Sensory attributes of Cabernet Sauvignon wines made from vines with different water status

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Abstract

The dependence of wine sensory properties on vine water status in *Vitis vinifera* L., cv. Cabernet Sauvignon was tested. Cabernet Sauvignon vines in the Napa Valley were subjected to three drip irrigation treatments: minimal irrigation (no irrigation added unless the midday leaf water potential dropped below –1.6 MPa), standard irrigation (32 L water/vine/week), and double irrigation (64 L water/vine/week). The minimal irrigation treatment produced midday leaf water potentials that were significantly lower than the other treatments throughout the season. Mean grape yields varied from 15.0 to 21.7 t/ha. Descriptive analysis conducted on the resulting wines demonstrated significant differences in several sensory attributes as per analysis of variance of the ratings. Analysis of variance and principal component analysis showed that the wines made from the minimal irrigation treatment were significantly higher in red/blackberry aroma, jam/cooked berry aroma, dried fruit/raisin aroma, and fruit by mouth than the wines from the irrigated treatments. The standard irrigation treatment wines were rated significantly higher than the minimal irrigation treatment wines in vegetal aroma, bell pepper aroma, black pepper aroma, and astringency. We conclude that vine water deficits lead to wines with more fruity and less vegetal aromas and flavours than vines with high vine water status.

Abbreviations

MIBT 2-methoxy-3-*iso*-butylpyrazine; **DI** double irrigated; **MI** minimally irrigated; **SI** standard irrigation

Keywords: *sensory evaluation, irrigation, water potential, descriptive analysis, aroma, flavour, Cabernet Sauvignon wines*

Introduction

Grape and wine qualities are often discussed in the viticulture literature with respect to irrigation. However, the use of both 'irrigation' and 'quality' can be problematic if not carefully defined. Vine water status can often be manipulated by irrigation, but if the vine water status is not measured, it is not clear whether irrigation relieves water deficits, has no effect, or causes flooding. Indeed, yield and other physiological responses may increase or decrease upon irrigation (Smart and Coombe 1983). Some assessment of physiological state of the vine with respect to water is required, usually measured as midday leaf water potential (Smart and Coombe 1983, Williams and Matthews 1990) but growth rate or stomatal conductance are also employed (du Toit et al. 2003). Similarly, 'quality' is a complex concept that can be defined and measured in several ways. In irrigated viticulture the term has been used to refer most often to the concentrations in the fruit of sugar or acid (Ough 1980, Webb 1981, Morris and Cawthon 1982), sometimes to colour (Freeman and Kliewer 1983, Tesic et al. 2002), and recently to polyphenols (Kennedy et al. 2000a, Medrano et al. 2003). The fruit assays, indeed viticultural practices, are concerned with wine quality, which ultimately is determined by sensory experience. The sensory analysis of wine quality can take several forms – expert ratings, trueness to type, absence of defect, or consumer acceptance (Meilgaard et al. 1991). Different results may be obtained depending on which definition and methodology is employed (Guinard et al. 1999).

For red winegrapes, the occurrence of some water deficit during the growing season has been interpreted as beneficial for quality (Bravdo et al. 1985, Hepner et al. 1985, Williams and Matthews 1990). However, these studies used either the Davis 20-point scale (Bravdo et al. 1985), which may not detect differences in wines that are free from defects even if they have different sensory profiles (Amerine and Roessler 1976), or fruit composition (Williams and Matthews 1990) for determination of quality. A connection from vine water status to fruit composition to differences in wine composition and sensory attributes was established by Matthews et al. (1990).

Sensory difference tests on wines made from four irrigation treatments and using trained panellists revealed significant differences in appearance, flavour, taste, and aroma among the treatments (Matthews et al. 1990). Although those results show that vine water status contributes to sensory differences among wines, they did not show how the wine aromas and flavours differed among irrigation protocols.

Descriptive analysis transcends quality and difference measurements by determining sensory attributes that differ among wines without reliance on preferences of the judges (Heymann and Noble 1989, Lawless and Heymann 1999). Yet, there have been few studies using descriptive analysis to characterise the impact of viticultural practices (see e.g. Chapman et al. 2004a), and no previous descriptive analysis studies have examined the effects of vine water deficits on sensory attributes of the resultant wines. Therefore, we conducted a study in which sensory attributes of wines from three irrigation treatments (minimal irrigation, standard irrigation, 2× standard irrigation) were evaluated by a descriptive analysis panel. Preliminary research with the 1999 vintage in the same vineyard showed that the wines made from minimally irrigated vines were rated significantly higher in molasses and soy aroma, red fruit flavour by mouth (strawberry, red raspberry, and cranberry), and astringency than wines from the two irrigated treatments (data not shown).

