# *Response of Blackberry Cultivars to Fertilizer Source during Establishment in an Organic Fresh Market Production System*





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Research Reports

# Response of Blackberry Cultivars to Fertilizer Source during Establishment in an Organic Fresh Market Production System

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Additional index words. *Rubus*, pelletized soy meal, processed poultry litter, fish emulsion hydrolysate, molasses, fruit quality, Brix, percent soluble solids

**Summary. Blackberry (*Rubus* ssp. *Rubus*) cultivars, three trailing types (Marion, Black Diamond, and Obsidian) and one semierect type (Triple Crown), were studied for their response to different types of fertilizer from 2011–12, at a certified organic, grower collaborator site located in Jefferson, OR. Plants were fertilized at a target rate of 50 lb/acre nitrogen (N) each spring using three different sources: 1) a liquid fish and molasses blend (4N–0P–1.7K); 2) pelletized soy (*Glycine max*) meal (8N–0.4P–1.7K); and 3) pelletized, processed poultry litter (4N–1.3P–2.5K). Plants were drip irrigated, and weeds were managed using a polypropylene, permeable landscape fabric (weed mat). Plant responses were greatly affected by cultivar, whereas the effects of fertilizer type were relatively minor. 'Triple Crown' produced the greatest yield in both years, whereas 'Black Diamond' and 'Marion' had the lowest yield in 2011 and 2012, respectively. 'Triple Crown' fruit had the highest percent soluble solids and were the least firm in 2011, whereas 'Marion' fruit were the least firm in 2012. Harvest date, within year, affected the fruit quality variables measured in all cultivars. Most soil nutrient levels were within the recommended range for all fertilizer treatments, except for boron (B), which declined to deficient levels in the second year. Fertilizer type had no effect on soil nutrient levels other than fertilization with the fish and molasses blend product increased soil potassium and sodium. Soil nutrient levels were affected by cultivar but varied by year for many nutrients. Primocane leaf tissue nutrient concentrations were above or within recommended standards for most nutrients, except for magnesium (Mg), calcium (Ca), and B, which, depending on the cultivar, were below standards. Over the 2-year study, the blackberry cultivars responded similarly to the three types of organic fertilizer. However, the cost of N varied from $8.16/lb for the liquid fish and molasses blend, $5.35/lb for the pelletized soy meal, and $2.54/lb for the pelletized, processed poultry litter. Supplemental fertilization with B, Mg, and Ca would be required with each fertilizer studied to maintain recommended soil fertility levels.**

Organic blackberry production in the United States increased from 180 acres in 2005 (Strik et al., 2007), to 495 acres in 2008 [U.S. Department of Agriculture (USDA), 2010]. West coast states accounted for 970 acres of certified or fully converted organic blackberry and red raspberry (*Rubus idaeus*) in 2007 (Granatstein et al., 2010). Significant expansion in organic plantings is expected in the next 10 years as consumer demand for organic products increases and growers become more interested in targeting higher-value niche markets [Organic Trade Association (OTA), 2013].

Guidelines for fertilizer and nutrient management in organic blackberry production are presently limited to overarching recommendations for nitrogen application rates and appropriate soil pH (Kuepper et al., 2003), and do not address different sources of N fertilizer or possible response differences among blackberry types [e.g., erect, semierect, and trailing types (Finn and Strik, 2014; Strik and Finn, 2012)].

The yield response of blackberry to increased rates of N fertilizer has been variable, depending on soil fertility, rates of N fertilizer used, and plant cultivar or age (Archbold et al., 1989; Naraguma and Clark, 1998; Nelson and Martin, 1986). Recommended rates of N application in conventional plantings vary with age and cultivar of blackberry grown, ranging from 25 to 70 lb/acre N (Bushway et al., 2008; Hart et al., 2006). In blackberry, primocane leaf nutrient concentration levels are typically used to adjust nutrient management programs (Hart et al., 2006). However, primocane leaf percent N may (Fernandez-Salvador et al., 2015a, 2015b; Harkins et al., 2013) or may not (Naraguma et al., 1999) differ among cultivars when grown under the same management. Fertilizer application is recommend for late winter/spring (Bushway et al., 2008; Hart et al., 2006), as blackberry plants require available fertilizer N for new primocane growth (Malik et al., 1991; Mohadjer et al., 2001; Naraguma et al., 1999).

