Pear Scab: Components of Potential Ascospore Dose and Validation of an Ascospore Maturity Model

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ABSTRACT

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Variables necessary to calculate potential ascospore dose (PAD) for *Venturia pirina*, the causal agent of pear scab, were measured: area of individual leaves averaged 20.0 cm², number of lesions per infected leaf ranged from 1.8 to 2.2, 13.5 to 41.7% of lesions were fertile (contained pseudothecia), number of pseudothecia per fertile lesion ranged from 15.2 to 24.4, and number of asci per pseudothecium averaged 131.5. The proportions of orchard floor covered with leaves (leaf litter density) were 0.34 and 0.67 for mowed and nonmowed orchards, respectively. Incidence of infected leaves ranged from 0.1 to 32.3%. Calculated PAD ranged from 1,114 to 708,320 ascospores per m² in a commercial and an unsprayed orchard, respectively. For validation of a previously published model relating ascospore maturity to degree-days with a 0°C base, a linear regression equation was developed using 11 data sets collected between 1981 and 1998. The slope of the line was not different ($P = 0.951$) from that of the original model.

Additional keyword: epidemiology

The occurrence of pear scab, caused by *Venturia pirina* Aderhold, in the western United States is closely related to meteorological conditions. The disease is present in all pear growing districts in Oregon but only in the White Salmon district in Washington (18). It occurs in the coastal areas of California but seldom in the drier interior valleys (2,15).

Ascospores from leaves on the orchard floor are the main primary inoculum (9,16); twig infections that produce primary conidial inoculum (7) have been observed infrequently (R. A. Spotts, *unpublished*). Gadoury and MacHardy (5) have developed the concept of potential ascospore dose (PAD) for *V. inaequalis*, a closely related fungus that causes apple scab, as an estimate of the amount of primary inoculum in the spring. PAD estimates are useful when comparing management strategies or control treatments in several orchards (10). In addition, PAD is the basis for developing an action threshold for initiating a fungicide program and for evaluation of sanitation in an integrated scab control program (10). Several variables are necessary to calculate PAD, and they include individual leaf area, number of lesions per infected leaf, number of

pseudothecia per lesion, number of asci per pseudothecium, leaf litter density, and incidence of infected leaves. Although some factors necessary to calculate PAD for *V. pirina* have been determined (16,17), other factors have not been measured.

Maturity of ascospores of *V. pirina* is closely related to accumulated degree-days with a base temperature of 0°C (16). Ascospore maturity for *V. pirina* in relation to degree-day accumulation lacks the initial lag observed for *V. inaequalis* (4,11). Approximately 98% of the ascospores are mature after an accumulation of 1,000 degree-days, which is usually reached in early June (16). A linear regression equation has been published relating ascospore maturity to degree-days and is based on data from 1981, 1982, and 1987 (16).

The purposes of this study with *V. pirina* were to (i) quantify all component variables necessary to calculate PAD, and (ii) provide additional validation of a previously published ascospore maturity model (16).

MATERIALS AND METHODS

PAD. Calculation of PAD was based on several factors used previously for *V. inaequalis* (5) and included individual leaf area, number of lesions per infected leaf, number of pseudothecia per lesion, number of asci per pseudothecium, leaf litter density, and incidence of infected leaves. Measurement of each of these factors is described below.

The areas of individual leaves from mature Anjou, Bartlett, and Bosc pear (*Pyrus communis* L.) trees at the Mid-Co-

lumbia Agricultural Research and Extension Center (MCAREC), Hood River, were measured in August 1998 and 1999 after terminal growth ceased and terminal leaves were fully expanded. Areas of leaves were determined with an area meter (LI-3000, Li-Cor, Inc., Lincoln, NE). The area of all leaves on five shoots per tree of five trees was measured for each cultivar in each year, and each shoot was considered a replicate.

