Blossom Blight Epidemiology

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Apple producers in New York have been plagued by fire blight for 200 years. The disease was first recognized as a problem in the late 1700's in the Hudson Valley. Fire blight, caused by the bacterium *Erwinia amylovora*, affects many rosaceous plants although the impact is greatest on apple and pear. Fire blight does not occur consistently each year; one year there might be no disease, the next year severe disease, and the following year mild disease. The sporadic nature of the disease depends on the weather during a particular season. For instance, warm weather and rain need to occur at just the right time for apple blossoms to become infected. Fire blight epidemics have become more frequent and severe over the last few decades because of the switch to new high quality, but very susceptible varieties. Use of susceptible dwarfing rootstocks, especially M.9, in modern high-density orchards makes the situation even worse. Considerable economic hardship from tree loss and subsequent orchard rehabilitation is a result of fire blight epidemics. Recovering from these unforeseen costs is especially difficult now that other input costs have increased dramatically. These factors have renewed the interest of researchers to understand how fire blight epidemics are caused, and how the relationship between the bacterium and the apple affects epidemics with greater detail.

"The two most commonly used blossom blight forecasters, *MARYBLYT* and *Cougarblight*, have had a successful prediction rate of 60-70%. To improve blossom blight forecasts, whether from *MARYBLYT, Cougarblight* or another system, a better understanding of the epidemiology of blossom blight is needed. From our work it is clear that the spread and multiplication of *E. amylovora* is strongly affected by temperature and blossom age. The effect of cultivar is not as influential as temperature and blossom age but is not negligible. Our studies show that the blossom blight forecasting systems can be substantially improved with a better understanding of epidemiology."

There are several distinct phases of fire blight: canker blight, blossom blight, shoot blight, trauma blight and rootstock blight. These phases contribute to making fire blight difficult to manage or predict because they act like separate diseases that are related to one another. This phenomenon has presented some difficulty for researchers because what is learned about how one phase of the disease works is not always applicable to another. Currently, the phase that is most effectively controlled is blossom blight. The most effective control of blossom blight is the application of preventive antibiotic sprays in the spring in combination with a blossom blight forecaster to time applications most effectively and not wastefully. Blossom blight control is essential to reduce the number of bacteria present in the orchard that can contribute to epidemics later in the season. Blossom blight infections can also lead directly to rootstock blight, which directly causes tree death. Because blossom blight control is critical to slow the late season phases of fire blight, it is important to have accurate forecasts of the blossom infection periods so that infection periods are not missed and there are no unnecessary antibiotic applications.

Blossom blight does not occur every year because several events need to happen in combination for infection to take place. Blossoms cannot be colonized by *E. amylovora* when they are closed, so if all of the conditions are otherwise favorable for a blossom blight outbreak, it will not happen because the bacteria will not reach the stigma surface. The exact source of bacteria in the very early spring has never been conclusively identified but there is good evidence that small cankers with difficult-to-see borders are an important source. It is likely that the bacteria are moved from the cankers to the stigma surface of the blossom by insects, such as flies, beetles or ants that are attracted by sugar sources. Bees are not involved in the initial movement of *E. amylovora* to blossoms but are effective at moving bacteria from one blossom to the next during pollination. Once on the stigma surface, *E. amylovora* needs to establish

a colony and multiply exponentially to a high population. Curiously, *E. amylovora* does not cause disease when on the stigma surface. In fact if nothing further occurs, the blossom would proceed to petal fall with no ill effects. All of the events described above, from the opening of the flowers to the multiplication of *E. amylovora* are temperature dependent. The ambient air temperature greatly affects the speed at which each process takes place. The final event that is necessary for blossom blight is a rain event or heavy dew. The rain or dew wets the surfaces of the blossoms so that the bacteria are able to travel from the stigma to the floral cup where the nectaries are located. It is through the nectaries that *E. amylovora* actually enters the blossom and causes an infection. The bacteria are unable to multiply in the floral cup and it is thought that this is because the sugar concentrations are too high for them to survive. The rain may also dilute the nectar, allowing the bacteria to survive and enter the blossom to cause the infection. Blossom blight is a very unusual disease because the part of the blossom where *E. amylovora* populations multiply is separate from where the infection takes place. It also means that the environmental factors that allow *E. amylovora* to multiply and spread may be different from those needed for an infection, but this must still be confirmed.

