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Northern Highbush Blueberry Cultivars Differed in Yield and Fruit Quality in Two Organic Production Systems from Planting to Maturity

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***Abstract*. Northern highbush blueberry (*Vaccinium corymbosum* L.) cultivars were evaluated from planting (Oct. 2006) through 2014 in a certified organic research site in Aurora, OR. The treatments included cultivar (Duke, Bluecrop, Reka, Bluejay, Bluegold, Draper, Legacy, Liberty, Ozarkblue, and Aurora), amendment-mulch ["compost + sawdust" (included preplant amendment and a surface mulch of either an agricultural on-farm crop waste compost or yard-debris compost and sawdust), and "weed mat" (no preplant amendments but with a sawdust mulch topped with weed mat)]. Adding on-farm compost as a preplant amendment and as part of the mulching program increased soil pH from 4.9 to 6.9, organic matter content (OM), and calcium (Ca), magnesium (Mg), and potassium (K) levels compared with the weed mat treatment. The reduced plant growth and yield in some cultivars grown in the compost + sawdust treatment was likely due to the higher soil pH. 'Bluegold' and 'Draper' were among the cultivars with consistently high flower bud set (40% to 57%), whereas others had consistently low values (e.g., 22% to 45% in 'Bluecrop'). The number of flowers per bud was affected only by cultivar. There was no effect of year or amendment-mulch treatment on percent fruit set which averaged 93% during the study; however, 'Ozarkblue' had a significantly lower fruit set (88%) than only 'Aurora' (96%). Berry weight was affected by year (plant age), cultivar, and amendment-mulch treatment. 'Ozarkblue' produced the largest berries. Type of amendment-mulch had little effect on berry weight, except in 'Ozarkblue', 'Aurora', and 'Reka' where plants grown with weed mat produced larger fruit than those grown with compost + sawdust. On average, 'Bluejay', 'Draper', and 'Liberty' fruit had the highest percent soluble solids (TSS) and 'Ozarkblue' the lowest. Fruit harvested from plants grown with weed mat were firmer than when compost + sawdust was used. 'Draper' fruit were much firmer than those of the other cultivars in all years of the study. The number of flower buds per plant multiplied by the number of flowers/bud and berry weight (cultivar specific) and average fruit set was a good predictor of yield in young plants. Yield per plant increased from the second through seventh growing seasons as plants matured in all cultivars except for 'Duke' which had the greatest yield in 2014. Cumulative yield was highest in 'Legacy' and lowest in 'Bluejay' and in 'Draper', which had relatively low yield when plants were young. Most cultivars had greater yield when grown with weed mat, whereas 'Bluegold' and 'Liberty' were unaffected by amendment-mulch treatment. Because weeds were managed in all plots, the cultivar response to amendment-mulch was likely a reflection of sensitivity to preplant amendment with on-farm compost and the resulting higher soil pH. It is possible that the cultivars differed in their adaptability to the various fertility regimes caused by the amendment-mulch treatments and fertilizers used in our study.**

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The Pacific northwestern United States is an important region for production of cultivated blueberry (*Vaccinium* spp.) (U.S. Department of Agriculture, 2014). The proportion of total U.S. blueberry production grown on certified organic and exempt organic (less than $5000/year gross income and not requiring certification) farms was relatively small (3%) in 2008 (U.S. Department of Agriculture, 2010). However, the Pacific northwestern region accounted for 49% of the total blueberry organic area planted in the United States in 2008, when the last survey was conducted. The certified organic area has grown considerably since the last survey, increasing to an estimated 915 ha in Oregon and Washington in 2011, 55% of total U.S. organic blueberry area (Strik, 2014). By 2014, the organic blueberry area in Oregon and Washington accounted for about 20% of total blueberry area planted. Growth in organic production continues as consumer demand for organic products remains strong, and this region offers substantial advantages for organic production (DeVetter et al., 2015; Strik, 2016; Strik et al., 2016; Strik and Yarborough, 2005).

A wide range of cultivars are grown in this region for the fresh and processed markets, offering a range in fruiting seasons from the earliest ('Duke') to the latest ('Aurora') (Strik et al., 2014). The development of yield and fruit quality of the range of cultivars grown has not been compared in research studies, likely because of the relatively long time from planting to maturity (about 8 years). Differences in the performance of cultivars have been found in organic production of 'Duke' and 'Liberty' blueberry (Larco et al., 2013a, 2013b; Strik, 2016; Strik et al., 2016) and various blackberry cultivars (Fernandez-Salvador et al., 2015).

Blueberry plants are adapted to soils with low pH (4.5–5.5) and high OM (>4%) (Hart et al., 2006). Organic and conventional growers are interested in using composts because of hypothesized OM, nutrient, and microbiological benefits (e.g., Forge et al., 2003) on soil properties and nutrients. Because organic sources of nitrogen (N) are expensive and often laborious to apply, the potential benefit from a slow-release N from compost is also of great interest to growers. However, use of plant- and animal-based composts as a preplant amendment may be problematic in this crop as these materials have a high pH and often a high salt content (animal-based) (Sullivan et al., 2014).

Our objective was to characterize yield and associated plant and fruit quality traits of important highbush blueberry cultivars in the region from planting to maturity and evaluate their adaptation to common organic amendments and mulches used in certified organic production.

Materials and Methods

Study site. The study was established in Oct. 2006 at Oregon State University's North Willamette Research and Extension Center, Aurora, OR (NWREC; lat. 45°28′ N, long. 122°76′ W). Weather data for this site are available from an AgriMet weather station (U.S. Deptartment Interior, 2014). The planting was certified as meeting the USDA organic criteria before the first fruit harvest year (2008) by a USDA-accredited agency (Oregon Tilth, Corvallis, OR). The soil at the site is a Willamette silt loam (fine-silty mixed superactive mesic Pachic Ultic Argixeroll) and had a pH of 4.9 and 3.7% OM. Details on preplant site preparation can be found in Larco et al. (2013a).

