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Introducing direct root-zone deficit irrigation to conserve water and enhance grape quality in the Pacific Northwest

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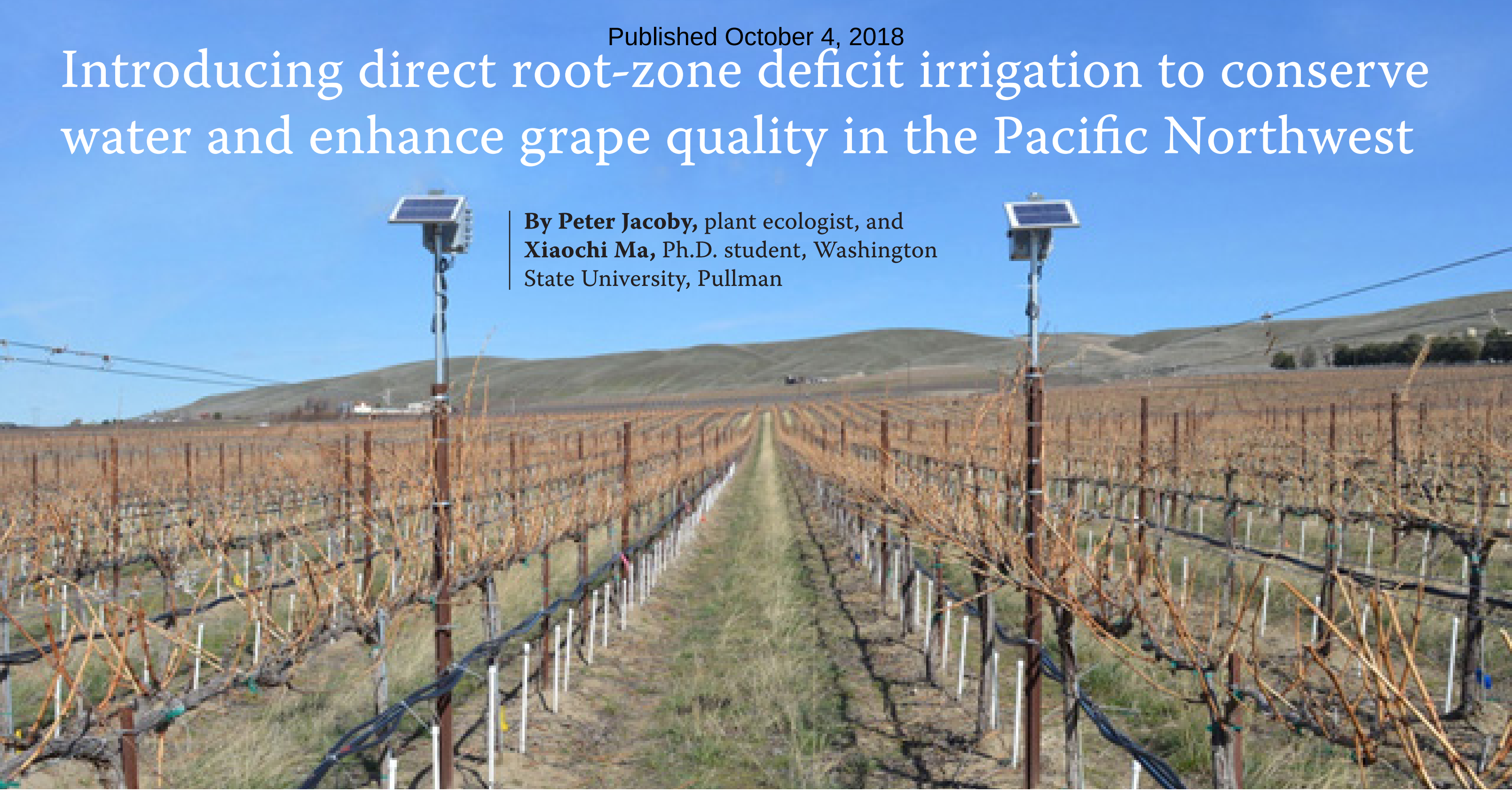

In 2015, a project was launched to evaluate the potential for using a new form of sub-surface drip irrigation. Rather than applying micro-irrigation through horizontal buried lines, drip irrigation was delivered into vertical tubes placed 1 to 4 ft into the root-zone soil. Juice and wine grapes were selected as the model plant systems for these proof-of-concept trials. Earn 0.5 CEUs in Soil & Management by reading this article and taking the quiz at www.certifiedcropadviser.org/education/classroom/classes/575.

