PREDICTION OF PHASIC DEVELOPMENT IN GRAPEVINES

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Abstract

A new method of calculating heat degree days for use in addressing the phasic development of perennial deciduous plants is developed from published data. The method allows estimation of the starting date for the commencement of plant physiological development as well as the prediction of the phasic development periods. The results are compared to those obtained using traditional methods.

Introduction

The analysis examines the phasic development of grapevines by way of the time required for plants to reach growth stages such as budburst, flowering, and harvest. The issue relates to physiological development or aging. The physiological activity of plants determines their development wherein physiological activity is largely determined by ambient temperatures. This dependence of plant physiological development on temperature has long been known for crops such as grapevines and wheat, as has its apparent independence from plant production by way of photosynthesis.

The traditional method used to predict phasic development in grapevines is generally attributed to Winkler (Amerine & Winkler, 1944). This has plant phasic development increasing linearly with temperature above a threshold or baseline temperature of 10C. With this scheme an average temperature of 15C for one day contributes 5 degrees to the plant age. The sum of the daily temperatures above the 10C baseline over time is referred to as Heat Degree Days (HDD), and this is a measure of physiological age.

The predictions of Gladstones are the current reference for phasic development in grapevines in Australia. Gladstones uses the Winkler method of a linear increase above a baseline temperature of 10C but limits the temperature contribution for any day to 9 degrees. This constraint means there is no increase in response above 19C. Gladstones sometimes also uses other adjustments to differing extents. Of these, only daylength (latitude) has a well defined, albeit poorly known, physiological basis.

Prediction of plant development using HDD is based on the premises that:

- No physiological development occurs below a baseline temperature.
- Physiological development depends solely on temperature and is independent of other aspects of growth such as photosynthesis, plant size or leaf area.

Winkler used 10C as the baseline temperature as bud burst does not occur below this level, and this arbitrary reference has been adopted by others. However, Moncurr et al experimentally determined that the baseline temperature for grapevines was between 5 and 6 degrees, which is similar to annual crop plants such as wheat[1]. Despite Moncurr et al. validating their laboratory results with field observations, and values around 6 degrees applying generally to annual crops, their results have been largely rejected.

Much of the uncertainty in addressing the phasic development of grapevines arises because of uncertainty as to when physiological growth commences. The physiological activity for annuals such as wheat commences when the seed is planted in moist soil and imbibes water. However, there is no means of determining the starting point for the commencement of physiological development in vines or any other perennial plants.

This issue is usually circumvented by using an observable growth stage as the starting point for predictions. For example, Gladstones nominally uses the budburst date, but this is given by a set reference date of October 1. This selection of an arbitrary set date introduces significant errors as the budburst dates observed in Australia span more than one month.

Basic considerations with the physiological development of perennial vegetation can be addressed using the analogy of a stopwatch. A trigger is required to reset the watch to zero. For plants this is commonly a low temperature, and is referred to as a vernalisation requirement. A vernalisation requirement is present in wild wheat and ensures that plants germinate when conditions favour plant growth. The vernalisation requirement has been bred out of most cultivated wheat varieties due to the desire for uniform germination regardless of temperature.

The next stage is a trigger to start the clock ticking, and for plants this is often daylength. The commencement of physiological activity is commonly triggered by a change to increasing daylength.

A stopwatch measures chronological time, but plant phasic development does not progress uniformly or proportionally to chronological time. Plant metabolism depends on temperature and plant temperatures generally follow the ambient temperature. Plant phasic development is therefore controlled by temperature as well as daylength. Prediction of the dates for different phases of plant development therefore depends on establishing the effect of these factors on the relationship between chronological and physiological time (aging or phasic development).

This analysis is based on data published by others, and long term average temperature records obtained from the Bureau of Meteorology. The data are analysed to derive a function that better reflects plant response than the linear functions normally used. This function is used to derive an estimate of the base temperature, and the date for the commencement of physiological development, as well as the durations of the different growth phases.

Methods

Coombe provides a table that identifies dates for budburst, flowering, and harvest for the main varieties of viticultural grapevines, and these provide the reference data. Only Shiraz was analysed as this is the largest dataset. Coombe does not provide a harvest date for Shiraz for Loxton where the harvest date for Grenache was used: the budburst and flowering dates for these varieties were essentially identical at Loxton.

