

## Phenologic and growth responses to early and late season water deficits in Cabernet franc

by

M. A. MATTHEWS, M. M. ANDERSON and H. R. SCHULTZ

### Beeinflussung der phänologischen Entwicklung und des Wachstums von Cabernet franc durch frühzeitigen und späten Wassermangel während der Vegetationsperiode

**Zusammenfassung:** In einem kalifornischen, am Hang gelegenen Weinberg wurden die phänologischen und ontogenetischen Reaktionen der Rebsorte Cabernet franc auf Wassermangel während der Vegetationsperiode untersucht. Der Wassermangel wurde durch Abschalten der Bewässerung entweder vor oder nach dem Beginn der Beerenreife erzwungen. Bei den stetig (1 d/Woche) bewässerten Reben sank das mittägliche Blattwasserpotential ( $\psi$ ) zwischen Austrieb und beginnender Beerenreife von  $-0,4$  MPa auf etwa  $-1,1$  MPa ab, obwohl die verabreichte Wassermenge das Doppelte der praxisüblichen Wassergabe betrug. Deshalb könnte Wassermangel im kalifornischen Hanglagenweinbau häufig ein begrenzender Faktor der Traubenproduktion sein. Wurde die Bewässerung bis zum Beginn der Beerenreife unterbrochen, so fiel das mittägliche  $\psi$  rascher ab und erreichte  $-1,4$  MPa, wenn die Bewässerung wieder aufgenommen wurde. Bei diesen Reben stieg der Wasserstatus langsam wieder auf das Niveau der ständig bewässerten Reben an. Der Wasserstatus derjenigen Reben, deren Bewässerung nach dem Beginn der Beerenreife eingestellt worden war, nahm nach dem Weichwerden der Beeren schnell ab und erreichte zum Erntezeitpunkt ein Minimum von  $-1,6$  MPa.

Diese Unterschiede im Wasserstatus der Reben hatten keinen Einfluß auf die wichtigsten phänologischen Daten, nämlich den Zeitpunkt der Blüte, der beginnenden Beerenreife und der Lese-reife (in Kalendertagen oder Grad·Tagen ausgedrückt). Früher Wassermangel verkürzte jedoch die Periode des Triebblängenwachstums und der Knotenbildung und beschleunigte die Ausbildung des Periderms an den 1jährigen Trieben. Die ökologische Bedeutung einer beschleunigten Peridermentwicklung wird diskutiert. Die Triebblänge und die Anzahl der Knoten je Trieb waren durch frühen Wassermangel um etwa 25% reduziert, auch das radiale Triebwachstum war hierdurch gehemmt, aber sehr viel geringer als das axiale Triebwachstum. Das Triebwachstum war bei allen Reben im wesentlichen abgeschlossen, ehe sich der späte Wassermangel auswirken konnte.

Die charakteristische doppelsigmoide Wachstumskurve der Beeren wurde unabhängig von der Wasserversorgung überall beobachtet. In allen Versuchsvarianten nahm der Beerendurchmesser während der ersten Wachstumsphase am stärksten zu. Die Geschwindigkeit des Beerenwachstums wurde durch frühen und späten Wassermangel verlangsamt. Der Ertrag war durch frühen Wassermangel stärker verringert als durch ein spätes Wasserdefizit.

**Key words:** water, drought, hydration, phenology, growth, lignification, yield, shoot, berry, USA.

### Introduction

In many grape producing areas of the world, including most of California (USA), irrigation is required to obtain economic yields. However, there is a dearth of quantitative information regarding the effects of plant water deficits upon vine growth and development. This information is important for several reasons. Fresh water for irrigation is an increasingly scarce resource upon which there will be increasing demand for efficient use. In several regions in which vines are grown (including California hill-sides), available irrigation water already is inadequate and water deficits at some point

in the season are inevitable. Although poorly documented, water deficits also frequently occur in areas where vines are grown without supplemental irrigation. Thus, regardless of the requirement for irrigation, data which describes vine growth/water status relationships is needed for the development of accurate vine growth models for both research and crop management.

In addition, it is a widely held assumption that water deficits have positive effects on periderm development (wood ripening) of canes and on fruit composition, particularly in regard to wine grapes, yet there is little data to directly support these notions. Even where vine responses to irrigation have been investigated, seldom has the water status of the vines been reported (e. g., EIBACH and ALLEWELDT 1983; BRAVDO *et al.* 1984). As a result, the extent to which the vines and tissues of interest experienced water deficits in many irrigation studies is unknown. Furthermore, without quantifying plant water status, it is difficult to extrapolate results from one climate (evaporative demand) to another, or from one soil texture (waterholding capacity) to another. This is clearly demonstrated by the variation in the results of investigations where the effect of irrigation on vegetative and reproductive growth has been reported without quantifying vine water status. In a recent review of such studies, the effect of irrigation on yield varied from -17 to +131 % of the nonirrigated vines (SMART and COOMBE 1983). Similarly, the response of pruning weight to irrigation varied from +4 to +137 % of the nonirrigated vines.

Therefore, this study was initiated to quantify the effects of supplemental irrigation on vine water status and to determine the effects of water deficits at various stages during the season upon the major aspects of vine growth and development.

