

Response of pruning severity on yield and fruit quality of ‘Duke’ highbush blueberry (*Vaccinium corymbosum* L.) under deficit irrigation

Emilio Jorquera-Fontena^{1*}, Vanessa Huerta-Mendoza¹, Jorge González-Villagra², Ricardo Tighe-Neira¹, Rafael López-Olivari³, and Josefina Bota⁴

¹Universidad Católica de Temuco, Facultad de Recursos Naturales, Temuco, Chile.

²Universidad Mayor, Facultad de Ciencias, Ingeniería y Tecnología, Temuco 4780000, Chile.

³Instituto de Investigaciones Agropecuarias, INIA-Carillanca, Vilcún, Chile.

⁴Universitat de les Illes Balears, Institut d' Investigacions Agroambientals i d'Economia de l'Aigua (INAGEA), 07122 Palma, Illes Balears, España.

*Corresponding author (ejorquera@uct.cl)

Received: 18 June 2026; Accepted: 13 September 2026, Available online: 29 October 2026.

doi:10.4067/S0718-58392027000100070

ABSTRACT

Blueberries (*Vaccinium corymbosum* L.) are highly demanded by consumers; however, increasing water limitations for irrigation in many production areas may compromise fruit yield and quality. The aim of this study was to evaluate the combined effect of pruning severity and deficit irrigation on plant water status, yield, fruit quality and water productivity of ‘Duke’ blueberry. A field experiment was carried out during two growing seasons (2018-2019 and 2019-2020) in a commercial orchard in Chile (38°06' S; 72°52' W). Plants were subjected to slight or moderate pruning severity, and full (100% crop evapotranspiration [ET_c]) or deficit (60% ET_c) irrigation. Treatments were arranged in a completely randomized two-factor factorial design with four replicates per treatment combination. Stem water potential tended to decline throughout the season, with more favorable water status in moderate- than slight-pruned plants under deficit irrigation. Slight pruning increased yield by 36% and 21%, whereas moderate pruning increased berry size by 9% and 12% in the first and second seasons, respectively. Deficit irrigation reduced berry size but increased water productivity by 26% and 22% across seasons, without affecting yield. Pruning significantly affected titratable acidity in both seasons, whereas changes in soluble solids were inconsistent across seasons. Berry firmness was unaffected by treatments. Overall, slight pruning favored yield, whereas moderate pruning favored berry size and plant water status. Deficit irrigation independently improved water productivity, highlighting the trade-offs between yield, fruit quality, and water use under water-limited conditions.

Key words: Fruit load, source-to-sink relationship, stem water potential, water productivity.

INTRODUCTION

Blueberries (*Vaccinium corymbosum* L.) are highly valued by consumers for their organoleptic and nutritional properties, as well as by growers for their economic returns (Gilbert et al., 2014; Ru et al., 2024). Consequently, worldwide production of fresh blueberries has increased 2.2 times during the last 10 years (FAO, 2024). However, a substantial proportion of commercial orchards are in regions increasingly affected by limited irrigation water availability (Almutairi et al., 2017; Ortega-Farias et al., 2021), a situation expected to be intensified under global climate change (Diftenbaugh and Barnes, 2023). Therefore, the development of water-saving strategies is crucial to maintain crop productivity while reducing water use.

Current research encompasses both long-term and short-term solutions to address water limitation, including selection of drought-tolerant cultivars (Ru et al., 2024), the use of biostimulants and growth regulators (Sandoval et al., 2024), and optimization of irrigation scheduling based on soil and meteorological data (Carroll et al., 2024). However, plant water requirements are determined not only by environmental conditions but also by biological factors influencing whole-plant water demand. Among these, crop load may play an important role because fruit growth represents a major sink both for water and assimilated during the reproductive phase (Fishman and Génard, 1998). In this regard, crop load adjustment has been reported to improve tree water status (Marsal et al., 2010) and reduce leaf transpiration (Bussi et al., 2010) and hydraulic conductivity (Nielsen et al., 2016). However, its effects on plant water status vary among fruit species and cultivars, likely because crop load in deciduous species can be regulated by winter pruning, fruit thinning, or both, each differentially affecting the leaf area-to-fruit ratio. For example, fruit thinning improved tree water status in ‘Groc de l’Escola’ peach (*Prunus persica* (L.) Batsch) and ‘Conference’ pear (*Pyrus communis* L.) (Girona et al., 2004; Lopez et al., 2011), whereas severe winter pruning impaired tree water status and total shoot length in ‘Alexandra’ peach (Bussi et al., 2010). By contrast, fruit thinning did not compensate the negative effects of deficit irrigation on plant water status, yield, and fruit quality in ‘Flordastar’ peach (Alcobendas et al., 2012) and ‘Elliot’ blueberry (Almutairi et al., 2017).

In commercial blueberry orchards, fruit load is annually adjusted by winter pruning (Strik et al., 2003; Hirzel et al., 2023) a practice that modifies both vegetative and reproductive growth (Jorquera-Fontena et al., 2014) and, consequently, can influence whole-plant water requirements. Previous studies have independently demonstrated that both pruning severity and irrigation management affect yield and fruit quality (Strik et al., 2003; Bryla et al., 2009; Jorquera-Fontena et al., 2014; Ortega-Farias et al., 2021); however, their combined effect remains poorly documented. This can be especially relevant when water deficit occurs during critical developmental phases, such as rapid fruit growth and ripening, when berry size can be severely affected and, consequently, the crop value (Hirzel et al., 2023).

