CHILEAN JOURNAL of AGRICULTURAL RESEARCH

CHILEANJAR
CHILEAN JOURNAL of AGRICULTURAL RESEARCH

RESEARCH ARTICLE

Effect of load regulation by winter pruning on fruit quality attributes of Duke and Legacy blueberry cultivars

Juan Hirzel[1*], Jorge Retamal-Salgado[1], Cristián Balbontín[1], Pablo Muñoz-Vega[2], and Ernesto Moya-Elizondo[2]

[1]Instituto de Investigaciones Agropecuarias, INIA Quilamapu, Av. Vicente Méndez 515, Chillán, Chile.
[2]Universidad de Concepción, Facultad de Agronomía, Av. Vicente Méndez 595, Chillán, Chile.
[*]Corresponding author (jhirzel@inia.cl).
Received: 28 December 2022; Accepted: 22 February 2023, doi:10.4067/S0718-58392023000400418

ABSTRACT

Legacy and Duke are the main blueberry (*Vaccinium corymbosum* L.) cultivars grown in Chile, with 32.8% of the total Chilean cultivated area with this fruit. The market demands fruit firmness, size, weight, and quality attributes, which are improved by some agronomic management practices such as winter pruning. The present study evaluated the effect on blueberry quality attributes and fruit yield of five fruit bud load levels, regulated by winter pruning during two consecutive seasons, on 'Legacy' and 'Duke'. The study was conducted in three commercial orchards under different soil conditions (Inceptisol, Andisol, and Entisol) in south-central Chile. Results indicated that there were differences in fruit load treatments between seasons, orchards, load levels, and week of harvest (first or second). Reducing the fruit bud load by winter pruning improved quality attributes of fruit firmness, size and weight, but negatively affected production per plant. We found in two seasons that pruning 60% of the fruit bud load level had the highest values for fruit firmness, size, and weight in both blueberry cultivars, but the production was 70% and 86% of the potential in 'Duke' and 'Legacy', respectively.

Key words: Blueberries, fruit quality, pruning, *Vaccinium*, yield.

INTRODUCTION

The area of Chile planted with fruit trees is 381 691 ha, and with blueberries (*Vaccinium corymbosum* L.) is 18 000 ha. The main cultivars planted are Legacy (3217 ha, 18.4%), Duke (2524 ha, 14.4%), Brigitta (2222 ha, 12.7%), and Brightwell (1182 ha, 6.7%) (INE, 2021).

Pruning is an agronomic management practice applied in growing blueberries, which increases crop longevity, selects better quality wood, improves floral induction and plant ventilation, maintains a balance between vegetative and reproductive growth, and enhances quality attributes such as fruit weight, fruit diameter, and accumulation of total soluble solids (TSS) (Strik et al., 2003; Yañez et al., 2009; Retamales and Hancock, 2012; Ehlenfeldt and Vinyard, 2015; Bhusal et al., 2017; Karimi et al., 2017; Muñoz-Vega et al., 2017; Kang et al., 2018; Strik, 2020; Strik and Davis, 2022). Kang et al. (2018) indicated that pruning 'Misty' blueberry (*V. corymbosum* hybrid) decreased yield and increased both fruit weight and firmness compared with the unpruned control. A drop in fruit weight was also observed through in-season harvest events. Likewise, Muñoz-Vega et al. (2017) reported that pruning intensity in 'Brigitta' decreased yield and fruit acidity, and increased fruit weight, fruit size, and TSS compared with the unpruned control, while pruning intensity was directly proportional to both fruit size and weight. In 'Legacy', less severe pruning increased the number of laterals produced per plant and

fruit yield, and this cultural practice had no negative effects on quality attributes (Strik et al., 2017b; Strik, 2019; 2020).

A four-season study conducted by Strik and Davis (2022) at Oregon State University North Willamette Research and Extension Center, reported that the traditional pruning system (T-trellis system) used in 'Legacy' did not affect the quality attributes of fruit weight, diameter, firmness, and TSS, compared with the simple divided canopy V-trellis system. Fruit weight values and fruit size in their experiment for 'Legacy' fluctuated between 1.4 and 2.2 g fruit^{-1}, and between 14.9 and 21.5 mm fruit^{-1}, respectively, while fruit firmness (FirmTech fruit firmness tester) was between 172 and 223 g mm^{-1}. In addition, these results enabled the authors to infer a directly proportional relationship between fruit weight and fruit size, and an inversely proportional relationship between both fruit firmness and size and fruit firmness and weight. De Moura et al. (2017) conducted a two-season pruning intensity experiment in 'Misty' blueberry in Moro Redondo, Río Grande, Brazil. They mentioned that hard pruning increased fruit production per plant, fruit diameter and weight, compared with the unpruned control for one of the two evaluated seasons. They also found that the phenolic compounds and antioxidant activity improved with hard pruning compared with the unpruned control; however, the TSS content was lower. In an experiment of consecutive two-season pruning with 'Jersey' blueberry, Kwon et al. (2018) at the National Institute of Horticultural and Herbal Sciences in South Korea, found that hard pruning decreased fruit yield compared with light pruning, whereas fruit weight increased in the first season and TSS increased in the second season.

The quality attributes of blueberry fruit are very important for marketing, whereas pruning management can regulate crop load and improve these attributes. Therefore, the objective of the present study was to evaluate the effect of five fruit load regulation levels by winter pruning on fruit yield, firmness, size, and weight, of 'Duke' and 'Legacy' blueberries under three orchard conditions during two consecutive seasons.

MATERIALS AND METHODS

Seasons and experimental sites

The present study was conducted during the 2020-2021 and 2021-2022 seasons in three blueberries (*Vaccinium corymbosum* L.) orchards with Xerochrepts (Inceptisol, Orchard 1), Melanoxerands (Andisol, Orchard 2), and Xerorthents (Entisol, Orchard 3) soils (USDA, 2014) in south-central Chile. Soil physicochemical properties at the 0-30 cm depth are shown in Table 1. The climate at the sites is temperate Mediterranean characterized by a hot, dry summer and cold, wet winter. Annual precipitation was 576 and 649 mm for the 2020-2021 and 2021-2022 seasons, respectively, which was concentrated from the end of autumn to the beginning of spring. The mean temperature was 14.3 and 13.5 °C and evaporation was 1060 and 940 mm for the 2020-2021 and 2021-2022 seasons, respectively (Agromet INIA, https://agrometeorologia.cl/). The locations of the three fields were Larqui (36°44′34″ S; 72°12′51″ W) for the Inceptisol, Capilla (36º32′08″ S; 71º54′59″ W) for the Andisol, and Santa Cruz de Cuca (36°39′44″ S; 72°26′22″ W) for the Entisol.