The numbers of lesions per infected leaf, pseudothecia per lesion, and asci per pseudothecium were determined for Anjou and Bartlett leaves in 1997 and for Bartlett leaves in 1998. Leaves used in 1997 were collected at early leaf drop in October 1996 and placed between two layers of nylon mesh in the herbicide strip on the orchard floor at MCAREC. Leaves used in 1998 were allowed to naturally drop in fall 1997 and covered in February 1998 with nylon mesh. Six to 22 leaves were removed and examined at weekly (1997) or 14-day (1998) intervals from bud swell in March through mid-June. Number of lesions per infected leaf and number of pseudothecia per lesion were determined with a dissecting microscope at $\times 12$. Ascospore development was assessed in five pseudothecia per leaf with the differential count method of Gadoury and MacHardy (3) in which asci are classified as immature, mature, or empty. The percentage of asci in each maturity class was corrected for underdeveloped asci in early spring and exclusion of disintegrated asci in late spring (3). The number of asci per pseudothecium also was determined. In addition, calculations for the number of asci per pseudothecium also included data obtained by the above methods from 1981 through 1995, and yearly values for each cultivar were considered as replicates.

Leaf litter density (LLD) was determined in March 1996, February 1997, March 1998, and April 1999 in two pear orchards at the MCAREC and in four commercial orchards. Not all orchards were sampled each year. In some orchards sampled in 1996, 1998, and 1999, the orchard floor had been mowed prior to sampling. LLD was determined by a point-intercept method (13) by stretching a tape measure diagonally across the row from trunk to trunk and recording the presence or absence of a leaf every 30.5 cm. Four sets of measurements were taken in each orchard. LLD was defined as the proportion of total readings that were positive for the presence

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of leaves, i.e., the proportion of orchard floor covered with leaves. LLD values from five mowed and five nonmowed orchards were used to calculate means and standard errors and to test the effect of mowing with a two-sample *t* test. Foliar incidence of scab was assessed at the end of the primary scab season in 1996 and 1997 by counting the number of leaves with lesions among all leaves on 10 shoots per tree on three to nine replicate trees per orchard.

PAD, defined as the number of ascospores per m² of orchard floor, was calculated similarly to the method of Gadoury and MacHardy (5) in which PAD = number of infected leaves/100 leaves × 1/leaf area

in m² of 100 leaves × LLD × number of lesions/leaf × proportion of total lesions that had pseudothecia × number of pseudothecia/lesion × number of asci/pseudothecium × number of ascospores/ascus.

Validation of ascospore maturity model. Previously, we developed a linear regression model relating ascospore maturity to degree-days (16) based on data from 1981, 1982 (two locations), and 1987 and validated in 1993 (two locations). Using the methods for determination of ascospore maturity described above, development of ascospores was determined weekly in infected pear leaves in 1994 (Anjou), 1995 (Bosc), 1997 (Anjou and

Bartlett), and 1998 (Bartlett). The cumulative proportion of mature asci, corrected as described above, was used as the dependent variable. Maximum and minimum temperatures were monitored daily with mercury maximum–minimum thermometers situated 1.5 m aboveground in a standard weather shelter located 380 m from the infected leaves. Cumulative degree-days were calculated with a computer program that uses daily maximum and minimum temperatures to calculate the area under a sine curve (1). The slope of the new regression equation developed with all 11 data sets from 1981 through 1998 (SigmaPlot 5.0, SPSS Inc., Chicago, IL) was compared with the slope of the original model (16) using ANOVA procedures of SAS (SAS Institute, Cary, NC).

RESULTS

PAD. Areas of individual leaves of cultivars Anjou, Bartlett, and Bosc averaged 19.0, 17.9, and 20.1 cm², respectively, in 1998, and 19.8, 19.1, and 24.4 cm², respectively, in 1999. Cultivar differences were not significant in 1998, but area of Bosc leaves was significantly (*P* = 0.05) larger than area of Anjou and Bartlett leaves in 1999. The area of an individual leaf averaged over cultivar and year was 20.0 cm², based on 2,441 leaves.

The mean numbers of lesions per infected leaf ranged from 1.8 to 2.2, but only between 13.5 (Anjou, 1997) and 41.7% (Bartlett, 1998) of lesions were fertile (Table 1). The number of pseudothecia per fertile lesion ranged from 15.2 to 24.4 (Table 1). The number of asci per pseudothecium averaged 137, 131, and 116 for Anjou, Bartlett, and Bosc, respectively, based on 5 (two locations in 1982), 2, and 2 years of evaluation, respectively. Cultivar differences were not significant (*P* > 0.05), and the mean number of asci per pseudothecium and standard error based on 10 data sets were 131.5 ± 4.3. The mean and standard error of proportions of orchard floor covered with leaves in mowed and nonmowed orchards were 0.34 ± 0.05 and 0.67 ± 0.03, respectively, and the difference was significant (*P* = 0.0014). Incidence of infected leaves ranged from 0.1 to 32.3% (Table 2).

