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FACTORS INFLUENCING PRIMARY BUD DEVELOPMENT AMONG DIFFERENT *VITIS* CULTIVARS

By

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ABSTRACT

FACTORS INFLUENCING PRIMARY BUD DEVELOPMENT AMONG DIFFERENT VITIS CULTIVARS

By

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Spring bud development of seven grape cultivars was observed for three years in several vineyards. The cultivars were compared and ranked according to rate and earliness of growth.

An attempt to use weather data as a predictor of development was made. Several heat unit formulae were statistically tested but only the number of days over threshold temperatures of 50°F and 45°F and time were found to be good predictors of bud burst.

Fall pruned and spring pruned 'Concord' vines showed little difference in bud development. Only when the canes were left long (more than 15 nodes) was growth retardation of 2-3 days observed. Horizontal canes developed more rapidly than vertical canes.

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TABLE OF CONTENTS

	Page
LIST OF TABLES	vi
LIST OF FIGURES	iv
INTRODUCTION	1
LITERATURE REVIEW	2
Plant Structure and Function	3
Role of Dormancy	6
Phenology Models	8
MATERIALS AND METHODS	13
Direct Comparisons and Ranking	13
Predictive Models	16
Histograms	20
Cultural Factors and their Effect on Concord Development	21
RESULTS	22
DISCUSSION	30

LIST OF TABLES

Table		Page
1.	Cultivars, vineyards, and years used in this study . .	14
2.	Origin of weather data used	19
3.	Percentage of buds in each of the developmental categories at Tabor Hill Vineyard in spring of 1980 . . .	35
4.	Percentage of buds in each of the developmental categories at HRC Vineyard in spring of 1980	36
5.	Percentage of buds in each of the developmental categories at Sodus Vineyard in spring of 1980	37
6.	Percentage of buds in each of the developmental categories of Sodus Vineyard in the spring of 1979 . . .	39
7.	Table of H.D. Days for each cultivar, vineyard, and heat unit formula at the date when each has 50% of buds at burst	41
8.	Ranked onsets of growth in 1980	42
9.	Ranked rate of bursting in 1980	43
10.	Onset of growth in 1979	44
11.	Classification of growth onset and rate in 1978 at SHRS .	45
12.	Comparison of percentage of buds per developmental category on the same dates, same year, and cultivar at different vineyards, 'Baco Noir' and 'Seyval' . .	46
13.	Comparison of weather conditions in 1980 and 1981, for the cultivars at the Sodus HRS for the last observation date in April and an observation date in early May	47
14.	Effect of time of pruning and cane length on winter kill of 'Concord' grape buds, percent dead primaries .	48

Table		Page
15.	Effect of spatial orientation of canes on phenological devevelopment of 'Concord' grape buds	49
16.	Percent primary buds at dormant or scale crack stages .	50
17.	All pair-wise comparisons using Tukey's H.S.D. test for unbalanced replication	51
18.	Coefficients of variation for all cultivars	52

LIST OF FIGURES

Figure		Page
1.	Calculations of heat units using four methods for an example day	17
2.	A-P. Percentage of buds at burst are shown versus dates of observation. The cultivar and year are shown for each figure	53
3.	Coefficient of variation for daily max-base versus base temperature. The lowest C.V. gives the best base temperature to use for a given cultivar	62
4.	Coefficient of variation for daily mean-base versus base temperaures. The lowest C.V. gives the best base temperature to sue for a given cultivar	62
5.	Coefficient of variation for number of days over the base. The lowest C.V. gives the best base temperature to sue for a given cultivar	64
6.	Coefficient of variation for Lindsay and Newman heat units. The lowest C.V. gives the best base temperature to use for a given cultivar	64
7.	Using 'Baco Noir' as an example, the different models are compared using the C.V. at the 45° threshold. The lowest C.V. gives an indication of the best model to use for the cultivar and threshold	66
8.	Using 'Aurore' as an example, the different models are compared using the C.V. at the 45° threshold. The lowest C.V. gives an indication of the best model to use for the cultivar and threshold	66
9.	Using 'De Chaunac' as an example, the different models are compared using the C.V. at the 45° threshold. The lowest C.V. gives an indication of the best model to use for the cultivar and threshold	68
10.	Percentage of buds in each developmental category at Table Hill vineyard in the spring of 1980	70

Figure Page

11. The percentage of buds in each developmental category at Tabor Hill vineyard in the spring of 1980 . . . 72

INTRODUCTION

Michigan ranks fourth in the United States in grape and grape products production (59). In 1981, Michigan growers harvested 53 thousand tons of grapes which sold for $14.4 million (27). The value of the grape crop has been modestly increasing through the years due to inflation and a shift toward growing the more valuable wine grapes. Although the acreage devoted to grape production is shrinking, the value of Michigan's crop is increasing. With such a valuable crop, growers are increasingly interested in frost protection systems to reduce damage from late spring frosts. To economically operate protection systems, the cold hardiness of developing grape buds must be known and development must be able to be predicted based on easily measurable environmental factors.

This research was undertaken to compare spring development of the standard cultivar, 'Concord' with recently introduced grape cultivars, to test the accuracy of several heat unit models used to predict primary bud development, and to evaluate cultural practices and how they affect bud development in 'Concord'.

REVIEW OF LITERATURE

The prediction of spring bud development in the grapevine would be an asset to the growers in Michigan. This state has become notorious for having late spring freezes after long periods of mild weather. The warm days initiate bud expansion and a late spring freeze can devastate the crop for that season by damaging the buds. The premise for this research lies in the different hardiness levels of the bud development stages. When buds are dormant, they are far more resistant to cold injury than after they begin to open in the spring. The more advanced the developing bud, the more sensitive it is to freezing temperatures (33). For example, buds at "full swell" were reported to withstand -4.5°C while dormant buds can withstand much lower temperatures (31).

As many new grape cultivars become commercially important, it is desirable to quantify the differences between them. This has been done in other crops such as apples (5). An accurate estimate of apple bloom can also assist with spray planning, thinning programs, work crews, and blossom festivals.

In addition to helping plan spring work, there is an indication that the harvest time is based to a large degree on the date of bloom in apples (5). Therefore, the timing of early spring development of the flowers and small fruits was found to be more effective in determining harvest time than weather occurring in the middle of summer (20).

There is evidence that a similar pattern of growth exists in grapevines as well. The first 100 days of the growing season after April 1 seem to be the most important for determining harvest time (55).

For Michigan, the ideal grape cultivar would be one that begins development rather late in the spring, (when there is less chance of a spring freeze) and develops rapidly. Breeders of new grape cultivars may be able to select seedlings having these characteristics (31). A better understanding of the interactions between spring temperatures and bud growth and development would be a boon to both growers and students of phenology.

Plant Structure and Function

Woody species in the temperate zone must respond to seasonal changes in their environment. They have adapted by becoming dormant in the winter. Woody species must have a mechanism to survive the cold and still flower and fruit in the summer season. The plants we usually think of as commercially important fruit producers, all flower in the spring and have the summer to mature their fruits. Unlike the tree fruits, woody vines, such as grapes, have a growth habit resulting from a strong apical dominance. Because of the nature of their growth pattern, the apical buds on *Vitis* canes begin growing first, and development continues proximally from the distal end of the cane (6,7).

The roots may have an input to spring bud development by mechanical action. Roots do not undergo a dormancy like the upper

part of the plant (51). They continue to grow until they get too cold and resume growth when the ground thaws. The first stages of bud development are probably the result of water coming into the bud and making it swell. Roots themselves cannot initiate development if the tops of the plants are still unprepared; they must work together with the crown and trunk and buds.

The crown and trunk are exposed to the elements and appear to enter a rest period (51). They must receive a minimum amount of chilling before they are capable of serving the buds. Esau observed the plugging of the phloem tubes as the plants went into winter (26).

Even with these and other changes, the primary emphasis is on the buds as the "seat of rest" (51). The buds grow after the crown and trunk are active again. It is common to prune dormant grapevines on a warm day and see the spring flush of sap dripping from the fresh cuts. The vine is active at this stage, yet the buds appear dormant.

If the buds are the seat of rest and growth, it is appropriate to review their morphology. In the grapevine the buds are mixed, that is, they contain both flower and shoot primordia (59). At the node, there is usually a compound bud, having both a primary and secondary bud along with a less well developed tertiary (54). Stergios and Howell studied the various degrees of cold hardiness in these three bud types (54), and noted that the primary was the most fruitful and least hardy, while the secondary and tertiary buds were less fruitful and more hardy. The hardiness levels can differ by as much as 10°C between the primary and secondary buds.

The primary bud develops first and represses the development of the secondary and tertiary companion buds. When buds open in the spring, the shoot which will arise from it is mostly differentiated. The apex of the flower clusters may, however, be a disorganized mass of meristematic cells (59). The shoot begins organization in the bud the summer before it will emerge. The first initiation of clusters begins in early June in California (59). The meristem becomes bilobed as a cluster is differentiated. One lobe becomes the cluster and the other continues as the growing point (59). This is the fundamental process resulting in the zig-zag or sympodial growth form of grape canes.

Flower differentiation in the grape is regular. The first thing to be organized is the calyx tissue, then the corolla, then stamens, and finally, the pistil. Vitis flowers have two carpels, from which four ovules arise. The ovary is epigynous and flower parts are in fives (32).

As buds begin to develop, the apical dominance of the plant dictates that the distal buds open first. Buds along a cane operate in pairs, on the same side of a cane. Pairs develop together, opening at the same time (8). As the buds develop, they pass through distinct stages named by Baggiolini (13). The first stage is the dormant stage (D). The second stage, called scale crack (SC), is characterized by the parting of the bud scale and emergence of the leaf rolled inside. The next two stages are swell one and well two (S1, S2). Swell one has a globular bud of a doeskin color. Swell two is tinged with pink and is 1.5-2.0 times longer than it is wide.

The burst stage (B) is defined as the dehiscence of the bud, exposing the first flat leaf.

Role of Dormancy

In order not to use confusing or ill-defined terms in the paper, I will use terms as defined by Samish (51). Dormancy is the "temporary suspension of visible growth . . . without regard to its cause." There are two reasons why a plant may be dormant. The first may be extremely harsh external environmental factors, such as drought, high or low temperatures, etc. This type of dormancy caused by external factors is called quiescence.

The second kind of dormancy is caused by internal factors. Even in mild weather, for example, unchilled grape buds will not grow until their chilling requirement has been satisfied. This is called the resting state. The term rest specifically excludes dormany caused by internal factors (within plant), but external to the bud. This type of dormancy has been called correlated inhibition. An example would be the dormancy imposed upon a basal bud by active apical buds.

The entrance of woody plants into rest is preceded by quiescence as the result of environmental factors like short days of autumn or freezing temperatures. From quiescence, the buds move into preliminary rest. In this state, buds will not grow if returned to a favorable environment, but can be easily forced by cold, heat, wounding, anesthetics, etc.

As time goes on, the buds enter mid-rest. It is very difficult to force buds in this state to grow. Even if they can be prompted into some response, it is often minimal or abnormal.

The buds later move into a state called after rest, which has the same characteristics as preliminary rest. Usually, this is followed by another quiescent period. The last quiescent period is often called induced or imposed dormancy. These stages of dormancy have been described in many woody species (14,36,61,43,12,37).

In most woody species, rest must be broken by a chilling period. The chilling requirement is defined as a period of cold with or without interruption, necessary for the resumption of normal growth. The length of time needed to break dormancy varies with the species of plant and variety.

In the grape, a new shoot emerges from a bud, and that shoot expands to eventually create buds of its own in the leaf axiles. The newly created buds are rarely seen to grow until they have passed through a winter. Under artificial conditions where the growing points and lateral shoots were removed within six weeks of bud break, they can be forced into growth (1). This is a good example of correlative inhibition.

In most cases, however, the canes continue to grow until the weather becomes too cold. The buds then enter quiescence, preliminary rest, mid-rest, and after rest. Many workers have tried to pinpoint the number of hours needed to satisfy the chilling requirement of grapes. This is the same as trying to find where after rest ends and induced dormancy begins. The answers vary due to variety differences, different ways of evaluating the buds and even factors such as whether or not the vines have been pruned.

The number of chilling units required by _Vitis labrusca_ 'Concord' have been reported as follows: 830 chill units (C.U. = 1 hour exposure at 6°C) in Utah (57), over 1400 hours in a growth chamber (39), 2,070 hours below 32°F or 3,580 hours below 45°F in Cornell, New York (34). Other varieties of grape such as Thompson Seedless (56), Carignane (15), or various _V. vinifera_ have been studied with much variation observed. In species other than grape, there is just as much disagreement. Several varieties of peaches are discussed by Richardson, et al. (48) and Maxwell, et al. (40). Eggert studied the chilling requirement for twelve apple varieties and eleven species of fruit (24).

Once the chilling requirement of various fruit varieties and species is defined and known, important decisions can be made (48). One can determine if there will be enough low temperature during winter to sufficiently chill certain fruits in a given geographical area. (This is often a problem in the southermost ranges of temperate fruit.) One can also decide when to begin accumulating growing degree days used in predicting bud development and fruit harvest (16,52,11, 19,49,6). One can also determine when plants are in need of artificial cooling from sprinklers to delay bloom by determining when plants begin to lose their cold hardiness.

Phenology Models

Many factors affect the spring development of buds in the grapevine. Presumably, the factor with the most impact is air temperature (28,47,52). Other workers stress the importance of

photoperiod, stating that it is the interaction of temperature and photoperiod that cause buds to open (18,21). In Quercus, it has been shown that bud opening is dependent upon the history of irratiation they have received, that is, buds differentiated in the shade open before those that differentiated in the sun.

The importance of soil moisture and photoperiod in bud development has been disputed (28,53). Generally speaking, as long as adequate moisture and warmth are given, the buds will develop. Changes from year to year in the timing of bud opening cannot be accounted for by photoperiod and soil moisture (38,53).

Some workers have adopted the holistic approach, naming a great many environmental and genetic factors that govern bud development in woody species. The factors most often studies are air temperture, soil moisture, light, and humidity (17,52). The author would also add genetically controlled enzyme systems (45) which would create differences among cultivars and species, chilling history (57), and nutrient status (38).

Since air temperature apparently has the greatest effect on bud development, most predictive models are temperature related (5,10, 11,9,14,19,23,20,25,30,38,44,49,50,53,55,58). They all involve the summation of degrees of temperature and time, giving a dosage of heat and time with response recorded as bud development (30).

The most accurate of the models use an hourly (or continuous) temperature reading and a growth threshold or base temperature. Time spent below the base is considered ineffective for plant growth. The

area under the curve but above the base is the dose the plant receives (38,19,10,5,11,49). In all the models, growth is approximated as linear as temperature increases because growth constants are unavailable for most woody species (25).

Other methods of accumulating temperatures use daily maximums instead of hourly readings, arguing that this method introduces little additional variation (14,53,44).

Successful models for a variety of crops were reviewed by Anstey (5). Included are the following formulae:

1. Summation (daily maximum minus base).
2. Summation (daily mean minus base).
3. Mean monthly temperature minus base x number of days.
4. Photothermal units (same as 1 and 2 but temperatures are effective only when the sum is up).
5. Summation (minimum/base) x (maximum-base).
6. Efficiency degree days using Van't Hoff and Arrhenius rule.

The most successful formula for apple, pear, cherry, peach, and apricot was proved to be the first, using summation of daily maximum temperatures above the base. The most ineffective system proved to be efficiency degree days.

In deciding which model is most appropriate for a crop, the most important criterion to measure is the amount of variability of the number of degree days required to get a standard response. The two ways variability has been measured are the standard deviation from the mean for the degree-hour sums for the different years, and the

coefficient of variation (S.D. as percent of mean) (38,14,44,10,5,9, 11,49). The standard deviation of the temperature is considered important. This is done for ten-day periods beginning at the date of burst and progressing backwards to February 1. (For example, February 1 through June 10 equals 130 days worth of temperature accumulation.) The formula with the least amount of variation was selected as the model for the crop (38).

When several years worth of data are available, the date when temperatures should begin to be accumulated can also be found (38). Summations are made using various starting dates and the date giving the least variation is used.

The use of the coefficient of variation to determine the date after which temperature should begin to be accumulated has been debated (9,38). The criticism of the use of this statistic has been based on the dependence of it on the mean values. An advancement in starting date increases the mean and thus reduces the C.V. When the C.V. is plotted on a graph versus the number of days heat units are summed, the relative rate of change can be observed. The C.V. is the proper statistic to use and is preferred to the S.D. when judging the amount of variability in days (9).