Water is the lifeblood for irrigated agricultural regions lying east of the Cascade Mountains in the Pacific Northwest (PNW). Much of this water originates from the annual accumulation of snow in the mountains and subsequent runoff to rivers and impound facilities that distribute water for summer irrigation. Combined effects of population growth, public awareness of climatic fluctuation, and environmental and natural resources use issues, have created concern and anxiety about future water availability among growers, irrigation districts, regulatory agencies, and legislative bodies. Increasingly, future adjudications of this precious resource could limit sustainability and growth of irrigated agricultural acreage unless better methods are found to enhance crop water use efficiency (Washington State Wine Commission, 2018).

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In 2015, a project was launched through funds obtained through a series of complementary grants to evaluate the potential for using a new form of sub-surface drip irrigation. Rather than applying micro-irrigation through horizontal buried lines, drip irrigation was delivered into vertical tubes placed 1 to 4 ft into the root-zone soil. Juice and wine grapes were selected as the model plant systems for these proof-of-concept trials (Jacoby, 2016). These perennial crops are typically planted in rows with trellis systems supporting aboveground drip systems.

Previous studies of root distribution in grape vines have reported that under surface drip irrigation, the vast majority of root biomass is concentrated within the top 18 inches of the soil profile. This rooting pattern impacts vine activity between irrigation events and could expose vines to stress or damage during periods of temperature extremes (Comas et al., 2010). By applying the water

Fig. 1, opposite page: Field sites for conducting proof-of-concept research were established in commercial vineyards such as Kiona vineyards near Benton City, WA (shown here during dormancy).

directly into the deeper soil profile, vines should respond by developing deeper roots capable of obtaining water between irrigation events and storing carbohydrate reserves for subsequent plant growth and fruit production. Additionally, if a dry zone could be created in the upper soil profile during the growing season, water loss from surface evaporation and weeds could be reduced or eliminated. To evaluate these potentials to increase water use efficiency, three sites were selected within established commercial vineyards in the Yakima River Valley for intensive research trials (Jacoby, 2017a, 2017b).

Direct root-zone deficit irrigation application methods

Our discussion in this article will focus on results obtained from a vineyard located within the Red Mountain AVA (American Viticulture Area) near Benton City, WA (Fig. 1). Soils on this site are in the Hezel series described as very deep loamy fine sands formed from glacio-fluvial sediments deposited from multiple flooding events during at the last ice age. Annual rainfall is approximately 8 inches, occurring mainly from fall to spring. Natural soil fertility is low, and fertilization is necessary for commercial grape production. Summer growing conditions are typically hot and dry; therefore, irrigation is required for warm-season crop production. Irrigation typically is initiated ahead of bud break, and season-long water use for wine grapes in this region averages 1.35 acre-ft.

In collaboration with the vineyard owner/operator, irrigation treatments were applied to 1,000 vines in a 1.2-ac site planted to Cabernet Sauvignon (clone 2) red wine grape vines that were eight years old 2015. Vines were own-rooted like the vast majority of vines used in Washington. Irrigation scheduling was determined by the owner based on strategies developed over four decades of wine grape production on this site. Rates of water applied by direct root-zone deficit irrigation (DRZ) delivery were reduced to approximately 60, 30, and 15 of the commercial rate applied through surface drip application (Table 1). Battery-powered controllers were pre-set to deliver only the designated amounts of water to the DRZ treatments, and small mechanical meters were used to quantify the actual amounts of water applied during each irrigation event (Fig. 2). The purpose of this experiment was not to directly contrast DRZ with surface drip, but to only establish the potential of DRZ to sustain crop production with lower amounts of water. The established rates of reduced irrigation were applied from fruit set until harvest.

