Analysis of Incidence–Severity Relationships for Strawberry Powdery Mildew as Influenced by Cultivar, Cultivar Type, and Production Systems

O. Carisse and A. Lefebvre, Agriculture and Agri-Food Canada, St.-Jean-sur-Richelieu, QC J3B 3E6, Canada; and H. Van der Heyden, Linda Roberge, and Luc Brodeur, Compagnie de recherche Phytodata Inc., Sherrington, QC J0I 2N0, Canada

Abstract

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The relationships between strawberry powdery mildew incidence (I) and severity (S) were investigated for various cultivars, for June-bearing and day-neutral cultivars, and for production systems (open-field and plastic-tunnel) with the objective of deriving a simple relationship for predicting severity (proportion of leaf area diseased [PLAD]) from incidence (proportion of diseased leaves). Data were collected from 2006 to 2011 at 11 commercial and experimental sites, for a total of 2,326 observations (*n*). For the cultivars grown in open fields, higher severity was observed on ‘Seascape’, with mean PLAD of 0.299 (*n* = 427); followed by ‘Chambly’, with 0.133 (*n* = 334); ‘Cavendish’, with 0.115 (*n* = 250); ‘Darselect’, with 0.111 (*n* = 321); and ‘Jewel’, with 0.105 (*n* = 276). In general, mean severity was higher when the strawberry plants were grown in plastic tunnels, with PLAD of 0.204, 0.199, and 0.181 for Chambly (*n* = 204), Darselect (*n* = 261), and Jewel (*n* = 253), respectively. A linear model based on complementary log-log transformation of I and S provided a good fit of the data (coefficient of determination [*R*²] adjusted for degrees of freedom

from 0.82 to 0.96). A covariance analysis indicated that the sampling year and site of sampling did not significantly influence the estimated slope of the I–S relationship, nor did the specific cultivar among the June-bearing ones, whereas the production system (open-field versus plastic-tunnel) and the cultivar type (June-bearing versus day-neutral) significantly influenced the estimated slope. From this analysis, we were able to develop three specific models for open-field-grown June-bearing cultivars (*R*² = 0.90), for the open-field-grown day-neutral cultivar (Seascape, *R*² = 0.91), and for June-bearing cultivars grown in plastic tunnels (*R*² = 0.92). From these results, it was concluded that strawberry powdery mildew leaf severity can be accurately estimated from incidence of diseased leaves. The I–S relationships developed in the present study may be used in making practical disease management decisions, especially for management programs that use information on disease level in the field to initiate fungicide spraying programs or to time the interval between sprays.

Strawberry powdery mildew, caused by *Podosphaera aphanis* (Wallr.) U. Braun & S. Takam (formerly *Sphaerotheca macularis* f. *fragariae* (Harz) Jacz), is present in a several of strawberry production areas worldwide (3,4,19,29). Strawberry production in eastern Canada is a limited (7), albeit valuable, component of the fresh market and of the expanding market for locally produced food. Cultivated strawberry, *Fragaria × ananassa* (L) Duch., is the result of a cross between *Fragaria chilonensis* (L) Duch. and *Fragaria × virginiana* Duch. (14). Strawberry cultivars are generally classified based on their response to photoperiod. In June-bearing cultivars, buds are initiated during photoperiods of less than 14 h/day, whereas day-neutral cultivars are insensitive to photoperiod with respect to flower induction (6). One of the greatest challenges that strawberry producers face in eastern Canada is to provide the market with high-quality fruit over a long period of time, ideally from June to September. This has led to profound changes in production systems, with a shift from conventional production systems based on field-grown June-bearing cultivars to day-neutral cultivars and to strawberry plants grown under large plastic tunnels. Most evaluations of strawberry cultivars for their susceptibility to powdery mildew were conducted on cultivars not grown in Eastern Canada (22). However, the most common day-neutral strawberry cultivar, ‘Seascape’, was evaluated in California and was reported as moderately susceptible, although field observations suggest that this

cultivar is highly susceptible (23). Plastic tunnels provide optimal conditions for powdery mildew development (32). Hence, powdery mildew is now a major constraint to strawberry production in eastern Canada.