The analyses are based on long term average monthly temperatures for meteorological stations near the locations identified by Coombe. Some locations did not have meteorological stations (Eden Valley, Tabilk), and the relationship between the meteorological station used and the

[1] There is a common physical basis to vernalisation and requirements such as the need to store food below 6C that will be addressed elsewhere. The correct temperature is 6C.

vine observation site was similarly uncertain for others. Moreover, the Coombe results were obtained over a brief period when the temperatures need not have been indicative of the long term average. These constraints introduce considerable uncertainty.

The calculations were based on daily increments in HDD due to the use of a nonlinear relationship. To obtain daily temperatures it was assumed that temperature changes linearly across each month. This approximation would have little effect on the absolute result and no effect on comparisons between methods.

The results are compared with those of Gladstones who provides harvest dates for 7 categories of vines for all wine regions in Australia. The base method of Gladstones was used here with a baseline temperature of 10 degrees, a linear increase in response to 19 degrees, and a constant response at higher temperatures.

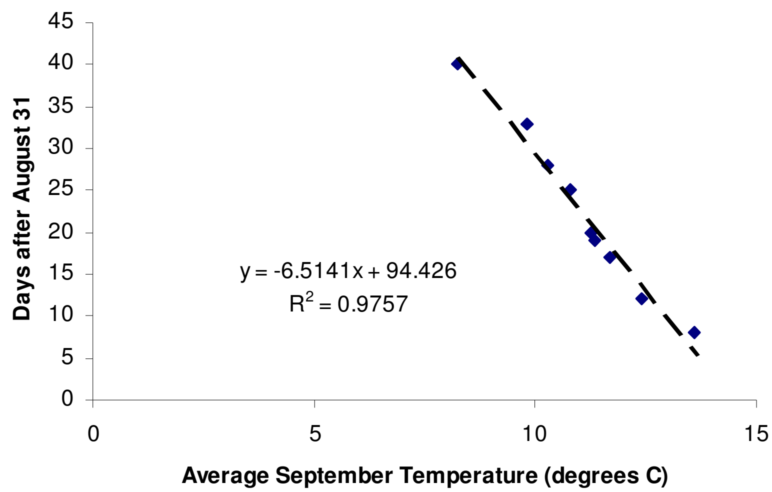

Fig. 1 Relationship between the average September temperature for the different locations and the date for budburst given by Coombe.

Results

Plotting the budburst date against the average September temperature for the different locations (Fig. 1) identifies a linear relationship. This regression illustrates the strong relationship between temperature and phasic development and allows prediction of budburst date from the mean September temperature.

While Fig. 1 indicates a linear relationship between plant physiological development and temperature, plotting the relationship between the HDD between budburst and flowing, calculated using the Winkler method, identifies that the rate of plant development is likely not linearly related to temperature (Fig. 2). The plant response to an incremental increase in temperature is higher at low temperatures than at high temperatures. It takes fewer HDDs to go from budburst to flowering at cooler temperatures than at higher temperatures.

The decline in the level of response of physiological development to incremental increase in temperature can be characterised using different numerical functions. While a second order polynomial provides a good approximation, the function used here takes the form of:

$$(1 - F\,T)\,T \qquad \text{-------------- (1)}$$

Where T is the temperature above the baseline, and F is a factor controlling both the decline in the rate of aging increase with increase in temperature and the maximum rate aging.

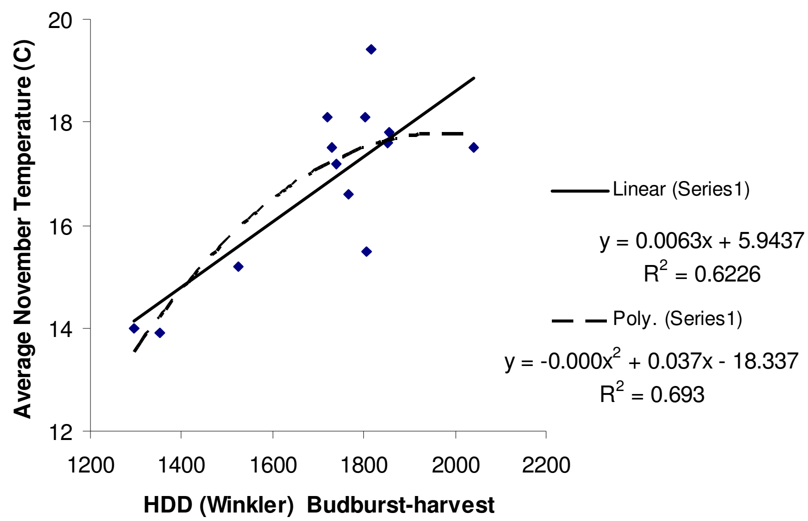

Fig. 2. Heat Degree Days from budburst and flowering for Shiraz (Coombe data) and the average temperature for November. HDD calculated using the Winkler method.

