FREQUENCY OF INFECTION PERIODS FOR *VENTURIA INAEQUALIS* IN NEW ZEALAND AND IMPLICATIONS FOR FUNGICIDE USE

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SUMMARY

Apple growing regions in New Zealand can be ranked Auckland > Nelson > Hawkes Bay > Canterbury, for expected frequency of infection periods for black spot (*Venturia inaequalis*) during the primary infection season (1 September and 31 December). In all regions, monitoring of infection periods could improve disease management through better timing of eradicant sprays. In Auckland and Nelson there is little scope to deviate from the standard programme of 7-10 day applications of protectant fungicides, because the expected interval between infection periods is less than 7-10 days. In Canterbury and Hawkes Bay, where infection periods are less frequent, there may be scope to increase the interval between protectant fungicide applications when periods of fine weather are forecast.

INTRODUCTION

The use of meteorological criteria to identify periods suitable for infection by *Venturia inaequalis* (Cke.) Wint. (apple black spot) was pioneered by Mills in New York State between the 1920's and 1950's (Mills and Laplante 1954). Mills' principles for improving the efficiency of black spot control involve applying fungicides with eradicant activity after a period of high infection risk has been monitored. These principles have been applied in many apple producing regions of the world (MacHardy and Gadoury 1989). Methods used to monitor infection periods have ranged from subjective visual assessments of leaf wetness to the use of electronic instruments (Jones *et al* 1984).

In New Zealand, Mills criteria were used during the 1970's and 1980's in conjunction with fungicide efficacy trials on DSIR Research Orchards to improve spray programmes for black spot control (Brook unpubl.; Pennycook 1983). A formal monitoring system developed from this work in the Nelson region, and information on the occurrence of "Mills periods" was disseminated by newspaper and radio (D. Cassidy pers. comm.). From 1986-1988 the New Zealand Meteorological Service and DSIR developed a weather forecasting and monitoring service for black spot, first in Nelson, and then Hawkes Bay (Anon. 1988). Trials were also run in Auckland and Canterbury. Information gathered in 1987 and 1988 was used in this study to assess the potential for using weather information to manage fungicide applications for black spot control in different apple growing regions in New Zealand.

MATERIALS AND METHODS

This study concerns weather associated with infection by ascospores of *V. inaequalis* (primary infection), and not subsequent secondary infection by conidia. The primary infection season was considered to run from 1 September to 31 December, encompassing the period when most ascospores mature (Brook 1976). The season was divided into two 61 day parts, Early (1 September to 31 October), and Late (1 November to 31 December). The Early part included the onset of infection to the time of peak ascospore release (Brook 1966), as well as bud burst, flowering and petal fall in

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most apple cultivars. The Late part included the period of declining ascospore numbers and early fruit development.

Infection criteria

Mills' infection criteria use duration of surface wetness and mean air temperature during the wet period to define thresholds for "light", "moderate", and "heavy" infection risk (Mills and Laplante 1954). We fitted exponential functions to their data:

$$\text{wetness duration for "light"} = 9.0 + 103 \times 0.735^t \text{ hours}$$

$$\text{wetness duration for "moderate"} = 12.4 + 137 \times 0.735^t \text{ hours}$$

$$\text{wetness duration for "heavy"} = 19.1 + 202 \times 0.735^t \text{ hours}$$

Where t = mean temperature during the wet period. The relationships are shown graphically in Fig. 1.

Fig. 1: Wetness duration and temperature thresholds for "light", "moderate", and "heavy" infection risk, as defined by Mills and Laplante (1954). See text for equations describing the curves.

In this study, only the "light" infection threshold was used. Infection periods began only during daylight, as few ascospores are released at night (Brook 1969). Wet periods were considered continuous if they were interrupted for no more than 4 hours.

Mills' infection criteria, and others for *V. inaequalis* (MacHardy and Gadoury 1989), identify periods when weather conditions are particularly suitable for infection and there is a high risk of a black spot epidemic beginning. This paper follows the practice of referring to these as "infection periods" (MacHardy and Gadoury 1989). It is, however, recognised that infection criteria of this type only indicate a general relative risk of disease, and that other factors which affect epidemics, such as microclimate within leaf canopies, inoculum and cultivar susceptibility, are not considered.