In June-bearing cultivars grown in fields, the onset of disease generally occurs after fruit harvest on regrowth of mown-off plants and, hence, does not cause direct yield losses during the current year. In 1969, Freeman and Pépin (9) reported that a severe epidemic of powdery mildew had no carry-over effect on yield in subsequent years. These results were further supported by Berrie and Burgess (2), who reported that, during the mild U.K. winters, strawberry plants that were severely mildewed in autumn showed reduced vigor, which was compensated for by the resumption of rapid growth in the following spring. It is not clear, however, whether severe epidemics occurring after harvest can cause a reduction in plant vigor and affect winter survival under the cold winters of eastern Canada. In day-neutral cultivars, direct yield losses are caused by infection of flowers and fruit, which are susceptible to infection in the early stages of development (4,5). Severe infections can kill flowers and contaminate the pollen with conidia, resulting in poor pollination (12,19). Infected green fruit may become hard and fail to ripen. Fruit infected at a later stage may be more prone to *Botrytis cinerea* infection and have a shortened shelf life (23,25,26,30). In addition, the presence of white mycelium and conidia makes the fruit less attractive to pick-your-own customers, who often discard them. In Eastern Canada, losses that can be attributed to powdery mildew could be up to 30% (5).

Despite the lack of evidence that post-harvest mildew on June-bearing cultivars is harmful, growers generally carry out thorough and expensive fungicide schemes involving the application of sulfur and myclobutanil, a demethylation-inhibiting fungicide, at 7- to 10-day intervals. On day-neutral cultivars, growers are advised to apply fungicides at regular intervals from the emergence of the first leaves to harvest. In general, powdery mildew is more severe in August and September, which renders fungicide management diffi-

Corresponding author: O. Carisse, E-mail: odile.carisse@agr.gc.ca

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cult in day-neutral cultivars because of the required preharvest intervals for most fungicides. In addition, recent reports on the development of resistance to demethylation-inhibiting fungicides in powdery mildew populations (28) point to the need for an integrated disease management approach, including the employment of host resistance and disease risk estimation.

In a recent study, the relationships between weather, airborne inoculum concentrations, foliar strawberry powdery mildew severity, and crop losses were analyzed using field data (5). The variable that most influenced crop losses was powdery mildew foliar severity. These results suggest that information on foliar powdery mildew must be considered when making disease management decisions. However, field assessment of strawberry powdery mildew is generally difficult, mainly because lesions typically occur as a diffuse colony on the abaxial leaf surface (18,21,29). The ability to monitor strawberry powdery mildew incidence rather than severity would facilitate adoption of management programs which include scouting data.

The relationships between disease incidence and severity or intensity have been studied in many diseases at one or more levels of host spatial hierarchy (11,16,20,24,33). For most of these diseases, it was possible to statistically describe these relationships and to develop models predicting severity from incidence at the same or a higher level of hierarchy (16). In general, the incidence–severity relationship is influenced by factors such as cultivar susceptibility, fungicide spray program, time of disease assessment within the season, season, or location (24). Therefore, it is important to study the incidence–severity relationships under a broad range of conditions. Therefore, the specific objective of this study was twofold: first, to characterize statistically the relationship between strawberry powdery mildew incidence and severity; and second, to determine the effect, if any, of sampling year, site, cultivar, cultivar type, and production system on the incidence–severity relationship.

Materials and Methods

Sampling sites and disease assessment. Data were collected from 2006 to 2011 at the Agriculture and Agri-Food Canada experimental farm located in Frelighsburg and at 10 commercial strawberry farms located in several strawberry-production areas of the province of Quebec, Canada. Powdery mildew data were collected in fields planted with the June-bearing ‘Cavendish’, ‘Chambly’, ‘Darselect’, and ‘Jewel’ during the first or second year of production; in fields planted with the day-neutral Seascape; and in large plastic tunnels planted with the June-bearing Chambly, Darselect, and Jewel. Data were collected one to three times weekly from mid-June to mid-September for an average of 16, 20, and 56 samplings for the June-bearing grown in open fields, June-bearing grown in tunnels, and day-neutral cultivars, respectively. The data used for analysis are described in Table 1. At all sites, fungicides were applied to manage gray mold caused by *B. cinerea*. First sprays were applied when blossoms opened, repeated every 7 to 14 days depending on rains, and ended at harvest. Fungicides used included boscalid, pyraclostrobin+boscalide, fenhexamid, iprodione, and vinclozolin. Powdery mildew management practices varied from farm to farm. In general, on June-bearing cultivars, fungicides were not applied before renovation unless the disease was a problem the previous year; however, fungicides were applied after harvest in August or September. On June-bearing cultivars grown in plastic tunnels and on day-neutral cultivars, powdery mildew was managed with fungicides applied at regular intervals or based on scouting results. Fungicides used included lime sulfur and myclobutanil.