The availability of fertilizer N depends on the fertilizer source (Gutser et al., 2005) and the method of application (Kowalenko et al., 2000; Strik, 2008). The number of organically approved N fertilizer sources for caneberries (*Rubus* sp.) is increasing as greater production of organic crops leads to more demand. Types of approved organic fertilizers include liquid products that are best applied using tank sprays (by hand to canopy or soil) or fertigation (diluted and applied through drip irrigation systems) or pelletized and granular products for localized bed or broadcast application using mechanical fertilizer spreaders. Common liquid fertilizers with N sources suitable for organic production include fish emulsion or hydrolysate, vegetable hydrolysate [e.g., corn (*Zea mays*) steep liquor], and molasses, whereas dry fertilizers include raw, composted, and processed animal manures (or manure-derived products), plant and animal by-products (e.g., plant-based meals such as soy meal and animal-based meals such as feather meal), or mineralized materials (e.g., sodium nitrate or bat and bird guano) [Organic Materials Review Institute (OMRI), 2013]. The organic fertilizer source (e.g., manure, other animal processing by-products, composts) affects N release rate, an important factor to consider when planning nutrient management programs and when targeting crop needs (Gutser et al., 2005). Growers should consider the availability and cost (per pound of N applied) of the fertilizer material and whether the rate of N release will likely match crop demand. For example, manure products are often readily available and cost effective, but have a slow N release rate, whereas liquid fish emulsion is more expensive to purchase, likely less expensive to apply when the drip irrigation system is used and has a relatively rapid N release rate (Gale et al., 2006). Crops grown in organic production systems may require fewer fertilizer inputs and still produce efficient growth and comparable yields to the same crop grown in conventional production (Mäder et al., 2002).

The objective of the present study was to evaluate the impact of three organic fertilizer types, including pelletized, processed poultry litter, pelletized soy meal, and a fish hydrolysate and emulsion blend with added molasses, on yield and fruit quality of blackberry cultivars grown in an organic production system at a grower collaborator site. Four popular blackberry cultivars, Black Diamond, Marion, and Obsidian trailing types and Triple Crown semierect type, were chosen for the study. 'Black Diamond' (Finn et al., 2005a), a cultivar grown for processed and fresh markets, and 'Marion' (Finn et al., 1997), grown predominantly for the processed market, account for >75% of the 7200 acres of blackberry produced in Oregon in 2012 (USDA, 2013). 'Obsidian' (Finn et al., 2005b) is the most widely grown trailing blackberry for fresh market in Oregon and is also grown in other production regions. 'Triple Crown' (Galletta et al., 1998) is a fresh market, semierect cultivar desired for its relatively late fruiting season and good flavor.

## Materials and methods

**STUDY SITE.** The study was conducted at a grower collaborator site in Jefferson, OR [lat. 44°40′N, long. 122°58′W, elevation 233 ft; USDA hardiness zone 8b, average annual extreme minimum temperature from 15 to 20 °F (U.S. Department of the Interior, 2013)].

The study site area consisted of three soil series: 1) Camas (sandy-skeletal, mixed, mesic Fluventic Haploxerolls) gravelly sandy loam, 2) Cloquato (coarse-silty, mixed, superactive, mesic Cumulic Ultic Haploxerolls) silt loam, and 3) Newberg (coarse-loamy, mixed, mesic Fluvaquentic Endoaquoll) fine sandy loam, distributed through the blackberry study site. A split plot design was used to account for these soil type and other differences (see the section Experimental Design). Before planting blackberry, the site was farmed as a conventional grass seed crop, growing bentgrass (*Agrostis* sp.) in rotation with other grass crops including creeping red fescue (*Festuca rubra*), and ryegrass (*Lolium perenne*).

**SITE PREPARATION.** In Sept. 2009, the farm was transitioned to organic production and the planting site was prepared by: 1) mowing the remnant grass seed crop; 2) subsoiling to a depth of 2 ft; 3) disking, harrowing, and rolling; and 4) bed shaping (8 inches high, 2 ft wide at the top, 3 ft wide at the base). Lime (calcium carbonate) was applied and incorporated at a rate of 444 lb/acre before bed shaping.

The grower divided the planting area into two 100 × 100-ft blocks with rows orientated in a north–south direction. The planting was established as a grower guided on-farm cultivar trial using common organic commercial practices (0.46 total planted acres).

Drip irrigation [one line of drip tubing (model UNIRAM; Netafim USA, Fresno, CA) with 0.42-gal/h in-line, pressure-compensating emitters spaced every 18 inches] was installed in the center of each row on top of the raised bed. The raised beds were then covered with a 6-ft-wide polypropylene woven 3.2-oz/yard² geotextile cloth ["weed mat" (model TerraTex Woven; Hanes Geo Components, Winston-Salem, NC)], which was centered and secured on the bed using 6-inch-long landscaping staples. Based on grower commercial management practices, the weed mat was cut at the center of the raised bed, to allow for it to be opened for fertilizer applications; the edges of the weed mat

