Effects of Plot Size and Border Width on Assessment of Powdery Mildew of Winter Wheat

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ABSTRACT

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A study was conducted to determine the effect of plot size (2.9 and 26 m^2), distance between plots (1.7 and 5.1 m), and pairing of cultivar plots (slow-mildewing cultivar paired with a susceptible cultivar or susceptible cultivar paired with a susceptible cultivar) on the development of powdery mildew of wheat in 1989 and 1990. Both plot size and cultivar pairing had a significant ($P < 0.05$) effect on area under the disease progress curve (AUDPC). AUDPC values calculated for the susceptible cultivar in the smaller plots compared with the larger plots were 10 and 17% lower over the 2 yr, respectively. The lower AUDPC values indicated that a net loss of inoculum affected disease development in the smaller plots more than in larger plots. The susceptible cultivar had the same AUDPC value whether paired with the susceptible cultivar or the slow-mildewing cultivar. AUDPC values from the slow-mildewing cultivar were about half that of the susceptible cultivar. There was a significant interaction of cultivar pairing with plot size in 1989 and with border width in 1990 on AUDPC. This interaction occurred because, in a given year, one of these factors affected disease development on the susceptible cultivar but not on the slow-mildewing cultivar. Thus, there was no direct evidence of positive interplot interference. Results indicated that negative interplot interference caused an underestimation of the effect of slow-mildewing resistance in small plots. The underestimation resulted from comparison of the slow-mildewing cultivar with the susceptible cultivar in small plots because the susceptible cultivar had lower AUDPC values in small plots than in larger plots. Regardless, small plots (2.9 m^2) of the susceptible cultivar had AUDPC values only slightly less than larger plots. Likewise, the effect of border width was minor. Thus, small plots with narrow borders could be used to evaluate cultivars for slow-mildewing resistance if estimates of errors attributable to interplot interference were recognized.

Additional keywords: *Blumeria graminis* f. sp. *tritici*, epidemiology, *Triticum aestivum*

Interplot interference confounds the ability of the plant breeder to recognize varying levels of resistance to disease in cultivars planted in small plots (3,4,10, 17,22). Interplot interference can be either negative or positive depending on the net movement of inoculum out of or into a plot (4,11). Negative interference may occur when a susceptible cultivar is planted adjacent to a resistant cultivar and more inoculum moves out than moves into the plot with the susceptible cultivar. This results in lower disease severity of the susceptible cultivar compared with when it is planted in a large commercial field or adjacent to another susceptible cultivar in small plots. This can lead to an overestimation of the level of resistance exhibited by the cultivar (17). Positive interference may result when a plot of a resistant cultivar is adjacent to a susceptible cultivar and the net movement of inoculum is into the plot planted with the resistant cultivar. The level of disease severity of the resistant cultivar would be greater than expected had it been planted next to a resistant cultivar or in a large commercial field. These confounding effects need to be recognized when designing field plots to evaluate cultivars with horizontal or rate-reducing resistance to disease (22).

Development of winter wheat (*Triticum aestivum* L.) cultivars with durable types of resistance to *Blumeria graminis* (DC.) E. O. Speer f. sp. *tritici* Ém. Marchal (=*Erysiphe graminis* DC. f. sp. *tritici* Ém. Marchal) has become a priority for breeding programs since the recognition of slow-mildewing resistance (2,19,21). This type of resistance could result from the single or combined effects of increased latent period, decreased sporulation capacity, and lower infection efficiency (20). However, detection of slow-mildewing by detailed measurements on plants is labor intensive and too time consuming for breeding programs attempting to assess large numbers of accessions (2). Selection criteria, such as analysis of disease progress curves and apparent infection rates (21), derived from disease assessments of breeding lines grown in replicated field trials and relying on natural inoculum, appears to be more economical in terms of time and funds. However, the major limitations to this type of approach are restricted field space for assessing accessions and the failure of small field plots to accurately represent disease progress in large commercial fields because of interplot interference (4,11,18).

