

# Pruning Method and Trellising Impact Hand- and Machine-harvested Yield and Costs of Production in ‘Legacy’ Highbush Blueberry

Bernadine C. Strik and Amanda J. Davis

Department of Horticulture, Oregon State University, 4017 ALS, Corvallis, OR 97331

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**Abstract.** A 6-year trial was established in Oct. 2015 in western Oregon to evaluate the effects of pruning and trellising on yield, hand- and machine-harvest efficiency, fruit quality, and costs of pruning and harvest of ‘Legacy’ highbush blueberry (complex hybrid based largely on *Vaccinium corymbosum* L. and *Vaccinium darrowii* Camp.). Pruning treatments began in Winter 2017–18 (before year 3) and continued each year through 2020–21 (year 6). Treatments included 1) recommended pruning for ‘Legacy’, removing less wood and leaving more short, thin laterals and a denser bush than is typical for most northern highbush cultivars (“control” with standard T-trellis), 2) control pruning and training to a V-trellis (“V”), and 3) standard northern highbush style pruning (“HB” with standard T-trellis). Fruit were harvested solely by hand in 2017 and 2018, and by hand for early harvests followed by machine for later harvests from 2019 to 2021. In most years, more wood was removed from HB- than control-pruned plants. On average, HB-pruned plants had a lower yield (6.7 kg/plant) than control-pruned plants, particularly those trained to a V-trellis (7.5 kg/plant). There was little effect of pruning treatment on fruiting season and hand- (7% drop) or machine-harvest efficiency (23% drop). Pruning method had no effect on berry weight, diameter, total soluble solids, or firmness over the study period or percent internal bruising in 2019. All of the ‘Legacy’ pruning methods studied required more time (358 to 561 h·ha<sup>-1</sup>) than the industry standard, ‘Duke’ (247 h·ha<sup>-1</sup>). Control and HB pruning did not differ in time to prune per unit area; however, in 2 of the 4 years, adding a V-trellis increased pruning time. On average, control and HB pruning had a similar cost per harvested fruit (\$0.20 to \$0.21/kg), whereas control pruning with a V-trellis (\$0.23/kg) cost more than HB pruning. All treatments required the same amount of time to harvest (12.7 and 0.5 min·kg<sup>-1</sup> for hand and machine picking, respectively). Total cost to prune and harvest ranged from \$1.63/kg in 2019 to \$3.43/kg in 2021 but was most heavily influenced by harvest costs rather than pruning. The one-time installation cost of \$637/ha for the V-trellis was not compensated for by increased yield or efficiency of pruning or harvest compared with the control method with a standard T-trellis. Pruning according to recommended methods for ‘Legacy’ (control) increased yield without having a negative effect on fruit quality and had similar or lower costs to prune per kg of fruit harvested as typical northern highbush pruning.

Northwestern United States is a major production region for blueberry (*V. corymbosum* L.), with 14,170 ha in Oregon and Washington combined and 55% of the total U.S. production of highbush blueberries in 2020 (North American Blueberry Association, unpublished data). There are many highbush blueberry cultivars grown in this region (Strik et al., 2014). ‘Legacy’, a midseason blueberry cultivar (complex hybrid based

largely on *V. corymbosum* L. and *V. darrowii* Camp.), was released in 1993 (U.S. Department of Agriculture–Agricultural Research Service and New Jersey Agricultural Experiment Station–Rutgers University, 1993). Starting in the early 2000s, ‘Legacy’ became popular in western Oregon for its high yield and fruit quality and is now widely planted. ‘Legacy’ is considerably less cold hardy than pure northern highbush cultivars (Ehlenfeldt et al., 2012) and is not recommended for colder regions of Oregon or Washington.

‘Legacy’ has a very different growth habit from the more typical northern highbush cultivars grown in the region. The plant is vigorous with an umbrella-like canopy shape, requiring a standard T-trellis for support, and can retain many of its leaves throughout the winter (Strik et al., 2014). Once plantings of ‘Legacy’ were established, many growers complained of high pruning costs per area

relative to other commonly grown cultivars, such as ‘Duke’ (B. Strik, personal observation). In hand-harvested ‘Duke’, pruning accounted for 11% of the total variable costs, compared with 73% for harvesting the fruit (Sutton and Sterns, 2020). Pruning northern highbush blueberry plants annually each winter is important to stimulate vigorous, renewal growth and to maintain a consistent yield, good fruit quality, and a concentrated fruiting season, but pruning method or severity has a large impact on pruning time and costs (Mainland, 1989; Seifker and Hancock, 1987; Strik, 2020; Strik et al., 2003). Pruning plants that retain leaves in winter increases pruning time as well. Although it is best to prune ‘Legacy’ as late as possible in winter to maximize leaf senescence, pruning time has little effect on cold hardiness of this cultivar (Ehlenfeldt and Vinyard, 2015).

Trials and experience have led to recommendations for pruning ‘Legacy’ less severely than other highbush cultivars, leaving more fruiting laterals that are often shorter and thinner, increasing yield while maintaining fruit quality (Strik, 2019, 2020; Strik et al., 2017). However, this method of pruning also leads to a denser plant canopy. In mature plantings, growers shared that picking efficiency was low in ‘Legacy’, particularly for later ripening fruit located deep within the canopy. Thus, many of these growers were using machine harvesters to pick later ripening fruit with a goal of reducing harvest costs (B. Strik, personal observation).

