

The Impact of Early Cropping on Subsequent Growth and Yield of Highbush Blueberry in the Establishment Years at Two Planting Densities is Cultivar Dependant

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Abstract. The effect of early cropping (no removal of fruit buds the first two years) and in-row spacing (0.45 or 1.2 m) on growth and yield of ‘Duke’, ‘Bluecrop’, and ‘Elliott’ northern highbush blueberries (*Vaccinium corymbosum* L.) was studied. Plants were grown on raised beds for four years. No yield was produced on the control plants in the planting year (year 1) and year 2. Plant growth at the start of year 3 was adversely impacted by early cropping in years 1 and 2. Early cropping reduced the dry weight of the root system, crown, and 1- to 3-year-old wood in all cultivars. ‘Bluecrop’ plants had less total dry weight than those of ‘Duke’ or ‘Elliott’. Roots accounted for 30% to 45% of the total plant dry weight depending on cultivar. Early-cropped plants had a lower percentage of fruit buds than control plants. Early cropping reduced yield 44%, 24%, and 19% in year 3, compared to control plants, in ‘Elliott’, ‘Duke’, and ‘Bluecrop’, respectively. Cumulative yield (years 1 through 4) was similar between control and early cropped plants in ‘Bluecrop’ and ‘Duke’, whereas early cropping reduced cumulative yield in ‘Elliott’ 20% to 40%, depending on in-row spacing. Plants spaced at 0.45 m produced 62% to 140% more yield per hectare than those spaced at 1.2 m, depending on cultivar. ‘Elliott’ plants seemed less suited to high density planting due to their large root system.

The area planted to highbush blueberry in the United States increased 24% from 1992 to 2003 to 22,622 ha and is projected to increase by 31% in the next 10 years (Strik and Yarborough, 2005). Significant growth is expected to continue to occur in other production regions as well, worldwide (Strik, 2005). The most common plant spacing in 1992 was 1.2 m in the row with 3 m between rows (Moore, 1994). Moore et al. (1993), in a 5-year spacing study with ‘Bluecrop’ and ‘Blueray’, reported the highest yield at 0.6-m spacing (compared to 0.9 and 1.2 m) with no differences between cultivars. Strik and Buller (2002) found that cumulative yield of ‘Bluecrop’ from years three through seven was 104% higher at an in-row spacing of 0.45 m compared to 1.2 m. In the past 10 years most new plantings have been established at higher density, usually with less than 1 m between plants and 3 m between rows (Strik and Yarborough, 2005). Strik and Buller’s (2002) research was on one cultivar and on flat ground. Many plantings, however, are on raised beds where root growth may be more restricted horizontally and many cultivars

other than ‘Bluecrop’ are now being planted (Strik and Yarborough, 2005).

Growers have been following recommendations in removing fruit buds to prevent production the first 2 years after planting (Pritts and Hancock, 1992; Strik et al., 1993). This standard procedure, usually performed by pruning off fruit buds in the winter, is thought to be necessary to promote good root and vegetative growth (Dodge, 1981; Eck, 1988). There has been little published research on the impact of early cropping on subsequent growth and yield in blueberry. In a study where blueberry plants did not grow well and there were no significant differences amongst pruning treatments, the recommendation was still to prune young plants to improve the balance between vegetative growth and subsequent fruit quality (Jansen, 1997). Early cropping showed promise in ‘Bluecrop’ in an earlier study by Strik and Buller (2005). Some cultivars may be more impacted by early cropping, because they are high yielding when immature and/or they have a late fruiting season with little time left for vegetative growth between fruiting and dormancy.

If growers were able to crop plants early (in years 1 and 2), then they would not only derive some income from the fruit, but would save an estimated \$125 to \$250/ha by not having to prune off the fruit buds (Eleveld et al., 2005).

The objectives of this study were to determine the effect of early cropping and in-row spacing on plant growth and yield of ‘Duke’, ‘Bluecrop’, and ‘Elliott’, early- to late-season cultivars, ranging in yield when immature.