Soil analysis

At the beginning of the experiment, composite samples were collected manually from the topsoil (0-30 cm). All samples were air-dried and sieved (2 mm mesh). Soil pH was determined in 1:2.5 soil:water extracts. Soil organic C was measured by Walkley-Black wet digestion (Sadzawka et al., 2006). Soil inorganic N (NO_3-N and NH_4-N) was extracted with a 2 M KCl solution and determined by colorimetry with a segmented flux spectrophotometer (autoanalyzer, Skalar Analytical BV, Breda, The Netherlands). Soil extractable P was extracted with 0.5 M $NaHCO_3$ (Olsen P) and determined by the molybdate-ascorbic acid method. Exchangeable Ca, Mg, K, and Na were determined by 1 M NH_4OAc extraction followed by flame spectroscopy: Absorption (Ca and Mg) and emission (K and Na). The soil exchangeable Al concentration

was determined with 1 M KCl extraction by absorption spectroscopy. Sulfur (SO_4^{2-}-S) was determined with calcium phosphate 0.01 M and by turbidimetry. Soil Fe, Mn, Zn, and Cu concentrations were determined in diethylenetriaminepentaacetic acid (DTPA) extract by atomic absorption spectrometry (AAS) (Lindsay and Norvell, 1978). Boron was determined by colorimetry in a solution obtained with hot water. Soil texture was analyzed by the Bouyoucos-hydrometer method.

Table 1. Soil chemical properties at the 0-20 cm soil depth before initiating the experiment (2020 season) in three soils.

Parameters	Orchard 1	Orchard 2	Orchard 3
Location	Larqui	Capilla	Santa Cruz de Cuca
Soil	Inceptisol	Andisol	Entisol
Clay, %	21.7	17.5	3.4
Silt, %	46.1	29.4	9.2
Sand, %	32.2	53.1	87.4
$pH_{(soil:water\ 1:2.5)}$	5.37	5.60	6.18
Organic matter, g kg^{-1}	6.60	9.96	1.52
Available N, mg kg^{-1}	9.4	16.9	12.5
Olsen P, mg kg^{-1}	35.3	107.2	45.7
Exchangeable K, $cmol_{(+)}$ kg^{-1}	0.96	0.56	0.41
Exchangeable Ca, $cmol_{(+)}$ kg^{-1}	5.03	7.22	2.94
Exchangeable Mg, $cmol_{(+)}$ kg^{-1}	1.01	1.25	1.42
Exchangeable Na, $cmol_{(+)}$ kg^{-1}	0.13	0.35	0.19
Exchangeable Al, $cmol_{(+)}$ kg^{-1}	0.22	0.11	0.02
Available S, mg kg^{-1}	106.3	92.0	50.8
Available Fe, mg kg^{-1}	49.6	60.6	36.6
Available Mn, mg kg^{-1}	6.3	6.4	2.1
Available Zn, mg kg^{-1}	12.7	24.1	17.7
Available Cu, mg kg^{-1}	1.6	2.3	5.0
Available B, mg kg^{-1}	0.71	1.31	0.13

Crop management

'Duke' (early season harvest) and 'Legacy' (medium season harvest) were grown in the three orchards. The orchards had between 6 and 10 yr (orchards at the maximum production stage). Row spacing for both cultivars in the three fields was 3 m and plant spacing was 1 m. The fertilization rates applied in the three orchards in both seasons and blueberry cultivars during the growing season were 80 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, 150 kg K_2O ha^{-1}, 25 kg CaO ha^{-1}, and 30 kg MgO ha^{-1} by fertigation. In addition, B was applied in the Entisol by fertigation at 2 kg ha^{-1} yr^{-1}. Irrigation consisted of replacing water in the evaporation pan adjusted by the crop coefficient (K_c). Phytosanitary managements were similar in the three orchards and cultivars and were those commonly used by growers in the area.

Treatments

The evaluated treatments were five levels of load regulation by winter pruning in which the number of fruit buds was counted in May of both seasons; the 100% (unpruned control), 80%, 60%, 50%, and 40% load levels were adjusted in both cultivars. The elimination of buds was carried out by pruning complete branches. Experimental units were plots of five plants per treatment with five replicates. In the Orchard 1, the potential load was 873 and 986 fruit buds per plant for 'Duke' and 1433 and 2140 fruit buds per plant for 'Legacy' in the first and second seasons, respectively. In the Orchard 2, the potential load was 724 and 1014 fruit buds per plant for 'Duke' and 2474 and 2305 fruit buds per plant for 'Legacy' in the first and second seasons, respectively. In the Orchard 3, the potential load was 1041 and 1090 fruit buds per plant for 'Duke' and 1442 and 2303 fruit buds per plant for 'Legacy' in the first and second seasons, respectively.

Sample collection and analysis

Fruit samples were collected at the commercial harvest stage (fruit with 100% blue color) during the first and second weeks of harvest in each season, to determine the quality attributes of fruit firmness, size, and weight. Sampled fruit were 100% for 'Duke' and 80% for 'Legacy'. The remaining 20% of 'Legacy' fruit was machine-harvested because of its inferior quality during the third week of harvest. Therefore, to determine total fruit with manual harvest, three plants were harvested during the first 2 wk of harvest for 'Duke' and during the first 3 wk of harvest for 'Legacy' from each experimental unit. Fruit was collected between 08:30 and 10:00 h in plastic trays and transferred to a thermal isolation container (IGLOO 144 L, Igloo Products Corp, Katy, Texas, USA). They were transported to the fruit analysis laboratory of the Instituto de Investigaciones Agropecuarias (Chilean Agricultural Research Institute) at the Quilamapu Regional Research Center in Chillán, Chile, to immediately determine fruit firmness, size, and weight. Fruit firmness and size of 60 fruits from each sample were individually measured with a FirmPro instrument (HappyVolt, Santiago, Chile) and fruit weight was determined with a digital balance (Model 100A-300M, Precisa, Dietikon, Switzerland). Fruit yield per plant was measured with a digital balance.

Experimental design and statistical analysis

The experimental design for each blueberry cultivar and week of harvest was a completely randomized block design with a split-split-plot arrangement. The main plots were the two seasons, the split-plot was the three orchards, and the split-split plot was the five fruit bud load levels with five replicates. Results were analyzed by ANOVA and Tukey's test ($p = 0.05$) using the SAS PROC MIXED Model procedure (SAS Institute, Cary, North Carolina, USA). For significant interactions, contrast analysis was used to separately compare the treatment effects.