The third way to decide when temperatures should begin to be accumulated is based on the physiological state of the plant (36,52, 11,49,63). The argument is made that the plant cannot begin to respond to warming spring temperaures until the chilling requirement has been satisfied. The use of chronological landmarks are not appropriate since the chilling requirement can be satisfied early or late

in the winter. As much as a two-month difference in emergence after rest in peach has been observed in Utah (49). It appears that the best way to determine the date to begin heat unit accumulation is based on the physiological state of dormancy the plant has reached.

The growth thresholds of many woody plant species have been determined graphically using both S.D. and the C.V. methods similar to those just described. The S.D. or the C.V. is plotted versus the various threshold temperatures used to calculate heat unit summations. A graphical interpretation gives the base temperature with the least variability (38).

An experimental approach to determining the base temperature used low temperatures in growth chambers (5). The advantage of this approach is the direct evaluation of the plant's physiological status.

The field observations and their interpretations that follow use some of the techniques presented here to compare models of growth, varieties, and threshold temperatures.

MATERIALS AND METHODS

This study consisted of four parts. The first involved careful observation of bud development of different cultivars, in different vineyards for three years. Ranking by cultivar, vineyard, and year showed a direct comparison of bud development.

The second portion of the study used statistical methods to attempt to predict certain stages of bud development based on growing degree days. The F max test by Bartlet was used to ascertain whether or not grape bud development was related to accumulations of heat units of several types.

The third section was devoted to histograms showing percentages of buds in developmental categories and how the percentages changed as time progressed. In addition, a fourth study of cultural manipulations and how they effect bud development was done.

Direct Comparisons and Ranking

The cultivars studies were 'Aurore', 'Baco Noir', 'Concord', 'De Chaunac', 'Seyval', and 'Vidal'. The vines evaluated were planted to an 8" spacing within the row and 10' between rows and were at least eight years old, in good health, and pruned to a balanced pruning formula appropriate to the cultivar. 'Concord' and 'Baco Noir' were pruned to a 30 + 10 formula and all others were pruned to 10 + 10.

All canes used for evaluation were 8 nodes in length, coming from a bilateral cordon on the top wire at a height of 1.8 meters.

The exception to this is 'Baco Noir' at the Tabor Hill vineyard which was trained to a Geneva double curtain trellis at a height of 1.8 meters.

A list of the cultivars, their corresponding vineyards, and years evaluated is shown in Table 1.

TABLE 1.--The seven grape varieties studied are shown versus the five vineyard locations used. Not all varieties were grown at all locations. The years that spring data was taken are shown in the body of the table for a variety and location.

Varieties	Locations				
	MSUHRC	SHRC	Warner	Lawton	Tabor Hill
Aurore		1978,'79,'80	1980		
Baco Noir		1978,'79,'80			1980
Concord	1978,'80	1978,'79,'80		1980	
De Chaunac	1980	1978,'79,'80			
Seyval		1978,'79,'80			1980
Vidal		1978,'79			1980
Vignoles	1980	1980			

The bulk of observations were done at Sodus Horticultural Research Station of Michigan State University (SHRS), in Sodus, Michigan. Data were also taken at the Horticulture Research Center of Michigan State University (HRC), located in East Lansing, Michigan.

In Lawton, Michigan, both the Warner vineyard and the vineyard of the William Cronenwett family (designated the Lawton vineyard) were studied. The Tabor Hill winery is located in Buchanan, Michigan.

Bud development was recorded as frequency data similar to the system used by Baggiolini (13), Weeks (57), and Johnson (33). The categories are abbreviated by a notation as follows:

D --Dormant, showing no growth or swell.
SC--Scale crack, showing a break of the bud scales and a slight visible shoot.
S1--Swell 1, earlier swell stage, globular.
S2--Swell 2, later swell stage with much more elongation than S1, length 1.5 times longer than wide.
B --Burst, stage when the first leaf comes away from the surface of the bud.

The total number of buds observed is given in the tables reporting the data for 1980 observations. In 1979 100 buds were selected at the outset of the observations and the number observed decreased due to bud loss during the experiment. Percentages of remaining buds were given in the 1979 data.

At the same vineyard, in the same year, the cultivars being grown together were compared directly. From the developmental data, ranking of cultivars by onset and growth rate was done. Onset was defined in two ways. Since the easiest stage of development to identify in the field is B, and there is therefore, less chance of error, the onset of burst was given importance in comparing growth. Growth really begins far earlier than the eye can detect it, so in addition to onset of burst, the first bud observed in the swell one category was used to help compare onset of growth in the cultivars.

The second facet of growth examined was the rate of burst. This was determined by the slope of the line on a graph showing percentage of buds recorded at burst versus time in days. The slopes were used in conjunction with the onset data to develop a simple ranking of cultivar growth for each vineyard and year.

The variation introduced by the different vineyards and years was compared directly in tables showing the frequency data collected. For vineyard comparison, Sodus and Tabor Hill vineyards were compared directly using 'Baco Noir' and 'Seyval' data because the two vineyards had those cultivars in common.

Weather conditions in 1980 and 1981 were compared directly using data at SHRS by comparing 'Aurore', 'Baco Noir', 'Chelois', 'De Chaunac', 'Vignoles', and 'Seyval'.

Predictive Models

Using the same development data from the previous observations, an attempt was made to predict stages of development based on temperature and time-related models. Four models based on temperature were used. The Lindsey and Newman model (38) attempted to estimate the amount of time spent above a threshold of growth. For example, with a maximum of 90°F, a minimum of 45°F, and a threshold (or base temperature) of 50°F, the Lindsey and Newman model was the area of the triangle over the threshold to give the number of heat units per day. The triangle's base is 24 hours long, its height is the daily maximum minus the daily minimum. The area of the triangle gives the heat units (38). The other models used were daily maximum minus the base,

daily mean minus the base and number of days over the base. These models are compared for an example day in Figure 1.

For an example day, with a maximum of 90°F and a minimum of 45°F, the different models deliver a wide variety of heat unit figures, ranging from 426 units to 1 unit.

← 90° maximum

← 50° threshold (base)

← 45° minimum

← 24 hrs. →

Diagram used for Lindsey and Newman units only.

Example Day with

Maximum = 90°F
Minimum = 45°F
Growth threshold = 50°F
(also known as base temperature)

MODELS

1. Lindsey and Newman: $(\frac{1}{2}(90-50) \times (24 \frac{(90-50)}{(90-45)} = 426$

2. Daily maximum-base = (90-50) = 40 units

3. Daily mean-base $\frac{(90+45)}{2} - 50 = 17.5$ units

4. Number of days over base 90° > 50° = 1 unit

Figure 1. Calculations of heat units using four methods for an example day.

In this study, the threshold temperatures examined were 45°, 50°, and 55°F. Since the item of interest was the variance of the cultivars in days, the models were equated by dividing the number of heat-time units it took for a variety to reach 50% B by the average daily accumulation of units. This gave a basis for comparison among the models and thresholds. Since the object of this study was to

determine the value of modeling based on temperature, the additional model of number of calendrical days from March 1 to 50% of burst was included for comparison. The thermograph was placed at Tabor Hill, HRC, and SHRS vineyards in 1980 only.

Weather data were taken with a thermograph having a seven-day clock mechanism and a chart recording pen. A maximum-minimum thermometer was used to assure precision and was checked at weekly intervals. In a few cases, missing temperature data due to mechanical or human error required that the weather data were estimated from the nearest weather station of the National Oceanic and Atmospheric Administration, the United States Department of Commerce, National Weather Service station's maximum-minimum readings. Table 2 shows the place of origin of the weather data used for the various locations and years.

The cultivars of grapes used were 'Aurore', 'Baco Noir', 'Concord', 'De Chaunac', 'Seyval', and 'Vidal'. The cultivar constituted the experimental treatment with the different vineyards and years making up the replications. The frequency data collected from all the vines within a vineyard were used to determine the one item of interest: the date on which one-half of that vineyard's buds, of a cultivar, were at burst. Different numbers of buds were used to determine that data, and these are reported on Table 7.

Using the weather data available for each vineyard and year, the number of daily heat units was claculated and summed from March 1 until the date of 50% burst. The heat unit sums are shown for location and date on Table 7. The variance within the cultivars was

TABLE 2.--Origin of weather data used to compare models.

Year and Dates	Location	Origin of Data
1978	Sodus, MI.	U.S. Dept. of Commerce, N.O.A.A. Weather Station, at SHRS
1978 3/1-3/31	Lansing, MI.	N.O.A. Weather Association, Lansing, MI.
1978 4/1-6/1	Lansing, MI.	U.S.D.C. Weather Bureau at M.S.U. Hort. Farm
1979 3/1-3/31	Sodus, MI.	N.O.A.W.A., Eau Claire Station
1979 4/1-6/1	Sodus, MI.	U.S.D.C.W.B. at SHRS
1980 3/1-6/1	Sodus, MI.	U.S.D.C.W.B. at SHRS and student's thermograph
1980 3/1-5/23	Buchanan, MI.	Student's thermograph at Tabor Hill Vineyard
1980 5/24-6/1	Buchanan, MI.	N.O.A.W.A., Eau Claire Station
1980 3/1-6/1	East Lansing, Mi.	U.S.D.C.W.B. at East Lansing, MI., M.S.U. Hort. Farm

calculated and recorded on Table 7 also. The variances were statistically tested using the F maximum test.

The means of the cultivars for each model were statistically tested using the Tukey test or honestly significant difference test (HSD) modified for unbalanced replication.

In order to aid the selection of appropriate thresholds of growth, the coefficient of variation was plotted versus the three thresholds considered. Then, using only the one threshold selected, the models for heat unit accumulation were compared with each other and with time.

One of the important questions asked in this thesis concerns the use of heat units to predict bud development. For the same number of heat units, and the same cv, is the development on that date the same for all vineyards and years? The comparisons that could be made were rather limited due to the fact that three observations of a cultivar at a particular heat unit accumulation point were considered minimum. Nevertheless, 'Vidal' was used first as an example variety because it appeared to respond to the most stable way, with the lowest variance of all the cultivars. Based on the outcome of the analysis of variance and the direct comparisons with 'Vidal', no other cultivars were used.

Histograms

A series of histograms of the stages of bud development at dates in the spring show the bud population distribution. Two cultivars, 'Vidal' and 'Baco Noir', were used. These histograms make it easy to visualize when frost protection measures would be the most cost effective.

Cultural Factors and Their Effect on 'Concord' Development

The time of pruning, cane length, and orientation were investigated to ascertain their effects on bud development. Five treatments were given 'Concord' canes at the Lawton, Michigan, vineyard in 1979-1980 fall through spring. The treatments were fall pruned to 8 node canes, fall pruned but left at 20 or more nodes, spring pruned to 8 node canes, spring pruned to the long canes (20+), and unpruned until

May 15, 1980. Developmental data were taken at 2-3 day intervals on nodes 1-8 throughout the 1980 spring using the D, SC, S1, S2, and B categories. Chi square analysis was done on the different treatments to test for significance at p = .05.

As an example of an analysis of variance using this data, the Tabor Hill, 1980, observations and Sodus, 1980, observations were used. The analysis of variance on May 13, 1980, compared 'Baco Noir', 'Vidal', and 'Seyval' at the same site and date. To change the categorical data into numerical for the analysis of variance, each developmental category was assigned a number from dormant being one through burst being ranked a five. The different cultivars observed at a vineyard were considered the treatment. The replications were the number of bud observations taken per cultivar.

RESULTS

Grape cultivars studied in the vineyards and years listed in Table 1 all had similar patterns of growth. Grapevines have a great tendency for apical dominance and this was very evident when taking bud development data. The canes, all pruned to 8-node length, developed proximally from the apical bud. The first set of tables (3 through 6) give the percentage of buds in each category for each cultivar on each data observed.

Table 3 shows 'Baco Noir', 'Vidal', and 'Seyval' in direct comparison at the same vineyeard and year. The number of missing buds slowly increased in most of these studies due to mechanical injury and insect damage. These data are particularly interesting because 'Vidal' and 'Baco Noir' are grown at the same site and clear differences can be seen in their development. 'Baco Noir' was so early that observations had to be started April 24, 1980, when more than 12% of 'Baco Noir' buds were in stage S2. 'Vidal' was first observed a week later and 53.4% of its buds were still in D. 'Seyval' was midway between the two. Nine observation trips to Sodus were required in the six-week period of study.

At the HRC, 'Vignoles' and 'De Chaunac' could be compared in the spring of 1980, as shown in Table 4. 'De Chaunac' appeared to be a faster developer than 'Vignoles'. On May 8, 1980, only 46.2% of the

'Vignoles' had reached S2 or B; but 97.9% of the 'De Chaunac' buds had reached S2 or beyond.

Table 5 shows how 'Aurore', 'Baco Noir', 'Concord', 'De Chaunac', 'Vignoles', and 'Seyval' developed as time progressed at the SHRS in 1980. 'Baco Noir' again was the earliest to begin growth. On May 5, 1980, 'Baco Noir' had 25.8% of its buds at burst, and only 'Concord' (with 4.6%) had any at that stage at all. Among 'Vignoles', 'Seyval', 'Aurore', and 'De Chaunac', it is difficult to say whether any were faster than the others. The first buds at B or beyond were noted for all of them on May 9, 1980, (although 'De Chaunac' had rougly 10% more at B than 'Aurore' and 'Seyval' and 13.6% more than 'Vignoles'). Comparing the four cultivars at early stages and lumping D and SC together, we see 'Seyval' way ahead with 20.2% beyond D and SC versus 'De Chaunac' with 5.7% beyond and 'Aurore' and 'Vignoles' with 0%.

Table 6 shows another comparison among 'De Chaunac', 'Seyval', and 'Aurore' in 1979 at SHRS. 'De Chaunac' was the first of the three to show bursting with 0.7% on May 8, 1979. In this case, 'Seyval' was not ahead of 'De Chaunac' in the early stages of D and SC. On the first day of observation, April 26, 1979, 'De Chaunac' had 44.9% beyond D and SC while 'Seyval' only had 12.7% and 'Aurore' had 0%.

Using the percentages available in Tables 3 through 6, Table 7 was created to summarize the growth onset data for the spring of 1980, within vineyard comparisons are shown first. The onset of growth was somewhat hard to define, so both the date of the onset of bursting and the date of the first observable growth (S1) were

compared. At Tabor Hill, in 1980, 'Baco Noir' was the fastest followed by 'Seyval' and 'Vidal', respectively.

At SHRS, seven cultivars were directly compared and ranked from fastest to slowest as follows: 'Baco Noir', 'Concord', 'De Chaunac', 'Seyval', 'Aurore', 'Vignoles', and 'Chelois'.

Only two cultivars were observed at M.S.U.H.F. in 1980. The variety 'De Chaunac' started growth before 'Vignoles', just as it did at Sodus.

At the bottom of Table 8 is a combination of the onset rankings taken from Tabor Hill, Sodus, and M.S.U. vineyards in the spring of 1980. With the possible exception of 'Aurore', the ranking is self-explanatory. 'Aurore' was given the slow to mid onset descriptor because even though the date of bursting put it into the mid category, the first S1 observed was late relative to the other cultivars.

The second facet of growth, besides onset, is the over-all rate. From the growth curves (seen in Figure 2), the slope of the line drawn through the point of inflection of the sigmoid curve was used to rank cultivars as shown on Table 9. By using the slope of the line, numerical comparisons could be made. 'Seyval', at Sodus in 1980, had a double sigmoid growth curve so both slopes were reported. One might think cultivars that have an early onset would develop slowly so the opening flowers would escape late spring frosts. One might think too that those cultivars with a late onset might have quick growth rates to compensate for their late start and assure that they have enough time to mature their fruits and seeds.

These grape cultivars were not, however, naturally selected. Characteristics that would insure survival cannot be dictated by the environment. The major theme running through the growth rate data in Table 9 is that the fast starters are also fast growers; the late starters are slow growers.

Table 9 shows the results of observations in the 1979 season in two vineyards (Sodus, Tabor Hill). All cultivars were beginning to burst within four days of each other.

Table 11 was adapted from Phenological development of different Vitis cultivars by Anderson, Howell, and Wolpert (2). The rate of growth is not comparable to rate defined in the previous tables. Rate in this case is defined by percentage of buds at B or beyond versus the number of days at 45°F or more. Note that instead of the trend seen earlier of early starters showing fast growth, this table shows early starters with slow growth and late starters with fast growth. This can be explained by the redefinition of the growth rate. An early onset cultivar has few days over 45° in which to grow in April. Many of the days over 45° are interspersed with cold days. The growth of grape buds is not controlled with a simple threshold switch and so the effect of the days exceeding the threshold was diluted by intermittent cold days. This may give support to the hypothesis that plants must remain at a relatively high temperature for a minimum period of time before growth begins in spring.

