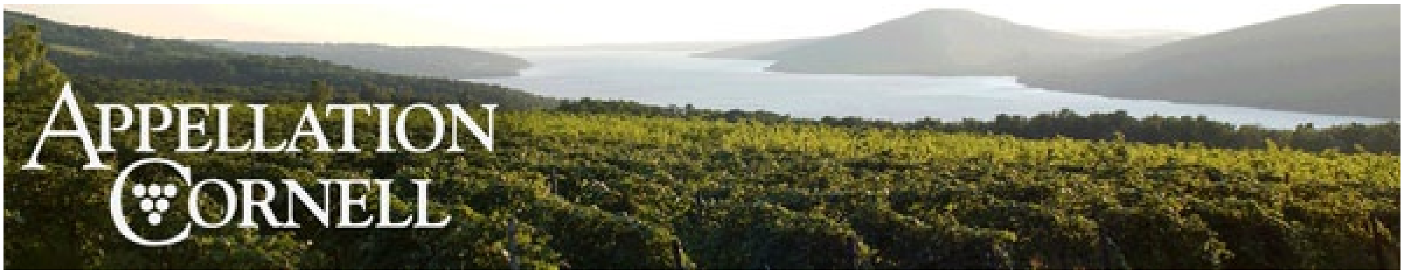


Research News from Cornell's Viticulture and Enology Program Research Focus 2013-2

RESEARCH FOCUS

Focus on Females Provides New Insights for Grape Berry Moth Management

Michael Saunders[1] , Rufus Isaacs[2] and Greg Loeb[3]

[1]Dept. of Entomology, Pennsylvania State University, University Park, Pennsylvania [2]Dept of Entomology, Michigan State University, East Lansing, Michigan [3]Dept. of Entomology, Cornell University, New York State Agricultural Experiment Station, Geneva, NY

Photos by Tim Weigle (top) and Mike Saunders (bottom)

Since the grape berry moth (GBM) sex pheromone was identified in the late 1960s, pheromone lures and traps (top) have been an important tool for research and management. However, because they solely attract males, they provide only an indirect measure of when female GBM are active and laying eggs. Studies using passive malaise traps (bottom) have enabled us to track female GBM activity directly and provided new insights on the timing of egg-laying and larval development. These will provide more precise, temperature-driven models to predict GBM activity in vineyards, which is increasingly important as older broad-spectrum organophosphate and carbamate contact insecticides are replaced with new narrow-spectrum insecticides which are only effective if they contact eggs or are ingested by larvae.

KEY CONCEPTS

- Grape berry moth larvae feed inside berries, so effective control depends upon targeting eggs and larvae before they start feeding internally.
- Pheromone lures to monitor moths are of limited value in predicting egg laying and timing for insecticide applications.
- Current recommendations using calendar date applications often miss the 'window' for the 2nd and 3rd brood egg laying and larval development in warmer or cooler than average years.
- Accurate timing is more important with many newer insecticides that have replaced broad-spectrum organophosphate and carbamate insecticides.
- By trapping females, we were able to validate a temperature-driven degree-day model to predict the timing of GBM generations (810 growing degree-days/generation).
- Timing of egg laying for the first generation is closely linked to bloom in wild grapevines.
- Growers can use wild grape 'bloom date' and growing degree day models to time insecticide applications targeted at mid-summer and later GBM generations.
- Short day length after August 4th induces eggs laid after that date to stop development at the pupal stage for overwintering.
- Early and hot summers before the diapause cutoff lead to an additional generation and high late-season populations of GBM larvae, often persisting until harvest.
- Additional insecticide applications may be needed to limit damage in warmer than average years.

Introduction. The grape berry moth (*Paralobesia viteana*; GBM) is the most severe insect pest of grapes in the eastern United States. A member of the Tortricidae family of leafrolling moths, GBM undergo multiple generations per year, and during warm growing seasons they can occur in very damaging numbers at harvest.

Effective control of GBM requires precise information about the timing of egg laying and larval development. Until recently, it was unclear how many generations GBM complete in a single season, how long it takes for a GBM egg to develop to an adult, how temperature affects these processes, and how and when diapause is initiated.

Life Cycle. GBM overwinter as pupae (**Figure 2**), which emerge from diapause as adults in the spring to mate and lay single eggs onto the outside of grapes. After hatching, the young GBM larvae chew their way into the grape berry, often feeding in multiple berries to complete development. Pupation typically occurs outside the grape berry, under flaps of bark or in the soil litter; rarely one will see a pupa in a rolled leaf edge as is characteristic of most Tortricid moths. After pupation, the adult stage emerges, mates, and lays eggs to establish the next generation of GBM. At some point late in the summer, GBM will stop development at the pupal stage and, rather than complete development to the adult stage, will enter a resting stage (diapause) to survive through the winter.