After adding any preplant amendments, if used (see below), raised beds were constructed using a bed shaper; beds were 0.3-m high and 0.4-m wide at the top and 1.5-m wide at the base when established, but settled to a height of ≈0.25 m by Autumn 2007. Plants were irrigated using a single line of polyethylene drip tubing (Netafim, Fresno, CA) with 2 $L \cdot h^{-1}$ pressure-compensating, inline emitters spaced every 0.3 m. The line was located along the row near the base of plants, under the mulch. Irrigation was controlled by electric solenoid valves and an automatic timer set weekly and scheduled to maintain a soil water content suitable for highbush blueberry production [25% to 30% soil water content from the soil surface to 0.3 m, based on time domain reflectometry measurements (SoilMoisture Equip. Corp., Santa Barbara, CA)] (L. Valenzuela-Estrada, unpublished data).

Amendment and mulch. Two preplant amendment-mulch treatments were evaluated. The "compost + sawdust" treatment included a preplant amendment and a mulch of compost and sawdust. Commercially available agricultural crop waste compost (Wilt Farms, Corvallis, OR) made on farm (≈2-cm deep centered on the row; 76 $m^3 \cdot ha^{-1}$) and fresh douglas fir sawdust (*Pseudotsuga menziesii* M.; ≈5-cm deep; 200 $m^3 \cdot ha^{-1}$) were incorporated before forming the raised beds in Sept.–Oct. 2006. The on-farm compost consisted of well-composted rye grass clippings and other agricultural crop waste products and had lime (107 $kg \cdot t^{-1}$ dry weight) added during the composting process based on the carbonate content of the raw material (note Ca content in Table 1). Immediately after planting, the beds were mulched with additional on-farm compost (≈2-cm deep; 76 $m^3 \cdot ha^{-1}$), and then, the compost was topped with sawdust (≈7.5-cm deep; 300 $m^3 \cdot ha^{-1}$) with a goal of creating a barrier to weed establishment. The mulches were spread mechanically in 0.75 m wide strips under and on each side of the plant rows. On-farm compost was used when the mulch needed replenishing in Autumn 2007, but in Jan.–Feb. 2011 and 2013, compost made with municipal yard waste clippings was used (Rexius, Eugene, OR). The composts and sawdust were analyzed by Soil Control Laboratory (Watsonville, CA) and total nutrient application was calculated (Table 1).

The second amendment-mulch treatment, "weed mat," involved no preplant amendments, but included a mulch of fresh douglas fir sawdust (≈7.5-cm deep; 300 $m^3 \cdot ha^{-1}$) topped with black, woven polyethylene groundcover (water flow rate of 6.8 $L \cdot h \cdot m^{-2}$ and a density of 0.11 $kg \cdot m^{-2}$ as measured by the manufacturer; TenCate Protective Fabrics, OBC Northwest, Canby, OR). Weed mat was placed over a sawdust mulch layer, not currently a commercial practice, with a goal of offsetting the reduction in soil OM observed under weed mat mulch in long-lived perennial crops such as apple (*Malus ×domestica* Borkh.) (Choi et al., 2011). The weed mat was 1.5-m wide and was centered over the planting beds before securing it in place with landscape staples. A 20-cm diameter hole was cut in the weed mat for each plant and the area covered with 5 cm of douglas fir sawdust mulch (1.4 $m^3 \cdot ha^{-1}$) after planting. The weed mat was replaced in Dec. 2010 with a similar product and was installed as a "zippered" system (overlapping and secured with landscape staples) such that the weed mat could be opened to apply any needed granular fertilizers. The sawdust mulch under the weed mat was still at an adequate depth (5–10 cm) and did not require replenishment in 2010.

Cultivars. Ten cultivars (Duke, Bluecrop, Reka, Bluejay, Bluegold, Draper, Legacy, Liberty, Ozarkblue, and Aurora) were selected to represent a range in fruiting or harvest season and are important commercial cultivars in the Pacific northwestern United States (Strik et al., 2014). Standard, 18-month-old container stock (3.8 L), with two to four whips per plant, was purchased from a commercial nursery and transplanted into the field at an in-row spacing of 0.75 m and a between-row spacing of 3.0 m (4385 plants/ha) in early Oct. 2006.

Experimental design. Each experimental unit consisted of a 5-m plot containing seven plants. The experimental design was a split-plot with amendment-mulch treatment as the main effect and cultivar as the subplot effect. The main effect (amendment-mulch) was limited to two replications because of the size and duration (cost) of the study and because the study was conducted in the guard rows of a 0.5-ha certified organic research planting established concurrently.

Planting management. The rate of fertilizer nutrients and the products applied to each amendment-mulch treatment in 2007–14 are presented in Table 2. Two fertilizer sources were used to achieve the total rate of N applied. Half of the N was applied as fish emulsion by hand as a drench around the base of the plants in 2007–09, sidedressed with a sprayer on each side of the row in 2010, and injected through the drip system (fertigated) in 2011–14 in seven equal applications every 2 weeks from mid-April to early July. The remaining N was applied using a granular soybean [*Glycine max* (L.) Merr.] meal applied in early March on top of the compost + sawdust mulch or under the weed mat. In addition, 258 $kg \cdot ha^{-1}$ of Ca (Ca sulfate applied as gypsum), 5.5 $kg \cdot ha^{-1}$ of Mg, and 7.3 $kg \cdot ha^{-1}$ of sulfur (S, as Mg sulfate) were applied to all plots in late Winter 2013. Elemental S was applied to the surface of the compost + sawdust mulch plots on May 2012 (335 $kg \cdot ha^{-1}$) when soil pH had increased to 6.7 and in Feb. 2013 (112 $kg \cdot ha^{-1}$) when pH was 5.8. No S was applied to the weed mat treatment as soil pH was within the recommended range of 4.5 to 5.5 (Hart et al., 2006).

The permanent grass cover crop (certified organic *Festulolium braunii* K. Richt.) in the alleys was mowed during the growing season as required. Weeds were managed using OMRI-approved (Organic Materials Review Institute) postemergent acetic acid (20%; WeedPharm®, Pharm Solutions, Inc., Port Townsend, WA), lemon grass oil or d-limonene (GreenMatch EX® and Avenger®, respectively; Cutting Edge Formulations, Inc., Buford, GA), and by hand weeding, as required in all treatment plots.