The onset of growth data does follow the trend noted in Tables 8, 9, and 10. 'Baco Noir' was the first to begin growth,

'Vidal' was the last, and the rest were not spectacularly early or late and very similar to each other.

So far the observations discussed have been based on percentages of buds in definite categories. Table 7 brings in another facet of spring bud development. Temperature has been used to compare development of 'Aurore', 'Baco Noir', 'Concord', 'De Chaunac', 'Seyval', and 'Vidal'. For 'Seyval', the Lindsay and Newman chart value with a threshold of 55°F has a significantly larger variance than number of days over the base (55°). Type I error was less than 25%.

'Vidal' had significantly lower variance (α = .25) under daily mean minus base (50°) than number of days over base (50° and 55°). Daily mean minus base also had significantly lower variance than time, with an α level of 1% for 'Vidal'. With these exceptions, none of the heat unit formulae were found to be significantly more accurate than time alone or any other formula.

Data of this type have many sources of variation so a side-by-side comparison of vineyards and years was undertaken and the results are shown in Table 12 and 13. Table 12 shows the percentage of buds in each developmental category for the same year, dates, and cultivars. Using this table, we can see the effect of the two locations on bud development. All the data taken at Tabor Hill was significantly different from data taken at Sodus HRS with varying levels of confidence. 'Baco Noir' was not affected as much by location as 'Seyval'. Nevertheless, this table points out the importance the vineyard site is in spring bud development.

Table 13 compares years directly using the same vineyard, dates of observation, and cultivars. The late April data in 1979 and 1980 is significantly different at the p levels shown on the table. The early May data are all significantly different at the p = .001 level. This high level of confidence in the differences between 1980 and 1979 show how dissimilar weather conditions are between years.

Skipping to Table 17, it will show the statistical basis of the comparisons of models given in Table 7. The numbers in the cells of the chart are the means of the cultivar, using a particular model and threshold, divided by the average daily accumulations. An all pair-wise comparison, modified for unbalanced replication, shows that daily mean minus base, number of days over base, and time, all have some significant differences in them between cultivars. 'Baco Noir' and 'De Chaunac' had significantly (α = .2) fewer heat units required to reach 50% burst than 'Vidal'. When heat units were daily mean minus base and base was 45°F. 'Baco Noir' required significantly (α = .2) fewer heat units than 'Vidal' to reach 50% burst when heat units were number of days over base and base was 55°. 'Baco Noir' and 'De Chaunac' required significantly (α = .2) fewer days to reach 50% B than 'Vidal'. It is important to note that only mean minus base was as good as time in picking up differences in treatments, and none of the heat unit models were better than time alone.

Table 18 shows the coefficient of variation (standard deviation/ mean) of the cultivars and heat unit models. You will recall that the CV unit is only used for direct comparisons and is not subject

to statistical tests in this case. The smaller the number, the more superior the measurement (less variation). Figure 3 shows CV of the daily max minus base model for all available cultivars and three base temperatures. For this model, 45° appears to be the threshold resulting in the least amount of variation. The best temperature to use with the daily mean minus base model is 45°, as shown in Figure 4. For number of days over the base temperature, Figure 5, the CV was lowest at 45° for 'Baco Noir' and 'De Chaunac', 50° was lowest for 'Aurore' and 'Seyval' and 55° was lowest for 'Vidal'.

The CV versus the base gives 50° as the best base result in Figure 6 as to which base is best when using the Linsey and Newman model. The CV is plotted for time alone to show how small the statistic is compared to all other models.

This point is brought home in the figure that follows, showing the various models versus time for the threshold of choice for a cultivar. Figure 7 shows that Time has a lower CV statistic than any other model for 'Baco Noir' with a 45° base. Similarly, Figures 8 and 9 show Time to be superior to any other model for 'Aurore' (45° base) and 'De Chaunac' (45° base), respectively. In summary, it would seen that none of the models tested would be more desirable than Time alone in predicting bud development.

The next portion of this study was devoted to cultural manipulations and how they affect buds and spring development. Table 16 shows five treatments as fall-pruned 8 node canes, fall-pruned long canes, spring pruned 8 node canes, spring pruned long canes and an

unpruned control. There was no difference in primary bud mortality among these treatments as seen in Table 14.

Table 15 shows the results of bud development around the cordon. The sides of the cordon showed more bud development in the advanced stages than the lower area of the cordon which was not exposed to the sun.

Table 16 shows the five treatments on eight dates. In every case, the 8-node canes were more advanced than the long cane treatments. Fall or spring pruning had little effect in the short canes, but in the long canes, fall-pruned seemed to have slower development than the spring or unpruned.

Figures 10 and 11 show the varieties 'Baco Noir' and 'Vidal' in developmental categories according to dates of observation. Frost protection systems such as overhead irrigation might be employed if the majority of buds are in the S2 or B category.

DISCUSSION

The first group of Tables, 3 through 6, were used to compare the cultivars with each other in Tables 8 through 9. In Table 8 the onset of growth of eight cultivars was ranked. Onset and rate of growth were recognized as separate aspects of growth. Other workers have separated onset and rate in tree seedlings (16) because they are important characteristics to select for in breeding programs. It is possible to use the ranking of these cultivars as an indication of their response to spring temperatures. In Michigan, a late onset grape cultivar would be the best at avoiding spring freeze damage. 'Chelois' and 'Vidal' would be good candidates while 'Baco Noir' and 'Concord' would not be.

Table 9 shows relative rates of growth in 1980. A fast growing grape would be best for Michigan because of its fairly short growing season. Several workers have observed that quick growth in the spring dictates harvest time more than summer temperatures (20,50,49,55). For our state then, the cultivars would be ranked 'Concord', 'Baco Noir', 'De Chaunac', 'Seyval', 'Vignoles', 'Aurore', 'Chelois', and 'Vidal'.

Since the cultivars that had early onset of growth also grew quickly, our "ideal" grape variety has not yet been observed.

Table 10 shows a ranking of cultivars in 1979. The cultivars fall into the same pattern as 1980 with the exception of the reversal

of 'Vignoles' and 'Aurore'. The cultivars seem to have consistent responses during two years and at three sites. The cultivars appear in a different order in Table 11 because in 1978, the rate of growth was defined as the slope of the line on a graph showing the percentage of buds at burst versus number of days over 45°F. In 1979 and 1980, growth rate was defined as the slope of the line at the point of inflection of the sigmoid curve shown on a graph of percentage of buds at burst versus time in days.

Table 7 uses spring temperature to observe the consistency of various methods of heat unit accumulations and time of bud development. The only factor observed in this study was temperature. Traditionally, only temperature is used in spring bud development models (5,8,9,10,11,14,17,19,28,29,38,44,56,46,47,49,52, 53). Based on the literature, the growth thresholds used were 45°, 50°, and 55°. (Lindsey and Newman consider 55° as too high for a growth threshold.) Thresholds of growth in apple (53), and grape (57) are similar.

In the literature, there is much discussion of dormancy and its role in spring bud development (6,11,12,14,18,36,37,40,43,45,58,61). The reason dormancy is so important is that the plant cannot respond to environmental cues while it is in deep dormancy. It would be nonsensical to begin accumulating heat units when the plant is physiologically unable to respond to them. Therefore, it is important to begin accumulating whatever heat units your model uses when the plant enters induced dormancy. In this study, weather data were collected March 1 through burst. No study of the dormancy states was done because the grapes entered induced dormancy far before March 1.

Even after February 1, Michigan had very few days warm enough to contribute heat units to the accumulated total until March.

With only a few exceptions, the models were not good predictors of bud development. For a model to have any merit, it must be more accurate than guestimates. There are some problems with using heat units to measure bud development. One of the most widely recognized problems is that models are based on air temperature and buds are responding to cane-bud temperatures. Grainger reported bud temperature departures from air temperature that were considerable (29). Evaporation and radiant energy absorption from the sun were given as causes. Radiant energy appears to be the most important factor, warming the canes and buds above air temperatures on windless days (38,15).

Models may also be inadequate because they discount the input of other factors (38,45,49). Some works feel that heat units cannot be summed and used in models because how they are perceived is based on the plant's previous history (9,41). Others feel that air temperature models would work if proper growth thresholds could be worked out since they change as the plant develops (17). Factors found to affect spring bud development include fertility (22), site (8,31), and pruning (8,31).

From Tables 12 and 13, this study demonstrates the importance of location and year in affecting bud development. If proper models using air temperature are attempted in the future, many more years worth of observations are needed. Ashcroft suggests six as a minimum (11).

The last portion of this study was devoted to cultural manipulations and how they effect buds and spring development. There was not a difference in primary bud mortality based on the five pruning treatments seen on Table 14. On 'Concord', then, leaving canes long or cutting them short, no matter when it is done, does not cause winter damage to primary buds.

Table 15 shows some observations which question the impact of the sun's radiant heat on bud development. If growth proceeds faster at higher temperatures, the top 120° of a horizontal cordon should show more growth than the sides. The sides should show more growth than the shaded lower 120°. The observations, however, show the sides of a cane to be at the optimum for bud growth and the upper, then lower 120° in order respectively. A possible explanation would be that bud development has an optimum temperature which the side buds more often obtain. The upper buds may exceed the optimum temperature and the lower buds may be under the optimum temperature.

Table 16 gives a strong indication that long canes left at pruning time retard bud development. This technique is an important manipulation the growers in Michigan can use to retard spring bud development and give themselves several days of weather "insurance" protection against late spring frosts.

These data support the current recommendations regarding cultural practices in Michigan vineyards. The more delay in spring development, the better because there is less chance of injury from a late spring freeze. The lesser developed buds are hardier and can

better withstand cold temperatures (33). From this data we would advise fall pruning leaving long canes to retard development, then coming through the vineyard and shortening them in late May or early June.

This group of observations on seven grape cultivars can be helpful in learning the spring development characteristics from direct comparisons in the field. Time seems to be the best predictor of all the temperature - time related models tested. We have seen that the population in a field is normally distributed in regard to its spring development. The last observation from this data is that long canes retard spring development and if left will provide a hedge against spring freezes of about two to three days.

TABLE 3.--The percentage of buds in each developmental category at Tabor Hill vineyard in the spring of 1980. Categories were designated: dormant (D), scale crack (SC), swell 1 (S1), swell 2 (S2), burst (B), missing (M), total number of buds recorded (Total), and number of buds given a D through B rating (T-M).

Date	Cultivar	D	SC	S1	S2	B	M	Total	T-M
4-24-80	Baco Noir	3.6	48.1	35.9	12.3	0.0	4.6	808	771
4-28-80	Baco Noir	3.9	10.2	68.4	17.4	0.0	2.7	752	735
5-1-80	Baco Noir	2.1	22.7	55.6	19.5	0.0	6.3	760	712
5-5-80	Baco Noir	4.2	7.1	22.9	52.7	12.9	6.7	736	687
5-9-80	Baco Noir	1.9	2.7	7.1	19.3	61.9	3.4	718	693
5-13-80	Baco Noir	0.5	0.7	9.4	5.8	83.6	17.2	728	603
5-1-80	Vidal	53.4	46.6	0.0	0.0	0.0	1.1	840	831
5-5-80	Vidal	12.4	81.9	5.7	0.0	0.0	1.6	832	819
5-9-80	Vidal	36.9	43.8	17.0	2.0	0.0	0.6	805	800
5-13-80	Vidal	39.1	27.9	13.2	16.2	2.8	1.5	856	847
5-16-80	Vidal	25.0	32.8	14.5	19.4	8.2	2.9	856	831
5-20-80	Vidal	23.5	22.2	13.4	15.7	25.2	1.3	840	829
5-23-80	Vidal	8.3	11.1	5.9	25.6	49.1	2.0	840	823
6-2-80	Vidal	23.2	2.2	0.7	0.4	73.6	1.3	840	829
4-24-80	Seyval	37.5	57.3	5.2	0.0	0.0	0.6	768	763
4-28-80	Seyval	18.4	70.6	10.9	0.0	0.0	0.9	784	777
5-1-80	Seyval	24.6	71.6	3.8	0.0	0.0	1.0	792	782
5-5-80	Seyval	7.1	36.9	51.6	4.4	0.0	2.6	792	771
5-9-80	Seyval	7.0	19.2	39.2	33.8	0.8	1.8	769	760
5-13-80	Seyval	5.8	10.5	18.9	48.9	15.9	4.4	768	734
5-16-80	Seyval	4.6	7.8	10.1	39.4	37.9	7.1	800	743
5-20-80	Seyval	7.1	2.5	5.4	17.8	67.2	5.8	752	708
5-23-80	Seyval	6.5	6.9	2.8	3.3	86.6	5.8	760	716

Table 4.--The percentage of buds in each developmental category at the HRC vineyard in the spring of 1980

Date	Variety	D	SC	S1	S2	B	M	Total	T-M
4-29-80	Vignoles	13.9	86.1	0.0	0.0	0.0	1.3	80	79
5-2-80	Vignoles	15.2	84.8	0.0	0.0	0.0	1.3	80	79
5-6-80	Vignoles	6.4	20.5	30.8	42.3	0.0	2.6	80	78
5-8-80	Vignoles	3.8	10.0	40.0	46.2	0.0	0.0	80	80
5-12-80	Vignoles	1.3	3.8	16.4	72.1	6.3	1.3	80	79
5-14-80	Vignoles	1.3	2.6	11.5	50.0	34.6	2.6	80	78
5-19-80	Vignoles	0.0	0.0	5.3	42.1	52.6	5.0	80	76
4-29-80	De Chaunac	16.8	73.4	9.8	0.0	0.0	0.7	144	143
5-2-80	De Chaunac	0.0	34.7	65.0	0.0	0.0	0.0	144	144
5-6-80	De Chaunac	0.0	0.0	5.6	36.4	58.0	0.7	144	143
5-8-80	De Chaunac	0.7	0.0	1.4	22.7	75.2	2.1	144	141
5-12-80	De Chaunac	0.7	0.0	0.7	4.9	93.7	1.4	144	142

TABLE 5.--The percentage of buds in each developmental category at the SHRS in the spring of 1980.