Plot size and shape and spacing between plots can be manipulated to control the magnitude of inoculum exchange among field plots (4,10,18,22). With all other factors being equal, square plots have less interference than rectangular plots (10,18). Also, larger plot size and interplot separation reduces interference (18). The appropriate plot size and shape and distance between plots needed to reduce interference depends on the dispersal characteristics of the pathogen (18). In general, as the steepness of the dispersal gradient decreases, plots need to be larger or farther apart to minimize interference.

Vanderplank (22) warned that interplot interference causes greater errors in

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estimating the level of resistance expressed by cultivars with horizontal (rate-reducing, slow-mildewing) rather than vertical (qualitative, race-specific) resistance. However, because of the numbers of accessions needed to make rapid progress in a breeding program and limited land available for planting, most plots used in breeding programs have been relatively small. Generally, preliminary breeding line evaluations have been conducted using adjacent plots 1–2 m long. Only in advanced trials, with fewer numbers of entries, has the use of larger plots been justified.

This study was conducted to determine the effect of plot size and spacing on development of powdery mildew of wheat in small plots to provide estimates of error observed in breeding nurseries. We evaluated a susceptible and a slow-mildewing wheat cultivar and two plot sizes and border widths to determine if interplot interference affected disease severity assessment.

Table 1. Plot size, border width, and cultivar pairing combination used to evaluate powdery mildew interplot interference

Plot size (m)	Border width[a] (m)	Cultivar pairing[b]
1.7 × 1.7	1.7	R-S
1.7 × 1.7	1.7	S-S
1.7 × 1.7	5.1	R-S
1.7 × 1.7	5.1	S-S
5.1 × 5.1	1.7	R-S
5.1 × 5.1	1.7	S-S
5.1 × 5.1	5.1	R-S
5.1 × 5.1	5.1	S-S

[a] Border width refers to distance between the two plots within cultivar pairs.

[b] Cultivar pairing code: R-S = slow-mildewing cultivar (Scotty) paired with susceptible cultivar (Becker); S-S = susceptible cultivar (Becker) paired with susceptible cultivar (Becker). In all presentations, the average value of the two susceptible cultivars paired together are presented.

MATERIALS AND METHODS

Field experiments. Plots were established at the Ohio Agriculture Research and Development Center, near Wooster, in fields (Ravenna silt loam) maintained under a corn-soybean-oat-wheat rotation. After plowing, the fields were fertilized with 336 kg of 6-24-24 (NPK) per hectare and then disked before planting. The plots were planted with 135 kg of seed per hectare on 6 October 1988 and 29 September 1989 for evaluation in 1989 and 1990, respectively. Plots will be identified throughout the rest of this article by the year in which they were evaluated. Plot sizes tested were dependent on the size of the plot drill normally used for planting advanced lines in our breeding nurseries. The drill planted seven rows, 17.8 cm between rows (125-cm-wide strip), and a 22-cm space between drill strips for traffic. Thus, 1.7-m-wide plots contained one drill strip and 5.1-m-wide plots contained three drill strips. All plots were top-dressed with 100 kg of nitrogen per hectare, as ammonium nitrate, on 27 March 1989 and 20 March 1990.

The basic experimental design was that used by Bowen et al (3) to determine the effect of negative interplot interference with wheat leaf rust (caused by *Puccinia recondita* Roberge ex Desmaz. f. sp. *tritici*). Pairs of plots were arranged randomly in a 2 × 2 factorial design. The factors were plot size (1.7 × 1.7 m [2.9 m^2] and 5.1 × 5.1 m [26 m^2]) and spacing between plots or border width (1.7 and 5.1 m). There were two cultivar pairings: susceptible cultivar Becker (PI 494524) paired with the same susceptible cultivar (S-S) or susceptible cultivar paired with a slow-mildewing cultivar Scotty (PI 469294) (S-R) (Table 1). Thus, disease assessments were recorded from three cultivar pair combinations (*R*-S, R-*S*, and *S*-*S*) where the italicized letter represents the cultivar from which assessments were obtained. In 1989, the border was planted to winter barley (*Hordeum vulgare* L. 'Pennol') but because of winterkilling, oats (*Avena sativa* L. 'Ogle') were replanted into the borders in the spring (25 March 1989). In 1990, the border plots were planted to a winter wheat cultivar highly resistant to powdery mildew (AGRA GR 876 [PI 515951]). Each plot pair was separated from other pairs by a minimum of 5.1 m planted to the resistant cultivar AGRA GR 876 both years to avoid additional sources of inoculum. Each treatment was replicated four times in each year.