We hypothesized that reducing fruit load by intensified winter pruning improves plant water status under deficit irrigation, thereby mitigating its negative effect on fruit yield and quality while increasing water productivity. Therefore, the aim of this study was to evaluate the combined effect of pruning severity and deficit irrigation on plant water status, yield, fruit quality and water productivity of ‘Duke’ blueberry under field conditions.

MATERIALS AND METHODS

Experimental site and plant material

The field experiments were carried out in the commercial orchard “Fundo San Patricio” located in Lumaco (38°06’ S, 72°52’ W), La Araucanía Region, Chile, during the 2018-2019 and 2019-2020 growing seasons. The site is characterized by warm and dry climate conditions from November to March. The soil at experimental site is classified as Inceptisols with a clay sandy loam texture (46% sand, 26% silt, and 28% clay). The field capacity and wilting point of the soil were 0.25 m³ m⁻³ and 0.15 m³ m⁻³, respectively.

The plant material consisted in 64 ‘Duke’ highbush blueberry (*Vaccinium corymbosum* L.) plants (an early-season maturity cultivar) established in 2008 at 3 × 1 m in east-west oriented rows. Pests and diseases were controlled following recommendations of the export fruit industry. The pre-harvest fertilization requirements were satisfied through fertigation before applying the deficit irrigation treatment.

Treatments and experimental design

Two pruning treatments (“moderate” and “slight”) were applied according to criteria described by Strik et al. (2003) criteria. Briefly, moderate pruning consisted in removing unproductive canes, thinning 1-yr-old shoots at the base, and eliminating the excess fruiting or unproductive wood from the upper canopy, resulting in a retention of approximately 51%-52% of the flower buds relative to unpruned plants. Slight pruning consisted in cutting one or two of the most unproductive canes from the base of the plant, resulting in a retention of approximately 83%-85% of the flower buds relative to unpruned plants (Table 1). After applying treatments, the exposed tissue was protected with a pruning seal to avoid drying and fungal infection. Because pruning is an unavoidable cultural practice in the Chilean commercial orchard for the export market, an unpruned-plant treatment was not considered for the experiment.

Table 1. Number of flower buds resulting from pruning criteria and its corresponding percentage relative to unpruned plants. Means ($n = 4$) and standard error are shown.

Pruning treatment	Flower bud number		Flower buds relative to unpruned plants (%)	
	Growth season		Growth season	
	2018-2019	2019-2020	2018-2019	2019-2020
Slight	564 ± 43.64	709 ± 27.65	84.7	83.2
Moderate	337 ± 30.48	419 ± 32.74	51.6	50.8

Two irrigation treatments were applied: Full irrigation (FI) at 100% of estimated crop evapotranspiration (ET_c) and late-deficit irrigation (DI) at 60% ET_c , similar to the irrigation level proposed by Almutairi et al. (2017) for highbush blueberry. The DI treatment was applied from beginning to the fruit coloring phase (42 d after full bloom [DAB] in 2018-2019 season, and 46 DAB in 2019-2020 season) to 10 d after the last harvest (81 DAB in 2018-2019, and 84 DAB in 2019-2020 season), then plants returned to 100% ET_c . The reference evapotranspiration (ET_o) was obtained from the San Rafael Automatic Weather Station located at 4 km from the experimental site, and ET_c was calculated as $ET_o \times K_c$ (Allen et al. 1998), using K_c values of 0.27 at bloom, 0.5 at fruit coloring and 0.75 from harvest onwards (Ortega-Farias et al., 2021). Daily effective rainfall was considered and computed following Acevedo-Opazo et al. (2010). Plants were irrigated every 2 d using two drip lines per row, with emitters spaced 50 cm apart. The water flow of emitters was adjusted to 2 L h^{-1} for FI and 1.2 L h^{-1} for DI and was verified by measuring the volume of water collected from specific emitters over a set timeframe. Irrigation duration varied among events according to ET_c and was the same for both treatments; the lower emitter discharge in DI supplied 60% of the volume applied to FI.

Treatments were arranged in a completely randomized two-factor factorial design with four experimental units per treatment combination. Each experimental unit consisted of four plants and adjacent units receiving different irrigation treatments were separated by four buffer plants.

Stem water potential

Stem water potential was measured at 7 d intervals using the pressure chamber (Model 600, PMS Instrument, Albany, Oregon, USA) technique. Leaves were enclosed in an opaque plastic bag for 1 h to prevent transpiration and allow equilibrium to be reached with water potentials in stems (Choné et al., 2001). For measurements, sun-exposed leaves located in the mid portion of fruit-bearing canes were randomly selected and measurements were conducted between 1 h before and after solar noon. Two leaves per experimental unit were measured and then averaged to obtain a single value per replicate at each measurement date.

Plant yield and water productivity

Berries from each replicated treatments were hand-picked in four dates along the harvest period to calculate total fruit fresh weight per plant during both seasons. Harvest dates were 7, 10, 15 and 20 December, for 2018-2019 growth season, and 5, 10, 17 and 23 December for 2019-2020 growth season. Fruit production across harvest dates were summed for each plant, and values from the four plants were then averaged to obtain one seasonal value per experimental unit. Water productivity was calculated as the ratio between total fruit yield ($kg\ ha^{-1}$) and total water supplied (irrigated and rained, $m^3\ ha^{-1}$) from the beginning of the irrigation season to the moment in which plants returned to 100% ET_c .

