Root-Zone Refrigeration Delays Budbreak and Reduces Growth of Two Containerized, Greenhouse Grown Grape Cultivars

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ABSTRACT

Following budbreak, grapevines grown in west Texas are particularly susceptible to freeze damage. If deacclimation or budbreak was delayed, damage from spring frosts could possibly be reduced. During spring 1999, two duplicate experiments were undertaken to determine if root-zone refrigeration delayed budbreak of two cultivars of *Vitis vinifera* L. ('Chardonnay' and 'Cabernet Sauvignon'). Under greenhouse conditions, one-year-old grafted vines were planted into containers and placed in water baths. Throughout experiments, thermostats in two water baths were set to maintain temperatures at 35°F and 45°F. In addition, a non-chilled control water bath was maintained. Water and soil temperatures along with greenhouse climatic data were measured. Evaluation of budbreak was performed on a daily basis. At the conclusion of each experiment shoot and root dry mass were measured. Results indicate that when compared to controls, root-zone refrigeration delayed budbreak for both cultivars. Refrigerated grapevines also had a lower percentage of budbreak. Root and shoot mass of control plants were generally greater when compared to refrigerated water treatments. Because prolonged budbreak may allow buds to escape spring frost injury, reductions of root-zone temperature during spring deacclimation could have significant impact on the west Texas viticulture industry.

KEYWORDS: Deacclimation, Frost injury, Viticulture

In 2000, Texas ranked fifth in the United States in vineyard acreage and wine production. During that same period, 1.25 million gallons of wine were produced in Texas with an economic impact of $105 million dollars (Dodd and Hood 2001). Of the six major grape-growing regions in Texas (Figure 1), vineyards in the High Plains region

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account for approximately 40 percent of Texas wine grape production (Dodd and Hood 2001). On the Texas High Plains, the primary risk for grape production is frost injury. Late spring (post-budbreak) temperatures often result in the loss of primary and secondary buds (Lipe et al. 1992).

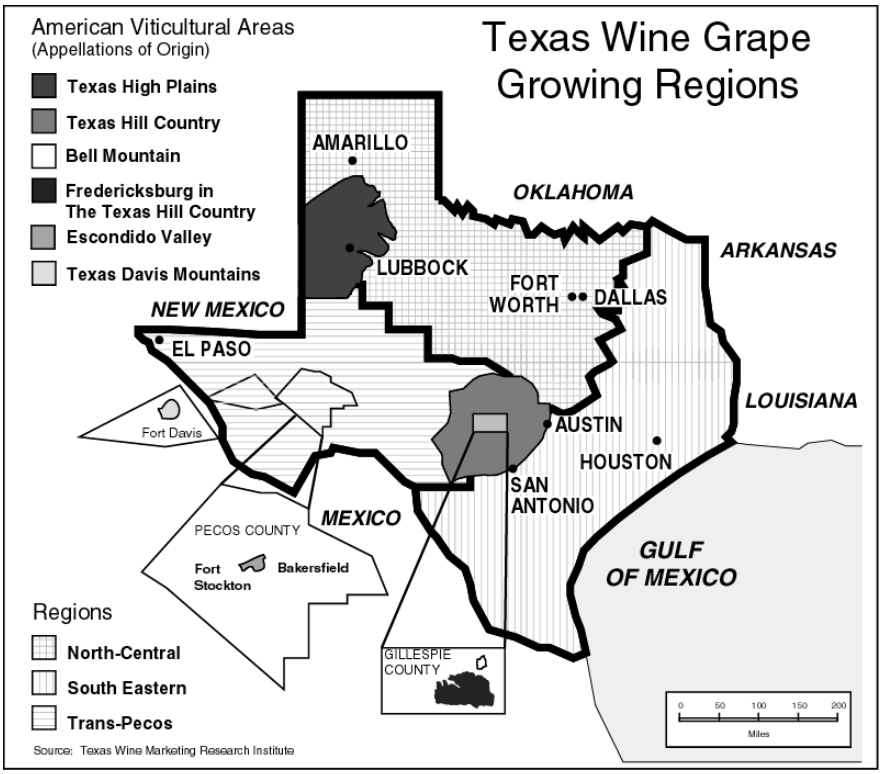

Figure 1. Texas wine grape growing regions (Source: Texas Wine Marketing Research Institute).

