Influence of Irrigation Strategies on the Photosynthetic Rate of Syrah

A Thesis
presented to
the Faculty of California Polytechnic State University,
San Luis Obispo

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Agriculture, with Specialization in:
Crop Science

By
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June 2010

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ABSTRACT

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Regulated deficit irrigation (RDI) is a common and useful practice for water conservation and improving grape quality. To attain better grape characteristics and wine quality, a substantial degree of irrigation stress is intentionally allowed to occur during the first part of berry formation and can continue until later into veraison. Understanding the effects of deficit irrigation on photosynthetic rates could be helpful in determining at what degree and duration a grower should perform this irrigation practice. The focus of this study was to determine the effects of using differing degrees of RDI in a vineyard located in Paso Robles, California (central coast region) on gas exchange of the Syrah variety. The target irrigation levels were set for each season at 75, 60, 45, and 30% E_{Tc} of a fully irrigated vine (100% ET). The 60% replication was considered as the control for this study, as it is the standard target ET rate for the vineyard where this study was conducted. A gas analyzer (LICOR 6200) was used to measure the overall rate of photosynthesis during two successive growing seasons (2004 & 2005). Measurements were taken from bloom through harvest and were compared among the four different irrigation levels. Along with overall photosynthetic rate, the leaf temperature, stomatal conductance, light level, and relative humidity were also measured. The results of the two year study were statistically compared through an analysis of variance (ANOVA) and analyzed for their significance. The results of the study showed that minor differences in the mean photosynthetic rates were found to occur during brief periods of the growing season. These differences ranged from 1-4 weeks and did not occur at similar times of the growing season. However, no statistical significant differences were found to exist when compared among the four irrigation levels for the entire growing season. Observed differences in canopy sizes indicated that irrigation amounts had affected the overall growth to some degree during this two year study. Several plant physiological measurements showed a significant difference in the measured gas exchange rates between sun exposed leaves and the shade leaves within the treatment area. A

significant correlation of the effect of leaf temperature on stomatal conductance was observed to exist in one of the irrigation treatments (45% ET) during this study. Other plant physiological measurements indicated that highly significant differences existed between the photosynthesis rate and leaf temperature. Photosynthetic rates were highly significantly correlated to leaf conductance, air temperature, and relative humidity. A significant difference of photosynthetic rates was identified to occur between stomatal conductance and air temperature. This study concludes that differential irrigation amounts on Syrah in the Central Coast region, specifically Paso Robles, have minimal effect on overall photosynthetic rate and does not fully support the anisohydric stomatal reaction that has recently been studied by plant physiologists working with this variety.

ACKNOWLEDGMENTS

I would like to acknowledge the individuals that were instrumental in my completing my graduate degree. First, my journey could have not begun without the help of my graduate committee. Dr. Keith Patterson is a critical part of my educational career. My relationship with Keith started over twenty years ago at Fresno State and expanded with my return to Cal Poly. His leadership and encouragement were the main reason I decided to complete this degree. Dr. Michael Costello was responsible for my interest in conducting research. Dr. Costello's sense of pursuing the question of why things work is something that has stuck with me throughout this portion of my education and career. Dr. Costello is the quintessential example of a great teacher. Also I would like to thank Mark Battany for stepping up to fill my third spot on my thesis committee on such short notice. His assistance in providing his knowledge and help with this research project would not have been possible without him. I would also like to thank the faculty and the staff at Cal Poly San Luis Obispo as a whole in helping me to complete this degree. I would like to thank the J Lohr winery and staff for the use of their vineyard in completing this study. I would also like to thank my many close colleagues for helping me complete this study. I would first like to thank Craig Macmillian. Craig is a very good and supportive friend whom I have the deepest respect for. Our discussions were often helpful in regenerating my interest in completing this study. Also I would like to thank Rick Loya and Mark Welch, both of whom were there to lean on for support and friendship. This thesis would not be complete without thanking my biggest supporters, my family. I would like to start with thanking my best friend and wife Kimberly. I remember discussing my dream of getting a graduate degree when we were first married. Your love, support, and encouragement were the most important factors in letting me have that dream. Also, I would like to thank my daughters Megan and Lauren for being patient and understanding with their daddy. There is not enough love that I can express in words that would come close to show how much I love my family.

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Chapter 1

Introduction

Wine grape growers strive to attain better wine quality. Their success is often tied to using growing techniques that enhance color and flavor characteristics of the fruit and ultimately the wine. Since 1960, the use of irrigation to influence overall vine growth has been researched (Vaadia, 1960). These early studies indicated that regulated irrigation can lead to significant changes in vine growth. Differential irrigation levels were also found to influence crop size and photosynthetic rates (Hardie, 1976). Further studies (Hardie, 1981, Smart 1974,) showed that irrigation influences were significant to stomatal control, berry size, and canopy size, with minimal loss of production. Later studies further analyzed the positive effects of reducing the amount of irrigation at specific times through the growing season (Jackson, 1993). With the introduction of drip irrigation, more precise irrigation amounts could be tied to evaporation and transpiration rates (ET) (Peacock, 1987). This allowed growers to apply only a small amount of water to meet plant demands and initiate some degree of deficit irrigation when needed. Research in the area of improving wine quality with the use of deficit irrigation increased and led to further research in the 1980's and 1990's in the United States, Israel and Australia (Hepner, 1985, Matthews 1989, McCarthy 1997).

Syrah acreage has increased dramatically during the last decade in California (CDFA 2007). Some growers had experienced weak vine performance and poor wine quality issues which initiated some research to begin to answer these problems (Stamp, 2004). Possible differences in the hydraulic architecture and the stomatal control of this variety have been recently researched (Schultz, 2003). The stomatal control of Syrah has been thought to differ when compared to other varieties, with a partial stomatal closure that occurs more frequently and for longer durations. These differences in the hydraulic architecture may lead to a near anisohydric situation in a severe drought condition. An anisohydric condition is defined as the inability of a plant to effectively control its water loss or avoid drought conditions when subjected to continuing drier soil conditions. This factor would likely impact the performance of Syrah vineyards and how they are managed when they are subjected to aggressive deficit irrigation. Due to the possible

differences in stomatal control of Syrah, the rate of gas exchange, overall photosynthetic rates or other physiological effects may be affected when subjected to differing degrees of deficit irrigation. The effect of this can be measured using a portable instrument called a photosynthetic measurement system (LICOR 6200) that measures the amount of CO₂ used for a given period of time. This rate can then be calculated using many factors that are involved with a plant's gas exchange. The ambient temperature, leaf temperature, stomatal conduction (external and internal), humidity, and CO₂ concentration are all used to calculate a relative photosynthesis rate, measured as micromoles of CO₂ per square meter per second (umol m⁻² / sec) (LICOR 1987).

Some growers in the Paso Robles area have limited experience with growing and vinifying the Syrah variety. These growers may not be aware of limitations or characteristics this variety may have when using regulated deficit irrigation over a long period of time. The direct effect of using limited water on the photosynthetic capacity and other physiological factors should be further investigated. This will benefit the growers and wine producers in the region growing the variety.

