Annual Progress Report
2013
For The Washington Grape and Wine Research Program

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Project Title: Predicting Key Phenological Stages for Grapevines. A Simple but Scientific Approach for Management and Site Selection.

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I. Project Summary:

Temperature is one of the most important and controlling factors in grapevine development. The base temperature (Tb) defined as the temperature threshold below which plant growth ceases varies depending on the cultivar. In general, cultivars with a lower Tb have earlier bud break than those with a higher Tb. Grapevine growth and development is proportional to biological time, or thermal time, which can be defined as the integral of time and temperature above a certain threshold. This constitutes the concept of growing degree days (GDD). The objectives of this study were (i) to determine the Tb of key phenological stages for grapevine and (ii) determine the duration for the key development stages as a function of grapevine cultivar. We used three phenological stages including budbreak, full bloom and veraison for four cultivars, including Cabernet Sauvignon, Chardonnay, Merlot, and Riesling. Different methods were used for determining Tb.

In general, we found an increase in Tb during grapevine development from first swell until veraison. Cabernet Sauvignon and Riesling had the highest values for Tb for all the phenological stages that were considered. GDD required from bud burst to veraison varied from 2010.6°F to 2284.2°F for Riesling and Merlot, respectively. The results of this study provided valuable information for determining the development of grapevine from available local weather data. Any delay in the initial developmental stages such as budbreak has an impact on the entire cycle. It is, therefore, a critical factor in the selection of a cultivar based on its precocity for vineyard establishment. Initial parameters were obtained for the development of a growing-degree day model for different grape cultivars that can ultimately be implemented on the AgWeatherNet web site as a decision support tool.

II. Materials, Methods and Experiments Conducted to Meet Stated Objective(s):

Objectives(s)

1. Develop a model to predict the key phenological stages for grapevine including budburst, bloom, veraison, and possibly maturity.
2. Determine the base temperature and duration for the key development stages as a function of grapevine cultivar.

III. Major Research Accomplishments:

Objective 1. *Develop a model to predict the key phenological stages for grapevine*

Phenological data including budburst, bloom and veraison were used for the development of a thermal time model to predict the key phenological stages for four different grapevine cultivars Cabernet Sauvignon, Merlot, Chardonnay, and Riesling. The data that were used were obtained from an existing database collected by the Viticulture and Enology Program located at WSU's Irrigated Agriculture and Extension Center (IAREC). The weather data were collected by the automated weather stations of AgWeatherNet (www.weather.wsu.edu) and based on the weather station located closest to the vineyards that were used for phenological observations. The duration of the key phenological stages in terms of days were determined. Cabernet had the shortest duration when compared to the other two varieties (Table 1).

Table 1. Duration in days, for successive phenological stages. Mean, standard deviation (S.D.), minimum (Min), and maximum (Max).

Cultivar by color	Budburst - Full bloom				Full bloom - Veraison				Budburst - Veraison			
	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max
Red cultivars												
Cabernet Sauvignon	49	1.6	41	64	63	1.8	52	80	112	1.7	103	125
Merlot	47	1.3	38	65	65	1.6	52	86	111	2.0	99	139
White cultivars												
Chardonnay	52	1.6	39	68	65	1.1	56	75	116	1.7	98	132
Riesling	49	1.3	42	62	66	2.1	54	81	115	2.1	106	134

The model was developed through the daily integration of phenological progression as a function of thermal time or growing degree days (GDD). In general, thermal time models use three input parameters; the starting date of heat accumulation, a critical temperature threshold or base temperature for effective heat accumulation, and a critical amount of heat required to reach the next phenological event. To determine the optimum starting date for heat unit accumulation the methodology proposed by Nendel (2010) was applied. GDD was calculated with the single triangle algorithm using base temperatures ranging from 32 to 52°F and assuming different starting dates from 1 January to 30 March until the appearance of the first swell. This procedure was applied for each cultivar in each year and the coefficient of variation (CV) of the GDD accumulated, was estimated to find the starting date that has the smallest variation using the response surface methodology.