Blossom Blight Forecasting Models

Two blossom blight forecasting systems are commonly used in the U.S. apple industry: *MARYBLYT* and *Cougarblight*. *MARYBLYT* historically has been most commonly used in the northeastern states of the USA but the use of *Cougarblight*, developed in Washington State, is becoming more widespread in the Northeast. The forecasting systems have tried to account for the effect of temperature and rainfall in their predictions of infection. To determine how well the two forecast systems really perform, their forecast accuracy was compared by analyzing historical data from British Columbia, England, Michigan, New York, Québec, Vermont, Washington State and West Virginia spanning the period from 1976 to 2002. The data were looked at as a whole and then split into geographic regions and cultivar susceptibility groups. The geographic regions were Eastern North America, England, and west coast North America and the cultivars were grouped as moderately susceptible and very susceptible. The overall accuracy of *MARYBLYT* and *Cougarblight* were equivalent, and both forecasters successfully predicted blossom blight infections 60-70% of the time. When accuracy of the forecasters was determined, both the number of correct infection predictions and the correct non-infection predictions were important. It is as important to know when an infection is not occurring as when one is occurring. Over-prediction leads to the expense of unnecessary antibiotic applications and could potentially lead to antibiotic resistance. The forecasting systems performed equally in the geographic regions of the east and west coasts of North America and on moderately susceptible cultivars. *Cougarblight* was significantly more accurate ($p < 0.05$) than *MARYBLYT* in England but *MARYBLYT* was significantly more accurate than *Cougarblight* with the very susceptible cultivars. Although the two forecasting systems were equally accurate overall, they did not always correctly predict the same infection periods. Ideally, to minimize the limitations of both forecasting systems, *MARYBLYT* and *Cougarblight* should be used together to insure that all infection periods are predicted.

Plant disease epidemiology is the study of factors, such as weather or characteristics of the host plant, that contribute to or influence the beginning, development, and spread of plant diseases. One of the reasons to study epidemiology is to be able to better predict when an infection event or the beginning of an epidemic occurs. As stated above, the predictions of blossom blight infection events by both *MARYBLYT* and *Cougarblight* were accurate 60-70% of the