Materials and Methods

A planting was established at the North Willamette Research and Extension Center, Aurora, Ore., in October 1999. The soil was a Willamette silt loam (fine-silty, mixed, mesic Pachic Ultic Argixerolls) with a pH of 5.5. Sawdust and fertilizer (66 kg·ha⁻¹ of N) were incorporated and raised beds (about 0.4 m high) formed prior to planting 2-year-old container stock. The treatments were 1) cultivar (Duke, Bluecrop, and Elliott); 2) in-row spacing (0.45 and 1.2 m; 7,407 and 2,778 plants/ha, respectively); and 3) with or without early cropping. In treatments without early cropping (control), fruit buds were pruned off plants in October 1999 and in February 2001 so there was no fruit production in 2000 and 2001. There were five replications of each treatment combination arranged in a randomized complete block design for a total of 60 plots. Each plot was 6 m long with 3 m between rows (13 or 5 plants/plot at the 0.45 or 1.2-m spacing, respectively). The planting was flanked by guard rows. The field received overhead irrigation to supply about 3.8 cm of water per week during the growing season when rainfall was inadequate. The planting was otherwise maintained according to standard commercial practices (Strik et al., 1993). All treatment plots were fertilized with 66, 34, 66, and 90 kg·ha⁻¹ of N in 2000 through 2003, respectively. The higher rate in 2000 was chosen due to preplant amendment with fresh sawdust.

Plots were harvested by hand, weekly, with time required to harvest each treatment plot recorded. Data collected annually included yield, average berry weight (25 berries/harvest), pruning weight, and total buds and fruit buds per lateral with percent fruit bud set calculated. Picking efficiency (kg·h⁻¹) was calculated from yield and harvest time data. Plants were pruned by B. Strik with pruning severity adjusted based on plant growth, as per standard commercial practice (Strik et al., 1990). In February 2002 and 2003 after pruning, one plant per plot was destructively harvested and divided into roots, crown, 3-year and older wood, 2-year-old wood, and 1-year-old wood and dry weights obtained for each. In late August to early September 2000 and 2001, after fruit harvest of ‘Elliott’, leaf tissue samples were collected from each treatment and analyzed for nutrient content.

Analysis of variance was performed for treatment effects using the GLM procedure in SAS (SAS Institute Inc., 1999). Treatment means were compared using a Fisher’s protected least significant difference (LSD) test.

Results

Data are presented as main effects (in tables) when interactions were not significant. ‘Duke’, ‘Bluecrop’, and ‘Elliott’ differed significantly

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Table 1. The effect of cultivar, in-row spacing and early cropping on yield from 2000–03 and total cumulative yield.

Treatment	Early crop (yes/no)	Yield/plant (kg)				Cumulative
		2000	2001	2002	2003	
Duke						
0.45 m	No	---	---	2.7	1.6	4.3
	Yes	0.096	0.75	2.1	1.5	4.2
1.2 m	No	---	---	3.5	2.0	5.7
	Yes	0.086	0.66	2.5	2.0	5.3
Bluecrop						
0.45 m	No	---	---	2.5	2.3	5.2
	Yes	0.066	1.1	2.3	2.0	5.2
1.2 m	No	---	---	2.4	3.1	5.5
	Yes	0.061	0.82	1.7	2.0	5.1
Elliott						
0.45 m	No	---	---	5.2	2.2	7.6
	Yes	0.092	1.0	3.4	1.8	6.0
1.2 m	No	---	---	9.2	2.9	12.1
	Yes	0.095	0.95	4.3	2.3	7.1
Significance ^z						
C		0.01	0.01	0.0001	0.01	0.0001
S		NS	0.05	0.0001	0.01	0.0001
EC		---	---	0.0001	0.01	0.0001
C × S		NS	NS	NS	NS	0.001
C × EC		---	---	0.0001	NS	0.0001
S × EC		---	---	NS	NS	0.05

^zC = cultivar; S = in-row spacing; EC = early cropping; P value is provided when significant. ^{NS}Nonsignificant.

in yield per plant from year 1 (2000) through 4 (2003; Table 1). In plants with early cropping, yield was <100 g/plant in 2000, because nurseries commonly prune off most fruit buds before shipping. Yield was significantly less in 'Bluecrop' than in 'Duke' and 'Elliott' and was not affected by in-row spacing. Plants that produced a crop in year 1 had lower pruning weights the following winter than those that were vegetative (Table 2). However, there was no treatment effect on percentage of fruit buds which averaged 46% (Table 3). In year 2, 2001, yield increased in all cultivars ranging from 0.7 to 1.1 kg/plant (1.7 to 7.3 t·ha⁻¹), depending on cultivar and in-row spacing (Table 1).

