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Trailing Blackberry Genotypes Differ in Yield and Postharvest Fruit Quality during Establishment in an Organic Production System

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Abstract. **Four blackberry (*Rubus* L. subgenus *Rubus* Watson) cultivars ('Obsidian', 'Black Diamond', 'Metolius', 'Onyx') and two advanced selections (ORUS 1939-4 and ORUS 2635-1) were evaluated during the establishment years of an organic production system for fresh market. The planting was established in Spring 2010 using approved practices for organic production and was certified organic in 2012, the first fruiting year. Plants were irrigated using a dripline under a woven polyethylene groundcover (weed mat) installed for weed management. Liquid fertilizers injected through the drip system were used at rates of 56 kg·ha^{-1} total nitrogen (N) in 2011–12 and 90 kg·ha^{-1} total N in 2013. Genotypes differed in the level of nutrients measured in primocane leaves. Tissue phosphorus (P), potassium (K), sulfur (S), iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) concentrations were within the recommended standards, but tissue calcium (Ca), magnesium (Mg), and boron (B) were deficient in some or all genotypes. Although two cultivars and both advanced selections responded well in terms of plant growth and yield to the organic production system used, yields in 'Onyx' and 'Metolius' were considered low for commercial production. In contrast, the higher yielding 'Obsidian' and ORUS-2635-1 appeared to be the best suited for organic fresh market production as a result of larger fruit size, greater fruit firmness, higher sugar-to-acid ratios, lower postharvest percent moisture loss in ORUS-2635-1, and the longest number of marketable storage days at 5 °C in 'Obsidian'.**

Blackberries are a very important specialty crop in the United States, especially in Oregon, where they are particularly suited to the climate (Strik and Finn, 2012). In Oregon, 23.9 million kilograms of conventional blackberries were produced on 2954 ha in 2011 (National Agricultural Statistical Service, 2013). In 2008, organic blackberries were harvested on a reported 348 farms in the United States for a crop value of $4.6 million (Geisler, 2012). Given the 12% growth of sales from 2009 to 2010 (Organic Trade Association, 2011) for organic fruits and vegetables, the outlook for organic blackberry production continues to be positive.

Organic production requires the use of various cultural and biological methods for pest management and the use of natural fertilizer sources (animal, plant, or mined origin) for nutrient management [U.S. Department of Agriculture (USDA), 2011]. In organic production, fertigation, the application of fertilizer through a drip irrigation system, has become more common (Fernandez-Salvador, 2014; Harkins et al., 2013; Schwankl and McGourty, 1992). System design and costs (Gaskell and Smith, 2007) need to be considered when adopting irrigation/fertigation systems. Blackberry fields can be successfully established using drip irrigation (Harkins et al., 2013), but fertigation with organic fertilizer sources may lead to plugging of the drip emitters over time (Fernandez-Salvador et al., 2015a). In the present study, organically approved liquid fertilizers that could be fertigated were selected.

Weed management during planting establishment is important for maximizing plant growth and yield (Harkins et al., 2013). The use of woven polyethylene groundcovers ("weed mat") has been shown to be an effective weed management strategy in plantings of trailing and semierect blackberry plants that do not produce primocanes from root buds (Fernandez-Salvador et al., 2015b; Harkins et al., 2013; Makus, 2011).

Growers who focus on fresh market production systems are interested in growing blackberry cultivars that extend the fruiting season, have a high yield, and produce high-quality fruit. Cultivars must have good postharvest fruit quality and an acceptable shelf life for shipping and for storage, which can range from 14 to 21 d (Fan-Chiang and Wrolstad, 2010; Joo et al., 2011; Perkins-Veazie et al., 1996, 1999, 2000; Perkins-Veazie and Clark, 2002). Unlike in conventional production (Finn et al., 1997, 2005a, 2005b, 2005c, 2011; Strik, 1992; Strik and Finn, 2012), there is relatively little information available on cultivar adaptation to organic production systems (Fernandez-Salvador et al., 2015b; Harkins et al., 2013).

The objectives of our study were to evaluate four fresh market blackberry cultivars ('Obsidian', 'Black Diamond', 'Onyx', 'Metolius') and two advanced selections (ORUS 1939-4, ORUS 2635-1) in an organic production system during the establishment years. Genotypes were compared for plant growth and yield and postharvest fruit quality and marketable days at 5 °C. 'Obsidian' is a trailing cultivar with vigorous plant growth, very high yield, and large fruit. As a primarily fresh market blackberry, it has excellent flavor and ripens early in the northwestern United States (Finn et al., 2005a; Finn and Strik, 2014). Under conventional management, yield and berry weight for 'Obsidian' ranged from 19 to 28 t·ha^{-1} and 5.5 to 6.8 g, respectively (Finn et al., 2005a). 'Black Diamond' is the second most important cultivar grown for processing in Oregon, where its characteristic high yield and thornless canes make it well suited to machine harvesting (Finn et al., 2005a; Finn and Strik, 2014). Yield has been as high as 21 t·ha^{-1} in conventional production (Finn et al., 2005a) and 13 to 17 t·ha^{-1} in organic production systems (Fernandez-Salvador et al., 2015b; Harkins et al., 2013). 'Black Diamond' may also be hand-harvested for fresh market, because fruit are large, firm, uniformly shaped, and have good flavor (Finn et al., 2005a). 'Onyx' is a relatively new cultivar producing vigorous canes and a moderate yield of uniform, firm, sweet, and excellent-flavored fruit suited for local and wholesale fresh markets (Finn et al., 2011). Yield of 'Onyx' averaged 14 t·ha^{-1} in conventional management systems (Finn et al., 2011). 'Metolius' is characterized

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by vigorous plant growth, a good yield, and medium-sized, firm fruit with excellent flavor (Finn et al., 2005b). In conventional production trials, the trailing, thorny ORUS 1939-4 had high yields with medium to large, firm, sweet fruit with excellent flavor. ORUS 2635-1 is a high-yielding selection that produces high-quality, large fruit on a fairly erect, thorny plant (Strik et al., unpublished data).