The objectives of this study were to 1) compare recommended pruning methods for ‘Legacy’ (Strik, 2020) with those more commonly used for northern highbush cultivars that growers find faster, particularly with commercial pruning crews, and 2) determine whether using a simple divided canopy (a V-trellis) along with the recommended pruning method improve hand- and machine-harvest efficiency. Treatments were compared for yield, harvest efficiency, fruit quality, and pruning and harvest costs per unit area and per volume of fruit harvested.

## Materials and Methods

The study site was within a 0.1-ha block established in Oct. 2015 at Oregon State University’s North Willamette Research and Extension Center (Aurora, OR; lat. 45°16′47″N, long. 122°45′23″W). Weather data for this site are available from an AgriMet weather station (U.S. Department of the Interior, 2016). The soil is mapped as a Willamette silt loam (a fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll).

*Site preparation.* The field was fallow in 2014 and throughout the spring and summer of 2015. Weeds were controlled using two applications of glyphosate before soil preparation. In Aug. 2015, the field was power spaded to a depth of 0.4 m and tilled to a depth of ≈0.2 m. A pooled soil sample taken in Sept. 2015 indicated that soil pH (4.9) was within a suitable range for highbush blueberry (4.5–5.5) and soil B (0.38 ppm)

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B.C.S. is the corresponding author. E-mail: bernadine.strik@oregonstate.edu

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was low (ideal 0.5–1.0 ppm); other nutrients, including P, K, Ca, and Mg, were at appropriate levels for blueberry (Hart et al., 2006). Before bed-shaping, 2.2 ton·ha<sup>-1</sup> dolomite lime was broadcast over the entire site to mitigate declines in soil pH over the study period that was expected from N fertilization, and 0.6 kg·ha<sup>-1</sup> of B (Solubor; U.S. Borax, Chicago, IL) was applied to the in-row area. Soil organic matter levels were 2.1%, which is lower than the 4% recommended, and thus an 8- to 10-cm-deep layer (target application rate of 282 m<sup>3</sup>·ha<sup>-1</sup>) of douglas fir sawdust [*Pseudotsuga menziesii* (Mirb.) Franco] was applied to the in-row area. The nutrient and sawdust amendments were incorporated by tilling them into the soil to a depth of ≈0.2 m. Amending with sawdust before planting is a standard commercial practice in this region (Sutton and Sterns, 2020). A bed shaper was used to create raised beds that were ≈1.2-m and 0.6-m wide at the base and top, respectively, and ≈0.3-m high. A composite soil sample (late October to early November) was taken each year to monitor soil pH and nutrient levels.

Industry-standard, 18-month-old ‘Legacy’ blueberry plants were removed from 2-L pots and transplanted on 16 Oct. 2015. Plant spacing was 0.9 m in the row and 3.0 m between rows (3588 plants/ha), with four plants per plot and 2.4 m between plots to allow for clearing of fruit between treatments when machine harvesting. There were four replicates arranged in a randomized block design.

**Field management.** Plants were irrigated with one line of 1.3-cm-diameter polyethylene drip tubing (Netafim, Fresno, CA) on each side of the plants and four 3.8 L·h<sup>-1</sup> emitters per plant (two on each side). Black weed mat (water flow rate of 6.8 L/m<sup>2</sup> per h; 0.11 kg/m<sup>2</sup>; TenCate Protective Fabrics; OBC Northwest Inc., Canby, OR) was then applied to the in-row area as a mulch. A trellis was installed, consisting of in-row metal t-posts with 0.6 m-long crossarms attached with a U-bolt; one post was located near the end of each treatment plot. One 12.5-gauge, high-tensile wire was installed on each side of the row and secured with a wire tightener. Wires were inserted into slots present on each crossarm. Crossarm height was adjusted, as needed, as plant height increased during establishment.

The planting was irrigated 3 to 7 d/week, generally from mid- to late-May through September each year, with irrigation adjusted based on air temperature and stage of plant development. Plants were fertilized through the drip irrigation system. Urea (46N–0P–0K; 2016, 2017, and 2020) or ammonium sulfate (21N–0P–0K–24S; 2018 and 2019) was applied weekly (2016) or twice per week (2017–21) from mid-April through early July. A total of 73, 139, 67, 81, 94, and 94 kg·ha<sup>-1</sup> N was applied in 2016 through 2021, respectively. Soil K levels declined from 250 ppm before planting to 89 ppm in Fall 2018. Because of this, coupled with leaf K at the low end of recommended sufficiency levels (0.40% to 0.55%; Strik and Davis, 2022) in

2018 (0.40%) and 2019 (0.42%), potassium thiosulfate was applied by fertigation in 2019 and 2020 at a total of 45 kg·ha<sup>-1</sup> K per year. Leaf and soil K levels were sufficient for the rest of the study, and therefore, K fertilization was no longer required. Boron (Solubor; U.S. Borax, Chicago, IL) was applied when leaf nutrient testing indicated values were below sufficiency (<30 ppm; Hart et al., 2006; Strik and Davis, 2022), using foliar applications in spring just before bloom (2018, 2019, 2021) and in fall before leaf senescence (2018, 2020) at rates of 0.4 to 1.5 kg·ha<sup>-1</sup> B per year.