It would be important to learn more about the impact of physiological processes such as photosynthesis and how they function under different irrigation treatments and the direct effect it has on the gas exchange of Syrah. Also, growers will benefit from a better understanding of how this variety reacts to aggressive deficit irrigation practices when developing a comprehensive irrigation strategy for vineyards grown in the Paso Robles viticulture area.

To help identify the influence of regulated deficit irrigation in Syrah, several sub goals were investigated:

- Measure photosynthetic rates during the growing season of vines being irrigated at four different irrigation regimes.
- Compare different irrigation amounts on photosynthetic rate for different seasons.
- Determine the effects of anisohydric response of Syrah in the Paso Robles area.

My specific goal in this study is to measure the photosynthetic rates of vines being irrigated at four different rates. This will allow me to ascertain the effects of using regulated deficit irrigation on the photosynthetic rates of Syrah grapevines.

The Assumptions

1. Photosynthetic rates will be significantly different among the various treatments;
2. Overall gas exchange will be significantly different between the sun side and the shade side of the vine row; and
3. Stomata closure should follow the anisohydric model in this variety as stated in research;

Chapter 2

Literature Review

Beginning in the mid-1990s, a significant increase of vineyard plantings occurred in California, resulting in a total of 568,000 acres by the year 2000 (NASS, 2001). The main reason for the increase in vineyard planting was a constant and ever growing demand for California wine (Wine Scan, 2002). The Paso Robles growing region experienced a 40% increase in vineyard planting from 1997 – 2005 (CDFA, 2007). During this period of time, new varieties were introduced or expanded for use in these areas. Due to some climate similarities between areas of California and France, many Rhone varieties were planted with the express purpose of creating similar wine quality (Trowbridge, 1997). Syrah was one of the major Rhone varieties planted in California for this purpose. The Paso Robles growing region encompasses the area from the northern San Luis Obispo County to the Santa Margarita area located south of the city of Atascadero. This viticultural area contains over 26,000 acres of vineyards and as many different mesoclimates (PRWCA, 2008).

Background of Syrah

The Syrah variety has been thought to have been brought to the Rhone Valley, France, by the Roman Emperor Probus from the city of Syracuse in Sicily. It is thought that the Syrah variety was indigenous to this region (Macneil, 2001). Other experts have also noted that the variety may have originated in a region of Shiraz of what is now Iran (Robinson, 1986). The variety has several synonyms such as Schiraz, Sirac, Syra, Syrac, Sirah, Sereine, Shiraz, Marsanne Noir, and Balsamia. The differences in a common name are often due to the influence of the region or country where they are grown.

Growing Regions

The Rhone valley has been the premiere growing area for this variety. The Northern Rhone valley is known to be the “Cradle of the Syrah’ (Fanet, 2001). The region is known for its varied climates with the cooler region to the north and increasingly warmer weather as you move to the south. Wines that are produced in the northern portion of the

Rhone region produce delicate aromas and subtle tannins. The wine begins to produce different characteristics as it moves to the southern end of the region. The warmer southern region wines begin to have more aromas of black fruits and bolder and more powerful wines (Fanet, 2001). The Rhone valley extends from the city of Vienne south of Lyon, to just south of Avignon. The Rhone Valley viticultural region is divided into two distinct regions. The Northern region “Septentrionale” extends from Condrieu to St Péray. This region is home to many acres of Syrah. The southern region, “Meridionale”, stretches from Donzère to the Avignon areas. These regions have very distinct climates which lead to differences in wine styles (Norman, 1996). The soils in this region are mostly granite outcrops (John, 2005). Soils are mainly shallow and thin and have relatively low water holding capacities, lending to smaller and more color intense fruit (Wilson, 1998).

Australia is a major producer of the Shiraz (also known as Syrah) variety. Shiraz has been an important variety in Australia for over a hundred years. The winemakers of Australia have used this variety as a varietal and for blending. A majority of the premium Shiraz wines produced in Australia are grown in the Barossa Valley and the Hunter Valley wine regions (Robinson, 1994).

Central Coast

As of 2008, a total of 29,000 acres of winegrapes were planted in San Luis Obispo County and 26,000 acres of winegrapes are planted in the Paso Robles area (CDFA, 2007). In 2009, 2,671 acres of Syrah were being grown in San Luis Obispo County (NASS, 2009), which accounted for a 45 % increase since 1999 (NASS, 2007), and about 10 % of the total grapes produced in the Paso Robles AVA (PRWCA, 2007). The total acreage of Syrah in California had grown by roughly 33% since 1999, to a total of 18,489 acres in 2006 (CDFA, 2007).

Irrigation Strategy

Current irrigation practices used in wine grapes require a degree of irrigation stress to enhance wine quality (McCarthy, 1984). These enhanced qualities include increased color development, higher phenolics, and increased water use efficiency (WUE) (Dokoozlian, 1996, Davies, 1991). Water stress can be induced through the use of regulated deficit irrigation (RDI). This type of irrigation strategy was first investigated as a way of controlling vigor in apple, peach, and pear crops for the purpose of increasing the size of the fruit (Gowing, 1990, Mitchell, 1989). RDI reduces the berry size, which will increase the amount of skin to juice ratio, enhance anthocyanin development for better color and lower fungal disease problems (Hamman, 2000, Gulber, 1987). This irrigation strategy has been used mainly on red grape varieties to induce moderate irrigation stress at critical grape developmental periods (Smart, 1991). Growers using this irrigation technique can induce water stress that would reduce vigor, limit berry size, and reduce crop load (Esteban, 1999). This limits the amount of leaf area and could possibly decrease the overall photosynthetic rate. This irrigation strategy requires the grower to be aware of many different issues during the growing year. A grower must be able to correctly manage the current soil moisture status and apply adequate irrigation water to meet the vine needs and to achieve the wine quality goals (Coombe, 1992). A grower should monitor the plant moisture status by way of plant-monitoring and soil based tools in order for this irrigation strategy to work correctly (Williams and Trout, 2005).

Overview of RDI

RDI is a term given for the practice of regulating or restricting the amount of irrigation water a vine uses. The ultimate goal for RDI is to control the canopy and berry size to a point which is beneficial for wine quality, but while not negatively affecting vine health (Dry, 1996). By controlling the vegetative growth, the grower can allow the canopy to reach a sufficient level to mature the fruit, while excess canopy is reduced. Having the proper amount of leaf area is a critical component for using RDI (Smart and Robinson, 1991). Canopies having excessive growth will cause shading to the interior grape

clusters. This shading can cause lower juice color by 10–12 % in some cases (Prichard, 2000)

The use of RDI could be detrimental if it is used incorrectly or is not suited for a particular region. Severe moisture stress could result in a loss of leaf area, loss of production and a devigoration in the vineyard over time. Many plant physiological functions are impacted in varying degrees as a result of using RDI (Smart and Coombe, 1983), including stomatal conductance in the leaves, hormonal balance within the plant and a reduction of the overall photosynthetic rate of a vine.