Several factors influence hardiness, deacclimation, and budbreak of grapevines. Winter bud survival can be attributed to cane characteristics such as sunlight exposure, periderm color, and cane diameter (Howell and Shaulis 1980). Cultivar differences can also affect bud deacclimation and bud hardiness at any given growth stage (Johnson and Howell 1981). For example, Lipe et al. (1992) reported that on the Texas High Plains, budbreak of 'Cabernet Sauvignon' normally occurs 10 to 15 days after 'Chardonnay'. Bud resistance to cold temperatures decreases with increasing bud moisture (as found during spring deacclimation) and advancing phenological development (Hamman et al. 1990). Air temperature also plays a key role in acclimation and deacclimation of buds (Dokoozlian et al. 1995). Warm air temperatures during spring, which often occur on the Texas High Plains, promote bud growth and decrease bud hardiness (Proebsting 1963). However, unlike many deciduous fruit crops, grapevines can tolerate relatively little chilling exposure to terminate bud dormancy (Dokoozlian 1999).

Suspending budbreak of grapevines has been a goal of viticulture research for many years. Breeding programs have developed several cultivars with improved cold hardiness (Bourne and Moore 1991, Moore 1986), but screening programs are often

complicated by sampling considerations of time, tissue type (bud versus stem), and geographical location (Bourne and Moore 1991). Efforts to use wild grapevines as a source of cold tolerance have also been attempted (Becker 1987). However, negative characteristics such as small fruit, undesirable color, and strong taste associated with wild grapes are challenges that breeders have yet to overcome. Several studies have investigated evaporative cooling (misting systems) to delay budbreak of grapevines on the Texas High Plains (Baumhardt et al. 1990, Lipe et al. 1990, 1992). This research has demonstrated that budbreak could be delayed without effecting fruit quality (Lipe et al. 1992). However, limited water supplies and poor water quality may preclude the adaptation of evaporative misting systems in west Texas (Lipe et al. 1977).

Each spring, growth hormones produced in plant roots move to shoots and influence shoot development (Young 1989). The xylem pathway is involved in transporting growth hormones (particularly cytokinin) to developing buds (Belding and Young 1989). Research has demonstrated the importance of cytokinins during budbreak and new shoot growth (Cutting et al. 1991). However, little research has been conducted on the use of soil temperature to delay budbreak of grapevines.

Skene and Kerridge (1967) found 'Thompson Seedless' grapevines grown under greenhouse conditions in an 86°F nutrient solution had greater cytokinin content, shoot elongation, and increased dry-matter accumulation when compared to grapevines grown in an 68°F nutrient solution. Kliewer (1975) found a greater percentage of budbreak and greater shoot growth for greenhouse grown 'Cabernet Sauvignon' grapevines grown at root temperatures of 77°F and 86°F compared to grapevines grown at 52°F or 59°F. Other investigators have reported similar results (Zelleke and Kliewer 1979, 1985). Thus, it appears a reduction of root cytokinin production during periods of low soil temperature and warm air temperature could delay budbreak in grapevines. The relationship between soil temperature, budbreak, and growth has been tested on just a few *Vitis vinifera* L. cultivars. An improved understanding of this relationship would be beneficial for grape producers on the Texas High Plains. Therefore, objectives of this research were to investigate the influence of root-zone chilling on budbreak and vine growth of two *Vitis vinifera* L. cultivars.

MATERIALS AND METHODS

Experiments were performed in greenhouses at the Texas Tech University greenhouse complex. During the spring of 1999, two experiments were conducted. Experiment One began 11 March and concluded 3 April (Julian day 70 to 93). Experiment Two began 25 April and ended 9 May (Julian day 115 to 129). Because of differences in budbreak timing, two species of *Vitis vinifera* L. ('Cabernet Sauvignon' and 'Chardonnay') grafted onto 5BB Kober rootstocks were selected. Dormant plant material was received in February and was placed in a cooler held at 39 °F until initiation of experiments.

