Effects of Irrigation on Wine Grape Growth and Fruit Quality

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ADDITIONAL INDEX WORDS. cold hardiness, soil moisture, soluble carbohydrates, Vitis vinifera Cabernet sauvignon, drip irrigation, wine color, pruning weight, crop load, total soluble solids, vineyard canopy

SUMMARY. Field studies were conducted to determine the effect of three drip irrigation regimes on grapevine growth, juice and wine quality, soil moisture, cold hardiness of bud and cane tissues and soluble sugar content of cortical cane tissues of *Vitis vinifera*, Linnaeus 'Cabernet Sauvignon'. This study was developed to help provide some irrigation management strategies that would improve fruit quality and reduce excessive vigor. Irrigation treatments of 192, 96, and 48 L (51, 25, and 13 gal) per vine per week were initiated at bud break until veraison (initiation of berry color) and then reduced by 25% through harvest. Significant differences of fruit weight per vine, crop load, soil moisture, average berry and cluster weight, shoot length and pruning weight per meter of canopy row were observed among treatments. Juice and wine compositions and wine color were also significantly different; however, cold hardiness and soluble sugar contents did not differ between treatments.

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This research was conducted at the Canyon Wind Vineyard, Palisade, Colo. The authors acknowledge the cooperation of Norm Christianson, the owner of Canyon Wind Wine Cellars, and the support and technical assistance of Susan Baker, Refugio Diaz, John Wilhelm, Diane Ross, and Pepe Seufferheld. This work was supported in part by the Colorado Wine Board. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

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Commercial wine grape production in Colorado is mainly located on the western slope of the Rocky mountains in Mesa and Delta counties (Hamman, 1993). These areas can be described as semiarid, desert-like regions where total annual rainfall typically ranges between 150 and 380 mm (6 and 15 inches). Therefore, irrigation is necessary for quality fruit production. Summers are normally hot with cumulative growing degree days (1 Apr. to 31 Oct. 10 °C base (50 °F) averaging 1,885 at Orchard Mesa Research Center in Mesa County (Hamman, 1996) and relative humidity ranges between 20 and 60%. Soils vary widely in these areas and range from well-drained, shallow, sandy soils to deeper clay loams that retain more moisture. Winegrape yield and quality are affected by climate, soil, genotype, and cultural management practices including irrigation (Smart, 1985). Poor irrigation management can result in water stressed or overly vigorous vines resulting in unbalanced growth, reduced yields and inferior fruit quality (Bravdo and Hepner, 1986; Jackson and Lombard, 1993; Smart and Coombe, 1983).

Grapevine water stress can occur if the supply of water to the roots is less than the evaporative demand. The cause for the stress may be low available soil moisture, high evaporative demand conditions, unbalanced shoot / root systems, a poorly developed root system, high salt levels or a combination of these (Evans et al., 1993; Smart and Coombe, 1983; Wample 1997). Unlike tomatoes (*Lycopersicon esculentum* L.), immediate signs of current season water stress are not clearly visible with grapevines. Symptoms are typically observed after repeated episodes of water stress (Jackson and Lombard, 1993; Kliewer et al., 1983; Evans et al., 1993; Wample, 1997; Porter, 1996).

Water stress can affect grapevine development in several ways. Water stress at bud break can result in uneven or stunted shoot growth. Under severe conditions nutritional deficiencies can occur. Poor flower development can occur on water stressed vines and, under severe conditions, flower abortion and cluster abscission may occur (McCarthy, 1984; Coombe and Dry 1992; Smart and Coombe, 1983). The following season's crop potential may be significantly reduced if the vines are stressed 2 weeks before full bloom when cluster initiation begins (Jackson and Lombard, 1993; Smart and Coombe, 1983). Water stress occurring immediately after fruit set, influences cell division and early cell enlargement causing reduced potential berry size at harvest and thus reduced yields. Water stress between veraison and harvest can result in rapid leaf senescence and abscission and eventual loss of canopy, contributing to fruit sunburn (Smart and Robinson, 1991; Kliewer et al., 1983; Coombe and Dry, 1992). High levels of stress during this period will result in an abscission of shoot tips.