Table 2. Mean square (MS) and significance (*P*) values for main and interaction effects of plot size, border width, and cultivar pair on area under the disease progress curve (AUDPC) for wheat powdery mildew

	1989		1990	
Effect	MS	*P*	MS	*P*
Plot size	19.99	0.011	61.40	0.002
Border width	0.08	0.839	6.38	0.204
Border width × plot size	2.09	0.335	1.81	0.509
Error A	2.00	. . .	3.43	. . .
Cultivar pair	417.22	<0.001	275.44	<0.001
CONT$_{S}$[a]	(0.06)	(0.829)	(0.63)	(0.712)
CONT$_{RS}$	(138.99)	(<0.001)	(81.35)	(<0.001)
Cultivar pair × plot size (PS)	6.63	0.004	4.75	0.384
CONT$_{R1}$	(2.29)	(0.188)	. . .	. . .
CONT$_{S1}$	(38.50)	(<0.001)	. . .	. . .
CONT$_{S}$ × PS	(0.12)	(0.760)	. . .	. . .
CONR$_{RS}$ × PS	(7.20)	(0.023)	. . .	. . .
Cultivar pair × border width (BW)	2.47	0.139	17.43	0.017
CONT$_{R2}$	. . .	. . .	(7.51)	(0.207)
CONT$_{S2}$	. . .	. . .	(6.00)	(0.258)
CONT$_{S}$ × BW	. . .	. . .	(18.80)	(0.048)
CONT$_{RS}$ × BW	. . .	. . .	(8.91)	(0.170)
Cultivar pair × PS × BW	1.97	0.216	6.89	0.225
Error B	1.27	. . .	4.54	. . .

[a] Linear contrasts of the means: CONT$_{S}$ = R-*S* vs. *S*-*S*; CONT$_{RS}$ = (R-*S* + 2[*S*-*S*])/3 vs. *R*-S; CONT$_{R1}$ = *R*-S (PS = 1.7^2) vs. *R*-S (PS = 5.1^2); CONT$_{S1}$ = (R-*S* + 2[*S*-*S*])/3 (PS = 1.7^2) vs. (R-*S* + 2[*S*-*S*])/3 (PS = 5.1^2); CONT$_{R2}$ = *R*-S (BW = 1.7) vs. *R*-S (BW = 5.1); and CONT$_{S2}$ = (R-*S* + 2[*S*-*S*])/3 (BW = 1.7) vs. (R-*S* + 2[*S*-*S*])/3 (BW = 5.1).

Inoculum of *B. g. tritici* was provided by natural sources. Disease severity was assessed at Feekes growth stages (GS) 8, 9, 10.3, and 10.5.1 in 1989 and GS 6, 8, 9, 10, 10.3, and 10.5.1 in 1990 (13). The percent leaf area covered by lesions was determined on the top three leaves (flag, second, and third leaves) of 10 randomly selected tillers per plot at each growth stage, except at GS 6 in 1990, when only the penultimate (second leaf) and third leaf could be assessed on each tiller. The percent leaf area covered by lesions was determined using disease assessment keys developed by James (9).

Analysis of data. The disease severity of each plot was calculated as the mean percentage of leaf area affected on the leaves assessed per 10 tillers. Area under the disease progress curve (AUDPC) was calculated according to Campbell and Madden (4). AUDPC values were divided by the time from the first to last assessment to standardize values among epidemics of different durations (4). AUDPC values were calculated for each replication separately.

