septoria infection were taken on 6 May and the head ratings were taken on 21 May 1975. The heading notes were taken when the wheat was in the dough stage or at 11.2 of the Feekes scale (8). During growth stage 11.2 we collected 10 heads from each plot and stored them in a freezer until the time of examination. The method of Leijerstam (9) was used with the modification that the percentage of discolored glume area was recorded for four bottom glumes, two middle glumes, and four top glumes of each spike. The mean percentage discolored glume area was obtained from 100 glumes per plot and this value was used for analysis. Severity of leaf rust and powdery mildew was not high enough to take disease ratings in 1974-75.

Other data collected were yield, test weight, 50% heading date, plant height, and lodging. The investigation was conducted in a randomized block design with four replications.

RESULTS AND DISCUSSION

The data collected on the cultivars provided a wide range in yield, disease severity ratings, and plant characteristics. Yield ranged from 875 to 4,624 kg/ha. *Septoria nodorum* severity ratings ranged from 1.0 to 7.0 and from 3.0 to 7.2 for the leaf and head ratings, respectively. Glume ratings for 1975 ranged from 4 to 38% discoloration. Leaf rust and powdery mildew rating ranged from 0 to 60% and from 0 to 70%, respectively. Grain yield (1,000-kernel weight) ranged from 19 to 39 g.

The linear correlation coefficients presented in Table 1 indicate the relationship that existed between quantitative components. The correlation coefficients are presented for both years and for the most part are significant and agree closely over years.

Yield was significantly correlated with 1,000-kernel weight, test weight, and with all methods of rating glume blotch. Powdery mildew was correlated with yield in 1973-74 only, and leaf rust was significant ($P = 0.10$) in 1973-74 only. The SDI improved the correlation with yield, and therefore is an improved estimate of disease severity. The Leijerstam glume-rating method used in 1974-75 appeared to be about equal to the leaf and head disease rating method, but is a very time-consuming procedure. The 1,000-kernel weight was positively correlated with yield and negatively correlated with glume blotch severity both years. This was expected since 1,000-kernel weight is an accepted method for determining the severity of glume blotch (2, 4). The negative correlation of 1,000-kernel weight with glume ratings in 1974-75 was greater than that with any other glume blotch rating method.

Test weight was positively correlated with yield and 1,000-kernel weight and negatively correlated with all of the Septoria disease ratings in 1974-75. However, in 1973-74 only the correlation with head rating was significant. The various methods of rating glume blotch severity were closely correlated, which indicated that each method should be fairly effective for rating the disease. Taller plant height is positively related to lower disease ratings; however, this is most apparent in relation to the glume blotch head disease ratings (Table 1). Heading date was not significantly correlated with glume blotch severity although there was a trend toward a negative correlation, which indicated that earlier-heading cultivars may tend to be more severely diseased. This agrees with another report (10).

Powdery mildew and leaf rust were of importance in this study only in 1973-74 (Table 1). The correlations

TABLE 1. Simple correlation coefficients on 30 and 33 wheat cultivars for 1973-74 and 1974-75, respectively, for various yield components and disease ratings

	Yield	1,000-kernel wt.	Test wt.	Plant ht.	Septoria leaf rating[d]	Septoria head rating[d]	SDI[e]	Glume rating	Powdery mildew (%)	Leaf rust (%)
Yield	[a]	.37*	.45**	.45**	−.57**	−.58**	−.61**	−.58**	. . .[c]	−.24
1,000-kernel weight (wt.)	.80**[b]		.72**	.36*	−.39*	−.41*	−.42*	−.69**	. . .	−.07
Test weight	.72**	.79**		.42*	−.40*	−.58**	−.53**	−.64**	. . .	−.08
Plant height (ht.)	.23	.24	.42*		−.34	−.53**	−.47**	−.33	. . .	.02
Septoria leaf rating[d]	−.47**	−.39*	−.20	−.14		.76**	.93**	.55**	. . .	.15
Septoria head rating[d]	−.50**	−.32	−.42*	−.64**	.46*		.94**	.66**	. . .	.20
SDI[e]	−.57**	−.42*	−.33	−.40*	.90**	.79**		.65**	. . .	.19
Glume rating	. . .[c]	. . .	. . .	. . .	. . .	. . .	. . .		. . .	.13
Powdery mildew (%)	−.55**	−.46*	−.45*	−.14	−.08	.13	.01	. . .		. . .
Leaf rust (%)	−.34	−.33	−.40*	.17	.17	.09	.16	. . .	.14	

[a]All values below the diagonal line are simple correlation coefficients for 1973-74. All values above the diagonal line are simple correlation coefficients for 1974-75.