Materials and methods

Viticulture

Irrigation treatments were imposed in a commercial vineyard (*Vitis vinifera* L., cv. Cabernet Sauvignon, clone 8 on 110 Richter rootstock) in Napa Valley, CA, USA. The vines were planted in 1989 at 1 m × 1.8 m (vine × row) spacing, trained to bilateral cordons, drip irrigated, and farmed with standard practices with the exception of the irrigation treatments. Irrigation treatments were established in a randomised block design replicated five times with each plot consisting of 18 vines in a row and a buffer row on either side. Treatments imposed different volumes of drip irrigation (using 3.8 L/hour emitters): standard irrigation (SI), 32 litres/vine/week; double irrigated (DI), 64 litres/vine/week; and, minimally irrigated (MI), 32 litres/vine applied once when midday leaf water potential (Ψ) was –1.6 MPa. The SI regime was the standard irrigation practice in the commercial vineyard. The DI and MI treatments were imposed by adding emitters to or annulling the drip irrigation line. Irrigation was initiated on 25 June and applied in single sets each week. Vine water status was monitored weekly on the day prior to irrigation from the first irrigation until harvest. Midday Ψ was determined for 2 to 3 leaves per replication using the pressure chamber technique as previously described (Matthews et al. 1987). Vine water status was monitored every 7 to 14 days by measuring the leaf water potential as described by Matthews et al. (1987) in each of the five replicates per treatment. Grapes were harvested at 24.1±1 °Brix on 25 September 2000. Aliquots of harvested fruit from each replication were assayed for pH and titratable acidity by standard procedures.

Winemaking

Wines were produced at the Robert Mondavi Winery in Oakville, California. Three wine replications were made from the grapes of each irrigation treatment following standard experimental winemaking practices (Kennedy et al. 2002). Fruit from field replications of each of the irrigation treatments was combined, divided into three equal lots (by weight), and crushed using a Zambelli crusher/destemmer (Saonara, Italy) into 80 L food-grade buckets. Sulfur dioxide (35 mg/L) was added to the must, the contents were mixed well with a paddle, and after 1 hr the must was inoculated with yeast (*S. bayanus*, Lalvin strain EC 1118) at a rate of 0.24 g/L. Lots were punched down twice per day. After 2 days at ~17°C the must was inoculated with 2% v/v active malolactic culture *(Leuconostoc oenos* strain ML-34) and stored at 27°C for 5 days. After 7 days skin contact, wines were pressed (Willmes, Model 100), using a 0.5/1.0/1.5 bar pressing program, with press wine up to 1.5 bar added back to the drain wine. Wines were transferred to 20 L glass carboys equipped with fermentation locks, and kept at 22°C until dry and through malolactic fermentation. Afterwards, wines were racked, aerated, and transferred to clean 20 L glass carboys. After 2 and 8 wks, wines were racked again, and the free SO_2 was adjusted to 18–20 mg/L as determined by aeration-oxidation method. After the final rack and SO_2 adjustment, wines were bottled into nitrogen-sparged, 500 mL bottles and sealed with crown caps. Wines were within 0.7% of 13.8% alcohol, had less than 2.0 g/L residual sugar, and had 0.5 to 0.6 g/L acetic acid. All wines were bench tasted for soundness prior to sensory analysis.

Descriptive analysis

Wines were evaluated by a panel of 13 trained judges (9 male, 4 female, ages 21–40, graduate or higher level students in Viticulture and Enology with extensive wine tasting experience) using a hybrid consensus training method that combined aspects of the Quantitative Descriptive Analysis (Stone and Sidel 1993) and Spectrum (Meilgaard et al. 1991) methods. Panellists were selected based on interest and availability and were compensated for their participation.

Sensory panel training

Panellists attended three one-hour sessions per week for four weeks. The panellists were introduced to descriptive analysis and generated terms to describe the wines of interest during the first five sessions. At each session they were given three experimental wines that were chosen to show differences. Panellists first listed descriptors for the wines individually, then discussed the terms as a group, and finally ranked the wines for the attributes. If there were disagreements among the panellists on the rank order of the wines for an attribute, the group discussed their differences and came to a consensus.