Table 1. Irrigation amounts from 2015 to 2017 (gallons/vine/irrigation event)

	Year		
Irrigation rate	**2015**	**2016**	**2017**
High	9.75	10.27	10.68
Moderate	4.88	5.13	5.34
Low	2.44	2.57	2.67

Direct root-zone deficit irrigation applied during 2015, 2016, and 2017 was delivered to three depths (1, 2, and 3 ft below soil surface) to determine if any advantage could be attributed to a specific depth of delivery in the soil profile. Vertical delivery tubes were installed approximately 1.5 ft either side of the vine trunk, and water was supplied from a suspended line to each delivery tube via 0.25-inch diameter line (Jacoby, 2017a, 2017b).

Influence of DRZ on grape production, quality, and berry development

Crop production at harvest was used as the primary measure of treatment effect reported in this article; however, other measures such as stomatal conductance, root imaging, and photosynthesis were used to monitor plant health and response to treatments, and these will be addressed in forthcoming publications. During each of the three growing seasons, production was mainly impacted by the amount of water applied, regardless of the depth of DRZ delivery (Fig. 3). Reducing the amount of water applied during each irrigation date was typically accompanied by a concomitant reduction in grape production; nevertheless, we were able to conserve water resources while achieving 70% or more of the desired commercial

Fig. 2. Direct root-zone deficit irrigation was regulated by battery-powered controllers to apply reduced water delivery to the last 30 vines of 27 rows.

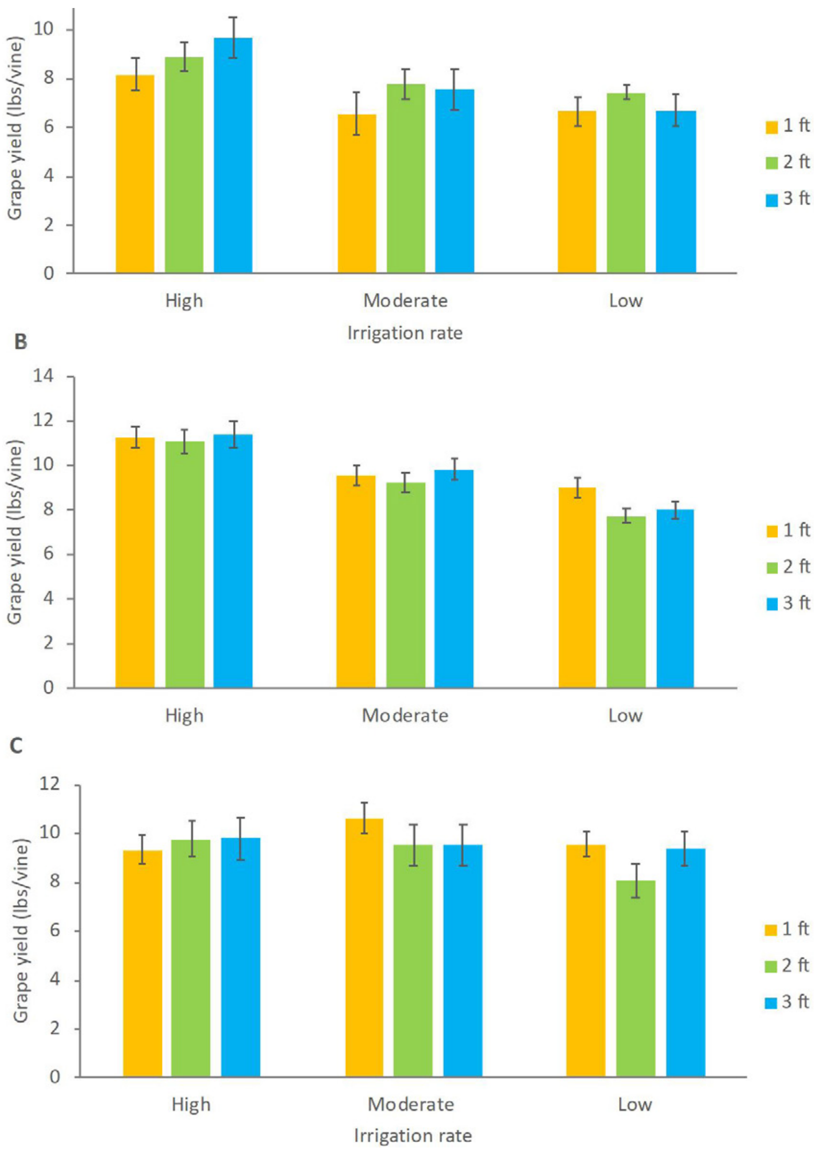

Fig. 3. Grape yields (lb/vine) under different irrigation rates and irrigation depths in 2015 (A), 2016 (B), and 2017 (C). Irrigation depths are: 1 ft (orange), 2 ft (green), and 3 ft (blue). Error bars represent standard errors. *n*=15~45.

production goal. This result demonstrates that through use of DRZ subsurface methods, a vineyard with limited water resources during a drought year could remain productive.