It is well documented that grapevines will grow excessively if provided with an abundance of water and fertilizer (Jackson and Lombard, 1993; Smart, 1985; McCarthy and Coombe, 1984; Smart and Coombe, 1983). Excessive shoot growth has been associated with poor fruit set, poor fruit bud initiation for the following season, increased powdery mildew (*Uncinula necator* Burr) pressure, a better habitat for insects and lower fruit quality (Evans, et. al., 1990; McCarthy and Coombe, 1984; Smart, 1985; Wample,1997). Excessive shoot growth requires more cultural management input, i.e., hedging, leaf pulling, and shoot thinning to produce quality fruit. Lateral shoot growth and reduced vine acclimation can occur from over irrigating following a water-stressed episode (Smart and Coombe, 1983). Under these conditions, a delay in fruit maturation could occur and if vines are exposed to extreme low temperatures, bud, cane and trunk survival could be reduced. It is now recognized by growers and vintners worldwide that in regions with little or no rainfall during the growing season, careful vineyard irrigation strategies should be used as a tool to control grapevine canopy growth and fruit quality characteristics (Evans, et al., 1990, 1993; Jackson and Lombard, 1993; McCarthy and Coombe, 1984; McCarthy et al., 1987; Smart and Robinson, 1991).

Objectives

This experiment was designed to evaluate current drip irrigation practices for 'Cabernet Sauvignon' at the Canyon Wind Vineyard located in Palisade, Colo. Excessive growth, reduced fruit quality and excessive irrigation were concerns in this 'Cabernet Sauvignon' vineyard since this cultivar is often characterized by excessive vigor. If vine growth is not controlled by irrigation management, then the expensive alternative of trellis modification to a divided canopy would be needed. The goal of this research project was to evaluate irrigation management strategies that would help determine whether the canopy could be managed and fruit quality improved through perfected irrigation techniques. The specific objectives of this experiment were to evaluate the effects of different irrigation rates on shoot length, yield components, and fruit and wine compositions. Also, during the dormant season, the effects of irrigation treatments on bud and cane cold hardiness, water content, and soluble sugar content were determined. This research project was conducted during the 1997 growing season.

Materials and methods

IRRIGATION TREATMENTS AND SOIL MOISTURE MEASUREMENTS. The 7-year-old 'Cabernet Sauvignon' vines used in this experiment were own-rooted. The vines were trained to a bilateral cordon system and spur pruned. The trellis system used was a six-wire vertical shoot position trellis. The vineyard has a vine density of 2392 vines per hectare (968 vines per acre) based on 1.5 by 2.75 m (5 × 9 ft) spacing. The soil was a sandy loam (60% sand, 22% silt, 18% clay) with a pH of 8.1 and an organic matter content of 2%. An analysis of a soil saturation extract taken in December 1996 and showed a soluble salt level of 0.30 mmhos / cm (0.12 mmhos / inch), which is considered adequate and nonhindering for grapevine growth (Coombe and Dry 1992). The soil drains very well and contains no hardpans within a 122 cm (48 inch) depth. Soil moisture measurements were made with a neutron probe (model 503 DR1.5 hydropobe; Campbell Pacific Nuclear, Martinez, Calif.) at 0.3, 0.6, and 0.9 m (1, 2, and 3 ft) depths every 2 weeks beginning on 5 May until harvest on 7 October. The probe was calibrated before measuring, as described by the University of California (1989). The neutron probe access holes, approximately 122 cm (48 inch) deep, were drilled under each vine row and within 30 cm (12 inch) from an emitter. Polyvinyl chloride (PVC) pipe with a 3.81 cm (1.5

inch) diameter and a 114 cm (45 inch) length was securely placed in each drilled hole. Each PVC pipe was plugged with a rubber stopper and covered with a plastic cap to prevent entry of rainfall or irrigation moisture. The PVC pipe access tubes allowed repeated, undisturbed soil moisture measurements. Each treatment had three neutron probe access tubes. Three soil moisture measurements per tube per date were recorded.