At the next session, the panellists were given a list of all the attributes they had generated. The group discussed which terms were most useful to discriminate among the samples they had tasted. A preliminary scorecard was designed based on this discussion. Six sessions were then

Table 1. Attributes and reference standards.

Attribute	Reference standard[a]
Aroma	
Vegetal	2.5 g chopped asparagus + 2.5 g chopped green bean (fresh)
Bell pepper	5 g chopped, fresh, green bell pepper (*Capsicum annuum*)
Black pepper	Pinch (0.05 g) of Safeway Crown Colony Coarse Ground Black Pepper
Fresh cherry	no standard (cherries not in season)
Red/Black berry	5 mL fresh strawberry/raspberry/ blackberry juice (squeezed through cheesecloth)
Jam/Cooked berry	1 mL each of Safeway red raspberry, blackberry, boysenberry, strawberry preserves
Dried fruit/Raisin	10 crushed Safeway California seedless raisins
Earthy/Musty/Mushroom	1.25 g sliced fresh mushroom
Soy/Molasses	2 drops Aloha Shoyu soy sauce and 1.5 g Grandma's 'Robust Flavor' Molasses
By mouth	
Astringent	0.22 Molar catechin
Bitter	0.56 Molar caffeine
Acidic/Sour	0.22 Molar citric acid
Vegetal by mouth	Bell pepper and vegetal aroma standards
Fruit by mouth	Red/black berry aroma standard
Black pepper by mouth	Black pepper aroma standard

[a] Standards prepared in 40 mL Cabernet Sauvignon base wine.

spent practising rating these attributes on a scale from 0 (not present) to 15 (most intense) and modifying the list to include only those attributes that would discriminate among the wines they had tasted. Standards were presented to the group, discussed, and changed if needed to fit the group's ideas of the terms. The final list of attributes, along with their definitions and reference standards, are listed in Table 1. Judge performance during training was monitored by computing standard deviations for the judges and by applying analysis of variance procedures to training data. With this approach, the ability to discriminate among the wines, the reproducibility, and the consistency with the rest of the panel could be measured for each judge. Based on these indicators, the panel was deemed ready after a month of training.

Sensory testing

The wines were stored in the UC Davis wine cellar at 12ºC and were brought into the sensory laboratory at least two hours prior to testing to equilibrate with the environment. Samples of wine (40 mL) were served in clear, tulip-shaped glasses covered with plastic covers to allow volatiles to equilibrate with the headspace. The wines were coded with three-digit random numbers.

Judges smelled the aroma standards before beginning each session in order to refresh their memories. The standards were available throughout the tests for the panellists to refer to.

Judges rated the 9 wines (3 irrigation treatments × 3 winemaking replications) in triplicate over a period of 6 sessions, with 4 or 5 wines presented monadically per session. Presentation order was randomised within each scoring repetition according to a Latin square design. Evaluations were conducted in individual booths under incandescent lighting and data was collected on paper ballots. Judges were instructed to rinse three times with water between samples. Each judge completed 3 sessions per week, over two weeks. Sessions lasted approximately 18–25 minutes.

2-Methoxy-3-iso-butylpyrazine analysis

Analysis for 2-Methoxy-3-*iso*-butylpyrazine (MIBP) was conducted in triplicate for each wine according to the method of Chapman et al. (2004b).

Tannin analysis

Wine tannins were assayed in duplicate for each wine by protein precipitation according to the method of Harbertson et al. (2002).

Data analysis

Analysis of variance was run for each attribute using the proc glm procedure in SAS (SAS Institute, Cary, NC) with the wine replications nested within the irrigation treatments and judges as a fixed effect (judge, treatment, wine replication (treatment), sensory scoring replication, interactions) in order to assess significant differences among the wines. Fisher's Least Significant Differences (LSD) test was used for multiple mean comparisons ($P \leq 0.05$).

Principal component analysis (PCA) was performed using JMPin4 (SAS Institute, Cary, NC) on the covariance matrix of mean attribute ratings across the wines (for the attributes that discriminated among wines based on the analyses of variance) in order to illustrate the relationships between the attributes and the wines.

