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Powdery mildew on winter wheat in Bulgaria, 1980: Relations between disease incidence, disease severity, and yield

T.D. ZAHARIEVA[1], W.A.J. DE MILLIANO[2] and J.C. ZADOKS[2]

[1] Plant Protection Institute, 2230 Kostinbrod, P.O.B. 238, Sofia, Bulgaria
[2] Department of Phytopathology, Agricultural University, Binnenhaven 9, 6709 PD Wageningen, the Netherlands

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Abstract

Mildew epidemics in 1980 on winter wheat cv. Sadovo 1 near Sofia, Bulgaria, were studied in detail. Half of the experimental plots were artificially inoculated, whereas the others were naturally infected. Fungicide treatments on all plots consisted of from nil to three applications of triadimefon. On four days, mildew severity, plant height and the yield components ear length, number of kernels, and grain weight per ear were determined. Mildew incidence showed to be a simple and reliable predictor of yield loss. It is suggested that mildew incidence can be used for decision making in the supervised control of wheat mildew in Bulgaria.

Additional keywords: crop loss, epidemiology.

Introduction

Powdery mildew *(Erysiphe graminis)* and brown rust *(Puccinia recondita)* are the most important foliar diseases of wheat in Bulgaria. Powdery mildew has become common after the recent large scale introduction of productive but susceptible cultivars of winter wheat. In areas where mildew is common, yield losses in experiments exceeded the 20% level (Donchev, 1965; Picco et al., 1971). Information about the relationship between powdery mildew incidence (fractions of leaves infected), powdery mildew severity (fraction of foliar surface infected), and crop yield is, however, limited. Well-known is the quadratic relationship between wheat yield and severity of mildew (Large and Doling, 1963). James and Shih (1973) suggested an exponential relationship between incidence and severity of powdery mildew. The present study was carried out to examine some aspects of these relationships using marked plants in small plots.

Materials and methods

The experiment was performed in 1980 at the Bojourishte Agro Industrial Complex near Sofia, Bulgaria, in a field of winter wheat cv. Sadovo 1. Management practices were as usual except that fungicides were applied only as experimental treatments. The seeding rate was 280 kg ha^{-1}. Each experimental unit (plot), measuring 1 m^2, was surrounded by a path of 0.5 m width. Nine plots in a 3×3 arrangement formed one replication (block). There were four blocks, separated by 40 m of the same crop. In each block, eight treatments were arranged as a 2×4 factorial design, with two methods of inoculation (natural and artificial) and four schedules of fungicide usage (0, 1, 2 and 3 foliar applications). One plot in each block was not used. Inoculation was performed by dusting fresh mildew conidia *(Erysiphe graminis* f. sp. *tritici),* produced in a greenhouse at the Plant Protection Institute of Kostinbrod, over the plants in the appropriate plots. Plants at the time of inoculation (Table 1) were free from mildew. Fungicide treatments consisted of zero to three applications of triadimefon (Bayleton®, 125 g ha^{-1} a.i.) at the days indicated in Table 1.

Tabel 1. Calendar of operations.

Date	Julian day	Assessment day	Stage of development[1]	Operation[2]
80.04.16	107		6	i f
29	120		10	f
05.13	134		10	a
15	136		10	f
23	144	D1	10.1	a
06.10	162	D2	10.5.1	a
07.14	196	D3	11.3	a h

[1] Feekes scale, interpolated values (Large, 1954).
[2] i = inoculation with mildew; f = fungicide application; a = mildew assessment; h = harvest, stem height, ear length, etc.

Observations were on 25 randomly selected and marked plants per plot at the days indicated in Table 1; the same plants were used on all observation days. Mildew was assessed on each of the three fully expanded stem leaves, numbered from top to bottom (1 = flag leaf). Mildew severity was assessed using the scale recommended in the Mutual Economic Assistance (ECOSOC) countries, which has the following nine values: 0, 1, 3, 6, 10, 20, 33, 55 and 75% leaf area covered. At the end of the growing season plant height in cm, ear length in cm, number of kernels per ear, and grain yield per ear in mg were assessed.

