Relationship Between Incidence and Severity of Powdery Mildew and Leaf Rust on Winter Wheat

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ABSTRACT

Disease incidence and severity data for powdery mildew (*Erysiphe graminis* DC. ex Mérat f. sp. *tritici* Em. Marchal) and leaf rust (*Puccinia recondita* Rob. ex Desm. f. sp. *tritici* Eriks.) of winter wheat (*Triticum aestivum* L.) were recorded during three surveys in Ontario in 1969 and 1970. An exponential equation was used to describe the relationship between the incidence (percentage of leaves infected) and severity (percentage of leaf area affected) for the two diseases on particular leaves. A linear regression was found to be adequate to estimate severity for incidence values of 65% or below. The relationship between incidence and severity for each of two diseases was consistent over a large geographical area, but differed for the 2 years.

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Additional key word: epidemiology.

The increase of a foliage disease in a cereal crop is usually the result of two simultaneous processes; an increase in the proportion of leaves infected and in the percentage of leaf area affected by disease, hereafter referred to as incidence and severity, respectively. During the earlier part of an epidemic of mildew or cereal leaf rust, incidence and severity increase until all the leaves are infected, but thereafter an increase in disease can only result from an increase in severity. The relationship between the increase of incidence and severity can be established either by making sequential records on one cereal crop during the progress of an epidemic or by assessing many cereal crops with different amounts of disease at one point in time.

The literature is replete with data showing the increase of disease with time (16), but there are few data on the increase of incidence relative to severity in the earlier part of the epidemic. The objective of this work was to obtain disease incidence and severity data from surveys of winter wheat crops with different amounts of mildew (*Erysiphe graminis* DC. ex Mérat f. sp. *tritici* Em. Marchal) and leaf rust (*Puccinia recondita* Rob. ex Desm. f. sp. *tritici* Eriks.) and to characterize the relationship between incidence and severity for each of the two diseases.

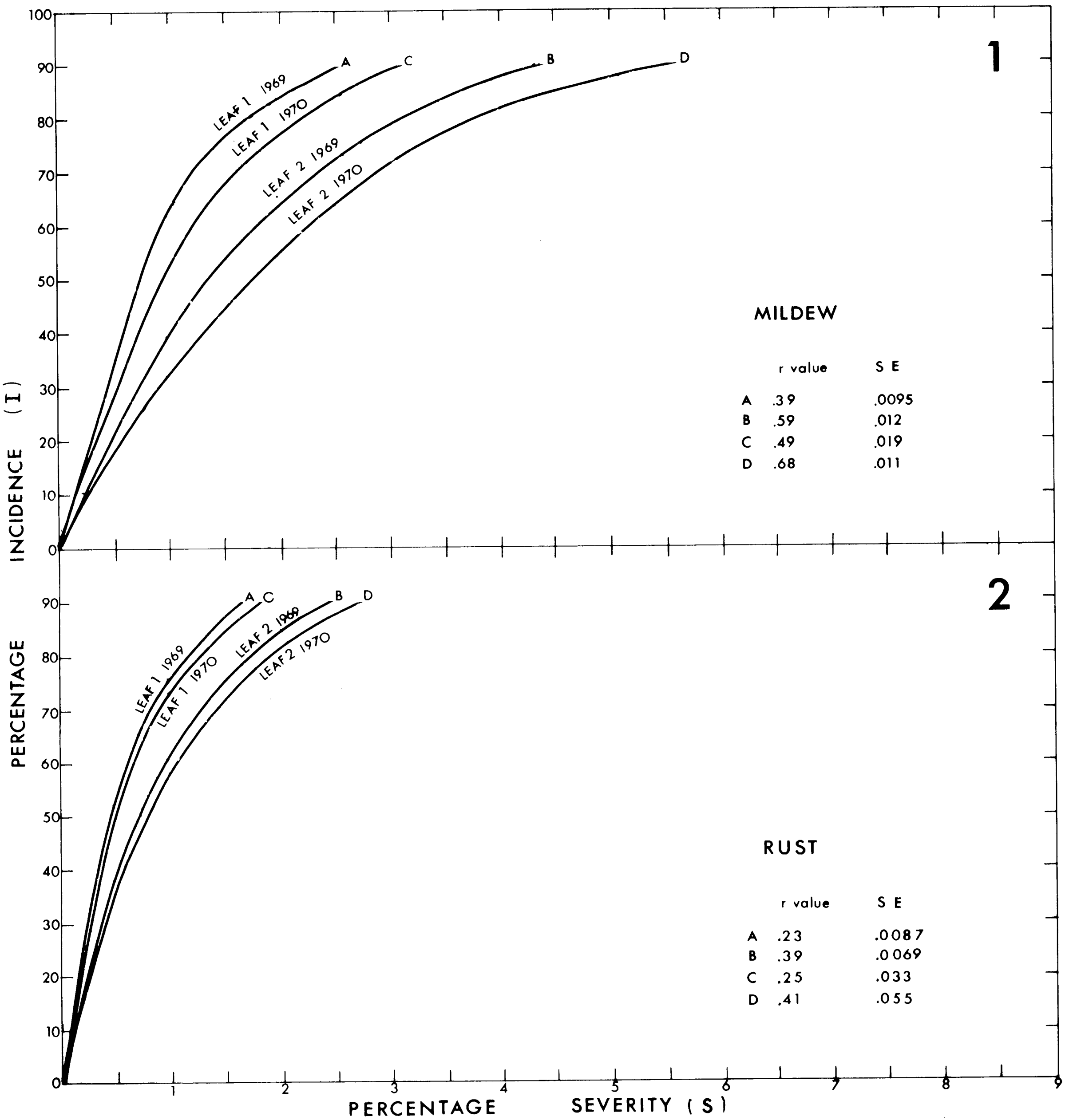
MATERIALS AND METHODS.–Surveys of foliage diseases of winter wheat (*Triticum aestivum* L.) grown in Ontario were conducted in 1969 and 1970 (8, 11). In order to provide a meaningful estimate of disease for the province, the number of fields selected per county was proportional to the winter wheat acreage.