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**Units**

| To convert U.S. to SI, multiply by | U.S. unit | SI unit | To convert SI to U.S., multiply by |
|---|---|---|---|
| 0.4047 | acre(s) | ha | 2.4711 |
| 0.3048 | ft | m | 3.2808 |
| 0.0929 | ft² | m² | 10.7639 |
| 3.7854 | gal | L | 0.2642 |
| 2.54 | inch(es) | cm | 0.3937 |
| 0.4536 | lb | kg | 2.2046 |
| 1.1209 | lb/acre | kg·ha⁻¹ | 0.8922 |
| 4.4482 | lbf | N | 0.2248 |
| 28.3495 | oz | g | 0.0353 |
| 70.0532 | oz/acre | g·ha⁻¹ | 0.0143 |
| 305.1517 | oz/ft² | g·m⁻² | 0.0033 |
| 33.9057 | oz/yard² | g·m⁻² | 0.0295 |
| 1 | ppm | mg·kg⁻¹ | 1 |
| 1 | ppm | mg·L⁻¹ | 1 |
| 2.2417 | ton(s)/acre | Mg·ha⁻¹ | 0.4461 |
| (°F – 32) ÷ 1.8 | °F | °C | (°C × 1.8) + 32 |

were patched with smaller sections of geotextile fabric and held in place by landscape staples. Weed mat was chosen as the in-row weed management strategy.

The area between rows (aisles) was seeded with 50 lb/acre fine fescue [a mixture of blue fescue (*Festuca longifolia*), chewings fescue (*F. rubra* ssp. *commutata*), red fescue (*F. rubra* ssp. *rubra*), slender creeping red fescue (*F. rubra* ssp. *litoralis*), and sheep fescue (*F. ovina*), cultivars unknown] following the USDA—Natural Resources Conservation Service recommendation for direct drill seeding species by Hoag et al. (2011) (Brillion model Sure Stand seeder; Landoll Corp., Brillion, WI).

**Planting establishment and management.** 'Marion', 'Obsidian', and 'Triple Crown' were obtained as rooted cuttings and 'Black Diamond' as tissue-cultured, plug stock in May and July 2009, respectively. All plants were potted into 1-gal pots and grown at the farm until planting in Oct. 2009 (north block) and May–June 2010 (south block), due to labor availability and winter weather conditions at the time of the first planting. Plant spacing varied between cultivars/blocks ranging from 3.0 to 4.5 ft in the row depending on cultivar vigor with 11 ft between rows (880–1320 plants/acre). In-row plant spacing was 3.0 and 4.5 ft in the north block and south block, respectively. A three-wire, vertical trellis was installed soon after planting with the lower trellis wire attached to steel posts at 2 ft above the top of the raised bed, the middle wire at 4 ft, and the upper wire at 6 ft. The trellis used for 'Triple Crown' had an additional 2-ft steel cross arm bolted to each post with a wire attached to each end of the "T." The posts in the row were spaced at 25 ft.

In 2010, all plants were fertilized on 21 May and 3 Sept. with the following: a) fish hydrolysate and emulsion blend with added molasses [3N–0.4P–0.8K, 2.7 lb/acre N per application (TRUE 315; True Organics, Spreckels, CA)], b) 2.3 lb/acre copper (Cu) as copper hydroxide, and c) 2.0 lb/acre zinc (Zn) as zinc sulfate. In 2010, the first growing season, primocanes were trained and tied to the trellis as they grew per standard commercial practice (Strik and Finn, 2012). Once the primocanes grew above the upper trellis wire, all the canes were looped in one direction (south). In 2011 and 2012 (the first and second fruiting seasons), the floricanes (previous year's primocanes) were hand-harvested and newly growing primocanes were trained to the lowest trellis wire during the fruiting season (for trailing cultivars). After fruit harvest, the dying floricanes were removed from each plant by pruning at crown height and then were flailed mowed (chopped) in the aisles (model SPF flail; Rears Manufacturing, Eugene, OR) during the fall and winter. In the trailing cultivars, primocanes were trained from August to September by looping half the canes in each direction down to the lower trellis wire and bringing them back toward the plant with one or two twists (Strik and Finn, 2012). In 'Triple Crown', once the dying floricanes were removed, the grower thinned the primocanes to two to three canes per plant and placed the canes between the cross-arm wires. The primocanes were topped at 5 to 6 ft to control plant height. As 'Triple Crown' primocanes tend to branch at the apical section of the cane during the growing season (3–5 ft height), the long branches remaining after topping were trained and tied in a circular pattern to each side of the plant. The field was managed following National Organic Program practices for crop production (USDA, 2011) from establishment through the study period and was first certified as organic in 2012 (California Certified Organic Farmers, Santa Cruz, CA) after the transition period was completed. Plants were irrigated typically in sets of 3 to 4 h, four times per week from June through September, or as required based on grower experience and visual observation of soil moisture status.