## Materials and methods

### Growth conditions

Field trials were conducted in a mature (planted in 1979) Cabernet franc (on A × R 1 rootstock) vineyard near St. Helena, California (latitude 38:30 N, longitude 122:28 W, elev. 110 m). The vineyard was located on a southwest facing hillside with slope of approximately 20 % on a shallow, gravelly loam soil. Vines (1.5 m × 3.3 m spacing) were trained to a bilateral cordon (6 two-bud spurs/cordon) with a double wire trellis. Irrigation treatments were imposed during the 1984 season by adding or removing emitters from the drip irrigation line in the vine row. Irrigation was applied 1 d/week. Treatments were: C, continual irrigation throughout the season at 90 l/vine/week (2 × the normal production practice of weekly applications of 45 l/vine); ED, early deficit, water withheld until veraison (when 10 % of the berries began to show color) at which time weekly irrigations were initiated and continued for the remainder of the season; LD, late deficit, weekly irrigation applied until veraison after which water was withheld. Each treatment was replicated 5 × utilizing 3 row × 7 vine plots. In each plot, only the middle 5 vines of the middle row were used for data collection.

The accumulation of degree days (°C·d) above 10 °C was calculated according to WILLIAMS *et al.* (1985 b) from continuous recordings of air temperature.

### Plant water status

Midday leaf water potential ( $\psi$ ) was determined for fully exposed, mature leaves which showed no visible sign of damage. The leaf was covered with a plastic bag, immediately severed at the petiole, and sealed into a humidified pressure chamber for

determination of the balancing pressure (TURNER 1981). Each week samples were taken on the day preceeding irrigation between 13.30 and 15.00 which was the period of minimum  $\psi$  in the experimental vineyard (diurnal data not shown). 2—5 leaves were sampled per plot (10—25 leaves/treatment).

### Growth measurements

The growth of various vine parts was determined weekly on the same day as the measurements of leaf water potential. 2 representative vines/plot were selected for intensive growth measurements. On each vine, 2 representative shoots were further selected for determination of shoot length and shoot diameter. Cluster length was determined on the basal cluster of each experimental shoot. 2 berries on each experimental cluster were marked and their diameters repeatedly determined. The diameters of berries and basal shoot internodes (midway between nodes) were determined with a hand-held micrometer taking care to return to the same orientation at each measurement. The development of bark (ripe wood) was noted by positive/negative visual scoring for the presence of the characteristic color change (green to brown) on shoot internodes of the selected shoots.

At harvest, the yield and number of clusters/vine was determined for 5 vines/plot. Pruning weights were determined during the dormant season for 5 vines/treatment.

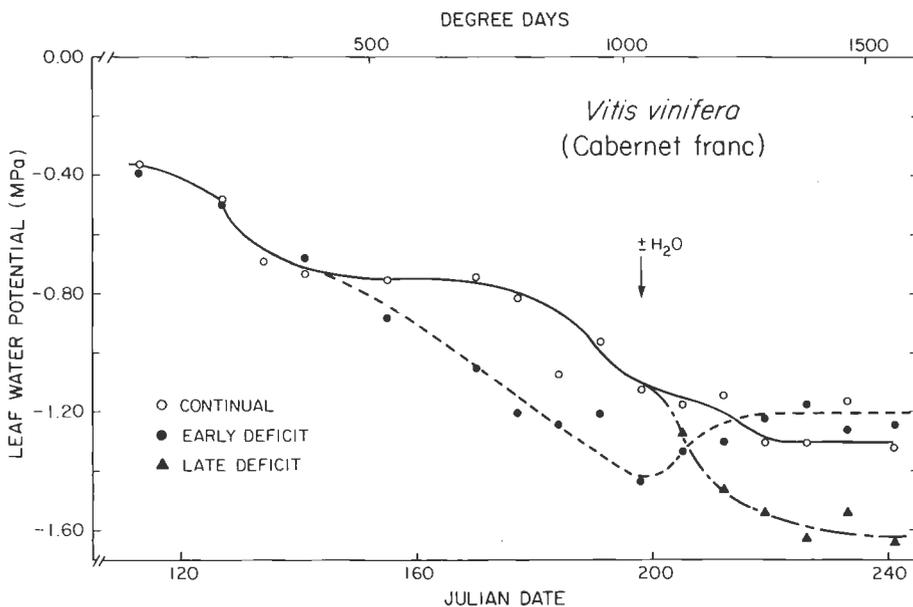


Fig. 1: Midday leaf water potential on various dates throughout the season for Cabernet franc vines which received different irrigation treatments. Arrow indicates date water was withheld from late deficit vines and resupplied to early deficit vines. Data are means of 5 replications. Standard errors were  $< 0.04$  MPa.

Mittägliches Blattwasserpotential zu verschiedenen Zeiten der Vegetationsperiode bei Reben der Sorte Cabernet franc, die unterschiedlich bewässert wurden. Der Pfeil bezeichnet den Zeitpunkt, zu dem in der Variante „Spätes Wasserdefizit“ die Bewässerung eingestellt und in der Variante „Frühes Wasserdefizit“ wieder aufgenommen wurde. Mittelwerte aus 5 Wiederholungen. Standardabweichung  $< 0,04$  MPa.

### Fruit maturity

The concentration of soluble solids in the 100 berry samples was determined with a hand-held refractometer.