A permanent rye and fescue grass blend [perennial ryegrass (*Lolium perenne* L. ‘Shining star’), creeping red fescue (*Festuca rubra* L. ‘Boreal’), hard fescue (*Festuca brevipila* R. ‘VNS’)] was grown in the row aisles and mowed during the growing season, as required. Weeds were controlled along the edges of the weed mat using herbicides and were pulled by hand when present around the plant crown, as needed. A scare alarm (Bird Gard LLC, Sisters, OR) was used to reduce depredation from birds. No other pests were observed or identified in the planting through the course of the study.

Plants were pruned in the 2015–16 dormant season to shape the plant and remove all flower buds so there would be no fruit in 2016, the first growing season. Plants had strong growth during that year and were deemed large enough to produce a crop the following year. Plants were pruned uniformly in 2016–17 to encourage vegetative growth and plant establishment, but sufficient buds were left at pruning for plants to produce a typical small crop in 2017 (Strik et al., 2017).

**Treatments.** Pruning and trellising treatments began in Winter 2017–18 (year 3) and continued each year through 2020–21 (year 6). Treatments included 1) standard pruning for ‘Legacy’ (“control”), 2) control pruning with a V-trellis (“V”), and 3) standard northern highbush style pruning (“HB”), as shown in Fig. 1A–D. Standard ‘Legacy’ pruning removes less wood and leaves more short, thin laterals and a denser bush than is typical for most northern highbush cultivars (Strik, 2020). Yield progression during establishment using this pruning method has been documented for ‘Legacy’ (Strik et al., 2017). An additional set of trellis wires was installed in the “V” treatment plots, one per each side of the row, ≈7 to 10 cm from the existing wires (Fig. 1C and D). The double set of wires per side allowed for positioning of the canes, after pruning, to open up the center of bush. The V-trellis was installed before the 2018 growing season. Standard HB pruning removes more canes, targets the removal of smaller laterals, and opens up the center of the bush more than control pruning. Lower stems and canes that might interfere with the catcher plates of the machine harvester or touch the ground when laden with fruit were removed in all treatments each year.

**Data collection.** Plant tissue samples (most-recent fully expanded leaves in late July to early August) were collected each year in all plots and were sent to a commercial testing laboratory (Brookside Laboratories, New Bremen, OH) for nutrient analysis. Leaf N was determined using a combustion analyzer with an induction furnace and thermal conductivity detector (Gavlak et al., 1994). Other leaf nutrients, including P, K, Ca, Mg, Al, B, Cu, Mn, Fe, and Zn, were determined using an inductively coupled plasma spectrophotometer after wet ashing the samples in nitric/perchloric acid (Gavlak et al., 1994).

Fruit were harvested by hand or using an over-the-row machine harvester equipped with standard, plastic catcher plates (Littau Harvester, Stayton, OR) as they reached commercially acceptable ripeness about every 7 to 15 d (Table 1). In years 2 and 3, when plants were young, all fruit were harvested by hand; however, in subsequent years, the first two harvests were by hand and later harvests were by machine, as is common for commercial production of this cultivar. The fruit were weighed from each plot and divided by the number of plants per plot to calculate yield per plant for each harvest. The percentage of total yield at each harvest was calculated to reflect fruiting season. A random subsample of 25 berries was taken from each plot on every harvest date to determine average berry weight (a weighted seasonal average mass was then calculated) and to assess berry firmness and diameter, using a FirmTech II (BioWorks, Inc., Wamego, KS). The berries were then homogenized by hand in a zippered plastic bag and measured for percent total soluble solids (TSS) using a temperature-compensating digital refractometer (Atago, Bellevue, WA). Berry diameter, firmness, and TSS are reported as seasonal averages. In 2019 only, an assessment of fruit bruising was conducted for both hand- and machine-picked fruit. Berries were kept at room temperature for ≈24 h after harvest and then were sliced across the equatorial center and visually rated for the percentage of the fruit showing tissue bruising, per methods of Yu et al. (2014).

After each hand or machine harvest, fruit that had fallen to the ground were collected from a 1-m-long section of each plot, including the entire raised bed and crown area, to calculate the total mass of dropped fruit per plant and percent drop per harvest [drop/(harvested yield + drop) × 100]. After harvest was completely finished in 2020–21, any remaining fruit on the plants (including green and overripe berries) was stripped, weighed, and divided by the number of plants per plot; this proportion of yield was deemed unharvestable by machine.

Data were collected on pruning weight per plot, with pruning weight per plant calculated in each year. Costs of these pruning treatments were estimated as follows. The time required to prune and harvest each plot (hand and machine), considering the total

## Results and Discussion

**Pruning weight.** In 3 of the 4 years, more pruning wood was removed with HB pruning than for the control (Table 2). This was expected, as the recommended pruning method for ‘Legacy’ is to retain more wood to increase yield, which has been proven to be possible while maintaining berry size and quality (Strik, 2020; Strik et al., 2017). Control-pruned plants trained to the V-trellis did not differ in pruning weight from HB-pruned plants because extra canes had to be removed from the center of the bush to train to the V-trellis (Table 2).