The experimental design was a randomized block consisting of three irrigation treatments and three replications. Each replicate (row) consisted of 53 to 62 vines. Each treatment was an irrigation rate expressed in liters per vine per week. Treatment 1 (T-1), 192 L (51 gal) per vine per week was the control. Treatment 2 (T-2) was half of T-1, 96 L (25 gal) per vine per week. Treatment 3 (T-3), the lowest rate was 48 L (13 gal) per vine per week. The vineyard drip irrigation system was a pressurized, filtered system with two 4-$L \cdot h^{-1}$ (1-gal / h) emitters per vine and was used to supply each replicated treatment independently. One pressurized delivery pipe supplied water to this zone of the vineyard and therefore modifications for individual treatment control were needed. The emitter flow rate was verified for each row by measuring the flow rate of ten emitters. The irrigation system was modified with manual valves installed at the head of each row. Depending on the treatment, the valves were manipulated during each irrigation for volume output control. Volume per irrigation was controlled by manually shutting off the valve after the desired running time was completed. This manual irrigation schedule was employed three times per week. T-1 received 8 h of run time per irrigation which was equivalent to 64 L (16.9 gal)of water. T-2 received 4 h of run time per irrigation which was equivalent to 32 L (8.4 gal) and T-3 received 2 h of run time per irrigation which was equivalent to 16 L (4.2 gal) of water. In order to allow timely shoot maturity and fruit ripening, all treatments were subjected to a 25% irrigation reduction on 11 August (veraison) through 10 Oct. (harvest).

All standard vineyard cultural practices except hedging were employed. The treated vines were not hedged for measurement purposes of shoot length and pruning weight. Weeds were mechanically controlled. The vines were fertilized with four applications of nitrogen at 8.4 $kg \cdot ha^{-1}$ (7.5 lb / acre) for a total of 33.6 $kg \cdot ha^{-1}$ (30 lb / acre) of actual nitrogen. The fertilizer (ammonium sulfate) was applied by injecting it through the irrigation system at bud break, and on 1 June, 10 July and 5 August. Netting for protection against birds was applied the second week in August during veraison. Powdery mildew was controlled with standard spray applications of sulfur and sterol inhibitors and no disease was observed in any treatment.

GROWTH CHARACTERISTICS AND YIELD COMPONENTS. Shoot length, cluster weight and berry weight were measured on two dates corresponding to different developmental stages. At harvest, yield components including average cluster and berry weights and yields were determined. Average cluster and berry weights were made by harvesting 10 vines per row and randomly selecting 10 clusters. Berry weight was determined by randomly sampling berries from the selected clusters and weighing 10 berries per cluster. Yields per vine were determined by dividing the harvest weight of each row by the number of producing vines. Average pruning weights were also taken on 30 Dec. to determine the crop load of each treatment.The crop load, as described by Smart and Robinson (1991), is the ratio of fruit weight to pruning

