

**Final Report**

19 August 2009

**Northeast Regional IPM Competitive Grants Program**

**"Using MARYBLYT to Manage Economic Risks of Fire Blight"**

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States involved: New York  
West Virginia

Grant #: 2004-41530-01858

Year grant was awarded: 2004

Length of Grant: 3 years  
No-cost extension to 06/30/2008 by Michael Fitzner, 06/13/2007

Funding amount: \$177,513

## **B. Nontechnical Summary**

Fire blight, caused by the bacterium *Erwinia amylovora*, is one of the most destructive and difficult-to-control diseases of apple. In recent years, consumer and market demands have forced major changes in horticultural practices that have resulted in an overall increase in orchard risk for infection. These horticultural changes have not only increased the potential incidence of infection but also the level of damage likely to occur. Fire blight can be controlled to manageable levels in most years with the antibiotic streptomycin. Streptomycin is highly effective at controlling disease when applied at the appropriate timings. In the Northeast, this is frequently achieved through the use of the forecaster MARYBLYT, a computer program for forecasting fire blight that predicts the four distinct types of infection events (i.e., blossom, shoot, canker, and trauma blight) as well as the appearance of symptoms that follow.

Blossom blight is the most destructive phase of the disease, providing inoculum for the shoot, root, and trauma blight phases. Consequently, management practices focus on controlling this phase. MARYBLYT monitors four risk factors to identify possible infection events: 1) blossom development; 2) epiphytic inoculum potential (EIP, an estimate of the pathogen population); 3) moisture in the form of rainfall or dew; and 4) average daily temperature. We are currently revising MARYBLYT to calculate a system of 'risk points' as function of the MARYBLYT risk factors. This will incorporate greater flexibility in the model and allow management thresholds to be selected based on the accumulation of 'risk points' that can be tailored to factors such as variety, inoculum pressure, and the users comfort for assuming risk. Ideally, however, management thresholds should be tied to a crop or economic loss function.

Receiver Operator Characteristic (ROC) curve analysis can be used to achieve this goal. ROC analysis is a graphical approach for comparing and selection of "competing" forecasters. ROC curve is a summary of the performance of a forecaster in terms of its 'sensitivity' and 'specificity' over the complete range of its output values. The 'sensitivity' is the ability of forecaster to predict disease when disease occurs; the 'specificity' is the ability of a forecaster to predict the absence of disease when disease does not occur. ROC curve analysis not only facilitates model selection, but the ROC curve itself provides a means for risk management.

The costs of correctly managing disease, the expected losses based on mismanagement, and a means to estimate disease prevalence are required. The objectives of this research are to: 1) Develop a spreadsheet to calculate the costs of disease management and the projected losses over the orchard recovery or reestablishment period under different risk scenarios; and 2) Develop a prevalence model for estimating inoculum pressure. Fulfillment of both objectives will provide the necessary information to optimize threshold selection in MARYBLYT or any other forecaster for which an ROC curve has been developed. In addition, completion of the first objective will provide a tool to assist growers in deciding whether trees in blocks affected by fire blight should be pruned or replaced.

## **C. Introduction**

With the increased level of interest in high-density orchards the economics of fire blight management are quickly becoming a driving factor in apple production (Bonn and van der Zwet, 2000; White, 2000). In an era when the Northeastern apple industry is struggling to compete, epidemics such as those that occurred in 1991 and 2000 are economically crippling to growers adapting to the changes of the industry. Add to this the fact that over the last 20 years spray expense per bearing acre is the fastest growing component of total farm costs next to labor in the Northeast (White, 2000). Growers must be able to make informed choices when managing fire blight. This means: (1) having a clear understanding of which blocks are at the greatest risk for damage when environmental conditions favor the development of fire blight; and (2) understanding how to select and order susceptible blocks for treatment so that the risk of economic loss is minimized; that is which blocks get sprayed first, which get sprayed last.