The optimum date to start with the accumulation of GDD was different for the four varieties evaluated, but was around the first week of February. These dates were then used to determine the number of GDDs to reach first swell and the model was ran for two contrasting years, including 2003 and 2011. The appearance of first swell was earlier and faster in year 2003, which was a warm year, compared to 2011, which was a cold year. Cabernet Sauvignon was the latest with respect to development compared to Merlot, Riesling, and Chardonnay. The model was evaluated using the classical method for GDD, which uses the difference between the daily mean temperature and the base temperature. Four different inputs were evaluated for the parameters starting date and base temperature (Table 2). When the parameters were fixed the starting date to heat accumulation was estimated through an optimization procedure, in which a wide range of starting dates and GDDs were proposed. The starting date varied from January 1 until up April 15 and GDD varied at 1ºC intervals. GDDs where calculated using either Tb=32ºF or Tb=50ºF.

Table 2. Parameters of the growing-degree days (GDD; °F) models that were evaluated

Model	Starting date	T_b (ºF)	Initial phenological stage
1	January 1†	32	First Swell
2	April 1†	50	First Swell
3	- *	32	Budburst
4	- *	50	Budburst

† Starting date fixed, * Starting date estimated using an optimization procedure.

For each model, the predicted date to reach first swell was compared to the observed date in terms of day of the year (DOY) and the root mean square error (RMSE) was calculated. For model 1 and 2, the starting date to predict first swell was estimated. However, for model 3 and model 4 the optimum date based on the optimization procedure occurred after the appearance of first swell, for these models the next phenological stage, i.e., bud burst was predicted. The GDDs were then estimated from the starting date until first swell or bud burst, and between successive phenological stages, the accumulation was also used to run the complete model until veraison. The combination of starting date and GDDs that minimized RMSE was selected as the optimum starting date and heat requirements for each cultivar (Table 3).

Table 3. Starting date to predict budburst in day of year (DOY), date, growing-degree days (GDD; °F), and standard error (SE) for four grapevine cultivars based on optimization.

Cultivar	Model 3				Model 4			
	DOY	Date	GDD	SE	DOY	Date	GDD	SE
Red cultivars								
Cabernet Sauvignon	78	19 March	691	14.8	97	7 April	67	5.2
Merlot	76	17 March	729	13.9	95	5 April	67	4.5
White cultivars								
Chardonnay	71	12 March	619	43.7	95	5 April	27	11.5
Riesling	70	11 March	686	5.0	98	8 April	38	15.8

Differences in starting dates and heat requirements between cultivars and phenological stages were found (Table 4). The highest GDD requirements were obtained for the developmental stages of bud burst to first bloom and full bloom to veraison independently of Tb used, major changes in phenology were observed from vegetative to reproductive period. With a Tb=50°F, the requirements for Cabernet Sauvignon were 1757°F from first swell to veraison, 1667°F for Chardonnay, 1755°F for Merlot, and 1760°F for Riesling, whereas for Tb=32°F, Cabernet Sauvignon required nearly 4876°F from first swell to veraison, Chardonnay 4687°F, Merlot 4849°F, and Riesling 4874°F (Table 4).

Table 4. Growing-degree days (GDD; °F) to successive phenological stage based on model 1

(Starting day = January 1 and base temperature = 32°F) and model 2 (Starting day = April 1 and base temperature = 50°F). Minimum (Min), average (Ave) and maximum (Max), duration in days, for each phenological stage. SE = Standard Error.

Cultivar	Model	First swell		Bud burst		First bloom		Full bloom		Veraison	
		GDD	SE	GDD	SE	GDD	SE	GDD	SE	GDD	SE
Red cultivars											
Cabernet Sauvignon	1	1012	43.9	207	11.0	1091	24.7	151	14.2	2417	84.2
	2	31	6.8	32	4.9	356	8.8	67	6.1	1271	56.5
Merlot	1	931	34.6	272	20.3	1138	23.8	130	13.7	2380	36.4
	2	20	4.5	43	6.1	385	8.8	50	6.1	1255	21.6
White cultivars											
Chardonnay	1	810	37.4	225	33.3	1087	47.2	117	13.3	2448	73.1
	2	9	2.9	29	10.3	342	13.3	45	5.0	1244	52.4
Riesling	1	869	50.9	221	19.1	1143	26.5	155	24.1	2484	114.5
	2	11	3.2	34	5.4	362	10.3	63	11.0	1291	66.8

The best model performance was obtained when the starting date was found using an optimization procedure and Tb was set to 50°F. Different starting dates were found for each cultivar and it varied according to the Tb that was used. The use of Tb= 50°F increased prediction accuracy for all phenological stages of grapevine tested. More effort should be focused on understanding the relationship that exists between starting date for GDD accumulation for perennial crops such as grapes for accurate prediction of budbreak.