Pest management was per standard commercial practice with a dormant application of agricultural sulfur to the canopy to manage cane disease in Dec. 2011 (REX lime sulfur; ORCAL, Junction City, OR) at a rate of 2.4 gal per 100 gal of water. In 2011 and 2012, the fungicides hay or grass bacillus [*Bacillus subtilis* (Serenade® MAX; AgraQuest, Davis, CA) and root streptomyces [*Streptomyces lydicus* (Actinovate® AG; Natural Industries, Houston, TX)] were applied in midspring (2011) or early and late-spring (2012) to help control gray mold (*Botrytis cinerea*), per label rate and recommendations. A spinosad (metabolites of *Saccharopolyspora spinosa*) insecticide (Entrust® SC; Dow Agro Science, Indianapolis, IN) was applied to the field twice in each season to control the adults of spotted wing drosophila (*Drosophila suzukii*), per label rate and recommendations.

Weather data (total daily precipitation and maximum and minimum daily air temperature) were obtained from 1 June to the end of harvest on 30 Sept. 2011 and 2012 from the closest available Pacific northwestern U.S. Cooperative Agricultural Weather Network AgriMet (U.S. Department of the Interior, 2013) weather station located at Oregon State University's Hyslop Field Laboratory, Corvallis, OR.

**Experimental design.** Our study was conducted in 2011 and 2012, the first and second fruiting years, respectively. Treatments were arranged in a split-plot design with three replicates and included four cultivars (Obsidan, Black Diamond, Marion, and Triple Crown) as main plots and three fertilizer types [pelletized, processed poultry litter (poultry), pelletized soy meal (soy), and a fish hydrolysate and emulsion blend with added molasses (fish)] as subplots. Each plot was 17 ft in length with the exception of two plots on the south block that were 14 ft in length; these plot size differences were accounted for in all calculations.

The three fertilizer treatments were applied at an equivalent target rate of N (50 lb/acre), based on the percent N in the product as stated on the label in both years of the study. All fertilizers were applied under the weed mat (by opening, applying the product, and then reclosing the weed mat). The fish fertilizer used was a blend of fish hydrolysate and fish emulsion with added molasses [4N–0P–1.7K (TRUE 402, True Organics)] and was diluted with 10 parts water (v/v) and applied by hand, using a backpack sprayer, to the in-row area around and between plants in four applications (30 Apr., 7 and 18 May, and 1 June 2011; 27 Apr., 12 and 22 May, and 3 June 2012). Pelletized soy meal [8N–0.4P–1.7K (Phyta-Grow® Leafy Green Special™; California Organic Fertilizers, Hanford, CA)] was broadcast in the row area on 30 Apr. 2011 and 26 Apr. 2012. Pelletized, processed poultry litter [4N–1.3P–2.5K–7Ca (Nutri-Rich; Stutzman Environmental Products, Canby, OR)] was broadcast in the row area on 30 Apr. 2011 and 26 Apr. 2012. The fertilizers studied were analyzed for total nutrient content (Brookside Laboratories, New Bremen, OH), and the rate of all macro- and micronutrients applied was calculated.

**FRUIT HARVEST.** Fruit were hand-harvested about twice weekly, per the grower's schedule, selecting fruit that were toward the end of the shiny black stage. Harvested fruit were separated into marketable (for fresh market) and unmarketable ("cull"; including overripe, sunburned, rotten, dropped, or otherwise damaged fruit) and total yield/plot calculated. Fruiting season (first to last fruit harvest date) was recorded. A 25-berry subsample per harvest date was used to determine average fruit quality variables, including fruit weight (seasonal, weighted average was calculated), fruit firmness, and percent soluble solids. The 25-berry sample was picked first, before the rest of the plot, randomly selecting fruit from both sides of the row and covering the entire length of the plot area. Fruit 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 0.5-inch-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. The fruit were then placed in a 1/4-gal polyethylene resealable bag and crushed by hand to obtain a homogeneous mixture for measuring percent soluble solids, on a temperature-compensated digital refractometer (Atago, Bellevue, WA).

**LEAF TISSUE AND NUTRIENT CONCENTRATION.** Primocane leaves were sampled on 3 Aug. 2012, per standard recommended practice (Hart et al., 2006). Samples per plot consisted of 10 of the most recent fully expanded primocane leaves, selected from both sides of the row and were sent to Brookside Laboratories for analysis of leaf tissue N, phosphorus (P), potassium (K), Mg, Ca, sulfur (S), B, iron (Fe), manganese (Mn), Cu, Zn, and aluminum (Al) concentration. Total leaf N was determined by a combustion analyzer using an induction furnace and a thermal conductivity detector (Gavlak et al., 1994). All other nutrient concentrations were determined via inductively coupled plasma spectrophotometer (ICP) after wet washing in nitric/perchloric acid (Gavlak et al., 1994). Nutrient concentrations in the primocane leaves were compared with published standards (Hart et al., 2006).

**SOIL SAMPLING AND SOIL NUTRIENT CONTENT.** Soil samples were collected on 3 Nov. 2011 and 5 Nov. 2012, using a 15/16-inch-diameter, 21-inch-long, slotted, open-side, chrome-plated steel soil probe (Soil Sampler model Hoffer; JBK Manufacturing, Dayton, OH). One sample was collected per treatment plot. Each sample was composed of four cores collected to a depth of 12 inches from the top of the raised bed (two from each side of the center plant and two from the inner side of the border plants); all cores were within the irrigation emitter drip zone of the in-row area.