Date	Variety	D	SC	S1	S2	B	M	Total	T-M
4-25-80	Baco Noir	4.2	45.4	47.5	2.8	0.0	2.1	144	141
4-28-80	Baco Noir	2.7	36.2	44.3	16.8	0.0	2.0	152	149
5-1-80	Baco Noir	0.7	10.3	50.0	34.9	0.0	3.9	152	146
5-5-80	Baco Noir	0.0	6.8	20.4	46.9	25.8	3.3	152	147
5-9-80	Baco Noir	0.7	0.7	11.9	23.8	62.9	0.0	143	143
5-13-80	Baco Noir	0.0	0.7	7.3	2.2	89.8	9.9	152	137
4-28-80	Vignoles	63.8	36.2	0.0	0.0	0.0	0.0	224	224
5-1-80	Vignoles	60.4	39.6	0.0	0.0	0.0	1.5	200	197
5-5-80	Vignoles	26.1	27.1	43.6	3.2	0.0	2.7	224	218
5-9-80	Vignoles	15.8	15.4	18.1	50.2	0.4	1.3	224	221
5-16-80	Vignoles	3.7	7.0	16.7	44.2	28.4	4.0	224	215
5-20-80	Vignoles	3.5	0.4	6.7	27.2	62.5	6.7	240	224
5-23-80	Vignoles	1.8	0.9	0.9	9.0	69.5	7.1	240	223
4-28-80	Seyval	36.8	42.9	20.2	0.0	0.0	5.0	120	114
5-1-80	Seyval	34.5	16.8	48.7	0.0	0.0	5.8	120	113
5-5-80	Seyval	22.6	6.6	30.2	40.6	0.0	5.3	112	106
5-9-80	Seyval	29.3	1.8	7.3	56.9	4.6	2.7	112	109
5-13-80	Seyval	28.3	0.0	2.6	28.3	40.7	5.8	120	113
5-16-80	Seyval	22.2	0.0	1.8	19.4	56.5	10.0	120	108
5-20-80	Seyval	19.8	0.0	0.9	2.8	73.6	11.7	120	106

TABLE 5.--Continued

Date	Variety	D	SC	S1	S2	B	M	Total	T-M
4-25-80	Aurore	66.5	33.5	0.0	0.0	0.0	2.7	224	218
4-28-80	Aurore	55.9	44.1	0.0	0.0	0.0	1.8	224	220
5-1-80	Aurore	46.9	47.4	5.7	0.0	0.0	4.0	200	192
5-5-80	Aurore	21.9	42.1	28.1	6.1	0.0	1.7	232	228
5-9-80	Aurore	19.9	14.3	20.8	40.7	4.2	0.0	216	216
5-13-80	Aurore	15.1	10.3	3.3	42.4	28.8	5.5	224	212
5-16-80	Aurore	15.1	8.7	4.5	22.8	48.8	5.6	232	219
5-20-80	Aurore	16.6	0.5	2.8	8.5	70.6	9.5	232	211
4-25-80	De Chaunac	43.1	52.3	4.6	0.0	0.0	1.1	176	174
4-28-80	De Chaunac	33.3	60.9	5.7	0.0	0.0	1.1	176	174
5-1-80	De Chaunac	22.8	55.0	22.2	0.0	0.0	2.8	176	171
5-5-80	De Chaunac	8.0	26.0	54.0	11.5	0.0	1.1	176	174
5-9-80	De Chaunac	12.4	7.1	13.6	52.7	14.2	N.D.	169	169
5-13-80	De Chaunac	6.8	2.5	5.1	34.9	50.2	8.2	256	235
4-25-80	Concord	52.0	46.5	7.3	0.0	0.0	1.7	296	291
4-28-80	Concord	33.4	50.2	16.4	0.0	0.0	1.8	280	275
5-1-80	Concord	32.8	38.1	28.7	0.4	0.0	2.6	272	265
5-5-80	Concord	8.5	14.2	23.1	49.6	4.6	1.5	264	260
5-9-80	Concord	4.5	3.8	9.4	24.1	57.7	2.9	272	265
5-13-80	Concord	1.7	0.9	2.2	8.2	87.0	9.8	256	231

TABLE 6.--The percentage of buds in each developmental category at the SHRS in the spring of 1979

Date	Variety	D	SC	S1	S2	B	Total
4-26-79	De Chaunac	28.9	26.1	44.6	0.3	0.0	100
4-29-79	De Chaunac	31.3	48.4	20.3	0.0	0.0	100
5-1-79	De Chaunac	30.0	37.7	32.2	0.0	0.0	100
5-5-79	De Chaunac	25.7	47.8	26.5	0.0	0.0	100
5-8-79	De Chaunac	14.4	21.4	25.2	38.4	0.7	100
5-10-79	De Chaunac	20.9	7.9	5.1	15.6	50.5	100
5-12-79	De Chaunac	5.6	1.6	3.5	5.2	84.0	100
4-26-79	Seyval	23.8	63.4	12.7	0.0	0.0	100
5-1-79	Seyval	4.2	63.9	31.9	0.0	0.0	100
5-5-79	Seyval	26.4	62.5	11.1	0.0	0.0	100
5-8-79	Seyval	27.4	23.0	21.8	27.8	0.0	100
5-10-79	Seyval	7.6	1.9	7.4	37.3	47.3	100
5-12-79	Seyval	0.0	0.0	3.1	6.0	91.0	100
4-26-79	Aurore	45.8	54.2	0.0	0.0	0.0	100
5-1-79	Aurore	44.6	55.4	0.0	0.0	0.0	100
5-5-79	Aurore	26.3	71.5	2.2	0.0	0.0	100
5-8-79	Aurore	4.4	40.0	37.1	19.0	0.0	100
5-10-79	Aurore	5.4	16.2	6.3	32.7	40.7	100
5-12-79	Aurore	1.2	4.3	6.1	9.0	79.4	100

TABLE 6.--Continued

Date	Variety	D	SC	S1	S2	B	Total
4-26-79	Chelois	91.4	9.0	0.0	0.0	0.0	100
5-1-79	Chelois	54.7	45.3	0.0	0.0	0.0	100
5-5-79	Chelois	26.0	74.0	0.0	0.0	0.0	100
5-8-79	Chelois	7.3	44.7	41.1	11.1	0.0	100
5-10-79	Chelois	0.0	13.8	12.5	64.1	9.0	100
4-26-79	Vignoles	66.6	32.4	0.0	0.0	0.0	100
5-1-79	Vignoles	7.0	92.9	0.0	0.0	0.0	100
5-5-79	Vignoles	19.0	74.5	1.5	0.0	0.0	100
5-8-79	Vignoles	1.5	45.7	48.3	15.1	0.0	100
5-10-79	Vignoles	1.6	16.0	15.3	49.9	21.2	100
5-12-79	Vignoles	1.4	7.0	14.3	50.9	21.2	100
4-26-79	Baco Noir	13.1	38.7	40.5	4.4	0.0	100
5-1-79	Baco Noir	3.9	47.8	44.5	3.8	0.0	100
5-5-79	Baco Noir	1.9	51.0	43.0	1.9	0.0	100
5-8-79	Baco Noir	0.0	14.2	48.9	34.3	2.5	100
4-26-79	Vidal	91.0	0.0	0.0	0.0	0.0	100
5-1-79	Vidal	85.8	14.2	0.0	0.0	0.0	100
5-5-79	Vidal	91.9	8.1	0.0	0.0	0.0	100
5-8-79	Vidal	6.3	66.7	25.1	3.4	0.0	100
5-10-79	Vidal	19.1	25.8	18.7	23.4	12.9	100
5-12-79	Vidal	14.9	11.5	9.0	20.8	44.5	100
5-14-79	Vidal	0.0	21.6	7.7	16.7	51.1	100

Table 7.--The number of heat units accumulated from March 1 through the date shown are given for the varieties, vineyards, and models shown. The column labeled time gives the number of days from March 1 until 50% of the buds are at burst or beyond. The dates given are the points in time when 50% of the buds have reached burst.

Cultivar	Locale	Date	# of Buds	Daily Max-Base			Daily Mean-Base			# days over base			Time	L and N Chart	
				45°	50°	55°	45°	50°	55°	45°	50°	55°		50°	55°
Aurore	Sodus	5-16-80	212	526	346	210	232.5	117.0	49.5	41	35	26	77	3293	1686
Aurore	Sodus	5-10-79	252	784	573	406	350.5	227.5	126.0	44	36	29	71	6108	4214
Aurore	Sodus	5-27-78	165	869	613	407	408.5	237.5	123.5	57	45	36	88	6603	3682
Variance in days				101	79.5	126	55.2	47.1	21.9	72.3	30.3	26.3	51.3	93.5	89.3
Baco Noir	T.H.	5-07-80	700	473	311	223	207.5	128.0	69.5	34	22	17	68	3400	2106
Baco Noir	Sodus	5-08-80	143	403	263	164	167.0	89.5	46.5	33	27	18	69	2566	1423
Baco Noir	Sodus	5-11-79	180	820	604	432	373.0	245.0	138.5	46	37	30	72	6528	3914
Baco Noir	Sodus	5-19-78	155	635	419	253	261.0	130.0	52.0	49	37	28	80	3942	1864
Variance in days				109.3	87.6	64.9	54.4	47.75	20.8	67	56.2	44.9	29.6	85.2	59.9
Concord	Sodus	5-08-80	265	403	263	164	164.0	167.0	89.5	33	27	18	69	2566	1423
Concord	H.F.	5-21-78	184	734	507	325	281.5	151.0	66.0	48	42	31	82	4433	2386
De Chaunac	H.F.	5-05-80	143	467	302	199	177.5	94.5	41.5	34	25	16	66	2648	1457
De Chaunac	Sodus	5-13-80	182	489	324	200	216.0	113.5	49.5	38	32	23	74	3146	1645
De Chaunac	Sodus	5-10-79	100	784	573	406	350.5	227.5	126.0	44	36	29	71	6108	2248
De Chaunac	Sodus	5-20-78	210	670	449	278	287.0	151.0	68.0	50	38	29	81	4446	2248
Variance in days				71.9	60.2	46.5	39.8	36.6	16.6	49	33	38.2	39	70.6	79
Seyval	T.H.	5-18-80	750	666	454	316	299.5	180.0	84.0	45	32	27	79	4887	2800
Seyval	Sodus	5-15-80	110	508	333	202	224.5	114.0	49.5	40	34	25	76	3192	1648
Seyval	Sodus	5-10-79	63	784	573	406	350.5	227.5	126.0	44	36	29	71	6108	4214
Seyval	Sodus	5-22-78	166	718	487	306	306.5	160.5	71.5	52	40	31	83	4755	2425
Variance in Days				43.7	38.1	34.2	18.8	23.5	11.8	24.9	11.9	6.7*	25.58	41.9	57*
Vidal	T.H.	5-23-80	826	800	563	400	379.5	235.0	114.0	50	37	32	84	6170	3624
Vidal	Sodus	5-14-79	198	868	637	450	393.5	251.5	138.5	48	40	32	75	6778	4305
Vidal	Sodus	5-28-78	149	914	653	442	437.5	261.5	142.5	58	46	37	89	7179	4144
Variance in days				10.4	8.9	3.6	6.4	1.9*	2.72	28**	21**	8.35	50.3***	7.7	6.0
Avg. accumulation per day				17.8	16.2	14.3	12.1	9.7	9.3	1	1	1	1	184.7	140

*F max test with α = .25
**F max test with α = .25
***F max test with α = .01

Table 8.--Growth onset in 1980 comparing the cultivars 'Baco Noir', 'Concord', 'De Chaunac', 'Seyval', 'Aurore', 'Vignoles', 'Chelois', and 'Vidal'. Frequency data shown in Tables 3, 4, and 5 was used to obtain the date of the first recorded bursts and the data of the first recorded swell ones.

Comparative Ranking of Growth Onset	Cultivar	Date of first recorded Swell One	Date of First Recorded Burst
	Tabor Hill Vineyard, 1980		
Faster	Baco Noir	Before April 24	May 1
↕	Seyval	Before April 24	May 5
Slower	Vidal	May 5	May 9
	SHRS Vineyard, 1980		
Faster	Baco Noir	Before April 25	May 1
↑	Concord	Before April 25	May 3
	De Chaunac	Before April 25	May 5
	Seyval	Between April 25 & 28	May 5
	Aurore	Between April 28 & May 1	May 5
↓	Vignoles	Between May 1 & 5	May 9
Slower	Chelois	Between May 1 & 5	May 11
	HRC Vineyard, 1980		
Faster ↕	De Chaunac	Before April 29	May 3
Slower	Vignoles	Between May 2 & 6	May 8

Combination of All Vineyards Showing Relative Ranking of Onset of Growth

Comparative Ranking of Growth Onset	Cultivar	"Score"
Faster	Baco Noir	Fast
↑	Concord	Fast
	De Chaunac	Mid
	Seyval	Mid
	Aurore	Slow-mid
	Vignoles	Mid
↓	Chelois	Slow
Slower	Vidal	Slow

Table 9.--Slope of curve of percent B versus time. The slopes of the curves at the point of inflection on Figures 2, A-K were used to quantify the varieties' growth. Cultivars studied were 'Aurore', 'Baco Noir', 'Chelois', 'Concord', 'De Chaunac', 'Seyval', 'Vidal', and 'Vignoles'. The steeper the slope the higher the number and the faster the variety reached burst with regard to time in 1980.

Comparative Ranking of Growth Rate	Slope	Cultivar
	SHRS, 1980	
Faster	16.7	Concord
↑	9.25	Baco Noir
	8.75	De Chaunac
	8.75 & 5.3*	Seyval
	8.5	Vignoles
↓	7.5	Aurore
Slower	6.7	Chelois
	HRC, 1980	
Faster	11.0	De Chaunac
↕	9.5	Baco Noir
Slower	9.2	Vignoles
	Tabor Hill, 1980	
Faster	16.0	Baco Noir
↕	7.1	Seyval
Slower	6.8	Vidal

Combined 1980 Rates of Development

Comparative Ranking of Growth Rate	Cultivar
Faster	Concord
↑	Baco Noir
	De Chaunac
	Seyval
	Vignoles
	Aurore
↓	Chelois
Slower	Vidal

*Double sigmoid curve with two points of inflection.

TABLE 10.--Growth onset in 1979 comparing the cultivars 'Aurore', 'Baco Noir', 'Chelois', 'De Chaunac', 'Seyval', 'Vidal', and 'Vignoles'. Frequency data shown in Table 6 from SHRS was used to obtain the date of the first recorded bursts and the date of the first recorded swell ones.

Growth Onset in 1979			
Growth Rate in 1979	Cultivar	Onset of Bursting	Onset of Growth
N.D.*	Baco Noir	May 5	Before April 26
Fast	De Chaunac	May 8	Before April 26
Fast	Seyval	May 8	Before April 26
N.D.	Vignoles	May 7	Between May 1 & 5
Mid	Aurore	May 8	Between May 1 & 5
N.D.	Chelois	May 8	Between May 5 & 8
Slow	Vidal	May 8	Between May 5 & 8

*N.D. indicates data were not taken or were unusable.

Table 11.--Classification of growth onset and rate in 1978 among cultivars at the Sodus Horticultural Research Station.

Cultivar	Onset	Rate
Baco Noir	Early	Slow
De Chaunac	Mid	Slow
Seyval	Mid	Slow
Vignoles	Mid	Fast
Chelois	Mid	Slow
Aurore	Mid	Fast
Vidal	Late	Fast

TABLE 12.--Previous tables have compared cultivars with each other at the same vineyards and years. In this table, the cultivar and year are constant and a comparison of two vineyards is shown. Cultivars 'Baco Noir' and 'Seyval' in 1980 are used to compare Tabor Hill and Sodus HRS vineyards using frequency data. The dates were analyzed separately using contingency tables and the χ^2 distribution. The hypothesis tested was whether the number of buds in the categories of development were independent of the vineyards. For all dates, the hypothesis was rejected, therefore, development and location were dependent. The confidence level varied and is reported in the last column under alpha.

Dates	Tabor Hill Vineyard						Sodus HRS Vineyard						α
	D	SC	S1	S2	B	# of Buds	D	SC	S1	S2	B	# of Buds	
Baco Noir													
4-24(25*)-80	3.1%	48.1%	35.9%	12.3%	0.0%	771	4.2%	45.4%	47.5%	2.8%	0.0%	141	.01
4-28-80	3.4%	10.2%	68.4%	17.4%	0.0%	735	2.7%	36.2%	44.3%	16.8%	0.0%	149	<.001
5-1-80	1.6%	22.7%	55.6%	19.5%	0.0%	712	0.7%	10.3%	50.0%	34.9%	0.0%	146	.005
5-5-80	3.7%	7.1%	22.8%	52.7%	12.9%	687	0.0%	6.8%	20.4%	46.9%	25.8%	147	.005
5-9-80	1.9%	2.7%	7.1%	19.3%	61.9%	693	0.7%	0.7%	11.9%	23.8%	62.9%	143	.1
5-13-80	0.0%	0.7%	9.4%	5.8%	83.6%	603	0.0%	0.7%	7.3%	2.2%	89.8%	137	.2
Seyval													
4-28-80	18.4%	70.6%	10.9%	0.0%	0.0%	777	36.8%	42.9%	20.2%	0.0%	0.0%	114	<.001
5-1-80	24.6%	71.6%	3.8%	0.0%	0.0%	782	34.5%	16.8%	48.7%	0.0%	0.0%	113	<.001
5-5-80	7.1%	36.9%	51.6%	4.4%	0.0%	771	22.6%	6.6%	30.2%	40.6%	0.0%	106	<.001
5-9-80	7.0%	19.2%	39.2%	33.8%	0.8%	760	29.3%	1.8%	7.3%	56.9%	4.6%	109	<.001
5-13-80	5.8%	10.5%	18.9%	48.9%	15.9%	734	28.3%	0.0%	2.6%	28.3%	40.7%	113	<.001
5-16-80	4.7%	7.8%	10.1%	39.4%	37.9%	743	22.2%	0.0%	1.85%	19.4%	56.5%	108	<.001
5-20-80	7.1%	2.5%	5.4%	17.8%	67.2%	708	19.8%	0.0%	0.9%	3.8%	73.6%	106	<.001

*25th taken at Sodus.

TABLE 13.--Previous tables have compared cultivars with each other at the same location and the same cultivar at different locations. In this table a comparison between weather conditions in 1979 and 1980, as regards bud development, is shown on nearly the same dates and the cultivars 'Aurore', 'Baco Noir', 'Chelois', 'De Chaunac', 'Vignoles', and 'Seyval'. The data were taken at Sodus HRS where all varieties grew side by side. Chi-squared analysis was done with the alpha percentage is shown under the last column.