Materials and Methods

Study site. The study was conducted at the Oregon State University North Willamette Research and Extension Center in Aurora, OR [(lat. 45°17′ N, long. 122°45′ W; elevation 46 m; USDA hardiness zone 8b (2012)]. Soil at the site is a Willamette silt loam (fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll). The soil had a pH of 5.3 before planting and contained 3.6% organic matter, 1.5 ppm NO_3-N, 2.3 ppm NH_4-N, 188 ppm P (Bray I), and 295 ppm K. Soil pH and K were low and below the ranges recommended for the crop (i.e., pH 5.6 to 6.5 and soil K greater than 350 ppm; Hart et al., 2006) and, therefore, based on McLean (1982), lime [calcium carbonate (2242 kg·ha^{-1}) and dolomite (4148 kg·ha^{-1})] and K-Mag fertilizer (102 kg·ha^{-1} K, 62 kg·ha^{-1} Mg, 102 kg·ha^{-1} S) + micronutrients [2 kg·ha^{-1} B (H_3BO_3), 1 kg·ha^{-1} Cu ($CuSO_4$), and 14 kg·ha^{-1} Zn ($ZnSO_4$)] were broadcast and incorporated into each row before planting.

The field was planted with tissue-cultured plugs on 26 May 2010. Weeds were managed using a 1.4-m wide strip of black, woven polyethylene groundcover (''weed mat''; water flow rate 6.8 L·h^{-1}·m^{-2}; 0.11 kg·m^{-2}; TenCate Protective Fabrics; OBC Northwest Inc., Canby, OR) centered on the row. Irrigation was applied using a single lateral of drip tubing (UNIRAM; Netafim USA, Fresno, CA) installed in each treatment plot immediately after planting. The tubing had 1.9 L·h^{-1} in-line, pressure-compensating emitters spaced every 0.6 m and was placed under the weed mat, at the base of the plants. Irrigation was scheduled weekly based on estimates of crop evapotranspiration and measurements of primocane leaf water potential and soil water content as described by Harkins et al. (2013). The site was first certified organic by a USDA-accredited agency (Oregon Tilth Certified Organic, Corvallis, OR), and although approved practices were conducted during 3 years before planting and in the establishment year, organic certification was not obtained until the spring of the first fruit harvest year in May 2012.

Experimental design. The study was conducted from 2011 to 2013, Years 2 through 4, and included the first and second fruiting years in Years 3 and 4. The study was arranged as a randomized complete block design with four replicates each of six blackberry genotypes ('Obsidian', 'Black Diamond', 'Onyx', 'Metolius', ORUS 1939-4, and ORUS 2635-1). Each plot consisted of four plants spaced 1.5 m apart in-row and was separated from plants in adjacent plots by a 3-m gap. The between-row spacing was 3.0 m (2222 plants/ha).

Primocane training. Pruning and training during establishment were similar to that described and illustrated by Harkins et al. (2013). Briefly, plants were trained on a two-wire vertical trellis system that was installed before planting. The lower trellis wire was attached to steel posts at 1.0 m above the ground, and the upper wire was attached at 1.6 m. Primocanes that grew in Year 1 (2010, the planting year) were removed the next winter (Feb. 2011) to increase subsequent growth, as per standard commercial practice (Strik and Finn, 2012). In Year 2 (2011), primocanes were trained to the trellis wires as they grew using twine. Once the primocanes grew above the upper trellis wire, half the canes were looped in one direction down to the lower trellis wire and brought back toward the plant with one or two twists, and the other half was looped in the opposite direction. In Years 3 and 4, primocanes were trained on the ground alongside the row below the floricane canopy (the previous year's primocanes). Primocanes were trained to the trellis in August, after the senescing floricanes were removed by pruning.

Fertilizer applications. All fertilizer applications were based on percent N in the product, as stated on the label. Before planting in Year 1, pelletized, processed poultry litter (4N–1.3P–1.7K–7Ca; Nutri-Rich; Stutzman Environmental Products Inc., Canby, OR) was incorporated into the soil (≈0.45 m diameter) at a rate of 28 kg·ha^{-1} N. In addition, Fish Agra (4N–0.4P–0.8K; Northeast Organics, Manchester-by-the-Sea, MA) was diluted with 10 parts water (v/v) and applied by hand around the base of plants in seven weekly applications of 4 kg·ha^{-1} N each from 14 July to 25 Aug. 2010 (28 kg·ha^{-1} total N). In 2011–12, a fish hydrolysate and fish emulsion blend combined with molasses (TRUE 402; 4N–0P–1.7K; True Organic Products, Inc., Spreckels, CA) was diluted with five parts water (v/v) before fertigation and was applied in four equal applications (total of 56 kg·ha^{-1} N) on 18 Apr., 13 May, and 3 and 24 June in 2011 and on 25 Apr., 11 May, and 1 and 15 June in 2012. In 2013, a soluble grain fermentation and nitrate of soda blend (Converted Organics 4–2–1; 4N–0.9P–0.8K; Converted Organics of California, LLC, Gonzales, CA) was diluted with four parts water (v/v) before fertigation and applied at a target rate of 45 kg·ha^{-1} N; and a fish hydrolysate and fish-emulsion blend combined with molasses (TRUE 512; 5N–0.4P–1.7K; True Organic Products, Inc.) was diluted with two parts water (v/v) before fertigation. The fertilizers were each applied in four equal portions on 5 and 19 Apr. and 3 and 17 May for the grain source and 7, 14, and 28 June and 7 July for the fish source at a total target rate of 90 kg·ha^{-1} N. The fertilizers were injected through the drip irrigation system using a combination of a water-driven pump fertilizer injector (Mix-Rite TF10-002; DEMA, St. Louis, MO) and an electric, high-volume fertilizer injection pump system (547-SE-N3T; Neptune Chemical Pump Co., Yuma, CO). Irrigation was run for 20 min before each injection to fully pressurize the system to 103.4 kPa and 1 h afterward to flush the driplines. The fertilizers were analyzed for total nutrient content (Brookside Laboratories, New Bremen, OH), and the application rate of all macro- and micronutrients was calculated. Additionally, 2.2 kg·ha^{-1} of B (Solubor; 20 Mule Team Borax, Englewood, CO), 560 kg·ha^{-1} of pelletized dolomitic lime [62 kg·ha^{-1} Mg and 112 kg·ha^{-1} Ca (Pro-Pell_it! Pelletized Dolomite; Marion Ag Service Inc., St. Paul, OR)], and 2242 kg·ha^{-1} of pelletized lime (Pro-Pell_it! Pelletized Lime; Marion Ag Service Inc.) were broadcast-applied to the plots and aisles on 8 Mar. 2013. Ground covers, as used in our study, have been shown to be permeable to fertilizers applied on top (Zibilske, 2010).