[b]Asterisks * and ** indicate significance at $P = 0.05$ and $P = 0.01$, respectively.

[c]Data were not taken in that year.

[d]Each plot rated on a scale from one to nine where one equaled no disease and nine equaled all plants killed by *Septoria nodorum*.

[e]SDI is Septoria disease index which is the sum of the Septoria disease severity leaf and head ratings.

(Table 1) indicate that powdery mildew reduced yield the first year and also reduced 1,000-kernel weight and test weight. The effect of presence (60% infection) or absence (5% infection) of powdery mildew together with glume blotch on yield is illustrated in the 1973-74 data (Fig. 1). The coefficient of determination for the regression of yield on glume blotch and powdery mildew was $R^2 = 0.49$ which indicates their importance in limiting yield. Leaf rust was not significantly correlated with yield, but it did reduce the test weight and appears to reduce yield slightly.

Leaf- and head ratings for Septoria infection were significantly correlated for each year and for the 2-year ($r = 0.55^{**}$) analysis. This indicates that either method can

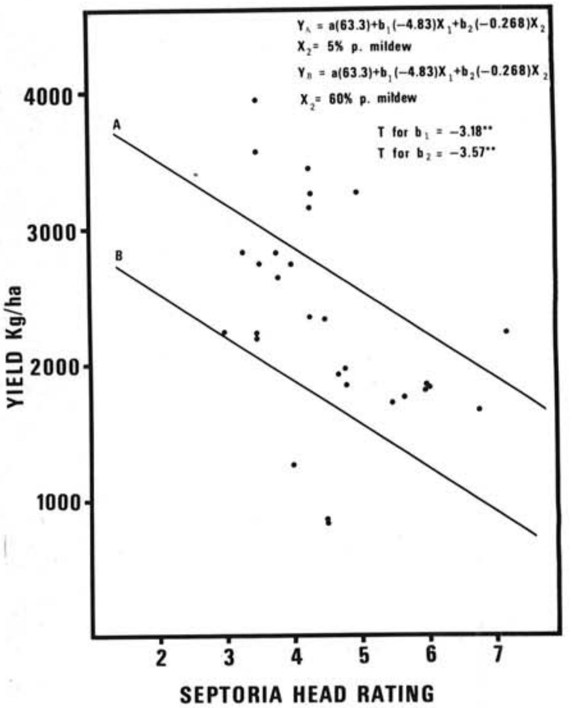

Fig. 1. Relationship of wheat yield to *Septoria nodorum* head disease rating at A = 5 and B = 60% powdery mildew in 1973-74. The multiple regression equation $Y = a + b_1X_1 + b_2X_2$ where Y = yield, X_1 = Septoria disease rating on heads, and X_2 = powdery mildew disease severity at either 5% or 60%. The symbol ** indicates significant difference, $P = 0.01$.

be used to rate severity of glume blotch; however, the coefficient of determination for both years is rather low and at most, only 30% of the variation in each of these two ratings might be explained from their association. The ratings were taken about 1 month apart and during that time disease severity may have changed on some cultivars while remaining the same on others.

The importance of 1,000-kernel weight in determining yield is well known and likewise the reduction in 1,000-kernel weight by glume blotch has been established (2, 4). In this study we had no nondiseased controls, and therefore were unable to determine precisely the reduction in 1,000-kernel weight due to glume blotch or other diseases. Glume blotch ratings were correlated negatively with 1,000-kernel weight (Table 1). Yield can be calculated with the multiple regression equation:

$$Y = 5.128 + 1.807X_1 - 1.447X_2$$

where Y = yield; X_1 = 1,000-kernel weight; and X_2 = SDI for 1973-74 (Table 2). In Fig. 2 the value of 2 or 6 was used for X_2 and we were able to estimate the effect of *S. nodorum* on yield in relation to 1,000-kernel weight. The 1,000-kernel weight was affected by Septoria disease severity, and both characters greatly influenced yield.

A multiple regression from the 1973-74 data for yield on the independent variables, 1,000-kernel weight, SDI, leaf rust, and powdery mildew resulted in an equation which accounted for 78% of the variation in yield (Table 3). In this equation, 1,000-kernel weight is the second most important factor in determining yield. Kernel weight is determined primarily by the genetic effect of the individual cultivars but it also is affected by the diseases. We feel that the true importance of the diseases in affecting yield may be better illustrated when 1,000-kernel weight is included in the regression equation. The most important independent variable in this equation, as determined by comparisons of absolute values of standardized partial regression coefficients, is the SDI; the 1,000-kernel weight is second in importance.