In 2011–14, the planting was sprayed weekly with a spinosad (metabolites of *Saccharopolyspora spinosa* Mertz & Yao) insecticide (EntrustSC; Dow Agro Science, Indianapolis, IN) or pyrethrins (PyganicEC 1.4; Valent, Walnut Creek, CA) from the time when 'Liberty' fruit first turned blue through harvest, to help control spotted wing drosophila (*Drosophila suzukii* Matsumura) per recommendations (DeFrancesco et al., 2014); applications to the earlier-season cultivars (e.g., Duke) were not required as insect populations were very low. In general, management for other pests was not required although scouting for any presence was done regularly. Some cultivars were affected by *Blueberry shock virus* (BlShV); the proportion of the plot showing symptoms (necrotic flowers) and thus not producing fruit was estimated annually. This pollen-borne virus was unaffected by amendment-mulch treatment, but cultivars do vary in their sensitivity (Pscheidt and Harper, 2014).

Plants were pruned each winter to maintain a balance of vegetative growth and fruit production (Strik and Buller, 2005; Strik et al., 1990, 1993).

Data collection. From 2008 to 2013, counts of vegetative and flower buds were taken on four lateral shoots (0.15–0.45 m long originating from 2-year-old wood) per plot and percent flower bud set was calculated (number of flower buds/total buds). In blueberry, buds are simple and flower buds may be distinguished from vegetative buds because of their relatively large size. In 2009, the number of flower buds was counted on two plants per plot after pruning and average flower buds/plant calculated. Four flower buds per plot (the third bud distal of the tip of the lateral) were randomly selected and labeled; the number of flowers/bud (per cluster) was counted at the late pink to 5% bloom stage and then the number of berries/cluster was counted in mid to late May and percent fruit set calculated. In 2009, yield/plot was estimated as follows: Estimated yield (kg/plant) = [no. flower buds/plant × no. flowers/bud × percent fruit set × average berry weight (g)/1000]; values were compared with actual harvested yield.

Ripe fruit were harvested by hand every 7–14 d from the second (2008; except for 'Aurora' that was first harvested in 2009 when plants were more vigorous) through the eighth (2014) growing seasons from the entire plot of each experimental unit and yield measured; yield per plant was calculated. A 25-berry subsample was taken per plot per harvest to determine average berry weight (and a weighted seasonal average mass was then calculated) and berry firmness

Table 1. Total nutrients applied as an amendment-mulch ("compost + sawdust") and as a mulch ("weed mat") at establishment (2006) and when the mulch needed replenishment (2011 and 2013, compost + sawdust treatment only) in an organic blueberry field at Oregon State University's North Willamette Research and Extension Center (Aurora, OR), 2006–14. Sawdust replenishment was not required in the weed mat treatment after establishment. Composts and sawdust were analyzed by Soil Control Laboratory (Watsonville, CA).

			Macronutrients (kg·ha^{-1})					Micronutrients (kg·ha^{-1})			
Yr	Treatment	Source	N	P	K	Ca	Mg	B	Cu	Mn	Zn
2006	Compost + sawdust	Compost[z]	974	593	62	4200	390	0.7	11.0	33.9	13.3
		Sawdust[y]	72	17	3	131	20	0.1	0.3	4.0	0.7
	Weed mat	Sawdust[y]	72	17	3	131	20	0.1	0.3	4.0	0.7
2007	Compost + sawdust	Compost[z]	487	296	31	2100	195	0.4	5.5	17.0	6.7
	Weed mat	Sawdust[y]	42	10	2	77	12	0.1	0.2	2.4	0.4
2011	Compost + sawdust	Compost[x]	385	63	227	454	112	0.7	1.3	22.0	5.2
		Sawdust[y]	31	2	33	44	6	0.7	0.1	3.8	0.3
2013	Compost + sawdust	Compost[x]	383	61	214	383	89	1.2	1.2	16.9	4.2
		Sawdust[y]	58	4	19	25	5	1.9	0.1	1.2	0.2

[z]Commercially available agricultural crop waste compost made on farm (Wilt Farms, Corvallis, OR), applied as a preplant amendment and as part of the initial surface mulch (along with sawdust) and mulch renewal in Autumn 2007.
[y]Douglas fir sawdust (Decorative Bark, Lyons, OR). In 2007, sawdust was placed in the planting hole area of the weed mat treatment.
[x]Yard-debris compost (Rexius Compost, Eugene, OR).

(FirmTech II; BioWorks, Inc.; Wamego, KS). The fruit were then macerated by hand, in a zippered plastic bag and TSS measured on a temperature-compensated digital refractometer (Atago, Bellevue, WA).

Soil samples were collected in 2006, before planting and annually in late Oct. to early Nov. 2010–14 from all 'Duke' plots. Samples were pooled in 2006 and in 2014 (not replicated). Soil samples were collected using a 2.4-cm diam., 0.5-m long, slotted, open-side, chrome-plated steel soil probe (Soil Sampler Model Hoffer; JBK Manufacturing, Dayton, OH). Mulch was removed from the soil surface before sampling to a depth of 0.2 m at the center of the row, between plants and within the water emitter drip zone or fertilization area. Soil samples were analyzed for macro- and micronutrient content, OM, and pH by Brookside Laboratories (New Bremen, OH).

Data analysis. Analysis of amendment-mulch and cultivar effects on plant traits and yield was done for a split plot design by year and for cumulative yield (during the length of the study) using the PROC MIXED procedure in SAS version 9.3 (SAS Institute, Cary, NC). The effect of year was analyzed using a split-split plot design [year as the main effect (n = 7 or 8, depending on the trait), amendment-mulch as the subplot effect (n = 2), and cultivar as the sub-subplot effect (n = 10)] for all plant and fruit traits except yield per plant, which was expected to change as plants matured. We did analyze whether yield significantly increased from year 7 to 8 (2013–14) for all cultivars. Mean comparison was performed using least-square means. The relationship between estimated yield and actual yield in 2009 was analyzed by linear regression, using a best fit as well as forcing the intercept through zero. Soil analysis results were analyzed for the effect of amendment-mulch, by year (2010–13) using PROC MIXED in SAS.