Results

Vine water status and yield

The water status of vines generally corresponded to the applied water in the irrigation treatments. The MI treatment resulted in more negative leaf water potential than the two irrigated treatments (SI and DI) throughout the ripening season, and the water potential of SI vines was usually intermediate to the other treatments (Figure 1).

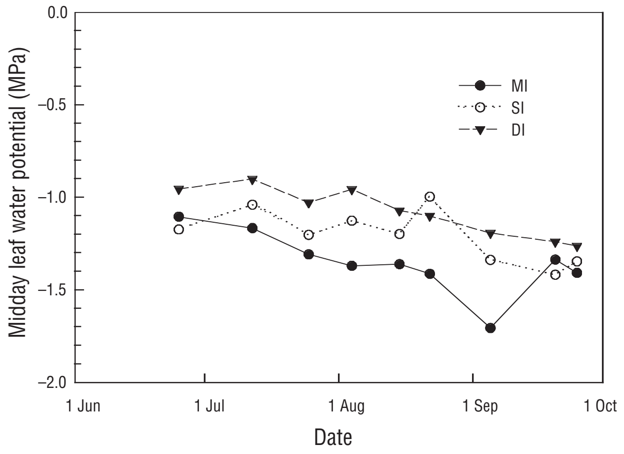

Figure 1. Midday leaf water potentials on various dates for Cabernet Sauvignon vines subjected to three irrigation regimes: minimal irrigation (MI), standard irrigation (SI), and double irrigation (DI) during the 2000 growing season. Data are means of 2 or 3 leaves per replicate for 5 replications on each date for each treatment; mean standard deviation was 0.12 MPa. Veraison was approximately 20 July 2000.

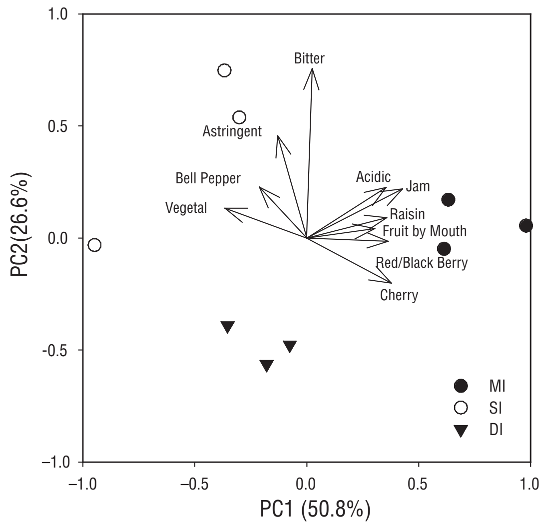

Figure 2. Projection of sensory attributes on principal components 1 and 2 for the irrigation treatment wines: minimal irrigation (MI), standard irrigation (SI), and double irrigation (DI); 3 winemaking replications each.

The leaf water potentials for the SI and DI treatments were generally similar to each other after the beginning of August. The mean leaf water potential after veraison was –1.03, –1.13, and –1.38 MPa for the DI, SI, and MI vines, respectively.

The irrigation treatments resulted in yields of 15.0 t/ha for the MI treatment, 17.6 t/ha for the SI treatment, and 21.7 t/ha for the DI treatment. The fruit used to make wine was similar in soluble solids (Table 2). The pH was low, 3.31 in MI fruit, and higher, 3.69 in SI fruit. The TA was correspondingly high in MI fruit, but was lowest in the DI fruit.

Descriptive analysis

The MI treatment led to the most fruity and least vegetal wines while the SI treatment led to the most vegetal and least fruity wines. The DI treatment led to wines that were moderate in both fruity and vegetal aromas and low in bitterness and astringency (Figure 2).

Significant differences ($P \leq 0.05$) among the irrigation treatments were found in 9 of the 15 attributes tested (Table 3). These were vegetal, fresh cherry, red/black berry, jam/cooked berry, and dried fruit/raisin aromas, astringent, bitter, sour, and fruity by mouth. There were no differences among winemaking replications for any of the attributes, and sensory scoring replications differed for only two attributes. Furthermore, no judge × wine interactions were found, attesting to the quality of the panel's performance. Mean ratings and LSD values for the irrigation treatments across all significant attributes are shown in Table 4.