The experimental design was a split-plot factorial with plot size and border width as whole plots and cultivar pair as the subplot. Analysis of variance (ANOVA) was used to evaluate the effects of plot size, border width, cultivar pair, and their interactions on AUDPC. Linear contrasts of the means (7) also were calculated to partially evaluate negative and positive interplot interference. Negative interference could be determined if the susceptible cultivar paired with the slow-mildewing cultivar (R-*S*) had less disease (i.e., AUDPC) than the mean of the paired susceptible cultivars (*S*-*S*). This contrast (labeled CONT$_{S}$) was calculated if the main effect of cultivar pairing was significant. If the interaction of cultivar pairing and any other factor was significant, the interaction contrast for CONT$_S$ also was calculated (CONT$_S$ × border width [BW], CONT$_S$ × plot size [PS]). An interaction of CONT$_S$ with one of the other factors indicates that the magnitude of the negative interference depends on plot size or border width. Negative interference also could be determined if AUDPC in the susceptible cultivar was influenced by plot size or spacing, regardless of the paired cultivar. This effect could be determined if there was an interaction of cultivar pairing and one of the other factors (CONT$_{S1}$ or CONT$_{S2}$, when there was an interaction) (Table 2).

Because the slow-mildewing cultivar was not paired with another slow-mildewing cultivar, positive interplot interference could be determined only by significant interaction of cultivar pairing and another factor. For instance, positive interference was indicated either if AUDPC of the slow-mildewing cultivar (*R*-S) in the small plot was greater than AUDPC in the large plot of the same cultivar (CONT$_{R1}$) or AUDPC of the slow-mildewing cultivar with the narrow border width was greater than AUDPC in the plot with the wide border (CONT$_{R2}$).

In addition to the above contrasts, the difference between AUDPC of the susceptible cultivar (whether paired with a susceptible or slow-mildewing cultivar) and the slow-mildewing cultivar was determined with another contrast (CONT$_{RS}$). When an interaction from ANOVA was significant, the interaction of CONT$_{RS}$ and the other factor was calculated. Finally, the least significant difference (LSD) ($P = 0.05$) was calculated for comparing pairs of means when a main effect or interaction was significant.

RESULTS

During both years of the study, powdery mildew was present on the lower leaves of plants by the first assessment date. Powdery mildew continued to spread within plots throughout the remainder of the growing season (Fig. 1). In 1989, disease increase was similar to previous years for this location from GS 8 to 10.5.1 (14) because of warm temperatures and high humidity during May and early June. By GS 10.5.1, percent leaf area affected on the top three leaves reached 55–60% in plots planted to the susceptible cultivar and 25% in plots planted to the slow-mildewing cultivar (Fig. 1A and B). In 1990, cool temperatures during the second and third week in May (GS 10–10.3) limited the spread of powdery mildew so that by GS 10.5.1, percent leaf area affected by powdery mildew was 26–34% in plots planted to the susceptible cultivar and 12–14% in plots planted to the slow-mildewing cultivar (Fig. 1C and D).

Analysis of variance indicated that the main effect of plot size had a significant effect on AUDPC in both 1989 and 1990 (Table 2). Overall, the 26-m^2 plots had significantly greater ($P \leq 0.05$) AUDPC values than the 2.9-m^2 plots (Table 3). Mean AUDPC values in the larger plots were 7.7 and 15.3% greater than in the smaller plots in 1989 and 1990, respectively. The main effect of width of the border between plots had no influence on AUDPC values either year (Tables 2 and 3). Because there was no significant effect of border width, it appeared that the oat border in 1989 and the resistant wheat border in 1990 did not contribute inoculum to the experimental plots or block dispersal of inoculum between cultivars within pairs.

The main effect of cultivar pair greatly influenced the amount of disease developing in plots as determined by significant ($P \leq 0.001$) effects on AUDPC values in 1989 and 1990 (Table 2). AUDPC values for the susceptible cultivar with either pairing (slow-mildewing or susceptible) were significantly higher than those for the slow-mildewing cultivar (CONT$_{RS}$ in Table 2; Table 4). However, there was no difference in the AUDPC values between the susceptible cultivar in the *S-S* and R-*S* cultivar pairs (CONT$_S$ in Table 2). This indicated that disease developed similarly in plots of the susceptible cultivar regardless of its pairing with a plot of the susceptible cultivar or a plot of the slow-mildewing cultivar.