Early cropping in 2000-01 reduced root, crown, 1-, 2-, and 3-year-old wood, and total plant dry weight in all cultivars in February 2002 (Table 4). 'Duke' and 'Bluecrop' plants had a lower mass of crown and older wood than those of 'Elliott'. 'Elliott' plants had a greater root mass, particularly in plants at 1.2 m, than 'Bluecrop'. There was a lot of variability in root dry mass, particularly in plants at 0.45 m without early cropping. This may have been related to difficulty in getting only the roots from an individual plant at a high planting density; roots from adjacent plants in some plots may have increased apparent root mass. Cultivar had a significant effect ($P < 0.0001$) on percentage of total plant dry weight in roots with 'Bluecrop' having 34% roots compared to 49% in 'Duke' and 53% in 'Elliott'. The top to root ratio was significantly higher ($P < 0.001$) in 'Bluecrop' (2.5) than in 'Duke' (1.2) and 'Elliott' (1.1). There was no effect of early cropping or in-row spacing on the proportion of total dry weight accounted for by roots or the top to root ratio in February 2002 (data not shown). However, cultivar and in-row spacing affected the pruning weight per plant with 'Elliott' plants spaced at 1.2 m having the most growth and subsequent pruning weight (Table 2).

In February 2002, the percentage of total plant dry weight in 1-year-old wood (potential fruiting wood) was significantly higher in plants without early cropping in 2000 and 2001 (20% vs. 13% in early cropped plants). The percentage of fruit buds in 2002 was reduced by early cropping, high density planting, and in 'Bluecrop' and 'Elliott' compared to 'Duke' (Table 3).

In year 3 (2002), all treatments were fruiting. The reduced growth (Table 4) and percentage of fruit bud set (Table 3) caused by early cropping in years 1 and 2 led to a reduced yield per plant in year 3, particularly in 'Bluecrop' and 'Elliott' (Table 1). High-density planting reduced yield per plant (Table 1), but increased yield per hectare 160% in 'Bluecrop', 100% in

Table 2. The effect of cultivar, in-row spacing and early cropping on pruning weight per plant in February 2001–03. Values for cultivar and spacing are averaged over early cropping. Main effects for early cropping are shown.

Treatment	Pruning wt/plant (g)		
	2001	2002	2003
Duke			
0.45 m	24	139	345
1.2 m	32	169	500
Bluecrop			
0.45 m	30	139	346
1.2 m	37	147	355
Elliott			
0.45 m	33	163	338
1.2 m	50	251	513
Early cropping			
No	55	168	503
Yes	13	168	296
Significance ^z			
C	0.001	0.0001	0.01
S	0.0001	0.0001	0.0001
EC	0.0001	NS	0.0001
C × S	NS	0.01	0.001

^zC = cultivar; S = in-row spacing; EC = early cropping; P value is provided when significant. ^{NS}Nonsignificant.

'Duke', and 47% in 'Elliott'. In plots that were not early cropped, yield in year 3 ranged from 6.5 to 24.7 t·ha⁻¹ for plants at 1.2 m and 16.9 to 36.4 t·ha⁻¹ for plants at 0.45 m, depending on cultivar.

Plants at 0.45 m had a reduced crown and total plant dry weight in Feb. 2003, particularly in 'Duke' and 'Elliott' (Table 4). The pruning weight of 'Bluecrop' plants in February 2003 was less affected by in-row spacing and was less in plants at 1.2 m than for 'Duke' and 'Elliott' (Table 2). Early cropping in years 1 and 2 still reduced pruning weights and the dry weight of 1-, 2-, and 3-year-old wood, and crown dry weight in February of year 4 (Tables 2 and 4). However, early cropping had no effect on percent fruit bud set in February 2003 (Table 3). 'Duke' and 'Elliott' had a greater fruit bud set than 'Bluecrop'. Also, plants at 1.2 m had a greater fruit bud set than those at 0.45 m (Table 3). Early cropping had no effect on the top to root ratio of plants (data not shown), but 'Elliott' plants had a lower top to root ratio (1.3) than 'Duke' (1.7) and 'Bluecrop' (2.5) plants ($P < 0.001$).