Data analysis was performed on the DEC10 computer of the Agricultural University, Wageningen, the Netherlands, using SPSS (Nie et al., 1975). Transversal and longitudinal (Zadoks, 1972) analyses were applied. Measuring errors were detected retrospectively. The measurements of plant height (stem height) were preferential with respect to recording classes. Multiples of 5 cm scored significantly more often than their neighbour values when tested by the sign test at $p = 0.004$. In view of the great number of measurements taken, this measuring error can be disregarded, as errors are cancelled out against each other. The mildew assessment is subject to some error because of the approximately exponential scale used, the intervals increasing with mildew severity. The heteroscedasticity in the original mildew observations may be due, at least in part, to the scale used. In view of the large sample size, the extra variance added by the choice of this scale can be disregarded.

Results

Variate distributions and relations

Disease relations. No disease was present on May, 13th. For the treatment with natural inoculation without fungicide application the Pearson correlation coefficients were calculated over all mildew observations (n = 100, Table 2). The correlation coef-

Table 2. Correlation matrix of mildew severity for three leaf positions on three assessment days. (Natural inoculation, no fungicide, n = 100). Entries are Pearson correlation coefficients r between mildew severities of different leaf layers on different days. $p \leqslant 0.05$ if $r \geqslant 0.17$; $p \leqslant 0.01$ if $r \geqslant 0.23$; $p \leqslant 0.005$ if $r \geqslant 0.32$ (one sided test).

Assessment days and leaf positions		Assessment days and leaf positions							
		D1		D2			D3		
		L2	L3	L1	L2	L3	L1	L2	L3
D1	L2	—	0.3	NS	0.34	NS	NS	0.20	NS
	L3		—	0.17	0.29	0.18	0.20	0.26	0.19
D2	L1			—	0.62	0.24	0.64	0.33	0.39
	L2				—	0.31	0.64	0.55	0.39
	L3					—	0.24	0.27	0.67
D3	L1						—	0.58	0.35
	L2							—	0.41
	L3								—

Table 3. Correlation matrix of mildew severity for three leaf positions on three assessment days. Plot observations, n = 32. Entries are Peason correlation coefficients r. $p \leqslant 0.01$ if $r \geqslant 0.41$; $p \leqslant 0.005$ if $r \geqslant 0.55$ (one-sided test).

Assessment days and leaf positions		Assessment days and leaf positions							
		D1		D2			D3		
		L2	L3	L1	L2	L3	L1	L2	L3
D1	L2	—	0.66	0.50	0.54	0.51	0.47	0.48	0.53
	L3		—	0.86	0.88	0.87	0.84	0.86	0.89
D2	L1			—	0.98	0.95	0.96	0.92	0.95
	L2				—	0.98	0.98	0.97	0.96
	L3					—	0.97	0.98	0.98
D1	L1						—	0.98	0.96
	L2							—	0.98
	L3								—

ficients vary from non-significant (NS) to + 0.67. The highest value (r = +0.67) is for the consecutive assessments on assessment days D2 and D3 (Table 1) on leaf L3 (leaf positions are numbered from top to bottom, flag leaf = L1). Very high correlations are also given for the D2 and D3 assessments on L2 and L1, but values are much lower for D1 and D2 correlations and D1 and D3.

The coefficients of correlation between leaf positions on the same day decrease with

Table 4. Correlation matrix of mildew incidence for three leaf positions on three assessment days. Plot observations, $n = 32$. Entries are Peason correlation coefficients r. $p \leqslant 0.05$ if $r \geqslant 0.30$; $p \leqslant 0.01$ if $r \geqslant 0.41$; $p \leqslant 0.005$ if $r \geqslant 0.55$ (one-sided test).

Assessment days and leaf positions		Assessment days and leaf positions							
		D1		D2			D3		
		L2	L3	L1	L2	L3	L1	L2	L3
D1	L1	NS	NS	0.30	0.26	NS	0.27	0.24	NS
	L2	—	0.54	0.50	0.53	0.50	0.52	0.51	0.49
	L3		—	0.80	0.81	0.94	0.80	0.82	0.93
D2	L1			—	0.98	0.93	0.99	0.92	0.80
	L2				—	0.86	0.99	0.97	0.84
	L3					—	0.84	0.88	0.99
D1	L1						—	0.95	0.82
	L2							—	0.88
	L3								—

Table 5. Correlation matrix of mildew severity (horizontal) and mildew incidence (vertical) for three leaf positions on three assessment days. Plot data, $n = 32$. Entries are Pearson correlation coefficients. $p \leqslant 0.5$ if $r \geqslant 0.30$; $p \leqslant 0.01$ if $r \geqslant 0.41$; $p \leqslant 0.005$ if $r \geqslant 0.55$ (one-sided test).