## Results and discussion

### Vine water status

Water deficits began to develop very early in the season despite 863 mm of dormant season rainfall which fully recharged the soil profile (ANONYMOUS 1984). Midday  $\psi$  of continual irrigation (C) vines declined from the initial measurement of  $-0.40$  MPa

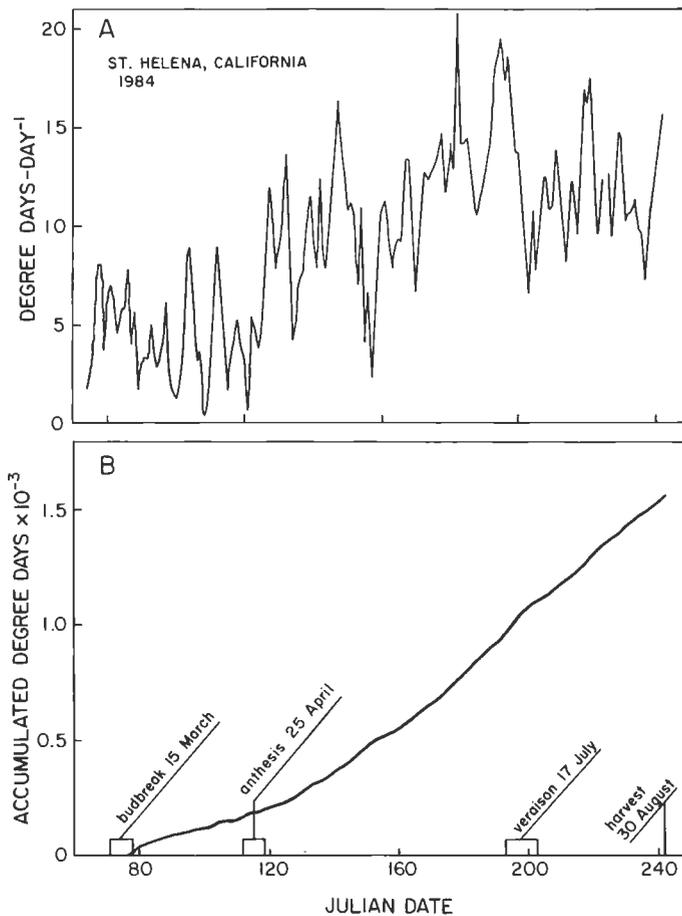


Fig. 2: Accumulation of degree days ( $> 10^{\circ}\text{C}$ ) during 1984 growing season in St. Helena, California: A, daily; B, cumulative. The major phenological events are indicated in B.

Akkumulierte Grad·Tage ( $> 10^{\circ}\text{C}$ ) der Vegetationsperiode 1984 in St. Helena, California: A) Täglich; B) kumulativ. In B sind die wichtigsten phänologischen Termine eingetragen.

on day 120 ( $150\text{ }^{\circ}\text{C}\cdot\text{d}$ ) to approximately  $-1.3\text{ MPa}$  on day 220 ( $1300\text{ }^{\circ}\text{C}\cdot\text{d}$ ) after which  $\psi$  was relatively constant (Fig. 1). The decline in vine water status from the initial measurement (and throughout the season) suggested that transpiration exceeded the capacity of the root system to supply water to the transpiring leaves despite a high soil water content. This suggestion is also supported by large diurnal fluctuations in  $\psi$  ( $0.4\text{--}0.8\text{ MPa}$  for C vines). LIU *et al.* (1978) made similar observations in a New York vineyard (var. Concord). Since vine water status declined significantly even when vines received weekly irrigation which was  $2\times$  the normal production practice, water deficits are likely to be a normal component of wine grape production in California hillside vineyards. The extent to which water deficits limit productivity and control fruit composition in premium winegrape production is unknown but will be investigated in this and subsequent studies.

In general, the midday  $\psi$  of C and LD (late deficit, irrigation withheld after veraison) decreased approximately  $0.1\text{ MPa/week}$  until about day 200. Midday  $\psi$  of LD vines was within  $0.1\text{ MPa}$  of C vines until water was withheld on day 200 (Fig. 1). Thereafter, midday  $\psi$  of LD decreased more rapidly than C reaching a minimum of  $-1.60\text{ MPa}$  at harvest (Fig. 1). Midday  $\psi$  of ED (early deficit, water withheld until veraison) vines was more negative than C by  $0.25\text{--}0.3\text{ MPa}$  during much of the season before veraison and recovered to a similar or higher  $\psi$  than C vines after water was resupplied (Fig. 1). However, the recovery required in excess of 2 weeks since midday  $\psi$  of ED vines increased by only about  $0.05\text{ MPa/week}$  after water was resupplied (Fig. 1). The cause of the slow recovery is not clear but may have been due to either inactive roots in the upper (and previously dry) soil layers, or diminished function of stem xylem created by cavitation (MILBURN and JOHNSON 1966).

Nevertheless, it is clear that the irrigation treatments produced significant differences in vine water status during the season. Withholding water until veraison resulted in midday  $\psi$  at veraison which was  $0.3\text{ MPa}$  more negative than in C vines. Similarly, withholding water after veraison resulted in midday  $\psi$  at harvest which were approximately  $0.35\text{ MPa}$  less than in the C vines. It is important to note that the data of Fig. 1 were obtained on the day before the weekly application of water to those vines receiving water. There was a significant weekly variation in midday  $\psi$ . For example, the midday  $\psi$  of C vines was  $-0.92\text{ MPa}$  and  $1.30\text{ MPa}$  on days 215 and 219, which was 1 and 5 d after an irrigation, respectively.