Objective 2. *<u>Determine the base temperature and duration for the key development stages as a function of grapevine cultivar</u>*

The base temperature (Fig. 1, Table 5) and the duration in GDD (Table 6) for bud burst, full bloom, and veraison were determined for the four selected cultivars using the least variance method. In general, an increase in Tb was found from first swell until full bloom. Cabernet Sauvignon and Riesling presented the highest values for Tb for all the phenological stages considered, while Chardonnay and Merlot the lowest values. Initially, for the estimation of Tb sap flow was set as a starting point of the temperature accumulation. New base temperatures were estimated also considering first swell as starting point for temperature accumulation due to the appearance of sap flow which depends on other factors such as a soil temperature and is not a very accurate good stage to initiate the accumulation.

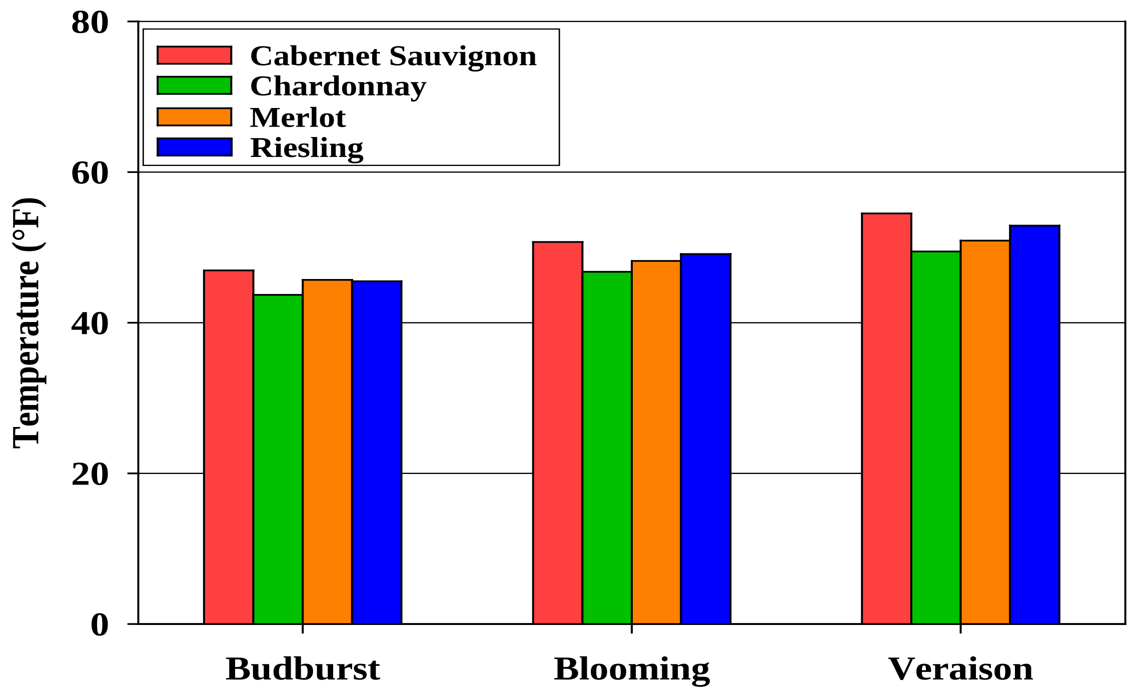

Figure 1. Base temperature estimated by the method of the least variance in GDD for each cultivar and phenological stage.

Table 5. Base temperature (°F) estimated by the method of the least variance in GDD for each cultivar and each phenological stage.

Cultivars by color	Budburst	Full bloom	Veraison
Red cultivars			
Cabernet Sauvignon	46.9	50.7	54.5
Merlot	43.7	46.8	49.5
White cultivars			
Chardonnay	45.7	48.2	50.9
Riesling	45.5	49.1	52.9

Table 6. Growing-degree days (GDD; °F) estimated using air temperature for each cultivar and each phenological stage using the Tb estimated by the model.

