Use of Petal Infestation to Forecast Sclerotinia Stem Rot of Canola: The Influence of Inoculum Variation over the Flowering Period and Canopy Density

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ABSTRACT

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The relationship in canola (oilseed rape) between the percentage of petals infested with *Sclerotinia sclerotiorum* and the incidence of Sclerotinia stem rot was investigated relative to changes in petal infestation during flowering and to canopy density. Using an agar-plate test, percent petal infestation was assessed in commercial crops of *Brassica napus* and *B. rapa* (=*B. campestris*) in various regions of Saskatchewan. Crop height, stem thickness, percent light penetration of the canopy, leaf area index, and the number of plants per square meter also were assessed at some locations. The incidence of stem rot was determined before harvest. Substantial changes in petal infestation were observed between early and late bloom. Most changes were increases; in 1989, however, infestation generally decreased. The changes were related to variation in rainfall, which probably influenced ascospore production and release. Higher disease incidence in denser crop canopies was attributed to more favorable microenvironmental conditions. Multiple regression analyses with petal infestation at early, full, and late bloom, light penetration, leaf area index and crop height as independent variables accounted for 55–98% of the variation in disease incidence. In general, disease incidence was positively correlated with petal infestation when the measurement coincided with favorable conditions for infection. For practical on-farm disease forecasting, changes in petal infestation could be accounted for by sampling at early, full, and late bloom. The effects of host and environment also require consideration, but simple measurements of these factors may be difficult to obtain.

The management of diseases caused by *Sclerotinia sclerotiorum* (Lib.) de Bary has focused largely on cultural practices and foliar-applied fungicides. Because of the pathogen's longevity and capacity for long-range dispersal, measures such as crop rotation and sanitation are relatively ineffective (2,16,24,33–35). Disease management with host resistance also has been difficult to achieve (15,16,26), especially in canola (oilseed rape, *Brassica napus* L. and *B. rapa* L. [=*B. campestris* L.]).

Foliar-applied fungicides are effective for the control of several Sclerotinia diseases because the diseases are monocyclic and infection occurs mainly during flowering (11,16,17,26,28). In spring-seeded canola in western Canada, disease incidence varies considerably among crops (31). Thus, the economics of spraying are influenced by the ability to recognize whether a disease risk exists. Timing of application during flowering also may be important. Krüger (13) concluded that control of stem rot of rapeseed depends on fungicide application at the correct time (i.e., coincident with ascospore release) and suggested that proper timing may be "difficult to determine." Steadman (25,26) and Morton and Hall (19) suggested that effective control of white mold of bean would be influenced by the time of blossom infection in relation to the timing of fungicide application. Thus, for effective management of diseases caused by *S. sclerotiorum*, suitable forecasting systems are needed to provide guidance for the use of fungicides (6,26).

From 1985 to 1990, Turkington et al (31) investigated the relationship between disease incidence and percent petal infestation with inoculum at early bloom (growth stage 4.1–4.2; [10]) in relation to Sclerotinia stem rot of canola. The objective was to use petal infestation as a forecasting tool. A significant positive correlation was demonstrated between disease incidence and petal infestation by linear regression analysis, but the strength of the relationship varied among locations and years. Petal infestation at early bloom (i.e., at a single growth stage) accounted for only 30% of the variation in disease incidence on average, and approximately half of the regressions were not significant. When disease risk according to petal infestation at early bloom was divided into three categories (low, moderate, and high), forecasts were most accurate when disease risk and incidence were low but were less so when they moderate to high. Thus, additional factors affected disease incidence and influenced the accuracy of forecasts. Although petal infestation can be assessed accurately at a particular time (30), disease incidence depends partly on moisture conditions after petal sampling. Petal infestation and disease risk may fluctuate in relation to changing moisture conditions during flowering. Changes in petal infestation (8) might cause under- or overestimation of disease risk based only on early-bloom values.

The host itself may directly influence the incidence of diseases caused by *S. sclerotiorum*. Not only do flowers provide an essential food base for infection by ascospores (12,14), a unique microenvironment also exists within a well-developed crop canopy (1,16,24). Through shading, a canola canopy creates favorable moisture conditions for both sclerotial germination and host infection. Thus, the canola canopy may have a major impact on disease development. Using a subjective estimate of canopy density, Turkington et al (31) found that in dense canola crops the incidence of stem rot was higher per unit of petal infestation.

The present study was undertaken from 1987 to 1990 to investigate the influence of fluctuations in petal infestation over the entire flowering period and variations in canopy density on the incidence of stem rot in canola. The objectives were to determine, for a wide range of commercial crops: 1) the extent of changes in petal infestation; 2) how changes might influence disease risk and incidence and the accuracy of forecasts based on petal infestation; 3) how changes relate to weather; and 4) how disease risk is modified by canopy density.

MATERIALS AND METHODS

From 1987 to 1990, petal infestation was assessed from early to late bloom in commercial canola crops in various regions of Saskatchewan, Canada. These crops were subsets of, or the same as, crops used in a previous study (31). In 1987, petal infestation

was monitored from 28 June to 30 July in five crops of *B. napus* and one of *B. rapa* near Melfort, SK, Canada. In 1988, 25 crops of *B. napus* and four of *B. rapa* near Meadow Lake, SK, were monitored from 24 June to 21 July, and nine irrigated crops of *B. napus* near Outlook, SK, were monitored from 28 June to 22 July. In 1989 and 1990, all crops monitored were near Meadow Lake; 14 crops of *B. napus* and one of *B. rapa* were monitored from 4 to 25 July in 1989, and 35 crops of *B. napus* and one of *B. rapa* were monitored from 5 July to 2 August in 1990.