Table 2. Targeted fertilizer rates and actual nutrients applied, based on nutrient analysis (Brookside Laboratories Inc., New Bremen, OH) in an organic blueberry field at Oregon State University's North Willamette Research and Extension Center (Aurora, OR), 2007–14.

			kg·ha^{-1}						
Yr	Source	Target N rate	N	P	K	Ca	Mg	B	S
2007–09	Fish[z]	56	59	19	25	1	6	0	5
2010	Fish[z]	50	50	6	10	10	1	0.02	n/a[y]
	Soybean[w]	50	68	6	23	3	3	0.19	n/a
2011–12	Fish[x]	50	48	7	56	1	1	0.05	108
	Soybean[w]	50	68	6	23	3	3	0.19	n/a
2013	Fish[v]	73	60	19	25	1	6	0.07	5
	Soybean[t]	67	68	6	23	3	3	0.19	n/a
2014	Fish[u]	73	67	15	20	0	5	0.07	4.3
	Soybean[t]	67	67	5	20	4	3	0.17	n/a

[z]Fish Agra (4–1–1; Northeast Organics, Manchester-by-the-Sea, MA).
[y]n/a indicates the analysis and thus the actual nutrient content was not available.
[x]True 402 (4–0–2; True Organic Products, Inc., Spreckels, CA).
[w]Leafy Green (8–1–2; California Organic Fertilizers, Fresno, CA); actual nutrient content not analyzed so estimated nutrients applied based on product label.
[u]Converted Organics 421 (4–2–1; Converted Organics, Gonzales, CA) and True512 (5–1–2; True Organic Products, Inc., Spreckels, CA).
[u]True512 (5–1–2; True Organic Products, Inc., Spreckels, CA).
[t]Leafy Green (7–1–2; California Organic Fertilizers, Fresno, CA).

Results and Discussion

Soil properties. A pooled soil sample taken before planting indicated that soil pH, OM, and all nutrients except for Ca (lower than recommended) were at appropriate levels (Table 3) for blueberry (Hart et al., 2006). No fertilizers or amendments were applied to the whole field before establishing the treatments and planting. We analyzed the composts and sawdust used in our amendment-mulch treatments for pH and nutrient content and calculated the total nutrients applied throughout the study (Table 1). The slow-release N provided by the compost was estimated at roughly 25 kg·ha^{-1}·yr^{-1} (3% of total compost-N applied), based on experience with similar composts applied before planting in grass (Sullivan et al., 2003) and sweet corn (Gale et al., 2006). However, the proportion or rate of availability of the nutrients applied in the composts or sawdust (Table 1) is not known. Although we have not yet determined impacts of mulches on soil microbiology, we noted differences in the impact of the amendment-mulch treatments on soil properties and nutrients (Table 3) (Larco et al., 2013b, 2014). The on-farm compost used as a preplant amendment was prepared using lime and thus had a high Ca content (Table 1) and a high pH (7.5). We chose this product because it was being commonly sold to commercial blueberry growers for use in new and established fields. In our study, incorporating this product before planting increased soil pH from 4.9 to 6.9 in 4 years (2010) such that the compost + sawdust treatment had a significantly higher soil pH than the weed mat (Table 3). Application of S in 2011–12 (Table 2) reduced the soil pH from 6.8 to 5.9 the following year. Whereas there was no significant amendment-mulch effect on soil pH in 2012–13, there were only two replications. It is important to note that soil pH in the compost + sawdust treatment remained above the desirable range for blueberry (4.5–5.5; Hart et al., 2006), whereas it was within this range in the weed mat treatment throughout the study (Table 3). Larco et al. (2013a) found lower soil pH under weed mat mulch than under a yard-debris compost + sawdust mulch in organic blueberry. However, use of a yard-debris compost only as part of a mulching program had benefits for mitigating the decline in soil pH that occurs with fertilization over time, while maintaining soil pH within the desired range for blueberry (Larco et al., 2013a; Strik, 2016).

In our study, the on-farm compost likely had a rapid effect on increasing soil pH because of the lime effect. Composts without added lime may not have a similar effect when used as a preplant amendment.

The amendment-mulch treatments led to differences in soil pH, OM, and particularly levels of soil Ca, Mg, and K (Table 3). Despite these differences in soil properties, Strik and Vance (2015) noted no effect of amendment-mulch on leaf nutrient concentrations in this same research planting other than for manganese (Mn) and aluminum (Al) whose availability is decreased at high soil pH. Therefore, although compost supplied a high rate of total N (Table 1), and an estimated 25 $kg \cdot ha^{-1}$ N released per year of the study, it apparently supplied low amounts of plant-available N, or the added N was not required by the plants. Larco et al. (2013b, 2014) also found that yard-debris compost provided little to no plant-available N when used as part of a mulching program in organic blueberry production. In our study, the nutrients applied via fertilization (Table 2) were thus considered sufficient for plant growth based on plant tissue analysis (Strik and Vance, 2015) and observed growth. The high pH in the organic amendment-mulch treatment, however, likely reduced plant growth and yield in some cultivars (see below).

Plant traits. The effects of year, mulch, and cultivar on the proportion of flower buds per lateral (flower bud set), flowers per cluster, and percent fruit set are shown in Table 4. There was no main effect of year on any of these variables, but there was a year × cultivar interaction on flower bud set. While some cultivars had consistently high flower bud set from 2008 through 2013 such as 'Bluegold' (46% to 57%) and 'Draper' (40% to 51%) or consistently low values such as for 'Bluecrop' (22% to 45%), 'Duke' had high flower bud set in 2008 (57%) followed by a particularly low value in 2009 (40%) and was again among the cultivars with the highest flower bud set in 2012–13 (48% to 52%; data not shown). 'Bluecrop' was also reported to have lower flower bud set than other cultivars in establishing and conventionally managed mature blueberry plantings/trials (Strik and Buller, 2005; Strik et al., 2003). On average, 'Bluegold' and 'Draper' had the highest percentage of flower bud set, whereas 'Legacy', 'Ozarkblue', and 'Bluecrop' had the lowest (Table 4). There was no effect of amendment-mulch treatment on flower bud set.

