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The Effect of Supplemental Irrigation on a Dry-Farmed *Vitis vinifera* L. cv. Zinfandel Vineyard as a Function of Vine Age

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Abstract: With natural rainfall and surface water availability becoming scarce, prolonged droughts are expected to become more frequent, thereby creating issues for agriculture. In viticulture, a lack of rainfall is often supplemented with irrigation during the growing season and/or dormancy. However, with surface and groundwater resources declining in addition to current changes in rainfall patterns, it is unlikely that supplemental irrigation will continue to be an available tool for most growers. As such, this study aims to evaluate the effect of dry farming and supplemental irrigation during the growing season on vine performance and fruit composition as a function of vine age in Zinfandel grapevines. A historically dry-farmed vineyard block with interplanted vines of varying ages was evaluated during the 2021 growing season. Treatments included young vines (5–12 years old), control vines (2:1 ratio of old to young vines representative of the block), and old vines (40–60 years old); each age designation included irrigated and dry-farmed vines. Based on age-specific ET_c and to replenish 95% of crop evapotranspiration (ET_c), irrigation was manually applied to the irrigated treatment vines at véraison and véraison + 4 weeks. Results indicated no significant changes in phenological progression, leaf senescence, or physical berry analysis when irrigation was added to dry-farmed vines, as most differences were driven by vine age in most parameters measured. Irrigated vines were slightly more advanced in phenological growth and senescence progression compared to dry-farmed vines. Results suggest that the practice of applying supplemental irrigation during the growing season, provided winter rainfall or additional winter irrigation is sufficient, does not have significant impacts on vine performance. Thus, dry farming during the growing season is a reasonable alternative practice in Zinfandel, even in periods of drought.

Keywords: vine age; Zinfandel; irrigation; dry-farmed; phenology; gas exchange; climate change

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1. Introduction

Climate change is a rising concern for viticulturists and winemakers alike across a diverse set of global growing regions. There is demand from both industry and consumers to institute environmentally conscientious viticultural practices in response to these climatic shifts. The application of supplemental irrigation during the growing season continues to be common in most California wine grape vineyards. Although extensive research aimed at improving water conservation and berry quality indices has been performed, most studies have not considered the role of vine age when evaluating performance factors under regulated deficit irrigation (RDI) [1,2], sustained deficit irrigation [3], and/or partial root-zone dry [4,5]. Applying water efficiently with targeted irrigation techniques and instituting more sustainable practices in viticulture [6] has become a key consideration in agricultural management to help combat severe water shortages and increasing global air temperatures [7].

The application of vineyard irrigation is typically tightly regulated and applied in such a manner as to create and/or maintain some level of vine water stress, a principle based on studies that have demonstrated specific vine performance factors and wine quality can potentially increase when a minimal-to-moderate degree of water stress is imposed on the vine. Water stress has been shown to influence vegetative growth, wine quality, including color and aroma, and increase yields when irrigation is reduced from cluster closure to harvest [3]. The negative impact that excessive water stress and the timing applied can have on the vines, including reduced crop yield [8,9], canopy development, berry number and size, and other tissue expansion factors [10,11], is well documented. Consequentially, vine water status needs to be closely monitored to ensure efficiency, improve water productivity, and limit the amount of irrigation above and beyond plant requirements through improved irrigation techniques [12].

With evaporative losses in irrigation systems predicted to increase and the continuous threat to surface water availability, irrigation management systems have some disadvantages as climate change progresses [13]. Climate change affects every water use sector, especially agriculture, which globally consumes over 80% of total freshwater withdrawals [14]. Inevitably, as vineyard and agricultural acreage generally increase to support a growing global population, readily available water will not be enough to irrigate the majority of acres planted. Agricultural droughts are and will continue to be an issue. Changing irrigation techniques to fit an evolving climate has proven beneficial. A commonly used irrigation technique to improve water use efficiency is regulated deficit irrigation (RDI), which uses crop phenology and the vines' ability to resist extended water stress periods to apply a calculated water rate to replace potential vine evapotranspiration [15]. A different irrigation technique known as partial root-zone drying (PRD) keeps about half of the root system watered while the other half remains dry, alternating the half watered using low water volumes [6,16,17]. However, while RDI and different irrigation strategies contribute to water use efficiency and are used to avoid yield losses, spatial variability in water requirements in a whole vineyard differs and limits the total efficiency [18]. The use and implementation of these irrigation methods can also negatively impact surface and groundwater resources, increasing the pressure on freshwater resources in Mediterranean regions on a global scale. Alternatively, using dry-farming techniques to reduce water use should be considered when practicing precision irrigation and optimizing it to increase vineyard profitability [18]. Grapevines can adapt and respond to environmental changes. Indeed, a recent study from a vineyard in South Australia with own-rooted *Vitis vinifera* L. cv. Cabernet Sauvignon dry-farmed vines showed enhanced resilience to prolonged drought conditions, increasing intrinsic water use efficiency [19]. Dry farming has a vast history globally, with vineyards producing wine with a well-known reputation; it is a technique that should be used to decrease the amount of water used in a vineyard and effectively decrease the water footprint [19]. To successfully implement dry farming in a vineyard, it is essential to have a deep understanding of viticultural techniques [19]. These techniques need to be adapted to suit the changing climate conditions and ensure optimal yield and quality [19,20]. This is especially important when you consider the well-established practice of dry farming in the old vine industry [19,20].

Considering increasing temperatures and extended periods of drought in California [14], it is reasonable to expect vineyard managers to modify their practices, especially water use [21]. Grape-growing regions in California are notably diverse in geography and climate. As of now, there are few vineyards that are truly dry-farmed. California and other new world regions often apply irrigation practices to control vegetative growth and productivity [22]. The Mediterranean climate regions in California typically have minimal rainfall during the growing season and little seasonal variation in natural rainfall events.

The Central Coast of California, a prominent region with several distinguished American Viticultural Areas (AVAs), is a Mediterranean-climate region stretching along the coast of California from San Francisco Bay to Santa Barbara County. Most vineyards on the Central Coast of California apply supplemental irrigation, intending to improve quality, yield, phenolic composition, and water efficiency [23,24]. Studies have shown that the timing of reduced deficit irrigation on grapes before and after véraison can increase phenolics and anthocyanins [12,23,25]. As the effects of climate change increase, yield and growth changes observed in vineyards will reflect the influence of climatic factors and the impact of management techniques, technology use, and atmospheric CO_2 contents in the atmosphere [26,27]. According to the most recent Intergovernmental Panel on Climate Change (IPCC) report released in 2022, human influence on emissions from fossil fuels and agriculture has caused an increase in CO_2, methane, and nitrous dioxide in the atmosphere and overall changes in the ocean cryosphere and biosphere [14]. In the last decade alone, the global surface temperature increased by about 1.09 °C and is predicted to increase by 1.5 °C between 2030 and 2052 if human activity continues to be the main driver of environmental changes [14]. Environmentally conscious agricultural practices must be adopted moving forward, including more sustainable grape production through the improvement of water management and usage.

Changes and adaptations are needed to maintain quality in a changing environment and simultaneously preserve natural water resources [18]. One potential option for the future would be to implement dry farming as a standard practice in more vineyards as a means to be more sustainable. However, not all varieties are suitable for dry-farmed systems, especially considering the impact climate, region, and soils can have on certain cultivars. Within these constraints, Mediterranean climate cultivars such as Zinfandel, Grenache, or Carignane are sometimes grown as dry-farmed on the Central Coast of California. Specifically, on the west side of the Paso Robles AVA, Zinfandel has gained a reputation as a high-quality cultivar due in part to the cool marine air influence. Unsurprisingly, dry-farmed vineyards are highly regarded as more sustainable in practice [28,29]. In this area, several renowned vineyards have practiced dry farming for a long time and have older vines. As demonstrated, the age of a grapevine affects its growth, which can impact its physiological and phenological development [30].