Sample grape clusters from treatment plots were submitted to a commercial analytical lab for determination of key components leading to production of high quality premium wines, including Brix (natural sugar content), acidity (measured as pH and titratable acidity), anthocyanin content, and tannin content. Additional cluster samples were transported to our lab and quantified by weight, number of grapes per cluster, and size of individual grapes. Generally, our results showed that grape quality was improved by increasing levels of stress imposed with applications of reduced amounts of water following fruit set. We observed that with increasing rate of stress, vines consistently produced grapes with less acidity and higher Brix, anthocyanin, and tannin content. Cluster weights were increasingly lower and individual grapes were smaller, but the number of grapes per cluster were higher with increasing levels of plant stress. These findings are consistent with published literature on deficit irrigation (Caceres-Mella et al., 2017; Cancela et al., 2016; Casassa et al., 2015; Chaves et al., 2017; Munitz et al., 2017; Phogat et al., 2017).

Influence of variable weather among years on efficiency of deficit irrigation

An ongoing challenge for achieving desired results through deficit irrigation is the unpredictable influence of weather, particularly precipitation and temperature that impact crops during the growing season (Fig. 4). Very different growing conditions occurred during 2015, 2016, and 2017 in the irrigated growing regions of the Pacific Northwest (PNW).

In 2015, the PNW experienced the hottest and driest growing season on record, according to weather records and reports from AgWeatherNet, which maintains more than 140 weather stations across the irrigated agriculture regions of WA. More than 90 growing degree days (GDD) had accumulated prior to April 1 as opposed to the long-term average of 23 GDD, leading to early initiation of growth and irrigation. Additionally, there was no significant precipitation during the growing season (WSU, 2018). Irrigation deliveries were curtailed for holders of junior water rights during the beginning of the growing season by some irrigation districts, given the requirement to offset low streamflow to facilitate fish migration with water impounded for irrigation.

The 2016 growing season, similar to 2015, was warmer than normal, but characterized by more moderate growing conditions than the 2015 growing season. By contrast, the 2017 growing season began with much higher soil moisture content accumulated from above-average precipitation during late fall of 2016 through spring of 2017 ahead of the growing season. May and June were relatively dominated by moist, cool conditions that delayed bud break by about two weeks later than in the two previous years (WSU, 2018). Only three irrigations were applied before July. Along with more cloud cover than observed in either of the previous two years, the first two weeks of September were dominated by heavy smoke from wildfires. These conditions may have imparted sufficient influence on photosynthesis and fruit development to account for reduced fruit production in 2017 than during 2016, despite favorable soil moisture. Because of favorable soil moisture, vine canopy growth was vigorous, and differences in plant development and fruit set were indistinguishable visually among the irrigation treatments. Berry development and cluster size appeared visually similar until late summer when higher air temperatures were experienced.

With soil moisture content during the first half of the 2017 growing season, the potential for deeper root development into the soil profile after three consecutive growing seasons of DRZ application is also a consideration. Periodic digital imaging of root growth in both field and greenhouse studies is currently being analyzed and may contribute to a better understanding of the root growth dynamics influenced by DRZ application (Zuniga et al., 2017, 2018). These data will be presented for publication following the completion of observations during the 2018 growing season.