Plant growth. Primocanes were counted at 0.3 m height in each plot in Mar. 2012, Feb. 2013, and Mar. 2014. Senescing floricanes were removed by pruning at the base of the plant (≈0.1 m high) after fruit harvest on 6 Aug. 2012 and 15 Aug. 2013, per standard commercial practice (Strik and Finn, 2012) and weighed to obtain total fresh biomass/plot. In 2012 and 2013, one floricane was randomly sampled from each of two plants per plot, weighed, oven-dried at 70 °C, and re-weighed to calculate average floricane fresh and dry weight (DW). Total floricane DW biomass/plot and per plant were estimated based on the number of floricanes/plot and plants/plot, respectively. Additionally, floricane length was measured, and the total number of nodes, fruiting laterals, and fruiting sites per cane were counted. The remaining floricane prunings were placed between rows and flail-mowed (chopped) as per standard commercial practice. Once the senescent floricanes were removed, the new primocanes were trained to the trellis as described previously.

Tissue and soil analysis. Primocane leaves were collected for tissue analysis on 17 Aug. 2012 and 16 Aug. 2013, per standard recommendations (Hart et al., 2006). Samples consisted of 10 recent fully expanded leaves, cut from both sides of the row on each plot, and were sent to Brookside Laboratories for nutrient analysis. Total N content was determined in each sample using a combustion analyzer, and P, K, Ca, Mg, S, Fe, B, Cu, Mn, Zn, and aluminum (Al) were determined using an inductively coupled plasma (ICP) spectrophotometer after wet washing the samples in nitric/perchloric acid (Gavlak et al., 1994). Nutrient concentrations in the primocane leaves were compared with published standards (Hart et al., 2006).

Soil was sampled on 2 Nov. 2012 and 23 Oct. 2013 using a 2.4-cm diameter, 0.5-m long, slotted, open-side, chrome-plated steel soil probe (Soil Sampler Model Hoffer; JBK Manufacturing, Dayton, OH). One sample was collected per block (replication) with each sample composed of one core per plot (six plots per replication) collected at a depth

of 0.3 m at the center of the row in between the two middle plants; all cores were within the water emitter drip zone of the in-row area. The core samples were homogenized in a bucket, and a subsample was sent for analysis to Brookside Laboratories. Extractable soil P (Bray I), K, Ca, Mg, sulphate-sulfur (SO_4-S), sodium (Na), B, Cu, Mn, and Zn were determined by ICP after extraction of the nutrients using the Mehlich 3 method (Mehlich, 1984). Soil nitrate-N (NO_3-N) and ammonium-N (NH_4-N) were determined using automated colorimetric methods after extraction with 1 M KCl (Dahnke, 1990). Soil organic matter was measured using Loss-On-Ignition at 360 °C (Nelson and Sommers, 1996), and soil pH was measured using the 1:1 soil:water method (McLean, 1982).

Yield and fruit quality. Ripe fruit were hand-harvested twice weekly from 28 June to 13 Aug. 2012 and from 20 June to 29 July 2013 using industry standard food-grade 3.8-L plastic buckets. Total marketable and unmarketable fruit (culls, defined as overripe, deformed, dropped, sunburned, damaged, rotten, or under-ripe fruit) were harvested, separated, and weighed on each harvest date, and total yield was calculated. A sample of 25 berries was hand-picked just before each plot's complete hand harvest, randomly selecting fruit from both sides of the row, and covering the entire length of the plot area. The subsample was used to determine average fruit quality variables, including individual fruit weight (seasonal, weighted average calculated), percent soluble solids (TSS, °Brix), fruit firmness, pH, and titratable acidity (TA); the sugar-to-acid ratio was calculated from TSS and TA. The firmness of each berry was measured using a University of California Manual Firmness Tester (Serial No. 364; Western Industrial Supply, San Francisco, CA) with a mechanical force gauge (Model LKG1; Ametek, Feasterville, PA) with a 1.2-cm diameter tip. Each berry was laid on its side and force was applied until the first drop of juice came out of one or more drupelets; average fruit firmness was then calculated for each harvest. The fruit were then placed in a 1-L polyethylene re-sealable bag and crushed by hand to obtain a homogeneous mixture for measuring TSS on a temperature-compensated digital refractometer (Model PR-32 α; Atago, Bellevue, WA). The remaining crushed, bagged fruit was used to determine TA using an automatic titrator (DL 12; Mettler-Toledo, LLC, Columbus, OH) with 0.1 N NaOH (BDH brand; VWR International LLC, Radnor, PA) as a reagent to a pH endpoint of 8.2, and acidity was calculated as percent citric acid.