Irrigation studies with vine age as a factor are scarce, though they are greatly needed to understand the effect of vine age on dry-farmed vine performance and determine if and how vine performance is influenced by dry-farming rather than providing supplemental irrigation. There is a knowledge gap in understanding the effect of irrigation on dry-farmed vines as a function of vine age. Although dry farming as a technique has been used in both the old world and new world, it has not been scientifically studied. By establishing dry-farmed vineyards with lower density, grape growers can opt for a sustainable method that reduces irrigation inputs [29,31]. While this method may result in lower yields, it can also lead to an increase in resilience to drought and reduced production costs [29,31]. However, further research is necessary to fully comprehend the physiological impact on dry-farmed vines as a function of vine age. Therefore, the aim of this study was to examine the influence supplemental irrigation has on vine performance and wine quality in traditionally dry-farmed vines as a function of vine age. This study was executed in a historically dry-farmed California Central Coast vineyard interplanted with young and old *Vitis vinifera* L. cv Zinfandel. This is the third publication in a series relating to dry-farmed vines with varying vine ages in an interplanted vineyard. This is a follow-up to two prior publications that focused on varying vine ages in a commercial setting during the 2019 and 2020 growing seasons. The purpose of this publication is to assess grapevine physiology, vegetative growth, and fruit composition in traditionally dry-farmed vines by introducing an irrigation treatment during the 2021 growing season, which marks the third year of the study [32,33].

2. Materials and Methods

2.1. Site Description and Experimental Design

This experiment was conducted during the 2021 growing season at a commercial vineyard in Templeton, CA (35°34′07.9″ N, 120°42′14.7″ W), USA, located in the Templeton Gap District of the Paso Robles AVA (American Viticultural Area). According to the CIMIS data analyzed from the nearest weather station in Atascadero (Station 163), the site is classified as a Winkler Region III. The commercial vineyard was first planted in 1945 and, aside from establishment and occasional winter applications of supplemental irrigation in uncharacteristically hot years, has been historically dry-farmed. This site is conventionally managed with head-trained, spur-pruned Zinfandel vines with a 2.44 × 2.44 m spacing. The leading soil series is Lockwood Channery loam with 0–2% slopes and a low runoff class in most of the experimental block, and some parts of the block with Lockwood Shaly loam with a 2–9% slope and a medium runoff class [34]. Soil pits about 1.73 m in depth were dug using a backhoe in the experimental block, which indicated deep to very deep, with depths of more than 139.7 cm deep, slightly acid to neutral loam soils [32].

The experimental block is interplanted with young and old vines; the old vines remain own-rooted (*Vitis vinifera* L. cv. Zinfandel), while the young vines are grafted onto St. George rootstock. When production decreased, the grower removed the older vines and replanted them with genetically identical scion material from the source plants grafted to St. George (*Vitis rupestris* Scheele). Given that there is no legal definition for an old vine, age was defined by the vines on the block, with the age range of the old vines being between 40 and 60 years old and the young vines being about 5–12 years old. The described vines from the experimental block were used to establish a completely randomized design [32].

An irrigation treatment was applied during the 2021 growing season to identify irrigation's effects on phenology, growth, and gas exchange factors in historically dry-farmed vines. A control treatment was included, representing the experimental block with a ratio of 2:1 old to young vines. In an effort to account for variations in sugar accumulation and phenological rates, the control treatment was included to represent the old:young vine proportion in the whole block. A total of 72 vines were used (n = 72), whereby half remained dry-farmed and the other half had irrigation applied during véraison and véraison + 4 weeks. A total of six treatments were established, as follows: irrigated old vines; dry-farmed old vines; irrigated young vines; dry-farmed young vines; irrigated control vines; and dry-farmed control vines (n = 12 for each treatment).

The amount of irrigation applied was calculated by a formula to find the average estimated water use of each age group, such that irrigation was applied to irrigate 95% of ET_c from the previous two-week period. The shaded area per grapevine, crop evapotranspiration from the California Irrigation Management Information System (CIMIS), and crop coefficient (K_c) were used to calculate total liters per vine to apply accordingly per age group. The crop coefficient (K_c) was first calculated using the shaded area per grapevine, specifically for head-trained vines, by calculating the average diameter of the shaded area north-south and east-west of each vine age treatment. The shaded area under the vines was calculated at midday, when the sun was at its highest point, to represent the shaded area well. Total grapevine crop evapotranspiration (ET_c) was then calculated by dividing the total reference crop evapotranspiration (ET_o), taken from the nearest CIMIS station, by the grapevine crop coefficient (K_c) already calculated (CIMIS station). The irrigation efficiency was then calculated to irrigate at 95% efficiency by dividing the total ET_c by 95% efficiency. The total ET_c in liters per vine was calculated by converting the total grapevine crop ET_c from cm to liters. Then multiplied by the time, it takes one liter to fully drain out from the holes at the bottom of the bucket, about 14 L/min, to find the time required to apply irrigation slowly.

Using these steps to calculate total irrigation applied for a 95% water use-efficiency recharge level, at véraison, 76.58 L/vine were applied to the old vines, 72.07 L/vine were applied to young vines, and 81.69 L/vine were applied to the control vines (n = 12). The amount applied at véraison + 4 weeks was calculated to account for the senescing vines and decrease in canopy area, with 74.23 L/vine applied to old vines, 69.88 L/vine applied to young vines, and 79.19 L/vine applied to control vines. Water was manually applied using four 18.83-L buckets on each of the four cardinal sides of the 36 vines selected for irrigation treatment. Total irrigation applied to old vines at véraison and véraison + 4 weeks was 150.81 L/vine; for young vines, 141.95 L/vine was applied, and for control vines, 160.88 L/vine was applied in total for both irrigation applications. The buckets were drilled at the bottom with two holes with a diameter of about 0.9525 cm, to minimize evaporation and allow for maximum plant uptake with the slow drip method. A slow drip method was used to meet the time needed for irrigation to be efficiently applied and used, with a rate of 59,769 mL/h for about 19 min total, to drain the water entirely.

2.2. Phenology and Senescence Tracking

Phenology tracking for all treatments started before véraison and ended at harvest using the modified Eichhorn-Lorenz (E-L) system [35]. Phenology was recorded every two weeks using the E-L scale to give a numerical indication of the phenology's progression throughout the 2021 growing season. The Dodson–Walker Senescence Scale was used to record the progression of senescence by tracking leaf chlorosis and abscission every two weeks starting after harvest [36].

2.3. Gas Exchange Measurements

Gas exchange measurements were collected the day after supplemental irrigation was applied to the vines at véraison and véraison + 4 weeks to collect data on photosynthetic rate (A_n), stomatal conductance (g_s), leaf water potential (Ψ_{leaf}), and active photosynthetic radiation. Measurements were performed diurnally five times throughout the day, including pre-dawn (0400), mid-morning (0800), mid-day (1200), mid-afternoon (1600), and sundown (2000). Three replicates of the six treatments were used during these diurnal measurements, with 18 total vines used. Photosynthetic rate (A_n) and stomatal conductance (g_s) were measured first using the LI-6400XT portable photosynthesis system (LICOR Biosciences, Lincoln, NE, USA) on a newly mature, fully sun-exposed leaf, specifically clamping onto the leaf on the right side of the main vein on each leaf. Immediately after, the stomatal conductance (g_s) was measured again using the LI-600 porometer/fluorometer (LICOR Biosciences, Lincoln, NE, USA) on the same leaf used before with the LI-6400XT. The following measurement was leaf water potential on the same leaf as before using a standard pressure chamber (PMS Instruments, Albany, OR, USA). The leaf was first covered with a plastic bag, then cut with a razor blade at an angle, and immediately placed into the pressure chamber to record the reading. All measurements were done consecutively and quickly, right after the other, using the same leaf and to the right of the main vein, except for leaf water potential measurements. All measurements were made in quick succession at each of the five measurement time frames throughout the day, during véraison and véraison + 4 weeks.