In 1969, 63 fields comprising ca. 750 acres were sampled, and three culms/acre were selected up to a maximum of 25 culms/field, chosen at equal intervals along a path through the field in the form of a W. Two surveys were conducted during the last week of May and June when crops were at growth stages 8 to 9 and 11.1 to 11.2 (12), respectively.

In 1970, 50 fields totalling 650 acres were surveyed, and 30 culms were chosen from each field at approximately equal intervals along one diagonal. One visit was made during June when the crops were at growth stage 11.1 to 11.2.

The severity of infection with cereal leaf pathogens differs considerably from leaf to leaf on the same plant (7); therefore, the method of disease assessment least prone to error is based on individual leaves (9, 10). The top (upper) leaves were assessed because they make a major contribution to grain dry matter (15). The top four leaves (top or flag = leaf 1) were assessed during the May sampling and the top two in June. Each leaf was assessed separately, and the percentages of leaf "area affected" by mildew and leaf rust were recorded using illustrated disease assessment keys as a guide (9, 10). "Area affected" in this context included the lesion and any associated chlorosis. For each field, we calculated severity separately for leaves 1 to 4 by dividing the sum of the percentage leaf area affected by one disease by the number of leaves in the sample (from one leaf position on the plant), whether they were infected or not. Disease incidence was calculated as the number of leaves infected expresses as a percentage.

RESULTS.–There were two objectives in examining the relationship between incidence and severity. Our first objective was to characterize the relationship between incidence and severity by examining the rate of increase of incidence relative to severity. For this purpose we used an exponential equation. The second objective was to develop a simple technique for estimating severity from incidence, a frequent requirement in practice. To achieve this objective we used a simple linear


1
LEAF 1 1969
LEAF 1 1970
LEAF 2 1969
LEAF 2 1970
A
B
C
D
MILDEW
r value S E
A .39 .0095
B .59 .012
C .49 .019
D .68 .011
2
RUST
r value S E
A .23 .0087
B .39 .0069
C .25 .033
D .41 .055
INCIDENCE (I)
PERCENTAGE
PERCENTAGE SEVERITY (S)