ANOVA indicated that the interactions of cultivar pairing and plot size and the cultivar pairing and border width were significant ($P < 0.05$) for AUDPC in 1989 and 1990, respectively (Table 2). The significant interaction of cultivar pairing and plot size in 1989 was attributable to the slow-mildewing cultivar being unaffected by plot size (AUDPC = 7.0 vs. 7.7) (CONT$_{R1}$ in

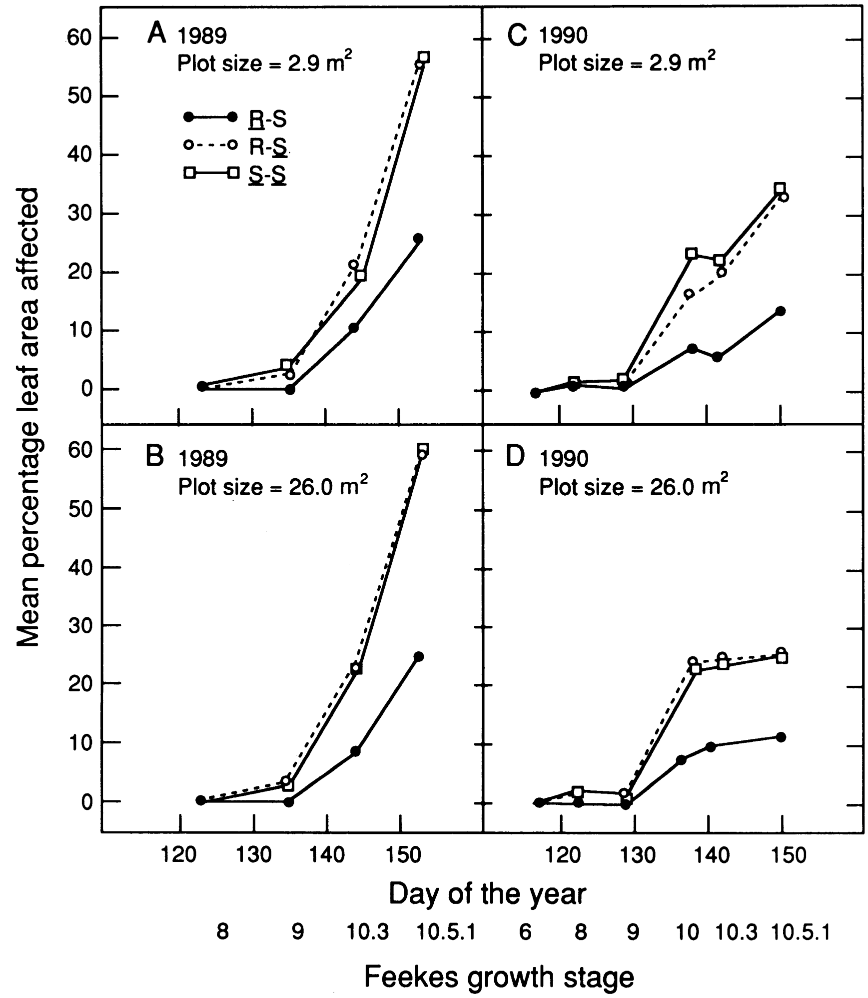

Fig. 1. Disease progress curve for wheat powdery mildew in cultivar pairs representing the slow-mildewing cultivar (Scotty) paired with the susceptible cultivar (Becker) (*R*-S), the susceptible cultivar paired with the slow-mildewing cultivar (R-*S*), and the susceptible cultivar paired with the susceptible cultivar (*S-S*) planted in **(A)** 1989 in 2.9-m^2 plots, **(B)** 1989 in 26-m^2 plots, **(C)** 1990 in 2.9-m^2 plots, and **(D)** 1990 in 26-m^2 plots. The mean percent leaf area affected was calculated from assessments of top three leaves (top two leaves at growth stage 6 in 1990) at each assessment time. Disease assessments were recorded for the italicized cultivar in the cultivar pair, and data presented for the *S-S* pair are the means of the plots within this cultivar pair.

