The Relationship Between Stem Rust and Loss in Yield of Spring Wheat

R. W. Romig and L. Calpouzos

Former Research Plant Pathologist, Crops Research Division, ARS, USDA, St. Paul, Minnesota; now Geneticist, Northrup King Research Center, Eden Prairie, Minnesota 55343; and Associate Professor, Department of Plant Pathology, University of Minnesota, St. Paul 55101.

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ABSTRACT

Yield loss was correlated with disease severity from four different stem rust epidemics on a spring wheat variety at one site. Polynomial and logit functions of the disease progress curves were derived. Area under the entire disease progress curve or any part thereof was not consistently proportional to the resulting yield loss. Yield loss was approximately equal to disease severity estimates made at growth stages late milk to early dough for short epidemics and to estimates made at hard dough stage for long epidemics. The best estimate of loss, however, was found with the $\log_e$ of disease severity taken when the developing caryopsis had reached three-fourths its final size. The data suggested that a reliable generalized method for estimating spring wheat losses due to stem rust is most likely to be developed by trying to find a critical growth stage of wheat at which to make disease estimates. Phytopathology 60: 1801-1805.

Additional key words: Puccinia graminis tritici.

Studies of loss in yield of small-grain cereals due to disease suggest that loss may be either proportional to the area under the disease progress curve (9) or proportional to disease severity at some critical stage of host development (2, 4). In support of the area hypothesis are the proposals that stem or leaf rust severity at different stages of wheat development can be directly correlated with loss (1, 6, 7), that a given stem rust severity causes a corresponding loss/week which accumulates for each week of the epidemic (3), and that loss is related to the wheat growth stage at which 1% severity of stem rust occurs (5). The critical-stage hypothesis is supported by findings that barley yield loss may be equivalent to approx two-thirds of the percentage of flag-leaf area visibly infected by *Rhynchosporium* scald at growth stage milky-ripe (4), and that wheat yield loss is equal to the square root of the percentage yellow rust at growth stage end-of-flowering (2).

For stem rust, *Puccinia graminis* (Pers.) f. sp. *tritici* Eriks. & E. Henn., on spring wheat (*Triticum aestivum* L.) there are insufficient data to determine which hypothesis may be applied to estimate loss. The objectives of the experiment presented in this paper, therefore, were to generate data for the evaluation of each hypothesis and to derive a preliminary estimate of the quantitative relationship between development of stem rust and loss in spring wheat.

MATERIALS AND METHODS.—Four different epidemics of stem rust were established at Rosemount, Minn., in 1968, in field plots of spring wheat Purdue 5481C-1-13-2. This wheat is derived from the cross (Red Bobs)^2 × Exchange, and is resistant to the prevalent races of *P. recondita* Rob. ex Desm., but susceptible to the prevalent races of *P. graminis* f. sp. *tritici.* The four epidemics were (i) long duration, high severity; (ii) long duration, moderate severity; (iii) short duration, high severity; and (iv) short duration, moderate severity. The epidemics were manipulated by varying the date of inoculation and the date and rate of fungicide application. The two long epidemics were started by inoculating plants on 31 May when they were at the jointing stage of growth. Uredospores of race 15B-2 in oil (Mobilsol 100) were applied with a mist blower to the outside rows of the appropriate plots at a concn of 1 g spores/liter of oil and a rate of 1 liter/0.4 hectare. The two short epidemics were started by inoculating plants at the heading stage on 2 July. Natural infection was not observed prior to artificial inoculation.

Fungicides were never applied to the long, high epidemic. The rates of increase of the other epidemics were regulated by varying the spray rates between 112 and 224 g of a coordination product between zinc sulfate and manganese ethylenebis dithiocarbamate (Dithane M-45) in 467 liters of water/hectare. Sprays were applied 1 or 2 times/week. Nickel sulfate at either 56 or 112 g/hectare was added in two sprays after heading of wheat. The check consisted of noninoculated plots, sprayed once or twice weekly with 2,238 g of maneb in 467 liters of water/hectare, beginning at the jointing stage of wheat growth. The checks also received the high rate of nickel sulfate in two sprays after heading. The sprays were applied from a tractor-pulled high volume sprayer with a side boom extending over the plots.

The field plot design was a 5 × 5 latin square. Each plot consisted of 16 rows of wheat 5 m long planted 30 cm apart. The plots were separated by 35 m of a stem rust resistant barley (*Hordeum vulgare* L. 'Trophy') to reduce the interchange of uredospores between treatments. The date of seeding was 29 April. Weeds were controlled by appropriate herbicidal treatment.