Cultivars by color	Budburst		Full bloom		Veraison	
	GDD	S.E.	GDD	S.E.	GDD	S.E.
Red cultivars						
Cabernet Sauvignon	189	18.0	432	21.8	1037	51.1
Merlot	275	86.4	551	13.7	1204	39.4
White cultivars						
Chardonnay	216	15.1	637	13.5	1273	46.8
Riesling	185	14.0	472	12.6	1109	60.3

Once the heat requirements were estimated for each developmental stage using the base temperature estimated, daily air temperature was used to accumulate GDDs from 1 January. Predictions for the last three years were made (Fig 2.) showing how phenology is highly temperature dependent. An increase in temperature and a shortening in the growing season length has characterized the last three years. 2013 corresponded to a warm year where temperature rapidly accelerated development compared to 2011 with a colder spring. The results indicate that the parameters that define heat requirements and base temperature are able to successfully describe the development of grapevine.

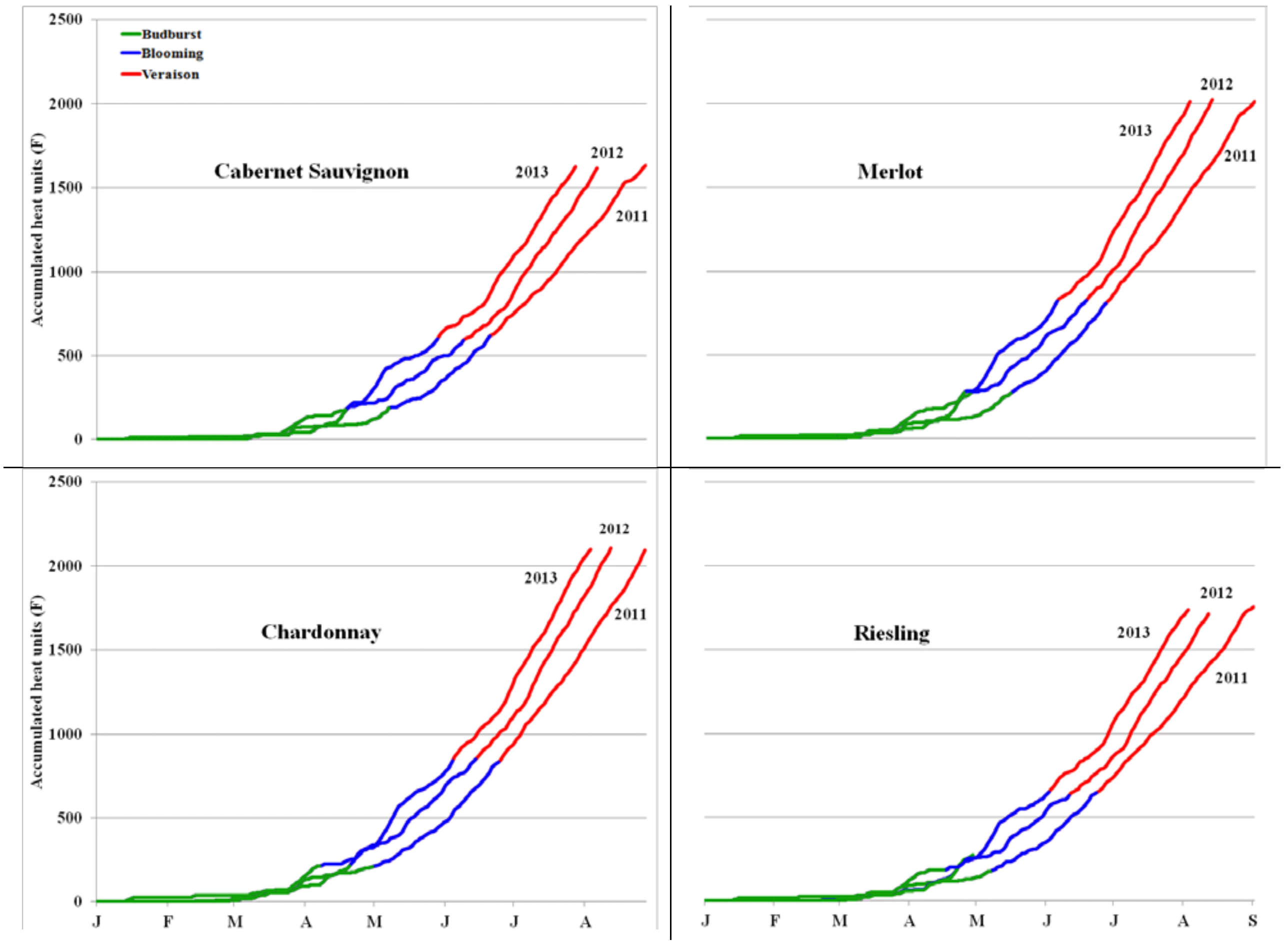

Figure 2. Growing-degree days accumulated (GDD; °F) for the appearance of budburst, blooming, and veraison using the base temperature estimated for each developmental stage and each cultivar for 2011, 2012, and 2013.