On each of two harvest dates in 2012 (9 and 12 July) and 2013 (27 June and 1 July), berries were hand-picked into four vented, clear polystyrene clamshells (no. 0.24; 11.4 cm × 11.4 cm × 4.5 cm high) until there was only one layer of fruit covering the bottom of the clamshell. All clamshells were stored in a walk-in cooler at the harvest site at ≈5 °C for 2 to 4 h before transport (≈1.5 h) to the Oregon State University campus in an ice chest without refrigeration. Clamshells were then stored at 5 ± 1 °C (at ≈85% relative humidity) for 14 to 21 d, depending on genotype and harvest year. Clamshells were weighed on a scale (± 0.01 g; PB4002-S; Mettler Toledo LLC, Columbus, OH) on Day 0 (harvest day), 4, 7, 9, 11, and 14 in 2012, and Day 0, 4, 8, 12, 14, 18, and 21 in 2013. Percent moisture loss was calculated by subtracting each day's weight from the previous day's weight for each clamshell, and the average (n = 4) was calculated for each plot. In addition, the marketable storage time of fruit was determined, in which fruit were considered no longer marketable when juice was present in the bottom of the clamshell or there was at least one non-marketable berry present (generally the presence of mold or fruit rot).

Data analyses. Data for yield, plant growth, and plant nutrient status were analyzed for a split-plot design with year as the main plot factor and genotype as a subplot using the General Linear Model procedure in SAS (Version 9.3; SAS Institute Inc., Cary, NC). Soil nutrient data were analyzed for a year effect (n = 4). Fruit storage data were analyzed by year as a result of large differences in weather (Fernandez-Salvador, 2014) and observed marketable days at 5 °C. The effects of genotype and harvest date on fruit storage were also analyzed using a split-plot design. Residuals were tested for normality using the Shapiro-Wilk test. Data were log-transformed and re-analyzed, where necessary, to meet criteria for normality and homogeneity of variance. Means were compared for treatment effects using least square means with α = 0.05.

Results and Discussion

Fertilizers applied. The fertilizers applied came from a different batch each year, which would not be unusual in commercial production. Although the rate of product applied was calculated based on the percentage of N, as stated on the label, for a target rate of 56 kg·ha^{-1} total N in 2011 and 2012 and 90 kg·ha^{-1} N in 2013, the actual rate of N applied (based on analysis of the fertilizers) was 50, 52, and 75 kg·ha^{-1} total N in 2011, 2012, and 2013, respectively (Table 1). As is common with organic fertilizer sources of N (Gaskell and Smith, 2007; Senesi, 1989), the products used in this study contained significant quantities of other nutrients (Table 1). The TRUE 402 fish fertilizer had more than 3-fold the K and 20-fold the Na than the Converted Organics 4–2–1 fermented grain and 10-fold the Fe as the TRUE 512 fish and molasses blend. In 2013, the Converted Organics 4–2–1 had more than 2-fold the Ca, 10-fold the Fe, and over a 30-fold less Na than the TRUE 512 (Table 1).

Soil and tissue nutrients. Soil pH was within the recommended range for blackberry production (5.6 to 6.5; Hart et al., 2006), but it significantly increased from 2012 to 2013 (Table 2). Soil organic matter content under the weed mat decreased during the study, corroborating reports in organic blueberry production (Sullivan et al., 2015). Most of the nutrient levels in the soil were within or above the recommended range for caneberries in Oregon (Hart et al., 2006). Soil B was below the recommended level (0.5 to 1.0 ppm) in both years (Table 2). Soil NH_4-N increased and P and Al decreased significantly from 2012 to 2013. The observed increase in NH_4-N may have been a result of the higher rate of N applied in 2013, whereas the decline in P may have been a result of plant uptake. Longer-term studies would be needed to determine the impact of organic fertilizers on soil nutrient status, particularly when using weed mat as a permanent mulch.

Table 1. Total nutrients applied to a new field of organic blackberry during the first 3 years after planting (2011–13) at the North Willamette Research and Extension Center, Aurora, OR.

	Macronutrients (kg·ha^{-1})						Micronutrients (g·ha^{-1})				
Fertilizer[z]	N	P	K	Ca	Mg	Na	B	Fe	Mn	Cu	Zn
2011											
TRUE 402	50	8	61	1	1	27	12	310	19	4	48
2012											
TRUE 402	52	7	62	1	1	26	12	354	18	6	38
2013											
TRUE 512	43	9	13	0	3	32	9	48	17	2	51
Converted Organics 4–2–1	32	15	19	2	4	1	5	468	13	1	16
Total	75	25	32	2	7	33	14	516	30	3	67

[z]Each fertilizer was analyzed by Brookside Laboratories, Inc. (New Bremen, OH). TRUE 402 (fish hydrolysate and fish emulsion blend combined with molasses fertilizer) was injected in four equal portions in Spring 2011 and 2012. TRUE 512 (fish hydrolysate and fish emulsion blend combined with molasses fertilizer) was injected in combination with Converted Organics 4–2–1 (grain fermentation soluble and sodium nitrate) in four equal portions each in Spring 2013. TRUE 402, TRUE 512, and Converted Organics 4–2–1 had a pH of 5.5, 3.7, and 4.1, respectively.

Table 2. Soil pH, organic matter (OM), and nutrient content in a field of organic blackberry after the second and third years after planting (2012–13) at the North Willamette Research and Extension Center, Aurora, OR (n = 4).

Treatment	pH	OM (%)	NO_3-N (ppm)	NH_4-N (ppm)	P (Bray I) (ppm)	K (mg·kg^{-1})	Ca (mg·kg^{-1})	Mg (mg·kg^{-1})	S (ppm)	Na (mg·kg^{-1})	B (mg·kg^{-1})	Fe (mg·kg^{-1})	Mn (mg·kg^{-1})	Cu (mg·kg^{-1})	Zn (mg·kg^{-1})	Al (mg·kg^{-1})
Year																
2012	5.6 b	3.0 a	0.73	2.98 b	304.3 a	270.0	979.0	136.5	14.5	27.0	0.28	318.5	24.8	0.81	1.99	1364 a
2013	6.0 a	2.7 b	1.30	7.15 a	175.8 b	240.0	1286.3	162.0	16.3	32.8	0.24	301.5	25.0	0.69	1.73	1278 b
Significance[z]																
Year	0.043	0.0439	NS	0.0011	0.0259	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0299

[z]*P* value provided unless nonsignificant (NS; $P > 0.05$).