Table 2) but the susceptible cultivar having higher disease severity in the large plots compared with the small ones (CONT$_{S1}$ in Table 2; Table 5). Also, the difference in AUDPC values between the slow-mildewing and susceptible cultivar depended on plot size (CONT$_{RS}$ × PS in Table 2). However, pairing the susceptible cultivar with the susceptible (*S-S*) or slow-mildewing (R-*S*) cultivar did not have an effect at either plot size (CONT$_{S}$ × PS in Table 2). In 1990, the susceptible cultivar tended to have a higher AUDPC in large plots compared with small ones (Table 5). The variability was too high, however, to detect significance.

Table 3. Main effect of plot size and border width on area under the disease progress curve (AUDPC)[a] for wheat powdery mildew in 1989 and 1990

	Plot size (m^2)		Border width (m)	
Year	**2.9**	**26.0**	**1.7**	**5.1**
1989	14.4	15.6*[b]	15.0	15.0
1990	10.5	12.4*	11.8	11.2

[a] AUDPC values calculated from four and six disease assessments in 1989 and 1990, respectively, and represent the means of four replicate plots.

[b] Asterisk indicates significantly ($P = 0.05$) greater AUDPC value in 26.0-m^2 plots than 2.9-m^2 plots, according to analysis of variance.

Table 4. Main effect of cultivar pairing on area under the disease progress curve (AUDPC)[a] of wheat powdery mildew in 1989 and 1990

Cultivar pair[b]	1989	1990
R-S	7.3	5.4
R-*S*	17.6	13.2
S-S	17.5	13.6
LSD ($P = 0.05$)	0.8	1.5

[a] AUDPC values calculated from four and six disease assessments in 1989 and 1990, respectively, and represent the means of four replicate plots.

[b] Cultivar pair code: *R*-S = slow-mildewing cultivar (Scotty) paired with susceptible cultivar (Becker); R-*S* = susceptible cultivar paired with slow-mildewing cultivar; and *S-S* = susceptible cultivar paired with susceptible cultivar (mean of both plots per pair). Disease assessments were recorded for the italicized cultivar in the cultivar pair.

The significant interaction of cultivar pairing and border width in 1990 was attributable, in part, to a greater AUDPC for the susceptible cultivar paired with the susceptible cultivar (*S-S*) and a 1.7-m border width (14.8) compared with a 5.1-m border (12.5) (Table 5). In addition, the susceptible cultivar separated by a 1.7-m border had a significantly greater AUDPC when paired with the susceptible cultivar than when paired with the slow-mildewing cultivar. These observations were confirmed by the significant CONT$_{S}$ × BW interaction in Table 2. Increasing the border width between plots of the paired susceptible cultivar had an effect similar to pairing the slow-mildewing cultivar with the susceptible cultivar with the smaller border width (Table 5). There was not an overall increase in disease severity in the susceptible cultivar as border width decreased (CONT$_{S2}$ in Table 2). Border width, moreover, did not affect AUDPC of the slow-mildewing cultivar as evidenced by the nonsignificant CONT$_{R2}$ contrast (Table 2). The difference between AUDPC for the slow-mildewing and susceptible cultivar also was not affected by border width (see CONT$_{RS}$ × BW in Table 2).

DISCUSSION

Our results indicated that disease severity of wheat powdery mildew was influenced by plot size and cultivar pairing. In some cases, the effect of cultivar pairing was altered by the width of the border between plots and plot size, as indicated by significant interactions. In general, only the susceptible cultivar was strongly influenced by plot size or border width. Differences in disease severity could be attributed, in part, to interplot interference.