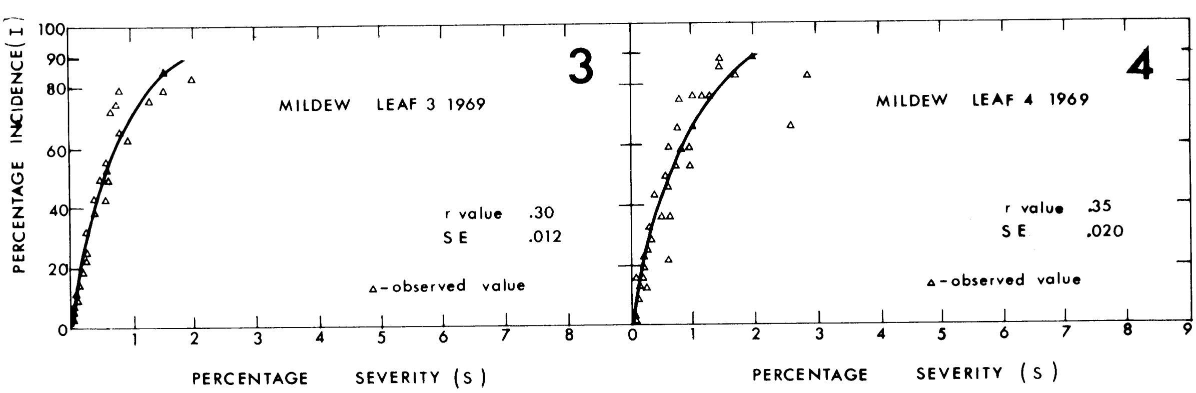

3
MILDEW LEAF 3 1969
r value .30
S E .012
△-observed value
PERCENTAGE INCIDENCE(I)
PERCENTAGE SEVERITY (S)
4
MILDEW LEAF 4 1969
r value .35
S E .020
△-observed value
PERCENTAGE SEVERITY (S)

Fig. 1-4. Incidence (percentage of leaves infected) and severity (percentage of leaf area affected) of foliage diseases of winter wheat recorded in foliage disease surveys in Ontario. The exponential equation $I = 100\ (1-r^S)$ was used to describe the relationship between incidence (I) and severity (S) for the two diseases. **1)** Mildew on leaves 1 and 2 in 1969 and 1970. **2)** Rust on leaves 1 and 2 in 1969 and 1970. **3)** Mildew on leaf 3 in 1969. **4)** Mildew on leaf 4 in 1969.

equation. The results are discussed under two subheadings.

Rate of increase of incidence relative to severity.—The exponential equation used was:

$$I = 100\ (1-r^S),\ 0<r<1$$

where I is disease incidence and S is disease severity. The equation satisfies the condition that I = 0 when S = 0, and that as S increases, I also increases until the incidence approaches 100%. In the equation, r describes the increase in incidence relative to severity. When comparing r values, a disease with a smaller r increases more by incidence relative to severity, and conversely, a larger r value implies that disease increases relatively more by severity than incidence. In the equation, the r values define increase in incidence at a decreasing rate relative to severity, and a fraction (1-r) of the healthy leaves will be infected when severity increases by 1%. For example, r was 0.3 for mildew on leaf 3 in 1969 (Fig. 3). When S = 1, 70% of the leaves were infected; when S = 2, 91% of the leaves were infected, and 9% of the leaves were healthy. If severity increased by another 1%, the incidence would increase by (1−0.3) X 9, or 6.3%, from 91 to 97.3%. In analyzing the data, incidence was regarded as error-free because it was based on the presence or absence of disease; however, severity was observed with error since it was calculated from estimates of the percentage leaf area covered by disease. The value r in the equation above cannot, therefore, be estimated by the least squares method, which requires that values of independent variables are observed without error. However, the least squares method can be used to fit the semilog equation:

$$S = b\ \log_e (1-I/100)$$

where b is the regression coefficient of a line through the origin, and the r value in the above equation was calculated as $r = e^{(1/b)}$ with an approximate standard error estimated by $(r/b^2) \times$ standard error of b.