The SI treatment received the highest ratings in vegetal aroma, bell pepper aroma, astringency, and bitterness. For vegetal and bell pepper aromas, the MI treatment was rated significantly lower than the SI treatment, while for astringency, both the MI and DI treatments were rated significantly lower than the SI treatment. The SI wines were also highest in tannin concentration, which matched with the sensory astringency ratings; however, the MIBP concentrations did not follow the vegetal aroma intensity ratings.

The MI treatment led to the most fruity wines. Fresh cherry, red/black berry, jam/cooked berry, and dried fruit/raisin aromas, as well as acidic and fruity by mouth were rated highest in the MI wines. The fruity intensities were significantly lower for both the SI and DI treatments in all cases except for fresh cherry aroma, where only the standard irrigation treatment was rated significantly lower.

Principal component analysis (PCA) was run on the covariance matrix of mean attribute ratings across the wines (Figure 2). PC1 (50.8%) ran from vegetal on the negative end to fruity on the positive end. PC2 (26.6%) separated wines that were high in bitterness and astringency from those which were not. The three irrigation treatments were well separated on the first two PCs, showing that the winemaking replications were consistent. The MI wines were located on the positive side of PC1 with high fruitiness and moderate bitterness and astringency. Two of the SI wines were located on the negative end of PC1 and the positive end of PC2, while the third was located very low on PC1 and high on PC2. These wines were the most vegetal, astringent and bitter.

Table 2. Brix, titratable acidity (TA) and pH of musts made to the wines used to obtain sensory data given in Table 3, Table 4, and Figure 2. Fruit was harvested from vines subjected to different water statuses (minimal (MI), standard (SI), and double (DI) irrigation regimes). Data are means ± s.e.m. (n = 3).

Treatment	°Brix	s.e.m.	pH	s.e.m.	TA g/L*	s.e.m.
MI	24.1	0.21	3.31	0.11	7.39	0.08
SI	25.3	0.49	3.69	0.04	6.93	0.33
DI	23.2	0.21	3.41	0.07	6.69	0.22

* as g tartaric acid equivalents

The DI wines were tightly clustered on the negative ends of PC1 and PC2. These wines were moderate in both vegetal and fruity attributes and were low in bitterness.

Discussion

The irrigation treatments resulted in lower water status in the MI vines and slightly higher water status in DI vines than in SI vines during fruit ripening. Low vine water status produced significant sensory aroma and flavour differences in the resultant wines, including reduced astringency and vegetal (bell pepper and vegetal) aroma. The MI wines were rated higher in all of the fruity descriptors than the SI and DI wines. This is consistent with the results of the preliminary study conducted the previous year, in which the MI wines were significantly fruitier than the SI and DI wines (data not shown). Also, the PCA separated the MI wines from the SI and DI wines on PC1 (50.8%) based on a contrast between fruity and vegetal descriptors. These differences in wine sensory attributes provide an initial basis for managing vine water status in irrigated winegrape production to produce a wine sensory profile.

Essential sensory

It is difficult but essential to carry vineyard experiments over to sensory analysis of wines if the ultimate objective is to manipulate wine sensory attributes through vineyard management. There are too few chemical analyses that predict wine sensory properties to make progress by stopping at fruit analysis. Brix, pH, and TA are the most commonly measured components of fruit composition, but the information about the sensory attributes of resultant wines that can be expected from the values of these parameters is limited. Therefore, these values are also limited

Table 4. Mean descriptive ratings on a 15-point scale, MIBP concentration (ng/L) and tannin concentration (mg/L catechin equivalents) with corresponding Fisher's least significant difference (LSD) values at $P < 0.05$ for wines made from vines subjected to different (minimal (MI), standard (SI), and double (DI) irrigation treatments.

	MI	SI	DI	LSD
Aroma				
Vegetal	6.25 b	7.22 a	6.79 ab	0.58
Bell pepper	3.91	4.54	4.10	0.50
Black pepper	3.35	3.93	3.46	0.52
Fresh cherry	4.37 a	3.39 b	4.09 a	0.53
Red/Black berry	6.08 a	5.10 b	5.38 b	0.58
Jam/Cooked berry	5.83 a	4.88 b	4.85 b	0.61
Dried fruit/Raisin	5.78 a	4.99 b	4.97 b	0.53
Earthy/Musty/Mushroom	5.21	5.54	5.42	0.60
Soy/Molasses	3.85	4.32	4.05	0.56
By mouth				
Astringent	6.53 b	7.15 a	6.41 b	0.53
Bitter	6.38 a	6.89 a	5.52 b	0.55
Acidic/Sour	7.44 a	6.73 b	6.65 b	0.53
Vegetal by mouth	5.62	6.05	5.88	0.50
Fruit by mouth	6.56 a	5.87 b	5.89 b	0.59
Black pepper by mouth	4.84	5.14	4.68	0.48
Chemical measurements				
MIBP	7.6 a	5.8 b	5.1 b	0.8
Tannin	447 b	501 a	481 a	21.0

Means with the same letter are not significantly different.