Life Cycle of the Grape Berry Moth

Figure 2. GBM overwinter as pupae (bottom row), which emerge as adults in the spring (top left) and lay single eggs on grapes (top middle). GBM larvae (top right) feed inside the grape berry, often requiring multiple berries to complete development.

Economic Injury. GBM larvae cause direct damage to berries through feeding and indirectly by creating sites for pathogens like *Botrytis* bunch rot to develop (**Figure 3**). Direct yield loss is modest, unless the infestation is heavy.

Photos by J. Ogrodnick (l) and G. Loeb (r)

***Figure 3.** At left, Concord cluster with multiple berries showing damage from GBM larvae and characteristic webbing within the cluster. Right, Chardonnay cluster with Botrytis bunch rot.*

Recent research in Michigan demonstrated a one ton/acre yield loss by GBM infestation associated with 50% of clusters infested with GBM (Roubos et al 2013). However, much lower infestation levels (in the range of 15% cluster infestation) will cause rejection of grape loads by major juice processors, who inspect grape deliveries for GBM. Increased incidence of fruit rots associated with GBM can also lead to unacceptable levels of off-flavors in wine.

Monitoring tools. The male sex pheromone, identified in the 1970s, promised a means of population control through the mating disruption technique (see Dennehy et al. 1991). When lures were used in wing traps (see photo, first page) they were less effective in monitoring the peaks and valleys in GBM population growth because the sex pheromone only attracts males. Counts of males from sex pheromone traps (**Figure 4**, top) often showed a large peak early in the season, but showed no clear pattern in the second half of the growing season and allowed no predictions of when females would be actively laying eggs in the vineyard.

In contrast, malaise traps, a type of passive trap that captures both females and males, indicated three to four distinct population peaks, corresponding to four generations (**Figure 4**, bottom). Anticipating these peaks, which can last 7 to 10 days in the 2nd generation, provides a solid basis for timing of control measures to coincide with the peak period of effectiveness. The key to improving the timing and effectiveness of insecticide sprays was to develop a temperature-driven model to predict periods of GBM activity and, in particular, egg laying by females.

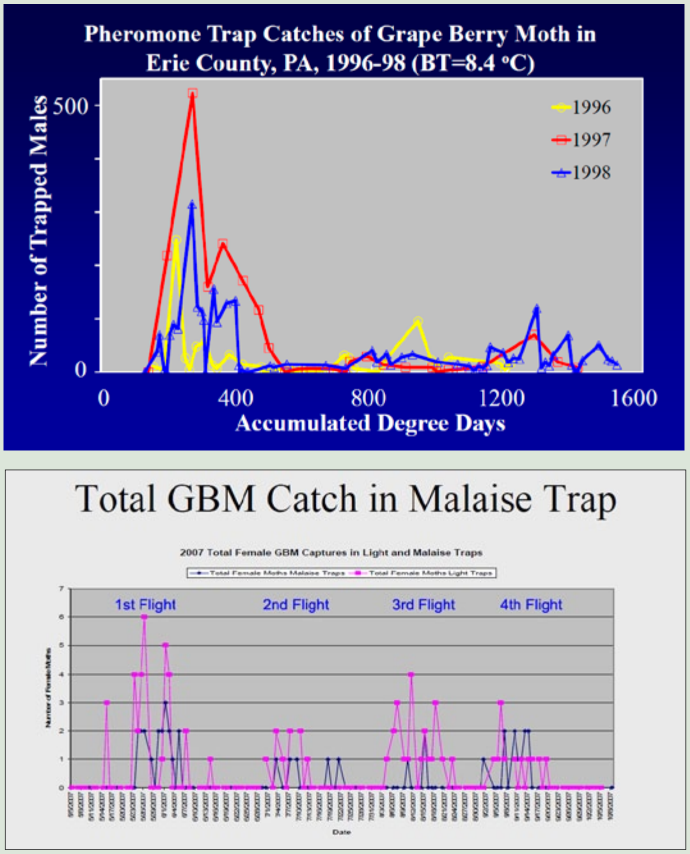


Photo by Terry Bates

__Figure 4.__ Seasonal population trends revealed by pheromone lures (top) targeted at male GBM (top) often showed a large peak in the springtime, and no distinct peaks in mid-season, providing little guidance for timing midseason insecticide applications. Malaise traps, which capture both males and females (bottom), have revealed three to four distinct generations, which provide discrete windows for sprays targeted at peak egg-laying times during the growing season.

