APPLICATIONS OF THERMAL TIME MODELS TO CRANBERRY MANAGEMENT

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Predicting the growth and development of both pests and crop is an important part of improved, integrated management of cranberries. For example, estimates of when a pest enters a stage in which it can (or must) be controlled allows scheduling of intensified scouting and chemical applications. Additionally, in order to devise improved management options we must understand the effects of relevant environmental factors.

When we can formulate a set of rules or equations that predict how something behaves in response to its environment, we have created a model. What we refer to as a model may be a single equation or a huge computer program. Regardless, it is like all models, simply a replica of the real thing. Possible models relevant to cranberry production include berry color development as affected by cloudiness, or water outflow from a marsh as determined by rain, irrigation, and sunshine. Computers now allow us to devise models that consider several factors at once. Models may be used in management decision aids, or as a way of combining and expressing what we presently know about a subject. Sometimes, a detailed research model must be developed and tested in order to see how a simple and easy-to-use model can be created.

An important and useful type of model used in agriculture combines time and temperature into what are called heat sums, degree-days, growing degree-days, physiological time, or thermal time. I think the best term might be thermal time, since the models are based on temperature rather than heat and because, as we shall see, a day may be too long of a time interval to use in calculations. Thermal time models have been around since the early 1700s.

A good example of a useful application of thermal time is estimation of heating degree-days to predict how much energy is required for home heating. When the air temperature stays near 70°F, our furnaces do not come on and we do not consume energy for heat. When daily temperatures are, say, around 20°F, however, we must heat our homes. Since no heating is required at outside temperatures of 70°F, we adopt this as the base temperature for a heating degree-day calculation. For each day of the winter when the outside temperature averages 60°F, we add (70 - 60) = 10 heating degree-days to the seasonal total. Fuel oil companies schedule deliveries based on heating degree-days and a factor for how much oil you typically burn for each degree-day.

Biological processes such as insect or plant development generally go faster at warm temperatures than at cool temperatures. There is a base temperature below which nothing happens and, sometimes, a maximum temperature at which the process is at maximum speed. Thermal time combines both the length of time temperatures are above the base and by how much the base was exceeded. If a thermal time model works properly, the same number of degree-days (or whatever the particular model uses) are required for, say, flowering, regardless of whether we have an early spring and warm summer, or a late and cool spring and summer.

Growth (size increase) and development (advancing from one stage to the next) of a living organism always take time. The rate of these processes, however, can be affected by a wide range of environmental factors. Generally, thermal time is associated with developmental events rather than with growth. For example, the length of time a corn leaf expands appears to be driven by thermal time, but the rate of expansion is not strongly affected by temperature over a fair range. Flowering is an important developmental stage of plants. It may be controlled by thermal time (as in corn) or by day length (as in soybean).

Calculating Thermal Time

The most common thermal time calculation is the degree-day. There are several methods for calculating degree-days (Higley et al., 1986), but the simplest is to average the daily maximum and minimum temperatures, subtract the base temperature, and add the resulting number to the summation. One must know the appropriate base temperature and, equally importantly, when to start adding them up. A slight variation is the “modified” technique, in which any minimum temperatures below the base are set to the base and any maximums above some threshold (often 85°F) are set to that maximum. This prevents negative daily values, implying that we believe the development process does not go backward on cold days. Also, very high temperatures may cause temporary cessation of development (and growth), so these time periods should not contribute to the sum. In applying a degree-day model, always use the same calculation method as was used to create the model.

Thermal Time Models for Cranberry

Development of thermal time models useful for cranberry management has trailed behind efforts for other crops. A number of good examples are now available, however, and more will undoubtedly be created. Scientists at the UW-Madison are leading the development of thermal time models to cranberry.

Larry Binning and a graduate student, Tom Bewick, demonstrated that emergence of swamp dodder in cranberry can be predicted from a thermal time model (Bewick et al., 1988). Their research suggests that the appropriate base temperature for dodder emergence is about 3.5°C (38°F). About 120° Celsius-days (210° Fahrenheit-days) must accumulate following ice-out before the first dodder will emerge. Field tests of the model showed it to be accurate to within one or two days in two widely different years: in 1986, dodder emerged on 2 May, while in 1987, emergence was on 20 April. The authors suggested that the degree-day sums be updated daily, and as the emergence value approached, scouting should be started in areas known to be infested.