Assesment days and leaf positions		Assessment days and leaf positions							
		D1		D2			D3		
		L2	L3	L1	L2	L3	L1	L2	L3
D1	L1	NS	NS	0.30	0.27	0.26	0.30	0.25	0.31
	L2	0.64	0.68	0.42	0.50	0.53	0.50	0.55	0.53
	L3	0.42	0.83	0.75	0.78	0.80	0.77	0.79	0.82
D2	L1	0.49	0.82	0.90	0.92	0.96	0.92	0.95	0.98
	L2	0.49	0.84	0.87	0.90	0.94	0.90	0.94	0.97
	L3	0.39	0.78	0.72	0.76	0.81	0.75	0.79	0.83
D3	L1	0.49	0.83	0.87	0.90	0.94	0.90	0.94	0.96
	L2	0.46	0.82	0.80	0.83	0.88	0.93	0.88	0.91
	L3	0.38	0.77	0.69	0.73	0.78	0.72	0.77	0.81

increasing separation of the leaf positions: on D2 the correlation between leaves L1 and L2 is 0.62, but falls to 0.24 between L1 and L3. On D3 these values are 0.58 and 0.35 respectively. On both days the correlation between L2 and L3 is intermediate. These results are consistent with the idea that mildew is non-randomly distributed within plots. For each leaf position, a high mildew severity on an assessment day leads, on average, to a high severity on the next assessment day. On any observation day, a high score on the lower leaf may increase the chance of a high score on the next higher leaf; this is mostly true for L1-L2, and less so for L2-L3.

Plot values of mildew severities of all leaf position * assessment day combinations correlate well (Table 3). Pearson correlation coefficients for D2 and D3 are over $r = 0.90$. When compared over all inoculation method * fungicide schedule combinations ($n = (2 \times 4) \times 4 = 32$), incidence values of different leaf positions and assessment days are highly significantly correlated, with one exception (Table 4). The flag leaf, leaf position L1 on assessment day D1, had so little mildew that its incidence does not correlate with the other incidence values. Considering all 32 plots, incidence and severity are highly correlated, L1 on D1 excepted (Table 5).

Growth, yield and disease. The correlations between mildew severities and yield parameters are always negative (Table 6), as can be expected; the more mildew the lower the yield. Correlations on assessment day D1 are generally low and they are not always significant. On D1, L3 correlates well with yield, as do L1 and L2 on D2, and L1, L2 and L3 on D3. Why leaf position L3 on assessment day D2 has no correlation with yield is not clear. On assessment days D2 and D3 leaf position L1 provides the best predictions of yield.

Table 6. Correlation matrix of mildew severity, plant growth and yield components for disease assessed on three leaf positions on three days. (Natural inoculation, no fungicide, $n = 100$). Entries are Spearman rank correlation coefficients r between mildew severity and yield parameters. $p \leqslant 0.05$ if $r \geqslant 0.17$; $p \leqslant 0.01$ if $r \geqslant 0.23$; $p \leqslant 0.005$ if $r \geqslant 0.32$ (one-sided test).

Assessment day	Leaf position	Plant height	Ear length	Number of kernels per ear	Grain weight per ear
D1	L2	−0.23	NS	NS	NS
	L3	−0.23	−0.35	−0.33	−0.33
D2	L1	−0.31	−0.69	−0.46	−0.48
	L2	−0.35	−0.42	−0.39	−0.44
	L3	NS	NS	NS	NS
D3	L1	−0.35	−0.73	−0.50	−0.60
	L2	−0.29	−0.44	−0.37	−0.53
	L3	−0.31	−0.29	−0.28	−0.31

Effect of inoculation method and fungicide schedule

Growth and yield. Inoculation method had a significant effect ($p < 0.001$) on plant height (PHT); the greatest difference found was 9 cm. The significant interaction (p

= 0.009) for plant height between inoculation method and fungicide schedule is difficult to explain; it is caused mainly by the single application of the fungicide which reduced plant height considerably in the artificially inoculated plots, but not in the naturally inoculated plots.

Artificial inoculation had a significant effect ($p < 0.001$) on ear length, increasing it by 0.5 cm on the average. Fungicide schedules had no main effects ($p = 0.238$) on ear length, but there was a significant interaction ($p = 0.013$): two applications of the fungicide increased ear length considerably in the artifically inoculated treatment but not so in the naturally inoculated treatment.