All soil samples were sent for analysis to Brookside Laboratories and extractable soil P (Bray 1 extraction), 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-nitrogen ($NO_3$-N) and ammonium-nitrogen ($NH_4$-N) were determined using automated colorimetric methods after extraction with 1 M potassium chloride [KCl (Dahnke, 1990)]. Soil organic matter was measured using loss-on-ignition at 360 °C (Nelson and Sommers, 1996) and soil pH using the 1:1 soil:water method (McLean, 1982).

**DATA ANALYSIS.** Data were analyzed for a split-split-plot design using year as a main plot factor, cultivar as a subplot, and fertilizer type as a sub-subplot. Due to significant year effects and plants maturing during the study period, data were reanalyzed by year as a split-plot (cultivar as main plot and fertilizer as subplot) using the General Linear Model procedure in SAS (version 9.3; SAS Institute, Cary, NC). Data were tested for normality and log transformed, if needed to meet criteria for normality and homogeneity of variance. Means were compared for treatment effects using a Fisher's protected least significant difference (LSD) with $\alpha = 0.05$. Comparison within interactions were analyzed for treatment effects using a least square means (LS Means) with $\alpha = 0.05$. The effect of harvest date on yield and fruit quality was analyzed by cultivar using a split-split-plot design with year as the main plot, fertilizer as the subplot, and harvest date as a the sub-subplot factor.

## Results

When the data were analyzed as a split-split-plot with year as the main plot factor, year had a significant effect on fruit weight ($P = 0.02$), fruit firmness ($P < 0.0001$), total yield ($P < 0.0001$), and marketable yield ($P = 0.001$). There was a significant year × cultivar interaction for fruit weight ($P < 0.0001$), fruit firmness ($P < 0.0001$), percent soluble solids ($P = 0.03$), and total yield ($P = 0.03$). Data for seasonal total and marketable yield and fruit quality variables were then analyzed and are presented by year (Table 1).

**FERTILIZER TYPE.** There was no significant main effect of fertilizer type on yield (marketable and total) or fruit quality in 2011 or 2012. However, there was a significant fertilizer × cultivar interaction on fruit weight in 2011, total yield in 2011 and 2012, and marketable yield in 2012 (Table 1).

The effects of fertilizer type on total yield varied with cultivar, but results were inconsistent among the two years (Table 1). 'Triple Crown' produced a higher total yield in 2011 when fertilized with soy than with poultry, but there was little fertilizer effect on total yield of this cultivar in 2012 or for all other cultivars in 2011 and 2012. Fertilizer type had no effect on marketable yield in 2011, but in 2012 'Obsidian' had a greater marketable yield when fertilized with soy as compared with fish. In 2011, there was no effect of fertilizer on fruit weight in 'Triple Crown' and 'Obsidian', whereas 'Black Diamond' tended to have the greatest fruit weight when fertilized with poultry or fish and 'Marion' when fertilized with poultry (Table 1). There was no effect of fertilizer on berry weight in 2012 or percent soluble solids and firmness in either year (Table 1).

The fertilizers applied in 2011 and 2012, came from the same batch. The calculated rate of all nutrients applied is shown (Table 2) for 2012 only, as the laboratory results for the

Table 1. Effect of cultivar and fertilizer type on fruit weight, percent soluble solids, fruit firmness, and total and marketable fruit yield in a new field of hand-picked organic blackberry at a grower collaborator site in Jefferson, OR during the first 2 years after planting (2011–12) as determined by analysis of variance for a split-plot design (cultivar as main plots and fertilizer as subplots).