Fruit quality traits

At each harvest date, 200 g berry samples were taken from each experimental unit and then transported in cooler to the laboratory for the subsequent analyses. After 8 h at 4 °C, 25 berry-subsample were randomly selected from each experimental unit to individually determine equatorial diameter with a digital caliper (accuracy ± 0.01 mm), and berry firmness (N) using a penetrometer FHT803 (General Tools & Instruments, New Jersey, USA). Then, juice was extracted from the berry subsamples to obtain total soluble solid (TSS, °Brix) and titratable acidity (TA, % citric acid) using Pocket Brix-Acidity Meter (ATAGO, Tokyo, Japan). Individual berry measurements were averaged to obtain one value per experimental unit at each harvest date. Values across harvest period were subsequently averaged to obtain one seasonal value per experimental unit.

Data analysis

The data were first submitted to the analysis of normality and equality of variances by means of the Kolmogorov-Smirnov and Levene test, respectively. Data were then subjected to two-way ANOVA to determine the main effect of pruning and irrigation and their interaction. Fisher's least significant difference (LSD) test at the 5% significance level was used to compare treatment combinations. Stem water potential was analyzed separately at each measurement date using one-way ANOVA followed by Fisher's LSD test ($P < 0.05$) to compare treatment combinations. All data analyses were carried out with R software (version 4.4.0; R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Environmental conditions

During the experiment, five and six rainfall events were recorded in 2018-2019 and 2019-2020 growing seasons, respectively (Figure 1). These events did not exceed 8.3 mm (2018-2019) and 4.3 mm (2019-2020). The accumulated rainfall between the beginning of the fruit coloring and the end of harvest period reached 19.0 and 16.8 mm in 2018-2019 and 2019-2020 growing seasons, respectively.

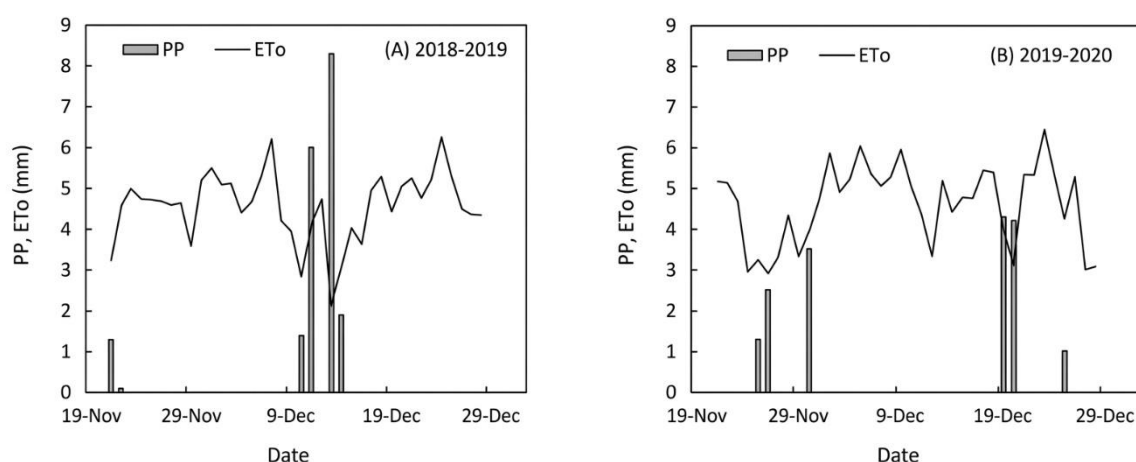


Figure 1. Daily reference evapotranspiration (ETo) and daily rainfall (PP) during 2018-2019 (A) and 2019-2020 (B) seasons. The time-interval shows the period in which deficit irrigation treatment was applied.

Stem water potential

In our experiment, stem water potential (Ψ_s) decreased along growing seasons in all combined treatments probably due to increasing water demand by plants and by absence of significant precipitation (Figures 1 and 2).

As observed in Figure 2, slight-pruned (SP) plants subjected to deficit irrigation (DI) showed a sharp decrease in Ψ_s , with values dropping almost 2-fold from beginning of DI treatment in both seasons. As resulted, Ψ_s of SP/DI treatment was significantly different to the other treatments mainly during the harvest period. Moderate pruning diminished the negative effect of DI on Ψ_s , showing values comparable to fully irrigated plants on most dates in both seasons.

Contrasting to what occurred at full irrigation (FI), the effect of pruning severity on Ψ_s was significant when plants experienced less irrigation. Thus, at 60% of ET_c , the Ψ_s was up to 3.2 bar higher in moderately pruned plants than in slight-pruned plants (Figure 2), indicating that pruning modified the response of plant water status to irrigation deficit.