2.4. Vine Yield and Pruning Weights

During harvest, cluster counts and yield were evaluated per sample vine (n = 12) for all six treatments. Harvest dates differed depending on maturity levels leading up to the target Brix level. Each sample vine was individually harvested into bins to determine the exact yield by counting clusters and the overall yield weight. Cluster counts and yield were evaluated on-site as soon as they were harvested. The bin weight was tared before weighing each vine.

During dormancy (225 days post-budbreak), the vines were professionally spur-pruned. All canes pruned were collected and weighed using a digital hanging scale (n = 12). The yield:pruning weight ratio (Ravaz index) was determined by dividing the yield per sample vine by the corresponding pruning weight of each sample vine for the current growing season.

2.5. Berry Physical and Chemical Analysis at Harvest

At harvest, 300 berries were randomly selected per treatment and frozen with the pedicel attached for future analysis. In the physical berry analysis, 30 berries per treatment were thawed to room temperature before starting the analysis. Each set of 30 berries was weighed and recorded before each berry was carefully peeled to remove the skin with little to no pulp with a small metal spatula and tweezers. The skin was carefully dried using a paper towel to remove any moisture and pulp retained on the skin before weighing it for treatment. Seeds were removed from the pulp, counted, and weighed for each treatment. The skins and seeds were oven-dried at 60 °C for 5 h for the seeds and 3–4 h for the skins.

Another set of about 300 fresh berries was collected on each harvest date and analyzed for basic chemistry, including titratable acidity (TA), pH, L-malic acid, tartaric acid, Brix, glucose + fructose, ammonia, alpha-amino compounds (as nitrogen), yeast assimilable nitrogen, and potassium, all at the respective harvest dates [37].

2.6. Statistical Analysis

All statistical analyses were performed using JMP 16 (SAS Institute, Cary, NC, USA). The collected data were analyzed using a one-way ANOVA and two-way ANOVA. Multiple comparisons were performed on variables that were statistically significant and evaluated using the Student's *t*-test. A one-way analysis of variance considering both vine age and irrigation was performed on all parameters. A two-way analysis of variance was performed on all parameters except phenology, considering the vine age and irrigation. Figures were created on GraphPad Prism Version 9.4.0.

3. Results

3.1. Climate Data

Weather data from the nearest CIMIS (California Irrigation Management Information System) weather station located in Atascadero (station 163) was used to determine annual and seasonal precipitation and calculate growing degree days (GDD). The 2021 growing season was classified as a Winkler region (III) with 1773.8 GDD, and seasonal precipitation was 67.1 mm. Weather data from 2011 to 2020 was used to compare differences in precipitation, temperature, and GDD from 10 years before this study. The average growing degree days from the 2011 to 2020 growing seasons were 1717.9 GDD, classifying it as a Winkler region (III) with an average of 10 years. Considering that the 2019 and 2020 growing seasons were classified as Winkler regions (III) [33], GDD in 2021 was lower than in 2020. Annual precipitation for 2021 was higher compared to the average of 2011–2020, while seasonal precipitation (April–October) was lower compared to the average of the previous ten years. The average GDD from 2011 to 2020 is lower compared to the 2021 growing season by 55.9 GDD (Table 1). The maximum air temperature was higher from May to July in the 2021 growing season, and the minimum air temperature was higher from July to September (Table 2). The average air temperatures in 2021 were higher from May to August compared to the average from 2011 to 2020 (Table 2). During the summer season leading up to harvest, the 2021 growing season had, on average, higher temperatures than the average of the previous 10 years.

Table 1. Growing degree days (GDD); Winkler region classification; and precipitation for Atascadero, California (USA) CIMIS weather station 163. Annual precipitation during 2021 does not include supplemental winter irrigation applied by the grower.

Growing Season	Growing Degree Days (GDD) [1]	Winkler Region	Annual Precipitation (mm) [2]	Seasonal Precipitation (mm) [3]
Average 2011–2020	1717.9	III	319.4	81.5
2021	1773.8	III	339.9	67.1

[1] Calculated from 1 April–31 October in degree Celsius with a baseline of 10 °C. [2] Sum of precipitation from 1 January–31 December for 2011 and 2021. [3] Sum of precipitation from 1 April–31 October for 2011 and 2021.

3.2. Phenology and Senescence Tracking

Phenology progression was evaluated and recorded for all treatments based on the Modified Eichhorn–Lorenz (E-L) system from véraison to dormancy during the 2021 growing season [35]. Statistically significant differences were observed at véraison + 6 weeks

(155 days post-budbreak), harvest (169 days post-budbreak), harvest + 2 weeks (183 days post budbreak), and harvest + 6 weeks (211 days post-budbreak) (Figure 1; $p = 0.0004$, $p \leq 0.0000$, $p \leq 0.0000$, and $p \leq 0.0028$, respectively). For most of the phenology tracking, after irrigation was applied at véraison and véraison + 4 weeks, the irrigated vines were slightly ahead developmentally compared to the dry-farmed vines. While this was evident, irrigation as an effect was not statistically significant, while age as an effect was statistically significant (Figure 1; $p = 0.0423$). Irrigated young vines and dry-farmed young vines were more phenologically advanced from véraison + 6 weeks to harvest + 2 weeks compared to the irrigated old vines and dry-farmed old vines. Vine age has proven to create a difference in berry maturity and ripening, as seen in the previous study. However, in the present study, irrigation did not produce a significant difference [33].

Table 2. Monthly average air temperature, minimum air temperature, and maximum air temperature for Atascadero, California (USA) weather station 163 during 2011–2020 and the 2021 growing seasons.

	2011–2020			2021		
Month	**Average Air Temperature (°C)**	**Minimum Air Temperature (°C)**	**Maximum Air Temperature (°C)**	**Average Air Temperature (°C)**	**Minimum Air Temperature (°C)**	**Maximum Air Temperature (°C)**
April	13.3	5.0	22.4	12.5	4.0	22.4
May	14.9	6.5	24.1	15.6	6.2	25.7
June	18.9	9.3	29.1	19.9	10.9	30.2
July	20.6	11.2	31.1	21.4	11.9	32.7
August	20.4	10.8	31.9	20.5	11.2	31.7
September	18.9	9.2	30.8	18.7	9.3	30.5
October	15.3	6.0	26.7	14.1	5.3	24.1