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Fig. 1. Box plots summarizing the distribution of **A**, severity and **B**, incidence of strawberry powdery mildew. Solid and broken lines within the box represent the mean and median, respectively, while the top and bottom lines of the box represent the 75th and 25th percentiles of the data, respectively, and the dots represent outliers.

Table 1. Description of the data used to study the relationship between incidence and severity of strawberry powdery mildew caused by *Podosphaera aphanis*

Cultivar	Sampling year ^a					
	2006	2007	2008	2009	2010	2011
Open fields						
‘Cavendish’	56 (4)	130 (7)	73 (4)	72 (4)	13 (1)	14 (1)
‘Chambly’	56 (4)	133 (7)	91 (4)	79 (4)	16 (1)	14 (1)
‘Darselect’	34 (2)	54 (3)	122 (6)	116 (6)	34 (2)	14 (1)
‘Jewel’	32 (2)	50 (3)	109 (6)	110 (6)	31 (2)	14 (1)
‘Seascape’	111 (2)	290 (5)	168 (3)	...	...	...
Large tunnels						
Chambly	...	62 (3)	76 (3)	101 (3)	...	...
Darselect	20 (1)	39 (2)	106 (5)	101 (5)	19 (1)	...
Jewel	10 (1)	35 (2)	119 (6)	95 (5)	18 (1)	...

^a Number of observations and fields surveyed (in parentheses). Each observation is the mean of 25 plants.

Disease assessments were performed weekly on 25 strawberry plants selected randomly from each field. Foliar powdery mildew severity was assessed on the three youngest fully expanded leaves per plant as the proportion of leaf area diseased using a diagrammatic scale with 0.05 steps (0, 0.05, 0.10, 0.15...1.00). Severity (S) was calculated as the mean severity (over all 25 plants). Powdery mildew incidence (I) was derived from the severity data by rating a leaf as diseased if severity was >0. Incidence was calculated as the proportion of diseased leaves. Only pairs of incidence and severity data with $I > 0$ were included in the analysis because incidence–severity relationships can only be analyzed when disease is present ($I > 0$) (24).

Analysis of the strawberry powdery mildew incidence–severity relationship. Data for each cultivar, cultivar type, and production system were first analyzed separately, then an analysis was conducted with pooled data. Incidence and severity data were transformed to complementary log-log (CLL) as $CLL(I) = \ln[-\ln(1 - I)]$ and $CLL(S) = \ln[-\ln(1 - S)]$, respectively. This model was selected based on the plots of severity as a function of incidence and because incidence and severity must lie between 0 and 1 (REF). Transformed data were modeled with linear ordinary least-squares regression analyses as $CLL(S) = \beta_0 + \beta_1 [CLL(I)]$ (equation 1). This is an equation for a straight line with an intercept (β_0) and a slope (β_1). Several other models for incidence–severity relationships were evaluated based on previous usage in other pathosystems (20,33). However, these models were not selected because

their residual plots were non-random, or the shape of the curve for predicted severity versus incidence diverged from the shape of observed severity versus incidence. A one-sided t test was used to determine whether the slope of equation 1 differed from 1, based on the estimated β_1 and its standard error. Model fit was evaluated based on the coefficient of determination adjusted for degrees of freedom (R^2_{adj}), squared correlation between back-transformed observed and predicted values (R^{*2}), and randomness of the residual plots. The analyses were performed with the GLM procedure of SAS (version 9.2; SAS Inc.).