Cultivar	D	SC	S1	S2	B	# of Buds	D	SC	S1	S2	B	# of Buds	α
	4-28-80						4-28-79						
Aurore	66.5	33.5	0.0	0.0	0.0	218	45.8	54.2	0.0	0.0	0.0	100	.005
Baco Noir	2.7	36.2	44.3	16.8	0.0	149	13.1	38.7	40.5	4.4	0.0	100	.001
Chelois	82.7	17.3	0.0	0.0	0.0	156	91.0	9.0	0.0	0.0	0.0	100	.1
De Chaunac	33.3	60.9	5.7	0.0	0.0	174	28.9	26.1	44.6	0.3	0.0	100	.001
Vignoles	63.8	36.2	0.0	0.0	0.0	224	66.6	32.4	0.0	0.0	0.0	100	.05
Seyval	36.8	42.9	20.2	0.0	0.0	114	23.8	63.4	12.7	0.0	0.0	100	.005
	5-9-80						5-8-79						
Aurore	19.9	14.3	20.8	40.7	4.2	216	4.4	40.0	37.1	19.0	0.0	100	.001
Baco Noir	0.7	0.7	11.9	23.8	62.9	143	0.0	14.2	48.9	34.3	2.5	100	.001
Chelois	37.6	17.8	22.9	19.7	0.0	157	7.3	44.7	41.1	11.1	0.0	100	.001
De Chaunac	12.4	7.1	13.6	52.7	14.2	169	14.4	21.4	25.2	38.4	0.7	100	.001
Vignoles	15.8	15.4	18.1	50.2	0.4	221	1.5	45.7	48.3	15.1	0.0	100	.001
Seyval	29.3	1.8	7.3	56.9	4.6	109	27.4	23.0	21.8	27.8	0.0	100	.001

Table 14.--Effect of time of pruning and cane length on winter kill of Concord grape buds, Cronenwett Vineyard-Lawton, Michigan, 1979-80.

Treatment	Percent Dead Primary Buds								
	Node Number								
	One	Two	Three	Four	Five	Six	Seven	Eight	One - Eight
Fall - 8 node	1.4	4.3	2.9	2.9	4.3	8.6	8.6	14.3	5.9a*
Fall - long cane	4.5	6.8	0.0	2.3	2.3	2.4	0.0	0.0	2.3a
Spring - 8 node	0.0	0.0	0.0	0.0	0.0	3.2	12.9	3.2	2.4a
Spring - long cane	4.5	9.1	0.0	4.5	4.5	0.0	0.0	4.5	3.4a
Unpruned until 5-15-80	0.0	0.0	0.0	0.0	0.0	4.3	0.0	0.0	0.5a

*Within columns, means followed by different letters significantly different at $\alpha = .05$ Chi-squar test.

Prepared by T. Mansfield.

TABLE 15.--Effect of spatial orientation of canes on phenological development of 'Concord' grape buds

Percent Primary Buds (Nodes 1-8) at Dormant or Scale Crack Stages of Development			
Cane Orientation	Date		
	4-25-80	5-1-80	5-5-80
Upper 120°	92.9ab*	62.1ab	16.1ab
Middle 120°	92.5b	60.4b	11.1b
Lower 120°	95.5a	68.5a	18.4a

*Within columns, means followed by different letters significantly different at $\alpha = .05$ by chi-square test.

Prepared by Tim Mansfield.

Table 16.--Percent primary buds (nodes 1-8) at dormant or scale crack stages.

Treatment	Date							
	4-25-80	4-28-80	5-1-80	5-5-80	5-7-80	5-9-80	5-13-80	5-16-80
Fall - 8 node	91.5c*	80.1c	47.5c	7.9bc	1.9c	2.0c	0.0c	0.0a
Fall - long canes	98.1a	95.0a	80.5a	23.3a	15.2a	13.6a	5.8a	0.0a
Spring - 8 node	87.2d	72.7d	54.4c	4.6c	1.5c	1.4c	0.0c	0.0a
Spring - long canes	95.6b	86.2b	72.7b	11.8b	7.8b	5.8b	2.1b	0.0a
Unpruned until 5-15	94.9bc	88.7b	75.3ab	12.1b	7.4b	7.7b	2.5b	0.0a

*Within dates, means followed by different letters significantly different at $p = .05$ by Chi-square analysis.

Prepared by T. Mansfield

Table 17.--All pair-wise comparisons using Tukey's honestly significant difference (HSD) test modified for unbalanced replication. The numbers in the cells of the chart are the means of the cultivars, using a particular model and threshold, divided by the average daily accumulations.

Cultivar	Treatment Means											
	Daily max - Base			Daily mean - Base			# Days over Base			L & N heat units		Time
	45°F	50°	55°	45°	50°	55°	45°	50°	55°	50°	55°	None
Baco Noir	32.75	24.65	18.75	20.80a	15.25	8.20	40.50	30.75	23.25a*	22.2	16.5	72a
Aurore	40.76	31.50	23.90	27.30	20.00	10.70	47.30	38.70	30.30	28.9	22.7	78
De Chaunac	33.80	25.43	18.93	21.28a	15.10	7.65	41.50	32.75	24.25	22.1	16.9	73a
Seyval	37.55	28.50	21.48	24.36	17.50	8.88	45.25	35.50	28.00	25.6	19.6	77
Vidal	48.3	38.10	30.07	33.33b	25.70	14.15	52.00	41.00	33.70b	36.3	28.4	83b

*Test statistics a and b differ significantly at $\alpha = .2$ but not at $\alpha = .1$; Tukey test, unbalanced replication.

TABLE 18.--The coefficients of variation for all models and cultivars are shown in this table. The smaller the percentage, the less dispersion of the observations shown on Table 7. Coefficients of variation smaller than 0.01 are rare in the biological sciences.* In biology, they usually range from 0.05 to 0.5. Since the CV is the ratio of the standard deviation to the mean, expressed in percentage, it is a unitless number and statistical comparisons using it are invalid.

Cultivar	Coefficients of Variation											
	Daily Max - Base			Daily Mean - Base			# Days Over Base			L & N Heat Units		Time
	45°	50°	55°	45°	50°	55°	45°	50°	55°	50°	55°	None
Baco Noir	.319	.379	.429	.354	.453	.556	.202	.244	.288	.916	.469	.107
Aurore	.246	.283	.470	.273	.343	.437	.179	.142	.169	.839	.418	.121
De Chaunac	.251	.305	.360	.296	.401	.532	.169	.175	.255	.380	.528	.122
Seyval	.176	.216	.272	.178	.277	.387	.110	.096	.092	.253	.386	.098
Vidal	.067	.078	.063	.074	.053	.116	.102	.111	.086	.176	.088	.030

*John Gill, Design and Analysis of Experiments in the Animal and Medical Sciences, Vol. 1 (Ames Iowa: Iowa State University Press, 1978), pp. 22-23.

Figure 2.A-P. Percentage of buds at burst are shown versus dates of observation. The cultivar and year are shown for each figure.

