# Estimating Damage to Wheat Caused by Puccinia recondita tritici

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ABSTRACT

Disease severities and per cent grain losses from 55 winter and spring cultivar-location combinations were used in a stepwise multiple linear regression computer program to study the relationship between leaf rust severity and yield loss at several wheat growth stages, and to construct general equations to predict crop losses. Coefficients of determination indicated that rust severities at early dough accounted for 64% of the variation in crop loss. However, when severities from boot ($X_2$), early berry ($X_5$), and early dough ($X_7$) were combined in linear regression equations, 79% of the variation in loss was explained. The equation $\hat{Y} = 5.3788 + 5.5260X_2 - 0.3308X_5 + 0.5019X_7$ satisfactorily predicted loss (%) with a standard error of 9%. When predicted severities were used in the equation instead of observed severities, the average variation was 8%.

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Damage to wheat caused by *Puccinia recondita* Rob. ex Desm. *tritici* is well documented (1, 6, 7). In some areas where leaf rust occurs frequently and in varying degrees of severity, little effort is placed in breeding for effective resistance. In 1931, Johnston (6) reported losses of 55% on susceptible cultivars. Our studies on current wheat cultivars corroborate that figure. The best way to control leaf rust is to use resistant cultivars. Alternative control measures might prove economically feasible if areas of potential loss were identified in time to reduce damage by application of effective fungicides.

Buchenau (2) devised a system to forecast disease severity and crop loss resulting from leaf and stem rust. In using his system, based on estimating rates of epidemic development from severities on the date of prediction and on the weather of the previous week, each grower plots the course of disease progress and potential loss. Depending on potential yield and expected income, the grower decides whether chemical control would be profitable. Buchenau's system assumes a linear relationship between disease severity and loss as described by Kingsolver et al. (8) and Romig & Calpouzos (9) for wheat stem rust. So it would seem that loss could be described as a linear function of disease severity.

Crop loss due to stem rust has been equated with disease severity at a particular growth stage (8, 9), but that relationship could change with duration of the epidemic (9). For example, crop loss might be equated with stem rust severity at hard dough with epidemics of long duration, but with severity at late milk to early dough with epidemics of short duration. Thus, loss:disease severity ratios should be described by more than a single point, especially if that relationship is to be applied to predicting loss.

Our studies indicate that we can predict the course of leaf rust development (3). To make such predictions useful, we need to be able to forecast damage from the disease and the following scheme can be used to do this.

MATERIALS AND METHODS.—Field plot procedures and location were the same as reported in our leaf rust prediction study (5). Rust severity data were recorded as per cent on flag leaves and per cent per tiller (tiller here refers to all foliar tissue on a culm except sheaths). Percentage losses of grain yields were obtained during 1968, 1969, and 1970 from 9 winter wheat cultivars (Bison, C.I. 12581; Triumph, C.I. 12132; Ottawa, C.I. 12804; Guide, C.I. 13856; Gage, C.I. 13532; Shawnee, C.I. 14157; Parker, C.I. 13285; Scout, C.I. 13546; Lancer, C.I. 13547) and 7 spring wheat cultivars (Baart, C.I. 1697; Crim, C.I. 13465; Chris, C.I. 13751; Manitou, C.I. 13775; Selkirk, C.I. 13100; Milam, C.I. 13369; Thatcher, C.I. 10003). Not all cultivars were tested each year. A 4-m strip on both ends of each plot was sprayed with maneb in 1968 and 1969, and with RH-124 (4-*n*-butyl-1,2,4-triazole) (12) in 1970. Eight 1-$m^2$ areas were harvested from sprayed and unsprayed portions of each cultivar, and grain weight measurements recorded in $g/m^2$. Percentage of grain loss caused by *P. recondita* was calculated for each cultivar.