Covariance analyses. A covariance analysis was conducted to measure the effect of the cultivar, cultivar type, production system, site, and year on the intercept (β_0) and slope (β_1) parameters of equation 1. The purpose of this analysis was to determine whether these factors affected the incidence–severity relationship. The test of a factor is not an indication of whether the factor had a significant effect on powdery mildew severity but whether the factor influenced the incidence–severity relationship by influencing the intercept (β_0) and slope (β_1) parameters. Cultivars used were Chambly, Darselect, Jewel, Cavendish, and Seascape and the cultivar types were June-bearing and day-neutral. The production systems were open field and plastic tunnel, and this factor was tested only for the cultivars that were monitored in both production systems (Darselect, Chambly, and Jewel). The site and year factors were tested separately for each cultivar type and each production system (open-field June-bearing, open-field day-neutral, and plas-

Fig. 2. Relationship between incidence and severity of strawberry powdery mildew for **A** and **C**, untransformed and **B** and **D**, complementary log-log (CLL)-transformed data for the June-bearing **A** and **B**, ‘Chambly’ and **C** and **D**, ‘Darselect’ grown in open fields. Each point represents the mean value from a sample of 75 leaves (25 plants $\times$ 3 leaves per plant). Solid lines represent the predicted values on a CLL scale.

tic-tunnel June-bearing). The covariance analysis was performed using the GLM procedure of SAS (version 9.2; SAS Inc.).

Results

The severity of strawberry mildew varied with cultivars and production systems. Under field conditions, the highest severity was observed for Seascope, which had mean severity of 0.299. Lower but similar powdery mildew severity values were observed for the other cultivars, with severity of 0.133, 0.111, 0.105, and 0.115 for Chambly, Darselect, Jewel, and Cavendish, respectively (Fig. 1). Seascope, Cavendish, and Jewel had similar mean incidence values of 0.647, 0.664, and 0.578, respectively (Fig 1). Powdery mildew incidence was lower for Chambly and Darselect, with incidence of 0.472 and 0.463, respectively. More variation in powdery mildew severity was observed when the strawberry plants were produced under plastic tunnels. Under tunnels, the mean disease severity values for Chambly, Darselect, and Jewel were 0.204, 0.190, and 0.181, respectively. Under plastic tunnels, the mean powdery mildew incidence values for Chambly, Darselect, and Jewel were 0.607, 0.485, and 0.477, respectively. The distribution of powdery mildew severity and incidence across cultivars and production systems is illustrated in Figure 1.

The relationship between CLL-transformed powdery mildew severity and incidence was linear (Figs. 2–6). For all cultivars, cultivar types, and production systems, these regressions explained a large proportion of the variation in transformed severity, with co-

efficients of determination ranging from 0.82 to 0.96 (Table 2). For all cultivars, cultivar types, and production systems, the parameter estimates for equation 1 (β_0 and β_1) were highly significant (Table 2). All F values were significant ($P < 0.001$), meaning that β_1 differed from 0. Estimated intercepts (β_0) ranged from -2.4307 to -1.8661 for the strawberry plants grown under field conditions and from -1.7987 to -1.5539 for the strawberry plants grown under plastic tunnels (Table 2). For the June-bearing cultivars grown in open fields, the slope parameters (β_1) varied between 0.9064 and 0.9522, whereas the range of values was 1.0112 to 1.0153 for the same cultivars grown under large tunnels. The estimate of the slope parameter for the day-neutral cultivar grown in open fields (1.2674) was similar to the estimate for June-bearing cultivars grown in plastic tunnels (Table 2). When all data were pooled, the estimate of the slope parameter was 1.0115 (Table 2). The estimate of the slope parameters for the June-bearing cultivars taken alone was 0.9182, which was lower than for the day-neutral Seascope ($\beta_1 = 1.2674$). When data for the June-bearing Darselect, Chambly, and Jewel were pooled, the estimate of the slope parameter was lower for the open-field production system compared with plastic tunnels, with estimates of 0.9358 and 1.0021, respectively (Table 2).