Estimates of disease severity found on the stems of plots in the interior rows of each plot were made on 21 and 28 June; 5, 10, 18, 24, and 31 July; and 14 August for the check plots. Disease severity estimates were based on the modified Cobb scale. Four inside rows of the plots with the epidemics were harvested by hand on 14 August. Inside rows of the check plots were harvested 6 days later. The grain was air-dried and weighed for yield.

RESULTS.—Disease severity data and growth stage data were recorded at intervals during the 41-day period, 21 June to 31 July, for each epidemic. The biological record of the epidemics is given in Table 1. Plots of the disease-severity data show four different sigmoid disease progress curves which correspond to the epidemics described above in MATERIALS AND METHODS.

The average grain yield associated with each epidemic is given in Table 2. The average yield of the sprayed check plots, 2,379 kg/hectare (35.4 bu/acre), is in the range of yield normally expected for spring wheats at this location. The sprayed check plots had 3.8% stem rust severity at late milk stage and 7.0% at the midhard dough stage. We assumed from the relationship shown in Table 3 that these check plots had a 4% loss in yield. Thus, the calculated disease-free yield would have been 2,478 kg/hectare (36.9 bu/acre), which was the figure used as the basis for all subsequent disease loss estimates in this paper.

Descriptions of the disease progress curves for analytical purposes were derived from the experimental data by calculating the regressions for the third-degree polynomial function and for the logit function. The best fit of the calculated disease progress curves (as judged by F ratios, correlation coefficients, and standard errors of estimate) to the disease data occurred when the starting date was taken as 28 June for the two long epidemics, and 5 July for the two short epidemics. The correlation coefficients of these curves ranged from 0.95 to 0.99. The trace amounts of disease occurring before these dates probably had little or no direct effect on loss. The subsequent analyses, therefore, were based on disease-progress curves starting from these dates.

Areas under the entire disease-progress curves were derived from the regression equations for both the polynomial and logit functions (Table 2). Nearly equal areas resulted under the curves of both functions for the long-moderate and short-high epidemics.

Comparison of the losses with the areas under the curves shows that the greatest loss was associated with the largest area, and the least loss with the smallest area; however, different losses were associated with each of the two epidemics which had nearly equal areas under the disease curves. This suggests that the relationship of loss to area is not one of simple linear proportionality.

TABLE 1. Average disease severity of four stem rust epidemics on a spring wheat at various growth stages from jointing to hard dough[a]

		Disease severity[b]			
		Epidemic			
		Long duration		Short duration	
Observation date	Growth stage[c]	High sever.	Mod. sever.	High sever.	Mod. sever.
1968		%	%	%	%
21 June	Jointing	<1	<1	<1	<1
28 June	Boot	3	1	<1	<1
5 July	Early anthesis	4	4	1	1
10 July	Late anthesis	12	5	1	2
18 July	Kernel 3/4[d]	81	35	23	10
24 July	Early dough	90	52	65	23
31 July	Hard dough	100	79	89	67

[a] Spring wheat variety Purdue 5481C-1-13-2 inoculated with stem rust race 15B-2.

[b] Each percentage is an average of five observations.

[c] Average growth stage for all four epidemics.

[d] Kernel 3/4 means the stage at which the developing caryopsis has attained three-fourths' its final size.

The relationship of area to loss expressed as a ratio is also given in Table 2. When the polynomial function was used, only the two short epidemics had similar ratios; when the logit function was used, none of the epidemics had similar ratios.

No consistent area:loss ratio was found in the foregoing comparisons with areas under the entire disease curve. But should the end point of each epidemic be progressively shortened by 1 day at a time, a shorter duration might be found where all epidemics would have the same area:loss ratio, thus supporting the area hypothesis. The areas of progressively shorter durations were derived for each epidemic, and a series of area: loss ratios were calculated and plotted (Fig. 1). From the area hypothesis, one might have predicted that there should be at least one point during the epidemic where the area:loss ratio is a constant, all four lines meeting at a common point. This did not happen. The data, therefore, do not support the area hypothesis.