Artificial inoculation did not affect the number of kernels per ear ($p = 0.976$) but the effect of fungicide schedule was significant ($p = < 0.001$). One application affected the artificially inoculated treatment positively and the naturally inoculated one negatively, an effect similar to that with plant height. Two applications of fungicide had a very positive effect on the number of kernels in both inoculation methods, whereas three applications were slightly damaging, reducing the number of kernels per ear by 1. The interaction described above was significant ($p = 0.004$).

Grain weight per ear was not significantly affected by inoculation method ($p = 0.175$), but fungicide schedules had significant effects ($p \leqslant 0.001$). Interaction was significant ($p = 0.05$) and followed the same pattern as with the number of kernels per ear.

Mildew severity. The courses of the mildew epidemics are shown in Fig. 1, representing the mean values of artificially and naturally inoculated plots without fungicide application. Leaf position L1 shows a slow increase in severity up to just over 0.23. Mildew on L2 increased more rapidly up to 0.44. On L3 mildew increased rapidly at first, slowly later up to 0.37. The main effect of inoculation method on mildew severity was significant in five out of seven cases; on assessment day D2 it was significant for all three leaf positions. Artificially inoculated plots scored higher than naturally inoculated ones, with a maximum difference of 0.08 for leaf position L1 on assessment day D3. The interaction between inoculation method and fungicide schedules was

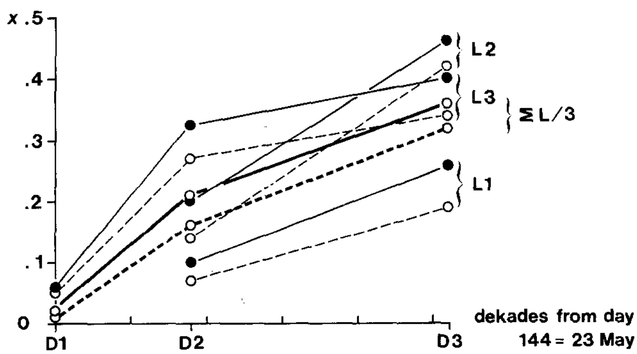

Fig. 1. Development of a mildew epidemic on winter wheat cv. Sadovo 1 in Bulgaria, 1980. D = observation day. x = fraction of leaf surface diseased. L = leaf position (L1 = flag leaf; ΣL = all three leaf positions heavy lines). Black dots = inoculated plots without fungicide. Open dots = non-inoculated plots without fungicide. Each dot represents 100 stems. Differences between inoculation treatments were always significant.

significant ($p < 0.05$) for the upper two leaf positions on assessment day D2 possibly due, at least in part, to heteroscedasticity.

Mildew incidence. Incidence is the (relative) frequency of infected leaves. Mildew incidence was determined per plot for each of the three assessment days and each of the three upper leaf positions and expressed as number of leaves infected per leaf position and per day. As there were 25 stems per plot, incidence ranged from 0 to 25.

Fungicide schedules. Fungicide applications were effective as shown in Fig. 2. One application gave a significant ($p < 0.001$) decrease of mildew; the largest reduction in mildew was recorded on leaf position L2 at assessment day D3. On the flag leaf, three applications were needed to keep mildew below $x = 0.05$; on L2 and L3 two applications were sufficient. Fig. 3 shows that two fungicide applications were needed to improve yield.

Analysis of epidemic growth. In longitudinal analysis (Zadoks, 1972), results are studied through time. In a way, the correlation studies do just this. Another approach is the analysis of epidemic growth rates.

Mean daily increment. One parameter, which can be determined for each plant and leaf separately is the mean daily increment (MDI) of the mildew

$$MDI = \frac{x_{t+\Delta t} - x_t}{\Delta t}$$

where x is the mildew severity on day t and Δt is the time interval in days between two successive assessments. When MDI's are calculated per stem, they can be subjected

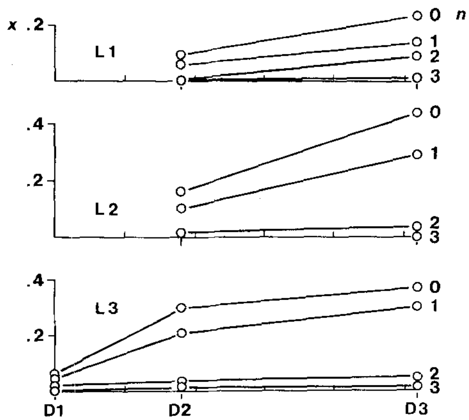

Fig. 2. Development of a mildew epidemic on winter wheat cv. Sadovo 1 in Bulgaria, 1980. D = observation day. x = fraction of leaf surface diseased. n = number of triadimefon treatments. L = leaf position (L1 = flag leaf). Differences between fungicide treatments were always significant. Each dot is based on 200 observations.