In year 4 (2003), rain during the pollination period (data not shown) reduced yield. However, yield was still affected by cultivar, in-row spacing, and early cropping (Table 1). High density planting increased yield per hectare 111% in 'Bluecrop', 93% in 'Duke', and 92% in 'Elliott'. In plots that were not early cropped, yield ranged from 5.4 to 8.4 t·ha⁻¹ for plants at 1.2 m and 11.4 to 16.2 t·ha⁻¹ for plants at 0.45 m, depending on cultivar. Effects of early cropping and in-row spacing may have been greater had yield not been reduced by poor fruit set.

Cumulative yield per plant was 77% to 120% greater in 'Elliott' than in 'Bluecrop' or 'Duke', depending on in-row spacing (Table 1). There was a significant cultivar by spacing interaction for cumulative yield per plant (Table 1). In plants not cropped early, 'Bluecrop' produced a similar cumulative yield per plant at 0.45 and 1.2 m, whereas 'Duke' and 'Elliott' produced a higher cumulative yield on plants

Table 3. The effect of cultivar, in-row spacing and early cropping on percentage of fruit bud set in February 2001–03. Main effects for cultivar, in-row spacing, and early cropping are shown.

Treatment	Fruit bud set (%)		
	2001	2002	2003
Cultivar			
Duke	47.2 a	63.5 a ^z	53.2 a
Bluecrop	44.7 a	47.8 b	43.2 b
Elliott	46.5 a	58.0 c	52.4 a
In-row spacing			
0.45 m	46.3	53.0	48.0
1.2 m	46.0	58.5	51.2
Early cropping			
No	45.7	58.2	50.1
Yes	46.6	53.4	49.1
Significance ^z			
C	NS	0.0001	0.0001
S	NS	0.01	0.05
EC	NS	0.05	NS

^zMeans followed by the same letter within cultivar and year are not significantly different ($P \geq 0.05$).

^yC = cultivar; S = in-row spacing; EC = early cropping; P value is provided when significant.

^{NS}Nonsignificant.

spaced at 1.2 m than those at 0.45 m (Table 1). Thus, 'Bluecrop' produced a 140% higher cumulative yield per plot at 0.45 m (36 t·ha⁻¹) than at 1.2 m (15 t·ha⁻¹) for plants that were not cropped early. 'Duke' produced 30 t·ha⁻¹ at 0.45 m, 97% greater than at 1.2 m, whereas 'Elliott' only produced 62% more yield at 0.45 m (53 t·ha⁻¹) than at 1.2 m. Cumulative yield was significantly affected by early cropping (Table 1). However, there was a cultivar by early cropping interaction, because cumulative yield was similar between early cropped and control plants in 'Bluecrop' and 'Duke' whereas early cropping reduced yield 20% to 40% in 'Elliott', depending on in-row spacing.

Cultivars differed in the concentration of many nutrients in leaf tissue in August 2000 and September 2001. 'Bluecrop' plants had significantly higher foliar concentrations of potassium (K) in both years and lower concentrations of calcium (Ca) in 2000, magnesium (Mg) in 2001, and manganese (Mn) and iron (Fe) in 2000 than 'Duke' or 'Elliott' (data not shown). 'Elliott' had a lower concentration of phosphorus (P) than 'Bluecrop' in both years. There was no effect of early cropping on tissue nutrient concentrations in 2000. However in 2001, early cropped plants had a higher con-

centration of P and lower concentrations of Mg, Fe, copper (Cu), and zinc (Zn) than control plants. In-row spacing had an inconsistent or little effect on tissue nutrient concentrations (data not shown).