Degree-Day Model. To better understand GBM within-season population dynamics and develop improved methods for GBM management, we conducted a series of studies in Pennsylvania, New York, and Michigan over several years to determine three fundamental life history processes of GBM:

- How long does it take for GBM to develop from egg to adult?
- When do the first pupae emerge from winter diapause in the vineyard?
- When do you last see them in the vineyard?

How long does it take for an egg to mature into an adult GBM? To determine the time it takes for GBM to develop, moth colonies were reared in growth chambers at constant temperatures (**Figure 5**). Insect growth and development is temperature dependent, and GBM reared in cooler temperatures develop more slowly than GBM reared in warmer temperatures. GBM cannot grow and develop at temperatures below 47.14°F , and above that threshold, 755 degree days Fahrenheit (the summed average of minimum and maximum daily temperatures, minus the 47.14 °F threshold) are required for 50% of the population to develop from egg to adult.

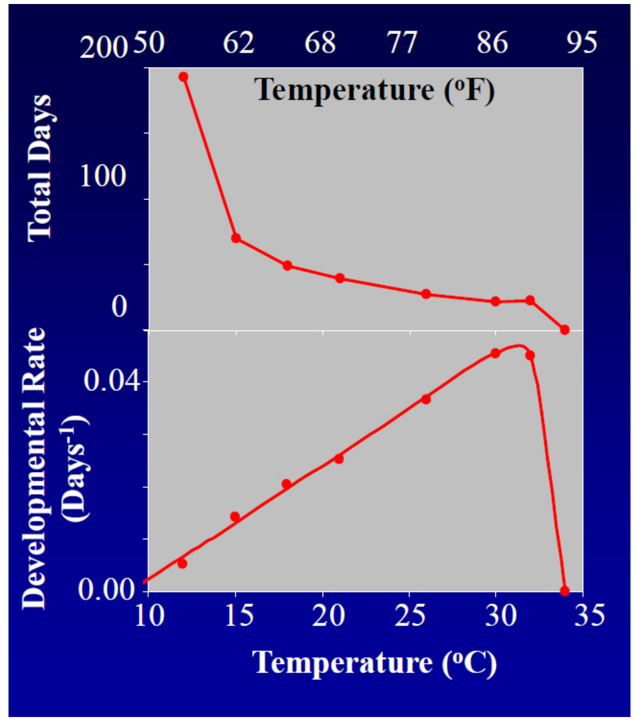


__Figure 5.__ The number of days to complete development decreases with increasing temperature (top graph). The developmental rate (the proportion of development that occurs per day) increases with increasing temperature (bottom graph). Note that at very warm temperatures (> 34 °C/ 93 °F) development stops (upper developmental threshold). The lower developmental threshold (temperature where no development occurs) is estimated to be about 8.4 °C/47.1 °F.

Additional degree days must be accumulated for the female ovaries to mature and for mating, resulting in a total of approximately 810 degree days for 50% of the population to transition from the eggs to the next generation's egg stage.

When do GBM adults first appear in the vineyard? The first emergence of overwintering GBM adults in the spring occurs after the accumulation of approximately 270 degree days (DD °F) , counting from January 1 of that calendar year. At approximately 342 DD °F , 50% of the GBM will have exited diapause, and at about 418 DD °F, 90% of the overwintered GBM will have emerged from diapause.

When compared to the development of most cultivated grapes, these dates of GBM emergence are very early. In fact GBM emerge from diapause weeks before bloom in cultivated grapes, and egg laying is well synchronized with the earlier bloom of native wild grapes. The date of wild grape bloom is a useful proxy for GBM emergence and is used as a 'biofix', or critical starting date for the degree day model described below. GBM's synchronization with wild grape bloom means that most first-generation eggs are laid on wild grapes, rather than cultivated grapes.