**Yield, harvest efficiency, and fruit characteristics.** Yield in the second growing season, before pruning treatments were initiated, averaged 1.0 kg/plant (data not shown). This was a higher yield than reported previously for similarly aged plants grown organically (Strik et al., 2017).

From 2018–21, year had a significant effect on yield, as expected during establishment (Fig. 2). Yield was higher than previously reported for ‘Legacy’ plants of a similar age (Strik et al., 2017), except in 2020 when yield was reduced from heavy bird depredation. In 2021, an extreme heat event occurred from 26 to 28 June, when maximum and minimum daily temperatures ranged from 41 to 45 °C and 19 to 29 °C, respectively, and relative humidity in late afternoon was unusually low at 13% to 16%. These unusual conditions occurred during the fruit ripening and sizing period and likely reduced yield in 2021, which was also observed in commercial fields of ‘Legacy’ (B. Strik, personal observation).

Averaged over all 4 years, HB-pruned plants had a lower yield (6.7 kg/plant) than control-pruned plants ( $P = 0.0086$ ), particularly those trained to a V-trellis (7.5 kg/plant). Typically, when more wood is removed at pruning, as with the HB method compared with the control, yield is lower (Seifker and Hancock, 1987; Strik et al., 2003). When analyzed by year, pruning method did not affect yield in 2018 or 2019 (Fig. 2). In 2020, control-pruned plants trained to a V-trellis had the highest yield (6.0 kg/plant), control-pruned with the standard trellis were intermediate (5.8 kg/plant), and HB-pruned with the standard trellis had the lowest (5.1 kg/plant) (Fig. 2). In 2021, control-pruned plants with a standard or a V-trellis (9.3 kg/plant) produced higher yield than HB-pruned plants (8.5 kg/plant) (Fig. 2). These yields are equivalent to 34.4 and 31.5 t·ha<sup>-1</sup> for control and HB-pruned treatments, respectively. Similar yields are common in well-managed,



Fig. 1. ‘Legacy’ blueberry after pruning according to three methods. (A) Control: standard pruning for ‘Legacy’, removing less wood and leaving more short, thin laterals and a denser bush than is typical for most northern highbush cultivars. (B) HB: standard northern highbush style pruning. (C) V-trellis: control pruning with an additional set of trellis wires to allow for positioning of the canes in a V shape. (D) V-trellis plants in summer, showing the regrowth of shoots with fruit in the center of the canopy. (A–C) were taken 10 Feb. 2020; (D) 3 June 2020.

harvested yield, was used to calculate pruning and harvest efficiency, respectively, as minutes per kilogram of fruit harvested. Labor was valued at \$14.70/h for general labor (pruning and harvest) and \$21.10/h for operators (Sutton and Sterns, 2020), which included workers’ compensation, unemployment insurance, and other labor overhead expenses. Labor requirements for pruning presented here are based on one person pruning and may be faster or more efficient with a commercial pruning crew.

**Statistical analysis.** Data were analyzed using PROC MIXED in SAS software package version 9.4 (SAS Institute, Cary, NC), and means were separated at the 5% level using Tukey’s honestly significant difference test. PROC UNIVARIATE was

used to ensure a normal distribution of data before analysis, and log transformations were applied as necessary. Yield components, fruit quality parameters, pruning cost per kilogram fruit harvested, time required to harvest, and leaf nutrients were analyzed across years using a split-plot design [with year as the main effect (2018–21, 2017 not included because treatments were not yet implemented;  $n = 4$ ) and pruning treatment as the subplot ( $n = 3$ )]. Pruning time and pruning weight were analyzed by year, as they were expected to increase annually as the plants matured. The amount and percentage of fruit dropped was also analyzed by year, because this was related to yield and expected to change during planting establishment.

Table 1. Dates and method of fruit harvest from 2017 through 2021 (years 2–6) for ‘Legacy’ blueberry grown at Oregon State University’s North Willamette Research and Extension Center, Aurora, OR. All treatments were harvested on the same dates. Pruning treatments began in Winter 2017–18.

Pick no.	2017		2018		2019		2020		2021	
	Date	Method	Date	Method	Date	Method	Date	Method	Date	Method
1	12 July	Hand	12 July	Hand	10 July	Hand	13 July	Hand	12 July	Hand
2	19 July	Hand	20 July	Hand	25 July	Hand	22 July	Hand	26 July	Hand
3	27 July	Hand	30 July	Hand	7 Aug.	Machine	5 Aug.	Machine	9 Aug.	Machine
4	–	–	9 Aug.	Hand	15 Aug.	Machine	–	–	–	–



Table 2. Effect of pruning method on pruning weight removed per plant and time required to prune ‘Legacy’ from the third (2017–18) through sixth (2020–21) growing seasons at Oregon State University’s North Willamette Research and Extension Center, Aurora, OR.