Soil temperature in grapevine phenology

The large fluctuation in air temperature compared to soil temperature could be used as a potential explanation of why soil temperature could be used to improve phenological predictions. Historical daily soil temperature records (Fig. 3) collected at a soil depth of 20 cm was used to estimate heat requirements for budburst, full bloom, and veraison.

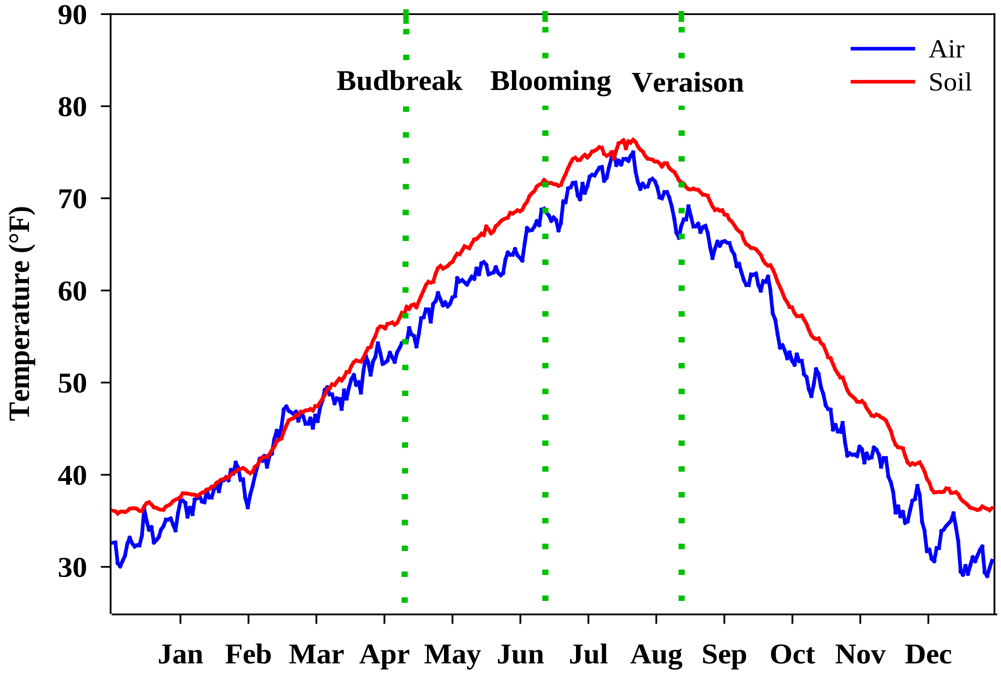

Figure 3. Historical average of air and soil temperature (1990 - 2013).

There were no significant differences among thermal time required for budbreak when using soil and air temperature ($p = 0.057$). In contrast, there were significant differences in heat requirements for blooming and veraison ($p < 0.001$), showing that GDDs are significantly different for these phenological stages (Fig. 4 and 5). Standard error in GDDs for budburst and full bloom were large when using soil temperature while for veraison the variation was quite similar (Table 6 and 7). Prediction errors in days slightly increased when soil temperature was used for some cultivars and developmental stages (Table 8). Full bloom had the lowest error in prediction for the stages that were evaluated.