Three stainless steel tanks were constructed. Each tank was supported by an individual frame that held the tank two feet above the greenhouse floor. Each tank had a height of 3.2 feet, a width of 2.6 feet, and was 4.2 feet long. To help maintain a constant temperature, R-13 insulation was wrapped around each individual tank. Two tanks were equipped with six horsepower compressor units circulating Freon through 0.25 inch copper tubing. Tubing was placed along the bottom of each tank at 6 inch spacing. A submersible 150-gallon per minute pump circulated water in each of the chilled water

tanks. For the duration of the experiment, tanks used for chilling were controlled by thermostats that were set at 35°F and 45°F. A third tank was set up as a non-chilled control (soil temperature dependant upon greenhouse air temperature and incoming solar radiation).

Five-gallon metal pots were selected as containers. To prevent leakage, container seams were sealed with waterproof silicone. To keep containers submerged, the bottom of each container was lined with three inches of pea gravel followed by three inches of coarse sand. Ball Growing Mix #1 (George J. Ball Inc., Pine Bluff, AR) was used as the growing medium. To ensure plants had water, prior to filling containers the growing medium was moistened. Pots were filled with potting medium to within 2 inches of the top of the container. Six containers were placed inside each tank and tanks were filled with water to the level of the potting media. Tank water was then allowed to chill to desired treatment temperatures. After the desired water temperature was obtained, two plants of each cultivar were planted in each container. Throughout the duration of the experiment, plants did not receive supplementary lighting, or additional irrigation.

Each grapevine was pruned to two canes with each cane having five buds. Budbreak was defined as when buds began to swell and new shoot growth was first evident (Zelleke and Kliewer 1989). Experiments concluded when budbreak occurred on a minimum of 50 percent of the buds on each grapevine. Evaluation of budbreak was performed on a daily basis. Each day, the number of new broken buds on each grapevine was recorded. After each experiment was terminated, new shoot growth and roots were harvested. After samples were dried, shoot and root dry mass were measured.

During each experiment, soil temperature was measured with two, type T (copper-constantan) thermocouples in each container (Omega Engineering, Inc., Stamford, CT). Each thermocouple was buried two inches below soil level near the root-zone of one vine. Water temperature was measured by one thermocouple placed in the center of each tank about six inches below the surface. Thermocouples were connected to a datalogger (Model 21X, Campbell Scientific, Inc., Logan, UT) using a multiplexer (Model AM416, Campbell Scientific, Inc.). Inside the greenhouse, incoming shortwave radiation was measured with a pyranometer (Model LI-200SA, LI-COR Inc., Lincoln, NE), and greenhouse air temperature and relative humidity were measured with a combination temperature and humidity sensor (Model CR500, Campbell Scientific, Inc.). Climatic data were recorded with a datalogger (Model CR10X, Campbell Scientific, Inc.). Sensors and thermocouples were scanned every 30 seconds and averages were taken every half-hour.

Each tank contained six pots and each pot contained two vines of each cultivar. For each experiment, 36 plants of each cultivar were evaluated. Data from each experiment were analyzed separately. Total budbreak (%), number of days in treatment until budbreak, and growth data were subjected to analysis of variance using the general linear model procedure appropriate for a split plot design (water temperature = whole plot, cultivar = split plot) (SAS version 8.0, SAS Institute Inc. 1999). If significant differences were found, means were separated by Fisher's least significance difference procedure ($P < 0.10$). Mean daily total shortwave radiation (MJ m^{-2} day^{-1}), greenhouse air temperature (°F), and container media temperature (°F) (± SE) were plotted against Julian day. Total daily shortwave radiation (independent variable) and mean daily greenhouse air temperature (dependent variable) data were analyzed by regression analysis. Linear or quadratic curves were selected according to significance of the equation and coefficient of determination (R^2) value (SAS 1999).

RESULTS

Greenhouse climatic conditions varied between Experiments One and Two (Figure 2). During Experiment One, mean total daily shortwave radiation was about 22 percent less than mean total daily shortwave radiation during Experiment Two. Mean daily greenhouse air temperature followed a similar trend. Due to cloud cover, total daily shortwave radiation and mean daily greenhouse air temperature fluctuated from day to day. During each experiment, container media temperatures were maintained near desired levels (Figure. 2).