Deficits at berry development

Grape berry weight can be affected by timed RDI (Hardie, 1976). A mild to moderate water stress applied during the latter part of bloom through the phase 1 (Fig. 1) period of berry development can limit berry size and vegetative growth by limiting the number of cells being developed (Matthews, 1989). This phase occurs after bloom and continues for four to six weeks and berry growth is by cell division. Withholding water at this time will result in a decrease in the number of cells and reduces the overall berry size (Ojeda, 2002). The reduction of berry size ultimately lowers the skin to pulp ratio and may improve wine quality (Ginestar, 1998).

This decrease of the skin to pulp ratio allows a higher percentage of the skin to contact the pulp, which serves to bring more color into the wine must. Grape skins contain the color pigments called anthocyanins, which ultimately make up the finished wine color (McCarthy, 1997). In grape berries, almost all color is in the skin and in a few layers of cells just below the skin.

Berry Maturity

Bloom *phase I* *phase II* *phase III*

(Berry growth increasing --→)

May August October

Figure 1- Effect of RDI on vegetative and berry growth of *Vitis Vinifera*

(Coombe and McCarthy, 2000)

Physiological changes within vines

During deficit irrigation, several physiological changes occur within the vine. These changes may be a gradual or an immediate response to the affects of water stress. For most plants, the onset of water stress brings a change of turgor pressure (Hsiao, 1973). As water stress increases, most plants begin to alter key metabolic processes that lead to a reduction of growth (Reid, 1985). This reduction of growth helps to increase and stimulate some viticultural responses for wine quality (Smart, 1974). These changes include stomata closure, an increase of abscisic acid, and a reduction of the transpiration rate (Chen and Gallie, 2004).

Differences in hydraulic architecture

The conductive tissues in plants have been found to react differently under fluctuating soil moisture or drought conditions. Plants have developed different stomatal reactions based on their relative genetic and environmental origins (Borel, 1997). Based on the

stomatal reaction, plants have been divided into two separate ecological classifications, anisohydric and isohydric stomatal (Stocker, 1956). Sunflower (*Helianthus annuus*) and barley (*Hordeum vulgare*) have been widely considered as examples of an anisohydric class of plants (Tardieu, 1996). Plant species such as cow pea, poplar, and maize are considered examples of isohydric stomatal control (Bates, 1981). Isohydric plants can experience higher leaf water potential by closing stomata completely while reducing the plants' carbon fixing ability (McDowell, 2008). In these cases, the plants are able to overcome the onset of severe drought, by conserving water, increasing water use efficiency, and avoiding total cavitation by way of the near total closure of the stomata (Poni, 2007). Anisohydric plants are defined as plants that experience decreasing leaf water potential as environmental demands continue to increase (Poni, 2007). In these plants, the stomata are less sensitive to drought conditions and do not completely close during high demand periods. This results in the plant continuing to exchange gas and transpire water vapor. This condition allows for little or no help for the plant to avoid complete hydraulic cavitation in severe drought conditions (Tardieu, 1997). Recent studies have indicated that not all grape varieties respond the same when dealing with drought conditions. Studies have indicated that Syrah has a mild stomatal response when experiencing drought conditions (Schultz, 2003).

As photosynthesis occurs in plants, O₂ gas and water vapor are released through small the stomata (Raschke, 1975). Grapevines varieties differ in stomatal behavior, stomatal size, and these can also be influenced by growing conditions (Smith, 1992). These varietal differences may have been associated with the geographical area of their origin. In researching this topic, the variety Grenache is used as an example of one from a Mediterranean origin, while Syrah was used as an example of one from a Mesic climate (Tardieu, 1998). These contrasting environments (warm and dry vs. cool and humid) are thought to have developed plants that response differently to drought conditions. Researchers have demonstrated that the Grenache cultivar attained near isohydric behavior when nearing drought conditions (Schultz, 2003). Grenache was proven to show that leaf water potential did not decrease below the minimum leaf water potential of a well watered plant. However, the Syrah cultivar behaved as an anisohydric plant in

which the leaf water potential decreased significantly below the minimum leaf water potential of a well watered grapevine. This led researchers to conclude that differences in the architecture of the conductive tissue were found to be a reason for the differences in the regulation of the hydraulic conductance (Schultz, 2003).

Stomatal control

There are many types of stimuli that affect stomatal movements. Factors such as light, wind, humidity and drought conditions influence the way the stomata open and close (Sheriff 1979, Schulze, 1986). The reaction of the stomata can also be influenced by leaf age, internal CO₂ concentrations, hormonal equilibrium and previous growing conditions (Blackman 1985, Thomas, 1976). In vines, row direction can influence the amount of stomatal control and gas exchange on vine vigor (Cuevas, 2006). As a primary action, CO₂ is taken in and water vapor and O₂ are simultaneously exchanged through these openings. The surrounding guard cells of the stomata open to allow CO₂ to enter as photosynthesis is occurring during the day. These openings are critical to allow water vapor to be released as the vapor pressure deficit (VPD) and other factors increase within the plant. The amount of water vapor lost during the day depends to some degree on the ambient temperature. This is due to the difference of pressures from the outside temperatures and the internal pressure. The driving force of water flow is the passive hydrostatic absorption caused by transpiration. Movement of water through the plants' xylem occurs as an action of cohesion within the xylem of the grapevine. As a plant undergoes increased water stress, the effort it takes to move water within the xylem tissue increases. Degrees of plant water stress have been defined as high (< -1.5 MPa), moderate (-1.2 – -1.5 MPa) and low (> -1.2 MPa) (Hsiao, 1973). The critical point at which stomata closure is induced for many grapevine varieties is at -1.3 MPa (Loveys and Kriedman, 1973); the internal pressure or water potential will build until approximately -1.5 MPa. At that point, the cohesion of the water stream begins to be disrupted and will cavitate within the xylem as the internal pressure increases further. This causes the plant to cavitation bubbles to form which breaks the water flow through the plant. This can impact the vigor of the plant and, over time, cause death if insufficient soil moisture continues.

The volume of CO₂ gas exchanged through the stomata can be correlated with the degree or level of water stress (Stoddart, 1980). As water stress increases, the stomata close to conserve water loss and in turn decreases the amount of CO₂ entering the plant. This results in a decrease of the photosynthetic rate and a gradual loss of vigor, growth, and production (Grimes and Williams, 1990). Grapevines that undergo repeated water stress can cause a progressive decrease in the overall threshold leaf water potential for stomatal closure (Thomas, 1976). Reactions of the stomata to drought conditions can be affected when continual water stress is experienced. These reactions are due to an increase of abscisic acid (ABA) in the root system and xylem (Blackman, 1985, Gowing, 1990). Gradual water stress allows plants to respond to these conditions by osmotic adjustment (Turner, 1986). This action has been identified to occur in grapevines growing in semiarid conditions (During and Loveys, 1982).