Based on the analysis of covariance, for the June-bearing cultivars grown in open fields, the cultivar, site, and year factors had a significant effect on the intercept ($P < 0.0001$, $P = 0.0002$, and $P < 0.0015$, respectively) but no significant effect on the slope param-

Fig. 3. Relationship between incidence and severity of strawberry powdery mildew for **A** and **C**, untransformed and **B** and **D**, complementary log-log (CLL)-transformed data for the June-bearing **A** and **B**, 'Jewel' and **C** and **D**, 'Cavendish' grown in open fields. Each point represents the mean value from a sample of 75 leaves (25 plants $\times$ 3 leaves per plant). Solid lines represent the predicted values on a CLL scale.

eter ($P = 0.4136$, $P = 0.3156$, and $P = 0.1698$, respectively) of the CLL(I)–CLL(S) relationship. Despite the significant effect of the cultivar, site, and year factors on the intercept, the ranges of estimated intercepts (back-transformed values) were small (0.84 to 0.112, 0.96 to 0.105, and 0.094 to 0.107 for cultivar, site, and year, respectively). For the day-neutral Seascape grown in open fields, the site and year factors had a significant effect on the intercept ($P = 0.0027$ and $P < 0.0002$, respectively) but no significant effect on the slope parameter ($P = 0.0932$ and $P = 0.2347$, respectively) of the CLL(I)–CLL(S) relationship. The ranges of estimated intercepts (back-transformed values) were 0.127 to 0.36 and 0.124 to 0.140 for site and year, respectively. Similarly, for the June-bearing strawberry plants grown in plastic tunnels, the cultivar, site, and year factors had a significant effect on the intercept ($P < 0.0001$, $P = 0.0003$, and $P < 0.0089$, respectively) but no significant effect on the slope parameter ($P = 0.4126$, $P = 0.3135$, and $P = 0.3371$, respectively) of the CLL(I)–CLL(S) relationship. Despite the significant effect of the cultivar, site, and year factors on the intercept, the range of estimated intercepts (back-transformed values) were small (0.153 to 0.171, 0.147 to 0.164, and 0.153 to 0.169 for cultivar, site, and year, respectively). For the strawberry plants grown in open fields, cultivar type (day-neutral versus June-bearing) had a significant effect on the intercept parameter ($P = 0.0007$; back-transformed intercept values of 0.101 and 0.113 for June-bearing and day-neutral, respectively) and on the slope parameter ($P < 0.0001$) of the CLL(I)–CLL(S) relationship (Table 2). For the

strawberry cultivars Darselect, Chambly and Jewel, the production system (open field versus large tunnel) had a significant effect on both the intercept ($P < 0.0001$, back-transformed intercept values of 0.106 and 0.171, for open field and large tunnel, respectively) and the slope parameter ($P < 0.0001$, back-transformed slope values of 0.101 and 0.113 for open field and large tunnel, respectively) of the CLL(I)–CLL(S) relationship. Based on these analyses, three specific models were developed: one for the June-bearing cultivars grown in open fields ($\beta_0 = -2.2449$, $\beta_1 = 0.9192$, $R^2_{\text{adj}} = 0.90$), one for the day-neutral Seascape grown in open fields ($\beta_0 = -1.8661$, $\beta_1 = 1.2674$, $R^2_{\text{adj}} = 0.92$), and one for the June-bearing cultivars grown in plastic tunnels ($\beta_0 = -1.6734$, $\beta_1 = 1.0021$, $R^2_{\text{adj}} = 0.92$).

Discussion

Although powdery mildew has been recognized as an important strawberry disease for more than a century (27), there is little information on its epidemiology (1,8,10,13,15,17,29,31), mainly because, until recently, the disease was managed mostly through the use of host genetic resistance (22,23). However, shifts in production systems and strawberry types, as well as increased fungicide resistance, have led to powdery mildew outbreaks in several strawberry production areas (28). Disease quantification is essential for epidemiological studies, surveys, and management decisions. However, field assessment of strawberry powdery mildew severity is generally difficult. Powdery mildew typically occurs as patches

Fig. 4. Relationship between incidence and severity of strawberry powdery mildew for **A** and **C**, untransformed and **B** and **D**, complementary log-log (CLL)-transformed for the day-neutral **A** and **B**, Seascape and **C** and **D**, the June-bearing ‘Chambly’, ‘Darselect’, ‘Jewel’, and ‘Cavendish’ grown in open fields. Each point represents the mean value from a sample of 75 leaves (25 plants $\times$ 3 leaves per plant). Solid lines represent the predicted values on a CLL scale.

