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Water Footprint, Productivity, and Wine Quality of Twenty Winegrape Cultivars Under Water Deficits in the San Joaquin Valley

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Project Summary

In recent years, deliveries of water for agricultural use in the San Joaquin Valley (SJV) have been reduced, or in some instances cut all together. Growers in the SJV would have the most potential to conserve water if the amount of irrigation water needed to produce a unit of product could be accurately measured.

Since 1980, the acreage of annual crops has decreased by 40%, while the acreage of perennial crops has increased 77%. Recent research has shown that perennial crops have a higher potential for water conservation. Also, it has been shown that yields do not decrease significantly under some levels of water stress. As trends in California agriculture shift away from traditional field crops, more detailed information is needed on the amount of water required to grow tree and vine crops.

Vineyards now account for nearly half of the total acreage of woody perennial crops. However, there is a lack of data detailing how much water is necessary to produce a ton of grapes. Similar in concept to the carbon footprint, the volume of water required to produce a ton of grapes is deemed the 'water footprint.' Knowledge of a vineyard's water footprint can help growers make better irrigation management decisions, effectively using less water to produce the same amount of fruit.

Our long-term goal is to identify red winegrape cultivars with lower water requirements than currently in production, and to develop irrigation requirements and strategies to minimize water use and maximize yield and quality for those cultivars. The overall objective we have for this project is to evaluate cultivar responses to water stress on a physiological level. It is our central hypothesis that cultivars respond differently to the same level and timing of water stress. We further hypothesize that wine quality to SJV can be improved through cultivar selection and water management.

The specific aims of this proposal are to:

1.) Impose water stress on various red winegrape cultivars and quantify blue water footprints of each cultivar.
2.) Measure physiological responses in vegetative and reproductive growth parameters.
3.) Make select wines to examine the effect of irrigation treatment and cultivar on wine quality.

This project addresses the need to generate detailed information on the amount of water to produce a specific agricultural product, and is pertinent to the California Institute of Water Resources' goal of developing science-based information on water issues. The outcomes of this research will be valuable in increasing knowledge of water use and fruit quality for specific cultivars, therefore allowing growers to apply a minimum amount of irrigation water to sustain profitable production levels.2

Introduction

Water is the linchpin of California's economic growth and development. The competition between urban and agricultural systems for regulated fresh water resources is increasing. This competition can be exacerbated yearly due to below average precipitation throughout the state coupled with a shrinking Sierra Nevada snowpack. It is well known that with less snowpack water storage, more precipitation will run off and put pressure on dams and levees (CDWR, 2009). A strain on this system would affect hydroelectric generation and lead to more frequent drought events (CDWR, 2009). Restrictions on irrigation water have already been implemented. For example, a reduction in pumping surface water has diverted water to the Delta and tributary rivers to maintain fisheries and wildlife habitats (Integrated Water Resources Plan, 2010). With freshwater becoming more limited, there is an urgent need for accurate information on the amount of water needed to produce agricultural products.

Trends in California agriculture show that more growers are shifting toward tree and vine crops, and away from traditional field crops (Sumner, 2013). Research has suggested that there may be greater water conservation potential in tree and vine crops since they are more highly coupled to the atmosphere than field crops (Fereres and Soriano, 2007). Vineyards constitute roughly 43% of all acres planted in tree and vine crops, or 847,000 of 2 million (California Grape Acreage Report, 2013). Previous work shows that one can increase water use efficiency (WUE) in a hot region in California via deficit irrigation without reducing yields (Grimes and Williams, 1990). However, there is little literature on grape water footprints, which is necessary to evaluate WUE. The ability to do so effectively would depend upon: (1) accurate measures or estimates of vineyard evapotranspiration (ET), (2) appropriate irrigation scheduling, and (3) knowledge of how fruit quality of specific cultivars respond to deficit irrigation.

The 'water footprint' of a crop is the amount of water required to produce an individual product. A crop's water footprint can be used as a metric to express water use efficiency in agricultural systems. It is usually expressed as volume of water per unit of product (i.e. m3 of water per ton of product) (Mekonnen and Hoekstra, 2011). The overall water footprint has been divided into various categories to include 'blue,' 'green,' and 'grey' water footprints. The blue water footprint is the volume of surface and/or groundwater used for consumptive water use of the crop, while the green water footprint is the volume of rainwater utilized for the same purpose. The grey water footprint refers to the amount of fresh water required to assimilate pollutants generated in the crop production process. The amount of irrigation water applied during the growing season would be classified as blue water, since the water was obtained from surface and/or ground water sources. Because the latter is of primary concern to California growers, this proposal focuses on blue water.