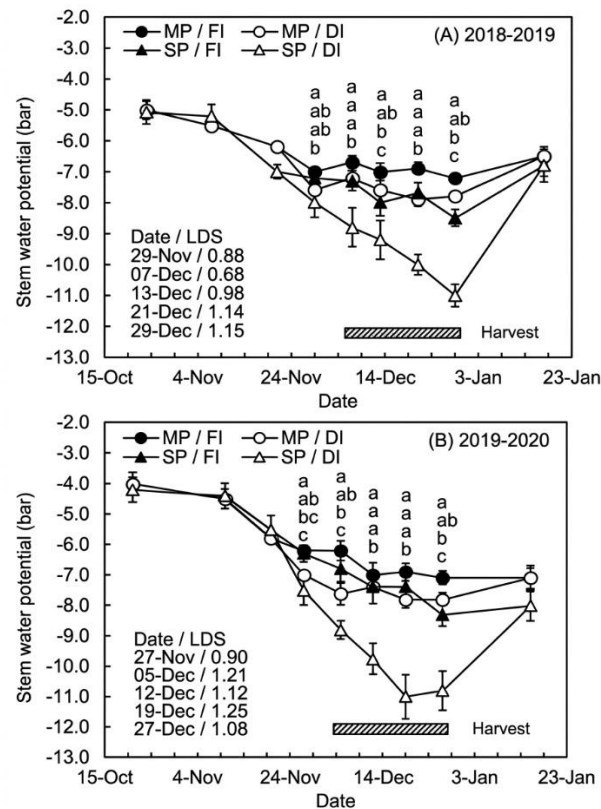


Figure 2. Stem water potential in highbush blueberry cv. Duke in the different treatments, moderate pruning (MP) and slight pruning (SP) combined with full irrigation (FI) or deficit irrigation (DI), during 2018-2019 (A) and 2019-2020 (B) seasons. Means ($n = 4$) and standard error are shown. Different letters represent statistical differences according to Fisher's least significant difference test (LSD) calculated for each measured date. The shaded area indicates the harvest period.

During the experimental period, total water supplied amounted to $1047 \text{ m}^3 \text{ ha}^{-1}$ in 2018-2019 and $1111 \text{ m}^3 \text{ ha}^{-1}$ in 2019-2020. Plants subjected to deficit irrigation received $294 \text{ m}^3 \text{ ha}^{-1}$ less and $297 \text{ m}^3 \text{ ha}^{-1}$ less water compared to those subjected to full irrigated plants for 2018-2019 and 2019-2020 growing seasons, respectively.

Fruit yield and water productivity

Slight-pruned plants exhibited 36% and 21% higher yield than moderate-pruned plants in the 2018-2019 and 2019-2020 growing seasons, respectively (Table 2). In contrast, Irrigation and Pruning $\times$ Irrigation interaction had nonsignificant effect on fruit yield in either growing season. Thus, the higher yield observed under slight pruning reflected the main effect of pruning irrespective of irrigation treatment.

Water productivity showed significant changes both by the effect of pruning and irrigation, but not by their interaction (Table 2). Thus, slight pruning increased water productivity by 39% and 20% in the 2018-2019 and 2019-2020 growing seasons, respectively, whereas deficit irrigation increased water productivity by 26% and 22%, respectively (Table 2).

Table 2. Fruit yield and water productivity in ‘Duke’ highbush blueberry as affected by pruning and irrigation. SP: Slight pruning; FI: full irrigation; DI: deficit irrigation; MP: moderate pruning. Means ($n = 4$), standard deviation and Fisher’s least significant difference (LSD) are shown.

Pruning/Irrigation	Yield (kg plant ⁻¹)		Water productivity (kg m ⁻³)	
	Season		Season	
	2018-2019	2019-2020	2018-2019	2019-2020
SP/FI	5.53 ± 0.31	4.93 ± 0.39	17.60 ± 0.99	15.52 ± 0.80
SP/DI	4.72 ± 0.29	4.21 ± 0.74	20.87 ± 1.26	17.24 ± 1.32
MP/FI	3.74 ± 0.24	3.81 ± 0.24	11.90 ± 0.77	12.12 ± 1.23
MP/DI	3.77 ± 0.66	3.69 ± 0.30	16.67 ± 2.91	15.13 ± 3.03
LSD	0.63	0.71	2.62	2.78
ANOVA				
Pruning (P)	< 0.001	0.005	< 0.001	0.010
Irrigation (I)	0.080	0.111	< 0.001	0.023
P × I	0.065	0.252	0.404	0.483

Fruit quality traits

The main effect of pruning was significant for berry size, with moderate-pruned plants reaching 9% and 12% larger fruits than slight-pruned plants for 2018-2019 and 2019-2020 growing seasons, respectively. Likewise, DI also modified berry size with reductions averaging 2.3% and 4.2% for 2018-2019 and 2019-2020 growing seasons, respectively (Table 3). The Pruning × Irrigation interaction was nonsignificant in either growing season (Table 3).

Table 3. Fruit quality traits in ‘Duke’ highbush blueberry as affected by pruning and irrigation. SP: Slight pruning; FI: full irrigation; DI: deficit irrigation; MP: moderate pruning. Means ($n = 4$), standard deviation and Fisher’s least significant difference (LSD) are shown.