Table 3. Significance levels (*P*-values) from analysis of variance for descriptive ratings of attributes of Cabernet Sauvignon wines made from grapevines subjected to three irrigation treatments.

Attribute	T *P* values[a,b]	W *P* values[a,b]	R *P* values[a,b]	J *P* values[a,b]	J*T *P* values[a,b]	J*W(T) *P* values[a,b]
Aroma						
Vegetal	**0.009**	0.319	0.660	**<0.001**	0.131	0.695
Bell pepper	0.054	0.667	0.153	**<0.001**	**0.001**	0.452
Black pepper	0.074	0.451	0.287	**<0.001**	0.444	0.498
Fresh cherry	**0.001**	0.442	0.520	**<0.001**	0.738	0.639
Red/Black berry	**0.006**	0.787	0.532	**<0.001**	**0.015**	0.809
Jam/Cooked berry	**0.002**	0.608	**0.008**	**<0.001**	**0.016**	0.894
Dried fruit/Raisin	**0.004**	0.232	**0.018**	**<0.001**	0.577	0.384
Earthy/Musty/Mushroom	0.590	0.671	0.880	**<0.001**	0.202	0.705
Soy/Molasses	0.281	0.567	0.632	**<0.001**	0.958	0.850
By mouth						
Astringent	**0.020**	0.130	0.472	**<0.001**	0.121	0.893
Bitter	**<0.001**	0.384	0.384	**<0.001**	**0.043**	0.206
Acidic/Sour	**0.012**	0.527	0.792	**<0.001**	0.331	0.924
Vegetal by mouth	0.281	0.346	0.755	**<0.001**	0.182	0.862
Fruit by mouth	**0.040**	0.663	0.858	**<0.001**	0.075	0.408
Black pepper by mouth	0.232	0.105	0.319	**<0.001**	0.337	0.998

[a] Code: T (irrigation treatments), W (wine fermentation replicates), R (sensory replicates), J (judge); [b] Bold values are significant at the 5% level.

in their potential to confirm or refute the validity of sensory data. The fruit or must °Brix should predict wine alcohol concentration, which carries an important sensory response. However, the physical and nutrient status of the fruit affect the efficiency of yeast conversion and extraction of sugars so that ethanol yields per °Brix vary considerably from year to year and region to region (Jones and Ough 1985). Fruit °Brix is not effective in predicting sugar or sweetness of wine because other factors determine residual sugar concentrations in the wine. Assays of fruit pH and titratable acidity (TA) might be expected to predict wine pH, TA, and sourness, even when malolactic fermentation significantly raises the pH. However, confirmation of this appears lacking.

There are analyses for some flavour and aroma attributes. The MIBP concentration in wines correlates excellently with perceived vegetal aroma and flavour (Allen et al. 1991, Chapman et al. 2004a). Recent development in wine tannin analysis (Harbertson et al. 2002) provides an assay that correlates well with wine astringency in sensory tests (Chapman, Guinard, and Matthews unpublished data). As with fruit acidity, it is not yet clear whether assays of fruit tannin and MIBP predict wine tannin and MIBP or wine astringency and vegetal attributes. Differences in wine aroma and volatile composition of fruit among some grape varieties, e.g., floral varieties such as Riesling and Muscat high in terpenes, are well correlated (Rapp 1988, Ebeler 2001). Beyond these examples there is little in the way of chemical assays that viticulture researchers can exploit to predict wine sensory attributes. Furthermore, a limited knowledge of volatile composition of the fruit does not fully predict the sensory properties of finished wines. Much of the wine aroma may arise from hydrolysis of non-volatile precursors in the grapes during fermentation (Ough 1982, Williams et al. 1993). Other complex reactions and chemical rearrangements occur during fermentation and aging so that the final composition and sensory properties of the wine may be very different from that of the original grapes (Rapp 1988). With the limited availability of chemical assays with clear connections to sensory attributes, research similar to that presented in this study is needed to develop a sound basis for cultural strategies in winegrape production.