Dan Mahr and Sherri Roberts tested the suitability of a thermal time model for predicting development of cranberry girdler (Roberts and Mahr, 1986). From their laboratory studies, base (or threshold) temperatures were found to be 9.4°C (49°F) for eggs, 7.3°C (45°F) for larvae, and 9.8°C (50°F) for prepupal-pupal stages. Degree-day sums required for hatch was 107° Celsius-days (193 “Fahrenheit-days), development of larvae to the pre-pupal stage (cocoon spun) required

484 “Celsius-days (870 “Fahrenheit-days), and emergence of moths occurred after another 390 “Celsius-days (702 “Fahrenheit-days). These degree-day sums have an uncertainty of at least 10%, and the model has not been verified in the field.

Steve Cockfield and others recently completed work on a thermal time model for hatch of blackheaded fireworm (Cockfield et al., 1993). Laboratory data on egg hatch collected by Rose Kachadoorian were used to create both a degree-day model and an hourly-development model. For six datasets collected during three years, the degree-day model was about two weeks late in predicting the mid-point of hatch. The hourly-development model was correct to within one day on average, but individual predictions were often in error by five days.

The poor showing of the degree-day model was because the relationship between temperature and egg development is not a straight line for this species. Scientists love straight lines and try to see them whenever convenient, but it just is not possible here. The hourly-development model is more complex than a typical degree-day model, and requires hourly temperature measurements. Complexity and frequent measurements are no problem for computers and automated weather stations, if they are available.

Finally, we do not yet have an ‘appropriate degree-day model for development of the cranberry plant. Experiments are now underway to see if thermal time models are applicable to the crop and, if the answer is yes, what the model should be. A complete model will include a base temperature (may be different for each phase of development) and degree-day totals for each stage. Joan Davenport at Ocean Spray has for now adopted a base of 45°F for calculating cranberry degree-days, but she stresses that this is only a guess. Perhaps soil temperature degree-days will be more suitable than those from air temperature.

Climatology of Degree-Days

Thermal time accumulation is one way by which we can describe individual growing seasons. Even in the absence of tested models, thermal time calculations allow comparisons of the current season with recent and/or memorable (good or bad) years past. A long-term record of daily temperature in Wisconsin is available from the Cooperative Observer Network organized by the National Weather Service. From maximum and minimum temperature records collected between 1940 and the present, I calculated growing degree-days with base 45°F and temperatures below that set to 45°F and above 85°F set to 85°F. Summations were started on 1 April and continued through the end of August. After making the calculation for all available years (40 to 50), the distribution of values on a given date in the season was estimated. From this, we can determine, for a given date, the DD sum below which the coolest 10% of all years must be, the value below which the coolest 30% must be, the median (half warmer, half cooler), etc. This is displayed graphically in Figures 1, 2 and 3; each figure is built from data collected in a major cranberry growing area of the state. On each figure is also plotted 1992 and 1991, two recent and memorable years. Degree-day accumulation for 1992 was close to 10% of the coolest; most of the cooler years were in the 1940s. Careful study of the 1992 line reveals a cool start, then fairly rapid warming in early June (compared to the median), then slower than typical accumulations after mid-June. These graphs will allow you to compare the coming year, as it unfolds, with the past 50.

In closing, thermal time calculations are a well-established principle for modeling the development of biological systems. Not all processes are suited for modeling by thermal time, however. Applications of the technique to cranberry are now becoming understood, and some will become standard management tools in the next couple of years.

