by cane selection and node limitation based on the general vigor of the vineyard. Since completely mechanized pruning with no follow-up cane selection or node adjustment appeared feasible for the first year of this study, the possibility of using a pruning cycle consisting of 1 year of completely mechanized pruning followed by a year of balanced pruning to a 30+10 schedule needs investigation.

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Prediction of 'Concord' Grape Maturation and Sources of Error[1]

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Abstract. **Fruit samples of grape (*Vitis labrusca* L., cv. Concord) from 6 vineyard locations were collected at 7 to 10-day intervals beginning prior to veraison and continuing through development of 16% soluble solids for a period of 19 years. The 19-year average date for peak bloom in these vineyards was May 19, for 8% soluble solids development was July 27 (69 days from peak bloom), and for 16% soluble solids development was August 23 (96 days from peak bloom). Heat unit summations were more closely related to development of soluble solids than to changes in either titratable acidity or color. Using degree-day accumulations and effective heat unit summations did not prove to be methods superior to use of the number of calendar days for predicting grape maturation. Predictions from 8 to 16% soluble solids development were more accurate than predicting from peak bloom (when 50% of clusters showed bloom). Variations between years and between vineyard locations within a given year prevented accurate predictions from the 3 methods. Other deterrents observed in predicting development of soluble solids included the cultural variables of fruit load and soil moisture.**

The concept of heat unit summation has been used extensively to relate grape maturation to variations in seasonal temperatures (2, 3, 4, 7, 12, 13, 14, 16). The maturity index generally used for grapes is soluble solids; however, Robinson et al. (7) reported that acidity may be a better indicator of maturity in New York. Use of degree-day accumulations for forecasting harvest of grapes has been useful (13, 14, 16), but variations in climate, species, and cultivar prohibit standardization of a prediction model.

Although degree-day accumulations have been related to quality changes in 'Concord' grapes in Arkansas (2, 4, 12), no information is available on use of heat unit summations to predict 'Concord' harvest under southern growing conditions. An early prediction of harvest would facilitate scheduling of transportation and plant operations. The purposes of this study were 1) to develop a prediction model for southern grown 'Concord' grapes and 2) to determine the variation encountered in predicting fruit maturation.

Methods and Materials

Grape maturation data for soluble solids, acids and juice color, and dates of peak bloom (when 50% of clusters showed bloom) were obtained from the National Grape Cooperative in Springdale, Arkansas. The data were collected over a 19-year period (1960-1978) at 6 vineyard locations in the Springdale district. All vineyards were located within a 16 km radius of the University of Arkansas Agricultural Experiment Station and all sites were at approximately the same elevation and had similar topography as the station. The elevation of this area is 434 m and lies 36° 3' north and 94° 8' west. The length of daylight ranges from 9 hr 42 min on the winter solstice to 14 hr 42 min on the summer solstice. The specific vineyards were selected because their early maturing characteristics governed the time for opening the processing plant. Three vineyard locations had to be substituted during the 19-year period and were replaced in the same area by comparable vineyard sites with regard to elevation and topography and with vines of comparable size and age. All vineyards were trained to either a 4-arm Kniffin or Umbrella-Kniffin system.

Each year uniform samples were collected from the same vines by the same individual starting prior to veraison and continuing on 7 to 10-day intervals until soluble solids developed to 16%. Twelve fruit clusters (1/vine) were selected

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Table 4. Prediction error using DD_{10}, $EHU_{5\text{-}32}$, and calendar days to forecast soluble solids development in 'Concord' grapes.

	Prediction error (days)								
	From peak bloom to 16% sol. sol.			From peak bloom to 8% sol. sol.			From 8% to 16% sol. sol.		
Year	DD_{10}[z]	$EHU_{5\text{-}32}$[y]	Days[x]	DD_{10}	$EHU_{5\text{-}32}$	Days	DD_{10}	$EHU_{5\text{-}32}$	Days
1960	–4[w]	–3	–5	+2	+1	–6	–2	–1	–1
1961	–6	–1	+2	+3	+4	–1	–4	–1	+1
1962	–4	–4	–5	+5	+4	–3	–5	–4	–4
1963	+1	–3	–2	+2	0	–4	+3	0	0
1964	–1	–5	–3	+3	0	–4	0	–2	–1
1965	–3	–2	–3	+5	+5	–2	–4	–3	–3
1966	+3	+3	+4	+11	+10	+4	–6	–3	–2
1967	–8	–5	0	+1	+3	+3	–5	–5	–5
1968	+2	+3	+2	+4	+5	0	+2	+2	0
1969	+10	+8	+4	+10	+7	–2	+3	+4	+4
1970	+9	+2	+1	+4	+1	–4	+9	+4	+3
1971	–2	–2	–5	+7	+1	–8	–2	+1	+1
1972	–8	–7	–6	–4	–4	–8	0	+1	0
1973	–8	–5	–6	+3	+4	–2	–7	–6	–6
1974	0	0	+1	+5	+3	–2	–1	+1	+1
1975	+2	+4	+2	+4	+4	–2	+1	+3	+2
1976	–8	–3	+5	0	+2	+3	–4	–2	0
1977	–3	–3	–4	+2	+1	–5	–1	0	–1
1978	+1	–1	–4	+5	+4	–4	–1	–2	–2
Range (days)	18	15	11	15	14	12	16	10	10
Predicted[v]	1399	1815	96	900	1222	69	445	542	27

[z]Degree-day accumulation using a base of 10°C and no upper temperature limit.