Water deficits impact virtually every aspect of plant metabolism (Bradford and Hsiao 1982, Niel and Burnett 1999) and, consequently, most aspects of fruit composition that have been investigated. Irrigation is critical to grape production in some environments, vine water status can be regulated in those environments, and there has been much study of vine growth and gas exchange responses to various water regimes. Yet, most irrigation research has not been carried through to a sensory evaluation of the resultant wines. A search of the BIOSIS and AGRICOLA databases produced the following results:

Search term	Hits in BIOSIS	Hits in AGRICOLA
irrigation and grape	403	258
irrigation and wine	68	40
irrigation and wine and sensory	3	1

Although not comprehensive, these results should accurately reflect the order-of-magnitude decreases in moving from grape to wine to wine sensory, culminating in an extremely limited literature on vine water status and wine sensory attributes. Thus, most conclusions about irrigation effects on wine and on its sensory attributes in particular are inferred rather than measured.

Water deficits and descriptive analysis

Descriptive analysis of Cabernet Sauvignon wines has often produced a contrast between fruity and vegetal descriptors (e.g. Chapman et al. 2004a, Heymann and Noble 1987). Again, in the current study most of the variability in wine sensory perception was explained by differences in vegetal and fruity notes. The MI wines had the lowest ratings for vegetal and bell pepper aroma and for 'vegetal by mouth' and had the highest ratings for fruity attributes. Our results are apparently consistent with those from Noble et al. (1995) in which fruity wines were associated with soils with low water holding capacities, and vegetal wines were associated with soils with high water holding capacities. However, water status of the vines and MIBP concentration in the wines were not measured in that study, so it is not clear whether the differences in soil texture had any impact on vine water status and physiology. We recently argued that these two descriptors could interact by a masking effect in which an increase in vegetal aromas and flavours could cause a lower fruitiness rating (Chapman et al. 2004b). In that study there were positive and significant correlations between vegetal intensity ratings and MIBP concentrations for 18 Cabernet Sauvignon wines with MIBP concentrations from <2 to 10 ng/L (Chapman et al. 2004b). In the present study, the MIBP concentrations in the wines were not well correlated with vegetal ratings, but all concentrations were below the reported threshold of 10–16 ng/L for MIBP in red wine (Maga 1990, Kotseridis et al. 1998, Roujou de Boubée et al. 2000). Other compounds, such as sulfur compounds, may have contributed to the vegetal aromas and flavours of these wines (Goniak and Noble 1987, Margalit 1997), but the interaction of vegetal and fruity attributes was apparently not dependent upon masking of fruity notes by MIBP.

We suggest that the interaction of vegetal and fruity attributes in this study may have arisen from a water deficit-induced increase in fruity compounds. Fruity aromas and flavours in wine are often due to ethyl esters and acetate esters of fatty acids (Ebeler 2001). The concentration of esters in wines is positively correlated with the concentration of some or all amino acids in the fruit (Guitart et al. 1999, Webster et al. 1993), and water deficits increase the nitrogen status of fruit (Peyrot des Gachons et al. 2005). Water deficits after veraison increase the concentration of proline (Matthews and Anderson 1988) and most other free amino acids in both the fruit and resultant Cabernet Franc wines (Matthews and Anderson, unpublished). Furthermore, the concentration of nor-isoprenoids that participate in wine aroma may have been increased by water deficits. There is a recent report that in berries of vines that were exposed to water deficits the concentration of the carotenoid precursors to norisoprenoids was increased compared to irrigated controls (Oliviera et al. 2003). Thus, the MI treatment may have led to a greater flux of carbon through alternate pathways, such as the biosynthesis of amino acids and carotenoids, that produce aroma compounds giving the MI wines a more fruity sensory profile.

Astringency and bitterness in wine are generally associated with polyphenols and tannins (Noble 1999). The lower tannin concentration in the MI wines than in the SI and DI wines is apparently not consistent with earlier studies where similar water deficits were imposed (Matthews et al. 1990, Kennedy et al. 2002b), but different methods to detect phenolic compounds were used for each study. The total extractable tannin subunits from Cabernet Sauvignon grape seed were lower in MI vines than in DI vines (Kennedy et al. 2000). Thus, it is important to resolve which grape phenolics are carried through to the finished wine.