Pruning/Irrigation	Berry size (mm)		TSS (°Brix)		TA (% citric acid)		Firmness (N)	
	Season		Season		Season		Season	
	2018-2019	2019-2020	2018-2019	2019-2020	2018-2019	2019-2020	2018-2019	2019-2020
SP/FI	14.45 ± 1.19	13.52 ± 1.53	11.13 ± 1.85	14.10 ± 1.08	1.31 ± 0.17	1.46 ± 0.28	13.93 ± 4.74	18.38 ± 4.74
SP/DI	13.67 ± 1.53	12.70 ± 1.14	12.52 ± 1.54	14.15 ± 1.18	1.33 ± 0.16	1.83 ± 0.42	14.23 ± 4.61	19.06 ± 4.16
MP/FI	15.93 ± 1.34	15.33 ± 1.25	13.18 ± 1.35	15.00 ± 1.17	1.24 ± 0.21	1.35 ± 0.22	15.65 ± 4.15	17.41 ± 4.14
MP/DI	15.62 ± 1.21	14.89 ± 1.35	13.45 ± 1.56	14.29 ± 1.09	1.25 ± 0.25	1.39 ± 0.35	16.47 ± 2.18	18.53 ± 2.13
LSD	0.44	0.63	0.54	1.08	0.20	0.31	2.74	5.14
ANOVA								
Pruning (P)	< 0.001	< 0.001	< 0.001	0.179	0.042	0.015	0.053	0.588
Irrigation (I)	< 0.001	0.011	< 0.001	0.388	0.117	0.068	0.228	0.515
P × I	0.109	0.541	0.002	0.321	0.240	0.139	0.967	0.874

Moderate pruning increased total soluble solid (TSS) by 13% compared with slight pruning in 2018-2019 growing season, whereas pruning had nonsignificant effect on TSS in 2019-2020. Irrigation treatment also modified TSS exclusively in the 2018-2019 growing season, having values 5% higher in DI plants than in FI plants. In this season, TSS was also influenced by the interactive effect of treatments, with deficit irrigation increasing TSS by approximately 11% in slight pruned plants (Table 3).

Titrateable acidity (TA) was significantly affected by pruning, whereas irrigation had nonsignificant effect. Thus, slight-pruned plants had 9% and 16% higher TA than moderate-pruned plants for 2018-2019 and 2019-2020 growing seasons, respectively. The Pruning × Irrigation interaction was nonsignificant in either growing season (Table 3).

Berry firmness was not significantly affected by pruning, irrigation, or their interaction in either growing season. However, in 2018-2019, berry firmness tended to be higher under moderate pruning than under slight pruning (Table 3).

DISCUSSION

Winter pruning and irrigation management play a crucial role in achieving long-term production stability and higher crop value in blueberry orchards. Although substantial technical and scientific information is available on methods to determine water demand in blueberry crops (e.g., Keen and Slavich, 2012; Carroll et al., 2024), pruning is often ignored as a factor potentially influencing plant water requirements. Because growing fruits represent major sinks for both water and assimilates (Fishman and Génard, 1998; Jorquera-Fontena et al., 2017), plants bearing higher fruit loads are expected to exhibit greater water demand and, consequently, lower stem water potential (Ψ_s) under restricted water availability for irrigation.

In this study, Ψ_s dropped throughout the season, with the lowest values generally observed under deficit irrigation. However, the magnitude of this decline was modulated by pruning severity. Slightly pruned plants under deficit irrigation exhibited substantially lower Ψ_s values than moderately pruned plants, whereas pruning effects were negligible under full irrigation conditions (Figure 2). These results suggest that crop load influenced the sensitivity of blueberry plants to water deficit. Similar responses have been reported in other fruit crops where crop load reductions improved plant water status under water deficit (Girona et al., 2004; Lopez et al., 2011).

Interestingly, differences in Ψ_s between pruning treatments remained evident during the harvest period despite progressive removal of fruit from plants. This observation suggests that the influence of crop load on plant water status may extend beyond instantaneous fruit demand. Recent evidence indicates that source-sink balance can induce vascular acclimation (Lv et al., 2025). Because leaf-to-fruit ratio in blueberry plants is largely regulated through pruning (Jorquera-Fontena et al., 2014), the persistent differences in Ψ_s during harvest period may reflect pruning-induced adjustments in vascular transport capacity established during earlier stages of fruit development. However, this interpretation remains hypothetical and requires further research.

The observed Ψ_s values in the slight-pruned plants subjected to deficit irrigation reflected moderate water stress (Estrada et al., 2015; Ortega-Farias et al., 2021). However, although yield tended to be lower under deficit irrigation, Irrigation and Pruning $\times$ Irrigation interaction had nonsignificant effect on yield either season (Table 2). Instead, yield was primarily determined by pruning, with slight pruning resulting in higher yield irrespective of irrigation dose. Similar trade-offs between crop load and yield have been amply associated with pruning-mediated changes in leaf-to-fruit ratio in blueberry (Jorquera-Fontena et al., 2014).

Water productivity was independently affected by both pruning and irrigation with no interactive effect between these factors (Table 2). Slight pruning increased water productivity primarily because of its positive effect on fruit yield, as previously observed in olives and date palms (Bustan et al., 2016; Zhen et al., 2020). Deficit irrigation also increased water productivity across pruning treatments, indicating that the reduction in water supply was proportionally greater than any associated change in yield (Table 2). This result contrasts with that reported by Ortega-Farias et al. (2021) in deficit irrigated 'Tifblue' blueberry, where reductions in yield were proportional to the amount of water supplied. Differences in genotype and atmospheric demand of experimental sites could explain these disparities. Water productivity values in our study were higher than those reported by Ortega-Farias et al. (2021) and Gavilan et al. (2024) although direct comparisons should consider that water productivity in the present study was calculated from the total water inputs from the beginning of irrigation season until full irrigation was restored in the deficit-irrigated treatment (Table 2).