An effort was made to account for as much of the variation in yield as possible for the 2 year's data. To do this we studied all of the earlier mentioned quantitative characters, then mathematically synthesized 20 new characters from the other recorded characters. Some examples of these are: SDI divided by plant height; SDI^2; SDI^3 divided by heading date; 1,000-kernel weight divided by plant height; and also interactions that

TABLE 2. Multiple regression for prediction of the effect of 1,000-kernel weight and Septoria (*S. nodorum*) disease index (SDI) on wheat yield for 1973-74

Variable	Description	Standardized regression coefficient	Regression coefficient	*t*-value
Y	Yield	. . .	. . .	. . .
	Intercept	. . .	5.128	. . .
X_1	1,000-kernel wt	0.685	1.807	5.941**[a]
X_2	SDI[b]	−0.276	−1.447	−2.393*
Multiple R = 0.84			$R^2 = 0.71$	
Standard error of estimate			$S_{y \cdot x} = 6.887$	

[a]Asterisks * and ** indicate significant difference, $P = 0.05$ and $P = 0.01$, respectively.
[b]Septoria disease index, which is the sum of Septoria disease severity leaf and head ratings.

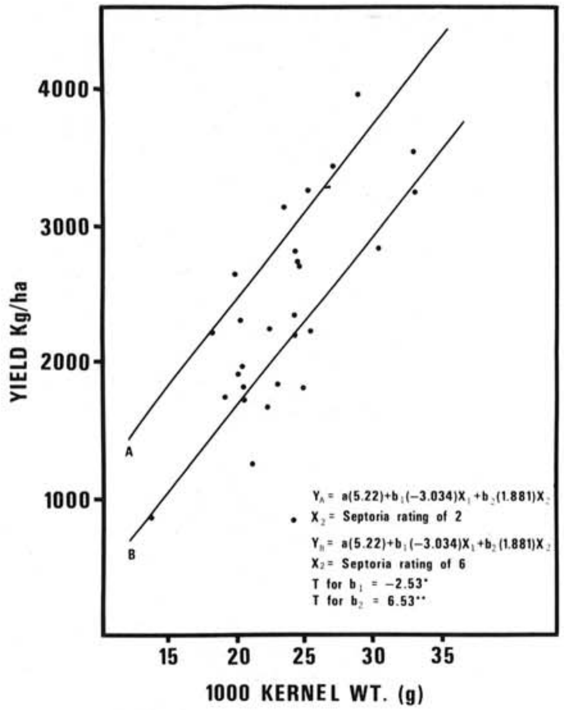

Fig. 2. Relationship of wheat yield to 1,000-kernel weight at a *Septoria nodorum* disease rating of A = 2 or B = 6 in 1973-74. The multiple regression equation $Y = a + b_1 X_1 + b_2 X_2$ where Y = yield, X_1 = Septoria rating of either 2 or 6, and X_2 = 1,000-kernel weight. The symbol * and ** indicates significant $P = 0.05$ or $P = 0.01$, respectively.

involved various characters and the effect of years. Some of these synthesized characters had significant and high simple correlation coefficients with various factors such as yield or disease ratings. To illustrate, we found that by squaring the SDI we increased its simple correlation with yield from −0.61 to −0.65. This indicates that perhaps the more highly diseased plots were not rated high enough. Instead of a 6, perhaps they should have received a score of 8 or 9.

We also found that if a glume blotch rating for a cultivar was divided by its own plant height, this synthesized rating also was more closely correlated with yield. For example, the simple correlation for SDI and yield was −0.61 but when the SDI for each cultivar was divided by its own plant height, the correlation coefficient increased to −0.67. When the SDI was squared and then divided by its plant height, the simple correlation with yield equaled −0.70. This indicates that yield reduction decreased with increasing plant height. Our disease ratings were significantly correlated with plant height and we improved the correlation with yield with this technique.

Using a step-down multiple regression analysis computer program, we obtained an equation for yield with all of the quantitative and synthesized factors. The equation accounted for 81% of the variation in yield for the 2 year's data (Table 4). All of the factors shown significantly affected yield. Years affected yield and tended to complicate the equation to some extent. Based on the magnitude of the standard regression coefficients, SDI, years, and 1,000-kernel weight were the most important factors in the equation.

By studying the factors that affect yield, and the

TABLE 3. Multiple regression for prediction of effect of 1,000-kernel weight, Septoria (*S. nodorum*) disease index (SDI), leaf rust, and powdery mildew on wheat yields for 1973-74

Variable	Description	Standardized regression coefficient	Regression coefficient	*t*-value
Y	Yield	. . .	. . .	. . .
	Intercept	. . .	24.492	. . .
X_1	1,000-kernel wt.	0.484	1.277	3.915**[a]
X_2	SDI[b]	−0.344	−1.802	−3.249**
X_3	Leaf rust	−0.085	−0.052	−0.858
X_4	Powdery mildew	−0.310	−0.169	−2.868**
Multiple R = 0.88			$R^2 = 0.78$	
Standard error of estimate			$S_{y \cdot x} = 6.145$	

[a]Asterisks ** indicate significant difference, $P = 0.01$.
[b]Septoria disease index, which is the sum of the Septoria disease severity leaf and head ratings.