In each crop, inflorescences were collected at early, full, and late bloom (growth stages 4.1–4.2, 4.3, and 4.3–4.4, respectively; [10]). Samples were typically obtained from five sites per crop on each date; however, in two crops, samples were collected at only one site, and in one crop, samples were collected at only four sites. All sites were located at least 10 m from the edge of the field and were spaced >25 m apart and marked with 1.8-m-long wooden stakes. Enough inflorescences were collected to provide 40 petals per site on each sampling date. Procedures for collecting and processing samples and determining petal infestation and disease incidence were as described previously by Turkington et al (31). In 1989 and 1990, the number of plants in a 1-m^2 quadrat was counted at each sampling site after the crops had been swathed.

Measurements of several factors thought to be related to canopy density were made at each sampling site. From 1988 to 1990 at Meadow Lake, measurements of crop height and stem thickness were made at late bloom. At each site, stem thickness of 10 plants was measured with calipers, and five measurements of crop height were taken. In 1988 at Outlook, values for crop height were derived from subjective estimates made during the flowering period. At Meadow Lake in 1988 and 1989, percent light penetration was measured when the crops were at late bloom. To determine light penetration, five measurements of light intensity were made above and below the crop canopy at each site, with a LI-COR LI-190SB Quantum sensor attached to a LI-COR LI 185B Quantum/radiometer/photometer (LI-COR Inc., Lincoln, NE). Light penetration was calculated as the percentage of above-canopy light that penetrated to the soil surface. In 1990, leaf area index (LAI) was assessed when the crops were at full bloom. The assessment of LAI was carried out with a LI-COR LAI-2000 plant canopy analyzer (LI-COR Inc.) that computes LAI from measurements of light interception by the canopy. Five measurements of canopy light interception were made at each site to derive LAI. Measurements of stem thickness, crop height, light penetration, and LAI were made nonselectively.

The Statistical Analysis System (23) was used to regress mean disease-incidence (MDI) values for each year on several independent variables. Residual analyses were performed initially with MDI and were arcsine-transformed MDI (TMDI) to determine if the underlying assumptions of the regression were met. The analyses indicated that TMDI more closely satisfied the assumptions. Thus, TMDI was used for all regressions. In 1988, 1989, and 1990, there were outliers excluded from the analyses. In 1988, the sampling sites in one crop were flooded in August, causing severe crop lodging, followed by plant-to-plant disease spread and very high disease incidence. In 1989, three late-seeded crops did not bloom until after 11 July. Disease incidence in these crops was low, even though petal infestation at early and full bloom were relatively high. Because the rainfall pattern during their entire flowering period was completely different from that of the other crops, they were excluded from the analysis. In 1990, one crop planted almost 2 wk later than the others was excluded.

Multiple regression models were proposed for each year and location to explain variation in disease incidence. The overall null hypothesis was that none of the independent variables had a significant influence on TMDI. More specific analyses also were performed to test the significance of partial regression coefficients. Appropriate sums of squares were derived to test each individual coefficient after accounting for the effects of all other coefficients (23). For final model selection, the independent variable with the lowest partial F value was eliminated, and the resulting reduced model was fitted to the collected data. This procedure was carried out until all remaining variables were significant at $P = 0.10$.

Environmental data were collected from 1987 to 1990. Measurements of temperature, relative humidity (RH), and leaf wetness in the canopy were made with Campbell Scientific Canada Corp. model CR 21 and 21X microloggers (Edmonton, AB). The microloggers operated with programs and sensor placement, as described previously (29,32). In 1987 and 1988, microloggers were set up in commercial canola crops in the Melfort and Meadow Lake study areas. In 1989 and 1990, microloggers were set up in small-plot experiments near Meadow Lake. The daily temperature, RH, and leaf-wetness values in the present paper represent means of the data from the respective microloggers in each year. Daily rainfall and hours of sunshine per day for May through

TABLE 1. Average minimum and maximum values for measurements of disease, inoculum, and crop characteristics at Melfort, Outlook, and Meadow Lake, SK, Canada, 1987–1990

Year and location	Values	No. of crops	Mean disease incidence (%)	Mean percent petal infestation				Mean crop height (cm)	Mean stem thickness (cm)	Mean light penetration (%)	Mean leaf area index	Mean plants/m^2
				Early bloom	Full bloom	Late bloom	Change during flowering[a]					
1987												
Melfort	Average	6	11	19	31	42	+15 (24)					
	Minimum		1	0	15	9	−1.5					
	Maximum		27	48	68	83	+82					
1988												
Outlook	Average	9	3	7	24	30	+15 (16)	92				
	Minimum		0	0	2	7	−0.6	65				
	Maximum		9	44	70	77	+67	150				
Meadow Lake	Average	29	7	14	40	59	+30 (33)	90	0.65	3.2		
	Minimum		0.2	0	10	26	−0.5	67	0.46	0.6		
	Maximum		60	63	91	96	+94	113	0.90	12.6		
1989												
Meadow Lake	Average	15	22	59	47	26	−22 (25)	104	0.58	2.9		129
	Minimum		3	20	14	0	+0.4	95	0.44	1.0		69
	Maximum		64	88	84	79	−88	127	0.73	5.2		218
1990												
Meadow Lake	Average	36	3	7	18	34	+18 (21)	103	0.64		3.6	104
	Minimum		0	0	0	2	0	84	0.48		1.7	31
	Maximum		14	31	62	77	+71	115	0.83		5.8	145

[a] Derived from the differences among mean percent petal infestation at early, full, and late bloom for each individual crop. Positive values are increases and negative values are decreases during flowering. Numbers in parentheses represent averages calculated from absolute values.

August at Melfort in 1987, Outlook in 1988, and Meadow Lake from 1988 to 1990 were obtained from Environment Canada stations located at Melfort, Outlook, and Meadow Lake (29,31). Although the environmental data from the various sources apply to particular locations, they provide information concerning general microenvironmental and weather trends in the study areas.

