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Irrigation level and time of imposition impact vine physiology, yield components, fruit composition and wine quality of Ontario Chardonnay

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ABSTRACT

An irrigation trial was performed in a Chardonnay vineyard in Niagara-on-the-Lake, Ontario, Canada, between 2005 and 2008. Treatments were three irrigation levels based on% of crop evapotranspiration (ET_c) [two deficit water regimes (50% ET_c, 25% ET_c) plus 100% ET_c] combined with two times of irrigation imposition [fruit set (FS), veraison (VRN)] plus a non-irrigated control. Water volume applied was based on ET_o values derived by the Penman-Monteith equation. Soil moisture (SM) followed the same trend in VRN-imposed vs. FS-imposed treatments (2006). VRN-imposed treatments (2007) showed lower SM than those imposed at FS. Vine water status was assessed by transpiration (E) rate and leaf water potential (ψ). E rate followed the same trend as SM (2006), with greatest difference between treatments in July and early August, with minimal differences by late August. E rate (2007) declined until late August, which coincided with highest daily temperatures and light intensities. The 25% ET_c/FS treatment did not differ from the control in SM and leaf ψ, while 100% ET_c had consistently higher SM and leaf ψ vs. control. Yield components differed in almost all treatments vs. control (2006–2007), and irrigated treatments had higher values for most yield components (2007). Shoot growth rate showed the same trend in all years, with irrigated treatments having higher growth rates vs. control; these were lower in deficit treatments vs. 100% ET_c. Multivariate analysis showed strong correlations between SM and leaf ψ. Medium soil water deficits were highly correlated with positive sensory attributes in the wines. Intensity of flavor and aroma attributes was associated with the degree of water deficit. Deficit irrigation treatments improved vine water status overall, even in years when only short periods of drought occurred, and sensory profiles were impacted positively.

1. Introduction

Water is a major factor affecting yield and composition of wine grapes in hot and dry regions (Wample and Smithyman, 2002). In recent years, water deficits have occurred in cool climate wine regions as well (Balint and Reynolds, 2013; Dragoni et al., 2006; Reynolds et al., 2007). In temperate climates, grapevines often face some degree of drought stress during the growing season (Morlat et al., 1992). Applying water to table grapes is not a topic of debate among grape growers, but applying irrigation to wine grapes in humid, temperate regions is still controversial among winemakers and grape growers. Frequency of drought stress phenomena in viticulture have often been linked to climate change, for which temperature increases of 1.6 °C between 2000 and 2050 and 3.4 °C between 2000 and 2100 are predicted (Dai et al., 2001). A significant component of the global warming phenomenon involves the frequency of extreme meteorological events (dry and hot seasons alternating with wet and cool seasons). This phenomenon has been seen often in the last decade in Niagara Peninsula, Ontario, where dry and hot seasons occurred in six of the past 15 vintages (Grape Growers of Ontario, 2014). This trend is accompanied by a change in rainfall distribution. In some years, even if annual rainfall remains constant, vineyards are subjected to prolonged drought during the growing season because of changes in its distribution pattern. These facts have caused the Ontario wine industry to reconsider using irrigation in vineyards.

Both excess water and lack of moisture in the soil profile have negative effects on grape composition (Van Leeuwen and Seguin, 1994). This fact leads to questions about when to apply and how much water to use to obtain premium wines. This requires knowl-

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edge on cultivar, water requirements, yield and quality responses to water, the constraints specific to each irrigation method and equipment, the limitations relative to the water supply system, and the financial and economic implications of irrigation practices. Severe water stress applied to container-grown Cabernet franc vines reduced yield by 94% because of lower berries per cluster and reduced berry weight (Hardie and Considine, 1976). Greater yield losses occur as a result of water deficit during early stages of berry development compared with deficits later in the season (Hardie and Considine, 1976). Yield losses occurred due to water deficits in Cabernet Sauvignon, and this was explained by the changes in berry growth patterns (Matthews and Anderson, 1989). Vine water status also influences the bud fertility either directly by the amount of water available for biosynthetic processes occurring during cell division and cell enlargement or indirectly via its effect on vine photosynthesis (Loveys and Kriedemann, 1973), nutrient uptake, and microclimate surrounding the bud (Dry and Loveys, 1998).

Periodic measurements of soil water status are often conducted for detection of potential vine water stress (Martin et al., 1990). Under drip irrigation, one point measurement of soil moisture (SM) is not representative, and many measurements are needed to interpret SM of the wettest zone beneath the dripper (Myburgh, 1996). To determine the influence of environmental and cultural conditions on vine water status, a sensitive physiological indicator that integrates both soil and climatic conditions is required in the application of regulated deficit irrigation (RDI) (Choné et al., 2001). Therefore, physiological indicators of plant water status have shown potential as accurate water stress indicators (Selles and Berger, 1990). Leaf water potential (ψ), and most recently, stem ψ, measured midday with a pressure chamber, have been proposed as standard parameters to determine plant water status for irrigation scheduling of fruit trees (Shackel et al., 1997).