| Treatments | Fruit wt (g)[z] | | | Soluble solids (%) | Firmness (gf)[z] | Total yield ($Mg\cdot ha^{-1}$)[z] | | | Marketable yield ($Mg\cdot ha^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Poultry[y] | Fish | Soy | | | Poultry | Fish | Soy | | | |
| Cultivar | | | | | *2011* | | | | | | |
| Black Diamond | 7.27 b [x] | 7.03 b | 6.70 bc | 10.4 b | 412 b | 7.9 bc | 7.1 bc | 5.9 c | | 5.2 b | |
| Marion | 5.90 cd | 5.87 d | 5.73 d | 12.0 a | 236 c | 12.8 b | 12.1 b | 12.2 b | | 10.3 ab | |
| Obsidian | 8.50 a | 8.67 a | 8.63 a | 12.0 a | 467 a | 10.8 b | 9.5 bc | 11.8 b | | 5.9 b | |
| Triple Crown | 8.43 a | 8.83 a | 9.20 a | 12.4 a | 208 d | 13.8 b | 15.9 ab | 18.6 a | | 14.0 a | |
| Significance[w] | | | | | | | | | | | |
| Fertilizer (F) | | NS | | NS | NS | | NS | | | NS | |
| Cultivar (C) | | <0.0001 | | <0.0001 | <0.0001 | | <0.0001 | | | <0.0001 | |
| C × F | | 0.02 | | NS | NS | | 0.04 | | | NS | |
| | | | | | | Poultry | Fish | Soy | Poultry | Fish | Soy |
| Cultivar | | | | | *2012* | | | | | | |
| Black Diamond | | 6.89 b | | 10.1 d | 269 b | 18.2 b | 16.9 bc | 16.2 bc | 10.9 c | 9.2 c | 8.5 c |
| Marion | | 5.43 c | | 12.7 b | 176 d | 12.3 c | 15.6 bc | 13.0 c | 9.2 c | 11.4 bc | 10.2 c |
| Obsidian | | 7.02 b | | 11.8 c | 329 a | 15.5 bc | 15.2 bc | 19.8 b | 11.3 bc | 11.1 c | 14.6 b |
| Triple Crown | | 9.81 a | | 13.0 a | 196 c | 26.6 a | 26.6 a | 27.8 a | 20.0 a | 20.0 a | 21.1 a |
| Significance | | | | | | | | | | | |
| Fertilizer | | NS | | NS | NS | | NS | | | NS | |
| Cultivar | | <0.0001 | | <0.0001 | <0.0001 | | <0.0001 | | | <0.0001 | |
| C × F | | NS | | NS | NS | | 0.009 | | | 0.0034 | |

[z]1 g = 0.0353 oz, 1 g-force (gf) = 0.0098 N = 0.0022 lbf, 1 $Mg\cdot ha^{-1}$ = 0.4461 ton/acre.
[y]Fertilizer products used were pelletized, processed poultry litter ["poultry," 4N–1.3P–2.5K–7Ca (Nutri-Rich; Stutzman Environmental Products, Canby, OR)], a blend of fish hydrolysate and fish emulsion with added molasses ["fish," 4N–0P–1.7K (TRUE 402; True Organic Products, Spreckels, CA)], and pelletized soy meal ["soy," 8N–0.4P–1.7K (Phyta Grow Leafy Green Special; California Organic Fertilizers, Hanford, CA)]. The three fertilizer treatments were applied at an equivalent total rate of N of 50 lb/acre (56.0 $kg\cdot ha^{-1}$) in 2011 and 2012, based on the percent nitrogen in the product as stated on the label.
[x]Means followed by the same letter within the treatment or the interaction were not significantly different via least square means at $P > 0.05$.
[w]Probability value provided unless nonsignificant [NS ($P > 0.05$)].

Table 2. Total nutrients applied in a new field of hand-picked organic blackberry in 2012 at a grower collaborator site in Jefferson, OR.

| Fertilizer[z] | Macronutrients (lb/acre)[y] N[x] | P | K | Ca | Mg | Na | Micronutrients (oz/acre)[y] B | Fe | Mn | Cu | Zn | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Poultry | 47 | 28 | 32 | 144 | 9 | 5 | 1 | 13 | 9 | 1 | 8 | 6 |
| Soy | 44 | 4 | 15 | 2 | 2 | 0 | 0 | 2 | 0 | 0 | 1 | 1 |
| Fish | 47 | 7 | 56 | 1 | 1 | 23 | 0 | 5 | 0 | 0 | 1 | 3 |

[z]Fertilizers were analyzed by Brookside Laboratories, (New Bremen, OH). Pelletized, processed poultry litter ["poultry," 4N–1.3P–2.5K–7Ca (Nutri-Rich; Stutzman Environmental Products, Canby, OR)] was applied as a band application on top of the soil at the center of the raised bed in spring. Fish hydrolysate and fish emulsion with added molasses mixture ["fish," 4N–0P–1.7K (TRUE 402; True Organic Products, Spreckels, CA)] was diluted with water (1:10, v/v) before application as a directed spray to the bed surface in four equal portions in spring. Pelletized soy meal ["soy," 8N–0.4P–1.7K (Phyta Grow Leafy Green Special; California Organic Fertilizers, Hanford, CA)] was applied as a band on top of the soil in the center of the raised bed in spring. "Poultry" had a pH of 8.3, "fish" had a pH of 5.5, and "soy" had a pH of 6.2.
[y]1 lb/acre = 1.1209 $kg\cdot ha^{-1}$, 1 oz/acre = 70.0532 $g\cdot ha^{-1}$.
[x]N = nitrogen; P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, Na = sodium, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, Al = aluminum.

samples sent in 2011 and 2012, were very similar. Although the amount of product to apply for each fertilizer was calculated based on the percentage of N, as stated on the label, and the target rate of N (50 lb/acre), the actual rate of N applied was 47, 45, and 44 lb/acre for the poultry, fish, and soy products, respectively (Table 2). Poultry litter contained more than 70-fold the Ca, 4-fold the P, and more than 3-fold the Mg, Fe, Mn, and Zn than the fish and soy fertilizers. The fish fertilizer contained 4- to 20-fold the Na as the poultry and soy fertilizer sources, respectively. Fertilization with fish also led to higher rates of K applied than when poultry and soy were used (Table 2).