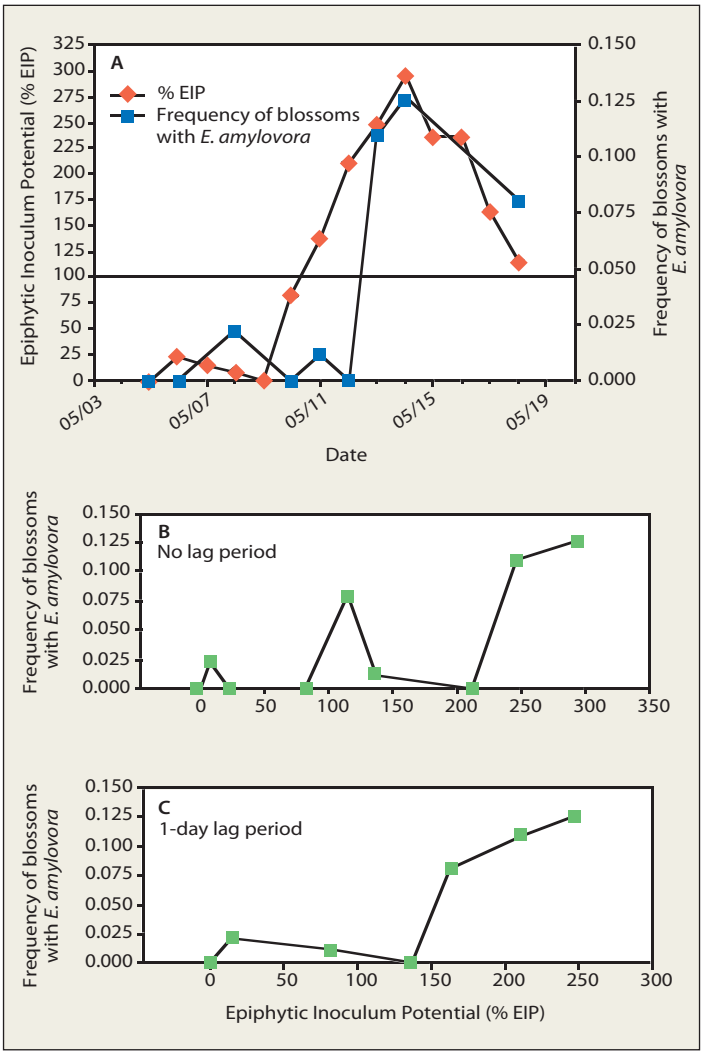

Figure 1. The epiphytic inoculum potential (% EIP) and frequency of blossoms with *E. amylovora* on the surface in 2004. A. EIP and frequency of blossoms with *E. amylovora* by date showing the delay between EIP and frequency. The solid line is the threshold level for EIP. B. Frequency of blossoms with *E. amylovora* plotted as a function of EIP without a lag period. C. Frequency of blossoms with *E. amylovora* plotted as a function of EIP with a 1-lag period which improves the relationship between the two variables.

time. While this accuracy rate is certainly better than flipping a coin to decide whether a blossom infection is likely to occur, there is clearly room to improve forecasts. The work outlined in this article was aimed to understand the epidemiology of blossom blight so that improvements can eventually be made in blossom blight forecasting. Since the accuracy of the two blossom blight forecasters was statistically equivalent, it was decided to concentrate on *MARYBLYT*, the most commonly used forecaster in the Northeast United States. In the current version of *MARYBLYT*, blossom infection is predicted to be imminent when the minimum values of all four of the following thresholds occur: 1) Open blossoms with stigmas and petals intact; 2) Epiphytic inoculum potential (EIP) ≥ 100%, which is 110 degree-hours (198 DH) at base 18.3°C (65°F) accumulated in the last 44.4 degree-days (80 DD) at base 4.4°C (40°F); 3) Precipitation event of either dew, ≥ 0.25mm (0.01 inch) on the current day, or previous day rainfall (≥ 2.5mm; 0.10 inch); and 4) Mean daily temperature ≥ 15.6°C (60°F). One of the results from the analysis of forecaster accuracy was that the EIP threshold, an estimate based on temperature of how many *E. amylovora* cells may be present in an orchard, was not working as effectively as possible. An initial investigation of how well the EIP was performing in relation to how many bacteria were found on blossoms in an orchard was undertaken. Blossoms were sampled for the presence of the *E. amylovora* over three years. In 2004, it was found that the EIP correctly predicted how frequently blossoms had *E. amylovora* on their surface 68% of the time. When EIP and the frequency of blossoms with *E. amylovora*