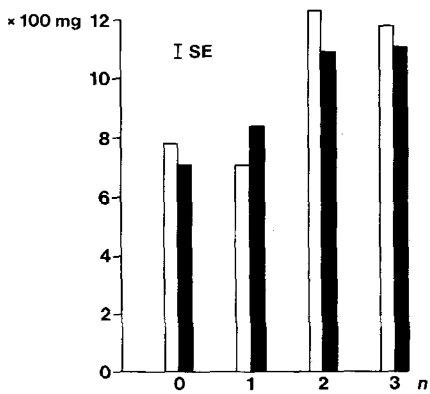

Fig. 3. Grain weight per ear (GWE) after a mildew epidemic on winter wheat cv. Sadovo 1 in Bulgaria, 1980. n = number of triadimefon treatments. Columns: white is without and black with field inoculation. Each column represents 100 ears. The figure shows the inoculation treatments * fungicide applications interaction.

Table 7. Mean daily increment (MDI) and logistic infection rate (LIR) of mildew severity during two time intervals (D1 to D2), (D2 to D3) of the epidemics associated with treatments T1 (artificial inoculation, no fungicide) and T8 (natural inoculation, 3 fungicide applications). Plot data. The differences between treatments are always highly significant ($p \leqslant 0.001$, two-sided test).

Interval	Leaf position	MDI		LIR	
		T1	T8	T1	T8
D1/D2	L1	0.0057	0.0000	0.39	0.00
	L2	0.0104	0.0000	0.24	0.00
	L3	0.0137	0.0001	0.10	0.06
D2/D3	L1	0.0048	0.0000	0.03	0.00
	L2	0.0079	0.0000	0.06	0.00
	L3	0.0025	0.0000	0.01	0.00

to ANOVA. Some characteristic results are given in Table 7. MDI is in the order of 0.01 in the artificially inoculated, no-fungicide plots during interval D1D2 and of 0.005 during interval D2D3. During interval D1D2 the highest value was found for L3 and during interval D2D3 for L2.

Logistic infection rate. Epidemiologic theory prefers *r*, the logistic or apparent infection rate, here called LIR:

$$\mathrm{LIR} = \frac{1}{\Delta t} \cdot (\mathrm{logit}\ x_{t+\Delta t} - \mathrm{logit}\ x_t)$$

Again, LIR can be calculated per leaf, except when x_t and or $x_{t+\Delta t}$ equal zero. As the data contained many zero values, two methods of circumventing this problem were examined. One way was to add a small value to all observations, large enough to eliminate zero's and small enough not to influence mean severity; the addition chosen was 0.0001. The other way was to eliminate all data pairs with at least one zero value. Both ways introduced error, but its effect was alleviated as only plot means of LIR are used in ANOVA. Results of the first method are shown in Table 7. The highest value, LIR = 0.39, was found in the first interval D1D2 for the flag leaf of the artificially inoculated, no-fungicide treatment. The differences between zero and three fungicide applications were always significant, but during interval D2D3 growth rates in the untreated plots were low.

Severity-incidence relations. As incidence can be determined faster and more accurately than severity, it is interesting to see whether severity can be estimated from incidence. Mean severity per plot (MS) was determined as the mean of the severities of the upper three leaf layers per plot per assessment day. The highest possible value is MS = 1.00. Similarly, mean incidence per plot (MI) was determined as the mean of incidences of the upper three leaf layers per plot per day. The highest possible value is MI = 1.00. Regression of MS on MI was determined according to the following equations

$$MS = a_0 + a_1 * MI \quad (1)$$
$$MS = a_0 + a_1 * MI + a_2 * MI^2 \quad (2)$$
$$MS = a_0 + a_2 * MI^2 \quad (3)$$
$$MS = a_0 + a_1 * MI + a_2 * \ln MI \quad (4)$$
$$MS = a_0 + a_2 * \ln MI \quad (5)$$

in which a_0 is the regression constant, and a_1 and a_2 are the regression coefficients representing the linear and the curvilinear components of the relation, respectively.