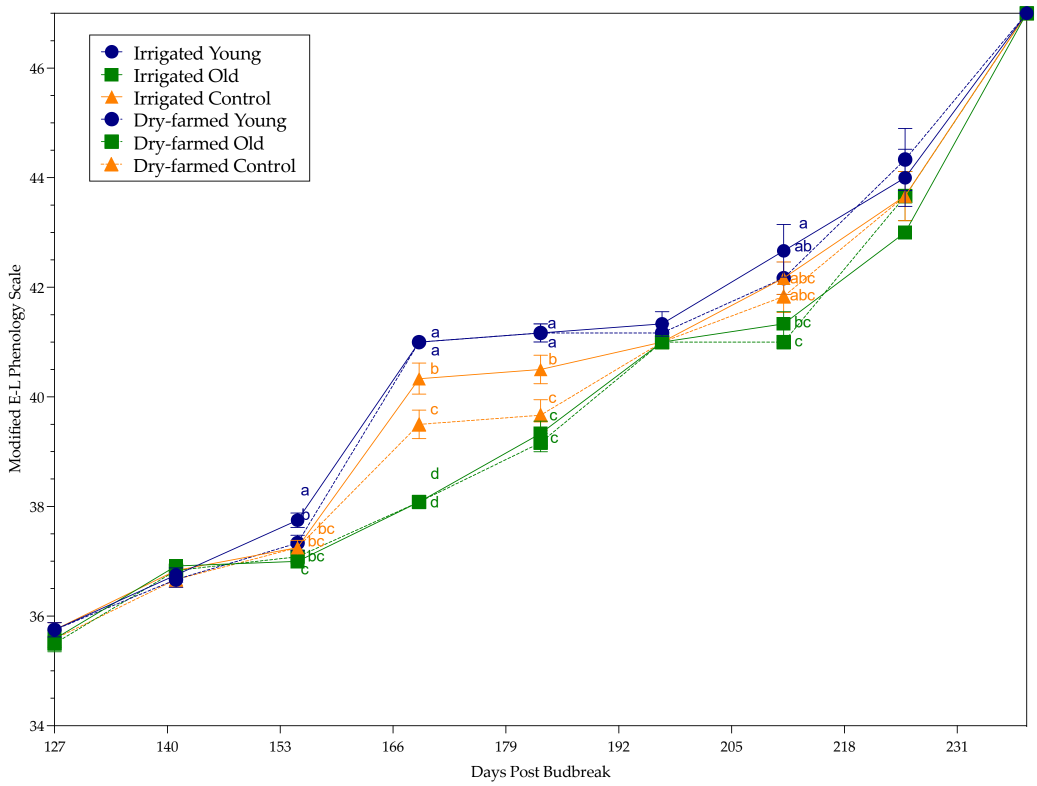

Figure 1. Phenology ratings throughout the 2021 growing season. Irrigation was applied at véraison and véraison + 4 weeks; phenology ratings for irrigated treatments started 113 days after budbreak (véraison). Treatment means are followed by standard error bars. Different letters indicate significant differences between treatment groups for the Student's *t*-test ($n = 12$).

Senescence progression during the 2021 growing season was evaluated and recorded using the Dodson–Walker Senescence Scale, starting at harvest for the first treatment [36]. Regardless of irrigation treatment, young vines consistently had a higher degree of chlorosis and leaf abscission than old vines as the season progressed. Although not statistically significant, the irrigated young vines had a slightly quicker progression of chlorosis compared to the dry-farmed young vines (Table 3). Statistically significant differences in leaf chlorosis between all treatments were seen at harvest (169 days post-budbreak), harvest + 6 weeks (211 days post-budbreak), and dormancy (225 days post-budbreak) (Table 3; $p = 0.0119$, $p = 0.0140$, and $p = 0.0068$). In leaf abscission, statistically significant differences were observed at 169 days and 183 days post-budbreak (Table 3; $p = 0.0320$ and $p = 0.0190$). The difference in the degree of leaf chlorosis and leaf abscission was evident, with young vines having a higher progression of overall leaf senescence than old vines. Irrigation as an effect showed no statistical significance in either leaf chlorosis or leaf abscission; most statistical differences were evident by vine age as an effect (Table S1). No significant differences were seen in the interaction between irrigation and vine age (Table S1).

3.3. Gas Exchange Measurements

In the 2021 growing season, there was no difference in mid-day stomatal conductance (g_s) at véraison. However, at véraison + 4 weeks, there was significant variation in mid-day stomatal conductance (Figure 2; $p = 0.0210$), yet only vine age had a statistically significant effect. Irrigation had no statistical significance in mid-day stomatal conductance at véraison or véraison + 4 weeks (Figure 2). At mid-day, stomatal conductance for young vines tended to be slightly higher compared to old vines at véraison; however, there was no significance across all treatments (Figure 2). At véraison + 4 weeks, mid-day stomatal conductance in irrigated young vines had slightly higher readings compared to mid-day at véraison. In contrast, old vines had stomatal conductance rates about the same on both measurement days (Figure 2). At pre-dawn in both véraison and véraison + 4 weeks, no statistical significance was recorded. Photosynthetic rate (A_n) had no statistical difference at pre-dawn and mid-day in both the gas exchange measurement days, at véraison and véraison + 4 weeks (Figure 2). No statistical significance was seen in the interaction effects of vine age and irrigation (Figure 2).

Leaf water potential (Ψ_{leaf}) was also measured consecutively during gas exchange measurements at véraison and véraison + 4 weeks during the 2021 growing season (Table 4). There was statistical significance at pre-dawn during véraison + 4 weeks (Table 4; $p = 0.0481$). Irrigation was a significant factor as an effect, but vine age was not (Table S2; $p = 0.0116$, $p = 0.1314$, respectively). No statistical significance was observed at véraison. A slight trend is seen in older vines being more stressed out and producing slightly higher levels of leaf water potential (Ψ_{leaf}), although this is not statistically significant (Table 4).

3.4. Vine Yield and Pruning Weights

Due to the differences in maturity progression and sugar accumulation, treatments had varying harvest dates to meet the target Brix. At harvest, cluster counts and cluster weights per vine were recorded at each harvest date, according to the target Brix of 23 ± 0.5. Irrigated young vines were harvested first at 156 days post-budbreak, followed by both the dry-farmed and irrigated control treatments at 167 days post-budbreak. At 171 days post-budbreak, the dry-farmed control treatment vines were harvested, followed by the irrigated and dry-farmed old vines at 180 days post-budbreak.

Differences among all treatments were significant in both cluster counts per vine and yield per vine. (Table 5; $p \leq 0.0001$; $p = 0.0142$, respectively). Both Old and Control vines had significantly more clusters per vine than Young vines in both Dry-farmed and Irrigated treatments (Table 5). Only vine age was statistically significant, whereas irrigation treatments showed no significance as an effect to cluster counts per vine (Table S3; Irrigation $p = 0.3069$; vine age $p \leq 0.0001$). Yield for Old vines averaged 8.98 kg/vine, while Young vines averaged 5.70 kg/vine; vine age showed statistical significance (Table S3; $p = 0.0594$).

Irrigation treatment did not show statistical significance. However, the differences in the averages were 1.78 kg, irrigated vines averaged 8.74 kg, and dry-farmed vines had an average of 6.96 k/vine (Table S3; p = 0.0062).

Table 3. One-way analysis of variance (ANOVA) showing senescence (leaf chlorosis and abscission) tracking during the 2021 growing season (n = 12). Treatment means followed by the standard error of the mean. Different letters within a column indicate differences between treatment groups based on the Student's t-test (n = 12). Significant p-values (<0.05) are shown in bold fonts.