Photos by T. Martinson

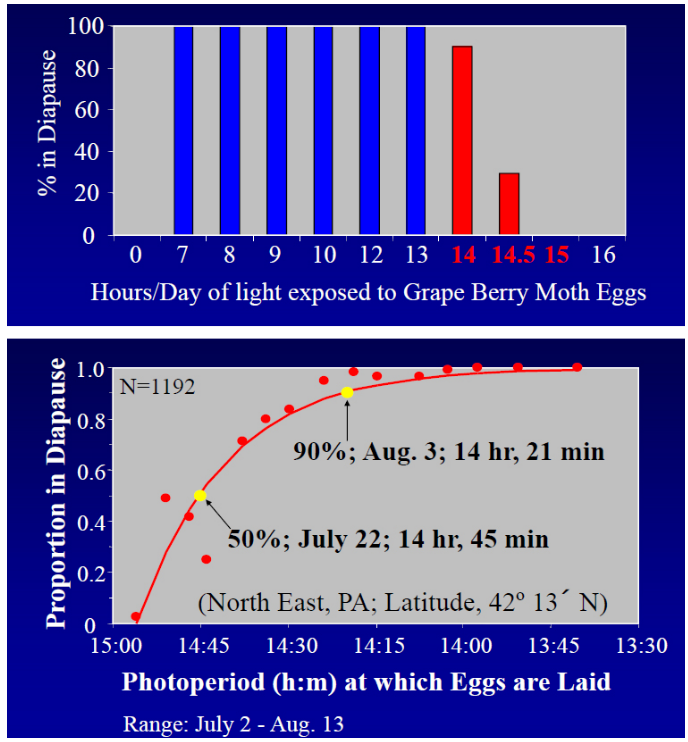
Figure 6. *Wild V. riparia with male flowers at bloom. V. riparia is the most common wild grape species growing in the northeast and north central regions of the United States. It typically blooms a week (150 degree days) before Concord vines.*

When do you last see GBM in the field? Many insect species in temperate climates like ours undergo diapause to escape the stresses of winter. Cues for impending winter include changes in daily temperature, humidity, host plant quality, or day length. Decreasing day length (also called the photoperiod) at the egg stage is the environmental cue that induces diapause in GBM (**Figure 7**). If an egg is laid when day length is 13 hours or less, it will enter diapause at the pupal stage rather than complete development to the adult stage. If an egg is laid at when day length exceeds 15 hours, it will develop through the pupal stage into a mating adult and produce another generation of eggs. Eggs laid at photoperiods between 13 and 15 hours will have intermediate levels of diapause.

This day-length cue is a key and predictable factor, because on a given date at a given latitude, the photoperiod is always the same. For example, at the latitude of the Lake Erie grape belt, an egg laid on July 22, when the photoperiod is 14 hours and 45 minutes long, has a 50% chance entering diapause when it reaches the pupal stage; an egg laid on August 3, when the photoperiod is 14 hours 21 minutes long, has a 90% chance of entering diapause when it reaches the pupal stage (**Figure 7,** bottom).

Our data on temperature-driven developmental rates, identification of wild grape bloom as a 'biofix', and the knowledge of when decreasing day length induces GBM to stop development at the pupal stage and enter diapause, has provided a solid foundation for predicting peak egg-laying dates – and timing management practices.

Seasonality and Management. The picture we now have of GBM seasonality is that adults will emerge in the spring, mate and each female will lay approximately 20 individual eggs directly on the surface of grape berries. The egg will hatch and the larva will eat its way into the berry, within which it will feed until larval development is complete. The mature larva will exit the grape and pupate either in a rolled leaf or in bark crevices or in the soil. After pupation is complete, adults will emerge, mate and initiate another generation. This pattern will continue until late summer, when shorter days trigger developing eggs to diapause in the pupal stage. The pupa will overwinter and emerge the following spring to begin the cycle anew.



Figures by M. Saunders

Figure 7. *As daylight hours (or photoperiod) increase beyond 14 hours (top), most eggs will develop to pupae and not enter diapause. Put another way (bottom), daylight hours decrease the proportion of pupae that enter diapause increases. In the Lake Erie grape belt, most grape berry moth eggs laid after early August will enter diapause as pupae.*

Temperatures during the growing season will affect how long it takes for each generation to mature, therefore temperature-based predictions of GBM population dynamics are necessary to effectively manage this troublesome pest and to prevent serious yield losses and load rejections at grape processing plants.

Are late-summer infestations increasing? Some growers perceive that late-season GBM problems are increasing. There are many possible causes, including insect resistance to existing insecticides and the different mode of action of newer insecticides. While older broad-spectrum insecticides killed on contact and had vapor action to penetrate the dense canopies and clusters, many of the newer compounds available for GBM control are not contact poisons; they must be ingested to have the greatest effect. Preliminary studies carried out at Penn State University have demonstrated that GBM larvae within grape berries are protected from insecticide sprays. Therefore, active insecticide residues must cover the cluster surfaces during

Grape Berry Moth Forecasting Models Available Online in New York, Pennsylvania, and Michigan