[y]Effective heat unit summation using a lower and optimum cardinal temperature of 5° and 32°C, respectively.

[x]Calendar days.

[w]"+" indicates soluble solids developed later than forecast.

[v]Actual prediction of accumulated units necessary for soluble solids development based on the 19 years of data from 6 vineyards.

Table 5. Variations in maturation of 'Concord' grapes for 19 years at 6 vineyard locations.

	Soluble solids	
Variable	8%	16%
Calendar dates		
Mean[z]	July 27	Aug. 23
Range between years[y]	July 14–Aug. 6	Aug. 9–Sept. 2
Range between vineyards[x]	July 11–July 22	Aug. 17–Sept. 1
Days from peak bloom		
Mean[z]	69	96
Range between years[y]	63–75	90–101
Range between vineyards[x]	63–74	90–105
Acidity (as % tartaric)		
Mean[z]	2.70	1.05
Range between years[y]	2.50–3.15	0.90–1.20
Range between vineyards[x]	2.45–2.95	0.95–1.45
Color (O.D.)		
Mean[z]	––––[w]	9.3
Range between years[y]	––––	6.4–15.6
Range between vineyards[x]	––––	8.1–15.1

[z]Average of 19 years and 6 vineyards.

[y]Variation between the earliest and latest years (the mean for each year was determined by averaging across 6 vineyards).

[x]Maximum variation between 6 vineyards in a year.

[w]Insufficient color development for determination at 8% soluble solids.

the range in prediction errors from the earliest to the latest years of 18 days for DD_{10} and 15 days for $EHU_{5\text{-}32}$. To reach 8% soluble solids from peak bloom, 900 DD_{10}, 1222 $EHU_{5\text{-}32}$, and 69 calendar days were required. Calendar days reduced the prediction error to a 12-day range. Use of $EHU_{5\text{-}32}$ was more accurate than DD_{10} for predicting the time from 8 to 16% soluble solids development, but calendar days were just as accurate. Development from 8 to 16% soluble solids required 445 DD_{10}, 542 $EHU_{5\text{-}32}$, and 27 calendar days.

Although it was not the objective of this study it was interesting to note that for the 19-year average, from 8 to 16% soluble solids, 'Concord' averaged a uniform increase of 0.3% per day. This rate is in agreement with Shaulis et al. (9) for soluble solids development in fruit on vines exposed to full light conditions in New York.

Van Den Brink (13) used a constant calendar date for beginning a prediction system for 'Concord' in Michigan. However, in our study the date of peak bloom varied considerably between years (Table 5). The 19-year average date of peak bloom in Arkansas was May 19, but bloom date ranged from May 8 to May 27. In this study the actual date of peak bloom for each year was used, since beginning a prediction model from peak bloom each year may remove a major source of variation.

The average dates that 8 and 16% soluble solids were reached were July 27 and August 23, respectively (Table 5). However, the dates ranged among years from July 14 to August 6 for development of 8% soluble solids and from August 9 to

Table 6. Possible variation extremes in development of soluble solids due to irrigation, fruit load and vines within the same vineyard.

Variable	Yield (MT/ha)	Date of 8% sol. sol.	Date of 16% sol. sol.	Days from 8% to 16% sol. sol.	Prediction[y] error (days)
Irrigated[z]					
High yield					
Vine 1	22.0	July 29	---[x]	--	--
2	24.5	July 28	---	--	--
Low yield					
Vine 1	11.4	July 25	Aug. 21	27	0
2	10.6	Aug. 2	Sept. 3	32	+5
Not irrigated					
High yield					
Vine 1	11.5	July 23	Sept. 6	45	+18
2	12.8	July 29	Sept. 7	40	+13
Low yield					
Vine 1	6.7	July 28	Aug. 21	24	−3
2	6.8	July 25	Aug. 25	31	+4

[z]Soil moisture tension maintained between 100–200 mb.

[y]Based on 27 days required from 8% to 16% soluble solids development. "+" indicates soluble solids development later than forecast.

[x]Fruit did not reach 16% soluble solids by Sept. 8 (on Sept. 8 Vine 1 had 14.4% and Vine 2 had 14.6% soluble solids).