The rationale for the development of this function cannot be recalled but derives from the results given in Fig. 2. The function is effectively linear at very low values of F but, over the range of F values relevant to plant development, asymptotes to a maximum and then declines (Figure 3). Also, the function is close to linear at low temperatures. This function has benefits over the use of a second order polynomial as the response is defined by a single parameter.

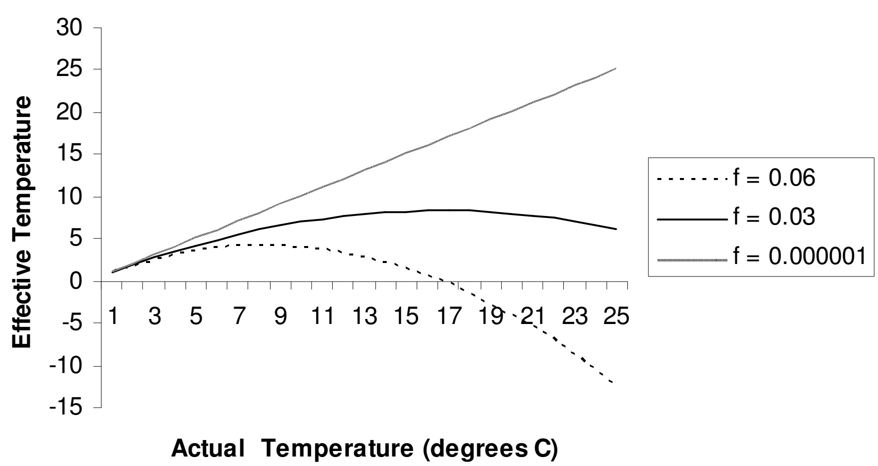

Fig. 3. Function used to characterise the nonlinear relationship between ageing and temperature. Effective Temperature = (1 – F * Actual Temp.) * Actual Temp.

The Coombe data for the intervals between different plant growth phases was used to optimise estimates of F and the baseline temperature. As there are two unknowns and only one measurement there is no explicit solution. The optimum values were therefore obtained through successive approximation using iterative changes in values and statistical testing of the results. The selected best combination of F and baseline temperature showed least difference between observations and predictions.

This testing identified a baseline temperature for Shiraz of close to 5.5C, and an F value of 0.033. The analysis is sensitive to these parameters with baseline temperatures of 5 and 6C providing a poorer result than 5.5. A value of F of 0.033 provided a significantly better fit than 0.03.

With these values the temperature for the maximum increment in HDD is around 21C compared with the 19C used by Gladstones. Also, the increment to HDD declines with increase in temperature above 21C when it is constant with the Gladstones method.

Application of this non-linear relationship between temperature and aging allows backward projection of the HDD leading up to budburst. Fig. 4 plots this for calendar days. The Canberra results indicate that the heat degree days from the commencement of physiological activity to budburst cannot be greater than 200 as Canberra winters are sufficiently cool for there to be no gain in HDD over July.