Soil pH was at the upper end of the recommended range for blackberry (5.6 to 6.5) (Hart et al., 2006) for all treatments in 2011, but by 2012, the pH had declined to the lower end of the range (Table 3). The soil organic matter content was unaffected by fertilizer type and would be considered high for typical blackberry fields in Oregon.

Most of the nutrient levels in the soil were within or above the recommended range for caneberries in Oregon (Hart et al., 2006) for all fertilizer treatments. Soil P, K, Ca, and Mg were considerably above

**Table 3. Effect of cultivar and fertilizer source on soil pH, organic matter, and nutrient content in a new field of hand-picked organic blackberry at a grower collaborator site in Jefferson, OR on 3 Nov. 2011 and 5 Nov. 2012 as determined by analysis of variance for a split-plot design [cultivar as main plots and fertilizer as subplots ($n$ = 3)].**

| | | | | | | K | Ca | | | Mg | Na | | | B | Fe | Mn | | | Cu | Zn | Al | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | OM[z] | $NO_3$–N | $NH_4$–N | P | (mg·kg$^{-1}$)[y] | | | | | | | | | | | | | | | | | |
| Treatments | pH | (%) | (ppm)[y] | (ppm) | (ppm) | | Poultry[x] | Fish | Soy | | Poultry | Fish | Soy | | | Poultry | Fish | Soy | | | Poultry | Fish | Soy |
| *2011* | | | | | | | | | | | | | | | | | | | | | | | |
| Cultivar | | | | | | | | | | | | | | | | | | | | | | | |
| Black Diamond | 6.4 | 4.7 | 6.82 bc[w] | 1.80 | 130 | 387 | 4,595 a | 4,422 ab | 4,038 ab | 785 | 60.7 d | 80.3 dc | 55.7 d | 0.56 c | 340.0 | 20.3 b | 31.3 a | 23.0 ab | 5.00 | 7.50 | 1,103 cd | 1,098 d | 1,187 abcd |
| Marion | 6.3 | 4.1 | 13.19 a | 1.86 | 151 | 405 | 4,266 ab | 4,260 ab | 4,156 ab | 806 | 71.0 dc | 99.7 bc | 74.0 dc | 0.76 a | 363.1 | 25.7 ab | 23.0 ab | 22.0 b | 5.10 | 6.70 | 1,248 ab | 1,272 ab | 1,220 abc |
| Obsidian | 6.2 | 4.2 | 9.41 ab | 2.39 | 157 | 496 | 4,398 ab | 3,833 ab | 4,308 ab | 785 | 77.7 dc | 122.3 ab | 74.0 dc | 0.71 ab | 370.6 | 22.3 b | 28.3 ab | 24.3 ab | 5.60 | 7.40 | 1,258 ab | 1,277 a | 1,194 abcd |
| Triple Crown | 6.1 | 4.7 | 3.67 c | 1.17 | 125 | 430 | 3,721 b | 3,732 b | 4,332 ab | 735 | 71.3 dc | 142.3 a | 71.0 dc | 0.62 bc | 341.2 | 27.0 ab | 28.3 ab | 21.0 b | 4.10 | 5.70 | 1,119 cd | 1,160 bcd | 1,173 abcd |
| Fertilizer | | | | | | | | | | | | | | | | | | | | | | | |
| Poultry | 6.3 | 4.3 | 8.19 | 1.70 | 139 | 398 b | — | — | — | 761 | — | — | — | 0.68 | 344.7 | — | — | — | 4.80 | 6.90 | — | — | — |
| Fish | 6.1 | 4.5 | 9.55 | 2.40 | 148 | 551 a | — | — | — | 758 | — | — | — | 0.65 | 359.8 | — | — | — | 4.80 | 6.50 | — | — | — |
| Soy | 6.3 | 4.4 | 7.08 | 1.40 | 135 | 339 b | — | — | — | 815 | — | — | — | 0.66 | 356.7 | — | — | — | 5.20 | 7.10 | — | — | — |
| Significance[v] | | | | | | | | | | | | | | | | | | | | | | | |
| Cultivar (C) | NS | NS | 0.048 | NS | NS | NS | | NS | | NS | | <0.0001 | | 0.026 | NS | | NS | | NS | NS | | 0.005 | |
| Fertilizer (F) | NS | NS | NS | NS | NS | <0.0001 | | NS | | NS | | 0.004 | | NS | NS | | 0.0007 | | NS | NS | | NS | |
| C × F | NS | NS | NS | NS | NS | NS | | 0.009 | | NS | | 0.003 | | NS | NS | | 0.009 | | NS | NS | | 0.015 | |
| *2012* | | | | | | | | | | | | | | | | | | | | | | | |
| Cultivar | | | | | | | | | | | | | | | | | | | | | | | |
| Black Diamond | 5.6 | 4.7 | 17.9 a | 4.62 | 204 | 592 | — | 3,655 | — | 613 | — | 71.6 | — | 0.46 | 352 | — | 27.3 | — | 5.19 | 6.39 | — | 1,138 | — |
| Marion | 5.7 | 4.7 | 10.4 b | 3.78 | 173 | 578 | — | 3,376 | — | 546 | — | 68.1 | — | 0.45 | 346 | — | 25.6 | — | 4.15 | 4.81 | — | 1,096 | — |
| Obsidian | 5.7 | 4.8 | 10.4 b | 5.19 | 184 | 619 | — | 3,342 | — | 540 | — | 77.3 | — | 0.45 | 345 | — | 28.0 | — | 4.32 | 5.30 | — | 1,087 | — |
| Triple Crown | 5.9 | 4.6 | 10.5 b | 5.71 | 180 | 509 | — | 3,588 | — | 603 | — | 73.7 | — | 0.44 | 336 | — | 26.8 | — | 4.76 | 6.08 | — | 1,047 | — |
| Fertilizer | | | | | | | | | | | | | | | | | | | | | | | |
| Poultry | 5.8 | 4.6 | 12.7 | 4.60 | 192 | 532 b | — | 3,534 | — | 568 | — | 60.7 b | — | 0.45 | 329.1 b | — | 25.6 | — | 4.32 | 5.87 | — | 1,051 c | — |
| Fish | 5.7 | 4.8 | 12.1 | 4.28 | 200 | 665 a | — | 3,453 | — | 571 | — | 104.4 a | — | 0.45 | 348.4 a | — | 28.2 | — | 4.97 | 6.19 | — | 1,090 b | — |
| Soy | 5.6 | 4.7 | 12.1 | 5.60 | 164 | 527 b | — | 3,483 | — | 587 | — | 52.9 b | — | 0.46 | 356.3 a | — | 27.0 | — | 4.53 | 4.88 | — | 1,135 a | — |
| Significance | | | | | | | | | | | | | | | | | | | | | | | |
| Cultivar | NS | NS | 0.01 | NS | NS | NS | | NS | | NS | | NS | | NS | NS | | NS | | NS | NS | | NS | |
| Fertilizer | NS | NS | NS | NS | NS | 0.033 | | NS | | NS | | 0.0001 | | NS | 0.011 | | NS | | NS | NS | | 0.0007 | |
| C × F | NS | NS | NS | NS | NS | NS | | NS | | NS | | NS | | NS | NS | | NS | | NS | NS | | NS | |