Several examples of PAD values were calculated using the above data (Table 2). To calculate PAD in 1997, percent leaf infection data from fall 1996, fungal development factors for spring 1997 (Table 1), and LLD for spring 1997 were used. LLD values for each specific orchard were used rather than mean values. PAD values ranged from 1,114 ascospores per m² of orchard floor for a commercial Anjou orchard in 1998 to 708,320 ascospores per m² for an unsprayed Bartlett orchard in 1997 (Table 2).

Validation of ascospore maturity model. A new linear regression equation was developed using all 11 data sets of

Table 1. Lesions per leaf, proportion of lesions fertile, and number of pseudothecia per lesion for pear leaves in 1997 and 1998

Factor	1997		1998
	Anjou	Bartlett	Bartlett
Incidence of leaf infection	9.5	9.9	19.4
Lesions per leaf	1.9	1.8	2.2
Proportion of lesions fertile	0.135	0.194	0.417
Number of pseudothecia per lesion	15.2	20.5	24.4
Number of infected leaves examined	213	341	126

Table 2. Potential ascospore dose (PAD) for *Venturia pirina* in several orchards in the Hood River Valley, Oregon

Year	Cultivar	Fungicide program	Percent leaves infected ^a	PAD
1997	Anjou	Unsprayed	32.3	481,110
1997	Anjou	Commercial	1.9	28,300
1997	Bartlett	Unsprayed	24.4	708,320
1997	Bartlett	Commercial	5.0	145,147
1998	Anjou	Commercial	0.2	1,114
1998	Anjou	Commercial	0.1	1,228

^a Determined at end of primary scab season of previous year.

Fig. 1. Maturation of ascospores of *Venturia pirina* in relation to cumulative degree-days. Regression is significant at *P* = 0.0001, *r* = 0.920. *Y* = proportion of mature asci. Eleven data sets were combined from 1981 through 1998 (solid line). Original model (dashed line) is from a previously published report (16).

ascospore maturity and degree-days (Fig. 1). The data were described with the equation

$$\ln(1/1 - Y) = 0.0745 + 0.00412X$$

where Y = proportion of mature asci and X = degree-days; $r = 0.920$, $P = 0.0001$. The slope of the new line was not significantly different ($P = 0.951$) from the previously published model that was based on four data sets (16).

DISCUSSION

In previous research on *V. pirina*, we determined some but not all factors necessary to calculate PAD (16,17). In this study, values for all factors for PAD calculation are included. The values for lesions per leaf, pseudothecia per lesion, asci per pseudothecium, and LLD are similar to those published for *V. inaequalis* (5); and calculated PAD values presented herein fall within the range of the *V. inaequalis* PAD values. Variability among cultivars and between years was small for most factors with the exception of the proportion of lesions in Bartlett leaves that contained pseudothecia. This value was 19.4% in 1997 and 41.7% in 1998. For *V. inaequalis*, this value was related to the incidence of shoot leaf infection in commercial orchards with less than 5% incidence and less than 10% fertile lesions (5). Incidence of leaf scab in Bartlett trees from which leaves were collected for the 1998 evaluation was almost twice as high (19.4 versus 9.9) as in the previous year. *V. pirina* is a heterothallic fungus (8), and high incidence of leaf scab increases the probability for pairing of the two mating types and subsequent formation of pseudothecia. However, other factors such as number of asci per pseudothecium were not affected by cultivar. Because the ascigerous stage of *V. pirina* is saprophytic, active mechanisms of resistance probably are not operative in dead leaf tissue. Ontogenic resistance in apple appeared to be lost, and pseudothecia developed when a polygenic resistant hybrid was inoculated in late season close to leaf senescence with sexually compatible strains of *V. inaequalis* (14). Additional data are necessary to examine this relationship with *V. pirina*.

LLD was significantly less in orchards where mowing was done prior to LLD evaluation. Small leaf pieces are more likely missed in the evaluation than intact leaves. In addition, smaller leaf pieces tend to decay more rapidly than intact leaves, especially when mowing is done several weeks prior to evaluation. Spring plowing reduced fruit infection by *V. pirina* (6), and composting (12) or spring shredding of leaves (19) reduced the ascospore dose of *V. inaequalis*. Previously, we reported that dolomite lime also increases apple and pear leaf decomposition and decreases ascospore dose of *V. inaequalis* and *V. pirina* (17).