Berry size was independently affected by both pruning and irrigation (Table 3). Moderate pruning increased berry size, whereas deficit irrigation reduced it, consistent with the sensitivity of fruit cell expansion to water availability during the second rapid fruit phase of blueberry fruit growth (Mingeau et al., 2001; Bryla et al., 2009). From commercial perspective, larger berries are generally associated with greater market value and consumer acceptance (Gilbert et al., 2014; Hirzel et al., 2023).

Fruit quality traits other than berry size showed less consistent responses across seasons (Table 3). Moderate pruning increased total soluble solids (TSS) only in the 2018-2019 season, whereas nonsignificant pruning effect was observed in 2019-2020. Similar increases in TSS following reduction in fruit load were observed in 'Farthing' and 'Brigitta' blueberry (Muñoz-Vega et al., 2017; Rubio Ames et al., 2025), likely reflecting changes in assimilate availability to developing fruit by changes in fruit-to-leaf ratio. Increases in TSS under water deficit have been reported in blueberry plants (Bryla et al., 2009; Almutairi et al., 2017; Lobos et al., 2018). Notably, the significant Pruning $\times$ Irrigation interaction observed in 2018-2019 season indicates that

the TSS response to irrigation depended on pruning severity during that season. However, this interaction was not observed in 2019-2020 (Table 3).

Titrateable acidity (TA) was primarily affected by pruning, with slight-pruned plants consistently exhibiting higher values than moderately pruned plants (Table 3). Similar responses have been associated with differences in fruit maturation rates and crop load effects on fruit development in 'Misty' and 'Brigitta' blueberry (Maust et al., 1999; Muñoz-Vega et al., 2017). Conversely, irrigation had nonsignificant effect on TA, and there was no evidence of a Pruning × Irrigation interaction in either season (Table 3). Concerning the irrigation dose, Almutairi et al. (2021) found inconsistent TA responses to irrigation strategies among blueberry cultivars, whereas Bryla et al. (2009) reported lower TA values in 'Elliot' blueberry irrigated at 50% crop evapotranspiration (ET_c).

Berry firmness showed the weakest response among the quality attributes evaluated (Table 3). Pruning had nonsignificant effect on berry firmness in either season, although firmness tended to be higher under moderate pruning in 2018-2019 (p -value = 0.053). Irrigation and the Pruning × Irrigation interaction were also nonsignificant in both seasons. Similar seasonal variability was reported by Hirzel et al. (2023), who observed that pruning effects on firmness varied among years and blueberry cultivars. Likewise, Almutairi et al. (2021) found that late preharvest water deficit reduced fruit firmness in 'Duke' blueberry, whereas no effect was observed in 'Bluecrop', highlighting the influence of cultivar, season, and stress timing on firmness response. Although plant nutrition can also influence fruit firmness through its effect on cell-wall properties (e.g., Song et al., 2025), fertilization was standardized across treatments in the present study, suggesting that the observed variability in firmness was more likely associated with seasonal environmental conditions than with nutritional differences.

CONCLUSIONS

This study demonstrated that pruning severity and irrigation independently influenced key aspects of production in 'Duke' blueberry. Slight pruning increased fruit yield and water productivity, whereas moderate pruning consistently improved berry size. Deficit irrigation reduced berry size but increased water productivity, while having nonsignificant effect on fruit yield, firmness, or titrateable acidity. Stem water potential dynamics showed that moderate-pruned plants maintained more favorable plant water status than slight-pruned plants under deficit irrigation, particularly during harvest. Taking together, these results indicate the trade-off between maximizing yield through slight pruning and increasing berry size and maintaining plant water status through moderate pruning. Deficit irrigation, irrespective of pruning severity, represents a viable strategy to improve water productivity while maintaining yield under conditions of this study.

Author contribution

Conceptualization: E.J-F. Methodology: E.J-F. Software: E.J-F., V.H-M. Validation: E.J-F., V.H-M. Formal analysis: E.J-F., V.H-M. Investigation: E.J-F. Resources: E.J-F. Data curation: E.J-F., V.H-M. Writing-original draft: E.J-F. Writing-review & editing: V.H-M., J.G-V., R.T-N., R.L-O., J.B. Visualization: E.J-F. Supervision: E.J-F. Project administration: E.J-F. Funding acquisition: E.J-F. All co-authors reviewed the final version and approved the manuscript before submission.

Acknowledgements

The first author acknowledges the Zanetti family from Fundo San Patricio, Lumaco, Chile, for facilitating plant material, and Camila Hidalgo and Yana Ceballos for their assistance with field data collection.

This study was supported by FONDECYT 3170734 and FONDECYT 11220732 from the Agencia Nacional de Investigación y Desarrollo de Chile (ANID, Chile).