RESULTS

'Duke' fruit firmness in the first week of harvest was affected by the season, orchard, fruit bud load level, and season-orchard interaction ($p < 0.01$) (Table 2). Both fruit size and weight were affected by the orchard and fruit bud load level ($p < 0.01$). In the second week of harvest, 'Duke' fruit firmness was also affected by the season, orchard, fruit bud load level, and Season×Orchard interaction ($p < 0.01$) (Table 2). Both fruit size and weight were affected by season, orchard, fruit bud load level, and Season×Orchard interaction ($p < 0.01$). Fruit yield per plant was affected by season ($p < 0.01$), orchard ($p < 0.05$), fruit bud load level ($p < 0.01$), Season×Orchard interaction ($p < 0.05$), and Season×Fruit bud load level interaction ($p < 0.01$) (Table 2).

Table 2. Significance testing for quality attributes in the first and second weeks of harvest and fruit yield for 'Duke' blueberry as affected by different seasons, soils, and fruit bud load levels. *Significant at $p < 0.05$; **Significant at $p < 0.01$; ns: nonsignificant.

	First week of harvest			Second week of harvest			Fruit yield per plant
Source of variation	Firmness	Size	Weight	Firmness	Size	Weight	
Season (Y)	**	ns	ns	**	**	**	**
Orchard (O)	**	**	**	**	**	**	*
Fruit bud load level (F)	**	**	**	**	**	**	**
Y × O	**	ns	ns	**	**	**	*
Y × F	ns	ns	ns	ns	ns	ns	**
O × F	ns	ns	ns	ns	ns	ns	ns
Y × O × F	ns	ns	ns	ns	ns	ns	ns

'Legacy' fruit firmness in the first week of harvest was affected by the season, orchard, fruit bud load level ($p < 0.01$), Season×Orchard interaction ($p < 0.05$), and Season-Fruit bud load level interaction ($p < 0.01$) (Table 3). Fruit size was affected by the season, orchard, fruit bud load level, and Season×Orchard interaction ($p < 0.01$) (Table 3). Fruit weight was affected by season ($p < 0.05$), orchard, fruit bud load level, Season×Orchard interaction ($p < 0.01$), and Season-Fruit bud load level interaction ($p < 0.05$) (Table 3). 'Legacy' fruit firmness in the second week of harvest was affected by the season, orchard, and Season×Orchard interaction ($p < 0.01$). Fruit size was affected by the season, orchard, fruit bud load level ($p < 0.01$), Season×Orchard and Season×Fruit bud load level interactions ($p < 0.05$), and Orchard×Fruit bud load level interaction ($p < 0.01$) (Table 3). Fruit weight was affected by the season, orchard, fruit bud load level, and Season×Orchard and Season×Fruit bud load level interactions ($p < 0.01$). Fruit yield per plant was affected by the season, orchard, fruit bud load level, Season×Orchard interaction ($p < 0.01$), and Season×Fruit bud load level interaction ($p < 0.05$) (Table 3).

Table 3. Significance testing for quality attributes in the first and second weeks of harvest and fruit yield for 'Legacy' blueberry as affected by different seasons, soils, and fruit bud load levels. *Significant at $p < 0.05$; **Significant at $p < 0.01$; ns: nonsignificant.

	First week of harvest			Second week of harvest			
Variation source	Firmness	Size	Weight	Firmness	Size	Weight	Fruit yield per plant
Season (Y)	**	**	*	**	**	**	**
Orchard (O)	**	**	**	**	**	**	**
Fruit bud load level (F)	**	**	**	ns	**	**	**
Y × O	*	**	**	**	*	**	**
Y × F	**	ns	*	ns	*	**	*
O × F	ns	ns	ns	ns	**	ns	ns
Y × O × F	ns	ns	ns	ns	ns	ns	ns

The highest 'Duke' fruit size and weight values in the first week of harvest were in the orchard 2 ($p < 0.05$) with an increase of 3.3% in size and 12.3% in weight compared with the other orchards (Table 4). When evaluating the effect of orchard as an average of the different fruit bud load levels in the first season for 'Duke', fruit firmness in the first week of harvest was not

affected by orchard ($p > 0.05$). Fruit firmness was higher in the orchard 1 ($p < 0.05$) in the second week of harvest. The highest fruit size and weight values occurred in the orchard 2 and the lowest in the orchard 3 ($p < 0.05$) (Table 5). Fruit yield per plant for 'Duke' was higher in both the orchard 1 and orchard 3 ($p < 0.05$) (Table 5).

Table 4. Effect of orchard on fruit size and weight of 'Duke' blueberry in the first week of harvest as an average of two seasons and five fruit bud load levels. Different letters in the same column indicate significant differences between soils according to Tukey's test ($p < 0.05$). Values are ± standard error.

Orchard	Fruit size	Fruit weight
	mm	g
1	15.2 ± 0.09^{b}	1.55 ± 0.02^{b}
2	15.7 ± 0.11^{a}	1.74 ± 0.03^{a}
3	15.2 ± 0.14^{b}	1.55 ± 0.03^{b}

Table 5. Effect of orchard on fruit firmness in the first week of harvest, fruit firmness, size, and weight in the second week of harvest, and on fruit yield per plant of 'Duke' blueberry as an average of five fruit bud load levels in the first season. Different letters in the same column indicate significant differences between soils according to Tukey's test ($p < 0.05$). Values are ± standard error.

	First week of harvest	Second week of harvest			
Orchard	Fruit firmness	Fruit firmness	Fruit size	Fruit weight	Fruit yield per plant
	g mm^{-1}	g mm^{-1}	mm	g	kg pl^{-1}
1	175 ± 3.7^{a}	178 ± 2.8^{a}	16.0 ± 0.14^{b}	1.7 ± 0.04^{b}	3.6 ± 0.3^{a}
2	167 ± 2.1^{a}	161 ± 2.2^{b}	16.8 ± 0.13^{a}	2.0 ± 0.04^{a}	2.2 ± 0.2^{b}
3	166 ± 2.4^{a}	154 ± 3.7^{b}	15.0 ± 0.22^{c}	1.5 ± 0.05^{c}	3.3 ± 0.2^{a}

The effect of orchard and average of the different fruit bud load levels in the second season on 'Duke' (Table 6) indicated that the highest fruit firmness value in the first week of harvest was observed in the orchard 2 ($p < 0.05$), while the lowest value in the orchard 1 ($p < 0.05$). The highest fruit firmness in the second week of harvest occurred in the orchard 2 (8.5% average increase) ($p < 0.05$), while the highest fruit size and weight were achieved in the orchard 1 ($p < 0.05$) with increases of 6.4% for size and 20.0% for weight, compared with the average of the other orchards (Table 6). Overall, there was a drop in firmness between the first and second week of harvest, and the average for the three orchards was 11%. Fruit yield per plant was higher in both orchard 2 and orchard 3 ($p < 0.05$). Overall, fruit yield per plant in the three orchards was higher in the second season (Tables 5 and 6).