There was a strong cultivar effect on the number of flowers per bud (flowers/cluster) with no effect of year or amendment-mulch treatment (Table 4). In Michigan, there was some variability in flowers/bud across years (Hancock et al., 2000). Some of the variability in flowers/bud within a cultivar among years and studies may be caused by climate (location), sampling location in the bush, and location of the bud on the lateral (Almutairi, 2016; Hancock et al., 2000). In our study, the consistency of bud sampling likely reduced variation among years. 'Ozarkblue' and 'Bluecrop' had the highest number of flowers/bud, whereas 'Bluegold', 'Duke', and 'Legacy' had among the fewest. In Michigan, 'Bluecrop' and 'Bluejay' did not differ in flowers/bud (7.1–7.8), but these cultivars had among the lowest values of six cultivars studied (Hancock, 1989).

Fruit set among the cultivars was similar, averaging 93% during the study (Table 4), except for 'Aurora' and 'Ozarkblue', which averaged 96% and 88%, respectively. It is possible that 'Ozarkblue' had a particularly low fruit set, because it also had a high number of flowers/cluster that may limit resources. Fruit set in our study was higher than the 78% to 90% and 72% to 87% reported by Strik et al. (2003) and Hancock et al. (2000) in 'Bluecrop' grown in Oregon and Michigan, respectively. It is possible that we counted berries per cluster and calculated fruit set before any berry drop that might have occurred; in some cultivars, such as 'Liberty', small berries may fall from the cluster reducing final fruit set (Almutairi, 2016). Percent fruit set is typically high in the Willamette Valley, OR, as compared with other production regions (e.g., Hancock, 1989) because of consistently favorable weather during bloom.

Yield. In 2009, when the plants were going into their third growing season, the total number of flower buds was counted to determine if this could be a good predictor of yield on young plants and be used as a tool to adjust severity of pruning; this method would likely be impractical on larger plants. The number of flower buds per plant was affected by cultivar ($P < 0.001$), but not amendment-mulch (data not shown). 'Draper' had the fewest average number of buds per plant (95), likely because these plants were short in stature because of their propensity toward a compact growth and/or an immature plant response to propagation by tissue culture. 'Aurora', 'Duke', 'Bluejay', and 'Bluecrop' had a moderate level of flower buds per plant (127–165), whereas 'Reka', 'Liberty', and 'Legacy' had the highest number (213–279). Too many plants of 'Bluegold' and 'Ozarkblue' were affected by BlShV or a somatic mutation (small leaves and berries) in 2009, respectively, to be able to get an accurate count of flower buds, so they were not included.

Although there was a significant linear relationship between predicted yield (based on the number of buds/plant) and actual yield, the strength of this relationship was reduced when the line was forced to have no intercept (Fig. 1). Yield was overestimated (slope <1) using either formula, particularly at higher bud numbers per plant, as has been found by others (Salvo et al., 2012). However, some yield loss would be expected because of a proportion of fruit being dropped during picking and pests (e.g., birds and possibly disease). In our study, the relationship between the number of flower buds/plant and yield, when considering the flowers/bud and berry weight (cultivar dependent) and typical fruit set for the region shows promise as a tool to adjust pruning and predict yield in young plants (Fig. 1). This relationship would be improved with the development of cultivar-specific formulae if more data points were available.

Yield per plant increased from the second through seventh growing seasons as plants matured (Fig. 2). Cultivar significantly affected yield in each year of the study. 'Aurora' did not produce its first crop until 2009, because plants were pruned to produce fruit in their second growing season only if they were vigorous enough; cropping plants in the second year can reduce plant growth and subsequent yield (Strik and Buller, 2005). The other cultivars were considered vigorous enough and were pruned to produce a limited crop in 2008. Plantings in this region are considered mature in year 7 or 8; our data agree with these findings as there was no significant increase in yield from 2013 to 2014, with the exception of 'Duke'. Yield can certainly differ among years for many reasons. For example, Nemeth et al. (2017) reported increased plant growth (biomass) and yield from year 9 to 10 in 'Elliott' blueberry. Based on our experience, once plants reach 8–10 years of age, yield tends to fluctuate about a mean typical for the cultivar with pruning having the largest influence on yield in our region.

Cumulative yield, on average, was highest in 'Legacy' (Table 4), a cultivar that is widely grown in Oregon's Willamette Valley. Yields of 35–40 $t \cdot ha^{-1}$ are common in mature commercial 'Legacy' fields that are well-managed (conventional or organic; B.C. Strik, personal observation); these yields are equivalent to what we harvested in 2013 and 2014 (Fig. 2). 'Ozarkblue' had the next highest cumulative yield. However, yield per plant in this cultivar was higher than what would be expected at an in-row spacing of 0.75 m because several plants per plot had a somatic mutation and had to be cut back to just above crown height, so they would not be harvested; this mutation likely occurred during tissue culture propagation and is the main reason this cultivar is no longer readily available from commercial nurseries. The remaining 'Ozarkblue' plants had more space to grow within the plots and thus yield per plant was higher. The lowest cumulative yield, on average, was measured in 'Draper', which had relatively low yield when plants were young (small bushes that needed hard pruning), and 'Bluejay'. The mature yield (2013 and 2014) of most of the cultivars we studied was similar to what is typically harvested in mature conventionally managed fields (B.C. Strik, personal observation). In a cultivar evaluation trial in Missouri, 'Legacy' and 'Reka' were among the highest yielding, 'Ozarkblue' and 'Bluecrop' were intermediate, and 'Duke' was in the lowest yielding group in conventional production (Kaps et al., 2010).

During the establishment years, amendment-mulch treatment only had a significant effect on yield in 2009 when those grown with weed mat averaged 2.1 compared with

Table 3. Soil nutrient properties by amendment-mulch treatment in an organic blueberry field at Oregon State University's North Willamette Research and Extension Center (Aurora, OR), 2006–14.