References

- Acevedo-Opazo, C., Ortega-Farías, S., Fuentes, S. 2010. Effects of grapevine (*Vitis vinifera* L.) water status on water consumption, vegetative growth and grape quality: An irrigation scheduling application to achieve regulated deficit irrigation. *Agricultural Water Management* 97(7):956-964. doi:10.1016/j.agwat.2010.01.025.
- Alcobendas, R., Mirás-Avalos, J.M., Alarcón, J.J., Pedrero, F., Nicolás, E. 2012. Combined effects of irrigation, crop load and fruit position on size, color and firmness of fruits in an extra-early cultivar of peach. *Scientia Horticulturae* 142:128-135. doi:10.1016/j.scienta.2012.05.003.
- Allen, R.G., Pereira, L.S., Raes, D., Smith, M. 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. *FAO Irrigation and Drainage Paper* N°56. FAO. <https://www.fao.org/3/x0490s/x0490s.pdf>
- Almutairi, K., Bryla, D., Strik, B. 2017. Potential of deficit irrigation, irrigation cutoffs, and crop thinning to maintain yield and fruit quality with less water in northern highbush blueberry. *HortScience* 52(4):625-633. doi:10.21273/HORTSCI11533-16.

- Almutairi, K., Bryla, D., Strik, B. 2021. Sensitivity of northern highbush blueberry cultivars to soil water deficits during various stages of fruit development. *HortScience* 56(2):154-162. doi:10.21273/HORTSCI15493-20.
- Bryla, D., Yorgey, B., Shireman, A. 2009. Irrigation management effects on yield and fruit quality of highbush blueberry. *Acta Horticulturae* 810:649-656. doi:10.17660/ActaHortic.2009.810.86.
- Bussi, C., Lescourret, F., Mercier, V., Génard, M. 2010. Effects of winter pruning and of water restriction on fruit and vegetative growth, water potential and leaf gas exchange during the final stage of rapid growth in an early maturing peach cultivar. *European Journal of Horticultural Science* 75:15-19. doi:10.17660/EJHS.2010/1301230.
- Bustan, A., Dag, A., Yermiyahu, U., Erel, R., Presnov, E., Agam, N., et al. 2016. Fruit load governs transpiration of olive trees. *Tree Physiology* 36(3):380-391. doi:10.1093/treephys/tpv138.
- Carroll, J.L., Orr, S.T., Retano, A., Gregory, A.D., Lukas, S.B., Bryla, D.R. 2024. Weather-based scheduling and pulse drip irrigation increase growth and production of northern highbush blueberry. *HortScience* 59(5):571-577. doi:10.21273/HORTSCI17527-23.
- Choné, X., van Leeuwen, C., Dubourdieu, D., Gaudillère, J. 2001. Stem water potential is a sensitive indicator of grapevine water status. *Annals of Botany* 87(4):477-484. doi:10.1006/anbo.2000.1361.
- Diffenbaugh, N.S., Barnes, E.A. 2023. Data-driven predictions of the time remaining until critical global warming thresholds are reached. *Proceedings of the National Academy of Sciences of the United States of America* 120(6):e2207183120. doi:10.1073/pnas.2207183120.
- Estrada, F., Escobar, A., Romero-Bravo, S., González-Talice, J., Poblete-Echeverría, C., Caligari, P.D.S., et al. 2015. Fluorescence phenotyping in blueberry breeding for genotype selection under drought conditions, with or without heat stress. *Scientia Horticulturae* 181:147-161. doi:10.1016/j.scienta.2014.11.004.
- FAO. 2024. FAOSTAT, Food and Agriculture Organization of the United Nations Statistics Division. FAO, Rome, Italy. Available at <https://www.fao.org/faostat/en/#data/QCL> (accessed 17 June 2026).
- Fishman, S., Génard, M. 1998. A biophysical model of fruit growth: Simulation of seasonal and diurnal dynamics of mass. *Plant, Cell and Environment* 21:739-752. doi:10.1046/j.1365-3040.1998.00322.x.
- Gavilan, P., Higuera, J.L., Lozano, D., Ruiz, N. 2024. The Riego Berry mobile application: A powerful tool to improve on-farm irrigation performance in berry crops. *Agricultural Water Management* 292:108682. doi:10.1016/j.agwat.2024.108682.
- Gilbert, J., Olmstead, J., Colquhoun, T., Levin, L., Clark, D., Moskowitz, H. 2014. Consumer-assisted selection of blueberry fruit quality traits. *HortScience* 49(7):864-873. doi:10.21273/HORTSCI.49.7.864.
- Girona, J., Marsal, J., Arbones, A., Dejong, T.M. 2004. A comparison of the combined effect of water stress and crop load on fruit growth during different phenological stages in young peach trees. *The Journal of Horticultural Science and Biotechnology* 79(2):308-315. doi:10.1080/14620316.2004.11511766.
- Hirzel, J., Retamal-Salgado, J., Balbontín, C., Muñoz-Vega, P., Moya-Elizondo, E. 2023. Effect of load regulation by winter pruning on fruit quality attributes of Duke and Legacy blueberry cultivars. *Chilean Journal of Agricultural Research* 83:418-431. doi:10.4067/S0718-58392023000400418.
- Jorquera-Fontena, E., Alberdi, M., Franck, N. 2014. Pruning severity affects yield, fruit load and fruit and leaf traits of 'Brigitta' blueberry. *Journal of Soil Science and Plant Nutrition* 14(4):855-868. doi:10.4067/S0718-95162014005000068.
- Jorquera-Fontena, E., Génard, M., Franck, N. 2017. Analysis of blueberry (*Vaccinium corymbosum* L.) fruit water dynamics during growth using an ecophysiological model. *The Journal of Horticultural Science and Biotechnology* 92(6):646-659. doi:10.1080/14620316.2017.1304810.
- Keen, B., Slavich, P. 2012. Comparison of irrigation scheduling strategies for achieving water use efficiency in highbush blueberry. *New Zealand Journal of Crop Horticultural Science* 40:3-20. doi:10.1080/01140671.2011.599398.
- Lobos, T., Retamales, J., Ortega-Farías, S., Hanson, E., López-Olivari, R., Mora, M. 2018. Regulated deficit irrigation effects on physiological parameters, yield, fruit quality and antioxidants of *Vaccinium corymbosum* plants cv. Brigitta. *Irrigation Science* 36:49-60. doi:10.1007/s00271-017-0564-6.
- Lopez, G., Larrigaudière, C., Girona, J., Behboudian, M.H., Marsal, J. 2011. Fruit thinning in 'Conference' pear grown under deficit irrigation: Implications for fruit quality at harvest and after cold storage. *Scientia Horticulturae* 129(1):64-70. doi.org/10.1016/j.scienta.2011.03.007.
- Lv, L., Zhang, C., Yang, Z., Zhao, Z., Wang, S. 2025. Analysis of walnut source-sink-flow anatomical structure under source-sink regulation based on fruit-bearing branch scale. *Applied Sciences* 15(13):7523. doi:10.3390/app15137523.
- Marsal, J., Behboudian, M.H., Mata, M., Basile, B., Del Campo, J. 2010. Fruit thinning in 'Conference' pear grown under deficit irrigation to optimise yield and to improve tree water status. *The Journal of Horticultural Science and Biotechnology* 85(2):125-130. doi:10.1080/14620316.2010.11512642.
- Maust, B.E., Williamson, J.G., Darnell, R.L. 1999. Effect of flower bud density on vegetative and reproductive development and carbohydrate relations in southern highbush blueberry. *Journal of the American Society for Horticultural Science* 124:532-553. doi:10.21273/JASHS.124.5.532.
- Mingeau, M., Perrier, C., Améglio, T. 2001. Evidence of drought-sensitive periods from flowering to maturity on highbush blueberry. *Scientia Horticulturae* 89(1):23-40. doi:10.1016/S0304-4238(00)00217-X.