ROC analysis can be used to achieve this goal. The ROC curve is a summary of the performance of a forecaster in terms of its ‘sensitivity’ and ‘specificity’ over the complete range of its output values. The ‘sensitivity’ is the ability of forecaster to predict disease when disease occurs; the ‘specificity’ is the ability of a forecaster to predict the absence of disease when disease does not occur. ROC curve analysis not only facilitates model selection (as used above), but the ROC curve itself provides a means for risk management. The ROC curve can be described in a functional form (i.e., an equation) for any forecaster; this forms the basis for the selection of optimal economic thresholds for disease management. Specifically, it is possible to integrate a cost function that can summarize the costs of correctly and incorrectly managing disease into the function characterizing the ROC curve. Entomologists have long argued that management thresholds should be tied to a crop damage function or an economic indicator (Pedigo et al, 1986). It is interesting to note that neither MARYBLYT, nor any other forecaster, considers the potential economic losses as criteria for deciding whether a spray is warranted or not. This research represents a fundamental step forward showing how the economics of disease management can be integrated with disease forecasting and represents a realization of “precision agriculture.” The MARYBLYT disease forecasting system not only provides us with a “model system”, but results from this research has the potential to significantly alter how one of the most destructive diseases of apple is managed.

#### **D. Objectives**

The ROC curve can be used to select thresholds that minimize the average costs associated with each of the four possible outcomes when management decisions are based on forecasts. This requires as input: a) the costs of correctly managing disease and the expected losses based on mismanagement; and b) an estimate of disease prevalence.

The objectives of this research are to:

- 1) Develop a spreadsheet to calculate the costs of disease management and the projected losses over the orchard reestablishment period under different risk scenarios.
- 2) Develop a prevalence model for estimating inoculum pressure.

Fulfillment of both objectives will provide the necessary information to optimize threshold selection in MARYBLYT or any other forecaster for which an ROC curve has been developed. In addition, completion of the first objective will provide growers with a tool to assist them in deciding whether trees in blocks affected by fire blight should be pruned or replaced.

## **E. Approach**

### ***Objective 1) Develop a spreadsheet to calculate the costs of disease management and the projected losses over the orchard reestablishment period under different risk scenarios.***

Alison M. DeMarree recently developed a comprehensive, apple budgeting workbook in Microsoft Excel for growers to calculate the costs of apple production. Budgeting is an essential component of apple production and an accurate budget allows growers to determine if an investment in apples will be profitable by considering production, market, and economic factors. The workbook provides projections for growers to see at what point they will reach the break even-point on their initial investment. The budgeting workbook does not explicitly account for damage or losses due to fire blight, which can have a substantial impact on the economics of production. However, using this workbook, it is possible to determine the economic losses due to fire blight based on past expenses and loss of future expected earnings during the replant period.

We will add to the current budgeting workbook a summary page (i.e., worksheet) that will account for the expected losses due to fire blight under different loss scenarios. We will develop the worksheet to consider the costs under the following conditions: 1) all affected trees are replaced (a likely scenario where highly susceptible variety is grafted onto a susceptible rootstock); 2) infections are pruned from affected trees; 3) various combinations of replacement and pruning. Calculation of these costs must consider the replacement costs (material, maintenance, and labor) and lower yield from the proportion of replanted trees, the reduction in fruiting capacity from pruned trees, and a projection of crop value.

### ***Objective 2) Develop a prevalence model for estimating inoculum pressure.***

The principal sources of primary inoculum are the margins of cankers formed in the previous growing season; however, little attention has been given to the detection of primary inoculum in and on cankers. Researchers generally are in agreement that the pathogen causes two types of cankers, determinate and indeterminate. Such indeterminate type cankers are thought to be the major contributors of primary inoculum in the spring, via ooze production and extension of cankers in healthy tissues (Beer, 1979; Beer and Norelli, 1977; Steiner and Lightner, 1992; van der Zwet, 1969) In a study on the etiology of canker type, Beer and Norelli (1977) found that indeterminate cankers tended to form later in the growing season, and in higher frequency on susceptible cultivars. In a more detailed study of canker formation by Biggs (1994), three apple cultivars varying in susceptibility to *Erwinia amylovora* were inoculated at biweekly intervals during the growing season. There was a significant interaction of cultivar with inoculation date, indicating cultivars that are more susceptible to the pathogen are more likely to

develop cankers with indeterminate margins. Cankers initiated earlier in the season were more likely to be determinate, suggesting that later season infections on susceptible cultivars carry over inoculum to the following season. Better understanding of over wintering cankers could help researchers and extension personnel to more precisely estimate disease pressure at the beginning of the new growing season.