The effect of the different fruit loads on 'Duke' on the two seasons and three orchards (Table 7) indicated that the highest firmness values in the first and second seasons were obtained at 40% and 50% fruit bud load levels ($p < 0.05$), which were 6.2% and 7.0% higher than the unpruned control, respectively. The highest values for fruit size in the first season were obtained at 40%, 50%, and 60% of the fruit bud load levels ($p < 0.05$), while the highest values for the second season at the 40% and 50% levels ($p < 0.05$). Overall, the highest values for fruit weight in the first and second seasons were obtained at the 40%, 50%, and 60% fruit bud load levels ($p < 0.05$). In the three load levels and two seasons, fruit weight increased an average 21.2% (Table 7). In addition, the 60% fruit bud load level for both weeks of harvest produced larger fruit size and higher fruit weight than the control with 100% fruit bud load level ($p < 0.05$).

Table 6. Effect of orchard on fruit firmness in the first week of harvest, fruit firmness, size, and weight in the second week of harvest, and on fruit yield per plant of 'Duke' blueberry as an average of five fruit bud load levels in the second season. Different letters in the same column indicate statistical differences between soils according to Tukey's test ($p < 0.05$). Values are ± standard error.

	First week of harvest	Second week of harvest			Fruit yield per plant
Orchard	Fruit firmness	Fruit firmness	Fruit size	Fruit weight	
	g mm^{-1}	g mm^{-1}	mm	g	kg pl^{-1}
1	149 ± 2.5^{c}	144 ± 2.0^{b}	15.8 ± 0.17^{a}	1.8 ± 0.05^{a}	5.6 ± 0.2^{b}
2	182 ± 1.5^{a}	154 ± 1.6^{a}	15.0 ± 0.14^{b}	1.5 ± 0.07^{b}	6.5 ± 0.3^{a}
3	161 ± 2.3^{b}	140 ± 1.9^{b}	14.7 ± 0.13^{b}	1.5 ± 0.03^{b}	6.1 ± 0.2^{a}

Table 7. Effect of five fruit bud load levels on fruit quality attributes of 'Duke' blueberry as an average of two seasons and three orchards. Different letters in the same columns indicate significant differences between fruit bud load level according to Tukey's test ($p < 0.05$). Values are ± standard error.

	First season			Second season		
Fruit bud load level	Fruit firmness	Fruit size	Fruit weight	Fruit firmness	Fruit size	Fruit weight
%	g mm^{-1}	mm	g	g mm^{-1}	mm	g
100	162 ± 2.8^{b}	14.6 ± 0.11^{c}	1.40 ± 0.03^{c}	149 ± 2.7^{b}	14.6 ± 0.18^{d}	1.45 ± 0.04^{c}
80	161 ± 2.4^{b}	15.0 ± 0.09^{b}	1.56 ± 0.03^{b}	153 ± 3.1^{ab}	15.3 ± 0.17^{c}	1.62 ± 0.04^{b}
60	166 ± 2.2^{ab}	15.6 ± 0.15^{a}	1.66 ± 0.04^{ab}	156 ± 3.2^{ab}	15.7 ± 0.17^{bc}	1.70 ± 0.04^{ab}
50	172 ± 3.4^{a}	15.9 ± 0.13^{a}	1.70 ± 0.03^{a}	159 ± 3.0^{a}	15.9 ± 0.18^{ab}	1.77 ± 0.05^{ab}
40	172 ± 3.2^{a}	15.9 ± 0.13^{a}	1.75 ± 0.03^{a}	160 ± 3.6^{a}	16.3 ± 0.14^{a}	1.79 ± 0.07^{a}

Among the evaluated quality attributes, fruit load regulation had the greatest effect on fruit weight. When comparing the 100% and 40% load levels in 'Duke', fruit firmness increased between 6.2% and 7.4%, fruit size increased between 8.9% and 11.6%, and fruit weight increased between 23.4% and 25.0%, respectively, for the 2 yr evaluation (Table 7).

Fruit yield per plant in 'Duke', over the three orchards in the first season (Figure 1), had the highest yield at the 100% fruit bud load level ($p < 0.05$), followed by 80% ($p < 0.05$), and no yield differences for the lower load levels ($p > 0.05$). Fruit yield per plant in 'Duke', over the three orchards in the second season, was also higher at the 100% fruit bud load level, surpassing only the 50% and 40% load levels ($p < 0.05$) (Figure 2). The highest values for 'Duke' quality attributes in both seasons were achieved with 60% of the fruit bud load level; adjusting this load per plant by winter pruning would result in an average of 70% of the yield obtained with the maximum load (Figures 1 and 2).

When comparing the effect of the three orchards on the quality attributes and fruit yield for 'Legacy' in the first season and as an average of the five fruit bud load levels (Table 8), the highest fruit firmness in the first week of harvest was obtained in the orchard 3 and the lowest in the orchard 1 ($p < 0.05$). Meanwhile, the highest fruit size and weight were observed in the orchard 2 ($p < 0.05$). The highest fruit firmness in the second week of harvest was reached in the orchard 2 and orchard 3 ($p < 0.05$) with no differences among the three orchards for both fruit size and weight ($p > 0.05$) (Table 8). Fruit yield per plant was higher in the orchard 2 and lower in the orchard 1 ($p < 0.05$).

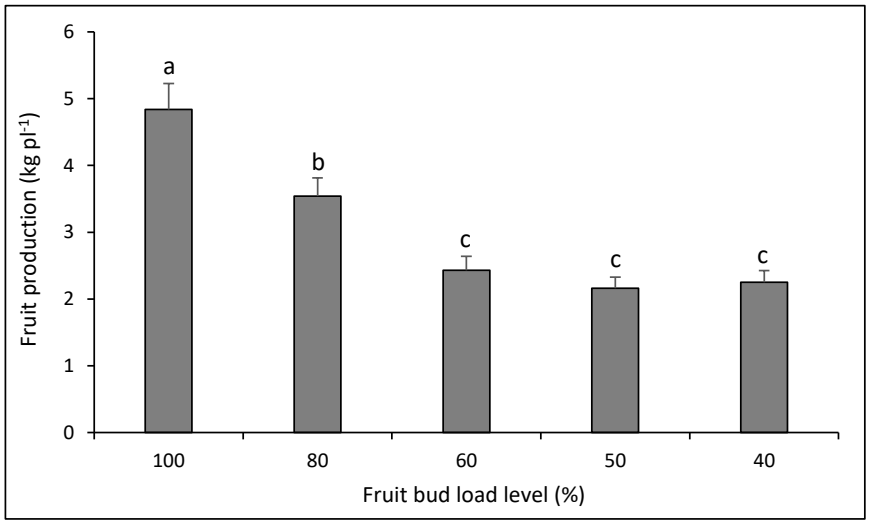

Figure 1. Fruit yield per plant in 'Duke' blueberry at different fruit bud load levels as an average of three orchards in the first growing season. Different letters over the bars indicate significant differences between treatments according to Tukey's test ($p < 0.05$). The lines over the bars indicate the standard error.