				Nutrient concn (mg·kg^{-1})												
Yr	Amendment-mulch	pH	OM	NO_3	NH_4	P[z]	Ca	Mg	K	Na	B	Fe	Mn	Cu	Zn	Al
2006	Pre-amendment[y]	4.9	3.7	11.4	3.9	132	536	61	275	25	0.1	67	16	0.7	1.6	n/a[x]
2010	Compost + sawdust	6.9	6.4	4.6	1.5	271	1778	224	360	50	0.4	320	52	2.2	3.6	1157
	Weed mat	5.4	4.3	1.6	1.4	242	640	107	191	45	0.3	330	41	0.9	0.9	1349
	Significance[w]	0.011	0.031	NS	NS	NS	0.018	0.026	0.030	NS	NS	NS	NS	0.020	0.003	0.048
2011	Compost + sawdust	6.8	6.3	6.4	2.1	233	2135	253	442	64	0.6	325	50	2.5	4.3	1177
	Weed mat	5.6	3.3	4.5	1.7	203	874	144	231	43	0.3	350	36	1.1	1.6	1488
	Significance	0.033	0.031	NS	NS	NS	NS	NS	0.010	NS	NS	NS	NS	NS	0.026	NS
2012	Compost + sawdust	5.9	5.6	20.1	4.0	494	1709	233	514	59	1.1	319	48	2.0	4.3	1168
	Weed mat	5.1	3.7	12.7	4.7	274	810	141	282	32	0.8	311	31	0.9	1.4	1329
	Significance	NS	NS	NS	NS	NS	0.016	NS	NS	NS	0.045	NS	NS	0.002	0.034	NS
2013	Compost + sawdust	6.1	5.1	11.2	12.6	316	1698	207	431	32	0.5	305	34	1.8	7.9	1127
	Weed mat	5.3	4.2	17.5	12.7	260	959	228	267	39	.	311	32	0.9	1.6	1275
	Significance	NS	NS	NS	NS	NS	0.012	0.010	NS	NS	.	NS	NS	0.002	NS	NS
2014	Compost + sawdust	6.3	6.4	7	4.7	235	1698	229	388	33	0.5	365	41	2.42	4.77	1110
	Weed mat	4.9	3.7	29.3	3.7	205	779	178	246	35	0.2	355	25	1.14	1.34	1334

[z]Phosphorus analyzed as Bray II (2006) and Bray I (2010–14).
[y]One composite soil sample was analyzed before any amendment and planting.
[x]n/a represents not available in this analysis.
[w]Nonsignificant (NS) or actual *P* value provided when significant by analysis of variance; no value for boron (B), as soil levels under weed mat were below detectable by the laboratory. Statistical analysis was not possible in 2006 and 2014 as the replications were pooled.

Table 4. Effect of amendment-mulch treatment and cultivar on percentage of flower buds per lateral, flowers/cluster, fruit set, fruit quality and yield from 2008 to 2014 in an organic blueberry field at Oregon State University's North Willamette Research and Extension Center (Aurora, OR).

	2008–13[z]	2009–13[z]				2008–14	
	Flower buds/lateral (%)	Flowers/cluster (no.)	Fruit set (%)	TSS (%)	Firmness (g·mm^{-1} deflection)	Berry wt[z] (g)	Yield/plant[y] (kg)
Amendment-mulch[x]							
Compost + sawdust	42.3	8.2	93	13.9	165 b[w]	2.10 b	18.2 b
Weed mat	43.4	8.0	92	13.8	170 a	2.15 a	24.1 a
Cultivar							
Duke	45.8 bc	7.1 f	94 ab	13.5 cd	177 b	2.19 bc	15.1 ef
Reka	43.6 cd	8.5 bc	92 ab	13.7 cd	149 g	1.80 d	23.8 c
Draper	47.4 b	7.6 def	93 ab	14.5 ab	221 a	2.19 bc	14.2 f
Bluecrop	31.7 f	8.9 b	94 ab	13.7 cd	153 fg	2.15 bc	20.6 cd
Bluegold	51.7 a	7.4 f	90 ab	13.8 bc	173 c	2.27 ab	14.2 f
Bluejay	41.9 ed	8.1 cd	94 ab	15.0 a	154 ef	1.75 d	13.6 f
Legacy	38.9 e	7.5 ef	94 ab	14.0 bc	170 c	2.12 c	39.3 a
Liberty	44.8 bcd	8.0 cde	91 ab	14.5 ab	157 def	2.11 c	19.6 cde
Ozarkblue	39.8 e	10.2 a	88 b	12.8 e	160 d	2.39 a	33.4 b
Aurora	42.6 cde	8.2 cd	96 a	13.1 de	158 de	2.28 n/a[w]	17.9 def
Significance[v]							
Year	NS	NS	NS	0.043	0.001	NS	n/a
Mulch	NS	NS	NS	NS	0.006	0.036	<0.0001
Year × mulch	NS	NS	NS	NS	NS	NS	n/a
Cultivar	<0.0001	<0.0001	0.038	<0.0001	<0.0001	<0.0001	<0.0001
Year × cultivar	<0.0001	NS	NS	0.016	<0.0001	<0.0001	n/a
Mulch × cultivar	NS	NS	NS	NS	NS	0.013	0.003
Year × mulch × cultivar	NS	NS	NS	NS	NS	NS	n/a

[z]Mean values presented are averaged over years.
[y]Cumulative yield.
[x]Compost + sawdust = addition of on-farm crop waste compost and sawdust as an amendment preplanting and as a surface mulch layer; weed mat = no preplant soil amendment but a surface layer of sawdust topped with weed mat applied as a mulch.
[w]Means followed by the same letter within treatment are not significantly different (LSMeans) ($P > 0.05$). Mean comparison not available (n/a) for 'Aurora' because of missing data in 2008.
[v]Nonsignificant (NS) or actual *P* value provided when significant by analysis of variance; n/a = not applicable, as cumulative yield analyzed.

1.6 kg/plant when compost + sawdust were used as the amendment-mulch (data not shown). Larco et al. (2013b) also reported a higher yield in the second growing season when 'Duke' and 'Liberty' were grown with a weed mat mulch (no sawdust present) as compared with a sawdust mulch alone, but found no difference between weed mat and a compost + sawdust mulch (with no preplant amendment). In our study, there was only a cultivar by amendment-mulch interaction on yield/plant in 2011 as all cultivars had greater yield with weed mat except for 'Bluegold' (data not shown).