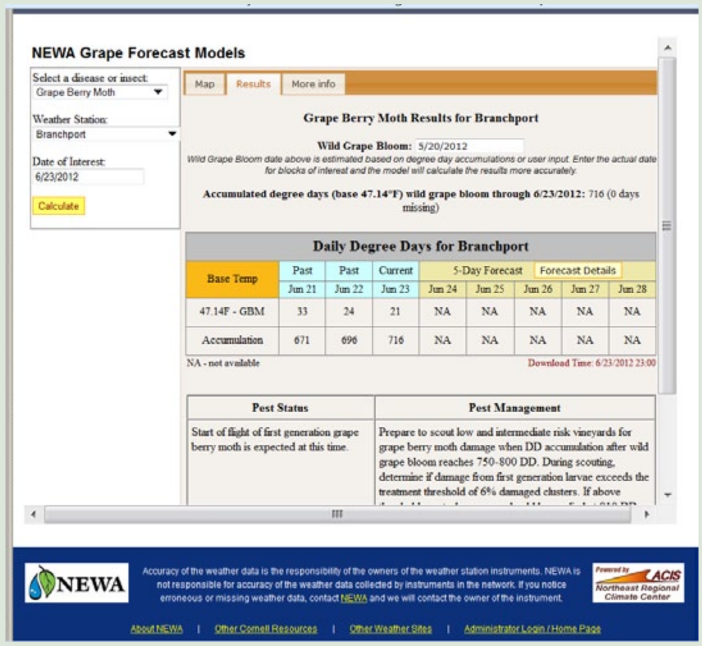
The GBM forecasting model has been incorporated into online advisory programs to predict dates of GBM egg-laying and to time insecticide applications.

Cornell's [Network for Environmental and Weather Applications](#) (NEWA) provides onsite weather information to over 50 locations in NY and PA, and a [user-friendly model](#) (right, top) to provide site-specific predictions. After entering the 'biofix date' (50% wild grape bloom) and selecting a nearby weather station, the program provides:

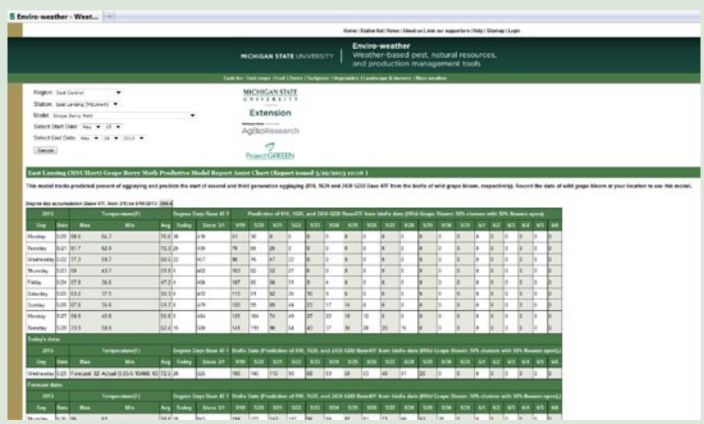
- Degree day accumulations since the biofix date
- A forecast of degree day accumulation over the next five days
- The predicted pest status and management recommendations for their vineyard.

Michigan State has a similar GBM forecasting program called [Enviroweather](#), with close to [100 weather stations](#) statewide.

[NEWA GBM Forecasting Site](#)



[Michigan State Enviroweather Site](#)



the brief window in which young GBM larvae are chewing their way out of the egg, through the grape skin and into the berry, or when they move between berries.

Another possible explanation for recent GBM control failures could be climate change. If the climate warms even slightly, the second generation of GBM may complete development more quickly and lay eggs before the critical photoperiod that induces diapause. As a consequence, the eggs laid by the second generation of GBM will not enter diapause as pupae but will develop into mating adults which could initiate another damaging late season generation in the period just before harvest, thereby increasing the risk of cluster contamination. Further exacerbating this issue is the increasing need to let grapes hang longer to meet higher brix standards.

From risk assessment to degree-day based management. In recent years, the grape berry moth risk assessment protocol (GBMRAP) (Martinson et al. 1991, summarized in **Figure 8**) has been used by grape growers in the eastern United States to estimate timing of insecticide applications for GBM management. Although the recommended first spray is tied to bloom time, which in turn, is driven by temperature, the other timings are based solely on calendar date irrespective of temperature.

Because development of GBM is temperature dependent, the GBMRAP timings for control using contact insecticides may work fairly well in an average year, but in cool years they may be applied too early and in warm years they may be applied too late. Hence, a temperature based development or phenology model should provide growers with a more reliable method to time management actions adjusted for each year's conditions.