Hormonal influences

The process of conserving water in plants is not simple and involves many different interconnecting bioprocesses. These bioprocesses and their effects are not universal to all plant species, including grapevines. Phytohormonal changes within the plants may act as metabolic messengers at the onset of a decrease of water potential (Reid and Wample, 1985). Gibberellins, auxins, ethylene, cytokinins, and abscisic acid (ABA) have all been investigated for their primary and secondary effects on stomatal control (Raschke, 1975). These plant hormones have been thought to act as interactions in some degree to affect stomatal opening and other plant responses (Drury, 1969).

Abscisic Acid (ABA)

Abscisic acid (ABA) has been found to have a greater effect upon stomatal closure and control than most other plant hormones (Dodd, 2003). It also has an important role in cell division, seed maturation, seed dormancy, and germination (Finkelstein, 2002). The concentration of ABA in grapevines can be stimulated with very little water stress and is redistributed through the plant body. This distribution occurs through the vascular

system of the vine. Alkaline xylem pH can promote the retardation of ABA catabolism and will store it into the leaves. This action leaves a higher concentration to flow into the guard cells and helps to maintain adequate turgor pressure during these drought periods (Sauter, 2001). The concentration of ABA will continue to increase and continue to build as the internal water potential decreases (Pierce and Raschke, 1980). This continued buildup of ABA is controlled via changes in the turgor pressure within the plant (Hsiao, 1971).

The inhibition of overall grapevine vigor could be achieved by the manipulation of the plants' turgor pressure (Souza, 2005). The lack of photosynthetic material can be attributed to the partial closure of the stomata (Hsiao, 1973). During moderate water stress, hormonal substances are created within the root system of grapevines (Loveys, 2000) and affect the overall growth. ABA is created as a response to water stress (Loveys, 2000). As concentrations of ABA increase, they signal for the closure of the guard cells surrounding the stoma as a function of water conservation (Gowing, 1990). The ABA is moved out of the root system where it is produced and is spread throughout the plant via the conductive tissues during transpiration. These concentrations of ABA continue to be present as long as the plant is under irrigation stress (Loveys, 1984). Gradients of ABA concentrations tend to be higher in the apex of the grapevine canes than in the lower nodes in grapevines (Soar, 2004).

Cytokinins

Cytokinins play many roles in plant growth from seed germination, root, and shoot development and the opposition of leaf senescence and pathogen invasion (Sakakibara, 2006). Its role in promoting stomatal opening and insensitivity to ABA concentrations has been shown to occur in plants (Bradford, 1983, Wilkinson, 2002). Cytokinins are sourced in the root system and are delivered to the xylem when the onset of water stress begins. The concentrations of cytokinin will begin to drop within the xylem fluid (Itai and Vaadia, 1965) and continue until the soil moisture has been replenished (Davies, 2002). These decreases can occur very quickly within some plant species. In grapevines, the change in the amount of ABA and cytokinins is directly influenced by water stress.

As water stress continues, the amount of ABA will continue to increase while the cytokinin concentrations decrease. In some plants, the concentration of cytokinin will reestablish near normal levels within 15 minutes of having irrigation given (Browning, 1973). The ratio of ABA to cytokinin can change significantly during the irrigation cycle of a grapevine (Stoll, 2000). The continued high ratio of ABA to cytokinin concentrations have been identified as having a direct influence on shoot development in grapevines (Dry, 1996). This influence will likely be advantageous for canopy management that allows for the increase of light infiltration to grape clusters leading to the improvement of wine quality.

Gibberellins

Gibberellins (GAs) are partly responsible for plant development and the acceleration of many processes such as seed germination, stem elongation, growth, leaf expansion and seed development (Sun, 2004). They have been identified as having a role in promoting stomatal development and epidermal cells in some plant species (Saibo, 2003). In response to water stress, the role of GAs is not universal among all dicots (Aharoni, 1997). Their importance in stomatal control is less understood than other plant hormones. Recent studies have shown that exogenous gibberellin applications have little or no effect on stomatal conductance in *Arabidopsis* (Tanaka, 2006). This may indicate that gibberellins could not be as critical to water stress avoidance as other phytohormones in grapevines.

Auxins

Auxins are a class of plant hormones that consist of indole-3-acetic acid (IAA) and other related molecules that have the ability to induce plant responses similar to IAA (Christian, 2008). Auxins are associated with promoting cell division, cell elongation, vascular tissue differentiation, stem elongation, and apical dominance (Kepinski, 2007). Endogenous levels of Auxins following water stress have not been clearly identified or are contradictory in many plant species. Research in squash and cucumber species has shown an increase in IAA following a period of water stress in the leaves and hypocotyls (Sakurai, 1985). However, a decrease in IAA was identified to occur during the early

seedling stage when progressively more water stress was given (Pustovoitova, 2003). Other plants, such as grapevines and tomato, show no significant change in IAA accumulation in response to water stress (Schultz, 2003)

Chapter 3

Materials and Methods

The experiments were conducted during a two year period from 2004-2005. The block used for the study consisted of a 10 year old planting of Syrah clone 6 grafted to a 420A rootstock. The vines were planted on 3.05 x 1.82 meter (10 x 6 foot) spacing, east – west row orientation, trained to a unilateral cordon two wire trellis system, and drip irrigated. The study site was located at the Seven Oaks vineyard in Paso Robles, CA. Four irrigation treatments were arranged in a randomized block design (Appendices, table 5) Treatments were: 30 % of Etc (50 % of control), 45% ETc (75% of control), 60% ETc (100 % of control) and 75% ETc (125% of control) the grower's normal irrigation pattern and the growers targeted canopy size of 60% ETc. Drip emitters were placed at each treatment so that a constant percentage of the treatment amount was given. The emitters were arranged in each treatment as follows; Control (2 * 2 liter), 125% (1* 2 liter and 1 * 3 liter), 75% (1* 3 liter and 1* 2 liter) and 50% (1 * 2 liter). Treatments were replicated four times in plots of three rows wide by 16 vines long. Measurements were made from the middle row while the two outer rows served as a buffer. Gas exchange measurements of the leaves were performed from bloom to harvest during the two year study. A total of 12 different vines were measured in each of the treatments during each data collection period. The leaf measurements were made using a gas analyzer (LICOR 6200, Lincoln, Nebraska).

The protocols for the measurement were used on the first fully expanded leaves at the first spur location on the measured vine, from both the sun and shade side (north/south) of the rows. Weekly measurements began at the daily maximum photosynthetic potential (solar noon) from four vines in each plot. The collected data from the two year study was statistically transformed (log transformation) and prepared for an analysis of variance (ANOVA), using a statistical computer program (Minitab 15 version 15.1).

Gas exchange analyzer – LICOR 6200

This instrument consisted of three main components: the leaf chamber, the IRGA (infrared gas analyzer) and a flow valve. The leaf chamber allowed for the simultaneous measurement of air and leaf temperature along with the relative humidity of a respiring leaf. A constant flow of air was pumped through a chamber which circulated it to the analyzer for the determination of the change of CO₂ concentration. A flow valve was used to divert a fraction of the air back through a desiccant for the purpose of maintaining a steady humidity level. The infrared gas analyzer (IRGA) was used to determine the absolute value of the gas exchange.