Simple linear regression (equation 1) is highly significant at all three days (Table 8). Though the coefficient of determination (r^2) on assessment day D1 is somewhat less than on the other two days, incidence can be used to estimate severity.

Simple linear regression is inappropriate because the relation between severity and incidence is curvilinear (Fig. 4). The fitting of the 2nd-degree polynominal equation (2) resulted in a non-significant a_1 and a highly significant a_2 (Table 8). Again, the coefficient of determination (r^2) on D1 is lower than on the other two assessment days. Nevertheless, incidence can be used to estimate severity. Equation (3) is sufficiently accurate, at least at the lower incidence values, to be used in predicting whether or not the disease will surpass an eventual damage threshold (Zadoks and Schein, 1979), but equations 4 and 5 also give good results

$$MS = (-0.066 \pm 0.004) + (0.18 \pm 0.03) * MI - (0.020 \pm 0.006) * \ln MI, \; r^2 = 0.81 \quad (4)$$
$$MS = (-0.032 \pm 0.007) + (0.015 \pm 0.002) * \ln MI, \; r^2 = 0.56 \quad (5)$$

Table 8. Parameter values for the equations of the regression of mildew severity on incidence. There are 32 data pairs (plots). Further explanation in text.

Assessment day	r^2 [1]	a_0 [2]	a_1 [3]	F^1_{30} [4]	p [5]
D1	0.73	−0.011 ± 0.005[6]	0.08 ± 0.01	81	<0.001
D2	0.86	−0.05 ± 0.03	0.21 ± 0.02	188	<0.005
D3	0.84	−0.13 ± 0.06	0.41 ± 0.03	160	<0.005
Assessment day	**r^2**	**a_0**	**a_2 [7]**	**F^1_{30}**	**p**
D1	0.81	−0.003 ± 0.004	0.17 ± 0.02	125	<0.001
D2	0.90	−0.012 ± 0.025	0.18 ± 0.01	273	<0.001
D3	0.90	−0.036 ± 0.049	0.33 ± 0.02	261	<0.001

[1] r^2 = coefficient of determination.
[2] a_0 = intercept.
[3] a_1 = regression coefficient (linear effect).
[4] F = variance ratio.
[5] p = probability level.
[6] The sign ± is followed by the standard error of the preceeding value.
[7] a_2 = regression coefficient (curvilinear effect).

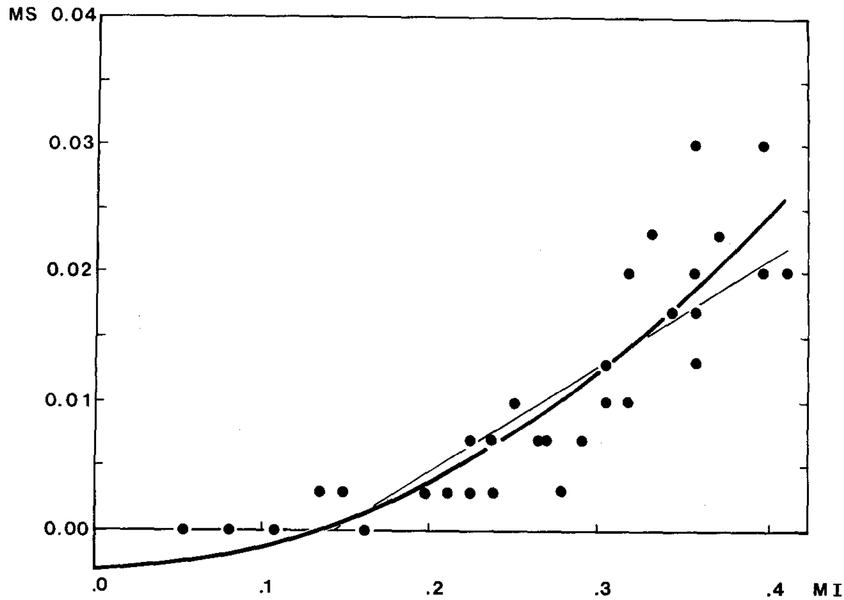

Fig. 4. Mildew on winter wheat cv. Sadovo 1 in Bulgaria, 1980. Regression of mean severity per plot MS on mean incidence per plot MI. Severity and incidence were averaged over the upper three leaf layers of D1, development stage F10.1, and expressed in proportions (figures between zero and one). For the regression equations see text.