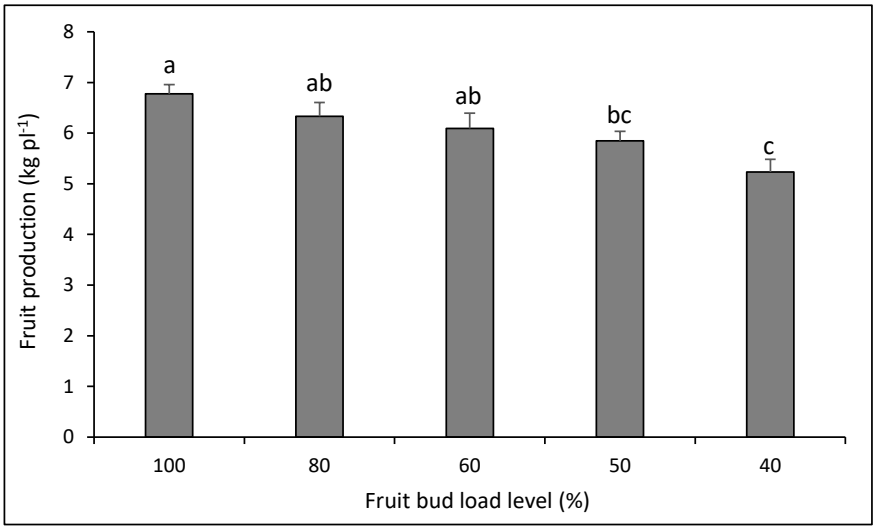

Figure 2. Fruit yield per plant in 'Duke' blueberry at different fruit bud load levels as an average of three orchards in the second growing season. Different letters over the bars indicate significant differences between treatments according to Tukey's test ($p < 0.05$). The lines over the bars indicate the standard error.

The effect of the three orchards for 'Legacy', as an average of the five fruit bud load levels in the second season, indicated that fruit firmness in the first week of harvest was higher in the orchard 2 and orchard 3 ($p < 0.05$), but there was no difference among the three orchards for fruit size and weight ($p > 0.05$) (Table 9). The highest fruit firmness in the second week of harvest was obtained in the orchard 2, while fruit size and weight were higher in the orchard 1 ($p < 0.05$). Fruit yield per plant was higher in the orchard 3 and lower in the orchard 2 ($p < 0.05$) (Table 9). Fruit yield per plant increased in the second season in the orchard 1 and orchard 3, while it decreased in the orchard 2 compared with the first season (Tables 8 and 9).

Table 8. Effect of orchard on fruit quality attributes in the first and second weeks of harvest and fruit yield per plant of 'Legacy' blueberry as an average of five fruit bud load levels in the first season. Different letters in the same column indicate significant differences between soils according to Tukey's test ($p < 0.05$). Values are ± standard error.

	First week of harvest			Second week of harvest			Fruit
Orchard	Fruit firmness	Fruit size	Fruit weight	Fruit firmness	Fruit size	Fruit weight	yield per plant
	g mm^{-1}	mm	g	g mm^{-1}	mm	g	kg pl^{-1}
1	165 ± 1.5^{c}	15.8 ± 0.21^{b}	1.7 ± 0.06^{b}	142 ± 1.2^{b}	16.4 ± 0.20^{a}	2.0 ± 0.06^{a}	3.8 ± 0.2^{c}
2	172 ± 2.0^{b}	16.8 ± 0.22^{a}	2.2 ± 0.08^{a}	160 ± 1.6^{a}	16.0 ± 0.21^{a}	2.0 ± 0.07^{a}	6.1 ± 0.3^{a}
3	179 ± 2.3^{a}	15.7 ± 0.17^{b}	1.8 ± 0.05^{b}	162 ± 1.1^{a}	16.1 ± 0.15^{a}	1.9 ± 0.05^{a}	5.0 ± 0.2^{b}

Table 9. Effect of orchard on fruit quality attributes of the first and second weeks of harvest and fruit yield per plant of 'Legacy' blueberry as an average of five fruit bud load levels in the second season. Different letters in the same columns indicate significant differences between soils according to Tukey's test ($p < 0.05$). Values are ± standard error.

	First week of harvest			Second week of harvest			Fruit
Orchard	Fruit firmness	Fruit size	Fruit weight	Fruit firmness	Fruit size	Fruit weight	yield per plant
	g mm^{-1}	mm	g	g mm^{-1}	mm	g	kg pl^{-1}
1	134 ± 1.7^{b}	15.7 ± 0.19^{a}	1.9 ± 0.06^{a}	139 ± 1.1^{b}	15.1 ± 0.13^{a}	1.7 ± 0.04^{a}	7.4 ± 0.1^{b}
2	147 ± 1.9^{a}	15.4 ± 0.18^{a}	1.8 ± 0.06^{a}	153 ± 1.9^{a}	14.2 ± 0.12^{b}	1.4 ± 0.03^{b}	4.6 ± 0.2^{c}
3	146 ± 1.4^{a}	15.4 ± 0.14^{a}	1.8 ± 0.05^{a}	137 ± 1.8^{b}	14.2 ± 0.14^{b}	1.5 ± 0.04^{b}	8.7 ± 0.2^{a}

The effect of the different fruit bud load levels on the quality attributes of 'Legacy' in the first season, the average of the three orchards showed that fruit firmness in the first week of harvest was higher at 40%, 50%, and 60% load levels. However, only the 50% load level surpassed the control with 80% of the load ($p < 0.05$) (Table 10). Meanwhile, fruit weight in the first week of harvest was higher at the 40% load level and surpassed the 60%, 80%, and 100% levels ($p < 0.05$). Overall, the highest fruit size and weight were obtained in the second week of harvest at the 40%, 50%, and 60% load levels ($p < 0.05$) (Table 10).