Plant reproductive processes are, in general, highly sensitive to water stress (Bradford and Hsiao 1982). Applying an environmental stress to the vine during floral initiation the year prior to flowering has shown to decrease flower number per inflorescence (differentiation) the following year. Matthews and Anderson (1989) demonstrated that flower development of Cabernet franc was dependent on vine water status; vines subjected to a water deficit before veraison (beginning of ripening stage) differentiated fewer flowers per inflorescence than did those vines receiving full irrigation or a water deficit after veraison. Moreover, the authors show that berries per cluster was the yield component most responsive to water stress. Because the water status of vines was different only after berry set, berries per cluster was interpreted as flowers per inflorescence (Matthews and Anderson 1989). Thus, the effect of early water deficits the first season inhibited floral primordia development and was carried over to the following year, reducing yield.

Much of the previous work in grapevine floral differentiation indicates that the role of the carbohydrate status of the vine plays an important role in its determination of yield potential. Also, the roles of environmental factors as external stressors have been examined in relation to inflorescence differentiation and flower formation. However, few studies have directly examined the response of grapevine floral initiation and differentiation to an environmental stress that alters carbohydrate reserves (Bennett et al. 2005; Dunn and Martin 2007) and none have investigated a broad range of genotypes.

It is widely known that reducing the plant-available water (by restricting irrigation) can be expected to reduce yield and increase WUE, but to also increase fruit quality of red wine grapes. The timing of water deficits also affects many of the vine responses to stress (Castellarin et al. 2007; Greenspan et al. 1996; Matthews and Anderson 1988, 1989) and the resulting wine sensory characteristics (Matthews et al. 1990). For example, early (pre-veraison) deficits have a greater effect on tannins than late deficits, whereas for anthocyanins (color) it is the reverse (Castellarin et al. 2011). Nevertheless, the studies that have established these phenomena were conducted in moderate (North Coast) climates and with common varieties such as Merlot, Cabernet Sauvignon, and Cabernet franc. This study aims to test whether those observations hold in a hotter, more arid climate (San Joaquin Valley; SJV) and with varieties specifically selected for potential adaptation to SJV conditions.

The overall objective of this project is to test the hypothesis that different red winegrape cultivars respond differently to the equally applied water stress. Specifically, this study will focus on the nature of those differences between different cultivars. This research will capitalize on an established cultivar trial at the Kearney Agricultural Research and Extension Center (KARE) to evaluate the effect of cultivar on the blue water footprint under different irrigation regimes. This work will also examine potential interaction effects with respect to various yield components, reproductive development, carbohydrate status, fruit chemistry (Brix, pH, TA) and wine quality (anthocyanins, tannins, total phenolics). Finally, this study will evaluate cultivars for drought tolerance and adaptation to SJV climate conditions for wine production.

Research Program

Methods

Vineyard Site and Cultivars. The study site is a 0.53 ha vineyard located at the Kearney Agricultural Research and Extension Center near Parlier, California (36° 48’N, 119° 30’W). The rootstock 1103P was planted in June, 2003 and the Vitis vinifera L. scions grafted May, 2004 at 3.05 x 1.83 (row x vine) spacing, for a total of twenty rows, each 48 vines in length. The vines were cordon trained and spur pruned. Twenty cultivars were field grafted in a pattern of twelve vines per experimental plot with four replicates. Cultivars were blocked across rows. The plot layout is a randomized complete block and comprised of four replicates with twelve vines per experimental unit within each experimental plot (12 vines in length). The cultivars (and clones) are:

Aglianico – 03
Cabernet Sauvignon – 08
Carmenere – 02
Cinsaut – 02
Durif – 03
Freisa – 01
Grenache noir – 515
Malbec – 06
Montepulciano – 02
Petit Verdot – 400
Refosco – 03
Souzão – 01
Syrah – 07
Tannat – 474
Tempranillo – 02
Tinta Amarela – 01
Tinta Francisca – 01
Tinta Madeira – 01
Tinto Cão – 04
Touriga Nacional – 02