TABLE 4. Multiple regression for prediction of the effect of several factors on yield for 1973-74 and 1974-75

Variable	Description	Standardized regression coefficient	Regression coefficient	*t*-value
Y	Yield	. . .	. . .	. . .
	Intercept	. . .	18.111	. . .
X_1	Powdery mildew	−0.240	−0.158	−3.05**[a]
X_2	1,000-kernel wt.	0.647	1.397	5.28**
X_3	Years	1.745	41.717	4.66**
X_4	SDI[b]	0.326	−55.659	−4.96**
X_5	(X_2 times X_3)	−1.626	−1.272	−3.95**
Multiple R = 0.90			$R^2 = 0.81$	
Standard error of estimate			$S_{y \cdot x} = 5.524$	

[a]Asterisks ** indicate significant difference, $P = 0.01$.
[b]Septoria (*S. nodorum*) disease index, which is the sum of the Septoria disease severity leaf and head ratings.

relationships between these factors and Septoria disease severity, a better understanding of diseases and their effect on plants will result. This knowledge should enable the plant breeder to develop genetic resistance to *Septoria nodorum* in his breeding program. An improved disease index for Septoria disease severity will improve the probability of selecting better breeding lines or cultivars which have disease resistance.

LITERATURE CITED

1. BROKENSHIRE, T. 1974. Predisposition of wheat to Septoria infection following attack by Erysiphe. Trans. Br. Mycol. Soc. 63:393-397.
2. BRÖNNIMANN, A. 1968. Zur Kenntnis von Septoria nodorum Berk., dem Erreger der Spelzenbraune und einer Blattdurre des Weizens. Phytopathol. Z. 61:101-146.
3. BRÖNNIMANN, A. 1968. Zur Toleranz des Weizens gegenuber Septoria nodorum Berk. Phytopathol. Z. 62:365-370.
4. COOKE, B. M., and D. G. JONES. 1971. The epidemiology of Septoria tritici and S. nodorum. III. The reaction of spring and winter wheat varieties to infection by Septoria tritici and S. nodorum. Trans. Br. Mycol. Soc. 56:121-135.
5. HOLMES, S. J. I., and J. COLHOUN. 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.
6. JONES, D. G., and K. ODEBUNMI. 1971. The epidemiology of Septoria tritici and S. nodorum. Trans. Br. Mycol. Soc. 56:281-288.
7. KRUPINSKY, J. M., J. A. SCHILLINGER, and A. L. SCHAREN. 1972. Resistance in wheat to Septoria nodorum. Crop Sci. 12:528-529.
8. LARGE, E. C. 1954. Growth stages in cereals: illustration of the Feekes scale. Plant Pathol. 3:128-129.
9. LEIJERSTAM, B. 1972. A method for assessing the degree of infection caused by Septoria nodorum on wheat. Medd. Statens Vaxtskyddsanst. 15:281-285.
10. NELSON, L. R., D. D. MOREY, and A. R. BROWN. 1974. Wheat cultivar responses to severe glume blotch in Georgia. Plant Dis. Rep. 58:21-23.
11. SHANER, G., R. E. FINNEY, and F. L. PATTERSON. 1975. Expression and effectiveness of resistance in wheat to Septoria leaf blotch. Phytopathology 65:761-766.
12. SHARP, E. L., A. BRÖNNIMANN, and F. H. MC NEAL. 1972. Reaction of selected spring wheat varieties to infection by Septoria nodorum. Plant Dis. Rep. 56:761-764.
13. SHIPTON, W. A., W. R. J. BOYD, A. A. ROSIELLE, and B. L. SHEARER. 1971. The common Septoria diseases of wheat. Bot. Rev. 37:231-262.
14. VAN DER WAL, A. F., and M. C. DOWAN. 1974. An eco-physiological approach to crop losses exemplified in the system wheat leaf rust and glume blotch. II. Development, growth and transpiration of uninfected plants and plants infected with Puccinia recondita f. sp. triticina and/or Septoria nodorum in a climate chamber experiment. Neth. J. Plant Pathol. 80:192-214.
15. VAN DER WAL, A. F., B. L. SHEARER, and J. C. ZADOKS. 1970. Interaction between Puccinia recondita f. sp. triticina and Septoria nodorum on wheat, and its effect on yield. Neth. J. Plant Pathol. 76:261-263.