September 2, for development of 16% soluble solids. Among the 6 vineyard locations used each year, the date of 8% soluble solids development showed a maximum range in one year from July 11 to July 22, and the date of 16% soluble solids development ranged from August 17 to September 1. Differences in development of soluble solids were not so large between vineyards as between years. However, vineyards used were selected on the basis of their early ripening characteristics and the variation between vineyards would probably have been greater if area vineyards had been selected at random.

The average number of days from peak bloom to 8 and 16% soluble solids development is 69 and 96, respectively (Table 5). Even though using peak bloom as a reference point probably reduced variation, the maximum range between years for reaching 8% soluble solids was 63 to 75 days from peak bloom and for reaching 16% soluble solids was 90 to 101 days. The range in days from peak bloom between vineyards can be as large as between years with a range of 63 to 74 days for 8% and 90 to 105 days for 16% soluble solids development.

Acidity and color, which did not show close relationships with the prediction models used (Table 3), varied considerably between years and between vineyards within a given year at a specified maturity level based on soluble solids development (Table 5). When averaged across 19 years and 6 vineyards, Arkansas-produced juice contained 2.70% acidity at 8% soluble solids. However, this acidity varied from 2.50 to 3.15% among years and from 2.45 to 2.95% among vineyards in the same year. Acidity at 16% soluble solids averaged 1.05%, but varied from 0.90 to 1.20% between years and from 0.95 to 1.45% between vineyards in the same year. Juice color, averaging 9.3 O.D. at 16% soluble solids development, ranged from 6.4 to 15.6 between years and from 8.1 to 15.1 between vineyards in the same year.

1978 observations. Using our best prediction model (calendar days from 8 to 16% soluble solids), the degree of variation in soluble solids development exhibited between years and between vineyards within a given year may also be evident within a single vineyard. Of the vines selected in the research vineyard in 1978 for monitoring soluble solids development, high yielding (60+10) irrigated vines developed 8% soluble solids on July 28 and July 29 but did not attain 16% by the time sampling was terminated (Sept. 8) (Table 6). One of the low yielding irrigated vines reached 8% soluble solids on July 25 and 16% on August 21. This interval matched the 27 days forecasted by the best prediction model. A vine which was treated identically required 5 days in addition to the predicted 27 days from 8 to 16% soluble solids. The 2 non-irrigated high yielding vines required 13 and 18 days beyond the predicted 27 days, a 5-day difference between the 2 vines. One of the low yielding non-irrigated vines developed 16% soluble solids 3 days earlier and the other vine 4 days later than predicted, a 7 day difference between the 2 vines.

The variations in soluble solids development which occurred in 1978 in the research vineyard, probably as a result of soil moisture and fruit load conditions, illustrate extremes which would not normally exist within a commercial vineyard. Yet the influence of these 2 factors on grape maturation, combined with vine to vine variation, is evidence of cultural and environmental influences other than temperature. Other research has indicated that cultural and environmental conditions such as trellising system (2, 9), light intensity or shoot positioning (2, 3, 9), pruning method (2, 3, 9, 12), vine size (6, 10) and soil fertility (3, 11) will affect fruit maturation. Until a prediction scheme is developed which will account for cultural and environmental differences to which 'Concord' is responsive, simple heat unit accumulations will provide only a rough estimate of fruit maturation. Additional research is underway to determine if improvement of the prediction accuracy is possible by incorporating soil moisture, cultural practices and fruit load variations into the prediction model. These additions may allow for a practical as well as theoretically sound method for predicting soluble solids development of 'Concord' grapes under Arkansas conditions.

Conclusions

Utilizing different combinations of base temperatures and upper temperature limits in degree-day calculations provided little improvement over the degree-day summation system using a 10°C base and no upper temperature limit. With changes in the assumed lower and optimum cardinal temperatures, effective heat units and degree-days produced similar results in prediction. However, use of actual calendar days in a prediction model with soluble solids development resulted in lower prediction errors than either of the heat unit accumulation systems. Therefore, under conditions of this study (using data from 6 vineyards for 19 years) the linear heat unit accumulation systems did not provide an improvement over the use of calendar days as a means of predicting 'Concord' grape maturation. The most accurate predictions were obtained from 8 to 16% soluble solids development using the number of calendar days or effective heat units at low and optimum cardinal temperatures of 5° and 32°C, respectively. Changes in acidity or color were not as predictable as soluble solids development during maturation. Coefficients of variation depicted differences in prediction accuracy better than correlation coefficients.

Climatic variations other than temperature between years and between vineyards within a year and differences in cultural practices prevent accurate and reliable use of a forecasting system for 'Concord' grape maturation in Arkansas. However, long range estimates from a prediction model may be useful to determine the start of initial fruit sampling but continuous monitoring of fruit maturation is necessary to determine actual harvest dates and scheduling of processing facilities.

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