Yield in relation to mildew severity and incidence. Yield and yield losses can be related to incidence and severity of the disease by means of regression analysis based on the equations (1) to (3), in which MS is replaced by the mean grain weight per ear and MI is maintained or replaced by MS. Significant regressions could be obtained only when two conditions were satisfied: (a) plot data ($n = 32$) had to be used instead of plant data ($n = 800$), (b) the three upper leaf positions should be taken together, instead of considering leaf positions separately.

All simple linear regressions of grain weight per ear (GWE) on MS and MI are significant (Table 9). For disease management purposes, information from assessment day D1 is most relevant. The r^2 value is lowest and a_1 is highest on assessment day D1. The regression equations for D1 are

$$GWE = 1161 - 17900 * MS \mid 0 \leqslant MS \leqslant 0.04 \quad (1)$$
$$GWE = 1417 - 1680 * MI \mid 0 \leqslant MI \leqslant 0.45 \quad (1)$$

The inequalities following the bars indicate the limits of validity of the equations. The first equation implies that, given the conditions of the experiment, the cultivar, and the development stage on assessment day D1, an increase in disease severity of 0.01 causes a yield loss of 179 mg per ear or 100 * 179/1161 = 15% of grain weight per ear. Similarly, the second equation implies that an increase in disease incidence of 0.01 causes a yield loss of 16.8 mg per ear or 100 * 16.8/1417 = 1.1% of grain weight per ear.

Table 9. Parameter values for equations of the regression of grain weight per ear on mean severity of the upper three leaves MS and on mean incidence on the upper three leaves MI. Curvilinearity is disregarded. Plot data, $n = 32$.

Regression on	Assessment day	r^2	a_0	a_1	F^1_{30}	p
MS	D1	0.63	1161 ± 135[1]	− 179 ± 25	52	<0.005
	D2	0.79	1149 ± 103	− 24 ± 2	110	<0.005
	D3	0.83	1163 ± 92	− 13 ± 1	143	<0.005
MI	D1	0.59	1417 ± 143	− 1685 ± 258	43	<0.005
	D2	0.84	1319 ± 90	571 ± 46	152	<0.005
	D3	0.83	1364 ± 92	597 ± 49	146	<0.005

[1] For symbol explanation see Table 8.

As a linear relation between yield and disease severity (and incidence) is unlikely over the full severity range, multiple regressions were tested that include terms for curvilinearity. Multiple regression of grain weight per ear GWE on MS based on equation (2) are significant in a_1 adn a_2 (Table 10), but p values for the coefficients are unsatisfactory for the regressions of GWE on MI. Regression of GWE on MI using equation (3) is, however, highly significant (Table 10). The equations describing curvilinear relations are:

$$GWE = 1234 - 365 * 10^2 * MS + 63 * 10^4 * MS^2 \mid 0 \leqslant MS \leqslant 0.033 \quad (2)$$
$$GWE = 1251 - 35 * 10^2 * MI^2 \mid 0 \leqslant MI \leqslant 0.41 \quad (3)$$

Discussion

The emphasis of the analysis is on the relations between disease incidence, disease severity, and yield. In this area, the data make sense. Some of the variables measured, such as plant height, gave surprising results, such as the increase of plant height in the artificially inoculated plots.

The wheat crop studied was a dense one, sown at a high seeding rate, with a stand density of ca 760 fertile and 10 infertile stems per m^2. Using the experimantal data, the estimated potential yield level of the crop was $760 * 1232.5 * 10^{-2} = 9367$ kg ha^{-1} (naturally inoculated, two fungicide applications). The yield without mildew control was 5376 kg ha^{-1} (naturally inoculated, no fungicide). The yield loss due to mildew was estimated, therefore, to be 3991 kg ha^{-1}, or 43 per cent of the potential yield.

The mildew epidemic was relatively late. On May, 13th, none of 200 inspected plants showed mildew. The logistic infection rate r was highest for leaf position L1 during interval D1D2 (Julian days 144 till 162; Feekes stages 10.1 to 10.51; early heading to early flowering), with a value up to 0.4. Such a value is high, even for susceptible crops. The disease assessment scale used may explain the high r values, at least in part. In interval D1D2, the higher the leaf position, the higher the r-values were. As Fig. 1

Tabel 10. Parameter values for equations of the regression of grain weight per ear on mean severity of the upper three leaves MS and on mean incidence on the upper three leaves MI. Curvilinearity is accounted for. Plot data, $n = 32$.