There was an effect of genotype on all primocane tissue nutrient levels except for Al (Table 3). Tissue P, K, S, Fe, Mn, Cu, and Zn concentrations were within the recommended standards during the study (0.19% to 0.45% P, 1.3% to 2.0% K, 0.1% to 0.2% S, 60 to 250 ppm Fe, 50 to 300 ppm Mn, 6 to 20 ppm Cu, and 15 to 50 ppm Zn; Hart et al., 2006). 'Metolius' and 'Obsidian' had higher leaf N and P than the other genotypes. 'Obsidian' also had a higher leaf B concentration than all other genotypes, a higher leaf K than all genotypes except for 'Metolius', and a higher leaf Fe than all genotypes except for 'Black Diamond' (Table 3). 'Black Diamond' primocane leaves had the lowest level of N, which averaged below the recommended standard (2.3% to 3.0% N; Hart et al., 2006) during the study. Leaf Ca was highest in ORUS 1939-4 and lowest in 'Black Diamond' and 'Onyx', but all genotypes had a leaf Ca concentration that would be considered deficient (0.6% to 2.0% Ca; Hart et al., 2006). Tissue Mg concentration was lower in 'Black Diamond', 'Metolius', and 'Onyx' than the other genotypes with measured values just below the recommended level (0.3% to 0.6% Mg). Whereas tissue B was highest in 'Obsidian' and lowest in ORUS 1939-4 and 'Onyx', all genotypes were deficient in B (30 to 70 ppm B). Genotypes may thus have different nutrient requirements. Additional studies are required to determine whether there is a need for cultivar-specific recommendations for nutrient management.

Primocane tissue P, Mg, S, Cu, and Zn increased, whereas K, B, and Mn decreased from 2012 to 2013 (Table 3). Even with the increased rate of N fertilizer applied in 2013, there was no effect on primocane N. The increase in primocane Mg was likely a response to the Mg applied in 2013; however, there was no such response to the Ca applied. The decline in soil K may reflect increased plant uptake. High K demand has been documented in 'Black Diamond' and 'Marion' (Harkins et al., 2014). Soils in the northwestern United States are often deficient in B (Hart et al., 2006), as confirmed at the present study site. Although B fertilizer was applied in early 2013, soil and tissue B concentrations declined. Additionally, each fertilizer applied through the drip system was relatively low in B. For these reasons, targeted foliar applications of B would be recommended to increase plant B levels to recommended standards.

Plant growth, yield, and fruit quality. Genotypes produced an average cane length of 3.6 m in 2011 (data not shown). There was a significant year and genotype effect on the number of primocanes/plant (Table 4). As expected, plants produced the most primocanes in 2011 during the "off year" (no floricanes growing simultaneously with the primocanes) and the fewest in 2012 during the first fruiting year (Bell et al., 1995; Cortell and Strik, 1997; Mohadjer et al., 2001; Strik and Finn, 2012). Cane number increased from 2012 to 2013, both of which were fruiting years, perhaps in response to the increased rate of N applied. 'Onyx' produced the greatest primocanes/plant, and 'Metolius' and ORUS 2635-1 produced the least (Table 4).

Total and marketable yield were affected by genotype but did not differ between the first and second fruiting seasons (Table 5). By comparison, yield of 'Marion' trailing blackberry was greater after an "off year" (primocane growth only) than an "on year" (primocanes grow in the presence of floricanes) (Bell et al., 1995; Cortell and Strik, 1997). In organic production, Harkins et al. (2013) found a greater yield of 'Marion' and 'Black Diamond' when the fruiting season followed an "off year" (primocane growth only during establishment) relative to an "on year." In our study, because there was no year-by-genotype interaction for yield, the genotypes may not have responded similarly to the primocanes-only growth years during establishment; slight differences among genotypes may have masked any treatment effects. Differences among blackberry cultivars in marketable yield have been documented in organic production systems (Fernandez-Salvador et al., 2015b; Harkins et al., 2013).

The proportion of non-marketable yield varied among genotypes, averaging 19% for 'Black Diamond', 16% for 'Metolius', 13% for ORUS 2635-1, 12% for 'Obsidian' and ORUS 1939-4, and 11% for 'Onyx' (Table 5). There was a significant year × genotype interaction on each fruit quality characteristic measured at harvest (Table 5). 'Obsidian' and ORUS 2635-1 produced the largest fruit, particularly in 2013, whereas 'Onyx' produced among the smallest fruit in both years. ORUS 1939-4 produced the smallest fruit in 2012 but had significantly larger fruit in 2013. Previous studies have shown cultivar differences in fruit weight in both organic (Fernandez-Salvador et al., 2015b; Harkins et al., 2013) and conventional blackberry production (Finn et al., 2005a, 2005b).

'Onyx' fruit had the highest TSS in 2013 and, along with ORUS 2635-1 and 'Obsidian', the highest TSS in 2012. 'Onyx' was the only genotype where fruit TSS increased from 2012 to 2013 (Table 5). 'Black Diamond' had the lowest fruit TSS in both years. The low fruit TSS in 'Black Diamond' agrees with previous reports (Fernandez-Salvador et al., 2015b; Harkins et al., 2013).

Fruit firmness declined from 2012 to 2013 in 'Black Diamond' and 'Metolius' but was unaffected by year in the other genotypes (Table 5). The firmest fruit were harvested from 'Metolius' in 2012, but there was relatively little difference among the other genotypes studied. The relatively low fruit firmness observed in 'Black Diamond', particularly in 2013, agrees with subjective firmness measurements reported by Finn et al. (2005a) but contradicts those of Fernandez-Salvador et al. (2015b), where 'Black Diamond' had similar to or greater fruit firmness than the other fresh market genotypes studied.

Fruit pH increased from 2012 to 2013 in 'Black Diamond', 'Metolius', ORUS 1939-4, and 'Onyx', whereas there was no difference between years in the other genotypes (Table 5).

Table 3. Effect of year and genotype on primocane leaf tissue nutrient concentration in organic blackberry on 8 Aug. 2012 and 15 Aug. 2013 at the North Willamette Research and Extension Center, Aurora, OR (n = 4).