To implement a degree-day approach for GBM management, a start date for accumulating degree-days must be determined. The bloom date of the earliest flowering grapevine species in an area should be the date from which degree-days are accumulated for GBM population monitoring, which we call the biofix date.

From the biofix date, the accumulation of degree days will determine the timing of population development and key opportunities for effective insect control. A rolling total of degree days is maintained to identify when each generation is predicted to be laying eggs: the first generation at 810 degree days, the second generation at 1620 degree days, and—in a long hot summer--the third generation at 2430 degree days.

The GBMRAP suggested a 10 day post-bloom spray for first-generation GBM control. Because it now appears likely that the first flight of GBM is synchronized with the wild grapes where most oviposition will occur, <u>we no longer recommend any treatment for this first flight</u>. Efforts directed at chemical control of GBM should be targeted at the second and subsequent egglaying periods of GBM (i.e. the offspring of the overwintered GBM). This second period of egglaying typically occurs in July in Michigan and in the Lake Erie grape belt, and it can vary from very early in the month in warm years to later in the month in cooler years. The next generation's egglaying is approximately one month later, again based on temperature.

Risk Category	10-day Post-bloom	Late July	Late August	Number of Sprays
High	Spray	Spray	Sample	2
Intermediate	Spray	Sample	No Spray	1-2
Low	No Spray	Sample	No Spray	0-1

Martinson et al 1991.

Figure 8. *GBM management recommendations based on the Grape Berry Moth Risk Assessment Protocols developed by Cornell entomologists in the late 1980s. Note that timing for mid and late season management decisions is based on the calendar date.*

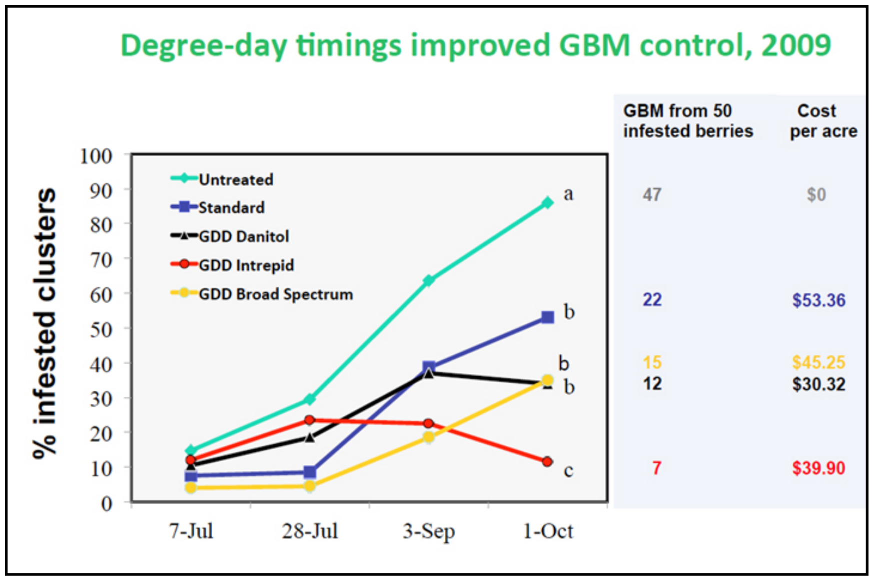


Figure by Rufus Isaacs

Figure 9. *Berry moth infestation in clusters through the season in Michigan vineyard plots treated with a program of broad-spectrum insecticides applied using traditional timings (Standard = GBMRAP) or guided by the degree day model (Standard GDD), or programs using Danitol or Intrepid applied at growing degree day-based timings for optimal selective insecticides. The lines show the percent of clusters infested through the season and illustrate the superior control achieved with two applications of Intrepid (810 and 1620 growing degree days). The numbers to the right show the surviving grape berry moth from infested clusters collected just before harvest and the approximate cost of the programs.*

Comparing management programs. We have compared GBMRAP with temperature-driven models to time sprays in commercial vineyard conditions in Michigan, Pennsylvania and New York. We compared GBM damage in vineyard blocks where spray timings were based on GMBRAP (calendar-based) with damage in vineyard block sprayed based on degree-day accumulations (temperature-driven). The results have consistently shown that spray timing based on temperature (see **Figure 9** for an example from Michigan) results in less GBM damage.