Water deficits impair grapevine shoot growth (Smart and Coombe, 1983) to a point where differentiation of inflorescence primordia is affected (Buttrose, 1974). Excess irrigation could promote unwanted shoot growth to a point where light levels in the renewal zone limit bud differentiation (Carbonneau and Casteran, 1979). Bud fruitfulness or yield per bud depends on number of clusters initiated during the previous season, number of flowers developed early in the spring, number of berries set, and individual berry size. Most studies indicate that early water deficits have more inhibitory effect on bud fruitfulness than late season deficits. Early-season water stress affects both cell division and cell enlargement in the developing berry, thus decreasing berry size (Matthews and Anderson, 1989). Persistent water stress depresses bud fruitfulness through a reduction in the number and size of inflorescence primordia (Buttrose, 1974). Inadequate water supply at any stage during the growing season limits the production and the quality of the fruit, particularly between flowering and veraison (Peacock et al., 2000). A combination of warm temperatures, sufficient illumination of the bud, and absence of water stress are required for optimum initiation (Petrie and Clingeleffer, 2005). Environmental factors exert their influence on flowering by modifying the internal chemical composition of the plant, particularly the balance of endogenous hormones, and also via their impact on vine photosynthesis (Vasconcelos et al., 2009).

Berry size reduction might enhance the skin/pulp ratio, which provides a more abundant polyphenolic source (Peterlunger et al., 2002). This could be also true for white aromatic cultivars, which have most of their volatiles in the skin. Monoterpene concentration increased in Gewürztraminer vines with irrigation deficits imposed at veraison compared to those with deficits imposed at post bloom or lag phase (Reynolds et al., 2006). The volatile compositional differences in grapes induced by water status could directly affect aroma composition of the wines (Matthews et al., 1990). Under non-drought conditions, slight water stress seems to improve wine quality. Vine water stress has been reported to increase the concentration of grape aroma glycosides (Bravdo and Shoseyov, 2000). Glycosidically-bound aroma compounds are released during fermentation or ageing, and contribute to varietal aroma and wine quality. C_{13} norisoprenoids contribute to complex aromas, including berry, honey, and fruity in many white wines. Total concentration of all norisoprenoids in wines was highly related to vine irrigation and vintage (Qian et al., 2009).

Chardonnay is the most widely planted white *Vitis vinifera* L. winegrape cultivar in Ontario, exceeding Riesling, with a production of 11,304 t in 2013 (http://www.vqaontario.com). Applying irrigation to Chardonnay in Ontario early in the season but ceasing at different phenological stages showed an overall benefit on fruit composition, especially in very dry seasons (Reynolds et al., 2007). In the Niagara Peninsula, grapevines are usually confronted with drought conditions between fruit set (FS) and veraison (VRN), but often these conditions can extend into the fruit maturation period (Reynolds et al., 2007). The purpose of this research was to study the effect of different irrigation regimes and time of imposed irrigation on vine water status, yield components, fruit composition and sensory attributes of Chardonnay. It was hypothesized that applying deficit irrigation either at FS or VRN would improve fruit composition without significant change in yield, and with additional benefits of increasing the intensity of positive aroma and flavor attributes (varietal typicity). This study also endeavored to learn how variations in soil moisture (SM) at various depths could affect yield and fruit composition of irrigated grapes in a cool and humid region.

2. Materials and methods

2.1. Experimental design and plant material

The trials were conducted at Lambert Vineyards, Niagara-on-the-Lake, ON, (43°13′ N, 79°08′ W). The experiment was set up in 2005, in 13 yr old Chardonnay grafted to C3309 (*V. riparia* x *V. rupestris*) rootstock. Vines were spaced 1.5 × 2.4 m (vine x row) in north/south oriented rows and were trained to a Scott Henry system. Vines were irrigated using RAM® dripline (Netafim Inc., Fresno, CA) with a flow rate of 1.5 L/h and 0.6 m dripper spacing. A randomized complete block design was used with three blocks where each treatment replicate corresponded to a row, with outside rows used as buffers. Seven treatments were assigned randomly to each block, and 10 equally-distributed "sentinel" vines were chosen for data collection in each row. Treatments were as follows: control –no irrigation; 100%, 50% or 25% ET_c (replacement water lost through evapotranspiration) combined with an early start (irrigation begun at FS) and late start (begun at VRN). Soil series was Chinguacousy clay loam, a gleyed brunisolic gray brown luvisol with imperfect drainage (7–9 L/h), wilting point (WP) of the Ap horizon (0–27 cm) 13.3% moisture, field capacity (FC) 27.3% moisture, and bulk density 1.25 g/cm^2 in horizon A to 1.69 g/cm^2 in horizon C (Kingston and Presant, 1989). The vineyard was tile drained at a 60 cm depth in the middle of each inter-row space. Soil management consisted of mowed sod row middles with ≈ 1.0 m herbicided strips under the vines.

Water was applied weekly as prescribed through individual valves at the end of each row. First treatments were 100% ET_c and two RDI (50% ET_c, 25% ET_c) initiated at FS, which occurred in late June [24 June (2005), 30 June (2006), 21 June (2007)]. VRN treatments began 29 July (2005), 7 August (2006) and 28 July (2007). Due to frequent rainfall, only VRN treatments were applied in 2008 in the last 3 weeks of August. Volume of irrigation water to be applied weekly was determined according to the previous week's total ET_o calculated by the Penman-Monteith equation (Allen et al., 1998).