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Al (ppm)
Year												
2012	2.41	0.30 b[z]	1.58 a	0.42	0.30 b	0.15 b	22.7 a	110.5	153.3 a	8.3 b	31.8 b	79.5
2013	2.63	0.33 a	1.41 b	0.42	0.32 a	0.17 a	18.2 b	122.0	129.7 b	11.6 a	36.7 a	77.4
Genotype												
Black Diamond	2.01 c	0.28 c	1.35 c	0.34 d	0.27 b	0.13 c	22.0 b	122.3 ab	128.7 bc	10.7 b	29.3 cd	94.0
Metolius	3.09 a	0.38 a	1.60 ab	0.45 bc	0.28 b	0.19 a	21.6 b	115.4 b	150.2 ab	12.4 a	37.3 b	74.5
ORUS 1939-4	2.09 c	0.26 c	1.39 c	0.55 a	0.33 a	0.13 c	16.0 c	110.2 b	150.0 ab	7.7 c	27.8 ab	77.1
ORUS 2635-1	2.62 b	0.32 b	1.53 b	0.39 cd	0.35 a	0.18 ab	20.2 b	100.9 b	133.7 bc	10.3 b	38.8 ab	64.4
Obsidian	2.92 a	0.38 a	1.70 a	0.46 b	0.34 a	0.18 b	28.6 a	144.3 a	176.1 a	10.6 b	40.6 a	87.6
Onyx	2.39 b	0.28 c	1.41 c	0.35 d	0.28 b	0.14 c	14.3 c	104.5 b	110.0 c	8.3 c	31.7 c	73.2
Significance[y]												
Year (Y)	NS	0.0383	0.0024	NS	0.0203	0.0035	0.0024	NS	0.0388	0.0006	0.0075	NS
Genotype (G)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0111	0.0109	<0.0001	<0.0001	NS
G × Y	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]Means followed by the same letter in a given column were not significantly different ($P > 0.05$).
[y]P value provided unless nonsignificant (NS; $P > 0.05$).

Table 4. Effect of year and genotype on number of primocanes per plant in organic blackberry in the years 2011–13 at the North Willamette Research and Extension Center, Aurora, OR (n = 4).

Treatments	Primocanes/plant
Year	
2011	11.2 a[z]
2012	7.6 c
2013	9.4 b
Genotype	
Black Diamond	10.8 b
Metolius	5.7 c
ORUS 1939-4	10.1 b
ORUS 2635-1	5.8 c
Obsidian	9.9 b
Onyx	14.2 a
Significance[y]	
Year (Y)	0.0055
Genotype (G)	<0.0001
Y × G	NS

[z]Means followed by the same letter within the treatment were not significantly different ($P > 0.05$).
[y]P value provided unless nonsignificant (NS; $P > 0.05$).

Fruit TA tended to be lowest in 'Onyx' and ORUS 1939-4, agreeing with other reports for 'Onyx' (Finn et al., 2011). The genotypes differed in perceived sweetness, as indicated by the sugar-to-acid ratio (Table 5). 'Onyx' fruit had the highest sugar-to-acid ratio, whereas 'Black Diamond', 'Metolius', and 'Obsidian' had the lowest, depending on year. Genotypes with the highest and lowest TSS such as 'Onyx' and 'Black Diamond', respectively, also had the highest and lowest pH and TA, respectively, resulting in a similar or equivalent sugar-to-acid ratio. In general, genotypes with a high TSS had a relatively low TA and vice versa (Table 5).

There was a significant year and genotype effect on floricane DW biomass/plant at pruning time. Biomass was 44% greater in 2012 than 2013 (Table 6), likely because 2012 followed an "off year," which has been shown to increase primocane growth (Bell et al., 1995; Cortell and Strik, 1997). 'Obsidian' and ORUS 2635-1 produced 38% and 50% greater floricane DW/plant than 'Black Diamond' and 'Metolius', respectively. Whereas 'Metolius' had among the lowest floricane DW, this cultivar produced longer floricanes than ORUS 1939-4 and ORUS 2635-1 and had among the highest nodes/cane and longest internode length (Table 6).

The percent budbreak on the floricanes was lower in 2012 than in 2013, likely related to the higher biomass produced in 2012 (Table 6). A reduction in percent budbreak was related to higher biomass produced in alternate-year production in conventional 'Marion' blackberry (Bell et al., 1995; Cortell and Strik, 1997). Percent budbreak was higher in 'Black Diamond' than any of the other genotypes studied (Table 6); this cultivar also had a high percent budbreak in other studies (Fernandez-Salvador et al., 2015a; Harkins et al., 2013). 'Metolius' floricanes had the lowest percent budbreak despite this cultivar having among the shortest canes. Percent budbreak is often higher on shorter canes, at least within cultivar (Bell et al., 1995). There were more fruit/lateral produced on floricanes in 2013 than in 2012 (Table 6). This may have been a result of greater intracanopy shading in the relatively dense canopies produced in 2011–12. Bell et al. (1995) found that 'Marion' primocanes trained in August produced more fruit/lateral than those trained in February, likely as a result of increased light exposure during the flower bud initiation and differentiation period. There was a year × genotype interaction on the number of fruit/lateral, because 'Black Diamond' produced among the fewest fruit/lateral in 2012 but had more fruit/lateral than the other genotypes in 2013 (Table 6). 'Obsidian' had among the fewest fruit/lateral in both years, but this was likely compensated for by a good percent budbreak on average-length canes and a relatively large berry weight.