Putting it all together. Grape growers in the Northeast and North Central regions are now able to take advantage of temperature-driven, predictive models to better manage this destructive insect. As part of a regional North East IPM (NEIPM) funded project, this new information has been built into a GBM degree-day model and incorporated into the NEWA system of weather stations in New York, Pennsylvania and surrounding states (see side bar). In Michigan, funding from Project GREEEN supported incorporating the same model being into the Enviroweather site. These stations record daily weather statistics and will calculate the status of GBM populations over the course of the growing season. These systems (see sidebar on p. 5) automate calculation of the following steps:

1. Beginning from (50%) bloom date of the earliest occurring grape variety in your area, likely a wild grape such as *V. riparia, V. labrusca, V. cordifolia*, record the daily high and low temperature (in Fahrenheit). Add these and divide by two to get average daily temperature.

2. Subtract 47.12 from the daily average temperature. This results in the GBM degree-day total for that day.

3. Continue to calculate daily degree-days and maintain a rolling total.

4. When you accumulate 810 DD, the second generation of adults is predicted to start laying eggs, and a spray to protect clusters from GBM is recommended in high and possibly intermediate risk vineyards.

5. Repeat for the next generation. At 1620DD, it will be time to treat the clusters to protect them from the third generation of GBM.

6. If you haven't harvested yet at 2430 DD (an indication of a long, hot summer), another spray may be required to protect grapes from a fourth generation.

In vineyards where there is a need to protect clusters from GBM infestation, the degree day model for this pest is valuable for highlighting the time in the season when insecticides can be used to greatest effect. The model is most useful for helping make the decision of when to start protecting clusters from the second and third generation egg laying, starting at 810 and 1620 degree days, respectively.

Sprays for the first generation at bloom time have been found to have minimal effect on the amount of infestation at harvest time, so we strongly recommend growers focus their "GBM control dollars" on achieving excellent control of the second and third generations.

In addition, because pest pressure is higher at the vineyard border--especially adjacent to woods, gullies, or tree lines--growers can focus their insecticide program in these more at-risk areas of their vineyards to make sure these regions are protected.

The late season presents challenges for both management and modeling. In warmer than average years, the third generation of GBM can emerge and lay eggs when the photoperiod is still quite long, and therefore few if any eggs will be programmed to enter diapause when they reach the pupal stage. These eggs will develop directly into adults and initiate an additional generation in the late season. It is this generation that will be present at harvest, potentially resulting in severe crop loss and load rejections.

Furthermore, because of the extended period of diapause termination in the spring, by late summer the generations may begin to overlap with one another leading to the need for continuous spray coverage for late season protection. The warning given by the NEWA system is as follows:

"If 1620 DD occurs prior to August 5, you can expect continuous pressure from grape berry moth through harvest. Model results are not good predictors of timing of population pressures. Multiple additional insecticide applications may be necessary in high pressure vineyards to address the extended egg-laying and overlapping generations. Continuous coverage is necessary to avoid excessive crop loss. NOTE: Insecticide applications after mid September will have limited effectiveness in preventing damage."

Different insecticides require different timing. To properly time different insecticides, some understanding of the different types of insecticides registered for use in vineyards is required.

- *Activity against eggs and new larvae:* Those that have activity on eggs and work well when the larva is hatching should be used close to (or at) these degree day target timings. This will help get the most effect from their activity on the younger stages, and in particular we consider **Intrepid, Altacor**, and **Belt** to be three excellent options for these early egg laying timings. These three products also have long residual activity, are relatively rainfast, and have low impact on beneficials with good worker safety. Make sure they are applied with excellent cluster coverage, and adjust your sprayer if needed to make sure that the cluster zone is targeted with sufficient water to get into the nooks and crannies of the clusters. These products also bring new modes of action to help with your resistance management.
- *Broad-spectrum contact insecticides:* For those growers looking to use more broad-spectrum insecticides including one of the many pyrethroids registered in vineyards, such as **Danitol, Baytroid**, or **Mustang Max**, a carbamate such as **Sevin**, or the organophosphate **Imidan** (watch the 14 day REI and PHI!), it is worth waiting a week or so from the dates when you reach 810 or 1620 GDD before spraying. This is because most of the broad-spectrum insecticides do not have two to three-plus weeks of residual activity. So, waiting 100 GDD to 910 and 1720 will ensure that these insecticides are present and most active during the main bulk of the GBM egg laying and especially the egg hatch period when the small larvae are walking across the berries to find a place to feed on the fruit.
- *Short-residual, repeated application:* For short-lived insecticides such as a pyrethroid or Sevin , it is also advisable to make a second application after 10 to 14 days to those areas of vineyards where there is the highest pressure from GBM (e.g., edges adjacent to

woods). This will help to cover the whole generation until the start of the next or until harvest. For all insecticide-related decisions, remember that the label is the law and there are some variations in what products are registered in Michigan, Pennsylvania, and New York. Talk to your local extension educator and consult the local recommendations to learn more about this topic.