Literature Cited

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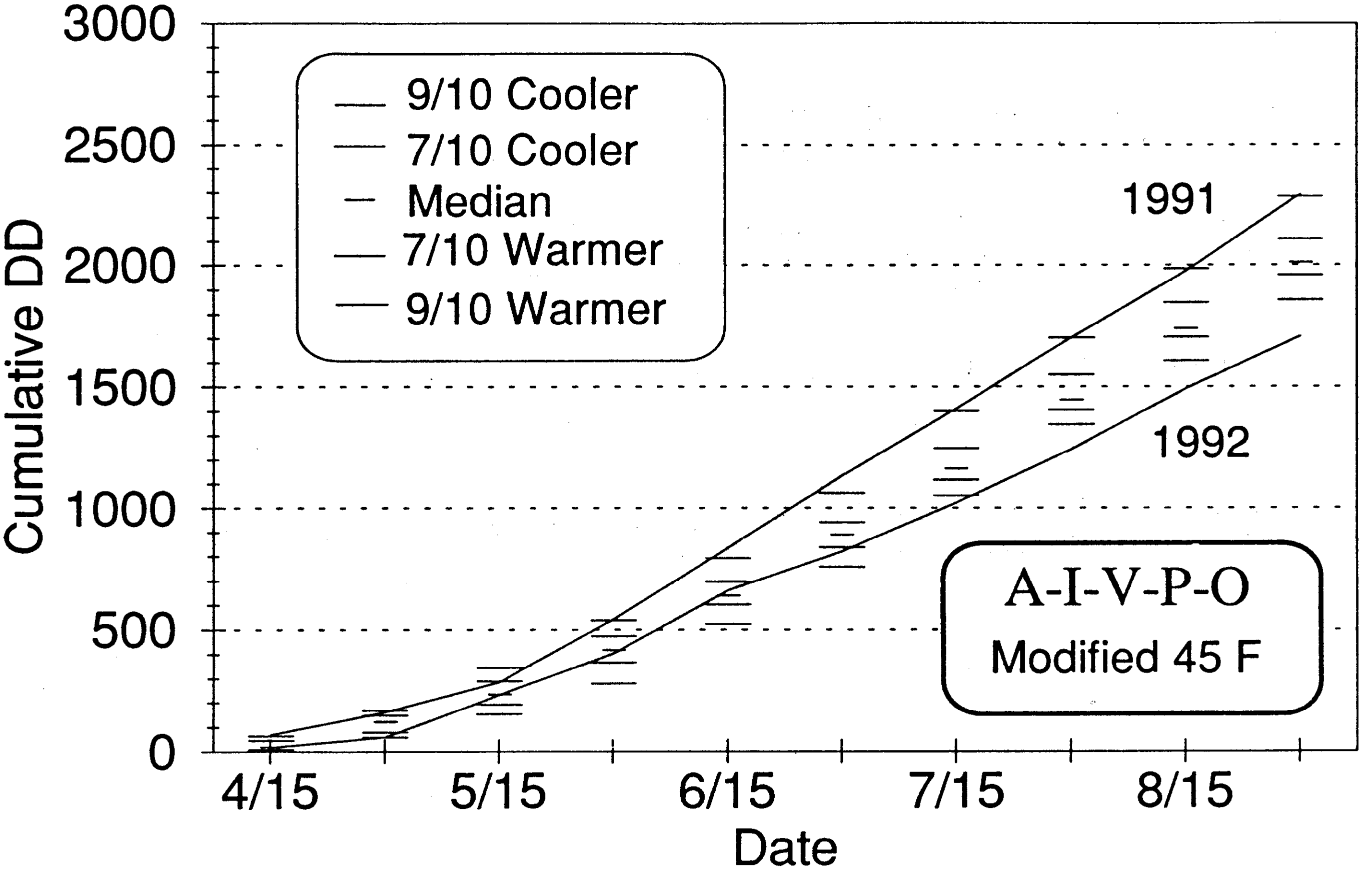

Figure 1. Cumulative degree-days for the growing season in the Northcentral cranberry region (data from Ashland, Iron, Vilas, Price, and Oneida counties). Calculations made using a base of 45°F and an upper limit of 85°F, using the modified average method. Five horizontal markers for each date indicate the distribution of values observed over the last 40 years. The lowest mark indicates that 10% of the years were below this value. The next mark up indicates that 30% of the years were below this mark (70% were warmer). The center mark is the median (half warmer, half cooler), and markers above the median are 30- and 10 percentiles for warm years.