RESULTS

Petal infestation and disease incidence were lowest at Outlook in 1988 and at Meadow Lake in 1990 and were highest at Meadow Lake in 1989. During the flowering period major changes in petal infestation occurred in all years (Table 1). Average petal infestation increased after early bloom and was highest at late bloom in each year except at Meadow Lake in 1989; in 1989, average petal infestation was 59% at early bloom, but decreased to 26% as crops progressed into late bloom. The largest average change in petal infestation occurred at Meadow Lake in 1988 and the smallest at Outlook. The largest increases and decreases in individual crops were observed at Meadow Lake in 1988 and 1989, respectively.

Differences in canopy characteristics among individual crops

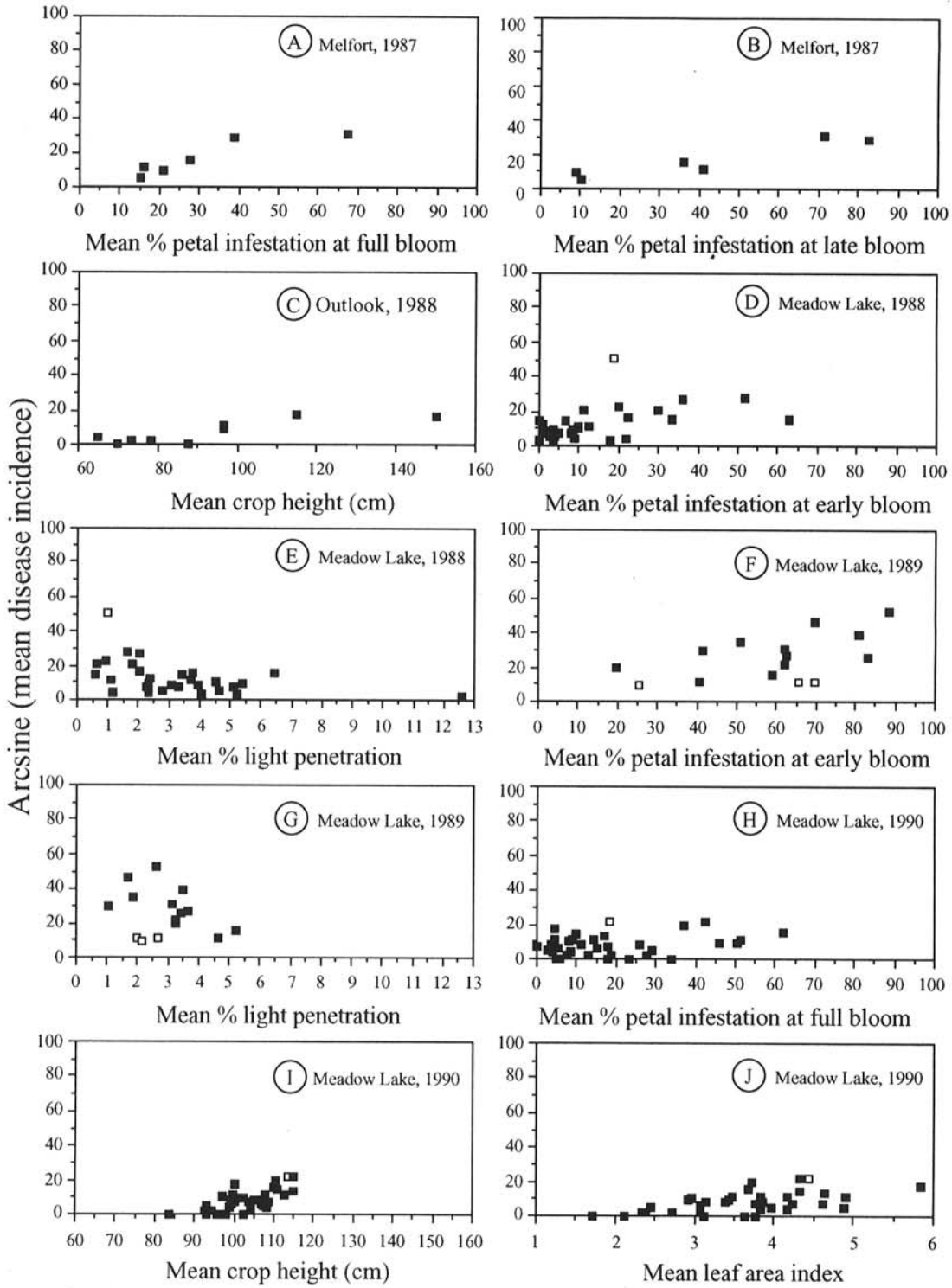

Fig. 1. Scatter plots of arcsine-transformed mean disease incidence versus mean percent petal infestation **A,** at full bloom and **B,** late bloom at Melfort, 1987; **C,** mean crop height at Outlook, 1988; **D,** mean percent petal infestation at early bloom and **E,** mean percent light penetration at Meadow Lake, 1988; **F,** mean percent petal infestation at early bloom and **G,** mean percent light penetration at Meadow Lake, 1989; and **H,** mean percent petal infestation at full bloom, **I,** mean crop height, and **J,** mean LAI at Meadow Lake, 1990. Open squares in **D–J** represent outliers.

TABLE 2. Results of multiple regression analyses of mean disease incidence per crop on significant independent variables by year and location

Year and location	Sample size	Independent variables[a]	Slope values (SE)	Level of significance (*P*)	Coefficient of determination (%)
1987					
Melfort, SK	6	MPPIFB	0.25 (0.06)	0.027	98
		MPPILB	0.21 (0.04)	0.014	
1988					
Outlook, SK	9	MHT	0.21 (0.05)	0.005	70
Meadow Lake, SK	28	MPPIEB	0.27 (0.06)	< 0.001	56
		MPLP	−1.3 (0.40)	0.004	
1989					
Meadow Lake, SK	12	MPPIEB	0.38 (0.1)	0.003	78
		MPLP	−6.6 (1.6)	0.003	
1990					
Meadow Lake, SK	35	MPPIFB	0.10 (0.04)	0.030	55
		MHT	0.35 (0.12)	0.007	
		MLAI	2.1 (1.0)	0.044	

[a] MPPIEB = mean percent petal infestation, early bloom; MPPIFB = mean percent petal infestation, full bloom; MPPILB = mean percent petal infestation, late bloom; MHT = mean crop height (cm); MPLP = mean percent light penetration; and MLAI = mean leaf area index.

existed in 1988, 1989, and 1990 (Table 1). However, average crop height was similar at Outlook and Meadow Lake in 1988 and was slightly higher at Meadow Lake in 1989 and 1990. Similar values for stem thickness were observed at Meadow Lake in all three years. Average light penetration was slightly higher at Meadow Lake in 1988 than in 1989. Mean LAI ranged from 1.7 to 5.8 in 1990.