Next, we examined the relationship of disease severity and stage of growth to loss to determine whether loss was proportional to disease at some particular stage. Loss estimates cannot be derived from the final disease severity alone, but for long epidemics (those which had at least 5% severity at anthesis), percentage loss in yield was nearly equal to the percentage severity at the hard dough stage. With epidemics of short duration, percentage loss in yield was approx equal to the percentage severity at the late-milk to early-dough stage

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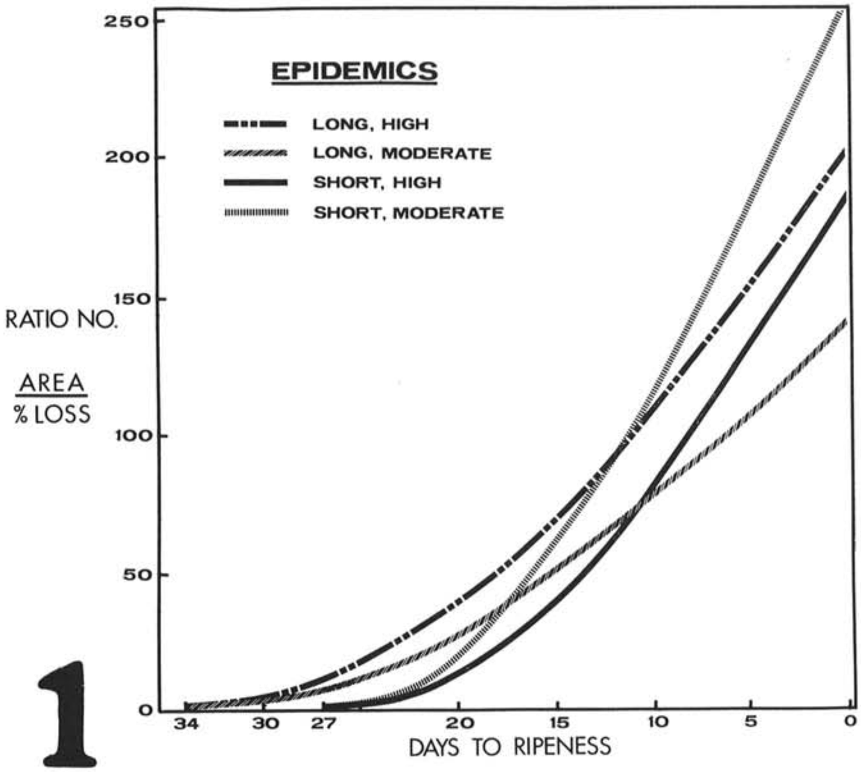
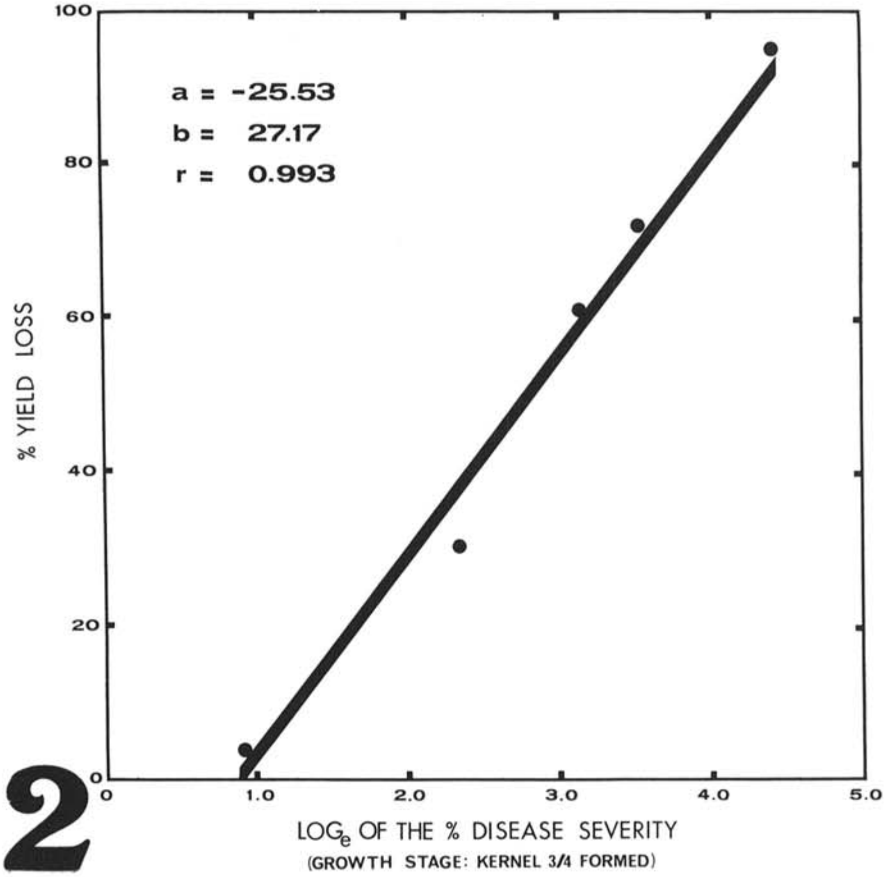
Fig. 1-2. **1)** Curves of the ratios of area under the disease progress curve (progressively lengthened by 1 day at the time) to the percentage loss. **2)** Regression of percentage yield loss on the $\log_e$ of stem rust severity on a spring wheat at the stage of growth at which the caryopsis had reached three-fourths' its final size (the untransformed disease data point from left to right, and are 2.6, 10, 23, 35, and 81%).