To determine the interaction of cultivar and date of infection, we propose to inoculate several cultivars of varying susceptibility with several isolates of varying virulence. To our knowledge, the interaction of pathogen virulence and host resistance upon over wintering efficiency has never been examined. The cultivars selected for this experiment will include 'Jonathan' (susceptible), 'Cortland' (moderately susceptible), and 'Red Delicious' (resistant) (van der Zwet and Keil, 1979). Inoculation dates will occur twice monthly beginning at about 6 cm shoot growth (mid-May) and continuing until no infections occur from inoculations made at later dates (late July or mid-August). Current-year's shoots will be selected at each inoculation date and then will be inoculated with a hypodermic needle on the shoot apex just below the second leaf with a  $1 \times 10^8$  colony-forming units/ml of WV strain # 581. Four shoots on each of four trees per cultivar will be inoculated on each of the approximately eight dates (32 trees total per cultivar). The number of leaves on four non-inoculated shoots per tree will be determined at the time of inoculation to assess the growth stage of the trees. Canker length will be monitored biweekly during season through 30 August, and then again in December. Canker margins will be rated visually in April the following year, on a scale of 1 to 4, with 1= severe cracking with well-defined margins (determinate), 2 = moderate cracking with moderately defined margins (mostly determinate), 3 = little visible cracking with poorly defined margins (mostly indeterminate), and 4 = no visible cracking and margins not defined (indeterminate) (Beer and Norelli, 1977). Data on mean canker length will be tested with analysis of variance using a full factorial design. Data on canker margin rating will be converted to frequency (arcsin-transformed percent) and analyzed with a general linear models procedure. Season trends in canker margin characteristics and the presence of associations among the various observations will be analyzed with linear regression and correlation analysis, respectively. Beginning prior to bud break, cankers will be sampled nondestructively for the presence of external *E. amylovora*. Cankers will be sampled periodically to determine their onset of activity in relation to the cultivar, inoculation date, and over wintering canker type. These data, among with estimates for fire blight incidence taken near the end of the growing season, should help to establish a most reliable estimate of early season disease pressure and improve fire blight prediction with the existing models.

## **F. Progress**

### **Objective #1**

An Excel computer spreadsheet workbook has been developed and revised to analyze the effects of various fire blight treatment regimes on various apple scion and rootstock combinations on the overall profitability of an orchard for a given period of time.

### **Objective #2**

The experiment was initiated in May 2005, at the West Virginia Univ. Kearneysville TFREC. The three cultivars selected for this experiment were 'Rome Beauty' (susceptible) on M.111 rootstock, 'Golden Delicious' (moderately susceptible) on M.111 rootstock, and 'Redchief (Campbell) Delicious'(resistant) on M.7 rootstock. Inoculation dates were 22 June, 24 July and 24 August, 2005; and 20 June, 22 July and 22 August, 2006. Current-year's shoots were selected and tagged at each inoculation date and then were inoculated with a hypodermic needle on the shoot apex just below the second leaf. Inoculations utilized  $1 \times 10^8$  colony-forming units of WV strain #581/ml (from K. Yoder, Virginia Tech, Winchester AREC, Winchester, Va.). Ten shoots on each of three trees per cultivar were inoculated on each of the three dates (9 trees total per cultivar) in each year of the study. The number of leaves on four noninoculated shoots per tree was determined at the time of inoculation to assess the growth stage of the trees. Canker length was monitored biweekly during the season through 30 Aug., and then in December. Canker margins were rated visually in Dec. 2005 and 2006, on a scale of 1 to 4, with 1 = severe cracking with well-defined margins (determinate), 2 = moderate cracking with moderately defined margins (mostly determinate), 3 = little visible cracking with poorly defined margins (mostly indeterminate), and 4 = no visible cracking and margins not defined (indeterminate).