Before proposing and evaluating multiple regression models for the data, TMDI for each year was plotted against each of the independent variables to reveal possible relationships. In all cases, the scatter of points suggested that simple linear relationships existed. Figure 1A–J contains scatter plots for all independent variables significantly correlated with disease incidence at particular locations.

In 1987, disease incidence was positively correlated with petal infestation at full and late bloom; these variables accounted for 98% of the variation in TMDI (Fig. 1A and B; Table 2). Rainfall was below average during June but above average during July, with frequent showers from 30 June to 23 July (31). Petal infestation was low during early bloom. Mean and minimum RH and daily leaf-wetness duration increased during early July, and favorable conditions for infection (1) persisted throughout full and late bloom, when petal infestation was higher (i.e., until 24 July) (Figs. 2 and 3).

Based on scatter plots for data from Outlook in 1988, disease incidence appeared to be most closely related to crop height and petal infestation at full bloom. However, only the partial regression coefficient for crop height (Fig. 1C) was significant; it explained approximately 70% of the variation in TMDI (Table 2).

At Meadow Lake in 1988, disease incidence appeared to be positively correlated with crop height and petal infestation at early, full, and late bloom and negatively correlated with light penetration ([29]; Fig. 1D and E). Based on multiple regression, only petal infestation at early bloom and light penetration were significant, and together they explained 56% of the variation in TMDI (Table 2). Although disease incidence was significantly correlated with early-bloom petal infestation, the values of both variables were low. Near-average rainfall was recorded for June, but most fell on 29 June (31). During July, average rainfall was recorded, but most occurred as frequent showers before mid-month. Mean and minimum RH and leaf-wetness duration were favorable for infection during late June and early July but decreased during the second half of July (Figs. 2 and 3), when petal infestation was higher. In general, full and late bloom did not coincide with conditions as favorable for infection as those during early bloom.

From the scatter plots for Meadow Lake in 1989, disease incidence appeared to be correlated with petal infestation at early bloom, crop height, stem thickness, and light penetration ([29]; Fig. 1F and G). However, only petal infestation at early bloom and light penetration were significant; they explained 78% of the variation in TMDI (Table 2). Frequent showers occurred during late June and early July (31), as the crops came into early bloom, and petal infestation was relatively high at early and full bloom (Table 1). Favorable moisture conditions for infection also occurred at early bloom and resulted in relatively high disease incidence. Very little rain fell after 11 July, and temperatures increased ([31]; Fig. 4). RH, leaf-wetness duration, and petal infestation generally decreased as crops progressed from full to late bloom (Figs. 2 and 3; Table 1).

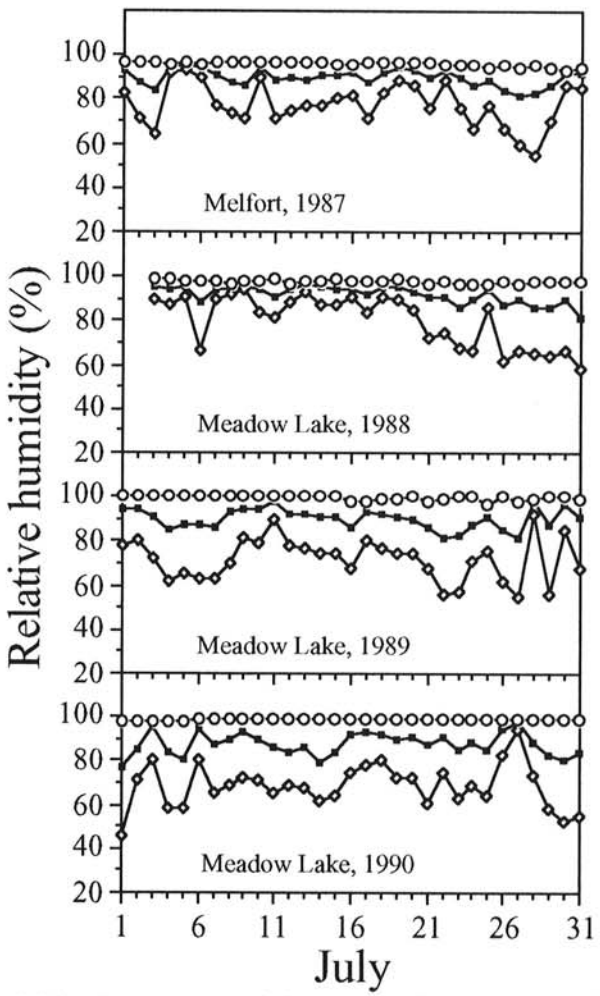

Fig. 2. Mean (closed square), minimum (open diamond), and maximum (open circle) relative humidity (RH) at Melfort, 1987, and Meadow Lake, 1988–1990. Data for RH represent mean values from all microloggers in each year.