Treatment <sup>z</sup>	2017–18		2018–19		2019–20		2020–21	
	Pruning wt <sup>y</sup> (kg/plant)	Pruning time (h·ha <sup>-1</sup> )	Pruning wt (kg/plant)	Pruning time (h·ha <sup>-1</sup> )	Pruning wt (kg/plant)	Pruning time (h·ha <sup>-1</sup> )	Pruning wt (kg/plant)	Pruning time (h·ha <sup>-1</sup> )
Control	0.35 b <sup>x</sup>	190	0.6 b	357 b	1.1	423	1.0 b	482 ab
HB	0.48 a	164	0.7 a	323 b	1.4	356	1.5 a	358 b
V	0.36 ab	182	0.8 a	484 a	1.1	444	1.2 ab	561 a
Significance <sup>w</sup>	0.0290	NS	0.0014	0.0039	NS	0.0669	0.0036	0.0066

<sup>z</sup>Treatments include Control: standard pruning for ‘Legacy’, removing less wood and leaving more short, thin laterals and a denser bush than is typical for most northern highbush cultivars; HB: standard northern highbush style pruning; and V: control pruning with an additional set of trellis wires to allow for positioning of the canes in a V shape.

<sup>y</sup>Fresh weight of all wood removed from the bush during dormant pruning.

<sup>x</sup>Means followed by the same letter are not significantly different between treatments, according to Tukey’s honestly significant different test ( $P > 0.05$ ).

<sup>w</sup> $P$  values shown when  $P < 0.10$ . NS indicates nonsignificance.

mature, commercial fields of ‘Legacy’ (B. Strik, personal observation).

Pruning method did not affect harvest efficiency, as measured by the percentage of fruit dropped on the ground during hand or machine harvest (Table 3). Although the V-trellis did separate the canes in winter, in summer when leaves and fruit were present, the center of the canopy was still dense and similar to plants with the standard trellis (Fig. 1D), thus it was not effective at increasing harvest efficiency. In 2020 and 2021, the amount of dropped fruit was lower for HB pruning, but because the harvested yield was also lower for this treatment, there was no difference in percent drop compared with the other treatments. In 2018, percent drop was significantly higher for the last hand harvest than the first, likely a result of pickers needing to search for remaining fruit within the dense canopy of ‘Legacy’. More fruit was dropped during machine harvest (third and fourth picks in 2019–21) than with hand harvest, as expected (Table 3). The percentage of fruit dropped with machine harvest declined

as plants matured and a larger proportion of the bush was above the catcher plates of the machine. Overall, there was no evidence that the percentage of dropped fruit increased as plants aged, despite the associated larger crown size, which affects the opening of machine-harvester catcher plates. More berries remained on the bush after harvest was complete for the season with control pruning or the V-trellis (128 g/plant averaged over 2020 and 2021) compared with HB pruning (50 g/plant), although these are small values relative to the total yield produced and harvested from each bush (data not shown).

On average, HB-pruned plants had an earlier fruiting season than control-pruned V-trellised plants, with a larger proportion of fruit harvested on the first pick, but there was no treatment effect for later picks (Table 4). A larger proportion of total yield was picked on the first harvest as plants aged (2020 and 2021 vs. 2018 and 2019) and developed a larger canopy (Table 4).

Despite differences in yield, pruning method did not affect berry weight over the study period (Table 4) or when analyzed by year (data not shown). Berry weight was similar to what has previously been reported for ‘Legacy’ (Strik et al., 2017), except in 2021 when we suspect the heat event significantly reduced berry weight (Table 4). Plants were well irrigated but over-canopy microsprinklers, which can be used for evaporative cooling to maintain fruit size and quality when air temperatures exceed 35 °C (Yang et al., 2019, 2020), were not installed. In 2021, blueberry growers reported lower than normal fruit size in ‘Legacy’ fields where no evaporative cooling was used (B. Strik, personal observation), similar to research in other cultivars in which berry weight increased when cooling was used (Yang et al., 2020).

Pruning method had no effect on berry TSS, firmness, or diameter over the study period (Table 4) or when analyzed by year (data not shown); however, year had a significant effect on all of these quality traits. In particular, TSS was higher in 2021 than in the prior 2 years, likely due to concentration of sugars in the smaller, drier berries resulting from the heat event (Yang et al., 2020). Berry firmness was higher in years when berries were smaller, as has been found in the past (Strik, 2019; Strik and Buller, 2014). Although heat damage often leads to berry softening (Lobos and Hancock, 2015; Yang et al., 2019), it is possible that the southern highbush parentage of ‘Legacy’ helped it fare better during a heat event than what was reported for other highbush cultivars in the region (Yang et al., 2020).

In 2019, a subsample of fruit was selected from the second (hand-picked) and third (machine-picked) harvests to assess bruising. Hand-picked fruit had an average of 4.6% of the surface area bruised, whereas machine-picked fruit averaged 28.9% bruising; however, there was no pruning treatment effect (data not shown). The lower incidence of bruising observed for hand-picked fruit as compared with fruit harvested by a machine was similar to that reported by DeVetter et al. (2019) for ‘Duke’.