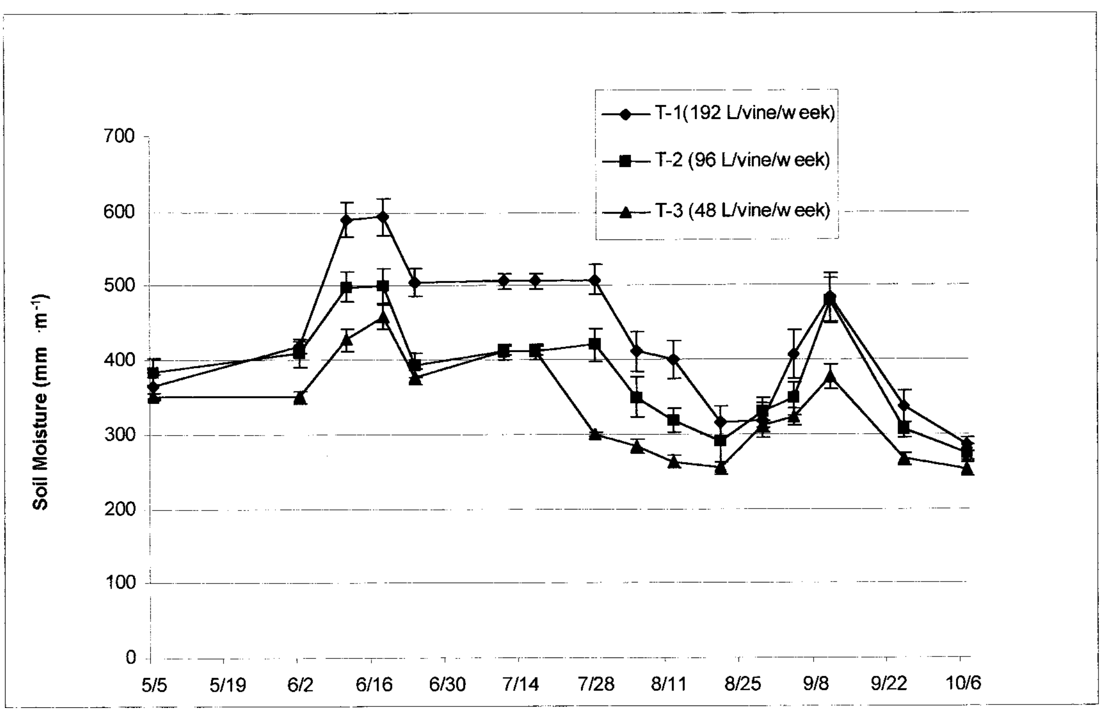

Fig. 1. Soil moisture profile of three irrigation treatments imposed on 'Cabernet Sauvignon' vines grown at the Canyon Wind Vineyard in Palisade, Colo., 1997. Measurements represent the means of the top 0.91 m (3.0 ft) of soil. 83.33 $mm \cdot m^{-1}$ = 1.0 inch/ft. Bars indicate SE. Significant differences at $P < 0.05$ were observed for all three treatments on 28 July using Tukeys multiple comparison test.

weight. Ten vines per row were randomly selected, spur pruned to 35 to 40 buds / vine and average weights of the prunings were determined. Juice composition measurements at harvest consisted of sugar (% total soluble solids), pH, and titratable acid content (TA, in g·L^{-1}). Wine composition measurements were done in January after the wine was stabilized but before any fining or oak additions. The wine lots were not replicated. Three separate wine samples were taken from each wine lot and analyzed. The wine measurements were TA, pH and wine color. Color analysis was made with a Beckman 640 DV-UV visible spectrophotometer (Beckman Instruments Inc., Fullerton, Calif.). Color density and absorbency at the 420 and 520 nm wavelengths were measured using spectral evaluation methods developed by Somers and Evans (1997).

COLD HARDINESS. Cane and bud cold hardiness was measured during the dormant season in November, December and January. On each date, dormant bud and cane tissues were collected and placed in plastic bags. Samples were subjected to gradual freezing by lowering the temperature 4 °C·h (8 °F / h) in a Tenney Jr. programable freezer (Tenney Engineering Inc., South Brunswick, N.J.). Each treatment was removed at 2 °C (4 °F) intervals, for each of four stress temperatures –20, –22, –24, and –26 °C (–4, –7.6, –11.2, and –14.8 °F) chosen to span the probable lethal temperature on a particular sampling date. The bud and cane samples were then thawed to 4 °C (39.2 °F) for 24 h, held at room temperature for 48 h and then excised and examined for browning (Stergios and Howell, 1973). The temperature corresponding to 50% survival (T50) was determined using the Spearman-Karber method (Bittenbender and Howell, 1974).

WATER CONTENT. Bud and cane tissues were also measured for water content. Fresh weights of the sectioned buds and 20 mm canes (0.78 inch) in length were measured independently within 4 h of collection. The tissues were dried at 70 °C (158 °F) for 7 d and dry weights were taken. Moisture content was calculated and expressed on a fresh weight basis.