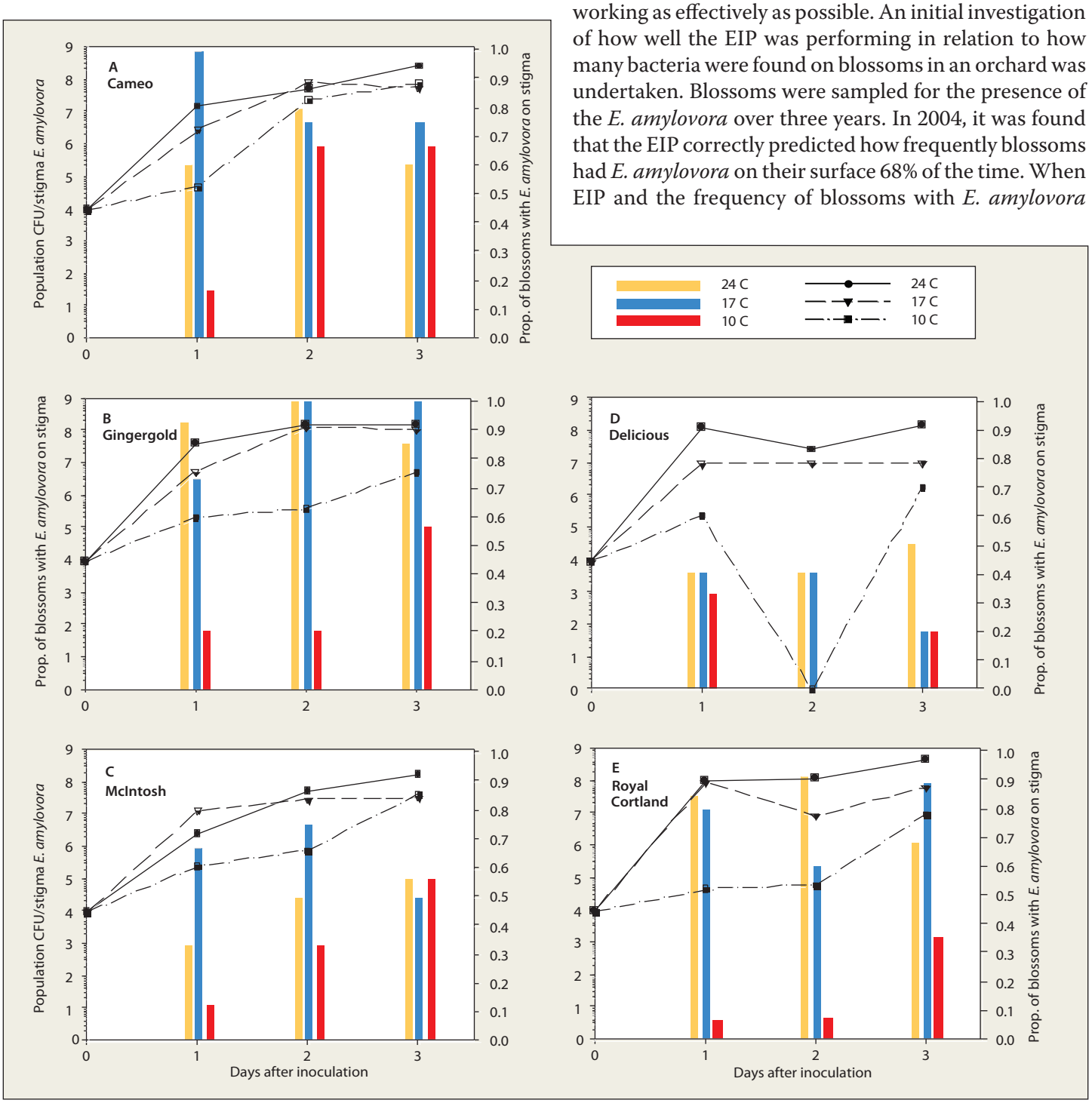

Figure 2. The population of *Erwinia amylovora* per stigma (lines) and proportion of samples with *E. amylovora* (bars) by day after inoculation for the cultivars A. Cameo B. Gingergold C. McIntosh D. Delicious and E. Royal Cortland.

were plotted by date, it was noted that the EIP curve peaked ahead of the curve of the frequency of blossoms with *E. amylovora* (Figure 1A). The fact that the EIP curve was ahead of the blossoms with *E. amylovora* curve suggested that the EIP could be improved by using the previous day's EIP forecast to predict the current day's frequency of blossoms with *E. amylovora*, otherwise known as a "lag period". When a one-day lag period was added to the EIP, 78% of the predictions of the EIP were correct, resulting in a 10% improvement (Fig. 1B,C). Unfortunately we were not able to confirm these results in either 2005 or 2006,because the cool weather in both those years did not allow for spread of *E. amylovora* in the orchard.

Another feature of the EIP calculation is a cool weather adjustment. The *MARYBLYT* program reduces the EIP by a third, then a half and finally to zero with each passing day that the maximum daily temperature is below 17.8°C (64°F), except if the EIP is above 200 and then there is no adjustment. This particular feature of the EIP seemed to be arbitrary. There was little evidence about this subject in the literature to help decide if the cool weather adjustment was appropriate. In fact, the growth of *E. amylovora* on blossom stigma surfaces at cool temperatures had never been fully determined. We studied the effects of cool temperatures on *E. amylovora* multiplication on the stigma surface of several cultivars over three days. As expected