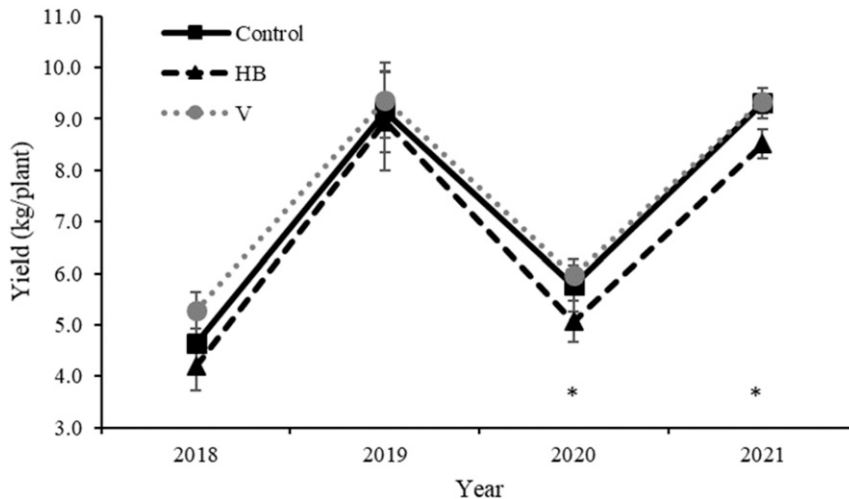


Fig. 2. Yield per plant as affected by pruning treatments (Control: standard pruning for ‘Legacy’, removing less wood and leaving more short, thin laterals and a denser bush than is typical for most northern highbush cultivars; HB: standard northern highbush style pruning; V: control pruning with an additional set of trellis wires to allow for positioning of the canes in a V shape). Error bars represent  $\pm 1$  SE. \*Means ( $n = 4$ ) are significantly different at  $P \leq 0.05$ .

Table 3. Effect of pruning method and pick number on the amount and percentage of fruit dropped during hand and machine harvest from the third (2018) through sixth (2021) growing seasons at Oregon State University's North Willamette Research and Extension Center, Aurora, OR.

Treatment <sup>z</sup>	2018		2019		2020		2021	
	Drop wt (g/plant) <sup>y</sup>	Drop (%) <sup>x</sup>	Drop wt (g/plant)	Drop (%)	Drop wt (g/plant)	Drop (%)	Drop wt (g/plant)	Drop (%)
Control	99	8	366	18	176 ab <sup>w</sup>	14	181 a	8
HB	95	9	326	18	129 b	10	134 b	7
V	99	7	355	16	212 a	11	182 a	8
Pick no.								
1	83	6 b	161 c	10 b	214 a	7 b	192 a	5 b
2	115	9 ab	276 bc	5 b	191 a	8 b	128 b	3 b
3	88	7 ab	606 a	26 a	112 b	21 a	177 ab	15 a
4	105	10 a	354 b	29 a	–	–	–	–
Significance <sup>v</sup>								
Treatment	NS	NS	NS	NS	0.0161	NS	0.0388	NS
Pick no.	NS	0.0152	<0.0001	<0.0001	0.0023	0.0073	0.0121	<0.0001
Treatment × Pick no.	NS	NS	NS	NS	NS	NS	NS	NS

<sup>z</sup>Treatments include Control: standard pruning for 'Legacy', removing less wood and leaving more short, thin laterals and a denser bush than is typical for most northern highbush cultivars; HB: standard northern highbush style pruning; and V: control pruning with an additional set of trellis wires to allow for positioning of the canes in a V shape.

<sup>y</sup>The amount of fruit dropped on the ground during the process of hand or machine harvesting.

<sup>x</sup>Calculated by dividing the amount of fruit dropped during picking by the harvested yield.

<sup>w</sup>Means followed by the same letter are not significantly different between treatments, according to Tukey's honestly significant different test ( $P > 0.05$ ).

<sup>v</sup> $P$  values shown when  $P < 0.05$ . NS indicates nonsignificance.

**Leaf nutrient concentrations.** All leaf nutrient concentrations were affected by year, whereas there was a significant year by pruning method interaction for leaf K and Mg, and pruning method affected leaf B (Table 5). Leaf nutrient concentrations were within recently published sufficiency levels (Strik and Davis, 2022), except for leaf K in 2021 (< 0.40%) and leaf B (< 30 ppm) and Cu (< 3 ppm) in several years. Although leaf N and P tended to decline as plants matured, similar to what was reported by Strik et al. (2019) for 'Duke' and 'Liberty' grown in organic production, but leaf Ca also declined, counter to the increase with planting age that they reported. Control-pruned plants had a lower leaf K in 2018 and 2019 compared with the other two treatments, but in 2020 and 2021, leaf K was similar among pruning treatments (data not shown). Leaf K was highest in the years in which K was fertigated

(2019 and 2020), indicating that this is a rapid way to adjust plant K status in deficient plants. However, the decline in leaf K in 2021 was unexpected because soil K was well above sufficiency levels in Fall 2020 (data not shown). The heat event in late June 2021 may have limited K uptake and movement to leaves during periods of expected low transpiration (Ragel et al., 2019). Lower leaf Ca in 2021 may also have been related to the heat event limiting plant Ca uptake. Leaf Ca was higher in control-pruned and V-trellis trained plants compared with those with HB pruning and standard trellising, indicating that canopy exposure may affect Ca uptake. Leaf B remained low through the study period despite applying foliar B, as found in other studies in Oregon (e.g., Strik et al., 2019).

**Costs of pruning and harvest.** Starting after the 2018 season, 'Legacy' required more time to prune, regardless of treatment (Table 2),

than the industry standard 'Duke' (247 h·ha<sup>-1</sup>; Sutton and Sterns, 2020). In 2 of 4 years (2018–19 and 2020–21), adding a V-trellis to the control-pruning treatment required more pruning time because of the additional work of tucking canes between the wires compared with the control (Table 2), with a similar trend in 2019–20. Our results thus confirmed grower experience that 'Legacy' requires more labor (per unit area) to prune than other standard cultivars.

