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2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

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Advancing Water Use Efficiency in Vineyards with Sub-surface Micro-irrigation Techniques

Pete W. Jacoby[1], R. Troy Peters[2], Sindhuja Sankaran[3], Lav Ramchandra Khot[3]

[1]Professor, Dept. Crop & Soil Sci., [2]Assoc. Professor, Dept. Biol. Systems Engineering., [3]Asst. Professors, Dept. Biol. Systems Engineering, Washington State University, Pullman, WA

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Poster Presentation

Abstract. *This poster presentation describes methods employed to increase water use efficiency in grapevines via micro-irrigation delivered sub-surface at depths ranging from 30 – 120 cm. The irrigation delivery system uses 1.27 cm (id) diameter PVC tubes inserted vertically into pre-drilled holes placed 45 cm either side of the vine trunk and in line with the dripline. A barbed connector with attached 15 cm length of 0.63 cm diameter tubing attached to a fixed rate drip emitter (2 L/hr) beneath a center drilled PVC cap secures the system in place and prevents exposure of the dripper to either atmosphere or soil. Plant root growth in response to wetting zone is quantified by periodic digital photography via a clear hard acrylic mini-rhizotron and camera system controlled by a laptop computer. Plant water stress is monitored by pressure bomb and auto-porometer, and compared to digital imagery obtained from a thermal sensing camera mounted on an unmanned aerial vehicle (UAV). While this technique is currently being used only for research to quantify physiological responses of the vine and its root system, its potential use in mature vineyards may permit more water efficient irrigation while reducing weeds and disease issues, as well as avoiding root pruning during installation and lessening problems from burrowing rodents impacting buried lines or clogging of emitters from contact with the soil. Published results are anticipated by 2017.*

Keywords. *Subsurface drip irrigation, microirrigation, vineyards, precision irrigation, grapevine roots, remote sensing.*

Introduction and Background

Wine and juice grape vineyard acreage in Washington (WA) continues to expand at a phenomenal rate, more than quadrupling in size from 11,100 acres in 1993 to over 75,000 acres in 2013 (WAWGG, 2013). WA ranks second in the nation in wine grape production, yet represents less than 10 percent of California's production; however, the quality of WA wines has become widely recognized, resulting in increased sales worldwide. Projections for increased grape acreage going into production could double the current acreage during the next 20 years.

WA's wine and juice grapes, along with a large tree fruit industry, depend on irrigation for their existence, most of which is adjudicated through irrigation districts on the basis of riparian right and seniority of use. Any increasing demand for water for irrigated crop production will likely create additional concern around issues of competing demands. For example, increase in vineyard acreage will require new irrigated land to have junior water rights or replacement of existing irrigated crops such as tree fruit with vineyard. Thus, without advancements in new irrigation technologies and management, future growth of a labor intensive industry such as wine grape production could be limited to a level below current projections of potential, directly impacting the future economic growth of many communities in southcentral WA.

Washington State's primary grape growing regions are predominantly an agro-environmental climate characterized by a hot, dry summer growing season with high evaporation and transpiration (E/T) rates. Irrigation in this region occurs mainly through pressurized surface irrigation systems. Most of the wine grape vineyards employ surface drip application while juice grape plantings use both overhead solid set impact sprinklers and/or surface drip systems.

Opportunity to achieve greater water use efficiency through the use of sub-surface micro-irrigation techniques would appear to have significant potential, given published reports that water use can be reduced by as much as half in production of annual crops in the Great Plains (Lamm and Trooien, 2003) and pumping costs reduced by one-third in corn production (Payero et al., 2005); however, a stigma surrounding the use of buried dripline systems exists among irrigating agriculturists based on some recognized short-comings of these systems. Among the most stated problems are: 1) difficult and expensive to install, especially in older, established plantings; 2) devastating impacts from burrowing rodents that chew into the buried drip lines; 3) potential of clogging in buried drip emitters that are in immediate contact with the soil; and 4) difficulty in detecting and repair problems before plant damage/death occurs. Similar issues for producers resisting the use of these buried systems have been cited in other regions (Payero et al., 2005; Reich et al., 2014).