Summary. Grape berry moth has been a pest in vineyards since the dawn of viticulture in North America. Recent insights into the biology and timing of this pest's development, when coupled with modern weather monitoring systems, provide growers with more sophisticated tools for GBM management. In particular, the development of the 810 and 1620 targets for the start of the second and third periods of GBM egg laying (typically in July and August) can greatly assist in answering that age-old question of when to spray. When combined with sampling and knowledge of pest distribution in vineyards, the degree day timings and online decision tools at the NEWA and Enviroweather websites provide a way to adjust spray timings based on the year's weather, rather than the calendar. Using this approach in combination with newer insecticides that have lower impact on beneficials and improved worker safety will greatly enhance grower ability to reduce the economic impact of GBM in vineyards.

References

Dennehy, T. J., Clark, L. and Kamas, J. (1991). Pheromonal control of grape berry moth: an effective alternative to conventional insecticides. New York's Food and Life Sciences Bulletin, number 135.

Isaacs, R., Teixeira, L., Jenkins, P., Botero Neerdals, N., Loeb, G., and Saunders, M. (2012) Biology and management of grape berry moth in North American vineyard ecosystems. pp. 361-381. In: Arthropod Biology and Management in Vineyards: Pests, Approaches and Future Directions. Eds: N. Bostanian, R. Isaacs, and C. Vincent. Springer.

Martinson, T., Hoffman, C.J., Dennehy, T.J., Kamas, J.S., and Weigle, T. (1991). Risk assessment of grape berry moth and guidelines for management of the eastern grape leafhopper. New York's Food and Life Sciences Bulletin, Number 138.

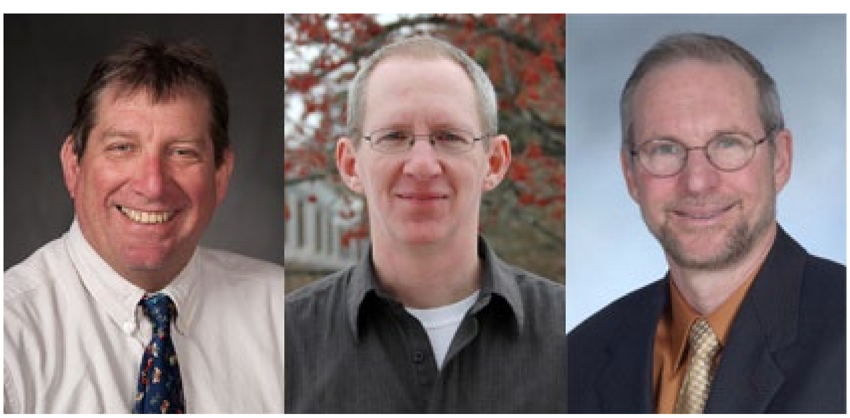
Roubos, C. K. S. Mason , L. Teixeira , and R. Isaacs (2013). Yield-based economic thresholds for grape berry moth (Lepidoptera: Tortricidae) in juice grapes. Journal of Economic Entomology 106:905-911.

Teixera, L., Mason, K.S., Van Timmeren, S., and Isaacs, R. (2011) Seasonal pattern of oviposition by the North American grape berry moth (Lepidoptera: Tortricidae). Journal of Applied Entomology 135: 693-699.

Acknowledgements

The research reported was funded by NIFA-RIPM awards #2010-41530-21275 and #2010-34103-21274, the Viticultural Consortium-East, the USDA-CSREES Crops at Risk Program project 2005-51100-02363, National Grape Cooperative, Project GREEEN, the Michigan Grape and Wine Industry Council, New York Wine and Grape Foundation, and the New York State IPM Program, and support of the grape industry and growers in PA, NY, and MI. We are also indebted to Patrick Tobin, Sudha Nagarkatti, Jody Timer, Andy Muza, Tim Weigle, Keith Mason, Steven Van Timmeren, Luis Teixeira, Craig Roubos, and Steve Hesler for their many contributions to this work over the years.

Cornell University
College of Agriculture and Life Sciences
Cornell Cooperative Extension



Michael Saunders is a professor of entomology at Pennsylvania State University with research expertise in insect ecology and decisions support systems.

Rufus Isaacs is a professor of entomology at Michigan State University with research expertise in insect ecology, pollination ecology and pest management.

Greg Loeb is a professor of entomology at Cornell University and the New York State Agricultural Experiment Station in Geneva, New York with research expertise in insect ecology and pest management.