SOLUBLE CARBOHYDRATES IN CANE CORTICAL TISSUES. The relationship between treatments and soluble sugar accumulation in cane cortical tissues was examined. It was hypothesized that reduced irrigation levels may alter the vine's capacity to produce high levels of soluble sugars and thus reduce its cold hardiness. Cane cortical tissue from each treatment was prepared and analyzed, as described for by Hamman et al. (1996), using a Dionex DX-300 series high pressure liquid chromatography system (Dionex Co., Sunnyvale, Calif.). The concentration of five soluble sugars (fructose, glucose, sucrose, raffinose, and stachyose) were quantified and were expressed as mole per gram on a dry weight basis.

STATISTICAL ANALYSES. Analysis of variance was performed on each experiment and treatment means were compared using Tukeys multiple comparison test (Gomez, 1984). The statistical analysis was performed using software from Graphpad Prism Version 2.0 (GraphPad Software Inc.,San Diego, Calif.).

Results and discussion

SOIL MOISTURE. The first soil moisture measurements were taken on 5 May 1997, one day before a scheduled irrigation. This period corresponded to bud break of 'Cabernet Sauvignon'. On this date, all treatments had similar soil moisture content (Fig. 1). However, subsequent moisture readings indicated significant differences among treatments throughout the season. T-1, receiving the highest irrigation rate, had the highest soil moisture. While T-3, with the lowest irrigation rate, had the least. T-2 was intermediate (Fig. 1). Peaks observed in Fig. 1 correspond to greater soil moisture resulting from rainfall during summer thunderstorms. Although irrigation rates were reduced by 25% on 11 August, soil moistures peaked in mid-September as a result of an unusual and significant rainfall (76 mm over 48 h). In general, the soil moisture profile closely followed a pattern expected as a result of the imposed irrigation treatments.

SHOOT AND FRUIT GROWTH CHARACTERISTICS. Canopy size differences among treatments were visible at bloom (11 June), when T-3 with the lowest irrigation rate appeared to have the shortest canopy height by this date compared to T-1 and T-2. Measurements, however, were not taken until one month after bloom, and at veraison (Table 1). On both dates, shoot and immature fruit growth was dramatically influenced by irrigation treatments. Lower irrigation rates in T-2 and T-3 resulted in shorter shoots, smaller clusters and lighter weight berries than did those of the highest rate in T-1 (Table 1). Similar findings were reported by McCarthy et al., (1987). We conclude that the reductions in shoot and fruit growth in T-2 and T-3 are responses to water stress imposed

Table 1. The effect of irrigation treatments on 1997 growth characteristics of 'Cabernet Sauvignon' at different phenological stages.

Date	Phenological stage	Treatment[z]	Shoot length (cm)[y]	Avg cluster wt (g)[x]	Avg berry wt (g)
11 July	One month after bloom	T-1	201 b[w]	95 b	1.7 c
		T-2	150 a	67 ab	1.0 b
		T-3	132 a	46 a	0.7 a
12 Aug.	Veraison				
		T-1	264 b	107 a	2.0 b
		T-2	188 a	100 a	1.7 a
		T-3	160 a	91 a	1.6 a

[z]T-1 = 192 L (51 gal), T-2 = 96 L (25 gal), T-3 = 48 L (13 gal).
[y]2.54 cm = 1.0 inch.
[x]28.35 g = 1.0 oz.
[w]Within a column, means followed by the same letter are not significantly different at the 5% level using Tukeys multiple comparison test.

Table 2. The effect of irrigation treatments on 1997 yield components[z], pruning weights[y] and crop load of 'Cabernet Sauvignon'.