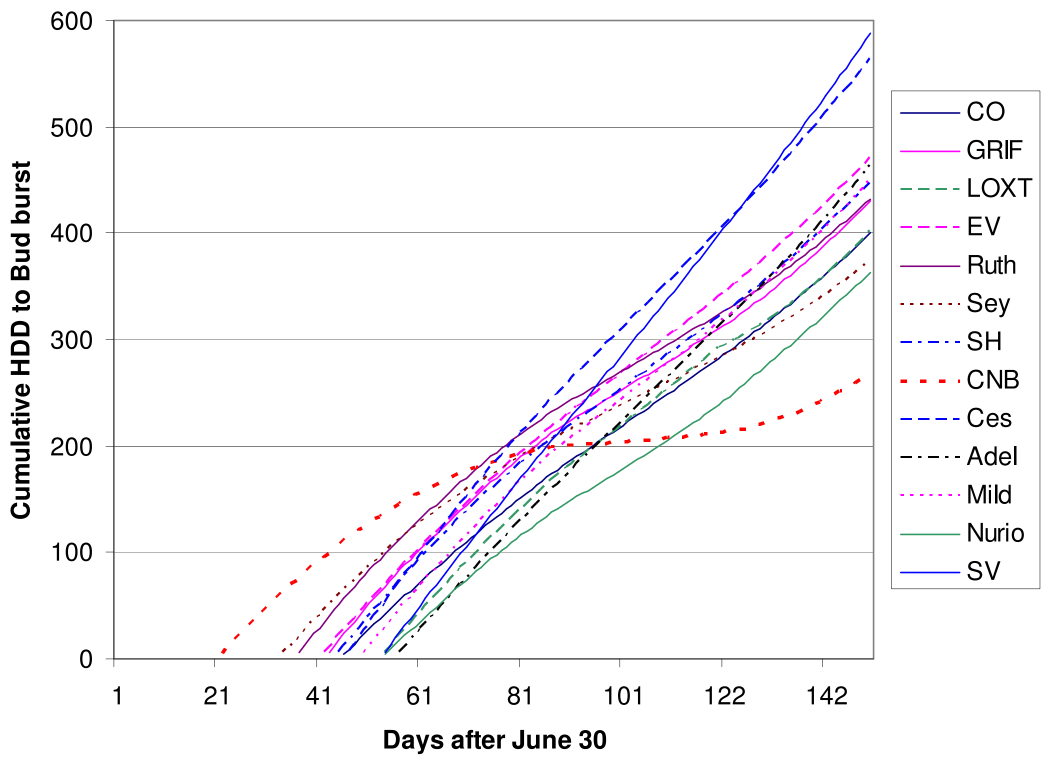

Fig. 4. Backward projection of HDD from the Coombe date for budburst using the equation 1 with a baseline temperature of 5.5 C and F = 0.033.

Examination of the results in Fig. 4 identifies that a HDD of 200 projected backwards from budburst occurs around August 1 for all locations. August 1 was therefore taken as being the commencement date for physiological activity, or time zero. This use of a single date for the commencement of growth at all sites can be valid as physiological activity is likely triggered by an increase in daylength, and change in daylength would show little variation over the range in latitudes of sites used in this study.

Calculations of HDD using F=0.033 and a 5.5C baseline were obtained using August 1 and the Coombe budburst date as the starting points, and the Coombe dates for flowering and harvest as the endpoints. This gives the HDD requirements for the different growth phases for comparison with the observations reported by Coombe (1988), and the methods of Gladstones

(1992) and Winkler (Amerine & Winkler, 1944). Comparisons with the Coombe data only demonstrate how well the modeling reproduced his field results.

Table 1 Duration in days for the different growth phases. A: Coombe data, B: non-linear prediction using the Coombe budburst date, C: non-linear prediction using and August 1 start date.

	Budburst		Flower			Harvest		
	A	B	A	B	C	A	B	C
Coonawarra	48	52	123	120	123	256	242	269
Griffith	51	48	106	110	108	217	232	206
Loxton	40	44	96	102	106	230	222	224
Eden Valley	52	48	128	140	113	253	234	230
Rutherglen	57	51	116	117	113	229	239	232
Seymore	60	59	124	124	124	250	243	249
Swan Hill	49	47	109	110	109	223	229	214
Canberra	71	69	131	136	138	260	259	259
Cessnock	47	39	99	104	98	211	244	217
Adelaide	38	43	114	102	106	223	221	223
Mildura	44	44	98	104	105	215	224	223
Nuriootpa	40	51	113	110	118	221	228	235
Swan Valley	40	38	102	101	99	236	223	220
Average	49	48.7	112.2	113.8	112.3	232.6	233.8	230.8
SED	9.47	8.31	11.79	12.94	11.14	16.80	11.16	18.21

Table 1 compares phasic development periods predicted using equation 1 with the development times given by Coombe. The average days for the different phases are effectively the same for the observations and predictions, and the levels of variation about the mean are also similar. While the prediction is well optimised this is not achieved by smoothing the data. Table 2 gives the predicted HDD requirements for the different phases.

Table 3 compares predictions of the HDD requirements of Shiraz obtained using different methods. Using the measured budburst date as reference the non-linear method provides better results than the August 1 start date for the early growth periods, but there is no difference in the estimate of the harvest date. The discrepancy between the predicted and actual harvest dates is less than the difference between the results of Coombe and Gladstones.

Table 4 presents the variations in estimates of the HDD requirements for grape maturation to harvest. Ideally the estimates should be the same for all locations, hence the variance identifies the level of error in the method. The Winkler method provides the worst result. The Gladstones method is similarly bad but only when tested against the results he provides. The evaluation of the Gladstones method is greatly improved when tested against the observations of Coombe. The best result is given by the non-linear prediction using August 1 as the start date.

Table 2 Heat Degree Days (HDD) for phases of vine development. Calculated from Coombe dates and equation 1 (baseline temperature 5.5C, F=0.033).