Regression on	Assessment day	r^2	a_0	a_1	F^1_{29}	p	a_2	F^1_{29}	p
MS	D1	0.69	1234 ± 125[1]	−365 ± 78	22	0.005	63 ± 25	6.2	<0.05
	D2	0.85	1184 ± 87	− 50 ± 8	43	0.005	1.4 ± 0.4	12	<0.00
	D3	0.87	1193 ± 83	− 25 ± 4	35	0.005	0.3 ± 0.1	84	<0.01
MI	D1	0.66	1130 ± 132	1099 ± 1162	0.9	NS	−5620 ± 2296	6.0	<0.05
	D2	0.84	1226 ± 89	−127 ± 372	0.1	NS	− 363 ± 302	1.4	NS
	D3	0.87	1156 ± 82	316 ± 318	1.0	NS	− 722 ± 249	8.4	<0.01
MI	D1	0.65	1251 ± 132				−3496 ± 472	55	<0.005
	D2	0.84	1199 ± 88				− 466 ± 37	160	<0.005
	D3	0.86	1231 ± 82				− 476 ± 35	189	<0.005

[1] For symbol explanation see Table 8.

Table 11. Weather data from Bojourishte, Bulgaria.

Month	Temperature T			Precipitation P		
	Monthly means in °C		ΔT	Monthly means in mm		ΔP
	average 1916/1955	1979/1980		average 1916/1955	1979/1980	
October	10.1	8.3	−1.8	57	40	−17
November	5.0	6.1	1.1	50	61	11
December	−0.2	2.2	2.4	37	20	−17
January	−2.1	−4.3	−2.2	41	54	13
February	−0.6	0.1	0.7	27	18	− 9
March	4.4	3.8	−0.6	29	68	39
April	10.1	7.4	−2.7	49	61	12
May	14.6	13.1	−1.5	78	127	49
June	18.0	17.9	−0.1	86	28	−58

shows, terminal severities were not very high, and they were abnormally low for the flag leaves. The explanation of the apparent discrepancy probably is to be found in the weather: March, April and May were relatively cool, with high precipitation (Table 11).

As other diseases were practically absent, and as mildew severity correlated well with yield, mildew can be held responsible for the observed crop losses relative to potential yield. Under Dutch conditions, two treatments with triadimefon (days 120 and 136) would have been highly profitable. The third treatment was effective against mildew, but as it induced a slight yield depression, it would not have been profitable. A different timing of the two treatments might have given an even better result. More than two treatments per season with triadimefon are undesirable in view of the risk of selecting fungicide-resistant strains of the pathogen.

Drawing far reaching conclusions from one experiment only is dangerous. Nevertheless, it can be concluded that there are solid relationships between incidence, severity and yield. These relationships are valid only within strict limits of incidence and severity. Respecting these limits, it seems possible to estimate severity from incidence as suggested by James and Shih (1973) and to predict future yield loss from severity or even from incidence at heading or flowering time, conform Large and Doling (1963). If so, supervised control of mildew in wheat, as e.g. the Dutch EPIPRE-system (Zadoks, 1981), based on mildew incidence counts, might be feasible in Bulgaria. Many experiments have to be performed before a final decision can be reached.

Samenvatting

Meeldauw op wintertarwe in Bulgarije, 1980: Verbanden tussen incidentie, aantastingsgraad en opbrengst

In 1980 werd een meeldauw-epidemie op de wintertarwe cv. Sadovo 1 in de buurt van

Sofia, Bulgarije, in detail bestudeerd. Van 32 veldjes van 1 m^2 groot, in vier blokken van acht veldjes verdeeld over een groot tarweperceel, werd de helft kunstmatig geïnfecteerd met meeldauw, terwijl de andere helft aan natuurlijke infectie werd blootgesteld. De bespuitingen variëerden van een tot drie bespuitingen met triadimefon, alsmede een onbespoten controle. Op drie dagen werden aantastingsgraad en incidentie van meeldauw bepaald aan de drie bovenste bladlagen. Een aantal relaties werd berekend tussen incidentie, aantastingsgraad en opbrengstvariabelen (planthoogte, aarlengte, aantal korrels per aar, korrelgewicht per aar). In ontwikkelingsstadium F 10.1 bleek meeldauw-incidentie een eenvoudige en betrouwbare maat te zijn voor toekomstige opbrengstderving. Meeldauw-incidentie kan als maat gebruikt worden bij de geleide bestrijding van meeldauw in Bulgarije, maar er zullen nog veel proeven nodig zijn om dit doel te bereiken.

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