or diffuse colonies on the underside of the leaves, making assessment of severity challenging (19). Hence, field estimation of strawberry powdery mildew severity is time consuming and requires well-trained personnel, which may limit the adoption of integrated management programs that require information on disease levels in fields (5). The estimation of disease severity from the incidence level should facilitate powdery mildew quantification considerably because it is easier to assess incidence than severity.

The main objective of this study was to establish a reliable statistical model describing the incidence–severity relationship of

strawberry powdery mildew. The approach used was to transform both the incidence data and the severity data. The complementary log-log (20,24) transformation was found to be the most suitable transformation method. A highly significant relationship between powdery mildew incidence and severity was observed for all data sets. Regardless of the variation in severity at high incidence values, the model based on the CLL transformation of incidence and severity data provided a good fit for all data sets, explaining between 82 and 96% of the variation in severity on a CLL scale. The squared correlations (R^2) between observed and predicted severity

Fig. 5. Relationship between incidence and severity of strawberry powdery mildew for **A**, **C**, and **E**, untransformed and **B**, **D**, and **F**, complementary log-log (CLL)-transformed data for the June-bearing **A** and **B**, 'Chambly'; **C** and **D**, 'Darselect'; and **E** and **F**, 'Jewel' grown in plastic tunnels. Each point represents the mean value from a sample of 75 leaves (25 plants $\times$ 3 leaves per plant). Solid lines represent the predicted values on a CLL scale.

Fig. 6. Relationship between incidence and severity of strawberry powdery mildew for **A** and **C**, untransformed and **B** and **D**, complementary log-log (CLL)-transformed for the June-bearing 'Chambly', 'Darselect', and 'Jewel' grown in **A** and **B**, open fields and **C** and **D**, plastic tunnels. Each point represents the mean value from a sample of 75 leaves (25 plants $\times$ 3 leaves per plant). Solid lines represent the predicted values on a CLL scale.

ranged from 0.84 to 0.94. Several authors who studied incidence–severity relationships for other diseases (20,24) reported that several factors, including host resistance, season, and site, may influence this relationship. In this study, the influence of cultivars grown in open fields, cultivar types (June-bearing versus day-neutral), production systems (open-field versus plastic-tunnel), site, and year of sampling was investigated. Overall, the site and the year of sampling did not influence the incidence–severity relationship for strawberry powdery mildew (no significant interaction with the slope parameter of the linear model relating CLL(I) to CLL(S)). Similarly, in this study, the specific cultivar used, whether Cavendish, Chambly, Darselect, or Jewel, did not influence the incidence–severity relationship. However, under open-field conditions, the cultivar type significantly influenced this relationship, as shown by the much higher slope for the linear model relating CLL(I) to CLL(S) obtained for the day-neutral Seascape (1.2674) compared with the June-bearing cultivars (0.9182). Seascape is generally considered to be highly susceptible to powdery mildew, whereas the other cultivars are considered to be moderately susceptible (4,22,23). This may explain why, for a given incidence, higher severity was observed for Seascape. For example, at an incidence level of 0.5 (50% of leaves diseased), the predicted severity for a June-bearing cultivar was 15.4% while the predicted severity for the day-neutral Seascape was 25.3%. Similarly, the production system significantly influenced the I–S relationship. When the June-bearing Chambly, Darselect, and Jewel were grown

in open fields, the slope of the CLL(I)–CLL(S) model was 0.9358, compared with 1.002 when the same cultivars were grown in plastic tunnels. At an incidence of 0.5, the predicted severity was 16.4% for the cultivars grown in open fields and 26.6% for the same cultivars grown in large tunnels.