During the measuring of the respiring leaf, when the CO₂ within the air tight chamber decreased the net exchange of the leaf and atmospheric CO₂ levels were calculated along with several other factors such as leaf area (cm²), leaf temperature (Celsius) and stomatal conductance (umol m⁻² sec)

Applied irrigation

Irrigation amounts were scheduled by the J Lohr vineyard management and used in part by weekly crop evaporation (ET_o) calculations supplied by a nearby weather station (PRWCA PR1-J Lohr vineyard). The crop coefficients (K_c) used in the irrigation calculations used rates were based on a 3.048 meter (10 foot) spacing sprawl trained canopy (Williams, 2001). The amounts listed in Table 1 are calculated amounts based on emitter output and calculated crop needs listed by the vineyard management. An estimation of the starting soil moisture was estimated at the time of bud break for each season of the top 0.609 meters (2 feet) of soil. This was performed to find if the soil moisture was at field capacity prior to plant demand. The estimations (Table 1) were made using a hand auger, making a judgment of the soil moisture at that time. The soil moisture was estimated through feeling the soil moisture and was determined to be drier at the start of 2004 than in 2005. The difference may have come due a wetter 2004 winter that helped to refill the soil profile. Sap flow measurements taken by Mark Battany (UC extension) suggested that differences in overall water transpired between the treatments, with drier treatment transpiring less water. The sap flow measurements were

part of research study being performed by Mark Battney during the same time as this study. The sap flow sensors were placed on three representative vines in each of the treatments. A data logger stored the information and was downloaded periodically. Sap Flow sensors have been used in several types of plants species to determine the water status (Ginstar, 1990). Sap Flow sensors measure the velocity of the sap in real time and convert it into a volumetric rate. Two stainless steel Teflon coated wires are inserted into transpiration flow of the vine within the trunk area of the vine. The probe needles measure the temperature difference (dT) between the heated needle and the sapwood ambient temperature below. The dT variable and the maximum dTm at zero flow provide a direct conversion to sap velocity (Dynamax, 2010).

Table 1: Seasonal irrigation amounts applied to treatment

	75%	60%	45%	30%	Estimated soil moisture (Bud break)
	Treatment	(Control)	Treatment	Treatment	
2004	300	240	180	120	90%
2005	329	263	219	132	100%

1) Calculated gallons per year applied by grower

2) Estimated available water prior to bud break

Results

Photosynthetic rate

The photosynthetic rate during the two year study was higher in the 2005 season than in 2004. The photosynthetic rate for 2004 ranged from 2.31-2.60 ($\mu\text{mol}/\text{m}^2/\text{sec}$) with an average photosynthetic rate of 2.5 $\mu\text{mol}/\text{m}^2/\text{sec}$ for the year. The photosynthesis rate for 2005 ranged from 2.30- 3.16 $\mu\text{mol}/\text{m}^2/\text{sec}$ with an average rate of 2.75. The accumulated average for 2005 was 0.245 ($\mu\text{mol}/\text{m}^2/\text{sec}$) higher on average than in 2004 (Fig. 2).

Figure 2- Photosynthesis rates compared for 2004 and 2005 season for all treatments. St. Dev. (+-) 0.17

Evapotranspiration rate (ETo)

The evapotranspiration rate (ETo), which is the sum of soil evaporation and plant transpiration, peaked in 2004 on June 10 with 204.98 mm (8.07 inches) and decreased until August 28 (Fig. 3). The average ETo rate for 2004 was 184.91 mm (7.28 inches) during the growing season. ETo rates ranged from 204.98 mm (8.07 inches) to 173.23 mm (6.82 inches) during the sampling period of June through October. The photosynthetic rate during this period generally was consistent through the season. The photosynthetic rate never increased over 2.6 $\mu\text{mol}/\text{m}^2/\text{sec}$ during the greatest ETo demand that occurred during the first weeks of July. In the 2005 growing season, the ETo ranged from 107.70 mm (4.24 inches) in May to the highest rate of 7.70 inches in mid July (Fig 4). Rates ranged from 180.34 mm (7.10 inches) to 171.70 mm (6.76 inches) during the sampling period. Photosynthetic rates were highest at the peak ETo that occurred during the latter part of June and the first week of July. The photosynthetic rate climbed to the highest rate of 3.16 $\mu\text{mol}/\text{m}^2/\text{sec}$ during this period. Average weekly ET rates for the entire 2004 and 2005 seasons can be found in the appendices (Table 2).

Figure 3– Total amount of gas exchange rate for 2004 in all treatments compared with ETo
St. Dev. (+-) 0.2

Figure 4 – Total amount of gas exchange rate for 2005 in all treatments compared with ETo
St Dev. 0.35 (+-)

Photosynthetic rate compared to treatment

The results of the two year study showed the 45% of ETo treatment as having the highest photosynthetic rate and the 30% treatment having the second highest rate, when compared to the control (Fig. 5). An ANOVA was calculated based on the four irrigation treatments (Appendices A-5). The results of the ANOVA confirmed that no significant difference ($F=0.024$, $df = 3$, $1,214$ $P=0.064$) were found to exist among the different irrigation amounts during the two year period.

Figure 5—Average photosynthesis rate ($\pm$ standard deviation) compared with treatments during the two year period. St Dev. 0.35 (+-)

Photosynthesis rate compared to air temperature

The photosynthesis rate of the two years of data was compared with the measured air temperature. The temperatures ranged from 15 – 48 Celsius (73-114 F). These results were statistically analyzed to determine the correlation of these two factors.

Photosynthesis rates appeared to keep increasing as the air temperatures increased. A scatter plot with a linear regression line was performed to determine the correlation (Fig. 6). The statistical analysis determined an $r^2 = 0.021$. An ANOVA was performed for the relationship of air temperature on photosynthesis rate ($F = 26.59$, $df = 1, 216$ $p = 0.001$) (Appendices, table 3). The ANOVA suggested that these factors were highly significant ($p < 0.0001$) when compared to each other.

Figure 6 - Regression Analysis: Photosynthesis rate vs. Air temperature in Syrah grapevines ($y = 1.48 + 0.046x$, $p < 0.0001$)

Photosynthesis rate compared to leaf temperature

A comparison of the measured leaf temperature and the photosynthesis rate for the four treatments was examined to find if any correlation for these two factors were found over the two year study. Averages for leaf temperatures ranged from 22 to 46 Celsius (73 – 114 Fahrenheit) over this two year period. These temperatures were slightly lower than the ambient air temperatures. A linear regression of the two years of data was calculated and yielded an $r^2 = 0.027$ (Fig. 7). The results of the ANOVA ($F = 33.76$, $df = 1, 1,216$ ($p < 0.001$)) (Appendices, table 3) showed that the relationship of leaf temperature on photosynthesis rate was shown to be highly significant ($p < 0.0001$)

Figure 7 - Regression Analysis: Photosynthesis to Leaf Temperature
($y = 1.35 + 0.045x$, $p < 0.0001$)

Photosynthesis rate compared to leaf conductance

The photosynthesis rate was compared to the leaf conductance. Results indicated that the 45 % irrigation treatment had a near identical rate as the control treatment. The other two treatments had slightly lower rates than the control. The 75% ETo treatment had the lowest stomatal conductance. Rates for leaf conductance ranged from 0.09975-0.10982 mol m² sec over the two year study. A linear regression was performed from the data that was acquired for the two year study (Fig. 8). The statistical analysis determined an $r^2 = 0.122$. An ANOVA was calculated for the relationship of conductance and photosynthesis rate during the two years worth of data ($F = 168.30$, $df = 1, 1216$) (Appendices, table 3). The results of the ANOVA indicated a highly significant relationship ($p = <0.0001$) existed for these two factors.