## Phenology

In California, Cabernet franc is an important wine grape variety, but there is little information regarding its phenology. Indeed, there is inadequate phenological data available for all varieties. The accumulation of degree days has been used frequently to indicate physiological time, particularly in models of biological development including a recent model of vine growth and phenology (GUTERREZ *et al.* 1985). The accumulation of degree days during the season and the major phenological events are indicated in Fig. 2 A and B. Although there was significant variability in daily heat accumulation throughout the season ( $\bar{x} = 9.3 \pm 4.4$ , Fig. 2 A), the rate of daily accumulation increased approximately  $2.5\times$  after the budbreak through anthesis period. Degree days accumulated at approximately  $4.5/\text{d}$  between budbreak and anthesis, and gradually increased to a relatively steady rate of  $11.5/\text{d}$  after day 120 (slope of curve in Fig. 2 B).

Despite the differences in vine water status throughout the season, there were no significant differences in the duration of vine developmental periods among treatments. Hence, seasonal water deficits caused no differences in phenology based upon the accumulation of degree days or time between the occurrence of budbreak, bloom, veraison, and harvest (Fig. 2 B).

WILLIAMS *et al.* (1985 a) tested the forementioned model's ability to predict the phenology of Thompson Seedless (timing of budbreak, anthesis, veraison, and harvest) at several California sites. Vine development between budbreak and anthesis required from approximately 375 to 450 °C·d, whereas the model predicted 411 °C·d. In the present study with Cabernet franc in a more northern and cooler site than those used for the Thompson Seedless analysis, only about 200 °C·d accumulated between budbreak and anthesis. During the same developmental period for four wine grape varieties in Davis, California, the accumulated degree days varied from 285 to 329 (Gui-

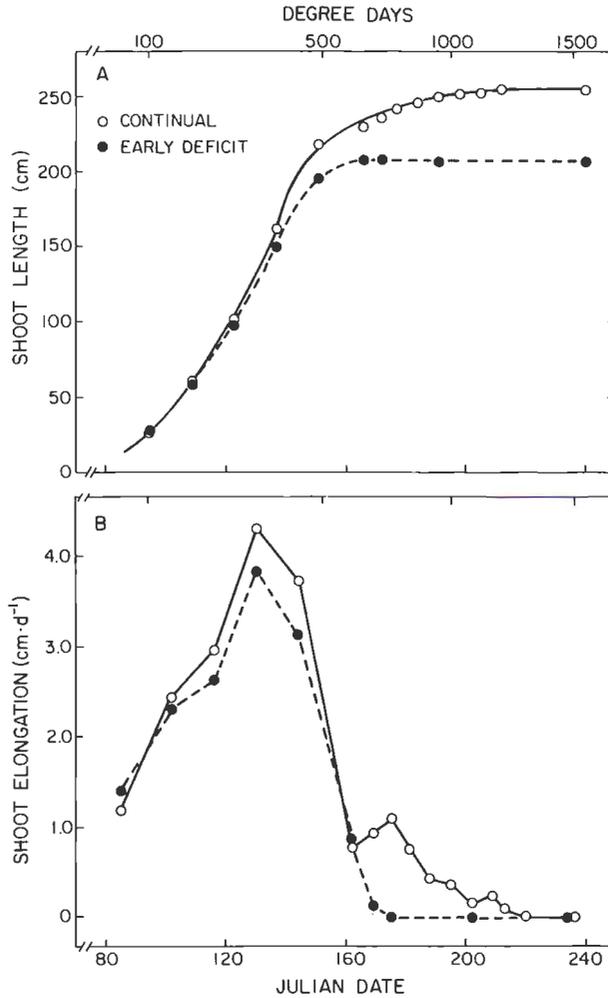


Fig. 3: Axial shoot growth of vines receiving different irrigation treatments: A, total shoot length; B, rate of axial shoot elongation. Data are means of 10 shoots. Standard errors were 13 cm and 4 cm for continual and early deficit, respectively.

Axiales Triebwachstum von Reben, die unterschiedlich bewässert wurden: A) Gesamte Trieblänge; B) Zuwachsrate der Trieblänge. Mittelwerte aus 10 Trieben. Standardabweichung für „Dauerbewässerung“ 13 cm, für „Frühes Wasserdefizit“ 4 cm.

TERREZ *et al.* 1985). However, the accumulation of degree days between budbreak and veraison (approximately 1000) and between budbreak and harvest (approximately 1600) was similar for Cabernet franc (present study) and for the other varieties tested by WILLIAMS and collaborators (GUITERREZ *et al.* 1985; WILLIAMS *et al.* 1985 a). Cabernet franc matures earlier in this hillside vineyard than in sites on the valley floor a short distance away. Hence, at least part of the earliness in the hillside sites is attributable to more rapid development between budbreak and anthesis.

Although the significant genotypic differences among domestic grape varieties can be expected to result in large differences in ontogeny and phenology, the degree days required for budbreak to anthesis for the various Thompson Seedless sites was similar to the range observed among varieties in the Davis study (GUITERREZ *et al.* 1985). Nevertheless, the variability among sites resulted in an error of not more than 4 d in predicting 50 % anthesis (WILLIAMS *et al.* 1985 a). Although WILLIAMS *et al.* (1985 b) suggested that accuracy of the model might be improved by incorporation of soil or plant water status, the results of the present study showed that water deficits (at least within the range encountered) have little effect on gross vine phenology.

#### Axial shoot growth and node development

In contrast to vine phenology, the degree of vegetative and reproductive growth was dependent upon vine water status. Shoot length was similar among treatments until about day 150 (500 °C·d, Fig. 3 A), which is when differences in midday  $\psi$  were observed between C and ED vines (Fig. 1). Thereafter, shoot length was greater in C vines than in ED vines. Final shoot length was approximately 25 % greater in C vines than in ED vines (Fig. 3 A). Since the differences in water status between C and LD vines developed after shoot growth had ceased in all treatments, no comparisons of shoot growth are shown between those treatments.