In the second season, average of the three orchards, the highest fruit firmness and weight for 'Legacy' in the first week of harvest was achieved with 50% of the load ($p < 0.05$). In the second week of harvest, the highest fruit size and weight were obtained with the 40% and 50% loads ($p < 0.05$) (Table 11). The 50% load level increased fruit firmness by 5%, fruit size by 4%, and average fruit weight by 20% compared with the control at the 100% load level (Table 11).

The orchard-fruit bud load level interaction on fruit size in the second week of harvest for 'Legacy' in the second season (Table 3) indicated that the highest fruit size value for the orchard 1 was obtained at the 40% load level, which only surpassed the 80% load level ($p < 0.05$). Meanwhile, the highest value for the orchard 2 was reached at the 40%, 50%, and 60% load levels and surpassed the control at the 100% load level ($p < 0.05$) (Table 12). The highest fruit size value for the orchard 3 was obtained at the 40%, 50%, 60%, and 80% load levels ($p < 0.05$) (Table 12).

Table 10. Effect of five fruit bud load levels on fruit quality attributes of 'Legacy' blueberry as an average of three orchards in the first season. Different letters in the same column indicate significant differences between fruit bud load levels according to Tukey's test ($p < 0.05$). Values are ± standard error.

	First week of harvest		Second week of harvest	
Fruit bud load level	Fruit firmness	Fruit weight	Fruit size	Fruit weight
%	g mm^{-1}	g	mm	g
100	162 ± 2.6^{c}	1.5 ± 0.03^{d}	15.2 ± 0.2^{c}	1.6 ± 0.04^{c}
80	169 ± 2.9^{bc}	1.8 ± 0.06^{c}	15.9 ± 0.21^{b}	1.9 ± 0.06^{b}
60	175 ± 2.7^{ab}	1.9 ± 0.08^{bc}	16.5 ± 0.15^{a}	2.0 ± 0.07^{ab}
50	177 ± 2.7^{a}	2.1 ± 0.11^{ab}	16.7 ± 0.21^{a}	2.2 ± 0.07^{a}
40	176 ± 1.9^{ab}	2.2 ± 0.08^{a}	16.7 ± 0.19^{a}	2.2 ± 0.07^{a}

Table 11. Effect of five fruit bud load levels on fruit quality attributes of 'Legacy' blueberry as an average of three orchards in the second season. Different letters in the same column indicate statistical differences between fruit bud load levels according to Tukey's test ($p < 0.05$). Values are ± standard error.

Fruit bud load level	First week of harvest		Second week of harvest	
	Fruit firmness	Fruit weight	Fruit size	Fruit weight
%	g mm^{-1}	g	mm	g
100	140 ± 0.2^{ab}	1.6 ± 0.18^{b}	14.1 ± 0.18^{b}	1.4 ± 0.18^{b}
80	143 ± 0.3^{ab}	1.8 ± 0.27^{b}	14.5 ± 0.27^{ab}	1.5 ± 0.27^{ab}
60	139 ± 0.3^{b}	1.8 ± 0.30^{b}	14.5 ± 0.30^{ab}	1.5 ± 0.30^{ab}
50	147 ± 0.2^{a}	2.0 ± 0.19^{a}	14.7 ± 0.19^{a}	1.6 ± 0.19^{a}
40	144 ± 0.3^{ab}	2.0 ± 0.25^{b}	14.8 ± 0.25^{a}	1.6 ± 0.25^{a}

Table 12. Effect of five fruit bud load levels on fruit size of 'Legacy' blueberry in the second week of harvest in three orchards as an average of two seasons. Different letters in the same column indicate significant differences between fruit bud load levels according to Tukey's test ($p < 0.05$). Values are ± standard error.

	Soil		
Fruit bud load level	Inceptisol	Andisol	Entisol
%	mm		
100	15.5 ± 0.3^{ab}	14.2 ± 0.2^{b}	14.2 ± 0.3^{b}
80	15.3 ± 0.2^{b}	14.9 ± 0.3^{ab}	15.2 ± 0.4^{a}
60	15.9 ± 0.3^{ab}	15.3 ± 0.4^{a}	15.4 ± 0.4^{a}
50	15.9 ± 0.4^{ab}	15.6 ± 0.4^{a}	15.6 ± 0.3^{a}
40	16.3 ± 0.3^{a}	15.6 ± 0.5^{a}	15.4 ± 0.3^{a}

Similar to the results for 'Duke', the fruit load regulation for 'Legacy' had the greatest effect on increased fruit weight. When comparing the 40% and 100% load levels, load reduction led to increases in fruit firmness between 2.9% and 8.6%, fruit size between 5.0% and 9.9%, and fruit weight between 14.3% and 46.7% (Tables 10 and 11).

Fruit yield per plant for 'Legacy' as an average of the three orchards in the first season (Figure 3) showed the highest yield at the 100% fruit bud load level ($p < 0.05$) and surpassed the 40%, 50%, and 60% load levels. Likewise, a directly proportional relationship was observed between fruit

yield and fruit bud load level (R = 0.63; data not shown). Fruit yield per plant for 'Legacy' in the second season with an average of the three orchards was once again higher at the 100% fruit bud load level, only surpassing the 50% and 40% load levels ($p < 0.05$) (Figure 4). Overall, the highest values in the quality attributes of 'Legacy' in both seasons were achieved with 60% of the fruit bud load level; adjusting this load per plant by winter pruning would result in an average of 84% of the yield obtained with the maximum load (Figures 3 and 4).

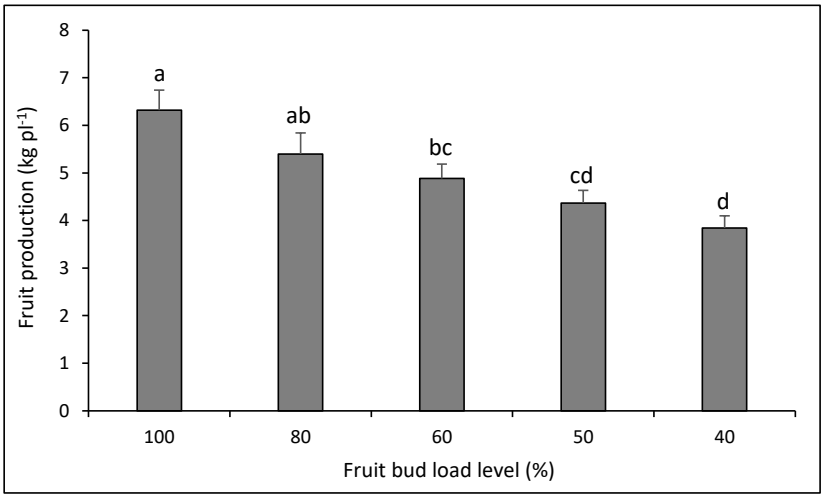

Figure 3. Fruit yield per plant in 'Legacy' blueberry at different fruit bud load levels as an average of three orchards in the first growing season. Different letters over the bars indicate significant differences between treatments according to Tukey's test ($p < 0.05$). The lines over the bars indicate the standard error.