Treatment[x]	Avg cluster wt (g)	Avg berry wt (g)	Yield (kg/vine)	Yield (t/ha^{-1})	Pruning wt (kg/vine)	Pruning wt/ m of canopy row (kg/m^{-1})	Crop load yield/ pruning wt (kg/vine)
T-1	136 b[w]	2.9 c	4.8 ab	11.6	1.0 b	0.65	4.8 a
T-2	109 ab	2.3 b	5.2 b	12.5	0.7 a	0.40	7.4 b
T-3	83 a	1.7 a	3.6 a	8.5	0.5 a	0.30	7.2 ab

[z]28.35 g = 1.0 oz, 0.45 kg = 1.0 lb; 1.49 kg·m^{-1} = 1.0 lb / ft.
[y]2.24 t·ha–1 = 1.0 ton / acre.
[x]T-1 = 192 L (51 gal), T-2 = 96 L (25 gal), T-3 = 48 L (13 gal).
[w]Within a column, means followed by the same letter are not significantly different at the 5% level using Tukeys multiple comparison test.

Table 3. Irrigation effects on 1997 'Cabernet Sauvignon' harvest juice composition.

Treatment	Total soluble solids[z] (%)	pH	Titratable acidity (g·L^{-1})[y]
T-1	22.3 b[x]	3.02 ab	8.6 a
T-2	21.7 b	2.99 a	8.9 a
T-3	20.2 a	3.08 b	7.4 a

[z]Total soluble solids are expressed as percent sucrose in g / 100 mL of solution.
[y]1.0 g·L^{-1} = 1000 ppm.
[x]Within a column, means followed by the same letter are not significantly different at the 5% level using Tukeys multiple comparison test.

by irrigation treatments. These results agree with previous studies (Evans et al., 1993; McCarthy and Coombe,1984; Bravdo et al., 1985; Smart and Coombe, 1983 and Wample, 1997) demonstrating reductions in shoot and fruit growth. Previous work by Wample (1997) has shown that visible differences in shoot reduction would not normally be manifested until after full bloom, but this was not true in this study.

YIELD COMPONENTS. At harvest cluster weight in T-1 was the greatest, but not significantly different from T-2 (Table 2). T-3 had the lowest cluster weight. Similar results were observed with berry weights (Table 2). The fruit weight per vine was the least in T-3 at 3.6 kg / vine (8 lb / vine), which corresponds to an estimated yield of 8.5 t·ha^{-1} (3.8 t / acre). T-2 averaged a higher cluster weight / vine than T-1, but the difference was not significant; consequently the yields were nearly equivalent (12.5 t·ha^{-1} (5.6 t / acre) in T-2 vs. 11.6 t·ha^{-1} (5.2 t / acre) in T-1). It is evident that the lowest irrigation rate (T-3) negatively affected the yield. T-2 produced a similar yield to T-1, although it received half the amount of water. This may suggest that with a moderate irrigation reduction, yields are not affected. It should be noted, however, that soil moisture of T-2 were nearly as high as T-1, ≈10 d after veraison, 21 August through harvest (Fig.1). This extra moisture (probably from rainfall) may have contributed to the slight increase in fruit weight per vine, and resulted in similar yields recorded between T-1 and T-2.

PRUNING WEIGHT, CROP LOAD AND VINE BALANCE. The highest irrigation treatment (T-1) had the greatest pruning weights at 1.0 kg / vine (2.3 lb / vine), followed by T-2 and T-3 at 0.7 (1.5 lb / vine) and 0.5 kg / vine(1.2 lb / vine), respectively (Table 2). Well balanced vines should have pruning weights ranging from 0.3 to 0.6 kg·m^{-1} (0.2 to 0.4 lb / ft) of canopy (Coombe and Dry, 1992). Vines from T-1 had pruning weights of 1.0 kg·m^{-1} (0.4 lb / ft)of canopy indicating a high-vigor condition. Visual observation of these vines during the growing season confirmed these results, and showed excessive canopy density. This particular situation may create shading problems and produce low fruit quality; thus vines of T-1 are considered to be out-of-balance. Crop load is another way to quantify whether there is a balance between vegetative growth and crop yield. Smart and Robinson (1991) show that crop load values between 5 and 10 are optimal and below 5 indicate excessive vegetative growth in relation to crop weight. It is concluded that due to excessive canopy vigor and the poor crop load value of T-1 (4.8),

Table 4. Irrigation effects on 1997 'Cabernet Sauvignon' wine composition[z] and wine color[y].