EPIDEMICS
LONG, HIGH
LONG, MODERATE
SHORT, HIGH
SHORT, MODERATE
RATIO NO.
AREA
% LOSS
250
200
150
100
50
0
34
30
27
20
15
10
5
0
DAYS TO RIPENESS

1


a = -25.53
b = 27.17
r = 0.993
% YIELD LOSS
100
80
60
40
20
0
0
1.0
2.0
3.0
4.0
5.0
LOG$_e$ OF THE % DISEASE SEVERITY
(GROWTH STAGE: KERNEL 3/4 FORMED)

2

TABLE 2. Relationship between the area under the disease progress curve and percentage yield loss for four stem rust epidemics on spring wheat[a]

Epidemic				Area under curve[c]		Area/% loss	
Duration	Severity	Yield	Yield loss[b]	Polynomial	Logit	Polynomial	Logit
		kg/ha	%			*ratio*	*ratio*
Long	High	133	94.6	16.1	184	0.170	1.945
	Moderate	677	72.7	8.9	104	0.122	1.430
Short	High	962	61.2	8.8	109	0.144	1.781
	Moderate	1,744	29.6	4.3	72	0.145	2.432

[a] Stem rust race 15B-2 on spring wheat Purdue 5481C-1-13-2. All numbers are average of five replicates.

[b] Based on a yield of 2,478 kg/hectare from a calculated disease-free check.

[c] Area expressed in arbitrary units.

(Table 3). This provides a simple and direct approximation of loss, but two estimates are needed and the estimates are imprecise for all but long epidemics.

The data were evaluated to determine whether they would fit the critical stage hypothesis. For each observation date, we plotted the average percentage yield loss against the average percentage severity for the four epidemics and the check. The plots for the last two dates gave no convincing evidence either for or against the hypothesis because of their dispersal. Earlier observations did not give meaningful correlations except for the 18 July observations, which were orderly and described a hyperbolic curve. The hyperbolic curve suggests that the percentage yield loss can be expressed as a natural logarithmic function of disease severity for the growth stage on this date. On 18 July, the developing caryopsis had reached about three-fourths its final size and form. The equation which best fits our data is: $Y = -25.53 + 27.17 \log_e X$, where Y = average percentage yield loss, and X = average percentage disease severity. The graph of this equation as well as the data points are given (Fig. 2). The regression coefficient of correlation 0.993 indicates that this equation accounts for almost all of the variation in our data.

DISCUSSION.—To determine the effect of disease on yield losses, epidemics ideally should be varied while other biotic and environmental factors remain the same. The key to this study was the creation of four different stem rust epidemics in the same field by means of different inoculations and fungicidal treatments. We cannot be entirely certain that the fungicidal sprays affected yield apart from controlling disease; however, our previous experience with the maneb and nickel fungicides suggests that the sprays in this experiment should have had little effect on yield.

Our data and analyses suggest that estimates of loss in yield of spring wheat due to stem rust can best be made by the critical stage approach. This conclusion is supported by physiological studies where major gains in dry wt of spring wheat grain resulted from photosynthates temporarily accumulated in the stem near the time of anthesis (8). This suggests that disease would be expected to exert a greater influence on yield loss at or near this growth stage. An important advantage of the critical stage method is that loss estimates may be derived without regard to the infection rate.

The particular equation which best fits the data may or may not be applicable to all wheat stem rust epidemics. Further trials are needed with other varieties and various environments to confirm the conclusions reached here.

TABLE 3. Relationship between percentage disease severity at two stages of growth and percentage yield loss for four stem rust epidemics on spring wheat[a]

Epidemic		Disease severity		
Duration	Severity	Late milk to early dough	Hard dough	Yield loss[b]
		%	%	%
Long	High	87[c]	100	95
	Moderate	52	79	73
Short	High	65	89	61
	Moderate	23	67	30

[a] Stem rust race 15B-2 on spring wheat Purdue 5481C-1-13-2.

[b] Based on a yield of 2,478 kg/hectare from a calculated disease-free check.

[c] A calculated figure from data taken at middough stage (90% severity).

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