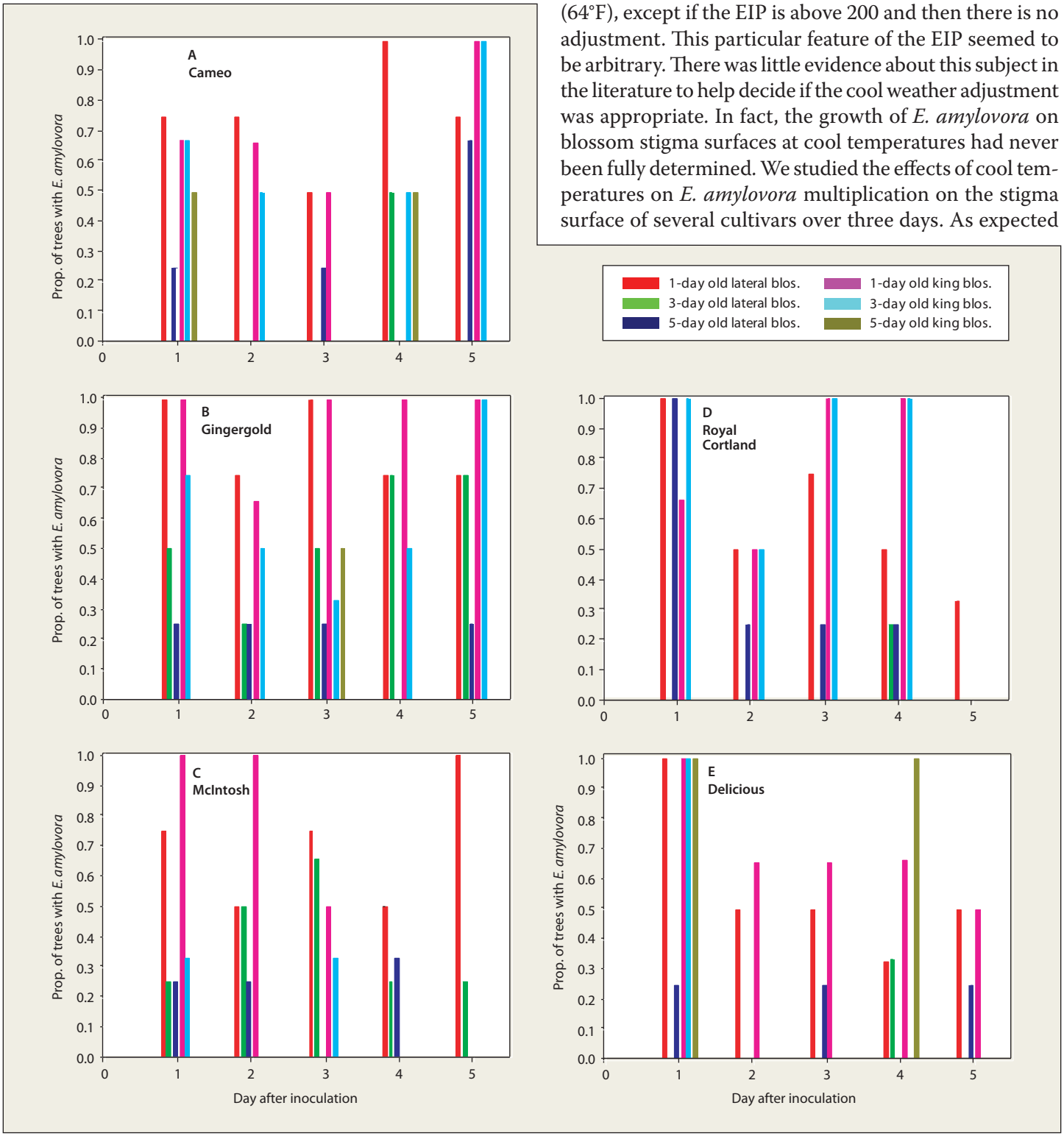

Figure 3. The proportion of trees with *Erwinia amylovora* by day after inoculation for lateral and king blossoms of each age (1-day, 3-days and 5-days old) for A. Cameo, B. Gingergold, C. McIntosh, D. Delicious and E. Royal Cortland.

we found that temperature was very important for the multiplication of *E. amylovora*. At the warmer temperatures of 25 and 18°C (77 and 64.4°F), multiplication of *E. amylovora* was rapid, reaching high levels the first day.

The population of *E. amylovora* was lower the first day at 18°C (64.4°F) than at 25°C (77°F) but reached comparable levels by the second and third days. The number of blossoms with stigmas with *E. amylovora* present was comparable for 25 and 18°C (77 and 64.4°F). At the low temperature of 11°C (51.8°F), it was less certain what we would find, as the assumption had been that *E. amylovora* would either slowly die or become inactive. In fact this was not always the case. Instead, we found that at 11°C (51.8°F), the population of *E. amylovora* dropped close to or below the level of detection on the day after inoculation, but by the second and third day the populations slowly rose (Figure 2). However, at the cool temperature there were fewer stigmas with detectable numbers of *E. amylovora* cells than at the warm temperature on each day that was sampled after inoculation. To sum it all up, at cool temperatures (approx. 10°C; 50°F), *E. amylovora* multiplied at a slower rate and on fewer blossoms than at warmer temperatures (Figure 2).

