Delaying irrigation initiation linearly reduces yield with little impact on maturity in Pinot noir

Joseph DeShields[1,2], Ricky Clark[2], Mariana Stowasser[2], and Alexander Levin[1,2*]
[1]Department of Horticulture, Oregon State University, Corvallis, OR 97331, USA
[2]Southern Oregon Research and Extension Center, Oregon State University, Central Point, OR 97502, USA

***Corresponding author:** alexander.levin@oregonstate.edu

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Abstract

When to initiate irrigation is a critical annual management decision that has cascading effects on grapevine productivity and wine quality in the context of climate change. A multi-site trial was begun in 2021 to optimize irrigation initiation timing using midday stem water potential (ψ_{stem}) thresholds characterized as departures from non-stressed baseline ψ_{stem} values ($\Delta\psi_{\text{stem}}$). Plant material, vine and row spacing, and trellising systems were concomitant among sites, while vine age, soil type, and pruning systems varied. Five target $\Delta\psi_{\text{stem}}$ thresholds were arranged in an RCBD and replicated eight times at each site: 0.2, 0.4, 0.6, 0.8, and 1.0 MPa (T1, T2, T3, T4, and T5, respectively). When thresholds were reached, plots were irrigated weekly at 70% ET_c. Yield components and berry composition were quantified at harvest. To better generalize inferences across sites, data were analyzed by ANOVA using a mixed model including site as a random factor. Across sites, irrigation was initiated at $\Delta\psi_{\text{stem}} = 0.24$, 0.50, 0.65, 0.93, and 0.98 MPa for T1, T2, T3, T4, and T5, respectively. Consistent significant negative linear trends were found for several key yield and berry composition variables. Yield decreased by 12.9, 15.9, 19.5, and 27.4% for T2, T3, T4, and T5, respectively, compared to T1 ($p < 0.0001$) across sites that were driven by similarly linear reductions in berry weight ($p < 0.0001$). Comparatively, berry composition varied little among treatments. Juice total soluble solids decreased linearly from T1 to T5 – though only ranged 0.9 Brix ($p = 0.012$). Because producers are paid by the ton, and contracts simply stipulate a target maturity level, first-year results suggest that there is no economic incentive to induce moderate water deficits before irrigation initiation, regardless of vineyard site. Subsequent years will further elucidate the carryover effects of delaying irrigation initiation on productivity over the long term.

Introduction

When to initiate irrigation is a critical decision that can have a significant impact on the current season's production. In addition to saving water and pumping costs, delaying irrigation initiation can have many positive direct and indirect effects on grapevine growth and development. It is well-documented that growth (cell expansion) is the physiological process most sensitive to water deficits (Hsiao, 1973). Delaying irrigation would impose an early season water deficit that would reduce shoot elongation and reduce vine vigor (Matthews, Anderson, & Schultz, 1987). Important indirect benefits would be an increase fruit quality by stimulating phenolic biosynthesis (Castellarin, Matthews, Di Gaspero, & Gambetta, 2007) and a decrease in disease pressure by creating a more favorable cluster microclimate (Stapleton, Barnett, Marois, & Gubler, 1990). Thus, it may be economically favorable to delay the initiation of irrigation just enough to create a slight water deficit and improve fruit and wine quality.

Delaying irrigation for too long, however, has many negative effects. Severe water deficits would result in a small canopy (Williams, Grimes, & Phene, 2010), inhibition of photosynthesis (A. Levin & Nackley, 2021; Williams, 2012) leading to large reductions in berry growth and yield (A. D. Levin, Matthews, &

Williams, 2020). In addition, fruit could be overexposed to solar radiation, causing sunburn and degradation of anthocyanin pigments that would reduce fruit quality (Bergqvist, Dokoozlian, & Ebisuda, 2001; Mori, Goto-Yamamoto, Kitayama, & Hashizume, 2007). Small, damaged fruit would mean low returns for the grower. Accordingly, waiting too long to turn on the water in an arid- or semi-arid growing area would have significant economic consequences.