Treatment[w]	Titratable acidity (g·L^{-1})[x]	pH	Color density	Absorbency 520 nm	Absorbency 420 nm
T-1	7.0 a[v]	3.53 b	6.41 a	3.74 a	2.67 a
T-2	7.1 a	3.49 b	7.41 b	4.37 b	3.04 b
T-3	7.9 b	3.43 a	8.70 c	5.21 c	3.50 c

[z]Wine lots not replicated, three separate samples from each treatment were analyzed.
[y]Color is based on light absorbency at the 420 and 520 nm wavelengths.
[x]1.0 g·L^{-1} = 1000 ppm.
[w]T-1 = 192 L (51 gal), T-2 = 96 L (25 gal), T-3 = 48 L (13 gal).
[v]Within a column, means followed by the same letter are not significantly different at the 5% level using Tukeys multiple comparison test.

Table 5. Irrigation effects on 'Cabernet Sauvignon' cold hardiness (T50)[z] and water content (WC) measured on 3 Nov. 1997.

Treatment[x]	T50 Bud (°C)	T50 Cane (°C)	WC-Bud (%)	WC-Cane (%)
T-1	–18.3 a[w]	–18.1 a	29.9 a	42.0 a
T-2	–17.1 a	–17.3 a	27.9 a	42.2 a
T-3	–17.7 a	–17.8 a	27.6 a	42.5 a

[z]T50 is the lowest temperature at which 50% of the population survives. $^0F = 1.8(^0C) + 32$.
[x]T-1 = 192 L (51 gal), T-2 = 96 L (25 gal), T-3 = 48 L (13 gal).
[w]Within a column, means followed by the same letter are not significantly different at the 5% level using Tukeys multiple comparison test.

the irrigation rate is too high at 192 L / vine (51 gal / vine) per week, especially early in the season.

T-2 had 0.4 kg (0.9 lb) of pruning weight per meter of canopy which is within the optimum vegetative growth range. The crop load value of 7.4 for T-2, was also within the optimum range and indicates a good balance between the canopy size and the crop that it supports. It was concluded that the medium irrigation treatment of 96 L / vine (25 gal / vine) per week provided the best balanced vines with optimum fruit to wood ratio. The pruning weight per meter of canopy for T-3 was the least at 0.3 kg (0.7 lb), but within the acceptable range. The T-3 crop load value of 7.2 was also within the acceptable range. Although these numbers lead to the conclusion of somewhat balanced vines, other considerations should be taken into account. In fact, field observations have indicated that T-3 vines were severely water stressed to the extent that fruit shriveled during the ripening stage in mid-August. Therefore, an irrigation rate of 48 L / vine (13 gal / vine) per week is not recommended under these conditions.

JUICE COMPOSITIONS. Juice compositions at harvest were analyzed and differences were observed. To facilitate Canyon Wind's harvest operations, all treatments were harvested and juice compositions determined 10 d earlier than anticipated. Although fruit maturity levels indicate slightly underripe fruit, juice composition levels were showing significant differences among treatments (Table 3). Significant differences in % total soluble solids (TSS) and juice pH were observed. Titratable acidities at harvest were similar among treatments. Previous studies (Wample, 1997; Bravdo, et al., 1985; McCarthy and Coombe, 1984; McCarthy, et al., 1987) have shown that late season reductions in irrigation can slightly increase sugar (TSS) levels at harvest which was not observed in this study. T-3 TSS levels of 20.2 were significantly lower than either T-1 or T-2. It is likely the vines underwent severe water stress causing a physiological adjustment that resulting in stomatal closure. This would have led to reduced photosynthesis and decreased levels of soluble sugars.

WINE COMPOSITION AND COLOR. Wines were made from each treatment with standard industry procedures as described by Margalit (1990) and aged in glass carboys without oak addition. The wines were sulphited with 40 $mg \cdot L^{-1}$ (ppm) of $K_2S_2O_5$ and racked three times. The wines were analyzed for TA, pH and wine color. The irrigation treatments influenced wine TA, pH, color density and color absorbency at industry standards of 420 and 520 nm wavelength with T-3 having the darkest (highest absorbency) colored wine (Table 4). This color enhancement observed in T-3 from a winemaker's view was a positive effect but should not be the only consideration to vineyard irrigation strategies.