Growth Stage	Days Post Budbreak	Irrigation	Vine Age	Degree of Leaf Chlorosis	Degree of Leaf Abscission
Harvest	169	Irrigated	Young	1.67 ± 0.33 a	0.42 ± 0.19 ab
			Old	0.83 ± 0.11 a	0.17 ± 0.11 b
			Control	1.25 ± 0.13 a	0.58 ± 0.23 ab
		Dry-farmed	Young	1.58 ± 0.15 a	1.17 ± 0.30 a
			Old	1.08 ± 0.19 a	0.42 ± 0.19 ab
			Control	0.83 ± 0.21 a	0.42 ± 0.19 ab
			p-value	**0.0119**	**0.0320**
Harvest + 2 weeks	183	Irrigated	Young	1.75 ± 0.33 a	1.33 ± 0.48 a
			Old	1.08 ± 0.08 a	0.17 ± 0.11 b
			Control	1.42 ± 0.15 a	1.00 ± 0.25 ab
		Dry-farmed	Young	1.75 ± 0.22 a	1.42 ± 0.29 a
			Old	1.25 ± 0.13 a	0.58 ± 0.23 ab
			Control	1.25 ± 0.22 a	0.42 ± 0.19 ab
			p-value	0.1104	**0.0109**
Harvest + 4 weeks	197	Irrigated	Young	2.92 ± 0.42 a	1.58 ± 0.43 a
			Old	2.08 ± 0.15 a	0.92 ± 0.08 a
			Control	2.00 ± 0.28 a	1.17 ± 0.30 a
		Dry-farmed	Young	2.42 ± 0.26 a	1.58 ± 0.26 a
			Old	1.92 ± 0.15 a	1.17 ± 0.21 a
			Control	2.08 ± 0.26 a	1.00 ± 0.25 a
			p-value	0.0962	0.3812
Harvest + 6 weeks	211	Irrigated	Young	3.50 ± 0.40 a	2.58 ± 0.40 a
			Old	2.42 ± 0.19 ab	1.92 ± 0.08 a
			Control	2.42 ± 0.26 ab	1.83 ± 0.27 a
		Dry-farmed	Young	3.17 ± 0.34 ab	2.42 ± 0.42 a
			Old	2.17 ± 0.17 b	1.83 ± 0.11 a
			Control	2.58 ± 0.31 ab	1.42 ± 0.26 a
			p-value	**0.0140**	0.0611
Dormancy	225	Irrigated	Young	5.00 ± 0.30 a	4.33 ± 0.43 a
			Old	3.67 ± 0.28 ab	3.08 ± 0.4 a
			Control	4.08 ± 0.34 ab	3.50 ± 0.47 a
		Dry-farmed	Young	4.58 ± 0.34 ab	3.75 ± 0.51 a
			Old	3.25 ± 0.41 b	2.83 ± 0.41 a
			Control	3.83 ± 0.34 ab	3.17 ± 0.44 a
			p-value	**0.0068**	0.2116

At dormancy, each treatment (n = 12) was pruned on a per-vine basis to measure seasonal vegetative growth. Pruned canes were collected and weighted using a hand-held scale (H-110 digital hanging scale, 222 American Weight Scales). Dry-farmed young vines had a higher average pruning weight compared to irrigated young vines, while irrigated old vines had a slightly higher average pruning weight compared to dry-farmed old vines (Table 5). Dry-farmed and irrigated young vines had a slightly higher average pruning weight per vine, although it was not significant (Table 5; $p = 0.2224$). There was no statistical significance in pruning weights for vine age, irrigation treatment, or the interaction of both as an effect (Table S3; $p = 0.1151$; $p = 0.4545$; $p = 0.3464$, respectively). Dry-farmed old vines had the highest yield-to-pruning weight ratio (Ravaz index), but it was not significant compared to irrigated old vines (Table 5). The Ravaz index was significantly affected by vine age, with young vines having an average Ravaz index of 5.05 in contrast with old vines, which had an average Ravaz index of 11.09 (Table S3; $p \leq 0.0001$). Irrigation treatment and the interaction between irrigation and vine age were not statistically significant (Table S3; $p = 0.7012$; $p = 0.5439$, respectively).

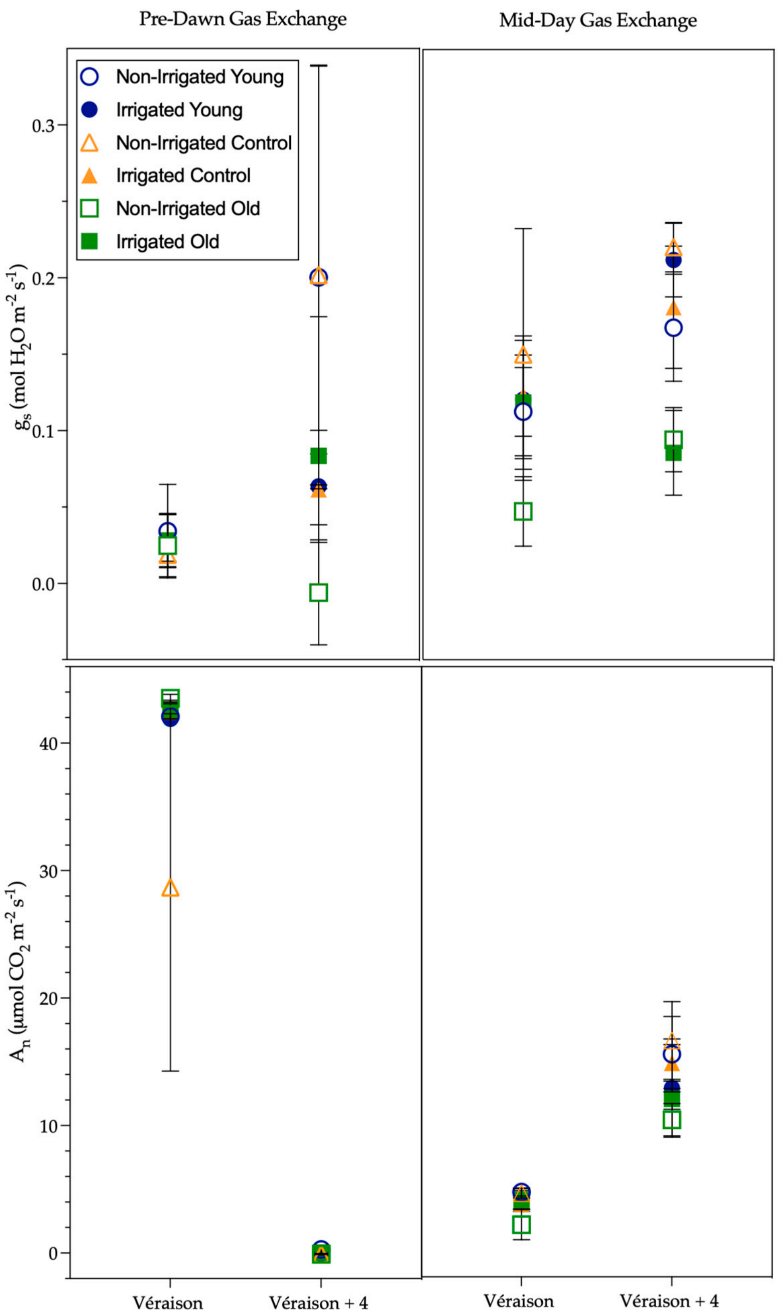

Figure 2. Gas exchange parameter showing pre-dawn photosynthetic rate (A_n) and stomatal conductance (g_s) at véraison and véraison + 4 weeks, also mid-day photosynthetic rate (A_n) and stomatal conductance (g_s) at véraison and véraison + 4 weeks ($n = 3$). Treatment means followed by the standard error of the mean.

Table 4. One-way analysis of variance (ANOVA) showing leaf water potential measurements at véraison (07/23/21) and véraison + 4 weeks (08/20/21). Treatment means followed by standard error of the mean. Different letters within a column indicate significant differences between treatment groups based on the Student's *t*-test ($n = 3$). Significant *p*-values (<0.05) are shown in bold fonts.