In 1990, disease incidence was significantly correlated with petal infestation at full bloom, crop height, and LAI (Fig. 1H–J; and Table 2). These variables accounted for 55% of the variation in TMDI. Well below-average rainfall occurred during June; however, during July, heavy showers on 3 and 9 July contributed to above-average rainfall for the month (31). Average petal infestation increased from <10% at early bloom to >30% by late bloom. Over half of the crops were at full bloom by 12 July, and showers on 16 and 17 July produced relatively favorable conditions for host infection (31). Mean RH remained relatively high until after the third week of July (Fig. 2). Most crops were at late bloom from 18 to 25 July, a period with little rainfall and abundant sunshine (29,31).

Variables thought to be related to canopy density were not consistently related to the incidence of stem rot. No significant correlations were observed for stem thickness and mean number of plants per square meter. Disease incidence was negatively correlated with light penetration at Meadow Lake in 1988 and 1989, positively correlated with LAI in 1990, and positively correlated with crop height at Outlook in 1988 and Meadow Lake in 1990. There was a major difference between 1988 and 1989 in the partial regression coefficients of disease incidence on light penetration. The value was −1.3 in 1988 but −6.6 in 1989 (Table 2). Average disease incidence was three times higher in 1989 than in 1988.

DISCUSSION

Disease incidence was related to petal infestation at most locations (Table 2). However, major changes in petal infestation occurred from early to late bloom, and the relative importance of values at different flowering stages varied among locations. Gugel (8) observed similar changes in petal infestation over several days in a small number of crops. The differences in disease incidence among years may be partially due to variation in June rainfall, which influenced sclerotial germination, ascospore production, and early-bloom petal infestation (31). However, the pattern and frequency of rainfall during July was probably equally important, because petal infestation was significantly correlated with disease incidence when measurements coincided with moisture conditions favorable for infection (1). For example, approximately average rainfall occurred during July at Melfort in 1987 and at Meadow Lake in 1988 and 1989 (31). However, in 1990 well above-average July rainfall was recorded, but petal infestation and disease incidence remained low. Most of the rainfall occurred on 3 and 9 July and these dates were followed by dry periods, when temperatures (Fig. 4) and sunshine (29) were conducive to high evapotranspiration. Thus, after both dates, high moisture levels in the canopy persisted for only relatively short periods (Figs. 2 and 3).

At Outlook in 1988, very high temperatures and infrequent, below-average rainfall occurred during June and July (29,31). These conditions probably restricted sclerotium germination and host infection, despite the fact that all crops at Outlook were irrigated. Thus, disease incidence was not significantly related to petal infestation at any flowering stage. These findings were consistent with a study of plots at Outlook in 1988 (B. K. Teo, *personal communication*). Teo found that several irrigation regimes did not increase disease incidence or petal infestation above levels in the present study, despite the incorporation of sclerotia into the soil.

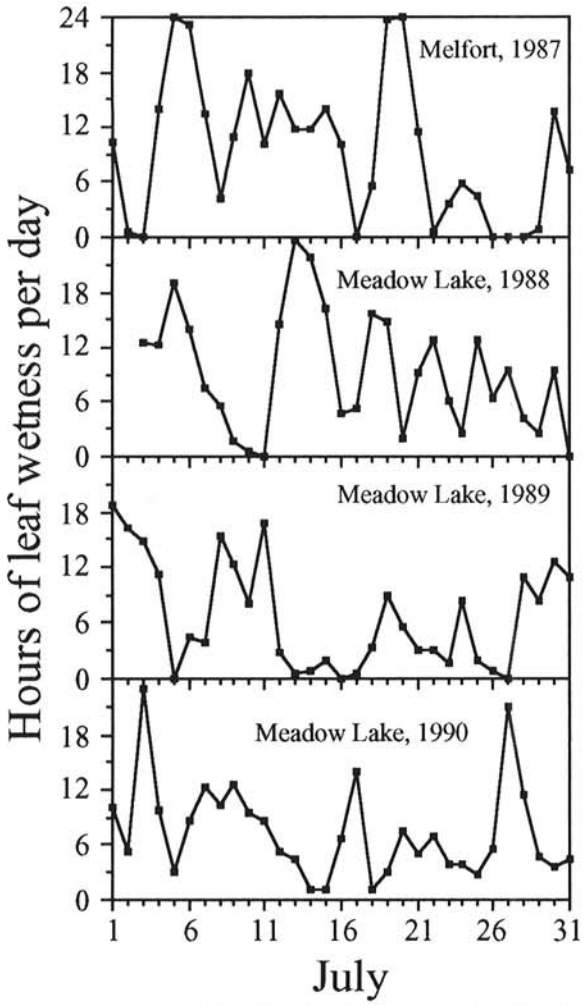

Fig. 3. Daily leaf-wetness duration at Melfort, 1987, and Meadow Lake, 1988–1990. Data for leaf-wetness duration represent mean values from all microloggers in each year.

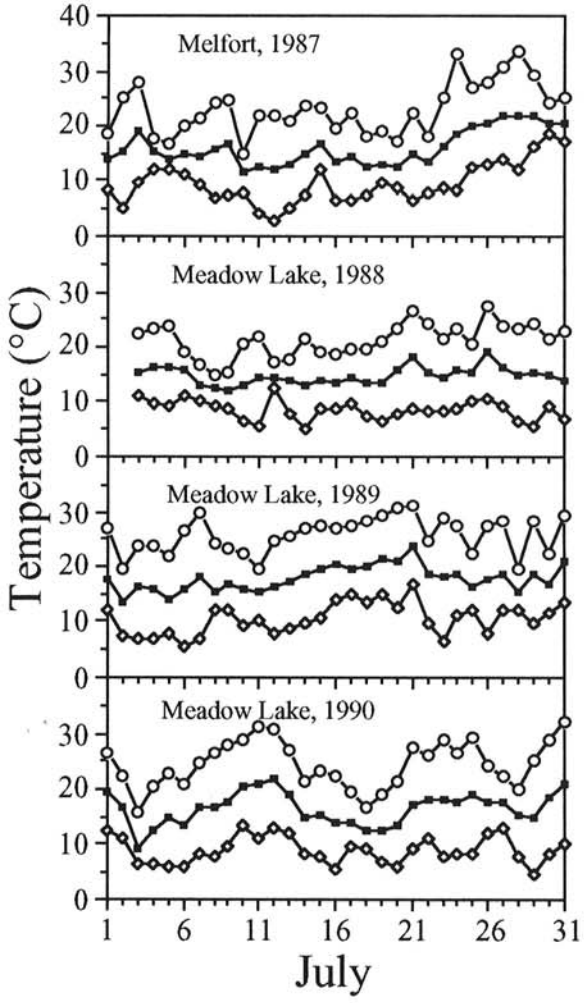

Fig. 4. Mean (closed square), minimum (open diamond), and maximum (open circle) temperatures at Melfort, 1987, and Meadow Lake, 1988–1990. Data for temperature represent mean values from all microloggers in each year.