Untransformed rust severities and grain losses (%) for 55 cultivar-location-year combinations were entered into a stepwise multiple regression computer program with per cent loss as the dependent variable. Independent variables were: $X_1$ = % rust on flag leaf at boot; $X_2$ = % rust per tiller at boot; $X_3$ = % rust on flag leaf at heading; $X_4$ = % rust per tiller at heading; $X_5$ = % rust on flag leaf at early berry; $X_6$ = % rust

TABLE 1. Coefficients of determination ($r^2$) from regression of *Puccinia recondita tritici* severities on flag leaves and per tiller on damage (%) at four growth stages

| Boot | | Heading | | Early berry | | Early dough | | |
|---|---|---|---|---|---|---|---|---|
| Flag | Tiller | Flag | Tiller | Flag | Tiller | Flag | Tiller | N[a] |
| 0.20 | 0.29 | 0.25 | 0.23 | 0.26 | 0.32 | 0.64 | 0.64 | 55 |

[a] Number of observations in analysis.

per tiller at early berry; $X_7$ = % rust on flag leaf at early dough; $X_8$ = % rust per tiller at early dough. Stepwise regression was applied to five groups of independent variables. Group I comprised variables $X_1$, $X_3$, $X_5$, and $X_7$; group II, $X_2$, $X_3$, $X_5$, and $X_7$; group III, $X_2$, $X_4$, $X_5$, and $X_7$; group IV, $X_2$, $X_4$, $X_6$, and $X_7$; and group V, $X_2$, $X_4$, $X_6$, and $X_8$. Significant variables were identified in the program by a "student" t-test; standard errors ($S_E$) of regression were calculated. Partial regression coefficients for significant variables were used to predict per cent loss on the 55 combinations. Appropriate "student" t- and F tests were applied to means and variances of observed and predicted losses. Losses on nine cultivars also were predicted using predicted rust severities rather than observed severities.

RESULTS.–Coefficients of determination of each variable ($r^2$) are recorded on Table 1. The Z test (10) showed $r^2$ values for rust severities on flag leaves, and rust severities per tiller were not significantly different within any growth stage. However, $r^2$ values for flag leaf severities and tiller severities at early dough were significantly different from those at the other growth stages. Similarities in $r^2$ values for individual variables are reflected in the identity of variables shown to be significant by the stepwise program. Equal $R^2$ values (coefficient of determination when two or more independent variables are involved) were obtained with groups II to V; however, in each group, rust severities at heading were not significant (Table 2).

The relation between observed and predicted losses is illustrated in Fig. 1, where regression coefficients and constant value from group II (Table 2) were used to predict loss within a standard error of 9%. The points which cluster around the line $Y = \hat{Y}$ indicate that the equation satisfactorily (in the range of losses observed) predicts damage caused by leaf rust. Variances and means of observed and predicted losses were not significantly different.

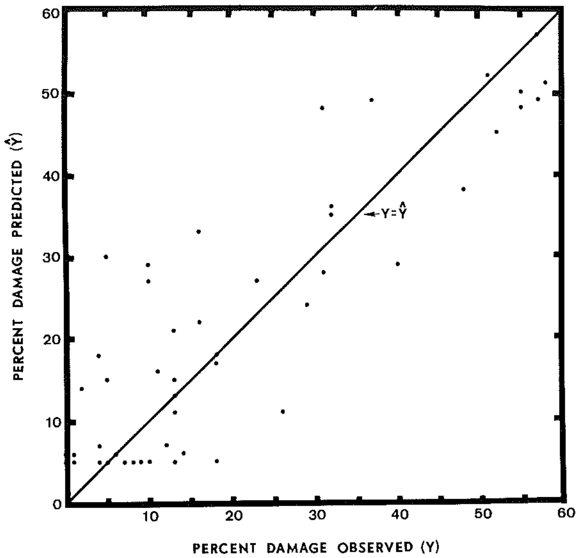


Fig. 1. Per cent damage by *Puccinia recondita tritici* on wheat cultivars observed versus per cent damage predicted by $\hat{Y} = 5.3788 + 5.5260X_2 - 0.3308X_5 + 0.5019X_7$.