- Muñoz-Vega, P., Serri, H., Lopéz, M., Faundez, M., Palma, P. 2017. Efecto de diferentes intensidades de poda sobre el rendimiento y calidad de fruta en arándano (*Vaccinium corymbosum* L.) cv. Brigitta. Chilean Journal of Agricultural & Animal Sciences 33(3):285-303. doi:10.4067/S0719-38902017005000706.
- Neilsen, D., Neilsen, G., Guak, S., Forge, T. 2016. Consequences of deficit irrigation and crop load reduction on plant water relations, yield, and quality of 'Ambrosia' apple. HortScience 51(1):98-106. doi:10.21273/HORTSCI.51.1.98.
- Ortega-Farias, S., Espinoza-Meza, S., López-Olivari, R., Araya-Alman, M., Carrasco-Benavides, M. 2021. Effects of different irrigation levels on plant water status, yield, fruit quality, and water productivity in a drip-irrigated blueberry orchard under Mediterranean conditions. Agricultural Water Management 249:106805. doi:10.1016/j.agwat.2021.106805.
- Ru, S., Sanz-Saez, A., Leisner, C.P., Rehman, T., Busby, S. 2024. Review on blueberry drought tolerance from the perspective of cultivar improvement. Frontiers in Plant Science 15:1352768. doi:10.3389/fpls.2024.1352768.
- Rubio Ames, Z., Rossi, F., Espinoza, N., Faulk, M. 2025. Selective hand pruning does not reduce yield of 'Farthing' (*Vaccinium corymbosum* interspecific hybrids). Journal of the American Pomological Society 79(2):21-37. doi:10.71318/jd8cfr52.
- Sandoval, Y., Tighe-Neira, R., Inostroza-Blancheteau, C., Soto-Cerda, B., González-Villagra, J. 2024. Melatonin improves plant water status, photosynthetic performance, and antioxidant defense system in highbush blueberry (*Vaccinium corymbosum* L.) plants subjected to drought stress. Scientia Horticulturae 323:112528. doi:10.1016/j.scienta.2023.112528.
- Song, Z., Xu, B., Kang, S., Dai, H., Zhou, X., Li, M., et al. 2025. Calcium chloride treatment delayed the softening of postharvest blueberries by regulating ABA biosynthesis and signal transduction. Scientia Horticulturae 339:113879. doi:10.1016/j.scienta.2024.113879.
- Strik, B., Buller, G., Hellman, E. 2003. Pruning severity affects yield, berry weight, and hand harvest efficiency of highbush blueberry. HortScience 38(2):196-199. doi:10.21273-HORTSCI.38.2.196.
- Zhen, J., Lazarovitch, N., Tripler, E. 2020. Effects of fruit load intensity and irrigation level on fruit quality, water productivity and net profits of date palms. Agricultural Water Management 241:106385. doi:10.1016/j.agwat.2020.106385.