In all treatments, the rate of shoot elongation increased rapidly after budbreak (Fig. 3 B) despite declining vine water status (Fig. 1), which suggests that early shoot growth was source (photosynthate)-limited. The maintenance of shoot growth during decreasing vine water potential status suggests that in Cabernet franc either shoot growth does not exhibit the expected high sensitivity to water deficits or significant osmotic adjustment occurs (SMART and COOMBE 1983). The maximum rate of shoot elongation was 4.4 cm/d and 3.8 cm/d for control and ED vines, respectively. Shoot elongation reached a maximum near day 130 and decreased thereafter in all treatments (Fig. 3 B). Therefore, shoot elongation had slowed considerably in all treatments by day 150, when irrigation treatments began to show effects upon shoot elongation. At that time, midday  $\psi$  had declined to approximately -0.75 and -0.9 MPa in C and ED vines, respectively. As a result of the difference in water status, elongation of shoots continued in C vines until day 220 but ceased in the ED vines by day 170 (Fig. 3 A and B).

In general, the rate of shoot elongation increased very rapidly to a maximum, and then decreased rapidly as well, such that there was no prolonged period of steady shoot elongation. Contrary to the suggestion of SMART and COOMBE (1983) that the rate of shoot growth reaches a maximum well before flowering, the rate of shoot elongation reached a maximum approximately 2 weeks after flowering in both C and ED vines. There was no evidence of recurring growth of ED shoots after water was resupplied.

Leaf (node) development in the primary shoot occurred in a pattern similar to shoot elongation (Fig. 4 A). The maximum rate of node production (approximately 0.42 nodes/d for all treatments) occurred between day 120 and 140 (Fig. 4 A), similar to shoot elongation (Fig. 3 B). The rate of new node production decreased thereafter in both C and ED vines but decreased more rapidly in ED vines. By day 170 (when shoot

elongation had ceased in ED vines) node production had ceased on the ED vines, but was approximately 0.28 nodes/d (greater than 50 % of the maximum rate) in C vines. Similar to shoot length, there was 25 % fewer nodes/shoot in ED than in C vines. As  $\psi$  progressed to less than  $-1.0$  MPa in the ED vines, the shoot apex frequently died as indicated by the slight decrease in mean nodes/shoot after day 170 (Fig. 4 A). The mean internode length (shoot length/number of nodes) increased with the increase in proportion of mature internodes on each shoot (Fig. 4 B). Mean internode length decreased after day 150 (approximately 20 d after the peak in the rate of shoot elongation) in all treatments but the effect was much more pronounced in C vines (Fig. 4 B) due to the greater decrease in the rate of shoot elongation than in new node production. As a result of the late season production of short internodes in C vines, mean internode

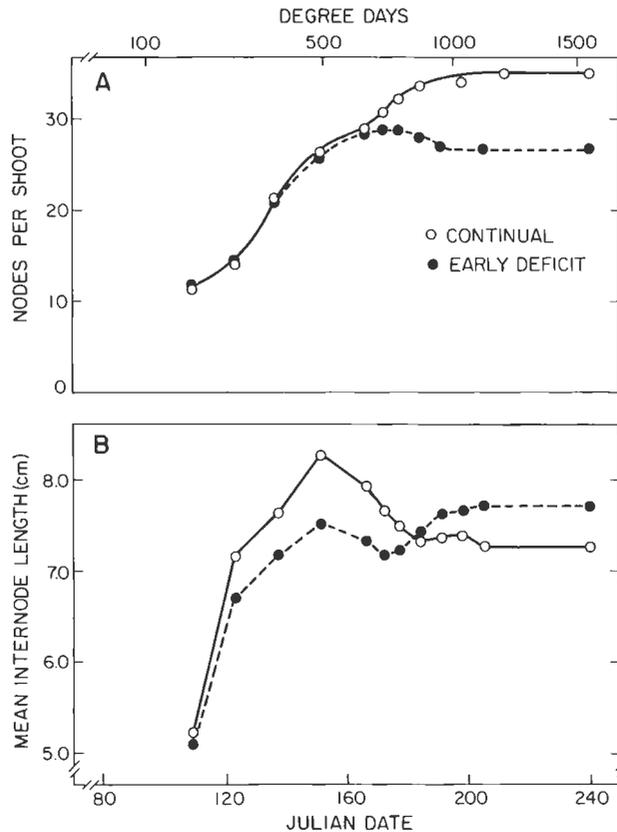


Fig. 4: The axial development of primary shoots of vines receiving different irrigation treatments: A, nodes per shoot; B, mean internode length. Data are means from 10 shoots. Standard error of the nodes/shoot was 1.3 and 0.6 for continual and early deficit, respectively. Mean internode length was obtained as the ratio of shoot length and nodes/shoot.

Axiale Entwicklung der Haupttriebe von Reben, die unterschiedlich bewässert wurden: A) Anzahl der Knoten/Trieb; B) mittlere Internodienlänge. Mittelwerte aus 10 Trieben. Standardabweichung bei der Anzahl der Knoten für „Dauerbewässerung“ 1,03, für „Frühes Wasserdefizit“ 0,6. Die mittlere Internodienlänge errechnete sich als Quotient aus der Trieblänge und der Anzahl der Knoten/Trieb.

length was greater in ED than in C vines (Fig. 4 B). In addition, unlike the C vines, there was a slight recovery of mean internode length in ED vines (Fig. 4 B) after day 175 due to the loss of short internodes at the shoot apex.