Table 7. Growing-degree days (GDD; °F) based on soil temperature for each cultivar and each phenological stage with the estimated Tb. SE = Standard Error.

Cultivars by color	Budburst		Full bloom		Veraison	
	GDD	SE	GDD	SE	GDD	SE
Red cultivars						
Cabernet Sauvignon	198	21.2	607	43.4	1228	40.5
Merlot	306	110.0	740	33.8	1399	29.2
White cultivars						
Chardonnay	227	18.5	826	36.0	1478	47.0
Riesling	178	12.6	637	36.7	1305	52.2

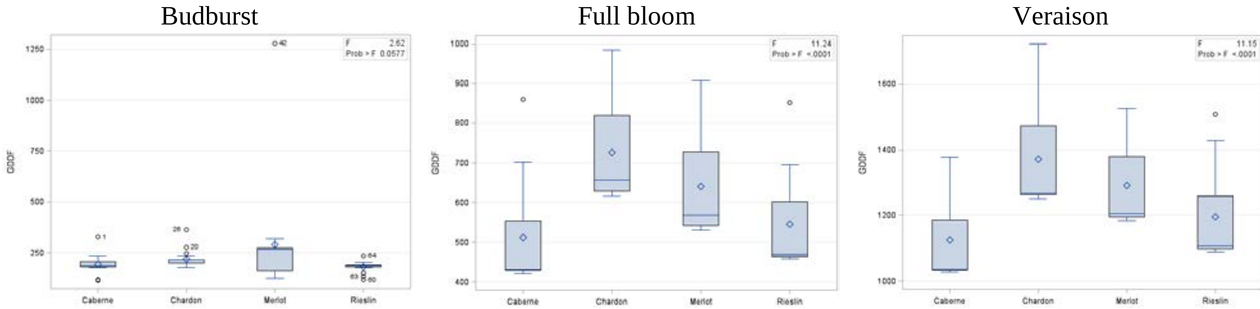

Figure 4. Distribution of growing-degree days (GDD; °F) using soil and air temperature for budburst, full bloom, and veraison.