Most agree that for high quality wine grape production, plant-based irrigation scheduling methods are superior since they directly measure the level of water stress in the plant (A. Levin & Nackley, 2021). The pressure chamber is considered the "gold standard" of plant-based measurement tools. Measurement of midday stem water potential (ψ_{stem}) has been shown in multiple woody perennial crop species to be a robust indicator of plant water status (Shackel, 2011). However, it is still sensitive to environmental conditions, which can often complicate data interpretation over time, thus making informed irrigation management decisions more difficult. By normalizing measured ψ_{stem} values to environmental conditions at the time of measurement, the user can remove the environmental variables from the equation and simplify data interpretation over time and space. This can be done by expressing measured values to a theoretical non-stressed baseline value (Williams & Baeza, 2007). This departure can be used as a relative marker of water deficit over time, across sites, and across cultivars to determine when to initiate irrigation.

The overall objective of this study was to delay irrigation initiation using departures from non-stressed baseline ψ_{stem} values to determine the optimal irrigation initiation time for commercial red wine grape production. The first year of this multi-year study was conducted in 2021 across three commercial vineyards of varying soils and mesoclimates, but similar plant material and vineyard design. Treatment effects on crop yield and quality parameters were evaluated as functions of plant water status at initiation time.

Materials and methods

Vineyard sites

This study was conducted across three commercial vineyard sites located in the Rogue Valley American Viticultural Area within blocks of *Vitis vinifera* L. cv. Pinot noir. Vines at all three sites were grafted on 3309 Couderc rootstock (*V. riparia* x *V. rupestris*), grown on a vertically shoot positioned trellising system, and had a row by vine spacing of 2.13 m x 1.22 m. Apart from irrigation management (described below), all cultural practices were conducted per industry standard.

Study sites differed in elevation, soil texture, soil available water supply (AWS), scion clone, vine age, row orientation, pruning, and management system. The study site near Eagle Point, Oregon (42.49 N, 122.76 W; 452 m asl) was planted in 2017 on loam-gravelly clay loam soil (76 mm AWS in top 1 m) using the Pommard clone (UCD 5) with a NNE-SSW row orientation. Vines were head-trained and cane-pruned to two 12-bud canes per vine, and the vineyard was managed conventionally. The study site near Jacksonville, Oregon (42.30 N, 122.95 W; 509 m asl) was planted in 2014 on gravelly silt loam soil (146 mm AWS in top 1 m) using the Pommard clone (UCD 5) with a NE-SW row orientation. Vines were trained to bilateral cordons and spur-pruned to 10 2-bud spurs per vine, and the vineyard was managed conventionally. The study site near Ashland, Oregon (42.18 N, 122.63 W; 637 m asl) was planted in 2012 on silty clay loam soil (143 mm AWS in top 1 m) using the Wädenswil clone (UCD 2A) with a NW-SE row orientation. Vines were head-trained and cane-pruned to two 12-bud canes per vine, and the vineyard was managed organically.

Measurement of vine water status

Vine water status was measured as midday stem water potential (ψ_{stem}) using a pressure chamber according to the methods of Levin (2019). Beginning the first week of June, measurements were taken weekly until the end of August, but frequency was increased to twice weekly based on proximity to initiation threshold and anticipated weather conditions.

Irrigation treatments

Irrigation treatments were initiated when measured ψ_{stem} differences from calculated non-stressed baseline midday stem water potential ($\Delta\psi_{\text{stem}}$) values reached thresholds of -0.2, -0.4, -0.6, -0.8, and -1.0 MPa for treatments T1, T2, T3, T4, and T5, respectively. Non-stressed baseline midday stem water potential values were determined using the methods of Williams and Baeza (2007). Treatments were imposed by unplugging plugged emitters. At each site, treatment plots (consisting of 4-5 vines/plot) were randomized across rows in blocks of five rows, and blocks arranged in an RCBD with eight replications. Upon treatment imposition, all plots were irrigated at 70% estimated ET_c using two 2 L/hr. emitters/vine.

Harvest data collection

Fruit was harvested just prior to commercial harvest by the collaborating commercial vineyard. Prior to harvest, 50-berry samples were collected from each plot for measurements of total soluble solids (TSS), pH, and titratable acidity using standard methods. Plot yields were recorded and divided by vines/plot to determine yield/vine then multiplied by vines/ha to estimate yield/ha.

Data analyses

All data analyses and graphics were conducted using R statistical software (www.r-project.org). Individual site data were analyzed via one-way ANOVA using linear mixed models in which *treatment* was the single fixed factor and *block* was a random factor. Combined (across sites) data were similarly analyzed via one-way ANOVA using mixed models, except models included *site* and *block* nested within *site* as random factors. Means separations were conducted using Dunnett's method in which individual treatment means were compared to the control.