Growth Stage	Irrigation	Vine Age	Pre-Dawn Ψleaf (mPa)	Mid-Day Ψleaf (mPa)
Véraison	Irrigated	Young	0.450 ± 0.08 a	1.100 ± 0.03 a
		Old	0.467 ± 0.06 a	1.100 ± 0.05 a
		Control	0.483 ± 0.04 a	1.067 ± 0.06 a
	Dry-farmed	Young	0.433 ± 0.02 a	1.133 ± 0.04 a
		Old	0.533 ± 0.04 a	1.133 ± 0.02 a
		Control	0.433 ± 0.03 a	1.133 ± 0.03 a
		p-value	0.7091	0.8176
Véraison + 4 weeks	Irrigated	Young	0.387 ± 0.05 b	1.003 ± 0.04 ab
		Old	0.420 ± 0.03 b	0.980 ± 0.07 ab
		Control	0.430 ± 0.02 b	1.030 ± 0.02 ab
	Dry-farmed	Young	0.443 ± 0.01 b	0.927 ± 0.06 b
		Old	0.547 ± 0.02 a	1.117 ± 0.02 ab
		Control	0.473 ± 0.04 ab	1.003 ± 0.05 a
		p-value	**0.0481**	0.1959

Table 5. One-way analysis of variance (ANOVA) showing treatment means followed by standard error of the mean. Different letters within a column indicate significant differences between treatment groups based on the Student's *t*-test ($n = 12$). Significant *p*-values (<0.05) are shown in bold fonts.

Irrigation	Vine Age	Cluster Count Per Vine	Yield Per Vine (kg)	Pruning Weights Per Vine (kg)	Ravaz Index
Irrigated	Young	32.33 ± 1.55 b	5.64 ± 0.61 c	1.16 ± 0.08 ab	5.09 ± 0.60 c
	Old	67.18 ± 8.61 a	10.65 ± 1.67 a	1.08 ± 0.15 ab	10.65 ± 1.02 ab
	Control	62.58 ± 7.58 a	9.38 ± 1.54 ab	1.19 ± 0.15 ab	8.75 ± 1.38 ab
Dry-farmed	Young	35.00 ± 3.10 b	5.76 ± 0.59 c	1.29 ± 0.15 a	5.00 ± 0.60 c
	Old	60.64 ± 5.07 a	6.90 ± 0.92 bc	0.82 ± 0.14 b	11.67 ± 1.36 a
	Control	57.83 ± 6.24 a	8.37 ± 1.16 abc	1.07 ± 0.12 ab	8.17 ± 0.98 b
	p-value	**<0.0001**	**0.0142**	0.2224	**<0.0001**

3.5. Berry Physical and Chemical Analysis

Physical berry analysis, including berry skin weight and seed weight (fresh and dried), was measured by treatment ($n = 30$) at harvest. Results were averaged on a per-berry basis in both fresh and dried weight (Table 6). Fresh and dried skin weight were statistically significant (Table 6; $p = 0.0030$; $p = 0.0077$, respectively), with vine age resulting in a significant effect in the interaction between vine age and irrigation (Table S4; dried skin weight $p = 0.0007$; $p = 0.0058$, respectively). However, in both fresh and dried skin weight, irrigation was not a significant contributing factor (Table S4; $p = 1.0000$; $p = 1.004$, respectively). Fresh berry weight, fresh and dried seed weights, and seeds per berry were not statistically significant in any individual variable or the interaction between variables. The solid (skin and seeds) ratio in the irrigated treatment was 11% of the total berry mass, and the skin proportion was about 7% of the whole berry mass. While nearly similar, the solid-to-liquid ratio in dry-farmed vines was 10%, and the skin proportion was 7%. Overall, the only differences in the physical analysis of berries at harvest were seen with age as an effect, only in fresh and dried skin weight, and with irrigation not as a contributing factor. Irrigation had no significant effect overall in the physical berry analysis.

Table 6. Berry fresh weight, dry weight, and seed weight/number analysis on a per single berry basis. One-way analysis of variance (ANOVA) showing treatment means followed by standard error of the mean. Different letters within a column indicate significant differences between treatment groups based on the Student's *t*-test (n = 12). Significant *p*-values (<0.05) are shown in bold fonts.

Irrigation	Vine Age	Berry Fresh Weight (g)	Fresh Skin Weight (g)	Fresh Seed Weight (g)	Seeds Per Berry	Dried Skin Weight (g)	Dried Seed Weight (g)
Irrigated	Young	1.75 ± 0.02 a	0.16 ± 0.01 a	0.06 ± 0.00 a	2.03 ± 0.04 ab	0.07 ± 0.01 a	0.05 ± 0.00 a
	Old	1.90 ± 0.09 a	0.13 ± 0.01 b	0.06 ± 0.00 a	1.86 ± 0.08 b	0.05 ± 0.00 b	0.05 ± 0.00 a
	Control	1.75 ± 0.05 a	0.10 ± 0.01 c	0.07 ± 0.00 a	2.03 ± 0.07 ab	0.05 ± 0.00 b	0.05 ± 0.00 a
Dry-farmed	Young	1.86 ± 0.07 a	0.15 ± 0.01 ab	0.07 ± 0.01 a	2.15 ± 0.09 a	0.05 ± 0.00 b	0.05 ± 0.00 a
	Old	1.90 ± 0.02 a	0.12 ± 0.01 bc	0.06 ± 0.00 a	2.03 ± 0.05 ab	0.05 ± 0.00 b	0.05 ± 0.00 a
	Control	1.91 ± 0.04 a	0.12 ± 0.00 bc	0.07 ± 0.00 a	2.01 ± 0.09 ab	0.05 ± 0.00 b	0.05 ± 0.00 a
	p-value	0.1619	**0.0030**	0.7708	0.2060	**0.0077**	0.9588

Berry chemistry properties were measured at each treatment-specific harvest date from a sample of 300 berries per replicate (n = 3). Differences in titratable acidity (TA) were significant, with irrigated vines having a higher average TA than the dry-farmed (Table 7; $p \leq 0.0001$). There was a significant irrigation treatment × vine age interaction in titratable acidity found at harvest (Table S5; p = 0.0112). Both vine age and irrigation were also statistically significant as individual effects on titratable acidity (Table S5; $p \leq 0.0001$; $p \leq 0.0001$; respectively). Vine age as an individual effect showed minor statistical significance for pH during harvest (Table S5; p = 0.0435); no significance was found in irrigation treatment or the interaction (Table S5; p = 0.6629; p = 0.1723, respectively). Brix levels at the time of harvest showed no difference, which is what was preferred, as target Brix levels need to be nearly the same (Target Brix 23 ± 0.5) to proceed with winemaking steps (Table 7; p = 0.9248).

Table 7. Berry analysis at harvest, displaying Brix, pH, and TA. One-way analysis of variance (ANOVA) showing treatment means followed by standard error of the mean. Different letters within a column indicate significant differences between treatment groups based on the Student's *t*-test (n = 3). Significant *p*-values (<0.05) are shown in bold font.

Irrigation	Vine Age	Brix	pH	Titratable Acidity (TA) (g/L)
Irrigated	Young	23.63 ± 0.29 a	3.59 ± 0.01 a	7.20 ± 0.10 a
	Old	23.20 ± 0.25 a	3.42 ± 0.01 a	5.93 ± 0.03 d
	Control	23.50 ± 1.12 a	3.45 ± 0.09 a	6.77 ± 0.03 b
Dry-farmed	Young	23.60 ± 0.21 a	3.50 ± 0.01 a	6.70 ± 0.06 b
	Old	22.97 ± 0.83 a	3.49 ± 0.02 a	5.87 ± 0.09 d
	Control	22.97 ± 0.09 a	3.43 ± 0.01 a	6.33 ± 0.03 c
	p-value	0.9248	0.0894	**<0.0001**

Berry samples at harvest were analyzed for additional berry chemistry and composition parameters. Significant differences were seen in L-malic acid, ammonia, alpha-amino compounds, and yeast-assimilable nitrogen (YAN) (Table 8). Both irrigated and dry-farmed old vines showed lower levels of malic acid during harvest, with the vine age treatments being the primary cause of the differences observed (Table S6). A significant irrigation treatment x vine age interaction was found in L-malic acid (Table S6; p = 0.0176), both vine age and irrigation treatment showed significance as individual effects (Table S6; $p \leq 0.0001$; p = 0.0079, respectively). Vine age as an individual effect showed statistical significance in ammonia, alpha-amino compounds, and yeast assimilable nitrogen (Table S6; p = 0.0016; $p \leq 0.0001$; $p \leq 0.0001$, respectively). However, irrigation did not show any significant effect on these response variables. Overall, besides the statistical significance seen in L-malic acid, the irrigation treatment as an effect showed no statistical differences in the different berry composition parameters collected at harvest.