Water deficits, yield, and fruit maturity

It could be argued that the differences observed here and in other irrigation studies arise from differences in the maturity of the fruit used to make the wine. In the conduct of viticulture experiments that require wines to be made from the fruit, the question arises as to whether to harvest plots on a common date or to harvest plots on various dates determined by an objective maturity assay. In the former case, which has been widely employed, differences in maturity among fruit at the harvest date and among the resultant wines are interpreted as treatment effects. The former approach may seem wanting: would such differences have been eliminated by harvesting at the same 'maturity'? In the latter case, perhaps more popular recently, differences in maturity are potentially eliminated. The implicit assumption is that treatment effects reveal physiological disconnects between 'maturity' and other aspects of fruit ripening. Although the latter might reveal differences that are more interesting from a physiological viewpoint, both approaches are useful and valid in viticulture for several practical reasons. First, there is at present no satisfactory means to ensure that large samples of fruit are harvested at a similar soluble solids level, but harvesting on a given date is almost always feasible. Second, commercial harvest decisions involve both approaches – waiting for a target maturity and harvesting at a specified time because circumstances or other considerations (e.g. fruit taste) require it. Third, the option to wait for similar soluble solids levels can be eclipsed by weather and the waning growing season. And, the use of °Brix as an objective maturity index is an arbitrary convention. This convention is openly in question at least in the Californian wine industry where it is suggested that important differences among fruit or wines arise simply as a consequence of different ripening periods or 'hang time' (Hirsch 2005). Although taking both approaches in the same study should be considered, limited resources at each step – including exhaustion of the sensory panel – often preclude this.

Sugar accumulation (measured as °Brix in this study) is the traditional, objective parameter of fruit maturity in viticulture. More information is needed regarding the effect of water deficits both on fruit maturation (sugar accumulation) and any ripening processes that are not directly related to sugar accumulation. The effects of various irrigation regimes on vine water status are variable, and the consequences for sugar accumulation can be positive, negative, or nil (Williams and Matthews 1990). The difference in midday leaf water potential between MI and DI in this study varied from 0.3 to 0.5 MPa during fruit ripening, and the minimum value reached was approximately –1.7 MPa. This is similar to the results in several studies with Cabernet varieties in the Napa Valley in which post-veraison irrigation was withheld (Matthews et al. 1987, Matthews and Anderson 1988, Kennedy et al. 2000b, Roby and Matthews 2004). In some studies, water deficits altered fruit ripening independent of sugar accumulation (Matthews and Anderson 1988). More severe water deficits may increase sugar accumulation during ripening (Kennedy et al. 2000b, Roby et al. 2004), but very severe water deficits decrease sugar accumulation (Hardie and Considine 1976) and irrigated vines sometimes produce fruit with higher sugar concentrations than non-irrigated vines (Esteban et al. 1999).

In the current study, the differences in wine sensory attributes were probably not due to a general response of fruit maturation (measured by sugar accumulation) to the irrigation treatments. All fruit was harvested at similar °Brix. The range of sugar concentration and pH in the fruit should not affect yeast growth and associated consequences for wine composition (Charoenchai et al. 1998). The panel did select and discriminate sourness as a variable among the wines, with the result that MI wines were more sour than the other wines. This is consistent with the higher TA in MI fruit, but the °Brix of MI fruit was intermediate rather than low. Therefore, we conclude that the several sensory differences detected among the wines arose from differential responses of specific metabolic pathways to vine water deficits.

In a separate study of the impact of viticultural practices on wine sensory quality, we found that when yield was adjusted by pruning, low yielding vines produced wines with less fruity and more vegetal aromas and flavours (Chapman et al. 2004a), and that when yield was adjusted by cluster thinning at veraison, few sensory differences were detectable. In the current irrigation study, the low yielding vines (MI) produced wines with the most fruity and least vegetal sensory notes. The relationships of irrigation-adjusted yield to sensory attributes were the inverse of the relationships for pruning-adjusted yield. Therefore, the viticultural practices used to control yield in a vineyard may be more important than the yield values per se in determining the sensory properties of the resulting wines.

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