Irrigation Treatments. The irrigation treatments will consist of: A. Early Deficit (ED) = no applied water until veraison and then irrigated at 50% ETc; B. Late Deficit (LD) = irrigated at 100% of ETc through veraison and then no applied water; C. Sustained Deficit (SD) = irrigated at 50% of ETc throughout the growing season. These irrigation treatments were imposed during the 2013 growing season. These same treatments will be imposed during the 2014 and 2015 growing seasons. The vineyard will be drip irrigated using two, 2 L emitters per vine. Emitters will be plugged or unplugged to impose the irrigation treatments. Inline (in the drip line) water meters will be used to quantify applied water amounts for determination of blue water footprints. Vineyard ETc will be estimated using the following equation: ETc = ETo * Kc, where ETo is reference ET and Kc is the crop coefficient. Reference ET will be obtained from the CIMIS weather station located at KARE. Variables measured and calculations used to determine daily ETo can be found in Snyder and Pruitt (1992). The seasonal crop coefficients will be those developed in this vineyard across seven growing seasons (Williams, L.E., unpublished data).

Vine responses to water deficits. Midday leaf water potentials (Ψl) will be measured as described by Williams and Araujo (2002) at regular intervals throughout the growing season for each cultivar listed above as a function of irrigation treatment. Stomatal conductance (gs) will be measured using a LI-COR 1600 steady state diffusion porometer at the same time. Diurnal measurements of both water status parameters will be conducted at key phenological stages. Prior to budbreak in 2014, carbohydrate status of vines will be measured by sampling basal cane wood of the three middle vines in each four vine replicate and quantified according to the methods described in Chow and Landhausser (2004). Flower number measurements will be taken at flowering according to the methods described in Bennett et al. (2005). Canopy development will be evaluated by measurements of percent shaded area according to Williams and Ayars (2005). Leaf drop will be quantified by counting missing leaves along selected shoots, and correlated with carbohydrate status. Pruning weights will be taken during vine dormancy.

Fruit and wine responses to water deficits. Fruit will be sampled at pea size, veraison and harvest to determine berry growth responses to water deficits. Veraison timing will be determined by quantifying the fraction of clusters/vine and berries/cluster with color. Blue water footprint of each cultivar (m3 applied water/ton of fruit) will be calculated at harvest as a function of irrigation treatment. Yield components of cluster number, berry weight and berries per cluster will be determined. At harvest, berries will be sampled and soluble solids, titratable acidity, pH, Harbertson-Adams assay of anthocyanins and total phenolics measured. Small lot wines will be made of selected cultivars as a function of irrigation treatments on the UC-Davis campus. The wines will be analyzed by Harbertson-Adams assay for anthocyanins and total phenolics.5

Notable Achievements

With increasing concern about the availability of water to SJV winegrape growers, more complete information is needed about the water use of different cultivars used in production viticulture. The experimental vineyard is established, well designed, and healthy. Irrigation regimes will be based in part on an estimated crop coefficient (Kc). Dr. Williams has been scheduling irrigations in this vineyard for the past seven years and has developed seasonal crop coefficients by measuring the amount of shaded area across cultivars and converting shaded area to a Kc using the technique developed by Williams and Ayars (2005). We have preliminary data that indicate a very high probability of success of finding cultivars with widely varying blue water footprints and responses to water deficits.

The three irrigation treatments to be utilized in this study were imposed last year (2013). Therefore, any carry-over effects of these treatments on the reproductive biology and carbohydrate status will be quantified the coming growing season. Yields were also measured last year as a function of both cultivar and irrigation treatment, and wines were made at the UC-Davis Pilot Winery. Initial data also show a wide range among cultivars in the responses of berry growth (size) and sugar accumulation across irrigation treatment and color and tannins across cultivars.

These data from one season indicate substantial differences among the cultivars in blue water footprint, vegetative growth, fruit growth, yield, and wine quality parameters. In the coming years, we hope to better elucidate the nature of the difference in drought response by cultivar. Ultimately, a tailored irrigation protocol will be developed per cultivar to maximize water use efficiency and wine quality in the San Joaquin Valley.

The Principal Investigators will disseminate the information obtained in this study by participating in grape industry meetings and those sponsored by the UC Cooperative Extension. It is anticipated that the results will also be published in the popular press and scientific journals such as Practical Vineyard and Winery and the American Journal of Enology and Viticulture.