When calculating the cost of pruning per kilogram of fruit harvested (Table 6), the control (recommended) method and HB pruning were similar (\$0.21/kg and \$0.20/kg, respectively, averaged over all four seasons), whereas the control-pruned with a V-trellis cost more than HB-pruned (\$0.23/kg). Cost per kilogram was highest in 2020 because, although pruning costs were the same, yields were artificially low because of bird predation. There

Table 4. Main effects of year and pruning treatment on fruit quality and harvest season of 'Legacy' blueberry grown at Oregon State University's North Willamette Research and Extension Center, Aurora, OR.

	Berry wt (g) <sup>z</sup>	TSS (%) <sup>y</sup>	Harvested (%)				Firmness (g·mm <sup>-1</sup> deflection)	Diam (mm)
			Pick 1	Pick 2	Pick 3	Pick 4		
Year								
2018	2.0 a <sup>x</sup>	15.3 ab	27 b	26 d	25 a	21 a	223 a	16.1 c
2019	2.2 ab	13.4 c	17 c	55 a	19 a	10 b	172 c	19.8 b
2020	2.2 a	14.7 b	53 a	38 c	10 b	–	186 b	21.5 a
2021	1.4 c	15.5 a	44 a	45 b	11 b	–	217 a	14.9 d
Treatment <sup>w</sup>								
Control	1.9	14.8	35 ab	41	16	17	201	18.1
HB	2.0	14.7	38 a	41	15	13	198	18.2
V	1.9	14.6	32 b	41	18	17	199	18.0
Significance <sup>v</sup>								
Year	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	0.0279	<0.0001	<0.0001
Treatment	NS	NS	0.0017	NS	NS	NS	NS	NS
Year × Treatment	NS	NS	NS	NS	NS	NS	NS	NS

<sup>z</sup>Seasonal weighted average for the year.

<sup>y</sup>Average percent total soluble solids (TSS) for the year.

<sup>x</sup>Means followed by the same letter are not significantly different between treatments, according to Tukey's honestly significant different test ( $P > 0.05$ ).

<sup>w</sup>Treatments include Control: standard pruning for 'Legacy', removing less wood and leaving more short, thin laterals and a denser bush than is typical for most northern highbush cultivars; HB: standard northern highbush style pruning; and V: control pruning with an additional set of trellis wires to allow for positioning of the canes in a V shape.

<sup>v</sup> $P$  values shown when  $P < 0.05$ . NS indicates nonsignificance.

Table 5. Main effects of year and pruning treatment on leaf nutrient concentrations sampled in late July/early August, 2018–21 of ‘Legacy’ blueberry grown at Oregon State University’s North Willamette Research and Extension Center, Aurora, OR.

	Leaf macronutrient conc. (%)						Leaf micronutrient conc. (ppm)					
	N	P	Mg	K	Ca	S	B	Fe	Mn	Cu	Zn	Al
Year												
2018	1.91 a <sup>z</sup>	0.10 a	0.18 a	0.40 ab	0.71 a	0.14 a	24 b	241 ab	218 b	2.8 a	11.5 a	231 ab
2019	1.58 b	0.09 b	0.17 b	0.42 a	0.67 ab	0.12 b	35 a	159 c	303 a	3.1 a	8.7 b	175 c
2020	1.83 a	0.09 b	0.18 a	0.41 a	0.61 bc	0.13 a	27 b	194 bc	264 ab	2.0 b	9.7 b	196 bc
2021	1.54 b	0.08 c	0.19 a	0.37 b	0.57 c	0.11 c	29 b	259 a	204 b	1.4 b	9.1 b	264 a
Treatment <sup>y</sup>												
Control	1.71	0.09	0.18 a	0.39	0.64 ab	0.12	27 b	212	242	2.2	9.8	213
HB	1.70	0.09	0.17 b	0.41	0.62 b	0.12	28 ab	213	240	2.4	9.7	217
V	1.74	0.09	0.18 ab	0.40	0.66 a	0.13	31 a	215	260	2.3	9.8	219
Significance <sup>x</sup>												
Year	<0.0001	<0.0001	0.0096	0.0162	0.0015	<0.0001	0.0004	0.0017	0.0035	<0.0001	0.0004	0.0034
Treatment	NS	NS	0.0238	NS	0.0012	NS	0.0114	NS	NS	NS	NS	NS
Year × Treatment	NS	NS	0.0274	0.0255	NS	NS	NS	NS	NS	NS	NS	NS

<sup>z</sup>Means followed by the same letter are not significantly different between year and treatment, according to Tukey’s honestly significant different test ( $P > 0.05$ ).

<sup>y</sup>Treatments include Control: standard pruning for ‘Legacy’, removing less wood and leaving more short, thin laterals and a denser bush than is typical for most northern highbush cultivars; HB: standard northern highbush style pruning; and V: control pruning with an additional set of trellis wires to allow for positioning of the canes in a V shape.