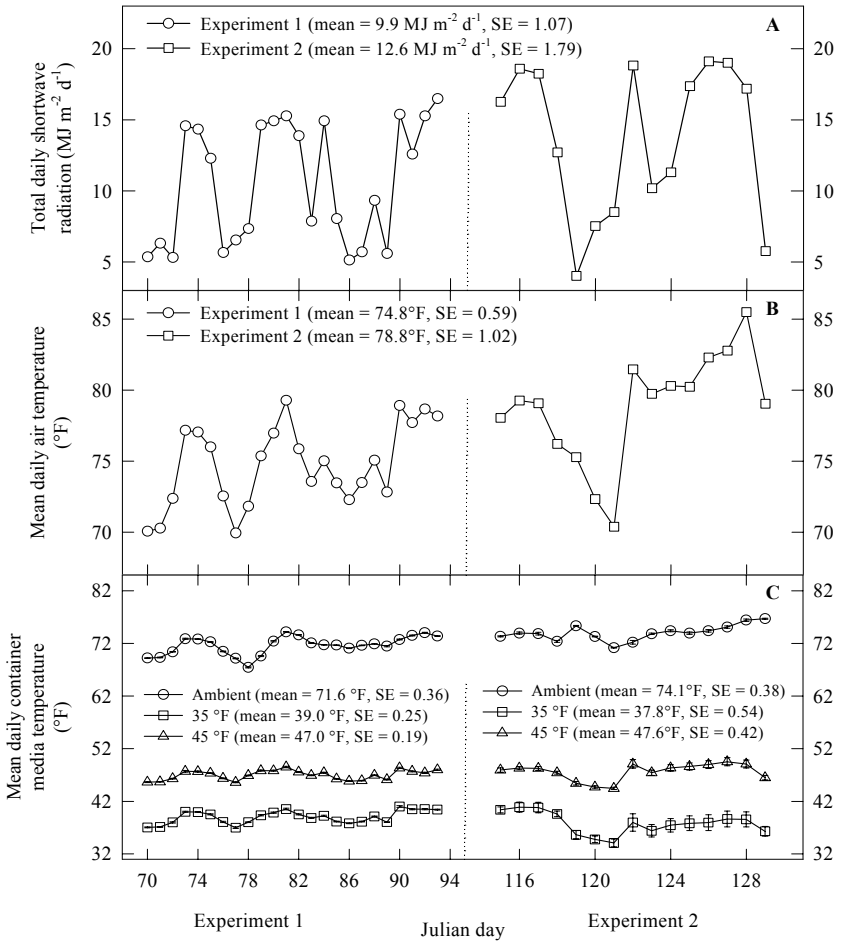

Figure 2. Daily total shortwave radiation (A), mean daily air temperature (B), and mean (± SE) daily container media temperature (C), for two cultivars of containerized *Vitis vinifera* ('Cabernet Sauvignon' and 'Chardonnay'), grown under greenhouse conditions during two experiments (Experiment One Julian day 70 to 93 and Experiment Two Julian day 115 to 129, 1999) in three water temperature treatments (ambient, 35°F, and 45°F).

For Experiment One, percent total budbreak was not different between root-zone temperature treatments ($P < 0.39$), but differences between treatments were present for Experiment Two ($P < 0.02$) (Figure 3). In experiment two, approximately 79 percent of buds on vines exposed to 35 °F water temperature broke dormancy, while about 93 percent of buds on vines exposed to ambient and 45 °F water temperatures broke dormancy. For Experiments One and Two, percent total budbreak between cultivars was different ($P < 0.02$ and $P < 0.07$, respectively). In each experiment, a greater percentage of 'Chardonnay' buds broke when compared to buds of 'Cabernet Sauvignon' (Figure 3).