	August 1-Budburst	Budburst-Flower	Flower-Harvest	Budburst-Harvest	August1-Harvest
Coonawarra	181	436	975	1412	1544
Griffith	223	382	821	1204	1423
Loxton	182	367	1011	1378	1507
Eden Valley	229	509	946	1455	1673
Rutherglen	241	408	835	1242	1477
Seymore	214	411	950	1362	1566
Swan Hill	219	406	859	1266	1479
Canberra	195	375	949	1324	1524
Cessnock	256	372	836	1208	1461
Adelaide	181	506	823	1330	1498
Mildura	207	364	878	1242	1443
Nurioopta	151	438	817	1256	1407
Swan Valley	222	419	993	1413	1630
Average	208	415	899	1315	1510
Standard Dev.	28.8	48.0	72.5	84.4	77.9

Table 3 Difference between measured (Coombe) and predicted dates in days for budburst, flowering and harvest (equation 1, base temperature 5.5C, F=0.033). The Coombe-Gladstones column compares their results for harvest dates. The % error is the twice the SED divided by the average duration of the phase.

Phase	Budburst	Flower		Harvest		Coombe
Start date	Aug. 1	Budburst	Aug. 1	Budburst	Aug. 1	Gladstones
Coonawarra	4	-3	0	-14	13	6
Griffith	-3	4	2	15	-11	-7
Loxton	4	6	10	-8	-6	-26
Eden Valley	-4	12	-15	-19	-23	22
Rutherglen	-6	1	-3	10	3	-5
Seymore	-1	0	0	-7	-9	-20
Swan Hill	-2	1	0	6	-9	-10
Canberra	2	5	7	-1	-1	-34
Cessnock	-8	5	-1	13	6	-4
Adelaide	5	-12	-8	-2	0	-13
Mildura	0	6	7	9	8	2
Nurioopta	11	-3	5	7	14	15
Swan Valley	-2	-1	-3	-13	-16	-19
Average	0.17	1.6	0.08	-0.31	-2.4	-7.2
Standard Deviation	5.1	5.9	6.7	11.2	11.2	15.9
Average interval	49	114	112	234	231	233
% Error	20.6	10.4	12.0	9.5	9.6	13.4

Overall, application of the non-linear method allows prediction of harvest dates to within 3 weeks at a 95% probability. Around 80% of occurrences would be correct to within two weeks. This is sufficiently reliable to be useful, particularly when the variation in the times of harvesting are considered. Harvesting is often staggered to obtain fruit with different qualities.

Table 4 Heat Degree Days (HDD) for vine development to harvest using different methods. All use an estimate of the date for bud burst for the start except where otherwise identified.

	Gladstones method & dates	Gladstones method, Coombe dates	Winkler method, Coombe dates	Non-linear Coombe	Non-linear August 1 start
Coonawarra	1287	1255	1295	1412	1544
Griffith	1265	1310	1804	1204	1423
Loxton	1246	1480	1852	1378	1507
Eden Valley	1652	1535	1766	1455	1673
Rutherglen	1358	1403	1857	1242	1477
Seymore	1270	1423	1526	1362	1566
Swan Hill	1263	1353	1730	1266	1479
Canberra	1130	1328	1351	1324	1524
Cessnock	1279	1315	1816	1208	1461
Adelaide	1227	1344	1739	1330	1498
Mildura	1323	1305	1721	1242	1443
Nurioopta	1494	1359	1806	1256	1407
Swan Valley	1308	1479	2042	1413	1630
Average	1315	1376	1689	1314	1510
Standard Dev.	130	82	208	84	78

Discussion

The Winkler method gave very poor results. The Gladstones method provided good results when evaluated using the harvest dates of Coombe. However, as Gladstones used an arbitrary reference date for budburst (October 1) that was almost invariably incorrect, the apparently good result can only arise through compensating errors.

The non-linear 5.5 baseline result is the best and maintains the same level of variability as the original data (does not smooth the result). This may simply reflect the testing of the model against the data used to develop it. However, the prediction based on August 1 as start date is better than when using the budburst date of Coombe. This indicates higher uncertainty in the observed Coombe budburst date than the August 1 date. Moreover, the method presented allows prediction of time for the commencement of physiological activity in a deciduous perennial, and may be applicable to addressing the phasic development of all perennials.

The results would likely be improved by the use of observations of phasic development obtained in conjunction with daily vineyard temperatures. However, the main consequence of improved data will be a reduction in variability and hence an improvement in confidence. It need have little effect on the functional relationships.

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