Monitoring procedures

For regional comparison, infection periods were monitored in four apple growing regions: Auckland (site 1) in 1987, and Hawkes Bay (sites 2a and 2b), Nelson (sites 3a and 3b), and Canterbury (sites 4a and 4b) in 1987 and 1988. Local variation in the occurrence of infection periods at five sites around Christchurch was monitored in 1987 and 1988 (4a-4f). Four of the five sites were the same in both years.

The sites, monitoring equipment used and who recorded the information are shown in Table 1. Infection periods were determined from hourly records. Regional sites used either thermohygrographs or wet and dry bulb thermometers (hygrometers) housed in Stevenson screens 1.3 m above ground level. For these, wet periods started at the onset of daytime rain, and continued while relative humidity (RH) was greater than 90% (Preece and Smith 1961).

The electrical resistance wetness sensors at sites 4c-4f were unpainted, of the type described by Davis and Hughes (1970). They were exposed horizontally 1.3 m above ground level, except site 4c which was at 0.25 m. They were considered wet when the voltage across the sensor was greater than the median value between the wet and dry voltages.

TABLE 1: Sites at which black spot infection periods were monitored in 1987 and 1988 (sites 1 and 4e, 1987 only; site 4f, 1988 only).

Site	Monitoring Method	Source of information
1 Whenuapai Airport	Hygrometer, raingauge	N.Z. Met. Service
2a Napier Airport	Hygrometer, raingauge	N.Z. Met. Service
2b Havelock North	Thermohygrograph, raingauge	DSIR, Dvn Hort. & Proc.
3a Nelson Airport	Hygrometer, raingauge	N.Z. Met. Service
3b Appleby	Thermohygrograph, raingauge	DSIR, Dvn Hort. & Proc.
4a Christchurch Airport	Hygrometer, raingauge	N.Z. Met. Service
4b Broadfield, Lincoln	Thermohygrograph, raingauge	DSIR, Crop Research Dvn
4c DSIR, Lincoln	Electrical wet. sensor	DSIR, Entomology Dvn
4d Lincoln Orchards	Electrical wet. sensor	DSIR, Plant Diseases Dvn
4e Styx Mill Orchards	Electrical wet. sensor	DSIR, Plant Diseases Dvn
4f Lincoln College	Electrical wet. sensor	DSIR, Plant Diseases Dvn

RESULTS

Regional monitoring

In 1987, Auckland had the most infection periods, followed by Nelson; Hawkes Bay and Canterbury had similar numbers (Table 2). In 1988, Auckland was not recorded; Nelson had the most infection periods; Hawkes Bay and Canterbury again had similar numbers. An approximate method was used to estimate the numbers of infection periods for each site and year in relation to rainfall and mean temperature data. For all seven sites, the total number of infection periods was regressed on rainfall (mm), and mean air temperatures (°C). This was done using Early and Late parts of the primary infection season, giving 26 data points, or using the whole season, giving 13 data points. Both simple and multiple linear regressions were performed, with rainfall and temperature as independent variables. In all regressions, rainfall gave significant regression coefficients, but temperature did not. The best prediction equation used the

TABLE 2: Numbers of black spot infection periods for Early and Late parts of the primary infection season in 1987 and 1988.

	Auckland 1	Hawkes Bay 2a 2b	Nelson 3a 3b	Canterbury 4a 4b
1987 Early	14	1 1	5 4	2 3
1987 Late	8	3 8	8 7	7 5
Total	22	4 9	13 11	9 8
1988 Early	—	0 0	17 14	1 3
1988 Late	—	5 5	8 8	6 5
Total	—	5 5	25 22	7 8

Early = 1 September to 31 October

Late = 1 November to 31 December

whole primary infection season; it was fitted through the origin, had a highly significant regression coefficient and explained 50% of site variation in numbers of infection periods:

$$\text{Number of infection periods} = 0.044 \times \text{rainfall} \quad (1)$$

Thirty-year normals for rainfall for each site were used with equation (1) to determine long term expectations for numbers of infection periods. Table 3 shows that the regression exercise ranked Auckland > Nelson > Hawkes Bay > Canterbury for expected numbers of infection periods. Although this method was only approximate, its predictions are reflected in the 10-year averages for sites 2a, 3a and 4a (Table 3).