To test the accuracy of predicting losses from predicted severities, we compared nine epidemics (ranging from light to severe) on several cultivars (Table 3). Rust severities were predicted from equations developed previously (3). To solve equation II (Table 2), we used rust severities on date of prediction (late joint to boot), on date of prediction plus 21 days (early berry), and on date of prediction plus 30 days (early dough). From that limited test, it appears that we can do as satisfactory a job predicting severe and moderate damage with predicted severities as we can with observed severities because the average variation ($\sqrt{\Sigma (Y - \hat{Y})^2 / N}$) from losses predicted from

TABLE 2. Partial regression coefficients, coefficients of determination ($R^2$), and standard error ($S_E$) for combination of significant variables in a stepwise multiple regression with per cent loss on wheat cultivars caused by *Puccinia recondita tritici* as the dependent variable

| Equation | Independent variable[a] | K[b] | Boot | | Heading | | Early berry | | Early dough | | $R^2$ | $S_E$ (%) | N[c] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Flag | Tiller | Flag | Tiller | Flag | Tiller | Flag | Tiller | | | |
| I | $X_{1,3,5,7}$ | 7.7647 | 35.6145 | | | | | | 0.4393 | | 0.73 | 11 | 55 |
| II | $X_{2,3,5,7}$ | 5.3788 | | 5.5260 | | | −0.3308 | | 0.5019 | | 0.79 | 9 | 55 |
| III | $X_{2,4,5,7}$ | 5.3788 | | 5.5260 | | | −0.3308 | | 0.5019 | | 0.79 | 9 | 55 |
| IV | $X_{2,4,6,7}$ | 5.3897 | | 6.3892 | | | | −0.4322 | 0.5294 | | 0.79 | 9 | 55 |
| V | $X_{2,4,6,8}$ | 3.9590 | | 5.9953 | | | | −0.3577 | | 0.5147 | 0.79 | 9 | 55 |

[a] Rust severity of flag leaf at boot ($X_1$), heading ($X_3$), early berry ($X_5$), and early dough ($X_7$), and on tillers at boot ($X_2$), heading ($X_4$), early berry ($X_6$), and early dough ($X_8$).
[b] Constant term–obtained from regression of disease severity on per cent loss.
[c] Number of observations in analysis.

TABLE 3. Comparison of observed and predicted severity of *Puccinia recondita tritici* and damage on wheat

| Location | Cultivar | Observed severity (%) | | | | Loss estimated from observed severity (%) | Predicted severity (%) | | | Loss estimated from predicted severity (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Boot[a] | EB[b] | ED[c] | Losses | | Boot[a] | EB[b] | ED[c] | |
| Manhattan, Kans. | Bison | 1 | 20 | 95 | 58 | 52 | 1 | 10 | 100 | 53 |
| Do | Bison | 1 | 25 | 95 | 55 | 49 | 1 | 4 | 66 | 38 |
| Do | Guide | 0 | 1 | 14 | 13 | 14 | 0 | 1 | 15 | 15 |
| Do | Shawnee | 0 | 1 | 1 | 14 | 8 | 0 | 1 | 7 | 11 |
| Hutchinson, Kans. | Bison | 1 | 1 | 16 | 2 | 15 | 1 | 1 | 4 | 10 |
| Do | Parker | 0 | 1 | 4 | 4 | 10 | 0 | 1 | 5 | 10 |
| Altus, Okla. | Bison | 1 | 24 | 24 | 5 | 13 | 0 | 12 | 10 | 9 |
| Do | Triumph | 1 | 1 | 20 | 4 | 17 | 1 | 1 | 12 | 13 |
| Do | Guide | 1 | 1 | 2 | 13 | 9 | 1 | 1 | 17 | 15 |

[a] Severity per tiller.
[b] Severity on flag leaf at early berry.
[c] Severity on flag leaf at early dough.

observed severities was equal to the average variation from losses predicted from predicted severities (8%). Also, the average variation term was essentially the same as the standard error ($S_E$) for all 55 loss estimates (9%).