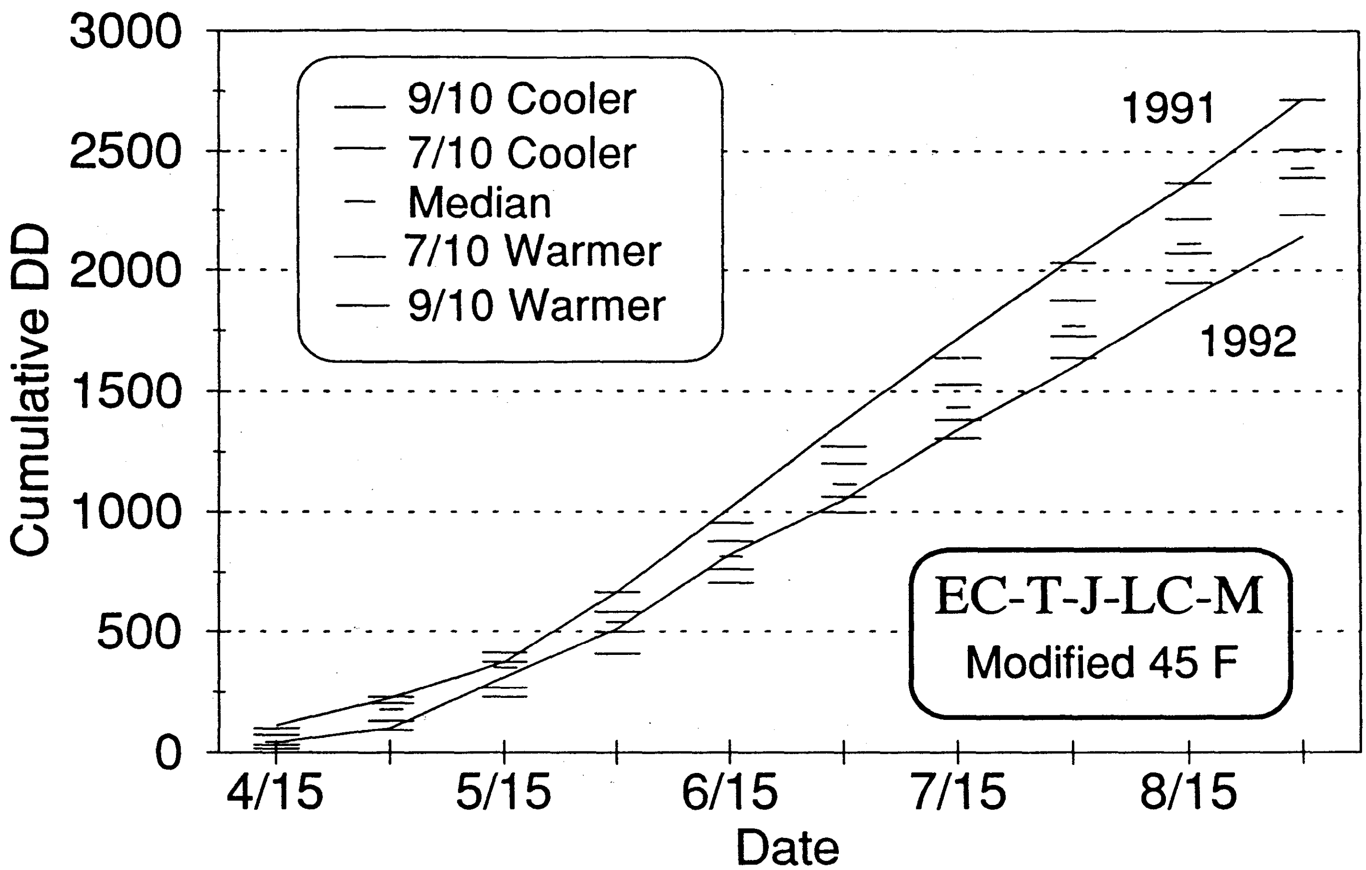

Figure 2. Cumulative degree-days for the growing season in the Eastern cranberry region (data from Eau Claire, Jackson, Trempealeau, Monroe, and La Crosse counties). Calculations made using a base of 45°F and an upper limit of 85°F, using the modified average method. Five horizontal markers for each date indicate the distribution of values observed over the last 40 years. The lowest mark indicates that 10% of the years were below this value. The next mark up indicates that 30% of the years were below this mark (70% were warmer). The center mark is the median (half warmer, half cooler), and markers above the median are 30- and 10 percentiles for warm years.