In addition to the practical applications that can be developed from incidence–severity relationships, knowledge of the functional relationship between incidence and severity is important, because it improves understanding of the epidemiology of the disease. In this study, for example, the I–S relationship was investigated in three June-bearing cultivars (Chambly, Darselect, and Jewel) grown in open fields or in plastic tunnels. Under open-field conditions, severity increased with increasing incidence at a lower rate than when these cultivars were grown in plastic tunnels (Fig. 6), as shown by maximum severity values of 38.97 and 62.03% for open fields and plastic tunnels, respectively. These results suggest that the conditions in plastic tunnels favor auto-infection, which is reflected in increased severity for the same level of incidence rather than disease spread expressed by increased incidence for the same level of severity. Spore dispersal and strawberry powdery mildew gradients were studied in plastic tunnels and glasshouses in France (31). The authors reported that spore dispersal occurred mainly within 1.20 m from the source and that spore dispersal was much greater in plastic tunnels than in glasshouses, most likely due to the higher wind speed in tunnels compared with glasshouses. In the present study, wind speed was not measured but it is reasonable to

Table 2. Summary of the regression analyses of the relationship between complementary log-log transformation of strawberry powdery mildew incidence and severity of strawberry powdery mildew caused by *Podosphaera aphanis*

Cultivar ^b	Obs ^c	Statistics ^a					
		β_0 (se)	β_1 (se) ^d	R^2_{adj}	MSE	F value	R^{*2}
Open fields							
‘Cavendish’	250	-2.4307 (0.0207)	0.9064* (0.0271)	0.818	0.1043	1,118.10	0.844
‘Chambly’	334	-2.1903 (0.0272)	0.9330* (0.0205)	0.862	0.2364	2,074.09	0.894
‘Darselect’	321	-2.1312 (0.0235)	0.9522* (0.0134)	0.940	0.1402	5,044.98	0.942
‘Jewel’	276	-2.2363 (0.0287)	0.9194* (0.0181)	0.904	0.1842	2,580.51	0.934
‘Seascape’	427	-1.8661 (0.0259)	1.2674* (0.0164)	0.916	0.2876	4,627.76	0.836
Plastic tunnels							
Chambly	204	-1.7987 (0.0249)	1.0153 (0.0153)	0.919	0.1255	2,303.55	0.914
Darselect	261	-1.5539 (0.0219)	1.0134 (0.0134)	0.956	0.1032	5,708.63	0.921
Jewel	253	-1.6806 (0.0342)	1.0112 (0.0220)	0.893	0.2467	2,111.42	0.878
Pooled data							
All	2,326	-1.9764 (0.0115)	1.0115 (0.0079)	0.874	0.2857	1,6152.9	0.872
June-bearing	1,181	-2.2449 (0.0129)	0.9182* (0.0091)	0.897	0.1803	1,0267.3	0.898
Open field	931	-2.1845 (0.0153)	0.9358* (0.0098)	0.907	0.1884	9,101.86	0.922
Plastic tunnel	718	-1.6734 (0.0163)	1.0021 (0.0109)	0.921	0.1686	8,379.71	0.906

^a Estimates of the intercept (β_0) and slope (β_1) of the regression lines, se is the standard error of the estimate, R^2_{adj} is the adjusted coefficient of determination, MSE is the mean square error, F value is the F statistic from the regression analysis of variance, and R^{*2} is the squared correlation between back-transformed observed and predicted values.

^b Factors used to group the observations. All, June-bearing, open field, and large tunnel included all observations; only observations for June-bearing cultivars grown in open field; observations for Darselect, Chambly, and Jewel grown in open field; and observations for Darselect, Chambly, and Jewel grown in large tunnel, respectively.

^c Number of observations used in the regression analysis (excluding observations with severity and incidence equal to zero).

^d Asterisks (*) indicate that the slope is significantly different from 1 based on a two-sided t test at the 0.05 confidence level.

assume that it was lower in the plastic tunnels than in the open fields, and that this favored within-plant infection (3).

Considering the influence of cultivar type and production system, three specific models were developed to predict strawberry powdery mildew severity in June-bearing cultivars grown in open fields or in plastic tunnels and for a day-neutral cultivar grown in open fields. To ensure the robustness of these predictive models, data were collected under a large range of conditions; however, field validation is likely required before these models can be used in other strawberry production areas. Nevertheless, the results show that strawberry powdery mildew severity can be estimated by counting the number of diseased leaves.

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