The importance of conditions conducive for infection to the relationships between disease incidence and petal infestation was further illustrated at Meadow Lake in 1989 by the three crops excluded from the regression analysis. These crops had relatively high petal infestation at early bloom, around 11 July. However, little or no rainfall occurred after 11 July (31), and a general decrease in RH and an increase in temperature occurred (Figs. 2 and 4). Leaf-wetness duration decreased to a very low level by 16 July (Fig. 3). Thus, conditions were much less favorable for host infection in these three crops than in earlier seeded crops. Disease risk, as indicated by early- and full-bloom petal infestation, was not translated into substantial host infection because of environmental conditions.

In a previous paper, Turkington et al (31) demonstrated significant positive correlations between TMDI and petal infestation at early bloom with slope values of 0.10–0.30. In the present study, the significant correlations between TMDI and petal infestation at various flowering stages had partial regression coefficients from 0.10 to 0.38. Weather conditions during flowering ultimately determine relationships between disease incidence and petal infestation. Lower regression coefficients may represent the relationship when the frequency of rainfall is limited during June and July. Intermediate values may represent relationships when there is below-average rainfall during June but frequent showers shortly before and during flowering. Higher coefficients may represent the relationship that applies with average or above-average rainfall and frequent showers during June and July. However, coefficients also will be affected directly by crop growth stage. As canola crops progress from full to late bloom, leaves abscise, and the number of petals available for infestation decreases. Thus, disease potential is limited by a shortage of petals and infection sites and by the possibility that leaf infections may not reach the stem before leaf abscission (9). Also, as leaves fall, the microenvironment becomes less conducive to disease development. These factors may all contribute to a decrease in regression coefficients for TMDI on petal infestation as crops progress from early to late bloom.

In the present study, environmental data were used to indicate general trends. Nevertheless, differences in rainfall and microenvironmental conditions occurred among the crops. Multiple regression with several independent variables derived from the host and pathogen explained 55–98% of the variation in TMDI from 1987 to 1990. The unexplained variation was probably partially due to variability among crops in rainfall and microenvironment.

The incidence of stem rot was inconsistently related to three measures of crop-canopy density: light penetration, LAI, and crop height. The values of LAI in 1990 were consistent with those reported by Clarke and Simpson (5) and in the *Canola Growers Manual* (27). Dense crop canopies promote and prolong microenvironmental conditions favorable for host infection by reducing penetration of radiation into the canopy and turbulent transfer between the macro- and microenvironment (7,20,36). Plot experiments (29) suggested that denser canola stands tended to have slightly higher mean and minimum RH and longer periods of leaf wetness than had lighter stands. Light penetration and LAI probably provided more effective estimates of the influence of canopy density than did other variables measured, because they are more closely related to the amount of plant material in a crop. However, there was a major difference between the partial regression coefficients of disease incidence on light penetration for 1988 and 1989, perhaps reflecting a nonlinear relationship between the two variables. At Outlook in 1988 and Meadow Lake in 1990, significant positive relationships were found between disease incidence and crop height. The lowest disease incidence of all years occurred at these locations; this may be an indication of unfavorable conditions for crop development. Perhaps because of leaf abscission, crop height became a more important factor influencing the microenvironment and disease development. Taller crops would restrict moisture loss from the canopy more than would shorter crops. Furthermore, taller crops may have developed where local rainfall or irrigation was greater.

In a previous study (31), canola crops were cross-tabulated according to forecast risk, based on early-bloom petal infestation and actual disease incidence. In this tabulation, percent petal infestation $<45\%$ corresponded to low disease risk, and crops were expected to have $<20\%$ disease incidence. Crops with 45–90% petal infestation were at moderate risk and were expected to have 20–40% disease incidence. Crops forecast to be at high risk had $\geq 90\%$ petal infestation and were expected to have $>40\%$ disease incidence. In 343 crops studied over a 6-yr period, 73% of the forecasts were correct. The success rate for 129 crops studied from 1987 to 1990 was 87% (31). The present study demonstrated that petal infestation changes substantially over the flowering period. The importance of these changes to forecasting disease risk could be accounted for by assessing infestation at early, full, and late bloom. Because canopy density also influenced disease incidence, it too could be used to increase the accuracy of forecasts.

Ninety-five crops involved in the present study (including those excluded from the regression analyses) were cross-tabulated according to disease risk at early bloom and actual disease incidence (31). Disease incidence was underestimated in six crops and overestimated in eight crops, for a success rate of 85%. Most of the incorrect forecasts could be explained by changes in petal infestation or below- or above-average canopy density (Table 3). For example, in one crop at Melfort in 1987 and in one at Meadow Lake in 1988 in which disease incidence was underestimated, considerable increases in petal infestation occurred after early bloom. In one crop at Meadow Lake in 1988 and three in 1989 flooding or above-average canopy density could account for the underestimation of disease incidence. Disease incidence was overestimated based on early-bloom petal infestation in five crops in which the canopy density was below average: one at Melfort in 1987, one at Meadow Lake in 1988, and three at Meadow Lake in 1989. Decreasing petal infestation also was sometimes a factor. Disease incidence was overestimated in two crops with above-average canopy density in 1989, but these were late-seeded crops in which major decreases in petal infestation occurred by late bloom. In addition, flowering occurred during, and was shortened by, hot, dry weather. There was only one crop at Outlook in 1988 in which an overestimation of disease incidence could not be explained readily. Thus, adjusting forecast disease risk according to changing petal infestation and canopy density potentially might have increased the accuracy of forecasts to 99%.