Results and discussion

In general, irrigation treatments were successfully applied at all sites in 2021, with initiation dates ranging from 1 June to 23 August across sites (Fig. 1; Table 1). As expected, however, there was substantial variation among sites regarding initiation timings in terms of calendar date. For example, both Eagle Point and Jacksonville dried down quickly (over the course of one month), but Eagle Point was the first one to be irrigated, with T1 initiated on the first SWP measurement date on 1 June. By 3 July, all treatments had been imposed, with soils drying so quickly that thresholds for T2 and T4 were missed (Table 1). By comparison, T1 initiation at the Jacksonville site occurred on 5 July, which up until that point had maintained the highest water status of all the sites. In contrast, treatments in Ashland were imposed over a 9-week period from 16 June to 23 August (Fig. 1). Total applied water amounts also varied accordingly among treatments and sites, ranging from 60 to 230 mm or 23 to 89 L/vine (Fig. 1).

Irrigation was initiated at Δ baseline ψ_{stem} values of -0.24, -0.49, -0.65, -0.93, and -0.98 MPa for T1, T2, T3, T4, and T5, respectively, when averaged across sites (Table 1). This corresponded to actual ψ_{stem} values of -0.75, -1.06, -1.16, -1.49, and -1.45 MPa for T1, T2, T3, T4, and T5, respectively, when averaged across sites. Accordingly, T1 would have been classified as a weak water deficit, T2 a weak to moderate water deficit, T3 a moderate water deficit, and both T4 and T5 as severe water deficits (van Leeuwen et al., 2009). The relationship between actual ψ_{stem} and Δ baseline ψ_{stem} was 1:1, strong, and did not differ across sites (slope = 0.97, $R^2 = 0.95$, $p < 0.001$), suggesting that using Δ baseline ψ_{stem} may not have been necessary under the conditions of this study.

Across all treatments and sites, yields ranged from 5.8 to 14.5 t/ha, with highest yields in Jacksonville, and lowest in Ashland (Table 2). Though treatment means did not always separate statistically within a given site, polynomial contrasts of treatment means showed consistent negative linear trends ($p < 0.05$) in yield at each site and across all sites in response to treatments. In other words, yields were linearly reduced with increased delays in irrigation initiation. This was driven by similarly strong linear reductions in berry FW (slope = 12.4, $R^2 = 0.94$, $p = 0.006$), also observed at each site and across sites. This was consistent with berry FW being the strongest determining factor of yield (A. D. Levin et al., 2020). In relative terms, delaying irrigation initiation from the control treatment reduced berry FW by 7, 12, 19, and 25% in T2, T3, T4, and T5, respectively. This corresponded to yield reductions of 15% for T2 and T3, 22% for T4, and 32% for T5.

In contrast to the strong responses of berry FW and yield, total soluble solids (TSS) did not respond strongly to treatments within each site despite large differences among sites across treatments (Table 2). At Jacksonville and Ashland, there were slight increases or no change, respectively, in TSS from T1 to T2, followed by a linear reduction until T5. In contrast, TSS increased slightly from T1 to T4 at Eagle Point. However, when calculated across sites, there was a slight increase (+0.2 °Brix) from T1 to T2, followed by slight reductions until T5 (-0.7 °Brix). Polynomial contrasts of treatment means across sites showed a negative linear trend ($p < 0.05$) and a marginally non-significant quadratic trend ($p < 0.1$) of TSS to delaying irrigation initiation.

Conclusion

Delaying irrigation initiation across three Pinot noir vineyards linearly reduced berry FW and yield and had a nearly significant quadratic effect on TSS. Thus, optimizing yield at harvest would require initiating irrigation as soon as a weak water deficit is experienced ($\psi_{stem} > -0.75$ MPa). TSS at harvest could be optimized (and irrigation water saved) through longer delays in irrigation initiation ($\psi_{stem} = -1.0$ MPa), but increases would be small (+0.2 °Brix) compared to the relatively large yield penalty (-15%). Because wine grape growers in the US are typically paid based on yield, these first-year results suggest that there does not appear to be an economic incentive to delay the initiation of irrigation unless there is a premium paid to growers for higher Brix fruit. Work is ongoing evaluating treatment effects on secondary metabolites in fruit and wine quality.

