Evaluation of a New York Ascospore Maturity Model for *Venturia inaequalis* in North Carolina

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Journal Series Paper 6606 of the North Carolina Agricultural Research Service, Raleigh.

Use of trade names in this publication does not imply endorsement by the N. C. Agricultural Research Service of the products named or criticism of similar ones not mentioned.

Appreciation is extended to Ray Pope for technical assistance, and to J. J. Bond, associate professor, Department of Biology, Appalachian State University, Boone, NC, for maintaining the monitoring site at Boone.

Supported in part by CSRS Project 701-15-76.

Accepted for publication 23 January 1981.

ABSTRACT

Sutton, T. B., James, J. R., and Nardacci, J. F. 1981. Evaluation of a New York ascospore maturity model for *Venturia inaequalis* in North Carolina. Phytopathology 71:1030-1032.

An apple scab ascospore maturity model developed in New York did not satisfactorily predict maturity of *Venturia inaequalis* ascospores during four seasons in North Carolina. The model predicted mature ascospores in the winter much earlier than they occurred in nature. The failure of the model under NC conditions appears to be due to certain aspects of the biology of *V. inaequalis* that were not accounted for by the model and were not noticed because of the environmental conditions in the Geneva, NY, area.

Additional key words: epidemiology, *Malus sylvestris.*

Apple scab, caused by *Venturia inaequalis* (Cke.) Wint., is one of the most serious apple diseases worldwide. Control of primary scab is critical for control through the season. This is usually achieved by three to five preventative or eradicative sprays applied preceding, during, and following bloom. Timing of these sprays to coincide with ascospore maturation is important in assuring satisfactory control. Knowledge of when ascospore discharge is complete is important in determining when the scab control program can be relaxed to a preventive maintenance level.

Ascospore maturation has been determined by observing crushed pseudothecia collected in the field (5), forceably ejecting mature spores in spore towers (1) and by spore trapping (4). All of these methods are time consuming and require specialized equipment. In 1974, Massie and Szkolnik developed a model for predicting ascospore maturity (3, and L. Massie, *personal communication*). The model, based on 17 yr of field data from Geneva, NY, predicts ascospore maturity from the date of 50% leaf fall:

$$Y = -5.75 + 3.34 \times \log_{10} (\text{accumulated degree days}) + 0.0013 \times (\text{accumulated precipitation})$$

in which Y = probit of the percent mature ascospores, degree days have a 32 F (0 C) base and precipitation is in hundredths of inches (2.54 cm; 1.00 inch entered as 100). The model satisfactorily predicted maturation in the Geneva area, but has not been fully validated. The purpose of this study was to evaluate the model under North Carolina conditions and determine its suitability for use in a pest management program in that state.

MATERIALS AND METHODS

Overwintering sites. The model was studied during the winters of 1976–1980 in orchards in Henderson County, NC, and during 1977–1980 at a site in Watauga County, NC (Boone). At orchard sites in Henderson County, temperature was measured with a recording hygrothermograph in a standard instrument shelter and rainfall with a recording top-weighing rain gauge. Data from the Asheville Airport (AV) were used as an historical base for seasonal comparisons in the Henderson County area. Orchard sites were located within 20 km of AV. The mean annual temperature and rainfall for AV are 12.8 C and 114.8 cm, respectively. Temperature at Boone was measured with a recording hygrothermograph in a standard instrument shelter and rainfall with a fence-post rain gauge. The mean annual temperature at Boone is 10.5 C and rainfall 135.1 cm.

Leaf fall in Henderson County was determined by estimating the percent defoliation on Delicious in the study orchards as well as in other nearby orchards. No leaf-fall data were taken at Boone.

Ascospore maturity. In Henderson County, ascospore maturity was studied at the Pace orchard in 1976–1977 and 1977–1978, at the Mountain Horticultural Crops Research Station (MHCRS) in 1978–1979, and at the Stepp orchard in 1979–1980. In 1976–1977, airborne ascospore catch, determined with a Burkard spore trap, was used to evaluate the model. The trap orifice was located about 45 cm from the orchard floor and the trap was adjusted to sample 10 L of air per min. In the remaining years of the study, ascospore maturity was determined by Szkolnik's method (5) and ascospore concentrations in the air were monitored with a Burkard spore trap. According to Szkolnik's method, ascospore maturity within the ascus is rated on a scale of 0–5. In this study, the sum of the percent asci in stages 4 (ascus with spores mature) and 5 (ascus empty) was used as a measure of the percent mature ascospores on each sample date. At Boone during 1977–1980, ascospore maturity was determined histologically by observing at least 50 pseudothecia on each sampling date. Leaves were fixed in FPP (45% propanol, 45% water, 5% propionic acid, 5% formaldehyde), dehydrated, embedded in paraffin, sectioned at 12 μm, and stained with a modified Connant's stain (2).