Table 5. Interaction of cultivar pairing and plot size, and cultivar pairing and border width on area under the disease progress curve (AUDPC)[a] for wheat powdery mildew in 1989 and 1990

	1989			1990		
Factor	***R*-S[b]**	**R-*S***	***S-S***	***R*-S**	**R-*S***	***S-S***
Plot size						
2.9 m^2	7.7	16.6	16.7	4.8	11.4	12.9
26.0 m^2	7.0	18.7	18.3	6.2	14.9	14.4
Interaction LSD ($P = 0.05$)		1.1			NS	
Border width						
1.7 m	7.6	17.3	17.5	4.8	12.7	14.8
5.1 m	7.0	18.0	17.5	6.2	13.6	12.5
Interaction LSD ($P = 0.05$)		NS			2.2	

[a] AUDPC values calculated from four and six disease assessments in 1989 and 1990, respectively, and represent the means of four replicate plots.

[b] Cultivar pairing code: *R*-S = slow-mildewing cultivar (Scotty) paired with susceptible cultivar (Becker); R-*S* = slow-mildewing cultivar paired with susceptible cultivar; and *S-S* = susceptible cultivar paired with susceptible cultivar. Disease assessments were recorded for the italicized cultivar in the cultivar pair.

Paysour and Fry (18) indicated that the most critical factor needed to predict effects of interplot interference in field research was an accurate estimation of the dispersal characteristics of the pathogen as measured by steepness of the dispersal gradient (*b*). Their calculations for dispersal gradients of *Phytophthora infestans* (Mont.) de Bary on potatoes ranged from 0.8 to 2.1/m, based on the exponential model (4). Experiments have been conducted to determine dispersal gradients for *B. graminis* (1,5,12). In an experiment on powdery mildew of barley (caused by *B. g. hordei* Ém. Marchal), Jenkyn and Bainbridge (12) found that separating fungicide-treated and untreated plots by 2 m reduced by half the amount of powdery mildew recolonizing sprayed plots. Bainbridge and Stedman (1), also working with powdery mildew on barley, found that concentrations of conidia collected in suction traps were reduced by half at a distance of 1 m away from a susceptible cultivar source, and by a distance of 4 m, the concentration of conidia was no different than background concentrations. Fried et al (5) determined the disease gradients of *B. g. tritici* to have a steepness of 1.7–1.9 using Gregory's power model (8). Reanalysis of these data indicated that *b* of the exponential model was about 2.1 to 2.3/m (L. V. Madden and P. E. Lipps, *unpublished*). McCartney and Bainbridge (16) estimated the dispersal gradient of *B. graminis*, by determining the dispersal of liquid droplets the size of conidia, as $b = 1.4–2.7$/m. These studies indicated that *B. graminis* has a steep dispersal gradient similar to *P. infestans* (18).

Although we did not measure conidial movement directly, the effect of inoculum movement was assessed in relative terms by disease severity (i.e., AUDPC) differences. Negative interplot interference apparently contributed to the lower AUDPC values in the 2.9-m^2 plots compared with the 26.0-m^2 plots (especially in 1989) because of a greater level of inoculum lost from the smaller plots. Assuming that *B. g. tritici* had a moderately steep dispersal gradient ($b = 1.0$/m) (5,16), Paysour and Fry's model would predict that the 26- and 2.9-m^2 plots would lose approximately 40 and 83% of their inoculum (18), respectively. Thus, the smaller plot was predicted to lose 50% more inoculum than the larger plot. If the dispersal gradient was steeper (i.e., $b = 2.0$/m), less inoculum would be lost from both plots. The level of inoculum loss in our study apparently caused a 10–17% lower AUDPC value in the smaller plots than the larger plots with the susceptible cultivar over the 2 yr of this study.