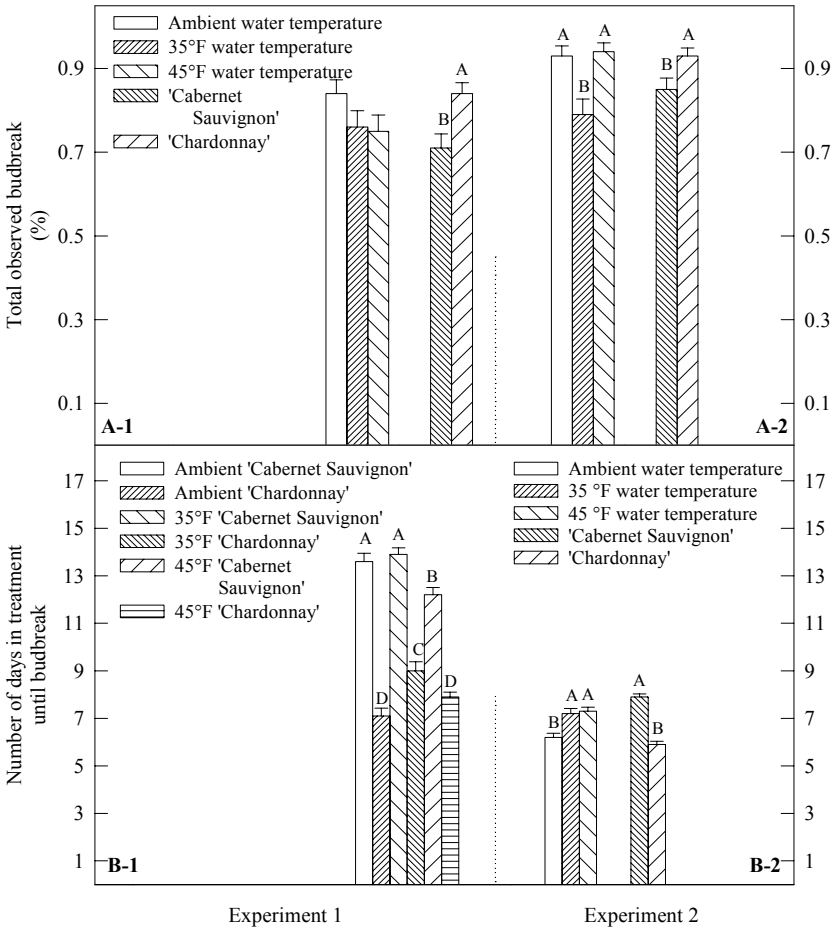

Figure 3. Total observed budbreak (A) and mean number of days in treatment until 50% budbreak (B) for two cultivars of containerized *Vitis vinifera* ('Cabernet Sauvignon' and 'Chardonnay') grown under greenhouse conditions during two experiments (Experiment One Julian day 70 to 93 and Experiment Two Julian day 115 to 129, 1999) in three water temperature treatments (ambient,35°F, and 45°F). Different letters over bars indicate differences among main effects (treatments and genotypes) (A-1, A-2, and B-2), or treatment x genotype interaction (B-1) ($P < 0.10$).

In Experiment One, cultivar and soil treatment had an interactive influence on mean number of days in treatment until budbreak ($P < 0.06$) (Figure 3). Mean number of days until budbreak was greatest for 'Cabernet Sauvignon' exposed to ambient (13.6 days) and 35°F (13.9 days) water temperatures. Mean number of days in treatment until budbreak was least for 'Chardonnay' exposed to ambient (7.1 days) and 45 °F (7.9 days) water temperatures. For Experiment Two, cultivar and soil treatment did not have an interactive influence on mean number of days in treatment until budbreak. However, differences were found between soil temperature treatments ($P < 0.004$) and cultivars ($P < 0.0001$). Grapevines exposed to ambient water temperature broke bud about one day earlier than vines exposed to either 35°F or 45°F water temperatures, and budbreak occurred approximately two days earlier for 'Cabernet Sauvignon' when compared to budbreak for 'Chardonnay' (Figure 3).

Root dry mass was influenced by soil temperature ($P < 0.002$) and cultivar ($P < 0.02$) in Experiment One (Figure 4).