The number of marketable days (shelf life) of fruit storage was affected by genotype but not harvest date in 2012; there was no treatment effect on fruit marketable days at 5 °C in 2013 (Table 7). In 2012, 'Obsidian' and 'Black Diamond' had the longest marketable days of storage until mold or fruit rot was observed. However, there was only a 2.2-d difference, on average, between the shortest and longest marketable days of storage observed. Marketable storage averaged 13.4 and 15.5 d in 2012 and 2013, respectively. 'Obsidian' and 'Black Diamond' had the most marketable days in our study, a similar number of days of storage to what has been reported for the erect cultivar 'Navaho' (firm fruited) and more days than 'Shawnee' (soft-fruited) when stored at a similar temperature (Perkins-Veazie et al., 1996, 1999). Shelf life (marketable days of storage in this study) might have been longer if these cultivars were stored at the lower temperature (≈1.5 °C) commonly used commercially. In addition, the clamshells in our study only contained a single layer of fruit; shelf life may have been reduced had the clamshell been full with more than one layer as they would be packed commercially.

In 2012 and 2013, percent moisture loss from fruit was affected by genotype on all evaluation dates during storage, but not by harvest date within season (Figs. 1 and 2). 'Metolius' fruit lost the most moisture during storage in both years, whereas the two advanced selections, ORUS 1939-4 and ORUS 2635-1, lost the least. Differences in percent moisture loss of fruit (Figs. 1 and 2) did not appear to be related to the number of marketable days at 5 °C (Table 7) but may have been related to storage temperature and/or packaging, which would affect fruit injury and subsequent pathogen growth as suggested by Perkins-Veazie et al. (1999).

Conclusions

Based on yield and plant growth, most of the genotypes tested responded well to the organic production system used, with the exception of 'Onyx' and 'Metolius', which were considered to have a low yield for commercial production. Within the higher yielding genotypes, 'Obsidian' and ORUS 2635-1 appeared to be the best suited for fresh market organic production as a result of their greater fruit size, firmness, sugar-to-acid ratio, low percent moisture loss (ORUS 2635-1), and a longer number of days of marketable storage ('Obsidian'). The fertilizers applied through the drip system during

Table 5. Effect of year and genotype on total and marketable yield and fruit weight, percent soluble solids (°Brix), firmness, pH, titratable acidity, and sugar-to-acid ratio in hand-picked, organic blackberry (2012–13) at the North Willamette Research and Extension Center, Aurora, OR (n = 4).

Treatments	Total yield (kg/plant)	Marketable yield (kg/plant)	Fruit wt (g)		Soluble solids (%)		Firmness (N)		pH		Titratable acidity (%) or (g/100 mL)		Sugar-to-acid ratio	
Year														
2012	7.4	6.4	6.8		12.2		3.1		3.43 b		1.0		12	
2013	7.7	6.6	7.3		12.1		2.9		3.62 a		1.0		13	
Genotype			*2012*	*2013*	*2012*	*2013*	*2012*	*2013*	*2012*	*2013*	*2012*	*2013*	*2012*	*2013*
Black Diamond	8.74 a[z]	7.11 a	6.0 de	6.4 de	10.9 de	10.0 e	3.00 b	2.58 c	3.25 g	3.43 ef	1.1 a	1.2 a	10 ef	8 f
Metolius	5.62 b	4.71 c	6.7 cd	6.3 de	11.8 cd	11.5 d	3.64 a	2.97 bc	3.33 efg	3.65 bc	1.2 a	1.0 ab	10 ef	11de
ORUS 1939-4	7.65 ab	6.73 ab	5.7 e	7.1 bcd	11.2 d	11.6 d	2.96 bc	2.94 bc	3.60 cd	3.85 a	0.9 bc	0.7 c	13 cd	16 bc
ORUS 2635-1	8.45 a	7.39 a	8.4 ab	8.9 a	13.6 ab	13.2 b	2.92 bc	3.19 b	3.43 ef	3.48 def	1.1 a	1.1 a	12 de	12 de
Obsidian	9.06 a	8.00 a	7.9 abc	9.3 a	12.7 bc	11.7 cd	3.04 b	2.96 bc	3.43 ef	3.53 cde	1.1a	1.2 a	12 de	10 ef
Onyx	5.87 b	5.22 bc	5.8 de	5.8 de	13.3 b	14.4 a	2.83 bc	2.83 bc	3.58 cde	3.80 ab	0.8 c	0.8 c	17ab	19 a
Significance[y]														
Year (Y)	NS	NS	NS		NS		NS		0.0061		NS		NS	
Genotype (G)	0.0059	0.0045	<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001	
Y × G	NS	NS	0.0151		0.0003		<0.0001		0.0027		0.0038		0.0005	

[z]Means followed by the same letter within the treatment or interaction or in a given column were not significantly different ($P > 0.05$).
[y]P value provided unless nonsignificant (NS; $P > 0.05$).

Table 6. Effect of year and genotype on floricane traits in organic blackberry (2012–13) at the North Willamette Research and Extension Center, Aurora, OR (n = 4).

Treatments	Floricane biomass DW (kg/plant)[z]	Floricane length (m)	No. of nodes	Internode length (cm)	Budbreak (%)	Fruit/lateral	
Year							
2012	1.6 a	6.30	123.8	5.31	44.8 b	5.25 b	
2013	0.9 b	4.67	92.8	5.11	63.0 a	7.42 a	
Genotype						*2012*	*2013*
Black Diamond	1.0 bc[y]	5.61 ab	120.8 a	4.55 c	69.3 a	5.5 cde	10.9 a
Metolius	0.8 c	7.18 a	129.0 a	5.61 b	53.6 b	4.9 de	6.6 bcd
ORUS 1939-4	1.1 abc	4.54 b	95.9 ab	4.64 c	57.4 b	5.7 cd	7.6 bc
ORUS 2635-1	1.6 a	4.77 b	102.5 ab	4.68 c	41.8 c	7.4 bc	8.2 b
Obsidian	1.6 a	5.49 ab	128.1 a	4.45 c	52.1 b	3.5 e	5.1 de
Onyx	1.4 ab	5.34 ab	73.6 b	7.31 a	49.2 bc	4.6 de	6.2 bcd
Significance[x]							
Year (Y)	0.0103	NS	NS	NS	0.0005	0.0076	
Genotype (G)	0.0012	0.0393	0.0195	<0.0001	0.0002	<0.0001	
G × Y	NS	NS	NS	NS	NS	0.0011	

[z]Floricane biomass DW indicates weight at pruning in August.
[y]Means followed by the same letter within the treatment or interaction are not significantly different ($P > 0.05$).
[x]P value provided unless nonsignificant (NS; $P > 0.05$).
DW = dry weight.