RESULTS

Seasonal environment data. During 1976–1977 at AV and 1977–1978 at AV and Boone, temperatures were 1.1–1.6 C below average for the period 1 November to 30 April (Table 1). During the 1978–1979 and 1979–1980 seasons, temperatures were about average for the same period at the two locations. The 1976–1977 season was coldest; temperatures in January were 7.3 C below

0031-949X/81/10103003/$03.00/0

average. Rainfall was above average during all periods except 1976–1977, when it was slightly below average (Table 1). Rainfall fluctuated greatly from month to month and year to year. February was the driest month in all seasons except 1978–1979. November 1977, November 1979 (at AV), January 1977 and 1978, March 1979 (at AV), March 1980 and April 1980 (at Boone) were the wettest months.

Leaf fall. Generally, leaf fall began after the first freeze in the fall and 50% leaf fall was achieved by 1 November in Henderson County. No leaf-fall data were taken in 1976, but most leaves had abscised by mid-November. In 1977, defoliation on Delicious averaged about 70% on 10 November in seven randomly selected orchards in the county. In 1978, leaf fall averaged 80% on 7 November in 15 orchards, and in 1979, leaf fall was about 78% on 9 November in 15 orchards. Based on these data, 1 and 15 November were used as representative leaf-fall dates in all years for model evaluation.

Although no leaf fall data were taken at Boone, leaf fall usually occurs about 1 wk before Henderson County. Therefore, 1 and 15 November were also used as base dates for Boone.

Ascospore maturity. In all years and at all locations, the model predicted ascospore maturity much earlier than it occurred in the orchard (Figs. 1–4). With 1 November as a base date, mature ascospores were usually predicted by mid- to late-November; with the 15 November base date, mature ascospores were usually predicted by mid-December. Mature ascospores were not observed in the orchard before mid-March. In years with November and December temperatures generally below normal, prediction of mature ascospores was delayed about a month (eg, Pace 1976–1977 [both leaf-fall dates]; Boone 1977–1978 [15 November

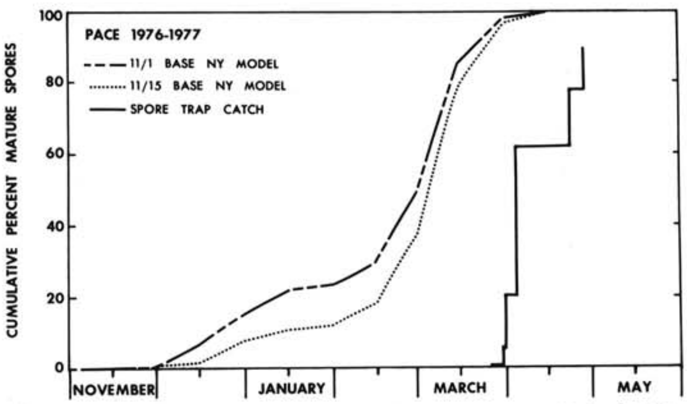

Fig. 1. Predicted maturity of ascopsores of *Venturia inaequalis* by the NY model and cumulative spore trap catch for the Pace Orchard in Henderson County, NC. Base dates for calculating maturity with the NY model were 1 and 15 November.

TABLE 1. Average temperature and rainfall for the Asheville (NC) airport, Boone (NC) and Geneva (NY) for the period November–May

	Asheville		Boone		Geneva	
Month	Temp (C)	Rain (cm)	Temp (C)	Rain (cm)	Temp (C)	Rain (cm)
November	7.55	7.49	5.56	10.26	5.00	6.65
December	4.61	9.88	1.56	9.96	−1.66	5.97
January	2.94	7.62	0.94	9.35	−3.33	5.61
February	3.61	9.25	1.50	10.82	−3.33	6.14
March	8.11	12.14	4.83	12.72	1.11	7.04
April	12.94	7.01	10.50	11.02	7.77	7.52
May	16.83	13.39	15.00	9.37	14.44	7.82