Table 8. Detailed berry composition parameters at harvest. One-way analysis of variance (ANOVA) showing treatment means followed by standard error of the mean. Different letters within a column indicate significant differences between treatment groups based on the Student's *t*-test (n = 3). Significant *p*-values (<0.05) are shown in bold font.

Irrigation	Vine Age	L-Malic Acid (g/L)	Tartaric Acid (g/L)	Glucose + Fructose (g/L)	Ammonia (mg/L)	Alpha-Amino Compounds (as N) (mg/L)	Yeast Assimilable Nitrogen (mg/L)	Potassium (mg/L)
Irrigated	Young	3.21 ± 0.03 a	6.90 ± 0.06 a	239.33 ± 4.06 a	171.00 ± 2.00 ab	192.00 ± 3.00 a	332.67 ± 2.60 a	2156.67 ± 34.80 a
	Old	1.37 ± 0.05 d	6.80 ± 0.10 a	236.33 ± 2.73 a	114.00 ± 1.00 c	119.67 ± 2.19 c	213.67 ± 2.73 c	1726.67 ± 33.33 b
	Control	2.18 ± 0.39 bc	6.93 ± 0.17 a	239.33 ± 13.64 a	122.00 ± 29.51 c	147.33 ± 14.38 b	248.00 ± 10.15 b	1993.33 ± 298.35 ab
Dry-farmed	Young	2.26 ± 0.04 b	7.00 ± 0.06 a	239.67 ± 1.86 a	178.67 ± 2.91 a	178.00 ± 1.00 a	325.33 ± 3.53 a	1983.33 ± 31.80 ab
	Old	1.53 ± 0.04 d	6.83 ± 0.09 a	233.00 ± 10.50 a	124.00 ± 4.04 c	135.67 ± 6.84 bc	237.67 ± 9.94 b	1890 ± 37.86 ab
	Control	1.67 ± 0.08 cd	6.87 ± 0.03 a	233.67 ± 0.88 a	138.33 ± 0.67 bc	138.33 ± 0.67 bc	252.00 ± 0.58 b	1860 ± 37.86 ab
	p-value	**<0.0001**	0.7128	0.9695	**0.0110**	**<0.0001**	**<0.0001**	0.3166

4. Discussion

The main objective of applying supplemental irrigation in vineyards during the growing season is to compensate for the lack of natural rainfall and increase yield, quality, or vegetative growth for the incoming growing season [38,39]. Specifically, in Mediterranean climates such as the Central Coast of California, winter rainfall may be sufficient to replenish water in the soil profile to achieve field capacity prior to budbreak effectively in vineyards planted with varieties of Mediterranean vocation. However, this has not been the case lately in coastal California areas, which have seen a reduction in winter rainfall [40]. Commercial demands for the wine industry caused the use of irrigation systems and/or techniques seen today in most of California, compared to many European vineyards that practice dry farming and cannot irrigate once vines are established.

This study was conducted over one growing season (2021) on the Central Coast of California and aimed at evaluating the effects of supplemental irrigation on grapevine performance and wine quality in historically dry-farmed Zinfandel vines as a function of age. The vineyard was interplanted with vines of varying ages. Old vines (40–60 years old), young vines (5–12 years old), and control vines (treated with a 2:1 ratio of old to young vines, representative of the experimental block) were compared with either irrigated or dry-farmed vines. During the 2021 growing season, the growing degree days were 1773.8, higher than the average of 1717.9 GDD from the 2011 to 2020 growing seasons.

Irrigation was calculated and applied to half the total sample vines at véraison and véraison + 4 weeks. Differences between the six treatments were clear and significant in data collection dates after véraison + 6 weeks (155 days post-budbreak), after both irrigation applications were made (Figure 1). There was some separation by irrigation treatments as vines progressed throughout the growing season; however, only vine age was a significant factor for phenology. Irrigated vines progressed slightly before the dry-farmed vines after 155 days post-budbreak, just before harvesting the first treatment. Irrigated young vines were harvested first (154 days post-budbreak), followed by dry-farmed young vines and irrigated control vines (167 days post-budbreak); then, dry-farmed control (171 days post-budbreak), while dry-farmed old vines and irrigated old vines were harvested last (180 days post-budbreak) according to the target Brix. While harvest dates and vine phenological progression showed the evident difference between irrigation treatments, no implications can be confidently made as no significant significance was seen with irrigation as an effect. As established by the previous study in this series of publications, vine age alone was significant; specifically, young vines progressed quickly leading up to harvest, as seen in this study [33].

Leaf senescence and the rate of progression can be valuable indicators of how vine age progresses and copes with environmental stresses, vine age, and phytohormones [41]. Vine age contributed to statistically significant differences in the degree of leaf abscission and leaf chlorosis. On most sampling dates, irrigated vines progressed quicker in leaf chlorosis; visually, this was evident but not statistically significant. While differences were seen between irrigation treatments, no implications can be confidently made as a substantial outcome. As they approached vine dormancy, young vines progressed slightly quicker in overall leaf senescence, similar to results seen in the previous study focusing on vine age [33]. Further analysis is needed over multiple growing seasons to confidently determine that irrigated compared to dry-farmed vines have no significant differences.

Gas exchange parameters and water status significantly indicate how different management techniques affect vine physiology and performance in a growing season. As climate change trends progress, gas exchange parameters and water status are greatly important to help change irrigation management to be more environmentally conscious. In this study, from pre-dawn to mid-day, the stomatal conductance increased in irrigated and dry-farmed for both véraison and véraison + 4 weeks. When comparing irrigation treatments, the differences were not consistent, contrary to some studies showing that dry-farmed vines had consistently lower stomatal conductance rates [42]. No significant differences were seen in the pre-dawn measurements of photosynthetic rate or stomatal conductance in both véraison and véraison + 4 weeks. However, significant differences in stomatal conductance at véraison + 4 weeks during the mid-day reading were observed. It can be concluded that the second application of irrigation caused a significant difference at mid-day in stomatal conductance rate; however, the difference was only seen in vine age as a significant factor. Old vines had a lower stomatal conductance, which translated to a slightly higher leaf water potential during the same reading, a result that opposes a study in which young vines generally had lower stomatal conductance and photosynthesis [43]. Irrigation was not a factor in the differences seen; this can be explained by previous studies where slight differences in stomatal conductance, transpiration rates [43], and photosynthesis were caused by varying vine ages [44]. An inconsistency was seen in how irrigation affected the vines as a factor, and we can conclude that irrigation did not change stomatal conductance or photosynthetic rate in a consistent and significant way in this study. Only vine age caused the differences, as previously seen in past studies where vine age was a factor [35,43]. Nonetheless, further studies are needed to explore this finding more thoroughly.