Table 7. Effect of genotype and harvest date on fruit shelf life [marketable days at 5 °C (± 1 °C)] in hand-picked organic blackberry in the years 2012 and 2013 at the North Willamette Research and Extension Center, Aurora, OR.

Treatments	Fruit marketable days	
	2012	2013
Genotype		
Black Diamond	14.6 a[z]	15
Metolius	12.9 b	14.8
ORUS 1939-4	12.4 b	14.8
ORUS 2635-1	13.6 ab	17.2
Obsidian	14.6 a	14.4
Onyx	12.4 b	16.5
Significance[y]		
Genotype (G)	0.0227	NS
Harvest date (H)	NS	NS
G × H	NS	NS

[z]Means followed by the same letter within a given column were not significantly different ($P > 0.05$).
[y]P value provided unless nonsignificant (NS; $P > 0.05$).

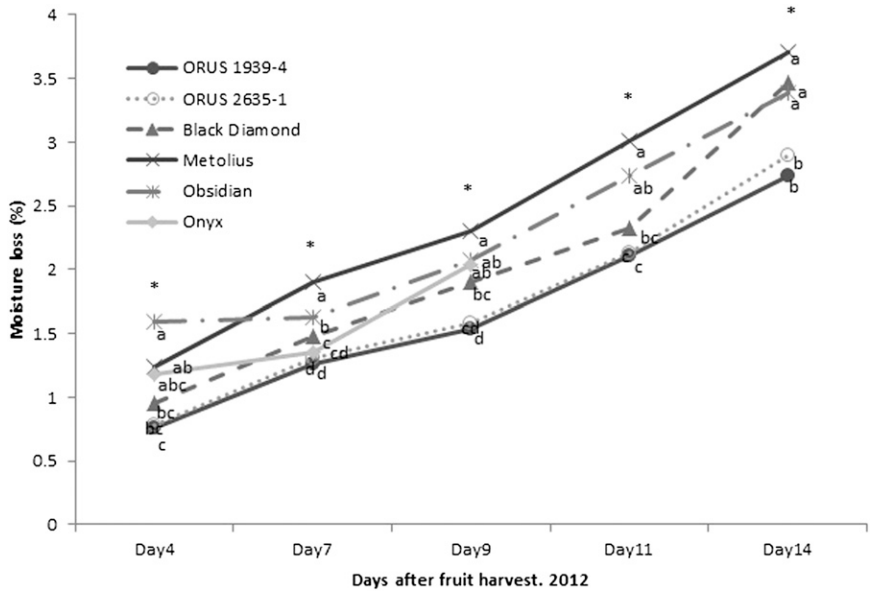

Fig. 1. Seasonal average blackberry fruit percent moisture loss in 2012 for the six hand-harvested genotypes in the study: ORUS 1939-4, ORUS 2635-1, 'Black Diamond', 'Metolius', 'Obsidian', 'Onyx' grown at the North Willamette Research and Extension Center, Aurora, OR. Genotypes were separated by Fisher's protected least significant difference on each date at the 5% level. NS, * = nonsignificant and significant at $P \leq 0.05$, respectively.

establishment had varying levels of macro- and micronutrients and produced or maintained acceptable levels of soil and leaf nutrient concentrations with the exception of soil and leaf B and leaf Ca and Mg.

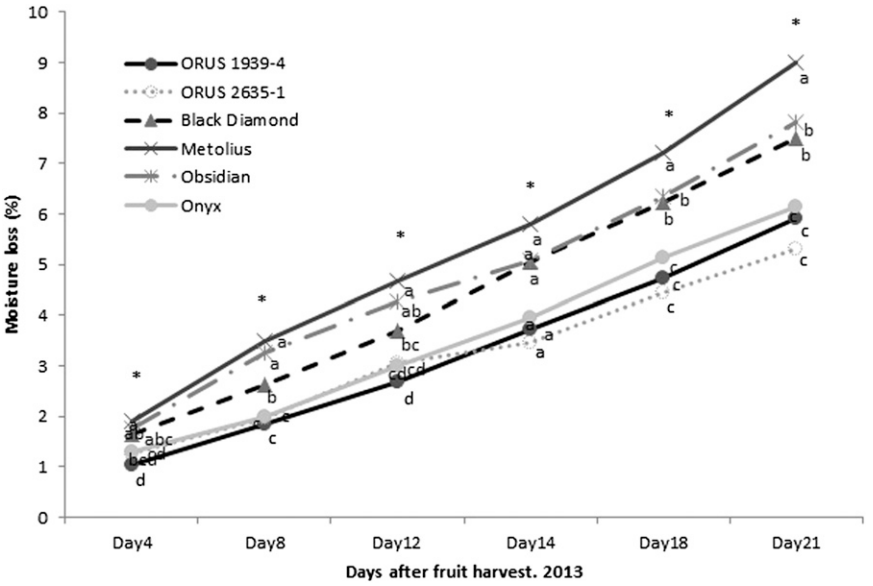

Fig. 2. Seasonal average blackberry fruit percent moisture loss in 2013 for the six hand-harvested cultivars in the study: ORUS 1939-4, ORUS 2635-1, 'Black Diamond', 'Metolius', 'Obsidian', 'Onyx' at the North Willamette Research and Extension Center, Aurora, OR. Genotypes were separated by Fisher's protected least significant difference on each date at the 5% level. NS, * = nonsignificant and significant at $P \leq 0.05$, respectively.

Genotypes differed considerably in many tissue nutrients, reinforcing the idea that tissue sampling should be done by cultivar (Hart et al., 2006) and suggesting that the current standards, which were developed primarily from measurements on 'Marion', may need to be further studied for other popular commercial cultivars.

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