Table 1. Responses of Δ baseline ψ_{stem} and actual measured ψ_{stem} at irritation initiation at each site and across all sites in 2021. For each variable, means followed by different letters within a column indicate statistically significant differences at $p < 0.05$.

Variable	Irrigation treatment	Site			All
		Eagle Point	Jacksonville	Ashland	
Δ baseline ψ_{stem} (MPa)	T1	-0.19 a	-0.37 a	-0.17 a	-0.24 a
	T2	-0.67 b	-0.45 a	-0.37 b	-0.49 b
	T3	-0.62 b	-0.63 b	-0.70 c	-0.65 c
	T4	-1.03 c	-0.88 c	-0.87 cd	-0.93 d
	T5	-0.99 c	-0.99 c	-0.97 d	-0.98 d
ψ_{stem} (MPa)	T1	-0.79 a	-0.89 a	-0.58 a	-0.75 a
	T2	-1.15 b	-0.98 a	-0.99 b	-1.06 b
	T3	-1.20 b	-1.13 b	-1.21 c	-1.16 b
	T4	-1.56 c	-1.53 c	-1.39 c	-1.49 c
	T5	-1.52 c	-1.47 c	-1.36 c	-1.45 c

Table 2. Responses of yield, berry fresh weight (FW), and total soluble solids to irrigation treatments at each site and across all sites in 2021. For each variable, means followed by different letters within a column indicate statistically significant differences at $p < 0.05$.

Variable	Treatment	Site			All
		Eagle Point	Jacksonville	Ashland	
Yield (t/ha)	T1	11.3 a	14.5	9.8 a	11.7 a
	T2	9.0 ab	13.6	8.3 ab	10.0 ab
	T3	9.1 ab	12.9	8.5 ab	9.9 ab
	T4	7.9 ab	13.5	7.1 bc	9.1 bc
	T5	7.3 b	12.3	5.8 c	8.0 c
Berry FW (g/berry)	T1	0.90 a	1.15 a	1.15 a	1.06 a
	T2	0.85 ab	1.05 b	1.08 a	0.99 b
	T3	0.85 ab	1.03 b	0.92 b	0.93 b
	T4	0.75 bc	0.99 b	0.86 bc	0.86 c
	T5	0.73 c	0.84 c	0.76 c	0.79 d
Total soluble solids (°Brix)	T1	20.9 b	25.1 ab	22.3 a	22.8 ab
	T2	20.8 b	26.0 a	22.3 a	23.0 a
	T3	21.0 b	25.8 ab	21.4 ab	22.7 ab
	T4	22.2 a	25.0 ab	20.3 b	22.7 ab
	T5	21.2 ab	24.8 b	20.3 b	22.1 b

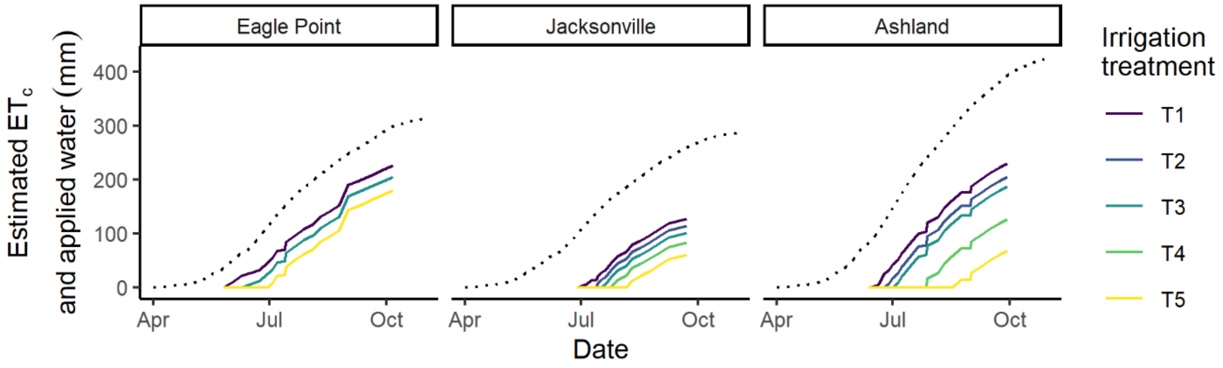

Figure 1. Applied water accumulation over the course of the growing season for each irrigation treatment at each site in 2021. Dashed line represents accumulation of estimated ET$_c$ at each site from 1 April to 31 October.

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