COLD HARDINESS AND WATER CONTENT. Bud and cane tissues for each treatment were subjected to freezing tests and analyzed for water content on three dates, 3 November 1997, 3 December 1997, and 9 January 1998. Differences among irrigation treatments in cold hardiness and water content of bud and cane tissues were not observed on any of the three sampling dates. Only data of November sampling are shown in Table 5. It is concluded that with these irrigation treatments, cold hardiness of buds and canes was not negatively affected. A previous study by Wample (1997) found similar results.

SOLUBLE CARBOHYDRATES IN CANE CORTICAL TISSUES. The accumulation of the soluble sugars (glucose, fructose, sucrose, raffinose and stachyose) in the internode stem tissue was measured and analyzed for treatment differences over the same sampling dates as above. Significant differences between treatments were not observed for any of the sugars analyzed on each date (Table 6). However, the concentration of each sugar increased from November to January with all treatments (Table 6). This accumulation of soluble sugars during the midwinter season is not a response to irrigation treatments, but a physiological response to low temperature as concluded by Hamman et al. (1996). Since irrigation treatments did not affect cold hardiness it is unlikely that they would affect carbohydrate accumulation.

Table 6. Irrigation effects on soluble sugar (10^{-5} $m \cdot g^{-1}$ of dry weight) of 'Cabernet Sauvignon' internode tissues from 1 November 1997 to 1 January 1998.[z]

	November			December			January		
Treatment[y]	T-1	T-2	T-3	T-1	T-2	T-3	T-1	T-2	T-3
Glucose	4.8	4.8	5.5	10.0	10.7	9.5	15.6	12.9	13.9
Fructose	2.0	1.4	2.2	6.2	7.6	6.9	13.2	12.4	10.9
Sucrose	4.2	3.9	4.1	5.9	6.4	6.6	10.9	10.0	8.6
Raffinose	4.3	3.4	3.1	1.3	1.5	1.1	2.4	1.5	1.9
Stachyose	1.2	1.1	0.9	2.7	1.9	1.9	2.4	1.5	1.4

[z]On each sampling date, no significant differences were observed between the three treatments for each sugar compared. Data are based on means of three replicates for each collection date.
[y]T-1 = 192 L (51 gal), T-2 = 96 L (25 gal), T-3 = 48 L (13 gal).

Conclusions

Several significant observations were made in this study. First, it is possible to control the canopy development of grapevines by irrigation management. It was found that for this particular soil and site, the rate of 96 L / vine (25 gal / vine) per week imposed until veraison (12 August), then reduced by 25% through harvest, provided the best balanced vines with good canopy size, good yields, and excellent fruit and wine quality. Growers should realize that these rates may change at other sites with different soil characteristics and weather conditions. In practice, rates should be modified according to the stage of development of grapevines and their seasonal water requirements. Second, cold hardiness of buds and canes was not affected by the imposed irrigation treatments. This implies that irrigation strategies could be used in Colorado vineyards for fruit quality control without compromising cold hardiness. Cold hardiness is an important factor to consider in this area due to the likelihood of winter injury. In addition, treatments with reduced irrigation were observed to have early cane maturity, thus less susceptibility to early fall frost. Third, carbohydrate reserves in canes were not affected by irrigation treatments. Therefore, reducing irrigation would not compromise carbohydrate storage or accumulation which is essential for cold hardiness.

Other advantages of reduced irrigation treatments are savings in cost of labor and materials associated with trellis modification and vineyard management practices such as irrigation, pesticide application, shoot and leaf removal, hedging, pruning, etc. It is concluded that given the proper irrigation and vineyard management practices, the canopy size of these'Cabernet Sauvignon' vines can be controlled and confined to the simple vertical shoot-position system without the need for canopy division.

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