Despite the ability to increase forecast accuracy by repeated assessments of petal infestation, the utility of determining disease risk after early bloom would depend on whether fungicide application would still be effective. Studies (17,18,21,22) have demonstrated that effective control is possible when high petal infestation and conducive environmental conditions do not occur until full or late bloom. However, the influence of increasing leaf abscission and decreasing petal production at late bloom need to be considered. Rude (21) demonstrated that yield losses in canola under controlled conditions were significantly lower when plants were infected at late rather than at early bloom. Thus, yield increases from fungicide application after early bloom may not always be economically worthwhile. However, results from 1987 in the present study indicate that substantial levels of disease can develop when inoculum and environmental conditions are not conducive to infection until full or late bloom. This may occur when cool, moist weather prolongs flowering and delays leaf abscission, increasing the period when petals and infection sites are available.

Recently proposed strategies to control stem rot (17,18,21) have the potential to reduce the risk of uneconomical control associated with delayed fungicide application and varying host and environmental conditions. Split applications and reduced doses (17) may allow farmers to achieve economical control by tailoring practices to the disease risk indicated by petal infestation at different times, as well as to crop-yield potential and environmental conditions. However, a petal-based system of forecasting, even with modifications for the influence of the host and environment, will not account completely for the influence of unfavorable environmental conditions after flowering.

The influence of both crop-canopy density and prevailing

TABLE 3. Petal infestation, canopy density, and disease incidence for 14 crops in which disease incidence was incorrectly forecast, based on early-bloom petal infestation at Melfort, Outlook, and Meadow Lake, SK, Canada, 1987–1989

Year and location	Mean percent petal infestation			Canopy density[a]	Mean disease incidence
	Early bloom	Full bloom	Late bloom		
1987					
Melfort	0	39	83	moderate	23
	48	21	9	light	2
1988					
Outlook	45	43	44	heavy	8
Meadow Lake	63	73	51	<average	7
	36	76	91	>average	21
	19	54	35	>average	60
1989					
Meadow Lake	42	17	6	>average	25
	70	32	16	>average	53
	89	52	0	>average	64
	83	73	68	<average	19
	62	64	39	<average	14
	59	79	43	<average	7
	66	42	3	>average	4
	70	60	4	>average	4

[a] In 1987 at Melfort and 1988 at Outlook, canopy density was assessed subjectively according to crop height and ground cover (31). At Meadow Lake in 1988 and 1989, canopy density was reported relative to the average percent light penetration for all crops (Table 1).

weather conditions should be recognized when using petal infestation to forecast disease. However, assessing the influence of these factors may be difficult for farmers. They can not afford the type of equipment used in the current study to assess canopy density or monitor environmental factors. Moderate temperatures, frequent showers, and overcast conditions would provide a crude indication of favorable conditions for infection. To account for the influence of canopy density, perhaps yield potential could be used. Thomas (27) used this criterion in an earlier risk assessment scheme for Sclerotinia stem rot of canola. Disease risk is higher in a crop with a yield potential of >2,000 kg/ha than in a crop with a potential of <1,400 kg/ha.

Although the influence of unfavorable environmental conditions after flowering may sometimes limit the value of a petal-based forecasting system, it is also a shortcoming associated with other systems for Sclerotinia stem rot, such as the Sclerotinia checklist (27) and the Danish system (3,4). The checklist is a risk-assessment scheme based on a series of mainly qualitative questions about host, pathogen, and environmental factors thought to influence disease development. The Danish system is based mainly on monitoring carpogenic germination of sclerotia in depots established throughout the country. Both systems provide qualitative forecasts: the checklist on an individual crop basis and the Danish system on a regional basis. However, in western Canada, forecasting based on monitoring petal infestation is potentially more useful, because it provides quantitative forecasts on an individual crop basis, allowing farmers to consider more effectively the benefits that may result from fungicide application. It also accounts more adequately for ascospores originating from apothecia located outside the field(s) in question.