Figure 8 - Regression Analysis: Photosynthesis vs. Conductance in Syrah Grapevines ($y = 1.51 + 10.5x$ $p < 0.0001$)

Conductance compared to air temperature

A comparison of the stomatal conductance and the relationship of air temperature (ambient temperature) were calculated (Fig. 9). These results indicate that increasing temperatures led to a reduction of leaf conductance. This confirms that a decrease in conductance as a response to higher temperatures is occurring and there is a reduction of the photosynthesis rate. An ANOVA was calculated for the relationship of conductance to air temperature during the two years of data. The results of the ANOVA showed a highly significant relationship ($F = 47.18$, $df = 1, 1,216$ $p = <0.0001$) existed between factors. A linear regression of the two years of data yielded an $r^2 = 0.0218$.

Figure 9- Regression Analysis: Conductance compared to Air Temperature ($y = 0.170 + -0.00178x$, $p < 0.0001$)

Photosynthesis rate compared to relative humidity

Photosynthesis rates were compared to the relative humidity that was measured during this study. The measured relative humidity during the two year study ranged from 42.2 – 45.52 %. A linear regression was performed for the data collected (Fig. 10) of the relative humidity and the photosynthesis rate. The statistical analysis indicated an r^2 of 0.010. A calculated ANOVA of the relative humidity and photosynthesis rate indicated a highly significant relationship ($F = 135.17$, $df = 1, 1,216$ $p < 0.0001$) (Appendices, table 3). This indicates that the photosynthetic rate increases as the relative humidity increases.

Figure 10- Photosynthesis Rate compared to Relative Humidity
($y = 0.45 + x \cdot 0.511$, $p < 0.0001$)

Stomatal conductance vs. leaf temperature when compared to irrigation treatments

A statistical analysis was performed to find if differences existed among different irrigation treatments and the measured leaf temperature compared to the stomatal conductance (Fig. 11). The results indicated that stomatal conductance decreased as the leaf temperatures increased. These results would be considered typical of other plant responses as a condition to warm temperatures. The results of a regression analysis comparing the control (60%) to the other three treatments found that no significant differences existed for the 75% and 30% irrigation amounts when compared to the measured leaf temperature. However, the 45% irrigation amount was shown to have a significant difference ($p=0.045$) of the leaf temperature (Appendices, table 3). This indicates that the rate of conductance at the 45% treatment significantly different than in the other treatment levels when compared to the control.

Figure 11 - Regression analysis - Stomatal Conductance vs. Leaf temperature compared to treatment.

$$y = 1.63 - 0.0449 (75\%) - 0.00691 (40) + 0.0068 (30)$$

75% = $P < 0.263$
 45 % = $P < 0.045$
 30% = $P < 0.852$

Regression equation = $- 1.63 \text{ cond.} - 0.0449 (75) - 0.0691 (45) + 0.0068 (30)$
 $- 0.0106 \text{ leaf temp}$

(75) $P = 0.263$
 (45) $p = 0.045 *$
 (30) $p = 0.852$
 * Significant

Rowside comparison

The rowside in each treatment was measured to determine its affect of the photosynthesis rate. Results of the accumulated gas exchange rates for the sun and shade canopy sides (south / north) were found to have significant differences between the rowside for the two year study ($F=22.08$, $df= 1, 1,209$ $P= 0.0001$, Fig. 12, Appendices, table 3). The rates for the southside were higher than the northside in both of the years.

Figure 12-Comparison for Photosynthesis rates of Syrah during the 2004 and 2005 seasons

The 75% treatment showed the greatest difference of the photosynthetic rate when compared between years. The 45% irrigation treatment (south) had a significant difference in the photosynthetic rate between the 2004 and 2005 seasons. The remaining treatments were all found to have very similar rates for the two years when compared to row side and irrigation amounts.

A general linear model was performed to determine if any statistical error was inherited between the sets at this site (Appendices, table 4). The results of the GLM demonstrated that no significant differences existed between the sets ($F=0.66$, $p=0.577$).

2004

The mean photosynthetic rate show that the south side of the vine row (sun exposed) had some differences in photosynthetic rates among the treatments that were compared to the control (Fig. 13). The 75% and 45 % treatment had higher rates during the post bloom period through the middle of verasion for the north side. However, the 30 % treatment finished the season with a higher photosynthetic rate than the control. The results of the north side of the plant (shade) generally had rates that were less volatile than the south side rates.

Figure 13 Comparison of rowside of photosynthesis rate replications 2004

2005

The north side photosynthetic rates readings (shade side) indicated that little differences in the photosynthesis rate occurred during the early part of berry sizing (Fig. 14). However, differences were identified later when the photosynthesis rates peaked at veraison. All of the treatments were found to have a decrease in the overall photosynthesis rate as harvest approached. Both sides of the canopies had very similar trends in photosynthesis rate during the data collection period of the season.

Figure 14- Comparison of rowside of photosynthesis rate replications 2005

Discussion

The data presented in this study demonstrated that using deficit irrigation does not significantly affect the photosynthetic rates of Syrah vines. In addition, the results of the study did not conclusively show that Syrah expressed a true anisohydric growing characteristics as was reported by Schultz (Schultz, 2003). The photosynthetic rates measured for the year and for each of the irrigation treatments were found to have minor differences in the mean gas exchange rates, but were not considered significant within the range of the prevailing soil moisture. The 45% treatment had higher photosynthesis rates during the study as compared to the control and to the other treatments. The 45% treatment photosynthetic rate was also higher than the well watered treatment (75%). This difference may be due to a specific response of this variety that is triggered during these soil moisture conditions. These reported photosynthetic rates were similar but not exact to the measured photosynthetic rates that Schultz (Schultz, 2003) reported for water stressed vines in his study. However, some significant differences in photosynthetic rates were found to occur among the irrigation treatments during small periods of the season which were not as apparent if viewed for the entire season. These differences were not consistent throughout the growing season or from year to year. This result would indicate that more responsive stomatal control occurs as soils dry for this variety which does not fully support the anisohydric condition that previous studies stated (Schultz, 2003) but suggest that an isohydric effect may be occurring. However, some of the differences in the results may be in part to differing study methods. Schultz based his conclusion of leaf water potential using a pressure chamber with vines having different rootstocks which may explain some of the differences. His technique used excised leafs and shoot nodes to help determine hydraulic conductance between two varieties (Syrah and Grenache) to determine if differences occurred between the two varieties hydraulic architecture. These different methods may have resulted in slightly different results and conclusions. This was performed only to establish that difference in growth was affected by differences in stored soil moisture and the applied seasonal irrigation amounts. Readings of sap flow measurements (Appendix, table 2) from an accompanying study suggest that an effect of the treatments on vine growth may have occurred and may correlate with stomatal conductance functions. Estimated soil moisture made during the

beginning of each season did confirm that the soil was not at field capacity at the start of the 2004 growing season, but was at field capacity at the beginning of the 2005 season. A high rainfall dormant season that occurred during the winter of 2004 helped to increase the soil moisture for the start of the 2005 season. This may help to explain the differences in the overall higher average measured photosynthetic rates for 2005 as compared to the previous year.