There was a significant cultivar × amendment-mulch effect on cumulative yield/plant (Table 4; Fig. 3). Most cultivars had greater yield when grown with weed mat, whereas 'Bluegold' and 'Liberty' were unaffected by amendment-mulch treatment over the length of the study. The presence of weeds has been shown to reduce yield, and mulch often improves yield when compared with unweeded plots (Burkhard et al., 2009). In our study, weed management costs were considerably higher in the compost + sawdust treatment because of greater weed presence as compared with weed mat mulch (data not shown). We found similar results in another organic study (Julian et al., 2012) as have others (Tertuliano et al., 2012). Because weeds were managed in all plots in our study, the cultivar response to amendment-mulch type was likely a reflection of sensitivity to the preplant amendment and resulting higher soil pH (Table 3). For example, 'Duke' is known to perform poorly in high pH soils, whereas 'Reka' is much more tolerant (B.C.

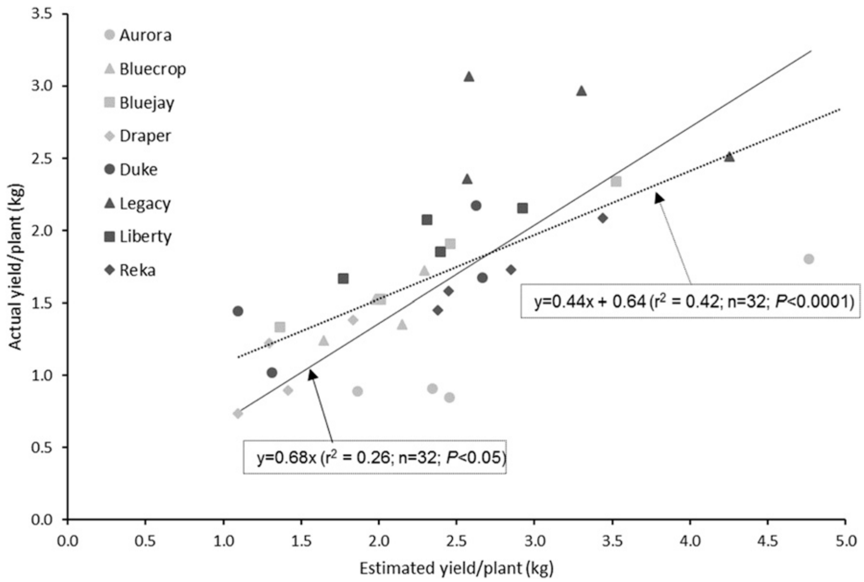

Fig. 1. Scatterplot of estimated yield/plant {estimated yield = [flower buds/plant × flowers/bud × percent fruit set × average berry weight (g)]/1000} and actual measured yield/plant for eight cultivars grown in an organic planting at Oregon State University's North Willamette Research and Extension Center, Aurora, OR. There were insufficient data to include 'Ozarkblue' and 'Bluejay'. Linear relationships shown for best fit and when forcing a 0 intercept.

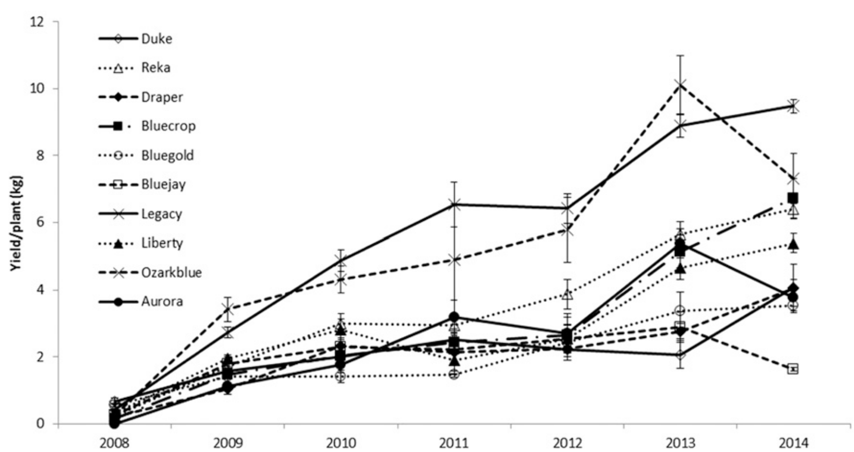

Fig. 2. Effect of cultivar on harvested yield per plant from 2008 to 2014 (note 'Aurora' was not harvested in 2008) in an organic planting at Oregon State University's North Willamette Research and Extension Center, Aurora, OR.

Strik, personal observation). While we observed symptoms of soil pH being too high in 'Duke' (lime-induced iron chlorosis), no symptoms were apparent in any of the other cultivars. It is possible that the cultivars differed in their adaptability to the various fertility regimes caused by the amendment-mulch treatments and fertilizers used in our study. Larco et al. (2013a, 2013b) and Strik (2016) observed differences in plant growth and yield between 'Duke' and 'Liberty' when fertilized with fish emulsion or feather meal in a certified organic production system.

Incorporation of a preplant amendment, particularly douglas fir sawdust in our region, is common (Julian et al., 2011a, 2011b) and has been shown to improve growth and production over the long-term compared with no preplant amendment in conventionally managed blueberry fields (Nemeth et al., 2017). Our study confirms the importance of testing any amendments before use in blueberry and either not using those with a high pH or acidifying them before use (Costello, 2011).

Fruit traits. Berry weight was affected by year (plant age), cultivar, amendment-mulch, and the interaction of year × cultivar and mulch × cultivar (Table 4). On average, 'Ozarkblue' had the largest berries (Table 4). 'Bluegold' and 'Bluejay' tended to have consistently large and small fruit, respectively, throughout the study (data not shown). In 2008, the first fruiting season, 'Ozarkblue' and 'Liberty' plants produced particularly large berries. 'Draper', 'Ozarkblue', and 'Aurora' produced relatively large berries in 2010. 'Reka' had particularly small berries in 2012, even though the plants did not appear to be overcropped (Fig. 2). Berry size in 'Liberty' fluctuated considerably from year to year (data not shown), even though plants were consistently pruned and there appeared to be little relationship between berry weight and yield, as is commonly found in blueberry (Strik et al., 2003). 'Liberty' tends to produce canes that look good at pruning time, but then proceeds to produce very small berries; growers call this "little berry," and this trait could have reduced average berry weight in this cultivar in our study. Even though plants were pruned relatively consistently from year to year, with a goal of balancing vegetative growth with fruiting potential (Strik et al., 1990, 1993), variability in pruning within cultivars from year to year could have caused differences in berry weight (Hancock and Nelson, 1985; Siefker and Hancock, 1987; Strik et al., 2003). The berry weights we found throughout the study period were higher than those reported for these same cultivars in some other studies (Hancock, 1989; Hancock et al., 2000; Kaps et al., 2010).