Irrigation delivery, mainly by drip or overhead sprinklers, also has associated shortcomings that have not been widely documented, including factors such as: (1) reduced efficiency for vines and trees to obtain moisture and nutrients because of weeds and absorption by residual plant material in the upper soil profile (Reich et al., 2014); (2) concentration of plant roots in the upper soil profile, making plants more susceptible to high wind damage and moisture stress during acute water shortage or irrigation disruption (Stevens and Douglas, 1994); (3) unwanted response of plants to rain events, causing excessive growth and subsequent need for pruning, often disrupting planned deficit irrigation management to improve fruit quality (Iland et al., 2011); (4) creation of more favorable microclimates for weeds, insects, and diseases in the sub-canopy soil surface (Reich et al., 2014); and (5) reduced soil quality and productive potential from either accumulation of salts on the soil surface or creating caliche and hard-pan zones in the soil profile (Davenport et al., 2008).

Objective(s) of Newly Initiated Research:

(1) Evaluate and determine the potential benefit of using a deep sub-surface irrigation delivery system to effectively provide sufficient soil water for maintaining targeted plant physiological functions;

(2) Determine the most appropriate depth and water required to alter root architecture while meeting required levels of growth and physiological activity throughout the growing season; and

(3) Contrast standard means of assessing plant water stress with thermal imaging techniques from airborne platforms (UAV) to develop early detection of vine water stress for site specific management of irrigation.

Justification and Importance of Proposed Research:

Advancement of viticulture practices to consistently produce higher quality grapes for wine depends largely on gaining more knowledge of the primary factors influencing the physiology of the grapevine and improving vine management skills essential to achieve the desired level of product quality. One of the most widely recognized methods to regulate activity of the vine involves skillful use of irrigation (Hamman and Dami, 2000). Gaining better understanding of how to more precisely regulate vines grown in hot, arid conditions such as those found in the lower Columbia Basin and most of growing regions east of the Cascade Range seems to offer abundant opportunities to advance the production of high quality, premium wines in the U.S. The role of the root system, partially because of its subterranean habitat, has received only a fraction of the research attention of that focused on the above ground portion of plants. However, there is a growing body of scientific evidence that during drought or purposeful restriction of water, perennial woody plants and some herbaceous plants tend to prioritize partitioning of carbohydrates to root system extension rather than to above-ground growth (Ansley et al., 2014; Yaqooh et al., 2013).

Our team intends to demonstrate *proof of concept* for the potential to increase plant water use efficiency while overcoming a number of the problems associated with surface irrigation listed above. We are conducting research to evaluate the potential use of deep sub-surface irrigation at soil depths of 30-90 cm via prototype devices adaptable to existing irrigation system infrastructure (Figure 1). We *hypothesize* that deep subsurface irrigation, can permit WA vineyard managers to employ water as a management tool to achieve precision viticulture goals by reducing management inputs currently required while simultaneously improving soil health, reducing costly herbicide and mechanical weed control measures, reducing water loss through E/T, and producing higher quality grapes and wine. Such improvements would occur by forcing plants to develop the majority of the root system at a deeper depth in the soil profile by relocating primary irrigation delivery from the shallow upper soil profile to a deeper depth in the soil profile through sub-surface delivery. This approach would save water, reduce weeds, and increase the opportunity to better regulate the vine through irrigation delivery timing and quantity to meet management objectives for grape quality. It would also transform the use of irrigation technologies throughout the irrigated regions of the arid western U.S., specifically in orchard and vineyard production areas, but applicable to many other high value irrigated crops grown in high E/T environments.

Procedures to Accomplish Objective(s):

Objective 1. Field installation of the experiment was initiated during September 2014 in a 2-leaf planting of Chardonnay wine grapes near Prosser, WA (Figure 2). A second site is being installed during early 2015 in a 5-leaf planting of Cabernet Sauvignon near Benton City. Irrigation being applied through both standard surface drip and through sub-surface drip treatments is being contrasted under timed application to apply three (3) levels of irrigation under continuous and pulsed time periods. Sub-surface irrigation is delivered through a series of Schedule 40 PVC tubes placed vertically into the soil 45 cm away from either side of the vine at pre-designated depths of 30-90 cm below soil surface in treatment plots of 15 vines each. Each tube is equipped with a top cap housing a fixed rate emitter connected by a section of 0.63 cm diameter tube which is attached by barbed connector to a suspended irrigation drip line. Electronic controllers (battery powered) were installed to deliver approximately 7.6, 15.2, or 22.8 L per vine on specific irrigation dates determined by the vineyard manager. Actual water usage is measured with a small mechanical water meter.

Experimental design is a randomized block design using water delivery depth as the main treatment effect, irrigation amount as a sub-treatment effect, and use of either uninterrupted or pulsed irrigation effects being analyzed as a split-plot.