#### Radial shoot growth and periderm development

The importance of 'wood ripening' (periderm development) of vine shoots for overwintering viability and for successful propagation was recognized early. KOVESSI (1901) reported, 'The presence of a large quantity of water in the tissues of badly ripened canes explains why they stand the cold of winter badly; the existence of a larger quantity of starch in the well-matured canes accounts for their greater suitability for grafting and for planting out as cuttings'. Later PEROLD (1927) observed that, 'Only properly ripened wood can pass through winter successfully. If a vine matures its shoots properly, they will assume a brown color almost to their tips. Any remaining green portion is not ripe, and during the cold winter it will die and become black'. Hence, bark development on the shoot is easily recognized once it has progressed to the point of forming a protective layer of dead cells.

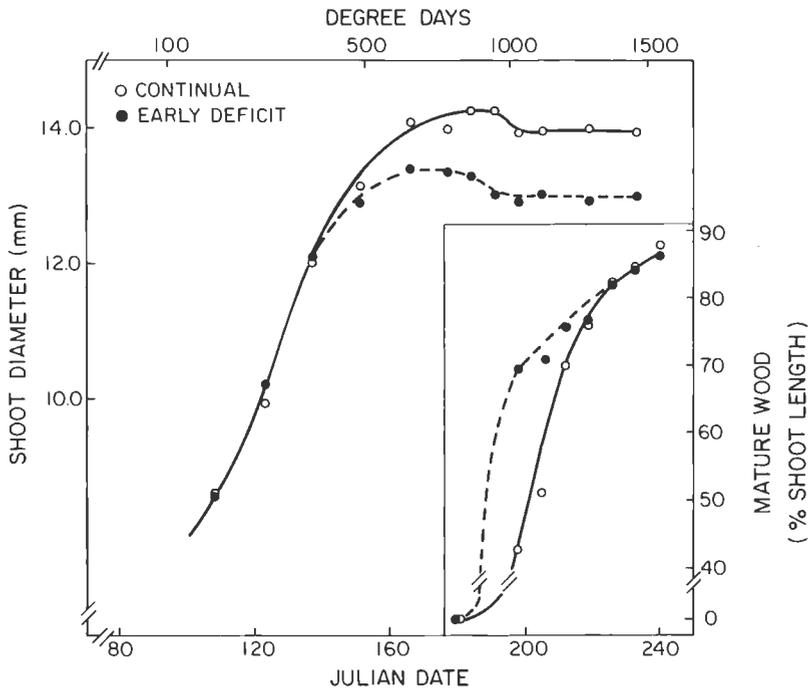


Fig. 5: Radial shoot development of vines receiving different irrigation treatments: basal internode diameter, curves and axis on left; wood ripening, curves and axis on right. Data are means of 10 shoots. Standard errors are 0.32 mm for shoot diameter of both continual and early deficit, and 4.7 cm and 2.0 cm for wood ripening of continual and early deficit, respectively.

Radiale Triebentwicklung von Reben, die unterschiedlich bewässert wurden: Links Durchmesser der basalen Internodien; rechts Holzreife. Mittelwerte aus 10 Trieben. Standardabweichung des Triebdurchmessers für „Dauerbewässerung“ und „Frühes Wasserdefizit“ 0,32 mm; Standardabweichung der Holzreife für „Anhaltendes Wasserdefizit“ 4,7 cm, für „Frühes Wasserdefizit“ 2,0 cm.

Since periderm development and cane diameter are factors of cold tolerance (PEROLD 1927; WOLPERT and HOWELL 1986) and are frequent criteria for pruning decisions and for selection of grafting material, the effects of seasonal water deficits on these parameters was also investigated. The effect of water deficits on the radial expansion of the basal internode was determined by repeated measurements of basal internode diameter during the season. In C and ED vines, radial expansion of the shoot reached a maximum at approximately the same time as shoot elongation, day 130, and decreased to nil by day 170 (Fig. 5). Hence, radial growth ceased at approximately the same time as axial growth in ED vines and ceased well before axial growth in C vines. Since the cane diameter in ED vines was only 7 % less than in C vines, the effect of withholding water in the early season was less on radial growth than on axial growth. Visual scoring of internodes for the presence of bark indicated that early season water deficits induced early periderm development (inset of Fig. 5). Bark was initially observed at approximately the same time that shoot elongation and new node production ceased in each treatment (inset of Fig. 5; cf. Fig. 3 and 4). At harvest, bark development was present on 85 % of the length of all shoots (inset of Fig. 5).

The difference in periderm development at midseason was not an artifact of expressing the data as a percent of shoot length since, for example, on day 198 there was 103 cm and 146 cm of ripe wood on C and ED vines, respectively. Although it has long been recognized that high irradiance and low humidity promote periderm development (BORGER 1973), the response of periderm development to plant water status apparently has not been addressed previously. In *Fraxinus* seedlings, periderm development was accelerated by increased irradiance (BORGER and KOZLOWSKI 1972 b) and decelerated by soil drying cycles or by culture in polyethyleneglycol (PEG) solutions (BORGER and KOZLOWSKI 1972 a). However, plant water status was not measured and it is not clear to what extent the osmoticum was taken up by the seedlings during the 21–35 d experiments. In the present study, the early development of periderm in the ED vines was unlikely to be due to increased incident irradiance upon the shoot internodes since similar results were obtained in controlled experiments with single, vertical shoots (var. Thompson Seedless) in which there was no difference in incident irradiance (data not shown). Therefore, the response of periderm development to water deficits can be positive or negative among different woody perennials.