Rates of gas exchange for the sun exposed and shade side rows were examined and confirmed to have significantly different gas exchange rates during the term of this study. The results of this study confirmed that the row direction had a favorable affect for increasing the photosynthetic rate when exposed to direct light in this variety. These results are similar with other studies that showed higher gas exchange rates on sun exposed rowside and photosynthetic rates of a defined isohydric variety (cv. Tempranillo) (Cuevas, 2006). The Cuevas study utilized several instruments to collect the data for his study. A steady state porometer was used to take simultaneous measurements of the leaf temperature relative humidity. A portable IRGA system (LICOR 6400) was used together to gather measurements of gas exchange. This instrument is similar to the instrument used in this study with the exception of a newer model used in Cuevas study. In comparing the assimilation of CO_2 rates and stomatal conductance taken at similar times of the day (15:00 h) resulted in near identical trends as to the results found in this study. Cuevas also concluded that an increase of photorespiration likely occurred at temperatures of 22 to 30 C. Photorespiration occurs when Rubisco is favored over its carboxylase activity which results in a net loss of carbon. At this temperature, photorespiration would have an increase 32 – 45 % depending on the variety. A majority of the readings were taken during this study ranged from 22 – 46 C and where taken at solar noon which is the warmest time of the day. I would surmise that these temperatures had some impact the measured photosynthetic rate in this study. I would conclude based on the results found in this study that the Syrah variety reacts more similar to known isohydric varieties with respect to higher photosynthetic rates when exposed to direct sun on its canopy. But as the temperature increase, the photosynthetic rates tend to flatten out and the carbon fixing ability begins to stabilize. This may explain the lower

photosynthetic rates that were experienced in this study as compared to studies researched for this study.

The data from the study did confirm that several other plant functions were significant to the photosynthetic rate of Syrah. An earlier study (During, 1987), showed that relative humidity impacted the photosynthetic rates of *V. vinifera* when subjected to drought conditions or long periods between irrigations. The results of the study showed that the overall photosynthetic rates were greater in higher relative humidity conditions.

Inversely, as drought conditions increased the photosynthetic rates decreased as well. In this study, the relative humidity significantly increased the photosynthetic rates for Syrah. Based on this, I would speculate that Syrah based on its' anisohydric background would do better in less arid areas than Paso Robles. Regions of the central coast that experience higher relative humidity would likely provide a better growing environment for this variety. However the data collected during this study indicated that the photosynthesis rate still continues to occur even though the climate in Paso Robles is not as conducive to maximum growth. Some benefit may be gained for growing this variety if additional management practices are instituted. One means for increasing the relative humidity would be to add a mister within the canopy area an increase the humidity and lower the leaf temperatures to within the more desired ranges. This action may provide the near ideal condition for which this variety was developed. These misters would only be applied when the relative humidity and temperatures reached a predetermined range. Other considerations such as overall water usage, increased disease pressures, and benefits to wine quality should be researched prior to the institution of this proposed practice.

Stomatal conductance was identified as having a significant effect on the photosynthetic rate of Syrah during this study. As more negative leaf water potentials are experienced, photosynthesis rates will decrease (Blackman, 1985, Schulze, 1986). During this study the stomatal conductance rates ranging from 0.09975-0.10982 mol / m² /sec were reported for the two year study. These rates are much less than the 0.5-24 mol / m² /sec, During reported in Syrah in his 1987 study. The photosynthetic rates taken for this study

were also less (2.30- 3.16 $\mu\text{mol} / \text{m}^2/\text{sec}$) that During reported photosynthesis rates (assimilation) of 10.5 $\mu\text{mol} / \text{m}^2/\text{sec}$ with no water stress and decreasing to 2.8 $\mu\text{mol} / \text{m}^2/\text{sec}$ at maximum water stress for (cv. Riesling) grown in a controlled environment. This would lead me to assume that Syrah studied in this project did have a substantial decrease in photosynthetic rates due to near full stomatal closure very early in the season. This result is similar to isohydric type varieties (i.e. Grenache) and not anisohydric as stated by During. However due to the differences of the condition, for which the vines were growing and the variety, could explain the substantial differences in the photosynthetic rates. Also the During study did not utilize a gas analyzer and based much of his conclusion using several instrument such as a porometer to monitor stomatal conductance , a open – system to monitor photosynthesis and transpiration rate in addition to measuring leaf water potential readings with a pressure bomb. The photosynthetic and transpiration data was collected from sunrise to sunset. Shultz calculated the raw data using equations from earlier work and made his conclusions from that data. Also the area of his study was based in Montpellier, France which has different environmental conditions than this study. These differences in sampling may account for some of the differences in the conclusions of this study.

The results from the scatter plot of comparing the relationship of leaf temperature and stomatal conductance showed a significant decrease in the stomatal conductance between the irrigation treatments occurred as warmer temperature was experienced. The Paso Robles area has historically experienced very high temperatures during the months of July through September. This time coincides with in part to berry formation (stages 1 and 2) in which RDI is most effective for reducing berry size and improving wine color. If soil moisture is not at adequate levels, a grower may not have enough moisture to overcome this degree of warmer temperatures. The correct irrigation management for these weather conditions is of extreme critical importance if a grower wants to gain the advantage of berry size reduction and provide sufficient water for normal vine functions. This study indicated that the 45% irrigation treatment had significantly higher stomatal conductance as compared to the other treatments as leaf temperatures increased. Based on these results some minor advantage may occur in growing Syrah when this degree of

irrigation is performed. One possible extension of this study is to look at all of the effects of that rate of irrigation and expand research in to other areas of vine physiology such as leaf water potential, soil water availability and rootstock interaction at this 45 % treatment. The interaction of water stress and hormonal influence was identified in earlier studies on stomatal responses (Dodd, 2003). Also, there may be some differences in ABA production and amounts that is produced at this specific irrigation level that could account for these differences on stomatal conductance and responsiveness to drought conditions.

Conclusion

The focus of this study was to examine the effects of different degrees of deficit irrigation on the photosynthetic rate of Syrah grown in the Paso Robles area. The need to conserve water and improving wine quality is paramount at this time. The results of this study would indicate there is no significant difference in the irrigation treatments.