Figures 1 to 4 illustrate the relationship between incidence (up to 90%) and severity for the two diseases, the same disease on different leaves, and the same disease on the corresponding leaf for different years, as characterized by the r values. In 1969 and 1970, the r values for corresponding leaves were consistently higher for mildew than for leaf rust. Both diseases had a higher r value for leaf 2 than leaf 1; and for mildew, r was higher for leaf 4 than leaf 3; the higher r value was always associated with the lower leaf at any one growth stage. The corresponding r values for mildew in 1970 were higher than in 1969, although the differences were small for leaf rust.

Estimation of severity from incidence.—Linear regressions of severity on incidence up to 65% were fitted. The line representing linear equation A in Fig. 5 is in good agreement with the observed values as indicated by the high percentage of variability

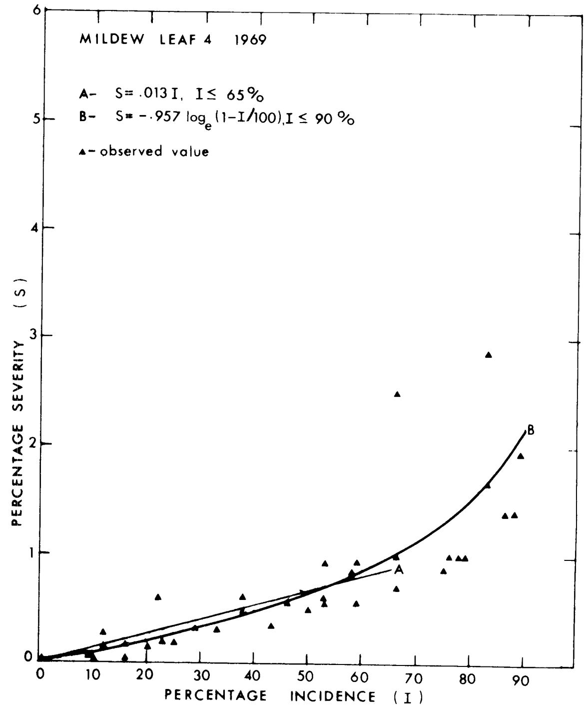


Fig. 5. Linear and semilog equations for estimating severity.

explained by the regression (Table 1). However, the difference between observed and estimated values for equation B (Fig. 5) illustrates the difficulties in estimating severity reliably for high values of incidence. Mildew had higher coefficients than rust for corresponding leaves, and both diseases had higher coefficients for lower leaves.

DISCUSSION.—Van der Plank (16) defined an epidemic as an increase of disease with time. Using graphical methods to plot the amount of disease against time on an arithmetic scale, the disease progress curves that result are often sigmoid-shaped (16). Such a disease progress curve does not exhibit the relative importance of incidence and severity in the first shallow part of the disease progress curve prior to the important logarithmic increase in disease in the steep part of the S-shaped curve. A method of exploring and characterizing the phenomena in the first shallow part of the S curve is offered in this paper. The exponential equation used to characterize the relationship between incidence and severity is of similar form to the equation used by Gregory (4) to represent the incidence of a pathogen from disease incidence expressed as percentage presence or absence on plots of standard area.

In our equation, the r value [not the same as the r

TABLE 1. Linear relationship between severity and incidence (≤65%) for mildew and leaf rust on various leaves of winter wheat[a]

Disease and survey date	Leaf number[b]	Regression coefficient with standard error[c]	% Variability explained by regression
Mildew			
May 1969	3	0.012 ± 0.00028	98
May 1969	4	0.013 ± 0.00054	95
June 1969	1	0.014 ± 0.00027	98
June 1969	2	0.025 ± 0.0013	87
June 1970	1	0.019 ± 0.0017	81
June 1970	2	0.032 ± 0.0015	94
Leaf rust			
June 1969	1	0.011 ± 0.00026	98
June 1969	2	0.014 ± 0.00051	94
June 1970	1	0.010 ± 0.00016	99
June 1970	2	0.017 ± 0.0015	93

[a] Regression coefficients were based on the linear regression equation y = bX, where y was the severity, X was the incidence, and b was the regression coefficient.