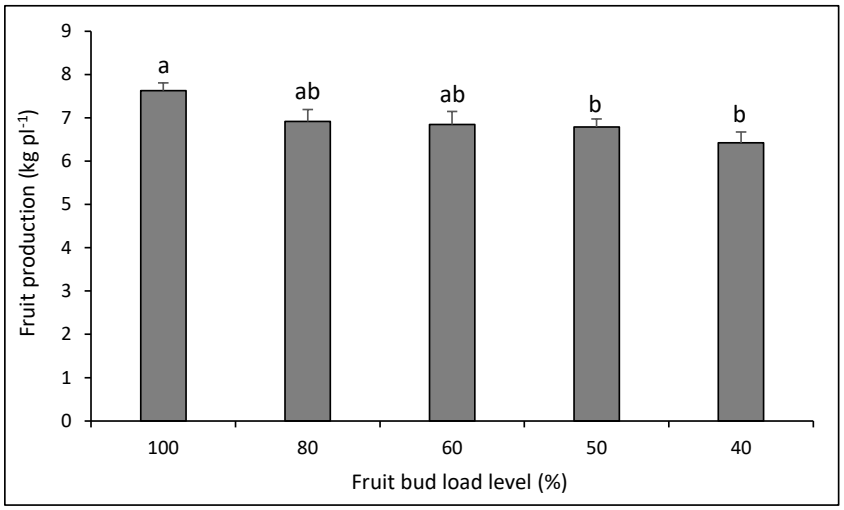

Figure 4. Fruit yield per plant in 'Legacy' blueberry at different fruit bud load levels as an average of three orchards in the second growing season. Different letters over the bars indicate significant differences between treatments according to Tukey's test ($p < 0.05$). The lines over the bars indicate the standard error.

DISCUSSION

The soil physicochemical properties were appropriate for blueberry (Retamales and Hancock, 2012), which enabled yields within the potential of each of the cultivars evaluated in the present study (Retamales et al., 2014; Strik et al., 2017a).

The fruit quality attributes of firmness, size, and weight were affected by the season; however, these can also be affected by variations in climatic conditions between seasons, differences in fruit load, and with a higher fruit load during the second season in the present experiment. A higher fruit load distributes reserve carbohydrates and those produced during the fruit growth cycle to a greater number of fruits per plant, which reduces both fruit size and weight (Karimi et al., 2019; Fang et al., 2020); it can also affect fruit firmness (Fang et al., 2020). Strik et al. (2017b) mentioned differences in fruit firmness for highbush 'Duke' and 'Liberty' at the same location for six of the seven evaluated seasons. Regarding the climatic effect, the higher mean temperature in the first season (2020-2021) could have increased the yield of reserves and higher yield in the second season, as well as reduced fruit firmness, size, and weight. Hancock et al. (1992) reported that an increase in air temperature from 20 to 25 °C increased CO_2 assimilation, which could increase carbohydrate accumulation during the first season and increase yield in the second season. Another aspect to consider in our experiment is that plants treated with a higher load showed greater vegetative development (data not evaluated), which increased yield per plant in the second season (greater number of fruit buds per plant), except for 'Legacy' in the orchard 2.

The three experimental locations also affected fruit quality attributes in both cultivars; Vance et al. (2017) reported this for blueberries. These differences among locations can be mainly explained by variations in orchard and fruit load; climatic conditions are similar at the three locations, considering that orchards are geographically very close (no more than 30 km between orchards in a straight line). However, the interaction between seasons, orchards in both cultivars, and weeks of harvest did not enable determining which of the three orchards provided the best conditions for fruit quality attributes. Increased yield in both cultivars from the first to the second season in the three orchards, except for 'Legacy' in the orchard 2, affected the values of the three evaluated quality attributes. This situation has been mentioned by some authors (Karimi et al., 2019; Fang et al., 2020).

The differences in fruit load affected the evaluated fruit quality attributes in the present experiment; this concurs with findings for blueberries by several authors (Muñoz-Vega et al., 2017; Kang et al., 2018; Kwon et al., 2018). Overall, lower fruit bud load levels increased the values of fruit firmness, size, and weight in 'Duke' and 'Legacy' in both seasons; but the interaction between load levels and seasons in both cultivars did not consistently determine the load level that maximized the values of the evaluated quality attributes. The effect of fruit load regulation mainly promoted increased fruit weight, as indicated by other authors (De Moura et al., 2017; Muñoz-Vega et al., 2017; Kwon et al., 2018). The effect of fruit load regulation showed, as usual, a directly proportional relationship between load reduction and decreased yield; as has also been mentioned by other authors (De Moura et al., 2017; Muñoz-Vega et al., 2017).

Meanwhile, fruit weight values were like those reported by these authors. Fruit firmness values for 'Duke' were lower than those indicated by Retamales et al. (2014) and like those reported by Yang et al. (2009). However, fruit firmness in these two studies was determined with a FirmTech instrument (BioWorks, Wamego, Kansas, USA) whose measurement scale differs from the FirmPro instrument used in our experiment.

Fruit firmness and size values for 'Legacy' in both seasons were slightly lower than values reported by Strik and Davis (2022), measured with the FirmTech instrument. Meanwhile, fruit weight values in both seasons were like those mentioned by the same authors. As for plant yield, values in the first season were slightly lower than values indicated by Strik and Davis (2022), while values in the second season were similar.

CONCLUSIONS

The results of the present study indicate that reducing the fruit bud load by winter pruning improved the quality attributes of fruit firmness, size, and weight of 'Duke' and 'Legacy' blueberries, but negatively affected fruit production per plant. The 60% fruit bud load level achieved the highest values for fruit firmness, size, and weight in both blueberry cultivars. This level produced 70% and 86% of the potential load in 'Duke' and 'Legacy', respectively, as an average of the two evaluated seasons.

Author contribution

Conceptualization: P.M-V., J.H. Methodology: P.M-V. Software, J.R-S., E.M., C.B. Validation: P.M-V. Formal analysis: J.H., P.M-V., J.R-S., C.B., E.M. Data curation: P.M-V., C.B. Writing original draft: J.H. Project administration: P.M-V. Funding acquisition: J.H., P.M-V. Visualization: P.M-V. Supervision: P.M-V. Critical review: J.R-S., P.M-V., E.M. All co-authors reviewed the final version and approved the manuscript before submission.