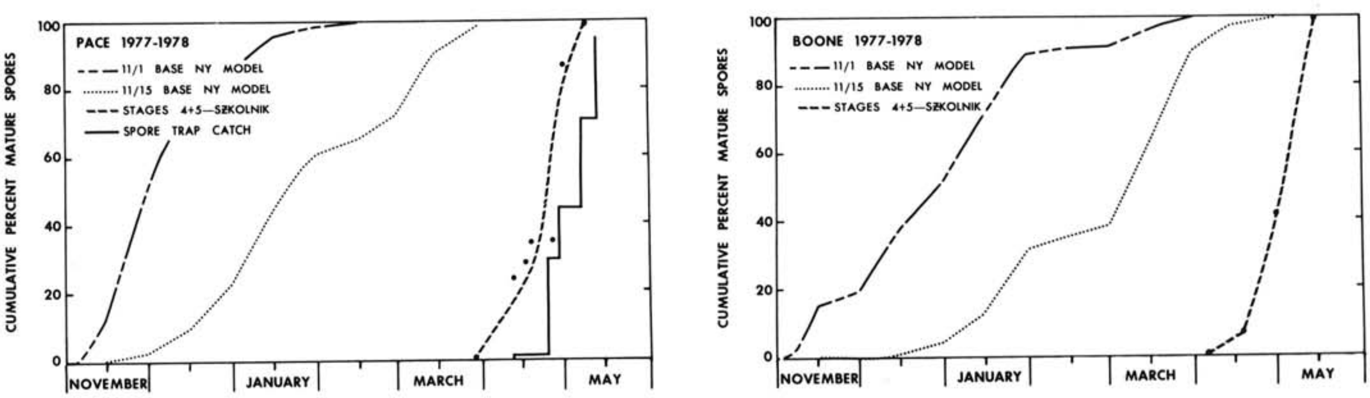

Fig. 2. Predicted maturity of *Venturia inaequalis* ascospores by the NY model, cumulative spore trap catch and percent mature ascospores (stages 4 and 5) for the Pace orchard in Henderson County, NC, and predicted ascospore maturity and percent mature ascospores (stages 4 and 5) for Boone, NC, 1977–1978. Base dates for calculating maturity with the NY model were 1 and 15 November.

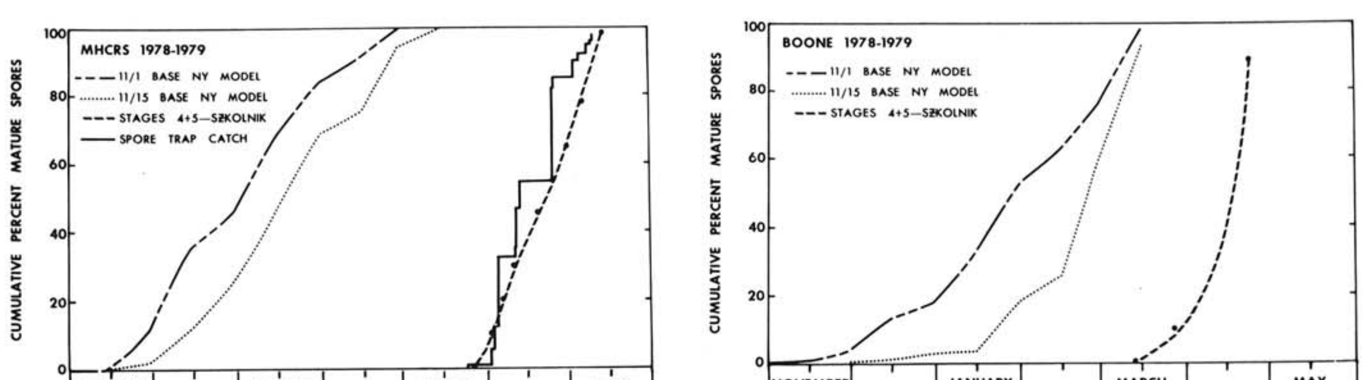

Fig. 3. Predicted ascopsore maturity, cumulative spore trap catch, and percent mature ascospores (stages 4 and 5) for the Mountain Horticultural Crops Research Station (MHCRS), Fletcher, NC; and predicted ascospore maturity, and percent mature ascospores for Boone, NC, 1978–1979. Base dates for calculating maturity with the NY model were 1 and 15 November.