The significant main effect of cultivar

pairing was primarily attributable to the difference in the level of disease developing on the slow-mildewing cultivar compared with the susceptible cultivar. The lower AUDPC values for the slow-mildewing cultivar occurred regardless of plot size or border width used (Tables 4 and 5), indicating that slow-mildewing characteristics of cultivars could be assessed in 2.9-m^2 plots with narrow border widths. The magnitude of the difference between the slow-mildewing and susceptible cultivar was influenced by plot size in 1 yr ($CONT_{RS} \times PS$ in Table 2; Table 5), but this was because the AUDPC of the susceptible cultivar varied with plot size, whereas the slow-mildewing cultivar was not significantly affected by plot size. The mean percent leaf area covered on the three top leaves of the slow-mildewing cultivar by the end of the season was about half that produced on the susceptible cultivar each year of the test (Fig. 1). Yield losses to powdery mildew have been lower on Scotty and other cultivars with similar responses to powdery mildew, than on susceptible cultivars tested (14, 15).

Because the slow-mildewing cultivar was not significantly affected by plot size (see $CONT_{R1}$ and $CONT_{R2}$ in Table 2; Table 5), there was no direct evidence for positive interplot interference. Obviously, there was movement of inoculum into and out of the slow-mildewing and susceptible cultivar plots. The net movement was negative for the susceptible cultivar as plots became smaller or farther apart. The opposite was not found for the slow-mildewing cultivar, which is partially supported by the theoretical results of Paysour and Fry (18). When a resistant cultivar had half the disease severity of the susceptible cultivar and the gradient was moderately steep ($b = 1/m$), they predicted that plots (25 m^2) would need to be at least 2.4 m apart to limit positive interplot interference to low or trace levels. With a steeper gradient ($b = 2/m$), plots would only have to be 0.6 m apart, less than our shortest distance. This would suggest that a steep dispersal gradient existed in our study. However, larger effects of inoculum loss on AUDPC of the susceptible cultivar (negative interference) should be evident with this gradient steepness. These predictions are based on all inoculum originating in the experimental plots. In our cultivar evaluation experiments with powdery mildew, natural inoculum initiated and contributed to all epidemics. The widespread distribution of inoculum in the area probably reduced some of the differences that would have existed if primary inoculum was present only in the experimental plots.

The effect of the steepness of the dispersal gradient can be further evaluated by considering the work of Bowen et al (3). They reported that negative interplot interference for wheat leaf rust was greater between large plots (16 m^2) than between smaller plots (4 m^2) of a susceptible cultivar. We observed a similar difference in the amount of powdery mildew developing on the susceptible cultivar planted in 2.9- and 26-m^2 plots. Bowen et al (3) also reported that plots separated by 4 m had greater disease severities than those separated by 2 m. In our study, the main effect of border width on disease development was not significant. However, in 1 yr, the interaction of cultivar pairing and border width was significant for AUDPC. Plots with the larger border width had a significantly ($P = 0.05$) lower AUDPC value than plots with the smaller border width from the susceptible-susceptible cultivar pair (Table 5). These differences indicate that the two pathogens may have different disease dispersal gradients. Paysour and Fry (18) indicated that both rust and powdery mildew fungi have relatively flat disease gradients, however, the literature reviewed here (1,5,16) and the results of our study indicate that powdery mildew fungi have a steeper dispersal gradient than the rust fungi.

Results of our study indicated that small plots could be used effectively to evaluate cultivars with slow-mildewing resistance. However, the effect of slow-mildewing resistance may be underestimated somewhat because of negative interplot interference. That is, susceptible cultivars may have less disease in small plots than they would in larger plots and, thus, the difference between AUDPC values of the susceptible and slow-mildewing cultivars could be smaller. Increasing plot size would not be very efficient, because in 1989, there was only a 10% increase in AUDPC of the susceptible cultivar when plot size was increased nearly 800%. Also, AUDPC increased only 0.08 per square meter of plot size. The plot sizes and border widths chosen for study were those most appropriate for use with our equipment where the smallest plot (1.7 m wide) represented one drill width and the largest plot (5.1 m wide) represented the greatest space we were willing to expend to evaluate one experimental unit (one cultivar or line). Based on the results, the plot size of 1.7 × 1.7 m and a 1.7-m border between plots would be sufficient for evaluating resistance of cultivars assuming the researcher is willing to accept some level of experimental error attributable to negative interplot interference.

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LITERATURE CITED

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