[b] Flag or top leaf = leaf 1.

[c] Standard errors were based on variation from field to field.

value defined by van der Plank (16)] can be used as a guide to study the development of disease on a population of cereal leaves at the same leaf position on the plant by establishing the increase in disease incidence relative to severity. The difference in r values reported for the two diseases prompts questions. For example, why were r values for mildew consistently higher than the corresponding values for rust? This may be explained by the larger size of the mildew lesion, but greater numbers and mobility of leaf rust spores giving rise to lesions on uninfected leaves could also contribute to the difference.

The r values for mildew were always higher for the lower leaf, and the reasons for this may have already been published. Last (13) found that the upper leaves of wheat were more resistant to mildew than were the lower leaves, and concluded that this was due to a depletion of the nitrogenous compounds which are necessary to maintain a high rate of growth of both wheat and mildew. However, Smith & Blair (14) concluded that the increase in mildew infection associated with nitrogen was due to greater leaf area, resulting in higher levels of relative humidity, which Cherewick (2) had shown to be positively correlated with germination of conidia. Measurements of the microclimate within cereal crops (1, 3) also show that the lower leaves are subjected to higher levels of relative humidity. However, Last (13) showed that "conidia deposited on susceptible and resistant leaves did not differ significantly in the extent to which they germinated and produced appressoria", and concluded that the increased susceptibility produced by nitrogen was due not to higher relative humidity but to physiological changes within the leaves. Experimental techniques used by Last (13) eliminated any relative humidity gradients normally found within the height profile of a cereal crop (1, 3). When severity levels are low and when disease distribution is not random (5), both the higher relative humidities and nitrogen values for the lower leaves may increase the chances of further infection on infected leaves compared to the top leaves; this would lead to higher r values for the lower leaves as compared to the top leaves. Other factors may also be responsible for the difference in r; for example, differences in spore production or spore deposition for the upper and lower leaves. Our theory is offered as a plausible explanation for the differences found. The relative importance of incidence to severity as characterized by r may be an important factor for determining the onset or rate of disease increase during the logarithmic increase which follows the first shallow part of the S curve, but the information in this paper cannot be used to investigate this possibility.

The exponential equation could also be used to estimate incidence for any given value of severity, although in practice there is usually no demand for the estimate. However, a method for estimating severity for any given level of incidence could be of practical importance because it simplifies the method of assessment to a noting of the presence or absence of disease. The semilog equation could be used to estimate severity for incidence values up to 90% but large errors are possible for incidence values above ca. 65%. If severity is estimated for incidence values up to 65%, a simpler linear equation through the origin provides as good an approximation (Fig. 5) as the semilog equation. The b values (Table 1) can then be used to estimate severity for incidence using the equation y = bX, where y is severity and X is incidence up to 65%.

Although the linear regression equations (Table 1) for predicting severity for mildew or leaf rust on a particular leaf differed slightly for the 2 years, the linear relationship between incidence and severity was stable within each year. The biological significance of this finding was that factors affecting disease development varied more between the 2 years than within the geographical area surveyed in any 1 year. This suggests the possibility that sequential records at one or two sites in 1 year may be adequate to estimate the b value which describes the relationship between incidence and severity for a larger area. It should be noted that the b values quoted are based on data recorded in two consecutive years for pathogen populations on commercial winter wheat crops in a large area of Ontario.

The estimation of severity from incidence data recorded in a disease survey could drastically reduce labor requirements because it would preclude the necessity to estimate severity using the time consuming conventional disease assessment methods (6, 10, 17) if the incidence was below 65%. In practice, a disease survey could be conducted using relatively unskilled labor to record incidence, with instructions that samples should be mailed to a plant pathologist only when incidence exceeded 65%; severity values could then be calculated using b values estimated from experiments. The technique could currently be used to advantage in Europe, to decide whether a fungicide should be applied to control powdery mildew of cereals, when a quick estimation of severity is required before the critical logarithmic increase in disease.

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