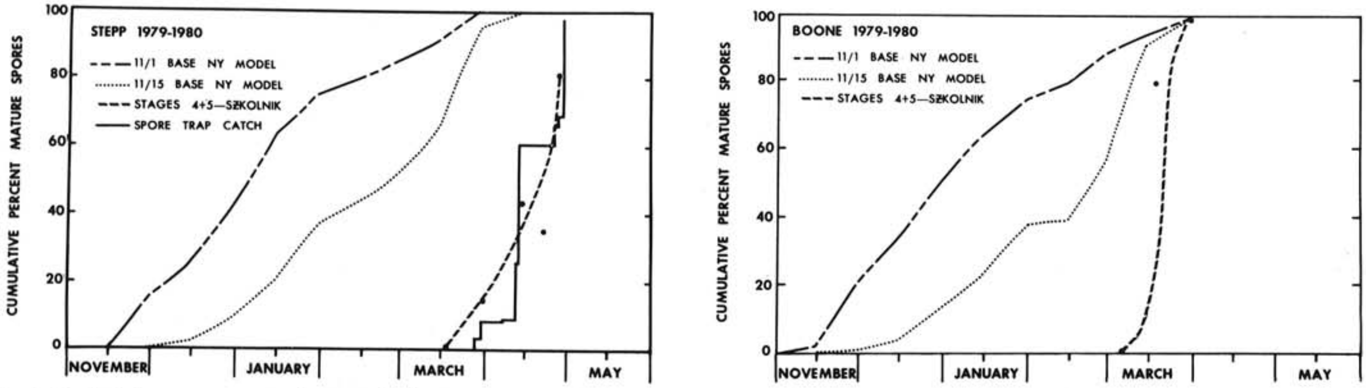

Fig. 4. Predicted ascospore maturity, cumulative spore trap catch, and percent mature ascospores (stages 4 and 5) for the Stepp orchard in Henderson County, NC; and predicted ascospore maturity, and percent mature ascospores for Boone, NC, 1979–1980. Base dates for calculating maturity with the NY model were 1 and 15 November.

leaf fall]; Boone 1978–1979 [15 November leaf fall]). In years with generally normal or above normal temperatures during November and December, mature spores were predicted by mid-November. This was most evident when the 1 November base date was used (eg, Pace 1977–1978; Boone 1977–1978; Boone 1979–1980).

DISCUSSION

The ascospore maturity model developed in NY failed to satisfactorily predict the maturity of *V. inaequalis* ascospores in NC. With 50% leaf-fall as a base, mature ascospores were predicted much earlier than they occurred in nature. This difference was consistent among seasons and between locations.

The prediction of mature spores much earlier than they occur in nature may be due to certain biological aspects of *V. inaequalis* not accounted for by the model. The model is based on the assumption that pseudothecial development is continuous after leaf fall if temperatures are above 0 C; in fact, development is discontinuous and closely tied to moisture availability (6, and J. R. James, *unpublished*). Apparently the effect of this modeling error on the prediction of ascospore maturity was masked by the environmental conditions in the Geneva area. Under Geneva conditions, average temperatures below 0 C are common during the winter (Table 1), and few degree days accumulate, thus giving the appearance that low temperature is the only factor retarding pseudothecial development. However, under NC conditions, the significance of the error becomes apparent. Temperatures between 5 and 10 C are common during the winter, degree days accumulate rapidly, and mature spores are predicted prematurely.

Because the model assumes continuous development of *V. inaequalis* from leaf fall, rainfall has an effect similar to temperature (Eq. 1). Rainfall accumulates through the season independent of temperature; thus, when temperature is below 0 C, some development is still predicted if rain occurs. Under wintertime conditions in Geneva, few degree days accumulate and accumulated rainfall alone is insufficient to result in a prediction of mature spores. However, under North Carolina conditions, accumulated rainfall functions with degree-days to accelerate the prediction of ascospore maturity. In addition, increased rainfall at North Carolina sites gives additional importance to rainfall in the model. At Geneva, rainfall for November through April averages 38.9 cm while at AV and Boone it averages 53.4 and 64.1 cm, respectively (Table 1).

Failure of the NY ascospore maturity model in NC illustrates the difficulty of developing a model from field data alone. Such models often work satisfactorily in the area in which they are developed, but because they do not reflect development over a wide range of environmental conditions, may not be universally applicable. Results of this study also demonstrate that environmentally driven models should not be used in another climatic region without evaluation in that region.

Another approach to the development of an ascospore maturity model for *V. inaequalis* is to build the model from data collected in laboratory or growth chamber studies. If these studies are conducted over a wide range of environmental conditions, the model should have broad applicability. We also feel that the model should reflect the discontinuous development that *V. inaequalis* undergoes in the orchard (6, and J. R. James, *unpublished*). We are currently in the process of developing such a model for *V. inaequalis* based on the above criteria.

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