Presence of *E. amylovora* on overwintering cankers was determined by using a subset of cankers on each of three sample dates. The first sample date was determined using the Maryblyt computer predictive model for fire blight at the value CMS = 100 (Steiner and Lightner, 1991). The next two samples were taken at 2 weeks and 4 weeks after CMS = 100. None of the cankers were sampled more than once. The presence of *E. amylovora* was determined by swabbing the surfaces of cankers with sterile rayon balls adequately moistened with sterile distilled water, and then streaking the rayon balls onto CCT medium. *E. amylovora* was identified by its typical appearance and isolates recovered in this manner had their pathogenicity confirmed on detached green apples.

Data were analyzed with analysis of variance using a full factorial design. Data on canker margin rating were converted to frequency (arcsin-transformed percent) and analyzed with a general linear models procedure for unequal sample numbers (PROC GLM, SAS Institute, 1987). Seasonal trends in canker margin characteristics and the presence of associations among the various observations were analyzed with linear regression and correlation analysis, respectively (SAS Institute, version 9).

## **G. Results**

### **Objective #1**

The workbook template allows researchers, extension educators and growers to input their actual yield changes and costs of treatment programs and tree replacement resulting from tree mortality. The user can also change tree density and overhead expenses.

Several scenarios are currently being developed for processing apple orchards and fresh apple orchards. Factors which effect the profitability include; tree density, variety, rootstock susceptibility to fire blight (causing tree death and cost of replanting), antibiotic treatment during bloom, hand labor costs in cutting out fire blight strikes, yield reduction due to infection, etc.

## Objective #2

Analysis of the canker margin ratings resulting from inoculations made on three dates revealed a significant cultivar x date interaction. Incidence of cankers was low on the cultivar 'Red Delicious' relative to the other two cultivars, and fewer cankers developed on 'Golden Delicious' when compared with 'Rome Beauty' (Table 1). It should be noted that these experiments were conducted under near-drought conditions. In a previous study, 'Red Delicious' exhibited uniformly determinate canker ratings from inoculations made at different times during the season and 'Golden Delicious' and 'Rome Beauty' exhibited cankers with increasingly indeterminate margins as inoculations were made later in the growing season (Biggs, 1994). This pattern of canker margin development was not generally observed in the present study, with the exception of 'Rome Beauty', the cultivar regarded as most highly susceptible to *E. amylovora*. Based on canker incidence and canker margin appearance, 'Rome Beauty' was the most susceptible cultivar, followed by 'Golden Delicious', and 'Red Delicious', which was almost completely resistant. Cultivar differences in mean canker rating were significant ( $P \leq 0.05$ ). The trend to form increasingly indeterminate cankers was linear for 'Rome Beauty', based on regression of the mean canker ratings against inoculation date (regression parameters significant at  $P \leq 0.05$ ). For 'Red Delicious' and 'Golden Delicious', the slope of the linear regression was not significantly different from 0 ( $P \leq 0.05$ ).

These results generally confirm those of Beer and Norelli (1977), who found that inoculation of young, nursery-grown trees in midseason (July) produced cankers with determinate margins, whereas those inoculated later in the season (September) produced cankers with indeterminate margins. They recovered *E. amylovora* from intact canker margin surfaces in 15% of the 130 cankers examined. The bacterium was recovered more frequently from cankers with indeterminate margins than from those with determinate margins. In the present study, recovery of *E. amylovora* was infrequent (6.7%) and limited to cankers initiated in July and August, but not in June.

**Table 1. Percent infection, subsequent margin rating of established cankers, and percent recovery of *Erwinia amylovora*.**

	Red Delicious			Golden Delicious			Rome Beauty		
	% I <sup>y</sup>	Margin rating <sup>z</sup>	Ea % <sup>w</sup>	% I <sup>y</sup>	Margin rating <sup>z</sup>	Ea% <sup>w</sup>	% I <sup>y</sup>	Margin rating <sup>z</sup>	Ea % <sup>w</sup>
2005									
22 Jun	3.3 a <sup>x</sup>	1.0	0.0	53.3 b	2.0 a	0.0 a	100.0 a	2.0 a	0.0 a
24 Jul	0.0 a	---	---	83.3 a	2.0 a	6.7 a	96.7 a	2.2 a	6.7 a
24 Aug	0.0 a	---	---	50.0 b	2.0 a	6.7 a	90.0 a	2.2 a	6.7 a
2006									
20 Jun	0.0 a	---	---	50.0 a	2.0 a	0.0 a	90.0 a	2.2 a	0.0 a
22 Jul	0.0 a	---	---	46.7 a	2.0 a	0.0 a	90.0 a	2.3 a	6.7 a
22 Aug	0.0 a	---	---	50.0 a	2.0 a	0.0 a	73.3 b	2.4 a	0.0 a