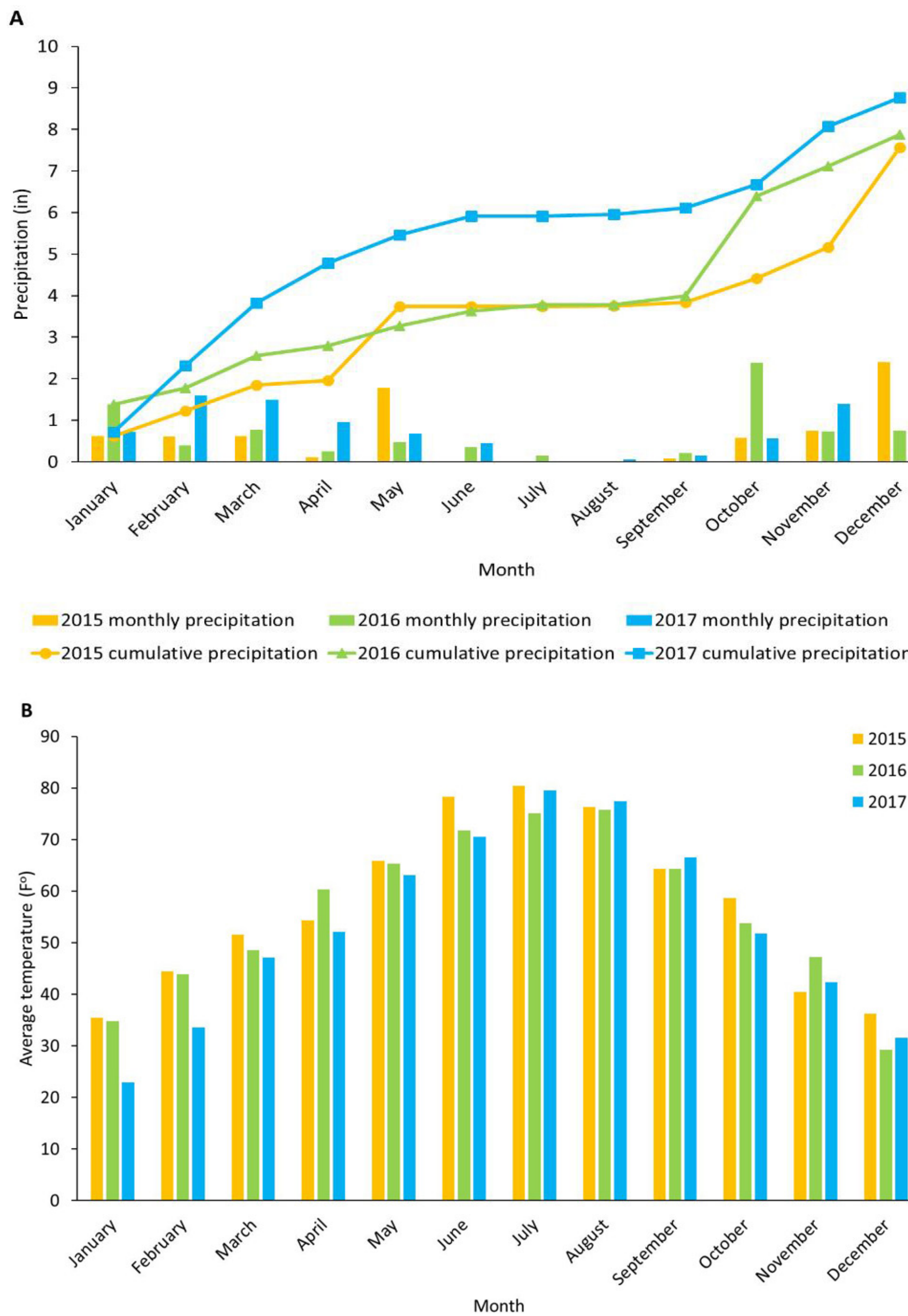

Fig. 4. Comparisons of differences in precipitation (A) and average temperature (B) from 2015 to 2017 at Benton City, WA (data from AgWeatherNet).

Summary of findings to date for advancing DRZ application

Three years of field research conducted in commercial wine grape vineyards have confirmed the original concepts related to DRZ. Direct root-zone deficit irrigation has proven effective in maintaining vineyard production during extreme drought conditions as well as demonstrating the ability to achieve commercial production goals on significantly less water than currently used methods. It appears to be advantageous in maintaining vineyard productivity and grape quality while conserving water resources. Studies have been initiated to directly compare DRZ and surface drip irrigation at equal rates to more precisely document the true potential and economic benefit for DRZ methodology. &

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