Treatment effects on vines will be assessed through measurements of plant water stress and photosynthesis rates as measured by CO_2 gas exchange throughout the growing season. Main treatment effects (depth of water delivery) are replicated 6 times and sub-treatment effect (irrigation amount) are replicated 3 times. Each of 66 treatment plots contains 15 vines each of which only the three (3) center-most vines are used as observation plants, using the remaining vines to buffer treatment effect from neighboring plots. Monitoring of soil moisture content will be made in accordance with research reported by Burgess et al. (2006) and Evett et al. (2002 & 2006) employing both a Diviner 2000 capacitance probe for spot measurement and an Envirotron recording capacitance probe (Sentek Technologies) to obtain a continuous record of soil moisture use and recharge during the growing season.

Objective 2. Sub-surface irrigation delivery, especially at deeper depths in the soil profile, will determine the potential of established grape vines to develop concentrations of new roots near the water application zone. Installation of mini-rhizotrons (Caldwell and Virginia, 1989) during the 2014-2015 dormant season will permit the collection of new root development in response to depth of water delivery after the start of the 2015 irrigation season. This technique involves the installation of highly polished, clear polycarbonate tubes through which is passed a camera system to obtain periodic digital images of root development (Vamerali et al., 2012). Soil moisture monitoring will verify evidence of whether these vines are exhibiting use of hydraulic lift and hydraulic redistribution that has been demonstrated in over 60 species of woody plants around the globe (Richards and Caldwell, 1987; Leffler et al., 2005; Bleby et al., 2010; Burgess, 2011). Except for limited work by Smart et al. (2005), there has been no published research in the western U.S. or elsewhere to demonstrate whether or not vines in cultivated plantings have the capacity to exhibit hydraulic redistribution from deep soil water sources to any significant extent. If this process is apparent, we will purposely exclude natural rainfall via sub-canopy rain shelters and install root barriers around some specified vines at a later phase of experimentation, limiting available water to only that delivered via deep delivery, to quantify the extent of this phenomenon. The same plant physiological measures as described in Objective 1 will be used to determine plant responses following specified irrigation events. Measurements of stem growth during the growing season will be taken periodically to contrast irrigation treatment effect. Photosynthetic rate and plant water status will serve as additional measurements of plant response to irrigation treatments, as described in Objective 1.

Objective 3. In order to advance precision viticulture practices associated with site specific management, both irrigation scheduling and remote sensing of plant water stress are being addressed by our team, in cooperation with commercial vineyard managers. We are using both constant and pulsed irrigation application, in addition to sub-surface micro-irrigation delivery at three depths and varying diurnal volumes of water. Additionally, we are including the use of infrared spectral sensing technologies to determine their potential application in detecting plant water stress and potentially replacing more labor intensive methods involving handheld field instruments, including the Scholander pressure chamber for measuring xylem pressure and the infrared gas analyzer to determine CO_2 reduction during photosynthesis via auto-porometer.

Treatment plots will be monitored for stress and vigor using thermal imaging (FLIR A65, FLIR Systems Inc.) and NVDI imaging (XNiteCanonNDVI®, LDP LLC.) systems. The geo-referenced imagery data will be acquired periodically and temporally synchronized with on-plant measurements describes above. The custom image processing algorithms will be developed to analyze the data in Matlab® (MathWorks, Natick, MA) environment. The key steps involved in imaging based crop stress assessment are: a) image preprocessing- distortion correction, background removal, stitching, etc.;

b) image band segmentation; c) feature extraction (vegetative indices) and dimensionality reduction; d) crop stress (level of stress) related pattern recognition, and e) establishing the relationship between the vegetative indices (stress) and ground-truth measurements. Use of these sensing systems will be integrated with ground and unmanned aerial vehicle (UAV) platforms, while the image analysis follow procedures developed and reported from previous work (Sankaran et al., 2013a; Sankaran et al., 2013b; Garcia-Ruiza et al., 2013) that will aid us in developing the custom image processing algorithms.

Figure 1. Vertical delivery device containing pressure compensating drip emitter just beneath cap on top of PVC tube.

Figure 2. Field installation of deep sub-surface micro-irrigation system for research purposed in 2-leaf Chardonnay commercial vineyard.

Conclusion or Summary

The research project described in this presentation is in the early stages of initiation and data collection will commence during the 2015 growing season. The authors anticipate having preliminary data available in the form of a handout during the November Irrigation Symposium in Long Beach, CA.

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