The cultivars differed in berry weight in all years of this study with 'Bluecrop' having the largest fruit (1.6 to 2.2 g), 'Duke' intermediate (1.1 to 2.0 g) and 'Elliott' the smallest (0.96 to 1.7 g; data not shown). In-row spacing had an inconsistent effect on average berry weight. There was no consistent correlation between berry weight and yield (data not shown). However, in 2002, plants that were early cropped, produced larger fruit (averaged 1.8 g) than those that were not cropped early (averaged 1.6 g) due to a negative correlation between berry weight and yield ($r = -0.56$; $P < 0.0001$). Cultivar was the only factor affecting berry weight in 2003 (data not shown).

Picking efficiency varied from 2000 to 2003 and was affected mainly by cultivar and in-row spacing (Table 5). In 2002, there was a greater picking efficiency in plants that were early cropped, because picking efficiency was positively correlated with yield ($r = 0.640$, $P < 0.0001$) and negatively correlated with berry weight ($r = -0.396$, $P < 0.0017$).

Table 4. The effect of cultivar, in-row spacing and early cropping on dry weight per plant part in February 2002 and 2003. Values for cultivar and spacing are averaged over early cropping. Main effects for early cropping are shown.

Treatment	Dry wt (g/plant part)					Total plant
	1-year-old wood	2-year-old wood	≥3-year-old wood ^z	Crown ^z	Roots	
2002						
Duke						
0.45 m	126	127	151	---	480	884
1.2 m	120	124	185	---	300	711
Bluecrop						
0.45 m	136	140	125	---	247	647
1.2 m	92	57	68	--	91	307
Elliott						
0.45 m	115	81	197	---	425	818
1.2 m	173	102	194	---	534	1001
Early cropping						
No	186	136	185	---	438	940
Yes	68	74	121	---	253	516
Significance ^z						
C	NS	NS	0.0001	---	0.0001	0.0001
S	NS	NS	NS	---	NS	0.05
EC	0.0001	0.0001	0.0001	---	0.0001	0.0001
C × S	0.01	0.01	0.05	---	0.001	0.001
2003						
Duke						
0.45 m	118	90	164	205	386	959
1.2 m	130	114	179	255	441	1117
Bluecrop						
0.45 m	124	104	85	143	222	678
1.2 m	137	114	76	130	174	629
Elliott						
0.45 m	123	98	77	222	405	923
1.2 m	152	135	84	264	458	1093
Early cropping						
No	117	136	117	221	365	956
Yes	143	81	104	185	328	841
Significance						
C	NS	NS	0.0001	0.0001	0.0001	0.0001
S	NS	NS	NS	0.05	NS	0.05
EC	0.05	0.001	NS	0.01	NS	0.05
C × S	NS	NS	NS	0.05	NS	NS

^zCrowns included in wood ≥3 years old in 2002.

^yC = cultivar; S = in-row spacing; EC = early cropping; P value is provided when significant.

^{ns}Nonsignificant.

Discussion

Early cropping in years 1 and 2 reduced yield in year 3 in all cultivars, because young plants bearing fruit had less vegetative growth and less total plant dry weight and fruit bud set than plants in which the fruiting sink had been removed. The adverse effect of cropping young plants on subsequent growth and yield has been documented in other perennial fruit crops (e.g., Avery, 1969, 1970; Maggs, 1963). In this study, producing fruit on plants in years 1 and 2, reduced the weight of the roots as much as 57% at the beginning of year 3 and adversely affected the growth of the above ground plant parts also. Early cropping in apple reduced root system weight by 50% to 70% compared to uncropped plants (Avery, 1970; Maggs, 1963). In February 2002, total plant dry weight was affected by cultivar and early cropping, but not in-row spacing, likely because the canopy was not yet full at the 1.2-m spacing.

Early cropping reduced yield 44%, 24%, and 19% in year 3, compared to control plants, in 'Elliott', 'Duke', and 'Bluecrop', respectively. Our results, confirm common recommendations of removing fruit buds and thus preventing fruiting in years 1 and 2 (Pritts and Hancock, 1992; Strik et al., 1993) to improve vegetative growth (Dodge, 1981; Eck, 1988). In year 4, there was still an effect of early cropping, in years 1 and 2, on yield per plant.