DISCUSSION.–Other workers (4, 8, 9) interested in relating crop loss to disease severity have proposed the critical-stage hypothesis. That hypothesis equates loss to disease severity at a particular growth stage. Our analysis neither fully supports nor denies the critical-stage hypothesis. Although we obtained the highest $r^2$ value between crop loss and leaf rust severity at early dough (which would support the critical-stage hypothesis), including severities at boot and early berry strengthened the severity:loss relationship, and increased the coefficient of determination from 0.64 to 0.79.

The critical-stage hypothesis suggests that loss estimates can be made without regarding infection rate (9). Our investigations of leaf rust epidemics have indicated that infection rate (11) is critical to accurate loss estimates because three severity estimates are superior to one in predicting loss.

Workers who support the critical-stage hypothesis have equated loss to the square root of the percentage of yellow rust severity (4) and $\log_e$ of stem rust severity (9). Coefficients of determination in our study were derived from untransformed rust severities. In earlier analyses, we did transform leaf rust severities to logarithms, but $r^2$ values were significantly lower than those obtained from untransformed severities, which suggests a linear increase in loss with an arithmetic rather than logarithmic increase in disease.

Losses were predicted with equal accuracy on cultivars that lack specific genes for resistance (Bison, Triumph, Guide) and those that do have specific genes (Parker, Shawnee). Also, we predicted severe losses and moderate to light losses with equal accuracy. Those capabilities in the prediction scheme are essential to accurate forecasts over a range of environments and cultivars.

LITERATURE CITED

1. ATKINS, I. M., MAXIMO ALCALA DE STEPHANO, O. G. MERKLE, & R. A. KILPATRICK. 1966. Influence on grain yields and yield components of leaf rust on wheat and crown rust of oats as measured by isogenic resistant and susceptible lines. Texas Agr. Exp. Sta. Bull. B-1053. 10 p.
2. BUCHENAU, G. W. 1970. Forecasting profits from spraying for wheat rusts. South Dakota Farm Home Res. 21:31-34.
3. BURLEIGH, J. R., M. G. EVERSMEYER, & A. P. ROELFS. 1972. Development of linear equations for prediction of wheat leaf rust. Phytopathology 61:947-953.
4. DOLING, D. A., & J. K. DOODSON. 1968. The effect of yellow rust on yield of spring and winter wheat. Brit. Mycol. Soc. Trans. 51:427-434.
5. EVERSMEYER, M. G., & J. R. BURLEIGH. 1970. A method of predicting epidemic development of wheat leaf rust. Phytopathology 60:805-811.
6. JOHNSTON, C. O. 1931. Effect of leaf rust infection on yield of certain varieties of wheat. J. Amer. Soc. Agron. 23:1-12.
7. JOHNSTON, C. O., & E. C. MILLER. 1934. Relation of leaf rust infection to yield, growth, and water economy of two varieties of wheat. J. Agr. Res. 49:955-981.
8. KINGSOLVER, C. H., C. G. SCHMITT, C. E. PEET, & K. R. BROMFIELD. 1959. Epidemiology of stem rust: II. Relation of quantity of inoculum and growth stage of wheat and rye at infection to yield reduction by stem rust. Plant Dis. Reptr. 43:855-862.
9. ROMIG, R. W., & L. CALPOUZOS. 1970. The relationship between stem rust and loss in yield of spring wheat. Phytopathology 60:1801-1805.
10. STEEL, G. D., & J. H. TORRIE. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., Inc., New York. 481 p.
11. VAN DER PLANK, J. E. 1963. Plant diseases: epidemics and control. Academic Press, New York. 349 p.
12. VON MEYER, W. C., S. A. GREENFIELD, & M. C. SEIDEL. 1970. Wheat leaf rust: Control by 4-n-butyl-1,2,4-triazole, a systemic fungicide. Science 169:997-998.