<sup>z</sup> Cankers rated on the basis of canker margin appearance in Apr. 2006 and 2007, on a scale of 1 to 4: 1 = severe cracking with well-defined margins, 2 = moderate cracking with moderately defined margins, 3 = little visible cracking with poorly defined margins, and 4 = no visible cracking and margins not defined.

<sup>y</sup> Percent infection calculated from the proportion of 30 inoculations per cultivar on each of the three dates in each year.

<sup>x</sup> Mean separation in columns by Waller-Duncan's k-ratio t-test ( $P \leq 0.05$ ).

<sup>w</sup> Percent recovery of *Erwinia amylovora* on CCT medium. Cankers were assessed beginning at Maryblyt CMS = 100 and then two additional times at two-week intervals.

The ability of the host to form periderm as a natural defense mechanism may be the reason why most cankers become determinate and the pathogen inactive. However, there are reports of pathogen isolation from determinate cankers (Beer and Norelli, 1977). Environmental conditions, such as high humidity and warm weather, and the ability of the plant to absorb soil moisture seem to enhance periderm formation by speeding the rate at which the barrier is produced and ultimately completed (Biggs, 1992). In addition, some workers have suggested that the degree of cultivar resistance may play an important role in wound boundary formation, which affects biochemical qualities of periderms (Biggs, 1992). More research is necessary to determine if apple, like peach, shows variation in the rate of this healing process by cultivar and if there is a correlation between periderm formation and field resistance, or between periderm quality and cultural practices known to affect resistance (i.e., fertilization, irrigation). If such correlations exist, it may be helpful in evaluating cultivar resistance in breeding programs. Furthermore, such information may be useful to more fully understand canker-forming diseases,

such as fire blight, by providing greater insight as to why some pathogens are not fully sequestered and are, therefore, capable of overwintering in cankers.

## References

- Beer, S. V. 1979. Fire blight inoculum: sources and dissemination. EPPO Bulletin 9(1):13-25.
- Beer, S. V. and Norelli, J. L. 1977. Fire blight epidemiology: factors affecting release of *Erwinia amylovora* by cankers. 1977. Phytopathology 67:1119-1125.
- Biggs, A.R. 1992. Anatomical and physiological responses of bark tissues to mechanical injury. In: Defense Mechanisms of Woody Plants Against Fungi. Blanchette, R.A. and A.R. Biggs, Eds. Springer-Verlag (Berlin) pp. 13-40.
- Biggs, A. R. 1994. Characteristics of fire blight cankers following shoot inoculations of three apple cultivars. HortScience 29:795-797.
- Bonn, W.G. and van der Zwet, T. 2000. Distribution and economic importance of fire blight in: Fire Blight: the disease and its causative agent, *Erwinia amylovora*, Ed. Joël L. Vanneste, CABI Publishing, Oxon, UK, 370p.
- Brooks, A. N. 1926. Studies on the epidemiology and control of fire blight of apple. Phytopathology 16:665-696.
- Hockenhull, J. 1974. Some anatomical and pathological features of healthy and diseased hawthorn (*Crataegus monogyna*) naturally infected by the fire blight pathogen *Erwinia amylovora*. Royal Veterinary and Agricultural University Yearbook. Copenhagen, Denmark. pp 125-136.
- Miller, P. W. 1929. Studies of fire blight of apple in Wisconsin. J. Agr. Res. 39:579-621.
- Pedigo, L.P., Hutchins, S.H. and Higley, L.G. 1986. Economic injury levels in theory and practice. Ann Rev Entomology 31:341-368.
- Pierstorff, A. L. 1931. Studies on the fire blight organism, *Bacillus amylovorus*. N.Y. (Cornell) Agr. Expt. Sta. Mem. 136, 53 pp.
- Rosen, H. R. 1929. The life history of the fire blight pathogen, *Bacillus amylovorus*, as related to the means of overwintering and dissemination. Ark. Agr. Expt. Sta. Bul. 244, 96 pp.
- Sackett, W. G. 1911. Hold-over blight in the pear. Colo. Agr. Expt. Sta. Bull. 177, 8 pp.
- Schouten, H. J. 1992. Pathological anatomy of fire blight caused by *Erwinia amylovora*. In: Cytology, histology and histochemistry of fruit tree diseases. A. R. Biggs (Ed.). CRC Press, Boca Raton, pp. 157-168.
- Steiner, P. W. and Lightner, G. W. 1991. Maryblyt™ :A predictive program for forecasting fire blight disease in apple and pear. The University of Maryland, College Park, MD.
- van der Zwet, T. 1969. Study of fire blight cankers and associated bacteria in pear. Phytopathology 59:607-613.
- van der Zwet, T., and Keil, H. L. 1979. Fire blight: a bacterial disease of Rosaceous plants. Agr. Handbook #510, USDA. Science and Education Administration, Washington, D.C.
- White, G.B. 2000. Trends in apple marketing and impacts on NY growers' profitability. NY Fruit Quarterly 8(2):7-12.