LITERATURE CITED

1. Abawi, G. S., and Grogan, R. G. 1979. Epidemiology of diseases caused by *Sclerotinia* species. Phytopathology 69:899-904.
2. Adams, P. B., and Ayers, W. A. 1979. Ecology of *Sclerotinia* species. Phytopathology 69:896-899.
3. Buchwaldt, L. 1986. Development of a simple forecasting system for attacks of *Sclerotinia sclerotiorum* in oilseed rape in Denmark. Paper presented at the 6th North Am. *Sclerotinia* Workshop.
4. Buchwaldt, L. 1989. The Danish forecasting system for attack by stem rot (*Sclerotinia sclerotiorum*) in oilseed rape. Nord. Plantevaernskonf. Helsingør. Pages 121-131.
5. Clarke, J. M., and Simpson, G. M. 1978. Growth analysis of *Brassica napus* cv. Tower. Can. J. Plant Sci. 58:587-595.
6. Dueck, J., Morrall, R. A. A., and McKenzie, D. L. 1983. Control of *Sclerotinia sclerotiorum* in rapeseed with fungicides. Can. J. Plant Pathol. 5:289-293.
7. Grace, J. 1983. Plant-Atmosphere Relationships. Outline Studies in Ecology. G. M. Dunnet and C. H. Gimingham, eds. Chapman & Hall Ltd., London. 92 pp.
8. Gugel, R. K. 1985. Factors affecting incidence of sclerotinia stem rot of rapeseed (canola). M.S. thesis. Univ. Saskatchewan, Saskatoon, Canada. 116 pp.
9. Gugel, R. K., and Morrall, R. A. A. 1986. Inoculum-disease relationships in sclerotinia stem rot of rapeseed in Saskatchewan. Can. J. Plant Pathol. 8:89-96.
10. Harper, F. R., and Berkenkamp, B. 1975. Revised growth-stage key for *Brassica campestris* and *B. napus*. Can. J. Plant Sci. 55:657-658.
11. Hunter, J. E., Abawi, G. S., and Crosier, D. C. 1978. Effects of timing, coverage, and spray oil on control of white mold of snap bean with benomyl. Plant Dis. Rep. 62:633-637.
12. Kapoor, K. S., Lamarque, C., and Berrier, J. 1983. Some aspects of the host-parasite relations between *Sclerotinia sclerotiorum* (Lib.) de Bary and rapeseed. Proc. 6th Int. Rapeseed Conf. Groupe Consultatif International de Recherche Sur le Colza. Pages 991-994.
13. Krüger, W. 1973. Massnahmen zur Bekämpfung des Rapskrebses, verursacht durch *Sclerotinia sclerotiorum* (Lib.) de Bary. Phytopathol. Z. 77:125-137.
14. Krüger, W. 1975. Über die Wirkung der Witterung auf den Befall des Rapses durch *Sclerotinia sclerotiorum* (Lib.) de Bary. Nachrichtenbl. Dtsch. Pflanzenschutzdienstes (Stutt.) 27:1-6.
15. Krüger, W. 1980. Wurzel- und Stengelkrankheiten des Rapses. Kali-Briefe (Büntehof) 15:179-192.
16. Morrall, R. A. A., and Dueck, J. 1982. Epidemiology of sclerotinia stem rot of rapeseed in Saskatchewan. Can. J. Plant Pathol. 4:161-168.
17. Morrall, R. A. A., Rogers, R. B., and Rude, S. V. 1989. Improved techniques of controlling Sclerotinia stem rot of canola (oilseed rape) with fungicides in western Canada. Med. Fac. Landbouww, Rijksuniversiteit, Gent, Belgie. 54:643-649.
18. Morrall, R. A. A., Verma, P. R., and Dueck, J. 1985. Recent progress in chemical control of Sclerotinia stem rot of rape in western Canada. Med. Fac. Landbouww, Rijksuniversiteit, Gent, Belgie. 50:1189-1194.
19. Morton, J. G., and Hall, R. 1989. Factors determining the efficacy of chemical control of white mold in white bean. Can. J. Plant Pathol. 11:297-302.
20. Rosenberg, N. J. 1974. Microclimate: The Biological Environment. John Wiley & Sons, Inc., New York. 315 pp.
21. Rude, S. V. 1989. Evaluation of fungicide application at late bloom for the control of Sclerotinia stem rot in rapeseed (canola). M.S. thesis. University of Saskatchewan, Saskatoon, Canada. 114 pp.
22. Rude, S. V., Morrall, R. A. A., Turkington, T. K. and Kaminski, D. A. 1987. Evaluation of late-bloom fungicide application for the control of Sclerotinia stem rot in canola, 1987. Pesticide Res. Rep. Agric. Can., OT. 211.
23. SAS Institute. 1985. SAS User's Guide: Statistics. Version 5 ed. SAS Institute Inc., Cary, NC. 956 pp.

24. Schwartz, H. F., and Steadman, J. R. 1978. Factors affecting sclerotium populations of, and apothecium production by, *Sclerotinia sclerotiorum*. Phytopathology 68:383-388.
25. Steadman, J. R. 1979. Control of plant diseases caused by *Sclerotinia* species. Phytopathology 69:904-907.
26. Steadman, J. R. 1983. White mold—A serious yield-limiting disease of bean. Plant Dis. 67:346-350.
27. Thomas, P. M. 1984. Canola Growers Manual. Canola Counc. Can., Winnipeg, ON.
28. Tu, J. C. 1983. Efficacy of iprodione against Alternaria black pod and white mold of white beans. Can. J. Plant Pathol. 5:133-135.
29. Turkington, T. K. 1991. Factors influencing a petal-based forecasting system for Sclerotinia stem rot of canola. Ph.D. thesis. Univ. of Saskatchewan, Saskatoon, Canada. 150 pp.
30. Turkington, T. K., Morrall, R. A. A., and Baker, R. J. 1988. Sample sizes in relation to forecasting Sclerotinia stem rot of canola. Can. J. Plant Pathol. 10:159-165.
31. Turkington, T. K., Morrall, R. A. A., and Gugel, R. K. 1991. Use of petal infestation to forecast Sclerotinia stem rot of canola: Evaluation of early bloom sampling, 1985–90. Can. J. Plant Pathol. 13:50-59.
32. Turkington, T. K., Morrall, R. A. A., and Rude, S. V. 1991. Use of petal infestation to forecast Sclerotinia stem rot of canola: The impact of diurnal and weather-related inoculum fluctuations. Can. J. Plant Pathol. 13:347-355.
33. Williams, J. R., and Stelfox, D. 1979. Dispersal of ascospores of *Sclerotinia sclerotiorum* in relation to Sclerotinia stem rot of rapeseed. Plant Dis. Rep. 63:395-399.
34. Williams, J. R., and Stelfox, D. 1980. Influence of farming practices in Alberta on germination and apothecium production of sclerotia of *Sclerotinia sclerotiorum*. Can. J. Plant Pathol. 2:169-172.
35. Williams, J. R., and Stelfox, D. 1980. Occurrence of ascospores of *Sclerotinia sclerotiorum* in areas of central Alberta. Can. Plant Dis. Surv. 60:51-53.
36. Zadoks, J. C., and Schein, R. D. 1979. Epidemiology and Plant Disease Management. Oxford Univ. Pr., New York. 427 pp.