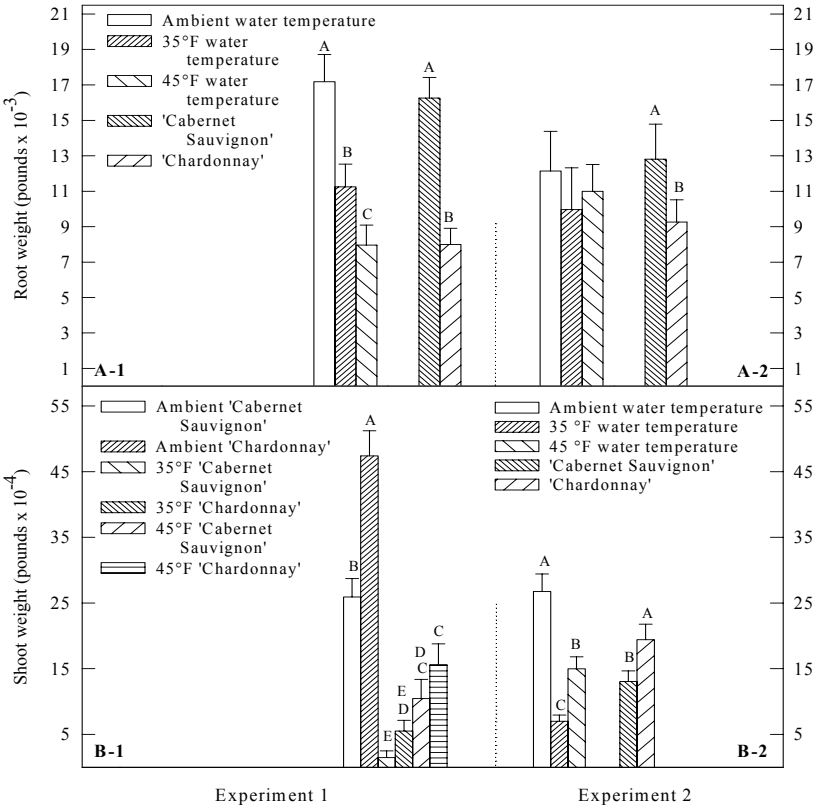

Figure 4. Mean root weight (A) and mean shoot weight (B) (± S.E.) for two cultivars of containerized *Vitis vinifera* ('Cabernet Sauvignon' and 'Chardonnay') grown under greenhouse conditions during two experiments (Experiment One Julian day 70 to 93 and Experiment Two Julian day 115 to 129, 1999) in three water temperature treatments (ambient, 35°F, and 45°F). Different letters over bars indicate differences among main effects (treatments or genotypes) (A-1, A-2, and B-2), or treatment x cultivar interaction (B-1) ($P < 0.10$).

Root dry mass was greatest for plants exposed to ambient water and least for plants exposed to the 45°F water treatment. Root dry mass for 'Cabernet Sauvignon' was over twice that for 'Chardonnay'. Root dry mass was only influenced by cultivar in Experiment Two. Once again, 'Cabernet Sauvignon' had greater root dry mass than 'Chardonnay'.

As was found for the number of days in treatment until budbreak in Experiment One, in Experiment One there was a cultivar and soil temperature interaction on shoot dry mass ($P < 0.02$) (Figure 4). Shoot mass was greatest for 'Chardonnay' grapevines grown in ambient water and least for 'Cabernet Sauvignon' grapevines exposed to 35°F water. However, shoot differences between 'Cabernet Sauvignon' and 'Chardonnay' only occurred in the ambient water treatment. In each of the other water temperature treatments, there were no differences in shoot growth between cultivars. Data from Experiment Two revealed that soil temperature ($P < 0.0001$) and cultivar ($P < 0.01$) influenced shoot growth (Figure 4). Grapevines exposed to ambient water temperature had approximately two times more shoot mass than grapevines exposed to the 45°F water treatment and approximately four times more shoot mass that grapevines exposed to the 35°F water treatment. Shoot mass for 'Chardonnay' was nearly 33 percent greater than shoot mass for 'Cabernet Sauvignon' (Figure 4).