Young plants spaced at high density (0.45 m) compared to the more traditional spacing of 1.2 m produced from 62% to 140% more cumulative yield in this study, depending on the cultivar. 'Elliott' was less adapted to high density planting than 'Duke' or 'Bluecrop'. 'Elliott' had a larger root system, accounting for 45% of the total plant dry weight compared to 37% and 30% in 'Duke' and 'Bluecrop' respectively. In addition, 'Elliott' had the smallest top to root ratio. The smaller root system of 'Bluecrop' and the higher top to root ratio appear to make this cultivar well suited to higher density planting. Our results on the effect of in-row spacing on yield are similar to those reported by Strik and Buller (2002) in 'Bluecrop'.

Cultivars, planted at the higher-density had reduced percent fruit bud set in the last 2 years of this study. We did not measure canopy light levels, but it is possible that flower bud initiation was reduced in the higher density plantings due to lower light levels, particularly in vigorous cultivars such as 'Elliott'. Gough (1994) speculated that increased canopy density might reduce flower bud initiation.

Ballinger and Kushman (1966) found no effect of yield on leaf tissue levels of P, K, Ca, and Mg, although the percentage of P, K and Mg was higher in the fruit of heavily cropped plants. Strik et al. (2003) found that conventionally pruned 'Bluecrop' plants had significantly higher foliar concentrations of K and P and lower concentrations of N, Ca, Mg, Mn, Cu, and B than higher-yielding unpruned plants. In our study, we were comparing plants that had just fruited to plants that had no crop. Many of the micronutrients were lower in plants that

Table 5. The effect of cultivar, in-row spacing and early cropping on picking efficiency from 2000–03. Main effects for cultivar, in-row spacing, and early cropping are shown.

Treatment	Picking efficiency (kg·h ⁻¹)			
	2000	2001	2002	2003
Cultivar				
Duke	4.4 a ^z	6.3 a	6.0 a	6.9 a
Bluecrop	7.3 b	4.5 b	6.3 a	8.2 a
Elliott	4.9 a	2.7 c	11.1 b	9.0 a
In-row spacing				
0.45 m	5.8	4.8	7.4	9.3
1.2 m	5.3	4.1	8.2	6.7
Early cropping				
No	---	---	7.2	8.4
Yes	5.5	4.5	8.4	7.7
Significance^y				
C	0.001	0.001	0.001	NS
S	NS	0.01	0.05	0.01
EC	---	---	0.001	NS

^zMeans followed by the same letter within cultivar and year are not significantly different ($P \geq 0.05$).

^yC = cultivar; S = in-row spacing; EC = early cropping; *P* value is provided when significant.

^{NS}Nonsignificant.

had fruited in 2001, but we did not see much of an effect on the macronutrients.

Picking efficiency varied amongst years and cultivars, perhaps mainly due to a strong correlation with yield and berry weight, but perhaps also to differences in picking speed amongst those harvesting the fruit. The range in picking efficiency found in this study is similar to that reported by Strik et al. (2003) for mature 'Bluecrop' plants that were conventionally pruned. In-row spacing had an inconsistent effect on average berry weight, as we've found in earlier studies (Strik and Buller, 2002; Strik et al., 2003). In 'Elliott' the cost of harvesting per kg of fruit was higher when plants were spaced at 0.45 m than at 1.2 m as more fruit could be picked per hour in the larger plants at 1.2 m.

In year 1, yield on all cultivars was less than 0.7 t·ha⁻¹ and picking efficiency was low, but fruit may have been economical to harvest depending on market and price. In year 2, yield ranged from 1.7 to 7.3 t·ha⁻¹ depending on cultivar and planting density. The yields per plant in our study, even in year 2, were much higher than the 0.5 kg/plant yield recommended

by Eck (1988) for plants in their third season. Based on the yields obtained in this study, growers would be able to recover a portion of establishment costs (Eleveld et al., 2005) early by harvesting fruit in year 2. However, early cropping did not improve cumulative yield (years 1 through 4) of 'Bluecrop' and 'Duke', and reduced cumulative yield significantly in 'Elliott'. This seems to support our hypothesis that early cropping is more of a stress on plants that have a high yield late in the growing season. Thus, there is a risk associated with early cropping and few apparent benefits.

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