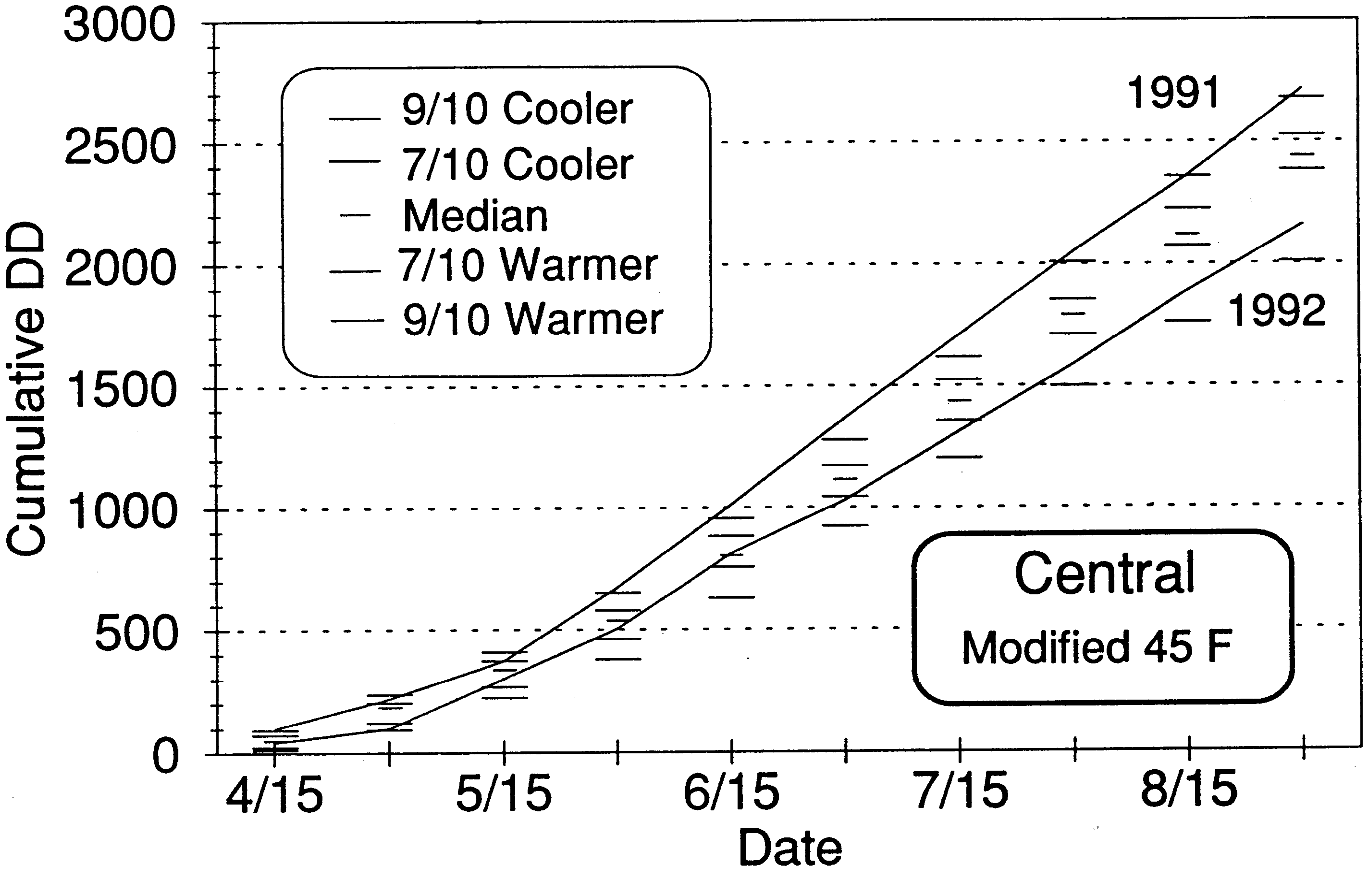

Figure 3. Cumulative degree-days for the growing season in the Central cranberry region (data from Wood, Portage, Waupaca, Juneau, Adams, Waushara, Marquette, and Green Lake counties). Calculations made using a base of 45°F and an upper limit of 85°F, using the modified average method. Five horizontal markers for each date indicate the distribution of values observed over the last 40 years. The lowest mark indicates that 10% of the years were below this value. The next mark up indicates that 30% of the years were below this mark (70% were warmer). The center mark is the median (half warmer, half cooler), and markers above the median are 30- and 10 percentiles for warm years.