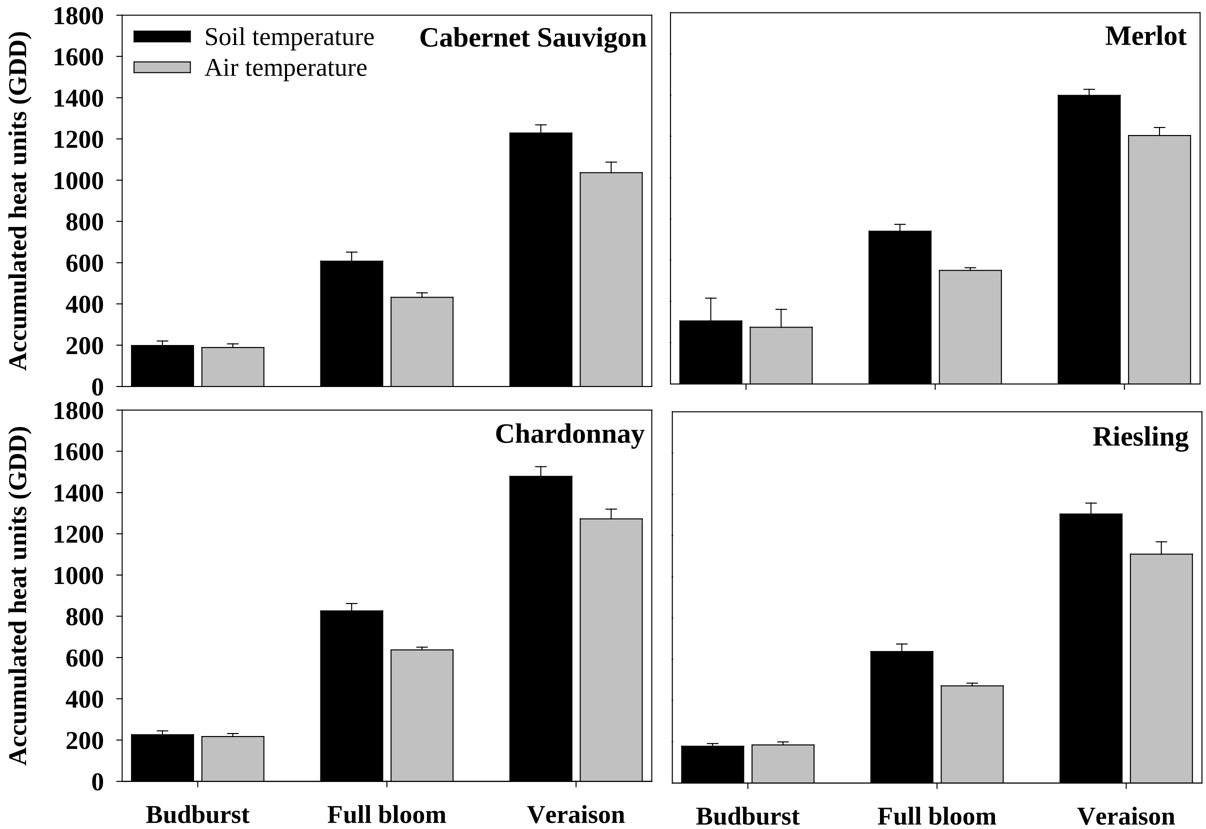

Figure 5. Comparison of growing-degree days (GDD; °F) required to budburst, full bloom, and veraison using the estimated base temperature. Heat accumulation for budburst started on 1 January.

Table 8. Root mean square error in days when GDDs were calculated using air and soil temperature for model calibration and evaluation.

Cultivar by color	Temperature used	Calibration			Evaluation		
		BB	FUB	VR	BB	FUB	VR
Red cultivars							
Cabernet Sauvignon	Air	9.0	4.3	9.3	7.9	4.3	5.7
	Soil	6.2	5.7	9.9	6.3	6.7	7.6
Merlot	Air	8.8	5.5	5.6	9.2	3.8	5.3
	Soil	8.2	8.1	7.9	10.6	8.2	10.8
White cultivars							
Chardonnay	Air	8.0	3.9	4.3	6.5	2.7	4.5
	Soil	5.3	5.3	3.9	7.6	7.5	9.2
Riesling	Air	5.1	3.9	9.9	3.5	3.0	5.8
	Soil	3.9	4.8	8.8	7.7	7.2	10.2

The results of this study provided valuable information to describe the development of grapevine from available local weather data. Any delay in the initial developmental stages such as bud burst has an impact on the entire growth and development cycle. It is, therefore, a critical factor in the selection of a cultivar based on its precocity for vineyard establishment.

IV. Outside Presentations of Research:

Zapata, D., M. Salazar, M. Keller, L. Mills, and G. Hoogenboom. 2012. Prediction of key phenological stages for grapevine. Poster presented at the 2012 Washington Association of Wine Grape Growers, Kennewick, Washington.

Zapata, D., M. Salazar, M. Keller, L. Mills, and G. Hoogenboom. 2013. How it works: starting date and base temperature for the prediction of the developmental stages of grape. Poster presented at the 2013 Washington Association of Wine Grape Growers, Kennewick, Washington.

Salazar, M., B. Chaves, M. Keller, L. Mills, D. Zapata, and G. Hoogenboom. 2013. Changes in wine grape phenology and the relationship with local climate in Washington. Poster presented at the 2013 Washington Association of Wine Grape Growers, Kennewick, Washington.

Zapata, D.M., Salazar M., Keller M., Mills L., and Hoogenboom G. 2013. A model for predicting budbreak, blooming, and veraison on wine grape cultivars. Oral presentation at 40th SACNAS National Conference - Society for Advancement of Chicanos and Native Americans in Science; 2013 October 3–6; San Antonio, Texas.

V. Project Budget Status:

The funds were used to pay for the monthly salary of a graduate student, Ms. Diana Zapata, who is enrolled in the Graduate Program of Biological Systems Engineering since January 1, 2013. In addition, partial salary support was provided for Dr. Melba Salazar, Assistant Research Professor, who supervises the research activities of Ms. Diana Zapata.

VI. Other Sources of Funding:

Cost-sharing was provided through the AgWeatherNet program by providing access to locally collected weather data and facility support. Support was also provided by the Viticulture Program through access to the historical data base of phenological data.