<sup>x</sup> $P$  values shown when  $P < 0.05$ . NS indicates nonsignificance.

was a year × treatment interaction on pruning cost per kilogram of fruit harvested because HB pruning led to the highest cost in 2018 but had the lowest in other years, except in 2020, when the costs were quite similar among treatments. Based on the cost of pruning ‘Duke’ per kilogram of fruit harvested (Sutton and Sterns, 2020), pruning costs were considerably higher for ‘Duke’ (\$0.30/kg) than for ‘Legacy’ in year 6 of our study (Table 6).

As previously mentioned, the V-trellis did not provide enough separation of the canopy to reduce picking time compared with a standard trellis (Fig. 1D). All pruning treatments required the same amount of time to harvest per kilogram of fruit (12.7 min·kg<sup>-1</sup> for hand picking and 0.5 min·kg<sup>-1</sup> for machine picking), which is equivalent to \$3.11/kg and \$0.15/kg, respectively, when considering the cost of labor for each harvest method (Table 6).

This is more than the industry standard of \$1.86/kg for hand-harvested ‘Duke’ in year 6 (Sutton and Sterns, 2020). However, ‘Legacy’ is more difficult to hand harvest with a denser canopy than ‘Duke’, and our reported costs would likely be lower if professional harvesting crews were used. Although the time and cost would have been reduced with more efficient picking expected from commercial crews, the effect of pruning methods would likely not have changed. The time and cost of harvesting per kilogram fruit was higher in 2018 (\$3.39/kg) because all fruit were hand-picked, and in 2021 because of smaller berry size from the previously described heat event. In 2019, a large percentage of fruit from all treatments was picked on the second harvest, which made hand harvest much more efficient. Total cost to prune and harvest ranged from \$1.63/kg in 2019 to \$3.43/kg in 2021 but was most heavily influenced by harvest costs rather than the relatively small cost of pruning (data not shown).

The additional set of trellis wires used in the V-trellis treatment added a one-time cost of \$637/ha at installation, which was not compensated for with increased yield or efficiency of pruning or harvest compared with the control method.

## Conclusion

Pruning according to recommended methods for ‘Legacy’ increased yield without any negative effects on fruit weight, diameter, firmness, or TSS, and required a similar cost per kg of fruit to prune as the typical highbush pruning method and a lower cost than values reported for ‘Duke’ (Sutton and Sterns, 2020). Adding a V-trellis did not show a clear benefit compared with the standard T-trellis system, as harvest costs were similar to the other treatments and pruning costs per kilogram of fruit were higher. We will thus continue to recommend a lighter

Table 6. Effect of pruning treatment on the cost of pruning and harvest for the third (2018) through sixth (2021) growing seasons for ‘Legacy’ blueberry grown at Oregon State University’s North Willamette Research and Extension Center, Aurora, OR.

Yr	Treatment <sup>y</sup>	Pruning cost (\$/kg) <sup>x</sup>	Harvest cost (\$/kg) <sup>z</sup>			
			Pick 1	Pick 2	Pick 3	Pick 4
2018	Control	0.15 d <sup>w</sup>	2.93	3.61	3.42	3.04
	HB	0.18 cd	2.72	3.53	3.25	3.28
	V	0.15 d	2.75	3.72	3.66	2.90
2019	Control	0.16 cd	3.09	1.62	0.06	0.10
	HB	0.15 d	3.03	1.77	0.06	0.13
	V	0.22 bcd	2.81	1.72	0.05	0.09
2020	Control	0.31 a	2.45	3.76	0.46	–
	HB	0.29 ab	2.23	3.84	0.39	–
	V	0.31 a	2.53	3.85	0.09	–
2021	Control	0.22 bcd	3.83	3.53	0.07	–
	HB	0.18 cd	3.51	3.13	0.10	–
	V	0.25 abc	3.61	3.91	0.07	–
Significance <sup>v</sup>						
Year	0.0001	0.0005	<0.0001	<0.0001	0.0006	
Treatment	0.0185	NS	NS	NS	NS	
Year × Treatment	0.0155	NS	NS	NS	NS	

<sup>z</sup>Costs were weighted by the proportion of fruit harvested on each pick. All harvests were by hand in 2018, whereas harvests 3 and 4 (no fourth harvest required in 2020 or 2021) were by machine in 2019–21 (Table 1). Labor costs for hand harvest are assumed to be \$14.70/h, whereas machine harvest costs assume one operator at \$21.10/h and one general laborer at \$14.70/h. Cost of machine harvester ownership/lease and maintenance are not included.

<sup>y</sup>Treatments include Control: standard pruning for ‘Legacy’, removing less wood and leaving more short, thin laterals and a denser bush than is typical for most northern highbush cultivars; HB: standard northern highbush style pruning; and V: control pruning with an additional set of trellis wires to allow for positioning of the canes in a V shape.

<sup>x</sup>Values assume a labor cost of \$14.70/h and were calculated based on the amount of time required to prune during the winter before the harvest season and the amount of fruit harvested from the same unit area.

<sup>w</sup>Means followed by the same letter are not significantly different between treatments within year, according to Tukey’s honestly significant different test ( $P > 0.05$ ).

<sup>v</sup> $P$  values shown when  $P < 0.05$ . NS indicates nonsignificance.

pruning for 'Legacy' with a standard T-trellis to support the canopy (Strik, 2020).

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