DISCUSSION

Mean greenhouse air temperature was maintained within the optimum range for apical grapevine growth (68°F to 96°F) (Kliewer 1975). Fluctuations in mean daily greenhouse air temperature were closely related to total daily shortwave radiation ($R^2 = 0.71$). This explains the relationship between mean daily greenhouse air temperature and mean greenhouse total daily shortwave radiation (Figure 2). Although water in chilled tanks was maintained near 35°F and 45°F (data not shown), media insulating properties likely increased container media temperature when compared to water temperatures (Figure 2). Zelleke and Kliewer (1979) reported optimal root temperature for 'Cabernet Sauvignon' budbreak and shoot growth is 77°F to 86°F. Results from our research indicate soil temperatures at or near this range for control grapevines and well below this range for water chilled grapevines (Figure 2).

Our research confirms findings of others (Kliewer 1975, Zelleke and Kliewer 1979) that budbreak increases, and shoot and root growth is greater, when grapevines are grown near optimal soil temperatures than when grown at sub-optimal temperatures. Grapevines grown in 35°F and 45°F soil treatments were more likely to break bud later and have a lower budbreak percentage than grapevines grown in the control treatment (Figure 3). Budbreak differences are probably due to the influence of temperature on hormone activities within the root-zone. Plant roots are a primary source of cytokinins (Cutting et al. 1991, Skene and Kerridge 1967) and cytokinins have been shown to hasten budbreak in grapevines (Weaver et al. 1968) and other fruit species (Belding and Young 1989). Low root-zone temperatures appear to reduce cytokinin production and, or translocation and therefore limit budbreak (Young 1989).

Despite identical rootstocks, 'Chardonnay' grapevines had greater budbreak percentage than 'Cabernet Sauvignon' grapevines in each experiment (Figure 3). In addition, in each soil temperature, 'Chardonnay' had fewer days in treatment until budbreak. This agrees with Lipe et al. (1992) that 'Chardonnay' breaks bud prior to 'Cabernet Sauvignon', and therefore 'Chardonnay' will have a greater percentage of buds

broken earlier in the growing season. Our data suggest cultivar traits, such as budbreak, may be maintained despite the fact different cultivars are grown on identical rootstocks.

In general, root and shoot mass were dependent upon root-zone temperature (Figure 4). Regardless of root-zone temperature, cultivar differences were apparent in each experiment. Root mass was greatest and shoot mass was least for 'Cabernet Sauvignon'. 'Cabernet Sauvignon' appears to concentrate early spring growth in the root-zone (greater root mass than 'Chardonnay'), and not in budbreak or apical growth (less budbreak and lower shoot mass than 'Chardonnay'). Despite differences in root mass due to treatments in Experiment One (Figure 4), differences due to treatments were not found in Experiment Two. The reason for this is unclear, but may be suggestive of within vine variation found by Howell and Shaulis (1980). Differences in apical growth (shoot mass) between species and treatments are clear in Experiments One and Two. Despite near optimal air temperatures (Figure 2) (Kliewer 1975), shoot growth was limited due to root-zone temperature. Shoot mass differences are most likely attributed to differences in cytokinin production and, or translocation (Young 1989). Unlike previous investigations, (Kliewer 1975, Zelleke and Kliewer 1979) our research was terminated immediately following budbreak. Therefore, the influence of sub-optimal root-zone temperatures on budbreak and plant growth later in the growing season was not investigated. However, Kliewer (1975) and Zelleke and Kliewer (1979) reported reduced post-budbreak growth on grapevines receiving sub-optimal temperature treatments throughout the growing season.

This research demonstrated that root-zone chilling can delay budbreak of greenhouse grown *Vitis vinifera* L. 'Chardonnay' and 'Cabernet Sauvignon' grapevines. For grape producers on the Texas High Plains, and in other regions where freeze damage can eliminate early grapevine growth, reductions of root-zone temperature during spring deacclimation could have significant impact on the viticulture industry. However, the economic value of designing systems to decrease root-zone temperatures has not been evaluated. Cultural practices known to reduce soil temperature, such as organic mulch (Montague et al. 2000), or increased soil moisture (Kliewer 1975) may be viable options. However, additional research is needed to better understand short and long-term effects root-zone refrigeration may have on grapevines. Future research could investigate the effect of root-zone refrigeration on water and nutrient uptake, root and shoot formation, and fruit quality.

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