At véraison + 4 weeks, irrigated vines had a higher leaf water potential during the pre-dawn gas exchange sampling point. Irrigation was a significant factor in the differences seen between all treatments. This suggests that irrigated vines were slightly less stressed compared to dry-farmed vines. However, an important confounding factor in the present experiment is that supplemental irrigation was applied by the grower because of the lack of winter rainfall, as further discussed below. Most of the day, during the second irrigation application at véraison + 4, irrigated vines followed a trend that showed they had a marginally higher leaf water potential. This could suggest that dry-farmed vines were slightly more stressed than when irrigation was added. However, more research regarding dry-farmed vineyards over multiple consecutive growing seasons is needed to determine this confidently. This is evident in a study where one treatment excluded supplemental irrigation during the winter season, prior to budbreak, in a commercial vineyard of *Vitis vinifera* L. Merlot in the Central Valley of California [45]. The two-year consecutive field trial consisted of significant differences between the two growing seasons; the first year (2009) was classified as a Winkler V region, and the second year (2010) was a Winkler IV region [44]. The study found that the amount of moisture in the soil before budbreak had a major impact on yields and canopy growth [45]. Insufficient rainfall levels could cause a decrease in canopy growth, resulting in imbalanced vines [45]. While this study differs in climate type compared to this study, results show that as growers are challenged with rising temperatures and less water availability, irrigation application, and vineyard management changes need to be adapted to the predicted climate changes.

Differences in moderate water stress have been studied in different cultivars, with a negative relationship between stomatal sensitivity and stomatal closure as vine water status declines [46]. Photosynthetic responses, stomatal conductance, and transpiration rate decreased when severe [47] or moderate [46] water stress was applied. None of the treatments indicated severe water stress at any time; mild stress was seen at mid-day and mid-afternoon. Irrigation trials suggest that adding significant irrigation to an already historically dry-farmed vineyard did not affect stomatal conductance, leaf water potential, or photosynthetic rates regardless of vine age, which encourages growers to pursue a more dry-farmed technique as part of their vineyard management. However, since this is a single-year study, a multiple-year study is needed to confidently suggest these results.

Creating water stress by restricting irrigation via techniques such as deficit irrigation does produce desired results from a winemaking perspective, including smaller berry size with a high skin-to-pulp ratio, which has been extensively researched by previous studies [10,48]. However, in the present study, berry size showed no significant difference between irrigated and dry-farmed vines. While a difference was seen in both dry and fresh berry skin weight, only vine age was a factor in this difference, although the difference was not substantial enough to draw a conclusion. In general, applying irrigation at véraison and véraison + 4 weeks did not result in significant differences in berry physical composition, as seen in a previous study [32]. As discussed, vine age was more of a contributing factor in skin weight differences than irrigation was.

A common trend throughout this study was the lack of effects caused by adding irrigation to a historically dry-farmed vineyard. A possible reason for this would be the supplemental irrigation added during the dormancy season right before this study began. During the winter season of 2020/2021, the grower applied irrigation twice with overhead sprinklers. Per pass, 8.89 cm of water were applied, for a total of 17.78 cm of water applied to reach field capacity. Because this study was performed on a commercial vineyard, the grower applied supplemental irrigation during the winter to compensate for the lack of appropriate winter rainfall and ensure a commercially viable crop. The added irrigation applied by the grower is a possible limitation in this study. A further limitation of the present study lies in the fact that the irrigation treatment was applied during one growing season, although this study is a third-year continuation of the previous study conducted during the 2019 and 2020 growing seasons [32,33]. The loamy, predominant texture of the soil was also ideally suited to ensure proper water retention and may have contributed to the rather minor effects of the irrigation treatments. A combination of the above factors may be the cause of the lack of effects herein seen; vines were neither stressed nor overwhelmed when the additional irrigation was added at véraison and véraison + 4 weeks as part of this study.

Nonetheless, findings indicate that providing additional irrigation during the crop growth period has a limited impact on vine productivity and maturity. Dry farming can prove advantageous for vineyard owners as it reduces water expenses and improves environmental sustainability without compromising the quality of grapes, wine, or vine development. According to a study, producing lower-value and lower-yield grapes resulted in an increase in gross profit compared to higher-value grapes with greater yield [31], contradicting the belief that irrigation is necessary to increase yield.

In addition to the importance of the growing season events, the dormant stage in grapevines is also important, as vines continue to metabolize at low levels and water may be needed to maintain hydration in woody tissues and buds [49]. Previous studies have shown that the absence of winter rainfall can cause a reduction in canopy growth and yield [45,50]. Although different varieties are more adapted to drought and dry farming, Zinfandel is a Mediterranean cultivar with a history and a strong current presence as a dry-farmed vine in California. It is also possible to conclude that the Zinfandel planted in the historically dry-farmed vineyard has adapted well to dry farming, causing a lack of effect from added irrigation during the growing season. Dry farming is a viable and sustainable option for grapevines that enables them to withstand droughts and adverse weather conditions. This practice encourages the development of deeper root structures, which aids in preparation for future periods when water may become even scarcer. The ability of vines to adapt to changing environmental conditions can be achieved through various short-term and long-term adjustments such as dry farming and vine spacing [18,19,29]. However, further research is needed to agree confidently on the results.

5. Conclusions

This study examined the influence of supplemental irrigation applications at véraison and véraison + 4 weeks on vine performance and fruit quality on historically dry-farmed vines as a function of age. Vine age significantly affected phenology, leaf senescence, harvest dates and yield, and specific berry composition parameters. Irrigation showed almost no significant effect on any of the different variables evaluated, except for differences in titratable acidity and L-malic acid, where significance was seen in the interaction of irrigation and vine age as an effect. Vine age was already established to be a significant factor in several aspects, including phenological timing; consequently, maturity rates and harvest dates were different between vine ages. Significant differences in phenological progression were seen in the other vine age groups. Adding irrigation to dry-farmed vines did not significantly affect phenological progression or fruit chemistry at harvest, regardless of vine age. This suggests that substantial supplemental irrigation applied at a high ET_c during this research did not impact vine performance or fruit quality at harvest. Still, supplemented winter irrigation may have been a confounding factor. Nonetheless, growers with dry-farmed vineyards can benefit from this and avoid water applications even with the progression of climate shifts, provided the cultivar is well-adapted to the soil and prevailing climate conditions. The results of this study indicate that irrigation did not create an interaction effect with vine age; there was little difference made by adding irrigation, regardless of the different vine ages. These results suggest that supplemental irrigation does not necessarily result in significant increases in vine performance and yield during harvest. Again, it is important to state that the soil at budbreak was likely at field capacity as the grower applied supplemental irrigation during the winter. Dry farming in vineyards has several advantages, including lower energy usage compared to pressurized irrigation systems and alternative methods like drip irrigation. Further studies should be conducted to fully understand how dry-farmed vines differ and may be better suited for climate changes in temperature and extended drought compared to other irrigation systems used in vineyards.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy13081998/s1, Table S1: Leaf Senescence; Table S2: Leaf Water Potential; Table S3: Harvest and Pruning Weights; Table S4: Berry Dry and Fresh Weight; Table S5: Berry Chemistry at Harvest; Table S6: Berry Composition at Harvest.

Author Contributions: Conceptualization, L.F.C. and J.C.D.P.; methodology, L.F.C. and J.C.D.P.; software, J.A.A., L.F.C. and J.C.D.P.; validation, J.A.A., J.M., L.F.C. and J.C.D.P.; formal analysis, J.A.A., J.M., L.F.C. and J.C.D.P.; investigation J.A.A., L.F.C. and J.C.D.P.; resources, L.F.C. and J.C.D.P.; data curation, J.A.A., J.M., L.F.C. and J.C.D.P.; writing—original draft preparation, J.A.A., J.C.D.P.; writing—review and editing, J.A.A., L.F.C. and J.C.D.P.; visualization, J.A.A., J.M., L.F.C. and J.C.D.P.; supervision, L.F.C. and J.C.D.P.; project administration, J.C.D.P.; funding acquisition, L.F.C. and J.C.D.P. All authors have read and agreed to the published version of the manuscript.

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