There was no information about whether the apple cultivar had a role in how well *E. amylovora* survived on the stigma of blossoms. We wanted to determine if the susceptibility of the cultivar to fire blight affected survival of *E. amylovora* on the blossom surface. Five cultivars of varying susceptibility were chosen. In order of susceptibility from high to low, they were Gingergold, Royal Cortland, McIntosh and (Red) Delicious. We also studied Cameo, which had never been experimentally tested for fire blight susceptibility, so was an unknown. Subsequently anecdotal reports have described Cameo as moderately susceptible. We showed that cultivar had a minimal effect on the population of *E. amylovora* but the number of blossoms with *E. amylovora* was affected (Figure 2). Gingergold had the most blossoms colonized, followed by Royal Cortland and Cameo. McIntosh and Delicious were the least likely to have *E. amylovora* on the stigma.

From the data presented here and the conclusions from other factors in the study of the effect of cool temperatures on *E. amylovora*, the three day reduction of EIP at temperatures below 17.8°C (64°F) does not seem warranted. A less drastic reduction of the EIP over a longer period of time is likely to better reflect the epidemiology of *E. amylovora*. Colonization appears to be the rate limiting step in the spread of *E. amylovora* through an orchard, so greater attention to this aspect of fire blight epidemiology is necessary.

A final area of interest was whether blossoms of different ages were equally able to support the growth of *E. amylovora*. This question is important because blossoms age in groups. If the majority of blossoms in an orchard are older and less susceptible by the time conditions for rapid spread of *E. amylovora* and blossom blight infection occur, then the risk of a major epidemic would be reduced. There was already good evidence that as blossoms aged they were less able to support high populations of *E. amylovora*, but no evidence about whether it was more difficult for the bacterium to become established and if there was a difference between king and lateral blossoms as well as cultivars. Our results agreed with previous studies; the populations of *E. amylovora* were much higher on young, newly opened blossoms than blossoms that were three or five days old when inoculated. We also showed for the first time that the newly opened blossoms were also better able to support the establishment of *E. amylovora* on the stigmas (Figure 3). When a blossom was king or lateral, there was no difference in the number of bacteria on a stigma or whether *E. amylovora* became established on a stigma. The same cultivars were used as in the experiment above and we had very similar results. Cultivar did not affect the population levels but it did affect the number of blossoms with *E. amylovora* on the stigma surface. In this experiment, Gingergold had far more blossoms with *E. amylovora* than any other cultivar and the other cultivars had comparable numbers. In conclusion, blossom age had an effect on the population and the number of blossoms with *E. amylovora*, but blossom position did not. Cultivar was important for the establishment of *E. amylovora* on the stigma surface, but not for the ultimate population size.

Conclusions

Blossom blight epidemiology is important for a better understanding of the processes that influence infection periods. We have shown that the two most commonly used blossom blight forecasters, *MARYBLYT* and *Cougarblight,* could be substantially improved. To improve blossom blight forecasts, whether from *MARYBLYT*, *Cougarblight* or another system, a better understanding of the epidemiology of blossom blight is needed. From our work and the work of others, it is clear that the spread and multiplication of *E. amylovora* is strongly affected by temperature and blossom age. The effect of cultivar is not as influential as temperature and blossom age but is not negligible. The studies in this work are the first to look at establishment of *E. amylovora* on the apple stigma. It is hoped that future work on blossom blight epidemiology will explore how other factors such as humidity, precipitation or inoculum dose influence establishment as well as population. Further research into how to best change blossom blight forecasters to reflect the new findings in blossom blight epidemiology is still needed so that apple growers will have better tools to predict when an infection period is likely.

Megan Dewdney is a former graduate student at Cornell University with Herb Aldwinckle. She is currently an assistant professor at the University of Florida. Herb Aldwinckle is a professor of plant pathology who leads Cornell's program on apple genetic engineering and the control of fire blight.