Acknowledgements

The authors wish to acknowledge funding by the Instituto de Investigaciones Agropecuarias (INIA) de Chile and the FIA EST-2019-0738 project, and the collaboration of the Asociación de Agricultores de Ñuble.

References

Bhusal, N., Han, S.G., Yoon, T.M. 2017. Summer pruning and reflective film enhance fruit quality in excessively tall spindle apple tree. Horticulture, Environment, and Biotechnology 58:560-567. doi:10.1007/s13580-017-0375-y.

INE. 2021. Censo Agropecuario y Forestal 2021. Instituto Nacional de Estadística (INE), Santiago, Chile. Available at https://www.ine.cl/estadisticas/economia/agricultura-agroindustria-y-pesca/censos-agropecuarios (accessed 5 September 2022).

De Moura, G., Vizzotto, M., Picolotto, L., Corrêa Antunes, L. 2017. Production, physical-chemical quality and bioactive compounds of misty blueberry fruit under different pruning intensities. Revista Brasileira de Fruticultura 39:e-158. doi:10.1590/0100-29452017158.

Ehlenfeldt, M.K., Vinyard, B.T. 2015. Pruning time × cultivar effects on flower-bud hardiness in northern highbush and southern highbush blueberry. HortScience 50:673-675. doi:10.21273/HORTSCI.50.5.673.

Fang, Y., Williamson, J., Darnell, R., Li, Y., Liu, G. 2020. Optimizing nitrogen fertigation rates for young southern highbush blueberry. Agronomy 10:389. doi:10.3390/agronomy10030389.

Hancock, J.F., Haghighi, K., Krebs, S.L., Flore, J.A. 1992. Photosynthetic heat stability in highbush blueberries and the possibility of genetic improvement. HortScience 27(10):1111-1112.

Kang, D.I., Shin, M.H., Lee, S.G., Kim, H.L., Kim, J.G. 2018. Influence of winter and summer pruning on bush growth, yield and fruit qualities in the Southern highbush blueberry 'Misty'. Horticultural Science and Technology 36:799-809. doi:10.12972/kjhst.20180078.

Karimi, F., Baba, T., Noma, S., Mizuta, D., Gook, J., Watanabe, M., et al. 2019. Summer pruning severity affected vegetative and reproductive traits in the rabbiteye blueberry (*Vaccinium virgatum* Ait.) The Horticulture Journal 88:315-319.

Karimi, F., Igata, M., Baba, T., Noma, S., Mizuta, D., Gook, J., et al. 2017. Summer pruning differentiates vegetative buds to flower buds in the rabbiteye blueberry (*Vaccinium virgatum* Ait.) The Horticulture Journal 86:300-304. doi:10.2503/hortj.MI-158.

Kwon, Y., Kang, I., Yoo, J., Woo, H., Koh, S., Kim, S., et al. 2018. Effects of pruning and fertilization on the growth of highbush blueberry 'Jersey'. Horticultural Science and Technology 36:521-528. doi:10.12972/kjhst.20180052.

Lindsay, W.L., Norvell, W.A. 1978. Development of DTPA soil test for zinc, iron, manganese and copper. Soil Science Society of America Journal 42:421-428.

Muñoz-Vega, P., Serri, H., López, M.D., Faúndez, M., Palma, P. 2017. Effect of different pruning intensities on yield and fruit quality of blueberry (*Vaccinium corymbosum* L.) cv. Brigitta. Chilean Journal of Agricultural and Animal Science 33:285-294.

Retamales, J.B., Hancock, J.F. 2012. Blueberries. 323 p. Crop Production Science in Horticulture N°21. CABI, Wallingford, UK.

Retamales, J., Lobos, G., Romero, S., Godoy, R., Moggia, C. 2014. Repeated applications of CPPU on highbush blueberry cv. Duke increase yield and enhance fruit quality at harvest and during postharvest. Chilean Journal of Agricultural Research 74:157-161.

Sadzawka, A., Carrasco, M.A., Grez, R., Mora, M., Flores, H., Neaman, A. 2006. Métodos de análisis recomendados para los suelos de Chile. Revisión 2006. Serie Actas INIA N°34. 164 p. Instituto de Investigaciones Agropecuarias (INIA), Santiago, Chile.

Strik, B.C. 2019. Frequency of harvest affects berry weight, firmness, titratable acidity, and percent soluble solids of highbush blueberry cultivars in Oregon. Journal American Pomological Society 73:254-268.

Strik, B.C. 2020. Pruning blueberry for growth, yield and quality. Oregon State University Professional and Continuing Education. Available at https://workspace.oregonstate.edu/course/pruning-blueberries (accessed 17 December 2021).

Strik, B.C., Buller, G., Hellman, E. 2003. Pruning severity affects yield, berry weight, and hand harvest efficiency of highbush blueberry. HortScience 38:196-199. doi:10.21273/HORTSCI.38.2.196.

Strik, B.C., Davis, A.J. 2022. Pruning method and trellising impact hand- and machine-harvested yield and costs of production in 'Legacy' highbush blueberry. HortScience 57:811-817. doi:10.21273/HORTSCI16640-22.

Strik, B.C., Vance, A.J., Bryla, D.R., Sullivan, D.M. 2017a. Organic production systems in Northern highbush blueberry: I. Impact of planting method, cultivar, fertilizer, and mulch on yield and fruit quality from planting through maturity. HortScience 52:1201-1213.

Strik, B.C., Vance, A.J., Finn, C.E. 2017b. Northern highbush blueberry cultivars differ in yield and fruit quality in two organic production systems from planting to maturity. HortScience 52:844-851. doi:10.21273/HORTSCI11972-17.

USDA. 2014. Keys to soil taxonomy. 12th ed. United States Department of Agriculture (USDA), Washington D.C., USA.

Vance, A., Jones, P., Strik, B. 2017. Foliar calcium applications do not improve quality or shelf life of strawberry, raspberry, blackberry, or blueberry fruit. HortScience 52(3):382-387.

Yang, W.Q., Harpole, J., Finn, C.E., Strik, B.C. 2009. Evaluating berry firmness and total soluble solids of newly released highbush blueberry cultivars. Acta Horticulturae 810:863-867.

Yañez, P., Retamales, J.B., Lobos, G.A., del Pozo, A. 2009. Light environment within mature rabbiteye blueberry canopies influences flower bud formation. Acta Horticulturae 810:471-473.