## H. Impact

## ***1. Safeguarding human health and the environment***

### **a) New IPM practices**

The implementation of the findings under this project, together with other recent findings on the infection of apple flowers by fire blight, must be incorporated in a comprehensive revision of the MARYBLYT forecasting program, which will then be used for IPM of fire blight in the Northeast. All apple orchards in the Northeast would potentially be impacted, with 40,000 acres in New York state alone.

### **b) Reduced risk**

The more efficient use of antibiotics with a revised MARYBLYT forecasting program would likely result in fewer applications and improved control of the fire blight disease.

### **c) Impact on human health and environment**

Reduced use of antibiotics for fire blight management lessens the probability of development of resistant strains of environmental bacteria and there the risk of transfer of resistances genes to other pathogens. Thus the improved forecasting program would have good potential for beneficial impact on human health and the environment.

## ***2. Economic benefits***

### **a) For clientele adopting improved IPM strategy**

More efficient use of control materials would result in reduced cost to apple growers. It would also result in reduced loss of the apple crop and trees due to fire blight infection. Thus growers could potentially benefit from use of improved IPM strategy for fire blight management by hundreds of dollars per acre, depending on the weather conditions that year.

It is likely that an improved MARYBLYT program would be implemented broadly in New York and other states by Cooperative Extension and private consultants.

### **b) IPM personnel**

An improved MARYBLYT program would be implemented by IPM personnel, but would probably not result in employment of additional personnel.

### **c) Client satisfaction**

Current IPM programs for fire blight management have some deficiencies that may result in losses and unnecessarily increased costs to apple growers. Improvements in such programs will likely result in increased satisfaction of growers.

### **d) Other financial benefits**

The reduced costs of control and reduced losses of crop and trees are the principal benefits of the project. There are also potential environmental benefits that are difficult to quantify.

## ***3. Implementation of IPM***

**a) IPM strategies validated**

This project did not include on-farm trials or large plot tests of IPM strategies. The fire blight budgeting worksheet simulates field trials and indicated significant benefits of improved fire blight management strategies.

**b) Educational materials**

The fire blight budgeting worksheet is in the hands of Cooperative Extension (A. DeMarree) and will be used in future educational materials.

**c) Personnel trained**

Training of growers and personnel in use of the fire blight budgeting worksheet will occur when its use has been further refined.

**d) Website**

The project's outcomes will be presented through the Tree Fruit and Berry Pathology Site (<http://www.nysaes.cornell.edu/pp/extension/tfabp/index.html>) sponsored by Cornell University College of Agriculture and Life Sciences, New York State Agricultural Experiment Station, and Cornell Cooperative Extension.

**e) Adoption of new IPM practices**

The practical use of the fire blight budgeting worksheet and the development of a revised MARYBLYT forecasting program are in the pre-adoption phases. Both are expected to impact large numbers of apple growers in New York and other northeastern states in the near term future.

**f) Other impact on IPM strategies**

The outcomes of the project will be refined, and then presented at local and regional meetings for growers in the Northeast.