However, the 45 % treatment showed the greatest differences in photosynthetic rate over the two year study. The 45% treatment showed a significant difference in stomatal control when higher leaf temperatures were compared to the other treatments. This fact may not fully support the anisohydric growing characteristic of Syrah grown in warm climates that recent research has stated. These results would indicate that the 45% irrigation treatment may have some importance when looking at growing this variety in warmer temperatures. Further research in production, effects in wine quality, and vine performance should be performed at this irrigation treatment.

In addition, the results indicate that a decrease in stomatal conductance occurs as leaf temperatures increase. As the air temperatures increase, the measured leaf temperature also increases. At these temperatures it is likely that the relative humidity surrounding the leaf and the interior relative humidity of the stomata will decrease. At this point the leaf water potential becomes more negative and the stomata begin to close as a response to the drier conditions. During this study, leaf temperatures were measured as high as 46 Celsius (114 Fahrenheit). At these temperatures the photosynthetic rate was continuing at a similar rate when to cooler temperatures were experienced. I would conclude that the results of this study would support some of Schultz's conclusions of Syrah ability to continue fixing carbon at greater environmental demands.

However, this study did not account for measuring leaf water potential along and measuring photosynthetic rates in conjunction with the soil water status. In the future, additional research could be performed to explore the possibility of using less water in producing Syrah. The focus of the research may look at using the 45% ETc rate as an irrigation level to investigate. The future research should account for the plant and soil status in offering a conclusive answer to the issue of this variety stomatal response to

water stress at this level of irrigation. For the issues that are occurring to Syrah grown in the Paso Robles area these may be due to other factors that are responsible for the less than normal growth. These factors may include increasing the affects of soil salinity building in area vineyards, an unidentified plant virus, graft union incompatibility, nutritional deficiencies, or the affects of continual drought conditions.

The differences in the rowside measured photosynthesis shows that photosynthetic rates were significantly different between the south facing canopy and the north side. This may influence a grower to plant rows in a north/south direction to maximize photosynthesis and to increase quality and grow a balanced vine. The use of regulated deficit irrigation has become a standard in the irrigation management of winegrapes. When possible, a grower may want to plant his vineyard on this row direction to maximize sunlight exposure and yields. Water use would likely be reduced to some degree because of the more efficient use of sunlight and the maximizing of photosynthesis.

As a closing point, the use of this study or studies like it may be used to determine baseline CO² depletion rates for vines for possible carbon credit legislation. By having a baseline photosynthetic rate for grape and specifically Syrah, governmental agencies can use them to calculate carbon credits a grower can produce or offset their carbon use. This would be especially helpful for a winery to know to so that they can offset CO² produced during the wine making process.

Appendices

Table 2

Weather Data

Weather information was accumulated via a nearby weather station (Paso Robles Wine County Association PR-1). The readings were acquired annually and were used to determine their influence on plant behavior.

Evaporation rate

Evaporation Rate - The evaporation rate was tracked for the two years of the study.

During the 2004 season, a total of 45.08 inches of water was recorded used by the PR1 weather station located near this sample site. The Evaporation rate recorded in 2005 was recorded to be 40.49 or 4.59 inches less than the previous year. The greatest ETo rates occurred during the months of June through July.

	2004	2005
In season (April – October)	45.08	40.49
Dormant (November – March)	10.60	8.37
Total	55.68	48.86 inches

Rainfall

Figure A-1 - Graph of seasonal rainfall 2003 & 2005

Data: CIMIS data (station 52)

Rainfall –The period of November 2003 through October 2004 had a total of 15.39 inches of rainfall. The period of November 2004 – April 2005 had 24.02 inches recorded at the CIMIS Station 52. This was a difference of 8.63 inches of rainfall that occurred through most of the 2004 dormant season.

November 2003- April 2004 (rain season)	13.09
May 2004 – October 2004	<u>2.34</u>
Total	15.39 inches
November 2004 – April 2005 (rain season)	22.06
May 2005 – October 2005	<u>1.96</u>
Total	24.02 inches

Temperature –The temperatures were at their highest during the months of July and August during these two years (Figure A-3). This is typical maximum daily temperatures for this area.

Table 3

Sap Flow readings of the four irrigation Levels (8/16-19/2004)

Table 4

Source	ANOVA Tables									
	DF	error	total	SS	error	Total	MS	error	F	P
Photosynthesis rate compared for 2004 & 2005	1	1216	1217	0.08	129.37	129.45	0.081	0.106	0.77	0.382
Total measured gas exchange 2004	3	382	385	1.93	41.918	43.847	0.643	0.11	5.86	0.001
							0.022	0.086		
Total measured gas exchange 2005	3	472	475	0.07	40.99	41.062	9	8	0.26	0.852
Photosynthesis rate vs. treatments	3	1214	1217	0.77	128.676	129.45	0.258	0.106	2.43	0.064
Photosynthesis rate compared to air temperature	1	1216	1217	114	5208.29	8	113.8	4.28	26.59	0.001
Stomatal conductance compared to air temperature	1	1216	1217	0.22	5.64051	6	0.218	0.004	47.18	0.001
Photosynthesis rate compared to relative humidity	1	1216	1217	532	4789.77	8	532.4	3.94	135.1	0.001
Photosynthesis rate compared to row side	1	1216	1217	2.31	127.141	129.45	2.309	0.105	22.08	0.001

Table 5: General Linear Model: Photosynthesis versus Year, Rep, Set, and Row Side

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Set	3	0.1495	0.2018	0.0673	0.66	0.577
Row Side	1	5.1377	5.1377	5.1377	50.37	0.0001
Error	1209	123.3044	123.3044	0.1020		
Total	1217	129.4497				

Table 6

Treatment design

Rep 4

75% = 1 - 2Liter + 1-3 liter

60% = 2- 2 liter

45% = 1- 3 liter

30% = 1- 2 liter

Rep 3

Rep 2

Rep 1

Photographs

Photographs by Daniel Rodrigues and Rick Loya

Photograph 1. Mature Syrah cluster

Photograph 2. Syrah cluster in the full canopy

Photograph 3. Replication divisions

Photograph 4. Canopy of control replication (60% ET)

Photograph 5. Irrigation system modification

Photograph 6. Gas Analyzer (LICOR 6200)

Photograph 7. Gas Analyzer in field

Photograph 8. Full canopy (side view)

Photograph 9. Full canopy (front view)

Photograph 10. Canopy at reading

Photograph 11. Growth differences of different irrigation amounts

Photograph 12. North rowside (full sun exposure)

Photograph 13. South rowside (shade side)

Photograph 14. Sampling row

Photograph 15. Preparing for sampling with Gas Analyzer

Photograph 16. Gas Analyzer with chamber in open position

Photograph 17. First fully expanded leaf (sample leaf)

Photograph 18. Leaf being loaded into sample chamber

Photograph 19. Sampling of a grape leaf (shade side)

Photograph 20. Photosynthesis rate being measured

Photograph 21. Showing light sensor

Photograph 22. Data being written down on sample form

Photograph 23. Interior of full canopy

Photograph 24. Example of least irrigated replication

Photograph 25. Fully assembled LICOR 6200

Photograph 26. Instrument panel of LICOR 6200

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