The teleological explanation for the phenomenon in the grapevine is not apparent, although the induction of periderm development by water deficits may be an adaptive mechanism for survival near intermittent streams. In such a habitat, late season water deficits may occur frequently. *Vitis* species form ring bark which originates deep in the cortex or within the phloem (ESAU 1965). The interxylary bark of herbaceous perennials diminishes the rate of desiccation of stem and root tissues which may allow plants to survive in arid environments that would otherwise be unfavourable to growth (MOSS 1934). Hence, it would be advantageous to initiate the production of phellum cells (relatively impervious to water) when the depletion of soil water is sensed. Alternatively, the timing of the cessation of flow in the intermittent streams may allow vines to use plant water status, rather than change in temperature or photoperiod as is commonly used in other species, as an early indicator of ensuing winter.

#### Reproductive growth

The response of reproductive growth to the irrigation treatments was determined by repeated measurements of cluster rachis length and of berry diameter. Linear expansion of the rachis was rapid (approx. 0.125 cm/d) during anthesis and decreased to nil by day 150 (inset of Fig. 6). There was no difference among treatments in timing or degree of expansion of the rachis (inset of Fig. 6). Fruit growth, as indicated by berry

diameter, exhibited the characteristic double-sigmoid pattern of development in all treatments (Fig. 6). Although the lag phase began at the same time for each treatment, the resumption of berry expansion occurred first in the rewatered ED vines and as much as 10 d later in C and LD vines (Fig. 6). The maximum rate of berry expansion (approx. 0.15 mm/d) occurred in the rewatered ED vines between day 212 and day 219 (Fig. 6) which corresponds to the period during which the midday  $\psi$  was greater in ED vines than in C vines (Fig. 1). This rapid rate of expansion is not likely to be due to rehydration since water was initially resupplied on day 200 and since no shrinkage or sign of shriveling was observed. Growth of ED berries decreased rapidly thereafter, although  $\psi$  remained similar in ED and C vines (Figs. 2 and 6).

The potential for berry size is determined largely by cell number per berry (CONSIDINE and KNOX 1979). Since cell division is completed in the berry mesocarp and dermal tissues during stage I of berry growth (CONSIDINE and KNOX 1979; COOMBE 1976) and ED vines experienced significant water deficits during stage I, the potential for berry growth in ED vines may have been diminished due to reduced cell number/berry. The data suggest that at harvest (day 242 at approximately 21.5 °Brix for all treatments) ED berries approached their maximum size whereas C and LD berries were still

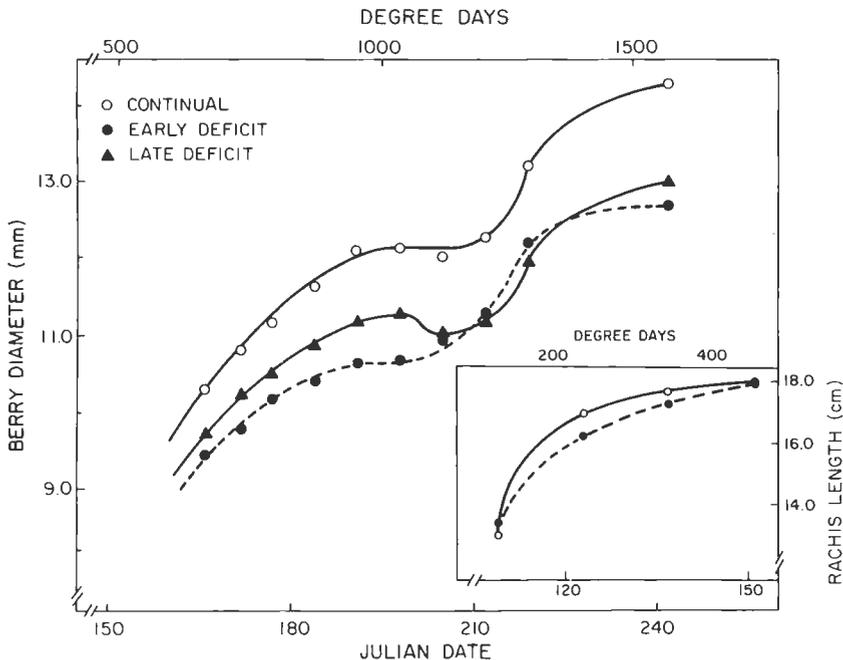


Fig. 6: Berry diameter of vines receiving different irrigation treatments. Data are means of 20 berries; standard error was 0.16 mm, 0.15 mm, and 0.21 mm for continual, early deficit, and late deficit, respectively. Inset shows rachis length for continual and early deficit; standard error was 1.2 cm and 0.8 cm for continual and early deficit, respectively.