The PAD in well-managed apple orchards in New England and New York typically is less than 600 and may vary from as low as 20 in an exceptionally well-controlled orchard to over one million at sites where disease control is poor (10). A PAD action threshold of 600 has been proposed for apple scab (10). No research has been done to determine a PAD action threshold for pear scab, and additional research is necessary before PAD estimates become a useful part of the management strategy for pear scab.

Addition of seven data sets to the ascospore maturity model did not significantly change the original model. The new model incorporates data from 8 years, three cultivars, and two locations. The high r^2 value (0.847) and the tight fit of data about the line add confidence to the model. It is not known if the model will prove valid for ascospore maturity outside of Oregon.

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LITERATURE CITED

1. Baskerville, G. L., and Emin, P. 1969. Rapid estimation of heat accumulation from maximum and minimum temperatures. *Ecology* 50:514-517.
2. Beardon, B. E., Moller, W. J., and Reil, W. D. 1976. Monitoring pear scab in Mendocino County. *Calif. Agric.* 30(4):16-19.

3. Gadoury, D. M., and MacHardy, W. E. 1982. Preparation and interpretation of squash mounts of pseudothecia of *Venturia inaequalis*. *Phytopathology* 72:92-95.
4. Gadoury, D. M., and MacHardy, W. E. 1982. A model to estimate the maturity of ascospores of *Venturia inaequalis*. *Phytopathology* 72:901-904.
5. Gadoury, D. M., and MacHardy, W. E. 1986. Forecasting ascospore dose of *Venturia inaequalis* in commercial apple orchards. *Phytopathology* 76:112-118.
6. Hearman, J. 1933. Control of black spot or scab of pears in Western Australia. *West. Aust. Dep. Agric. Leaflet* 380.
7. Kienholz, J. R., and Childs, L. 1937. Twig lesions as a source of early spring infection by the pear scab organism. *J. Agric. Res.* 55:667-681.
8. Langford, M. H., and Keitt, G. W. 1942. Heterothallism and variability in *Venturia pirina*. *Phytopathology* 32:357-369.
9. Latorre, B. A., Yanez, P., and Rauld, E. 1985. Factors affecting release of ascospores by the pear scab fungus (*Venturia pirina*). *Plant Dis.* 69:213-216.
10. MacHardy, W. E. 1996. Apple Scab Biology, Epidemiology, and Management. American Phytopathological Society, St. Paul, MN.
11. MacHardy, W. E., and Gadoury, D. M. 1985. Forecasting the seasonal maturation of ascospores of *Venturia inaequalis*. *Phytopathology* 75:381-385.
12. Miller, P. M., and Rich, S. 1968. Reducing spring discharge of *Venturia inaequalis* ascospores by composting overwintering leaves. *Plant Dis. Rep.* 52:728-730.
13. Mueller-Dombois, D., and Ellenberg, H. 1974. Aims and Methods of Vegetation Ecology. John Wiley & Sons, New York.
14. Olivier, J. M., and Lespinasse, Y. 1981. Evolution des recherches sur la resistance du pommier a la tavelure. II. Etude du parasite et strategies de lutte. 1er Colloque sur les Recherches Fruitières, Bordeaux, 1981. pp. 145-156.
15. Smith, R. E. 1905. Pear scab. *Univ. Calif. Agric. Exp. Stn. Bull.* 1963.
16. Spotts, R. A., and Cervantes, L. A. 1994. Factors affecting maturation and release of ascospores of *Venturia pirina* in Oregon. *Phytopathology* 84:260-264.
17. Spotts, R. A., Cervantes, L. A., and Niederholzer, F. J. A. 1997. Effect of dolomitic lime on production of asci and pseudothecia of *Venturia inaequalis* and *V. pirina*. *Plant Dis.* 81:96-98.
18. Spotts, R. A., and Covey, R. P. 1990. Survival of *Venturia inaequalis* and *V. pirina* on leaves in controlled atmosphere and air storage. *Can. J. Plant Pathol.* 12:180-182.
19. Sutton, D. K., and MacHardy, W. M. 1993. The reduction of ascospore inoculum of *Venturia inaequalis* by orchard sanitation. (Abstr.) *Phytopathology* 83:247.