Although there was a significant amendment-mulch × cultivar interaction for berry weight (Table 4), the effect was small; only 'Ozarkblue', 'Aurora', and 'Reka' produced heavier fruit (≈10%) when grown with weed mat as compared with the compost + sawdust amendment-mulch treatment (data not shown). Larco et al. (2013a) also noted cultivar differences in response to mulch type.

There was a year × cultivar interaction on TSS (Table 4). 'Bluejay' had the highest TSS in most years of the study (data not shown), likely because this cultivar is typically machine harvested for processing, and fruit were thus left to hang before harvest; the entire crop was harvested in two pickings, and the fruit were thus ripe to overripe. 'Ozarkblue' fruit had the lowest TSS in many years. Most cultivars had a higher fruit TSS when they were young and in their second growing season, except for 'Duke', 'Reka', 'Aurora', and 'Ozarkblue' (data not shown). On average, 'Bluejay', 'Draper', and 'Liberty' fruit had the highest TSS and 'Ozarkblue' the lowest (Table 4). There was little difference in TSS among the other cultivars.

Berry firmness was affected by year, cultivar, amendment-mulch, and the interaction of year and cultivar (Table 4). The fruit harvested from plants grown with weed mat were firmer than when the compost + sawdust amendment-mulch was used. 'Draper' fruit were much firmer than those of the other cultivars in all years of the study (data not shown). 'Duke' fruit were next firmest, except in 2012 when 'Bluegold' produced firmer fruit than 'Duke'. 'Reka' and 'Bluecrop' produced the least firm fruit in 2011 and 2013, respectively. While fruit firmness was relatively similar in 2010 and 2011 in most cultivars, firmness increased in 'Ozarkblue' and 'Aurora'. On average, 'Draper' fruit were the firmest and 'Bluecrop' and 'Reka' the softest (Table 4).

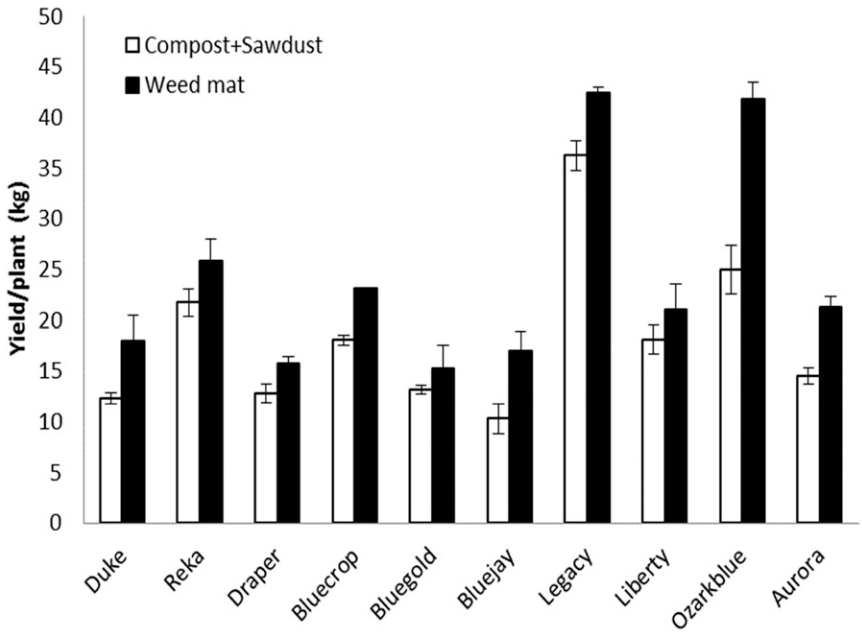

Fig. 3. Effect of amendment-mulch treatment ("compost + sawdust" = preplant amendment with on-farm crop waste compost and sawdust plus a mulch of on-farm and yard-debris compost, depending on year, topped with sawdust; "weed mat" = sawdust mulch topped with porous black polyethylene groundcover) and cultivar on cumulative yield/plant (2008–14; except for 'Aurora' which was not harvested in 2008) in an organic planting at Oregon State University's North Willamette Research and Extension Center, Aurora, OR. SE bars provided. Cultivars are listed in approximate order of ripening.

Conclusions

All of the cultivars studied grew and produced well under the amendment-mulch treatments used during the 8-year study. However, cultivars differed in their apparent tolerance to the higher soil pH resulting from using the on-farm compost, which contained lime, as a preplant amendment. Maintaining soil pH within the current recommended standard of 4.5–5.5 is thus important for many cultivars for optimal growth and production. Cultivars differed relatively consistently in percent flower bud set and the number of flowers per bud throughout the study, whereas percent fruit set was consistently high for all cultivars. Predicting yield in young plants is possible by counting the number of flower buds per plant and using cultivar-specific data on the number of flowers/bud and berry weight along with a typical fruit set value for the region; however, yield was overestimated using this method. Yield increased from the second to the seventh growing season in most cultivars, but yield continued to increase between year 7 and 8 in 'Duke' indicating these plants may not yet have been mature. Average cumulative yield was highest for 'Legacy' and lowest for 'Draper' and 'Bluejay'. Most cultivars had lower yield when grown in plots amended and mulched with on-farm crop waste compost than when grown with weed mat; this was likely a negative response to the high pH of the on-farm compost, as weeds were controlled in all treatments. On average, plants grown with the weed mat mulch produced firmer and larger berries than those grown with the compost + sawdust amendment-mulch. The differences among cultivars in the measured fruit quality parameters were similar to what has been observed in conventional production systems.

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