Beerendurchmesser von Reben, die unterschiedlich bewässert wurden. Mittelwerte aus 20 Beeren. Standardabweichung für „Dauerbewässerung“ 0,16 mm, für „Frühes Wasserdefizit“ 0,15 mm, für „Spätes Wasserdefizit“ 0,21 mm. Der Einsatz zeigt die Länge des Traubengerüstes. Standardabweichung für „Dauerbewässerung“ 1,2 cm, für „Frühes Wasserdefizit“ 0,8 cm.

expanding at significant rates. Although there was no apparent effect on the total duration of fruit growth, berry growth may not have ceased by harvest in the C and LD treatment. The significant growth of LD berries during stage III (after day 210) suggests that fruit growth can be maintained despite low and rapidly decreasing vine water potentials (see Fig. 1). The effects of seasonal water deficits upon berry size were reflected in vine yields. Continually irrigated vines produced greater yields than LD vines, which had greater yields than ED vines (Table). Yield was reduced approximately 15 % in ED vines but only 8 % in the LD treatment whereas pruning weights were decreased approximately 10 % in both treatments (Table). All of the differences in yield were attributable to the effects of water deficits on berry expansion since there were no differences in berries/cluster or clusters/vine.

Yield and pruning weight of vines which received different irrigation treatments · Data are means with standard errors, n = 5

Traubenertrag und Schnittholzgewicht von Reben, die unterschiedlich bewässert wurden · Mittelwerte (n = 5) mit Standardabweichungen

Treatment	Yield		Pruning wt.	
	(kg · vine <sup>-1</sup> )	(%)	(kg · vine <sup>-1</sup> )	(%)
Continual	5.69 ± 0.29	(100)	1.93 ± 0.05	(100)
Late Deficit	5.22 ± 0.26	(91.7)	1.70 ± 0.07	(88.1)
Early Deficit	4.81 ± 0.31	(84.5)	1.73 ± 0.02	(89.6)

### Conclusions

The results of this study allow several observations regarding vine development and its response to seasonal water deficits. Major aspects of vine phenology were not affected by seasonal water deficits. When water was withheld before or after veraison, there was no difference in the timing of anthesis, veraison, or harvest. The period of maximum shoot and fruit growth was similar and the characteristic biphasic fruit growth was present with similar timing in all treatments. Early season water deficits may have decreased the duration of fruit expansion.

Although the early deficit inhibited the maximum shoot growth rate and maximum leaf (node) production rate by about 10 %, the major effect of the early deficit on shoot elongation and node production was via an accelerated decline in shoot growth following the period of maximum growth. For example, at d 170 the rate of shoot elongation was 22 % and 3 % of the maximum rate observed in C and ED vines, respectively. Similar results have been obtained with other varieties (SMART and COOMBE 1983). In addition, the rate of new node production is less sensitive than shoot elongation to water deficits, since at day 170 the rate of new nodes/day in C and ED vines was inhibited to only 56 % and 20 % of the maximum rate observed. Similar results were obtained by MERIAUX *et al.* (1976) and EIBACH and ALLEWELDT (1983). Radial shoot growth ceased before veraison and earlier in the season than the cessation of shoot elongation. Radial shoot growth was less sensitive to water deficits than axial shoot growth. Overall, the early deficit diminished the period of shoot growth by about 30 d relative to C vines.

Water deficits induce early periderm development on shoots of *Vitis vinifera*. It is suggested that this phenomenon may be of adaptive significance, especially in riparian habitats near intermittent streams.

In Cabernet franc, most growth and the maximum rate of berry expansion occurred during the first growth phase. The extent to which this was due to the continually decreasing vine water potential is not known. The maximum rate of fruit growth was inhibited about 10 % during the first growth phase by the early deficit and during the second growth phase by the late deficit. As a result of these developmental patterns, the early deficit had a greater effect than the late deficit on fruit size at harvest. Similar results were obtained with potted Cabernet franc vines (HARDIE and CONSIDINE 1976).

### Summary

Phenologic and ontogenic responses to seasonal water deficits were investigated in the wine grape variety, Cabernet franc, in a California hillside vineyard. Water deficits were imposed by withholding irrigation water before or after the onset of veraison. In continually irrigated vines, midday leaf water potential ( $\psi$ ) declined from  $-0.4$  MPa to approximately  $-1.1$  MPa between budbreak and veraison despite weekly irrigation at a rate which was  $2 \times$  the normal production practice for that commercial vineyard. Hence, water deficits may be a common component of grape production in hillside vineyards of California. When water was withheld until veraison, midday  $\psi$  declined more rapidly and reached  $-1.4$  MPa at the time water was resupplied. For these vines, water status slowly recovered to the level of the continually irrigated vines. The water status of late deficit vines, (water withheld after veraison), decreased rapidly after veraison, reaching a minimum of  $-1.6$  MPa at harvest.

These differences in vine water status had no effect on the major phenological indicators, i. e., the timing (on basis of time or accumulation of degree days) of bloom, veraison, and harvest. However, early season deficits shortened the period of shoot elongation and node production, decreased the maximum rate of shoot elongation and node production, and accelerated periderm development on current season shoots. Possible ecological implications of accelerated periderm development are discussed. Shoot length and the number of nodes/shoot was reduced approximately 25 % by the early season water deficits. Radial shoot growth was also inhibited by early deficits but much less than axial shoot growth. Shoot growth had essentially ceased in all vines before late season deficits developed.

The characteristic double-sigmoid growth pattern of berries was observed regardless of seasonal water deficits. Most fruit growth occurred during the first growth phase in all treatments. The rate of fruit growth was inhibited by early and late season water deficits. Yield was decreased more by early deficits than by late deficits.

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M. A. MATTHEWS  
 Assistant Professor  
 of Viticulture  
 Department of Viticulture  
 and Enology  
 University of California  
 Davis, CA 95616  
 USA