Figure 2-A Year 1979 Cultivar Chelois

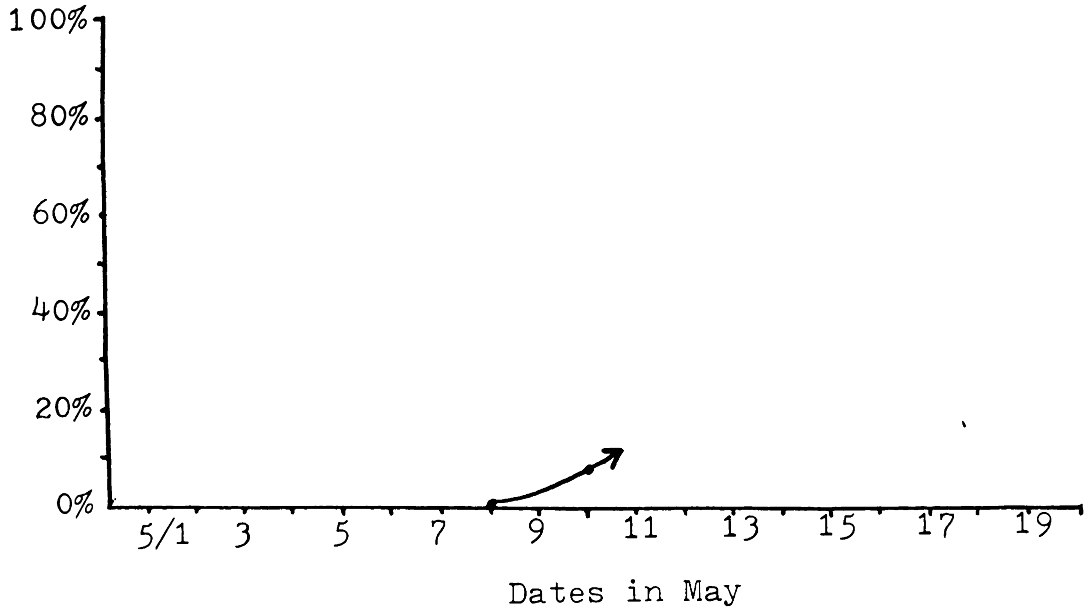


Figure 2-B Year 1979 Cultivar Vidal

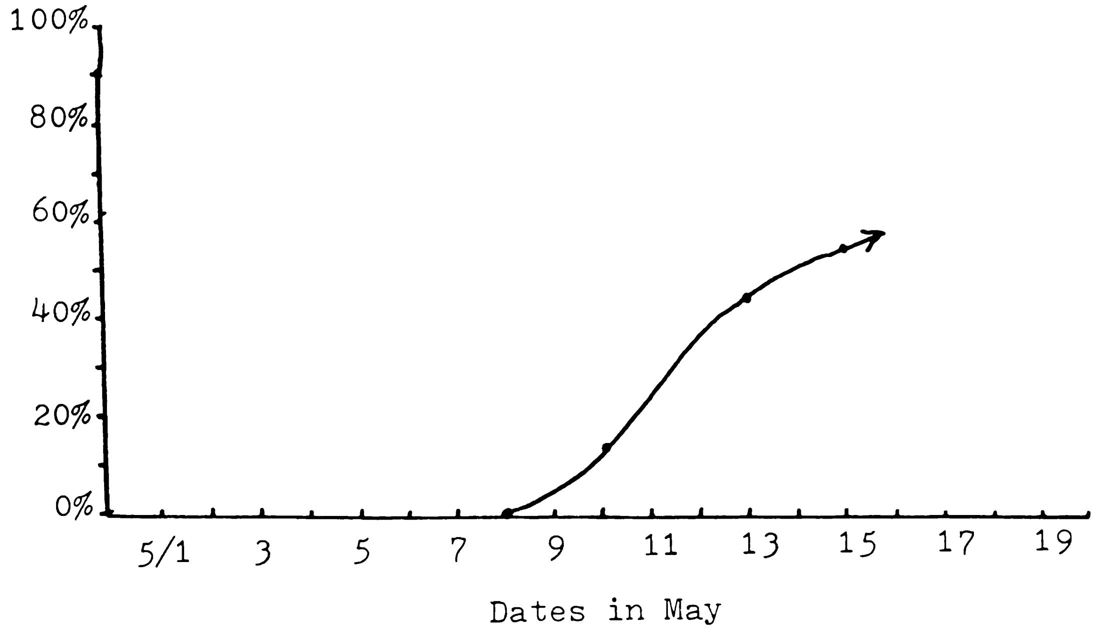


Figure 2-C Year 1979 Cultivar De Chaunac

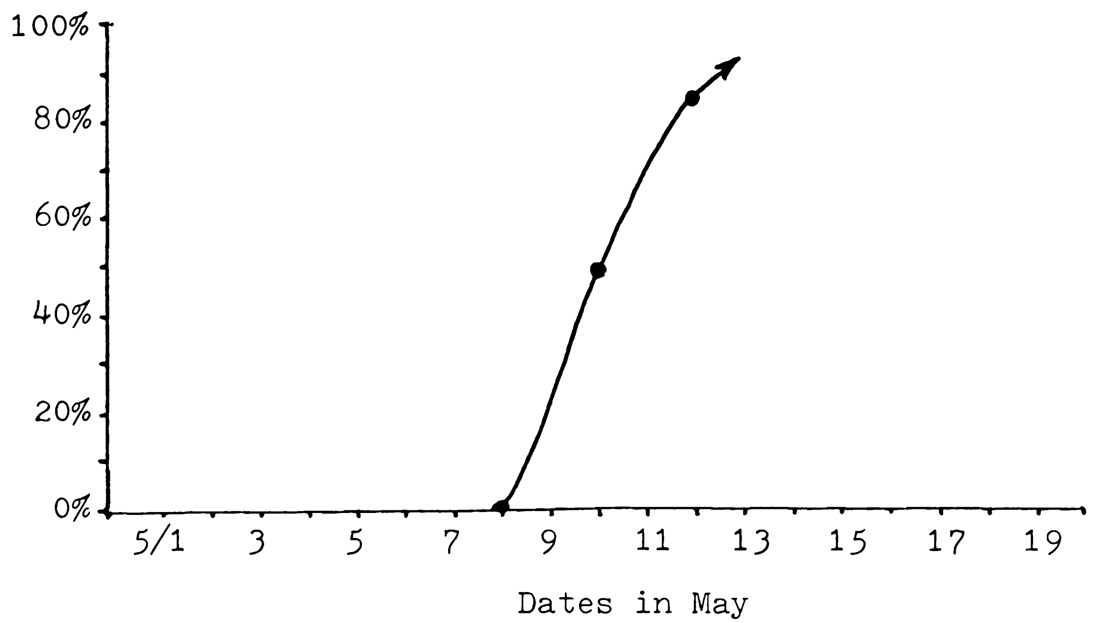


Figure 2-D Year 1979 Cultivar Seyval

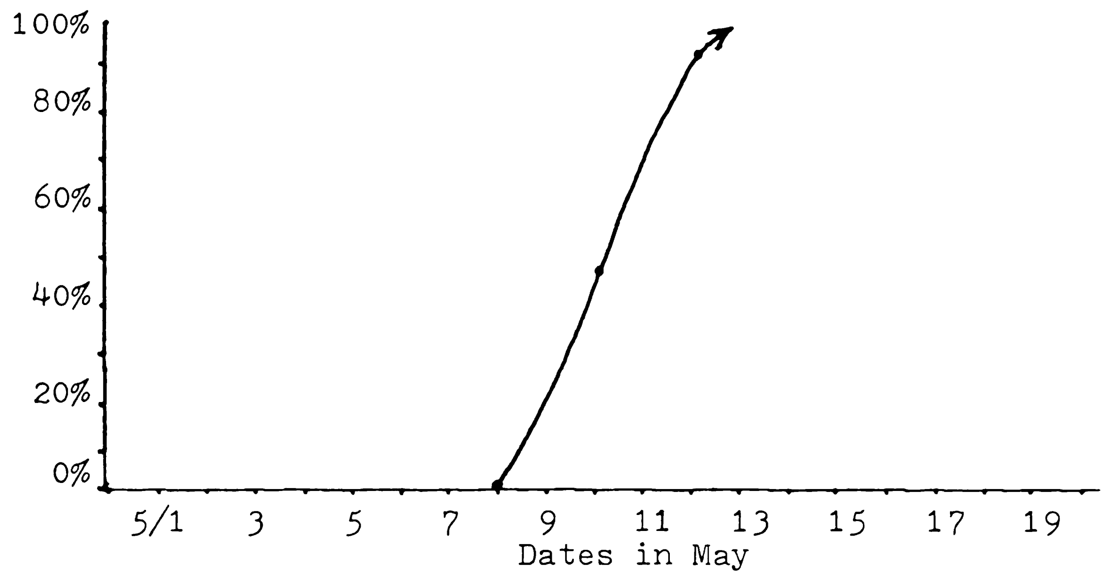


Figure 2-E Year 1979 Cultivar Aurore

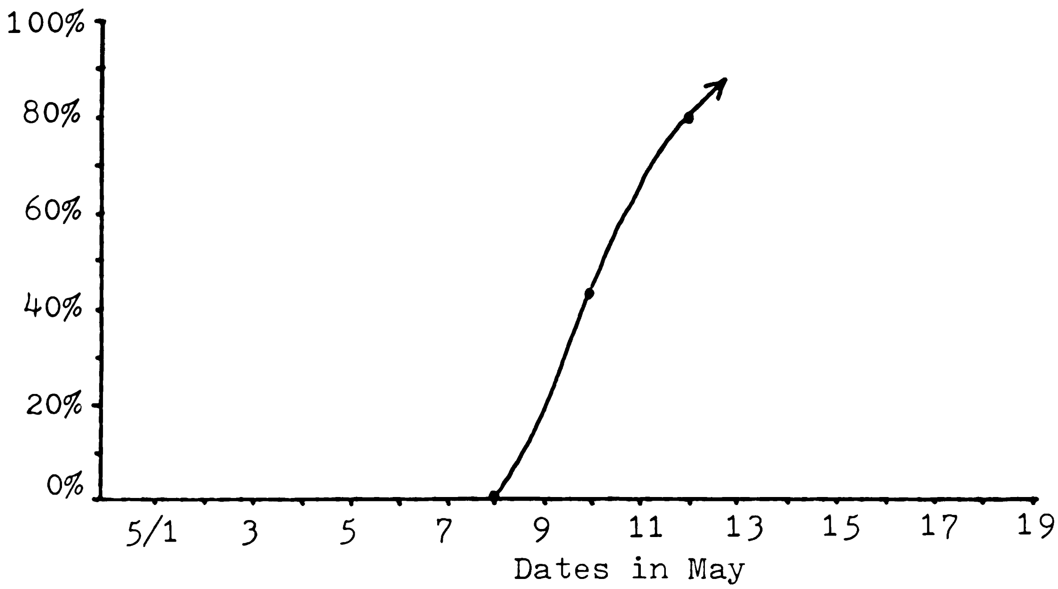


Figure 2-F Year 1980 Cultivar Concord

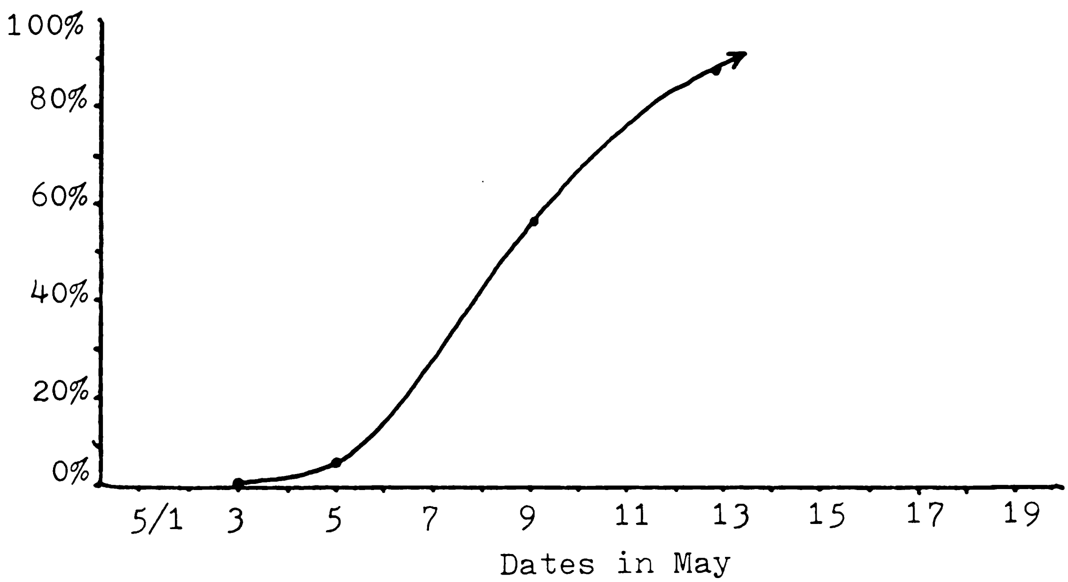


Figure 2-G Year 1980 Cultivar Concord unpruned

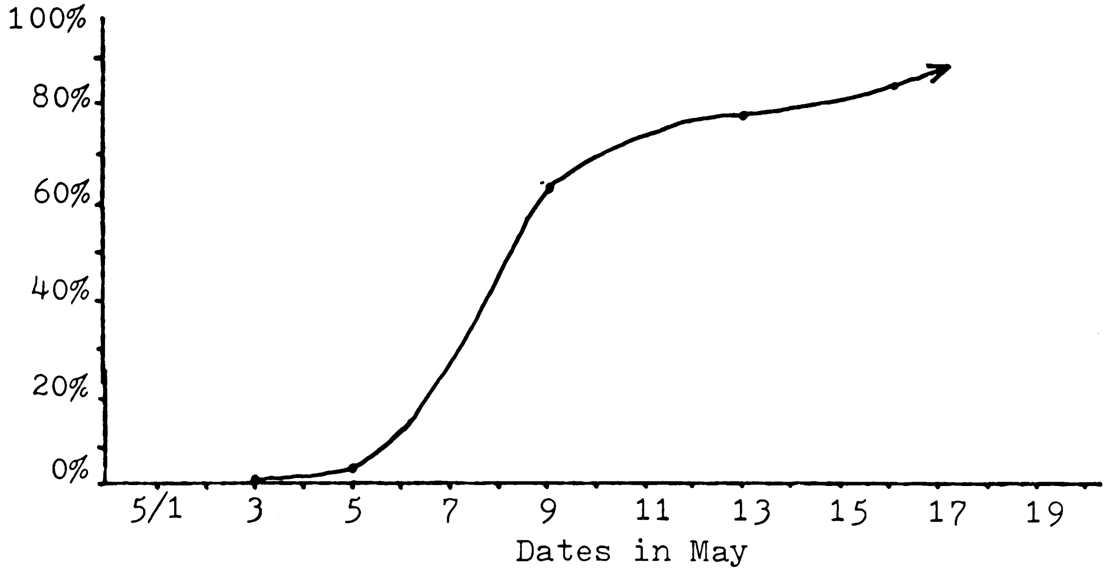


Figure 2-H Year 1980 Cultivar Aurore

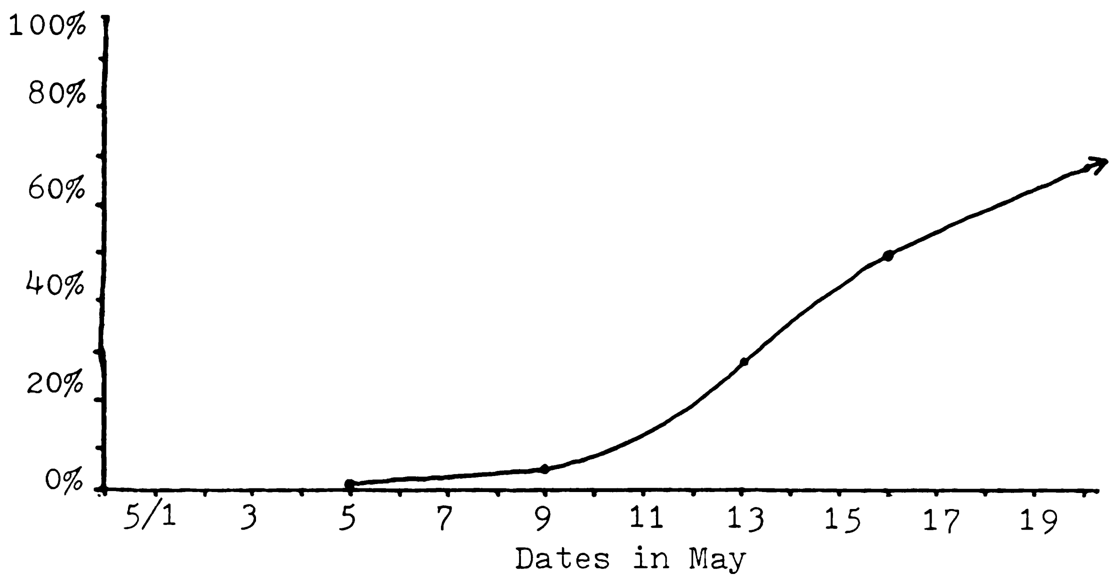


Figure 2-I Year 1980 Cultivar Chelois

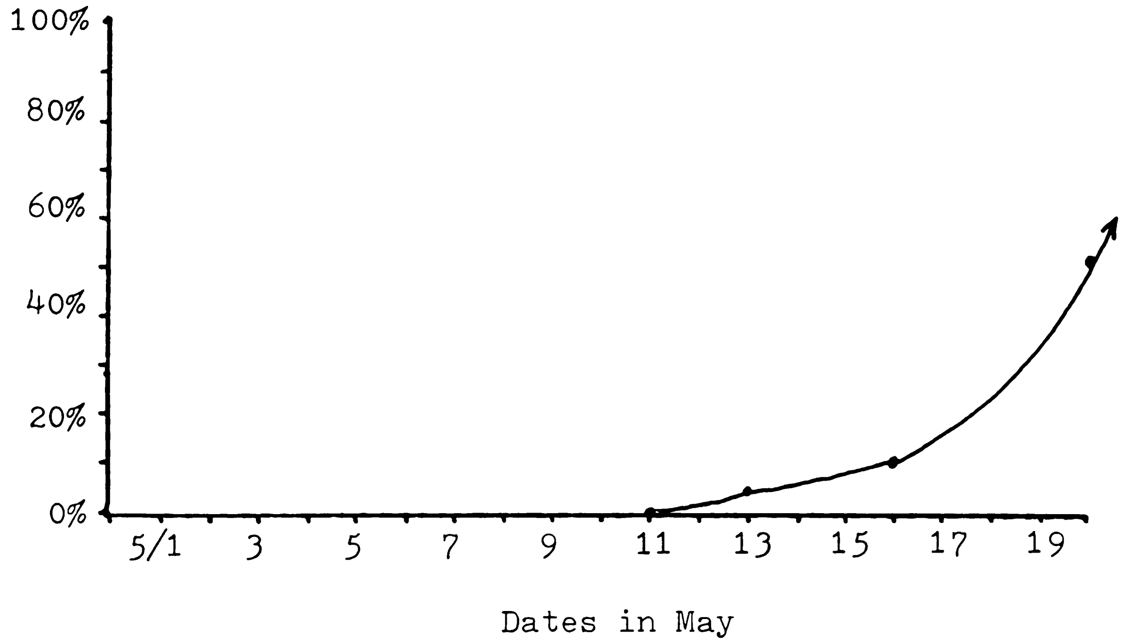


Figure 2-J Year 1980 Cultivar De Chaunac

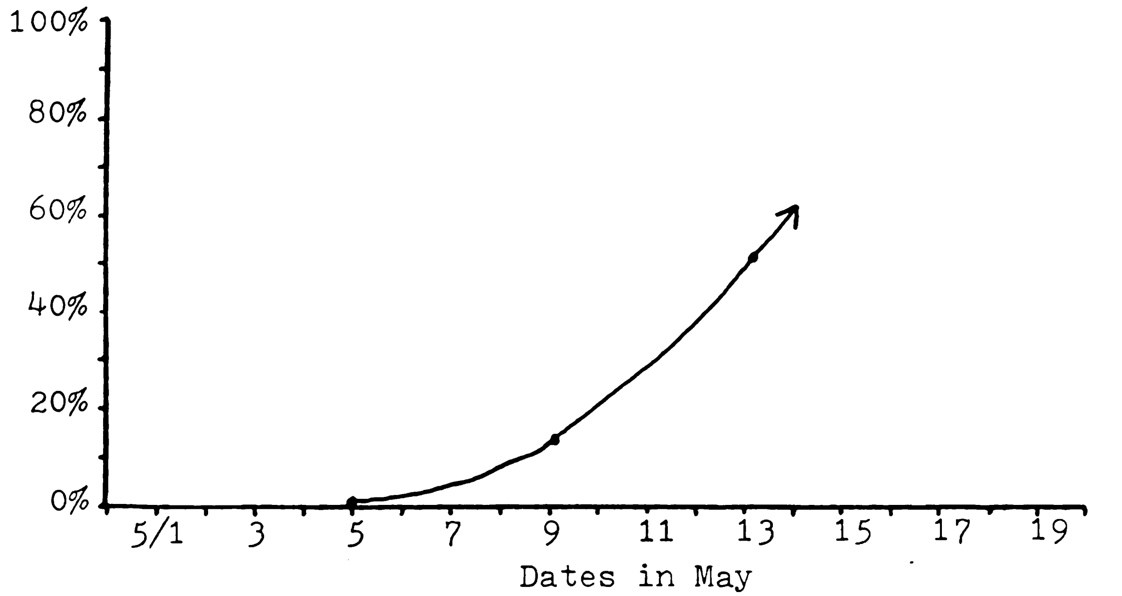


Figure 2-K Year 1980 Cultivar Baco noir

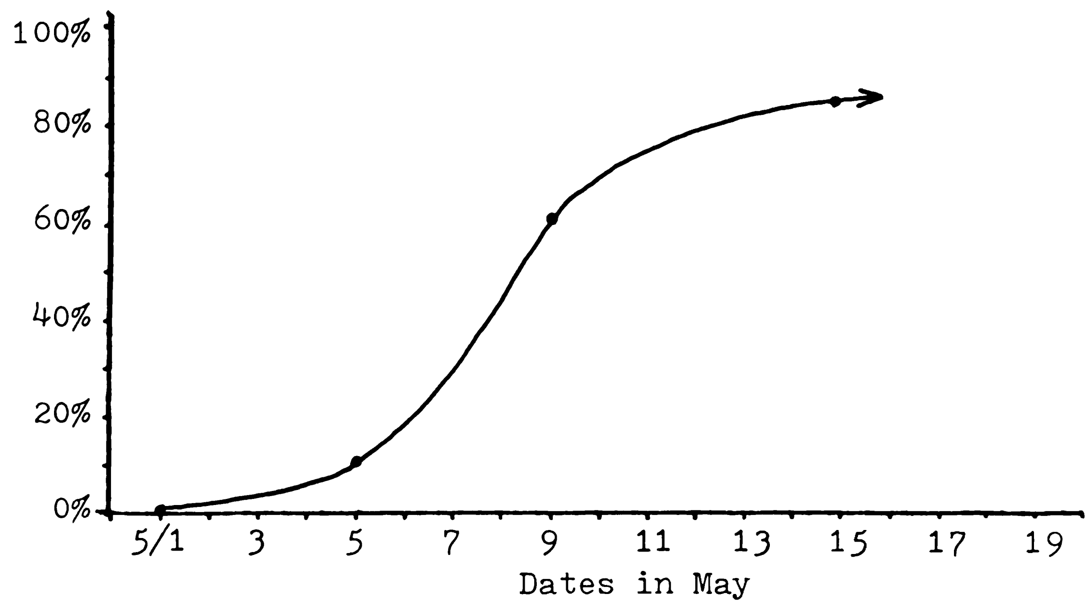


Figure 2-L Year 1980 Cultivar Vignoles

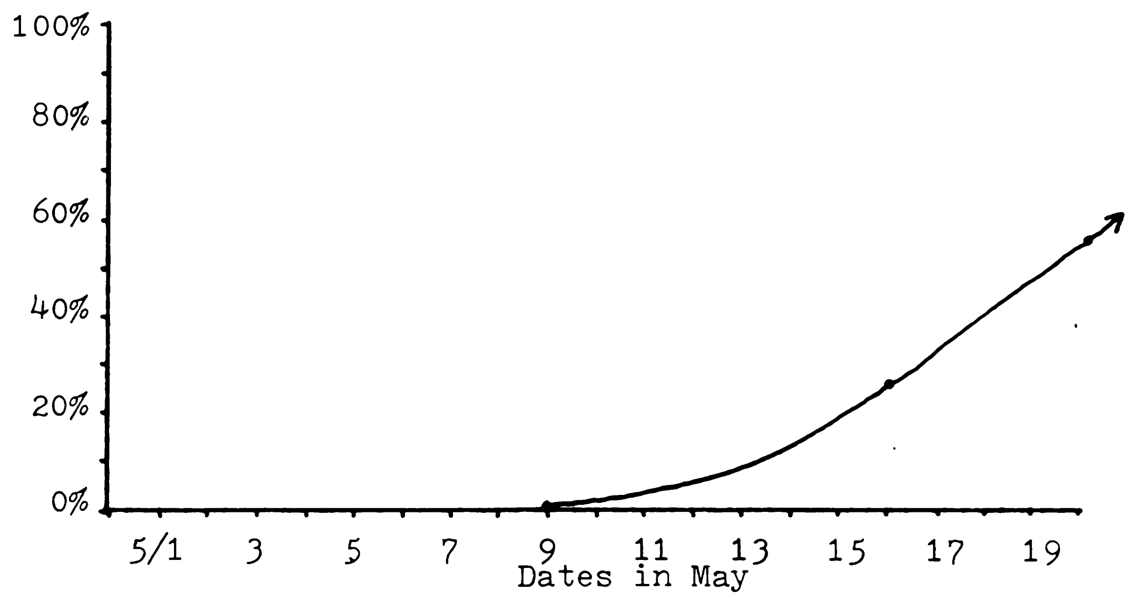


Figure 2-M Year 1980 Cultivar Seyval

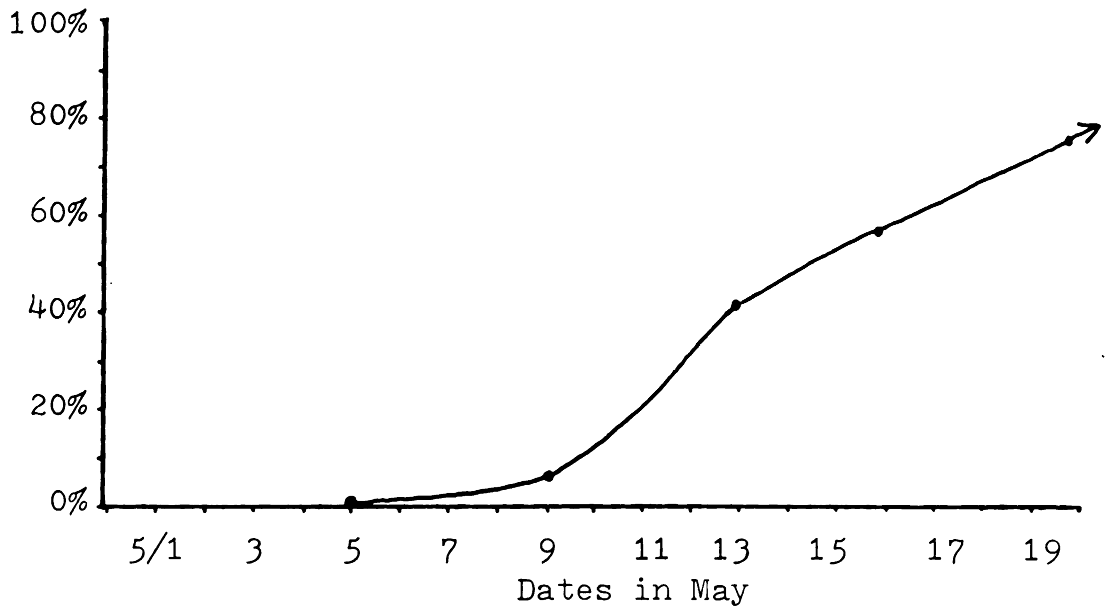


Figure 2-N Year 1980 Cultivar Vidal

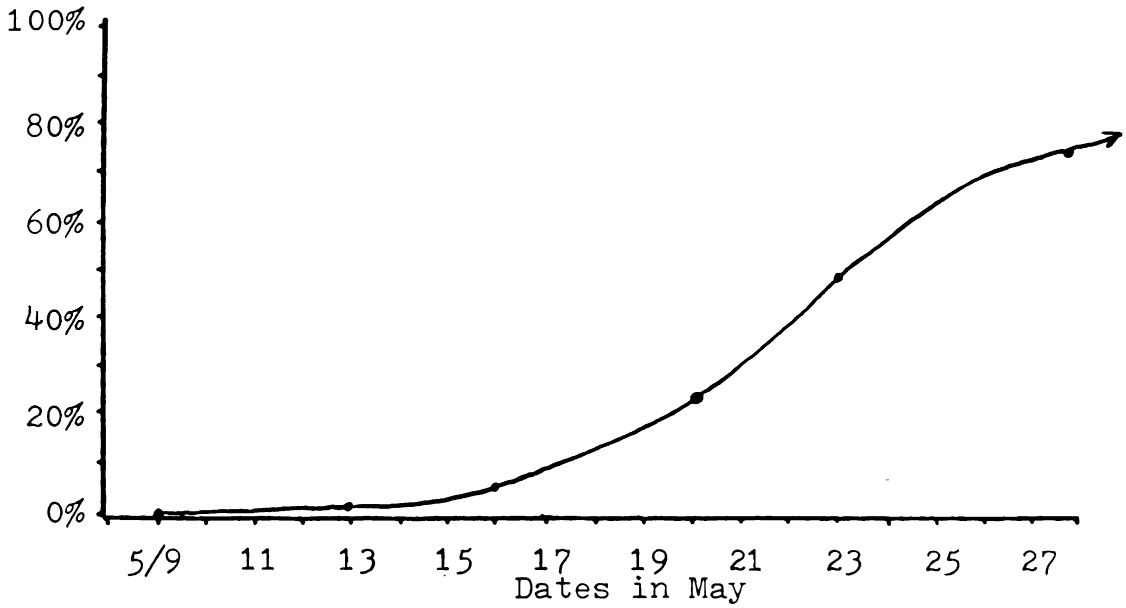


Figure 2-O Year 1980 Cultivar Baco noir