Local monitoring around Christchurch

Numbers of infection periods varied among sites (Table 4). Sites using electrical wetness sensors (4c-4f) recorded more infection periods than those using RH methods in 1987, although in 1988, the difference was less marked. Site 4c recorded a number of infection periods which did not occur anywhere else. This was because the wetness sensor was low to the ground, exposing it to longer periods of surface wetness.

At every site in both years, fewer infection periods were recorded in the Early half of the season than in the Late half. This was because of low temperatures during wet periods in the Early part, rather than because of short wetness durations. At low temperatures (< c. 8 °C), the risk of infection is affected greatly by small changes in temperature, whereas at higher temperatures (> c. 12 °C), it is affected more by small changes in wetness duration (Fig. 1).

TABLE 3: Thirty-year rainfall normals, expected numbers of black spot infection periods, expected intervals between infection periods, and actual infection periods (10-year average) for the whole primary infection season.

	Auckland 1	Hawkes Bay 2a 2b	Nelson 3a 3b	Canterbury 4a 4b
Rainfall	413	259 227	312 300	184 215
Expected infection periods	18	11 10	14 13	8 9
Days between infection periods	6.7	10.7 12.2	8.9 9.2	15.1 12.8
Actual infection periods		9.5	18.0	8 . 4

TABLE 4: Numbers of black spot infection periods recorded at five sites in the Christchurch area in 1987 and 1988.

	4a	4b	Christchurch 4c 4d	4e	4f
1987 Early	2	3	6 3	2	—
1987 Late	7	5	9 11	14	—
Total	9	8	15 14	16	—
1988 Early	1	3	4 2	—	3
1988 Late	6	5	7 5	—	6
Total	7	8	11 7	—	9

Early = 1 September to 31 October

Late = 1 November to 31 December

DISCUSSION

Data presented in this paper deal with weather monitoring to identify regional differences in the occurrence of black spot infection periods. The findings are now used to generalize about the use of both monitored and forecast weather information for managing fungicide applications.

Monitored weather and fungicide application management

Monitored infection periods are of use in timing eradicant fungicides more effectively. The success of this approach will depend on the quality of the monitored information, the eradicant properties of the fungicide ("reach back period"), and how quickly growers can spray orchards after infection periods.

Electrical wetness sensors record wet periods more accurately than do methods using relative humidity. The type of wetness sensor and positioning are important. For monitoring wetness on a regional basis it is not appropriate to place the sensor within an apple canopy, as wetness duration will be influenced more by the peculiarities of the chosen canopy than by the larger scale factors which are of interest.

Monitoring around Christchurch showed that infection periods local to a given site can make up a significant proportion of the number recorded at that site. Regions with large topographical variation will show more local variability, but this is likely to be explainable. The number of infection periods at a given site will result from regional climatic factors, local microclimatic (topographical) factors, and random variation. The effects of the leaf canopy microclimate on the occurrence of infection periods will depend on tree age, the growth stage within a season and on tree training and pruning methods.

Forecast weather and fungicide application management

Forecast weather information can be used in two ways; either to forecast infection periods, and apply protectant fungicides in advance (positive forecasting), or to forecast intervals when no infection periods will occur (negative forecasting), and extend the time between fungicide applications. The usefulness of positive forecasts will depend entirely upon their accuracy. The usefulness of negative forecasts will depend on there being long intervals when infection is unlikely to occur as well as on their accurate prediction. If the expected interval between infection periods is greater than the 7-10 days between fungicide applications in the standard spray programme, then there may be scope to delay applications when weather forecasts predict no infection periods. Prediction of nil infection periods with a high degree of certainty appears to be possible (Anon. 1988).

The New Zealand Meteorological Service has experience in forecasting infection periods for up to 5 days in advance in the apple growing regions in this study. Generally, positive forecasts have not been accurate enough to allow growers to make spray timing decisions. In a replicated fungicide trial, Manktelow *et al* (1989) found that reliance on protectant fungicides applied according to forecast infection periods did not prevent infection.

In Auckland and Nelson, infection periods can be expected at less than 10 day intervals, and there is probably little scope to deviate from the standard programme. In Canterbury and possibly Hawkes Bay, however, where infection periods are less frequent, there may be scope to increase the interval between protectant fungicide applications when periods of fine weather are forecast. This would offer a flexible approach to fungicide management in these areas, which would save sprays in seasons with few infection periods.

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