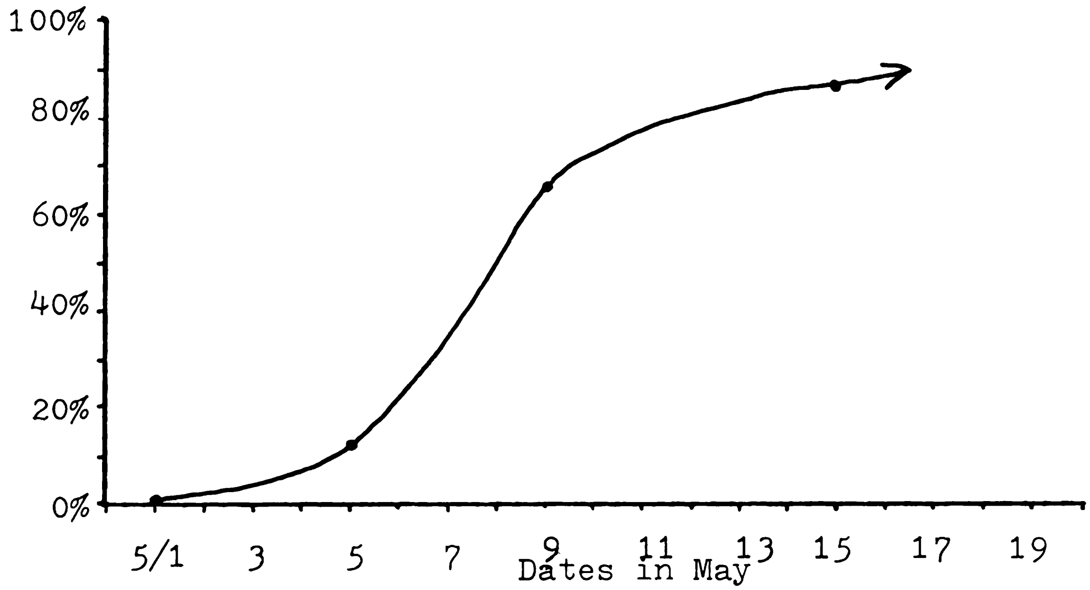


Figure 2-P Year 1980 Cultivar Seyval

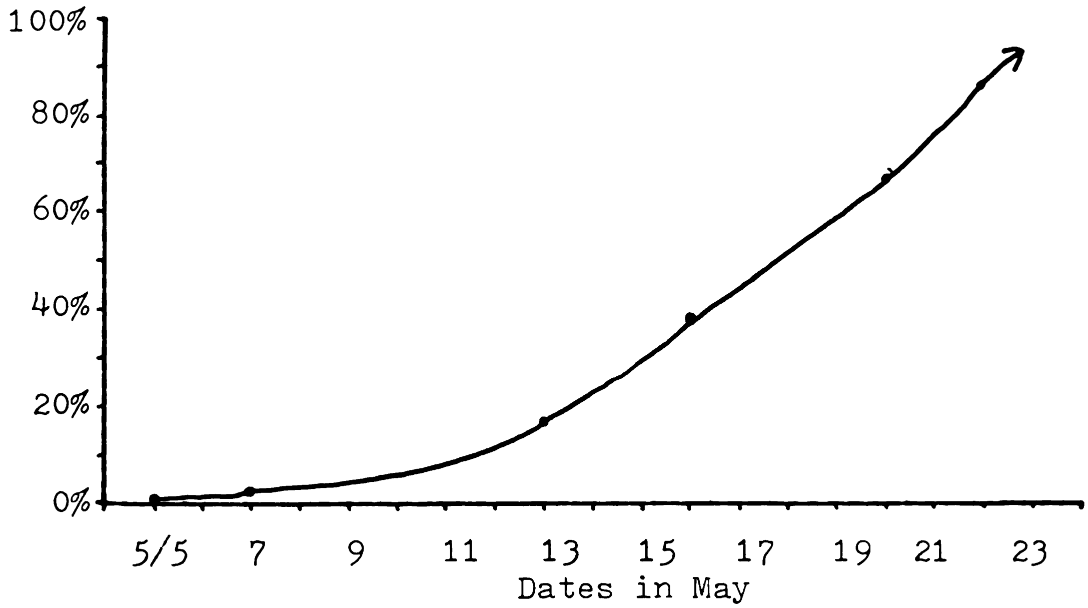


Figure 3. Coefficient of variation for daily max-base versus base temperature. The lowest C.V. gives the best base temperature to use for a given cultivar.

Figure 4. Coefficient of variation for daily mean-base versus base temperatures. The lowest C.V. gives the best base temperature to use for a given cultivar.

Figure 3 Daily Max - base

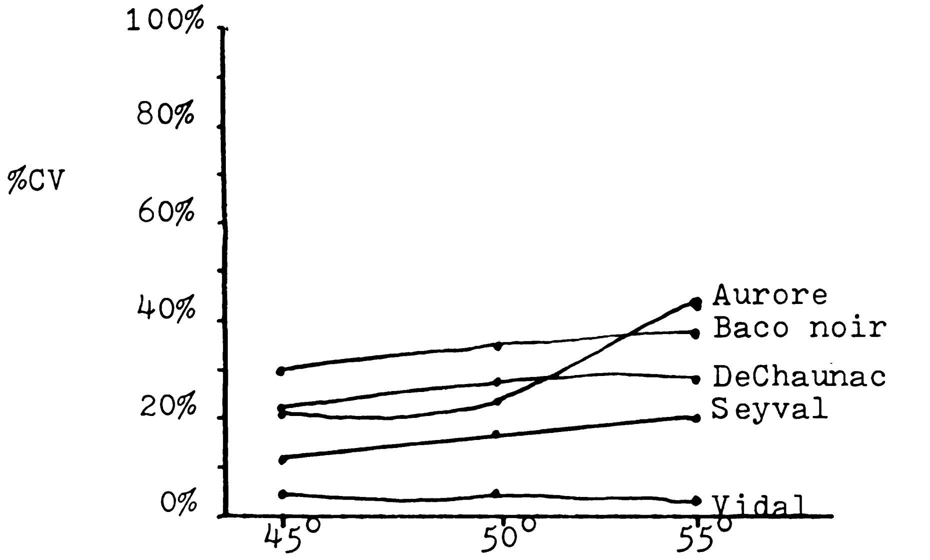


Figure 4 Daily mean - base

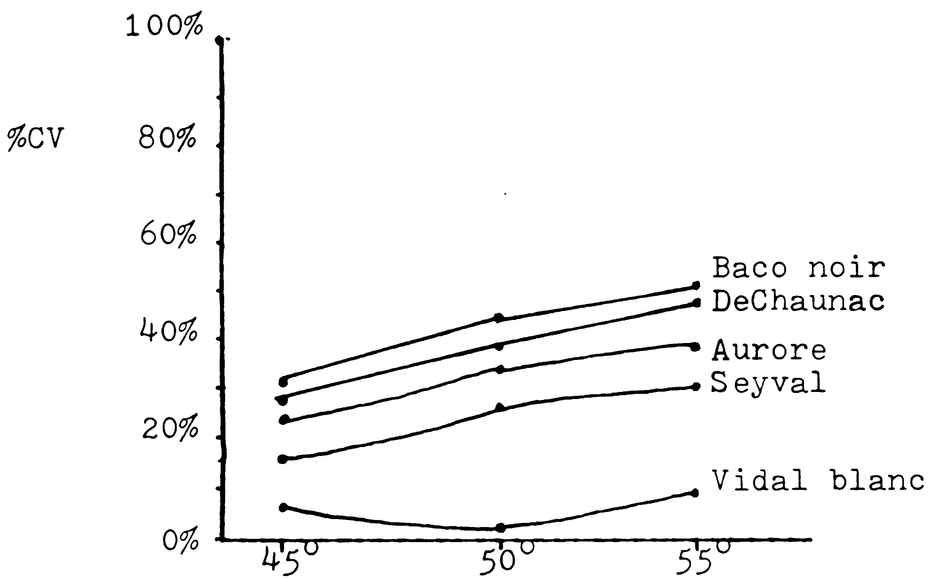


Figure 5. Coefficient of variation for number of days over the base. The lowest C.V. gives the best base temperature to use for a given

Figure 6. Coefficient of variation for Lindsay and Newman heat units. The lowest C.V. gives the best base temperature to use for a given

Figure 5 Number of days over base

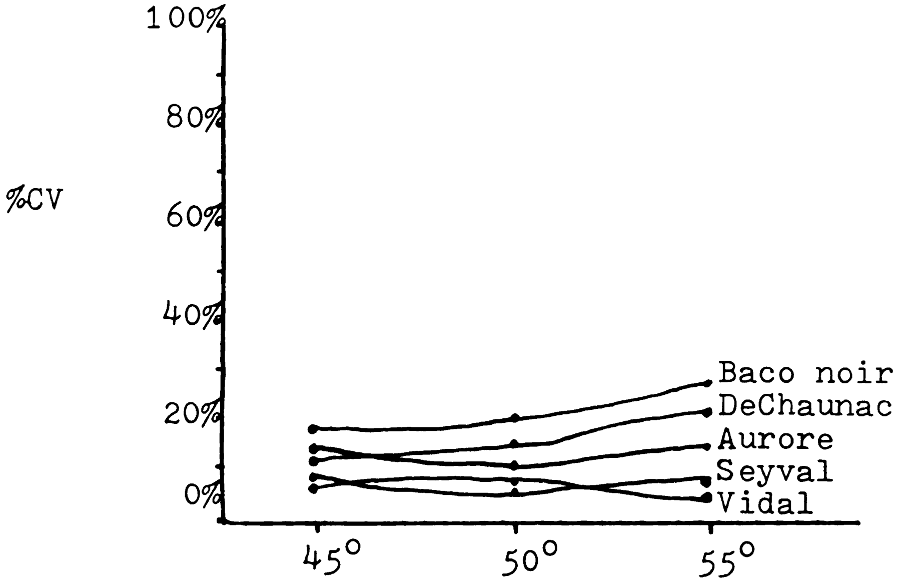


Figure 6 Lindsey and Newman units and Time

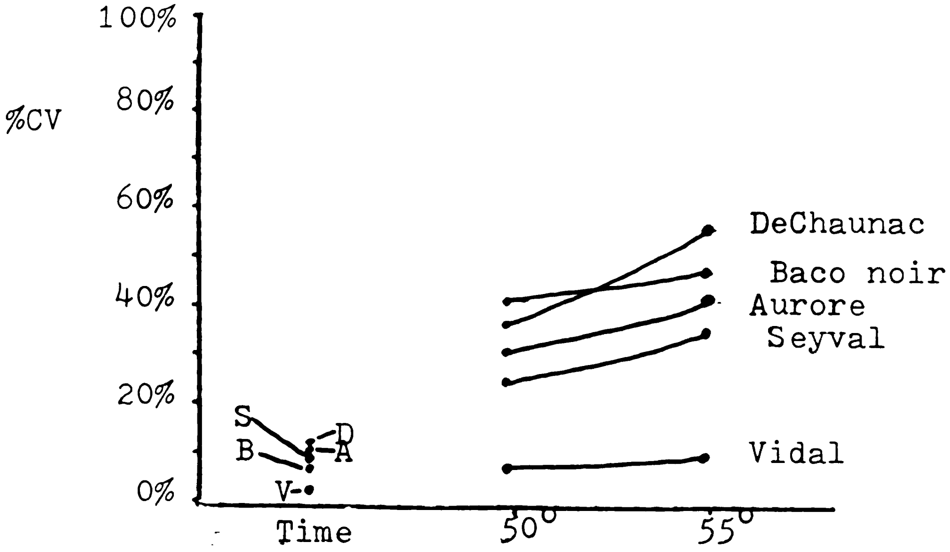


Figure 7. Using 'Baco Noir' as an example, the different models are compared using the C.V. at the 45° threshold. The lowest C.V. gives an indication of the best model to use for the cultivar and threshold.

Figure 8. Using 'Aurore' as an example, the different models are compared using the C.V. at the 45° threshold. The lowest C.V. gives an indication of the best model to use for the cultivar and threshold.

Figure 7 Baco noir at 45° threshold

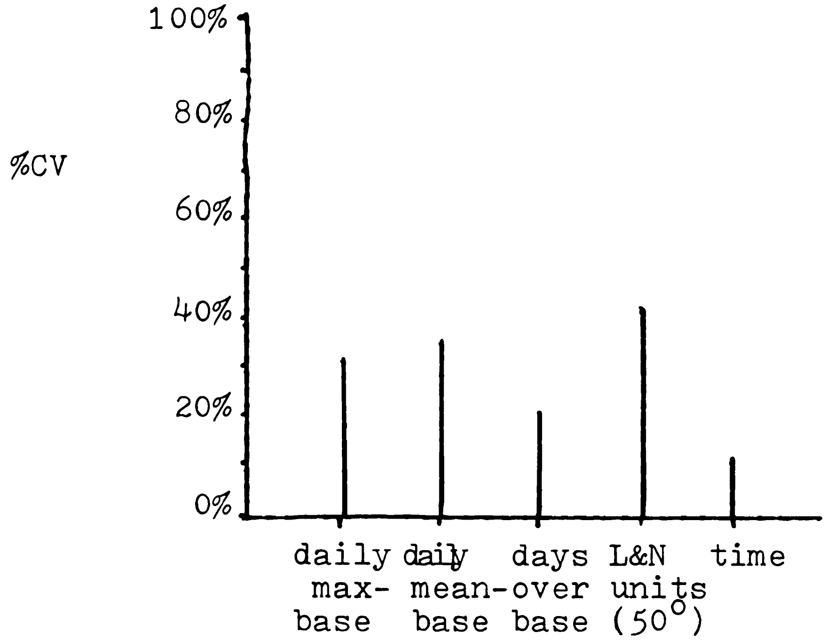


Figure 8 Aurore at 45° threshold

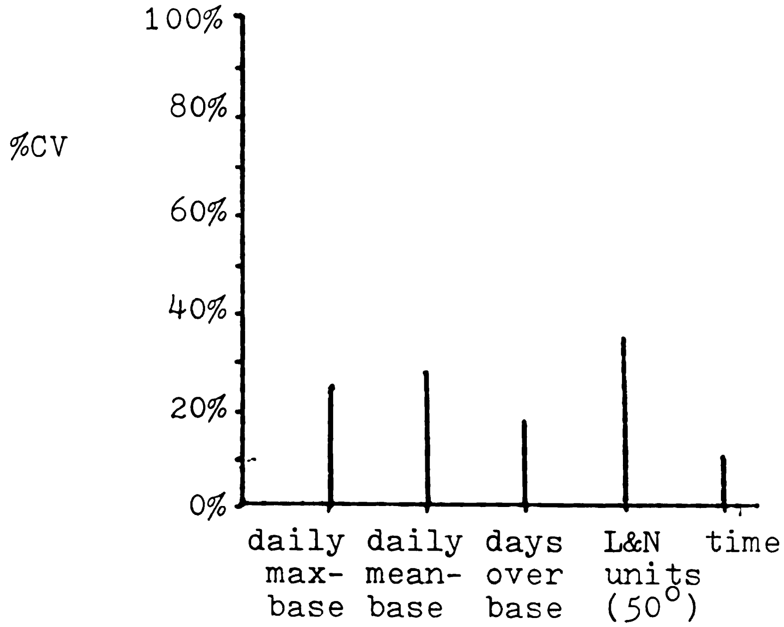


Figure 9. Using 'De Chaunac' as an example, the different models are compared using the C.V. at the 45° threshold. The lowest C.V. gives an indication of the best model to use for the cultivar and threshold.

Figure 9 De Chaunac at 45° threshold

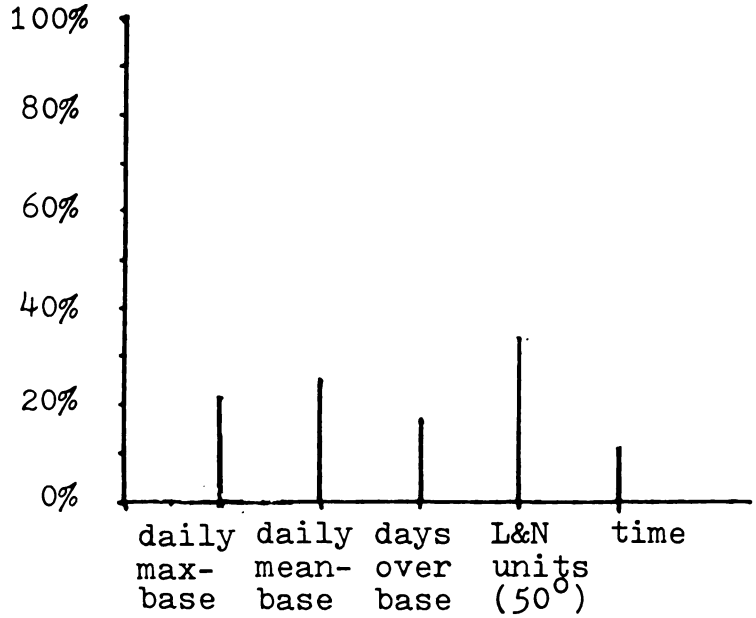
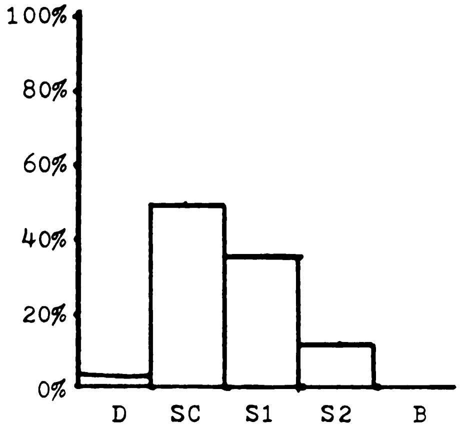
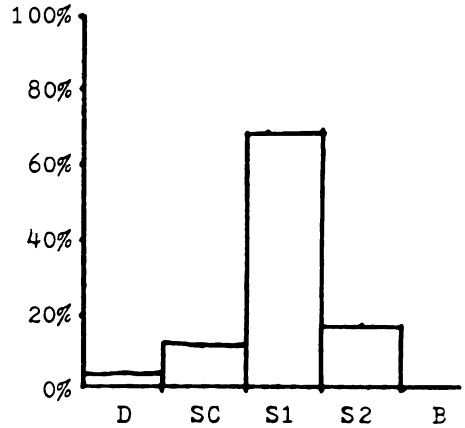


Figure 10. Percentage of buds in each developmental category at Tabor Hill vineyard in the spring of 1980.

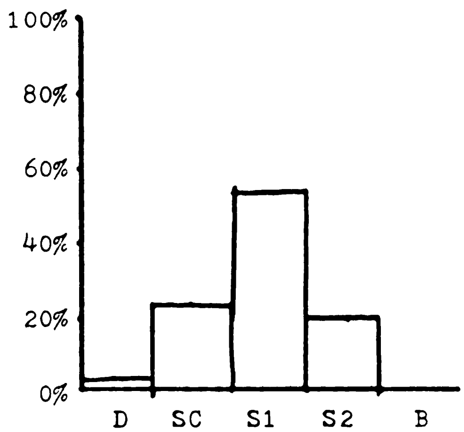
Baco Noir on 4-24-80



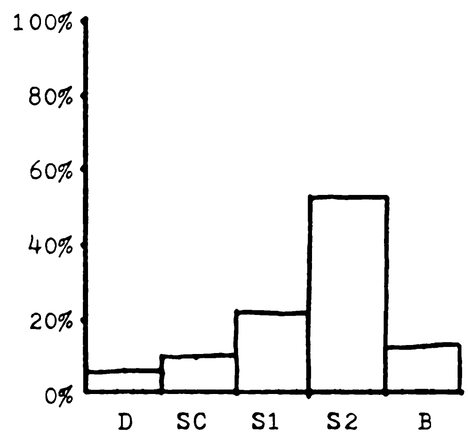
Baco Noir on 4-28-80



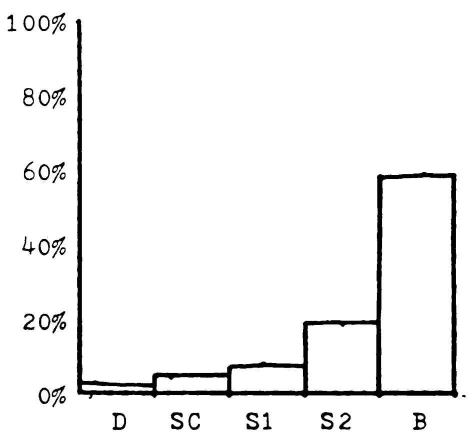
Baco Noir on 5-1-80



Baco Noir on 5-5-80



Baco Noir on 5-9-80



Baco Noir on 5-13-80

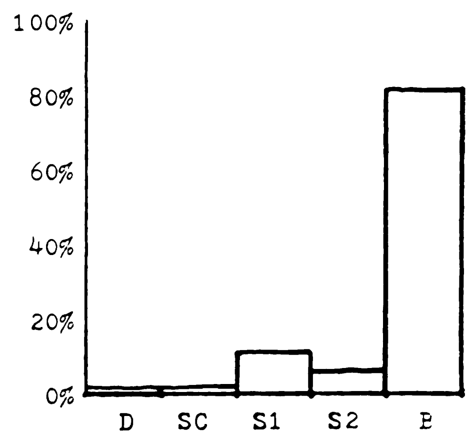
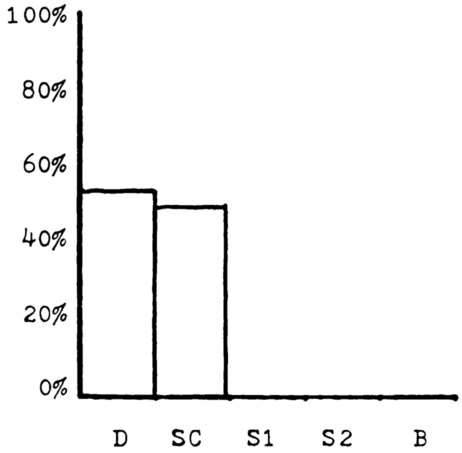
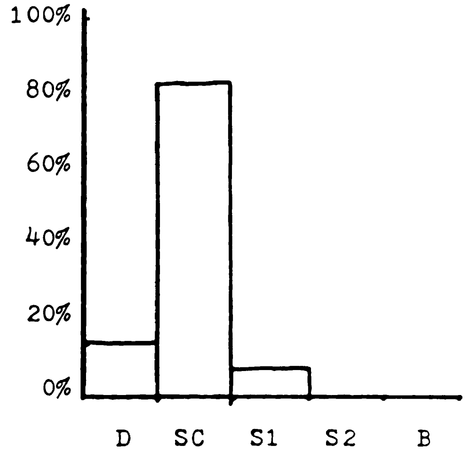


Figure 11. The percentage of buds in each developmental category at Tabor Hill vineyard in the spring of 1980.

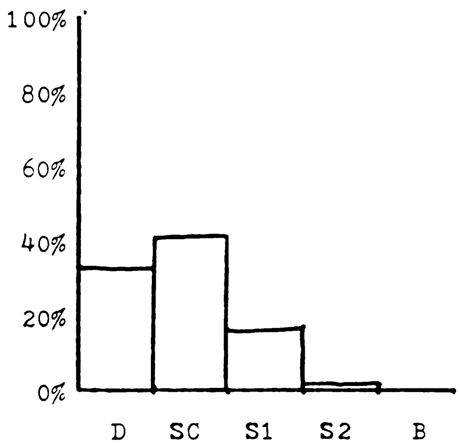
Vidal on 5-1-80



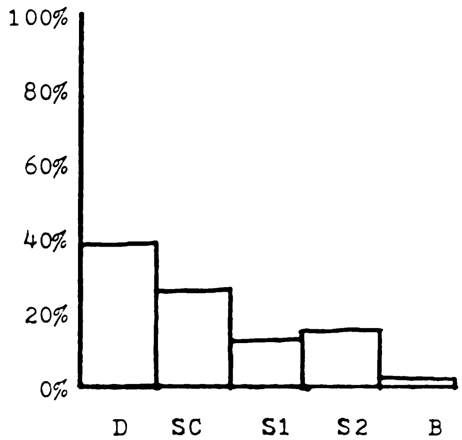
Vidal on 5-5-80

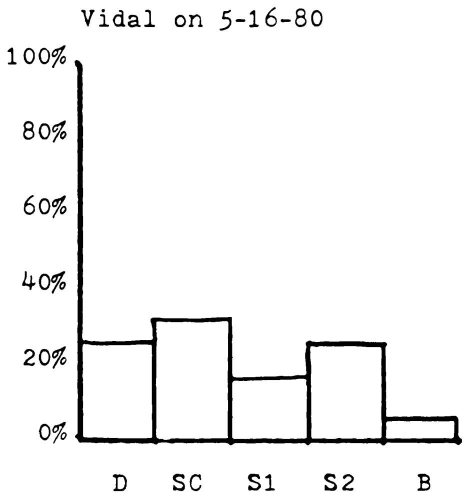


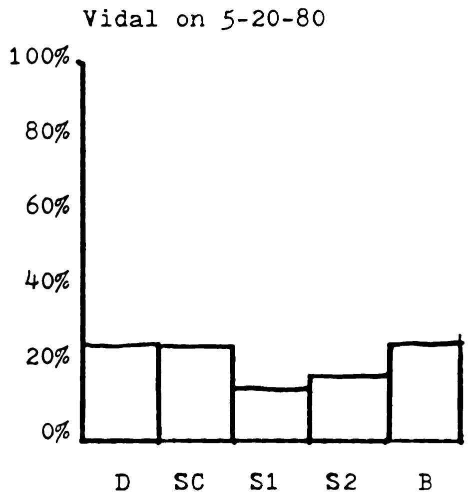
Vidal on 5-9-80

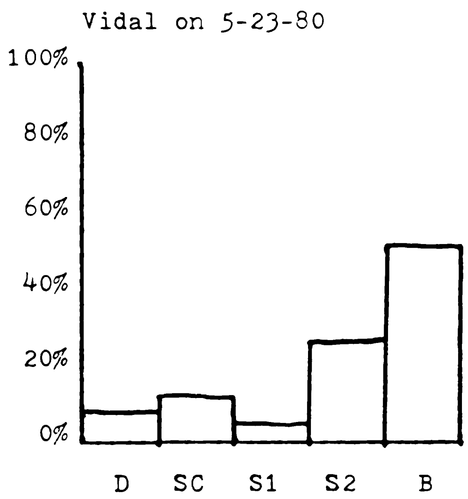


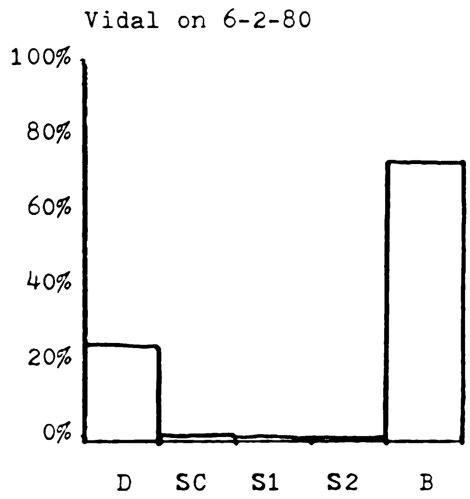
Vidal on 5-13-80




Vidal on 5-16-80
100%
80%
60%
40%
20%
0%
D SC S1 S2 B


Vidal on 5-20-80
100%
80%
60%
40%
20%
0%
D SC S1 S2 B


Vidal on 5-23-80
100%
80%
60%
40%
20%
0%
D SC S1 S2 B


Vidal on 6-2-80
100%
80%
60%
40%
20%
0%
D SC S1 S2 B

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