[z]OM = organic matter, $NO_3$-N = nitrate nitrogen, $NH_4$-N = ammonium nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, Na = sodium, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, Al = aluminum.

[y]1 ppm = mg·L$^{-1}$, 1 mg·kg$^{-1}$ = 1 ppm.

[x]Fertilizer products used were pelletized, processed poultry litter ["poultry," 4N–1.3P–2.5K–7Ca (Nutri-Rich; Stutzman Environmental Products, Canby, OR)], a blend of fish hydrolysate and fish emulsion with added molasses ["fish," 4N–0P–1.7K (TRUE 402; True Organic Products, Spreckels, CA)], and pelletized soy meal ["soy," 8N–0.4P–1.7K (Phyta Grow Leafy Green Special; California Organic Fertilizers, Hanford, CA)]. The three fertilizer treatments were applied at an equivalent total rate of nitrogen of 50 lb/acre (56.0 kg·ha$^{-1}$) in 2011 and 2012, based on the percent nitrogen in the product as stated on the label.

[w]Means followed by the same letter within the treatment or interaction or in a given column were not significantly different via least square means at $P > 0.05$.

[v]Probability value provided unless nonsignificant [NS ($P > 0.05$)].

recommended levels (P-Bray = 20 to 40 ppm, K = 150 to 350 ppm, Ca = 1000 ppm, Mg = 120 ppm) in both years (Table 3). Soil Mn was at the lower end of the recommended level (20 to 60 ppm) in both years. Soil B was within the recommended level in 2011 (0.5 to 1.0 ppm), but declined to just below the recommended level in 2012 (Table 3).

Fertilizer type affected soil K in 2011 and there was a fertilizer × cultivar interaction on soil Ca, Na, Mn, and Al (Table 3). In 2012, fertilizer treatment affected soil K, Na, Fe, and Al. There was no effect of fertilizer on available soil $NO_3$-N and $NH_4$-N in either year. Fertilization with fish increased soil K in both years compared with poultry and soy. In 2011, soil Ca was highest in 'Black Diamond' plots when fertilized with poultry, but was highest in 'Triple Crown' plots when fertilized with soy. In contrast, there was relatively little effect of fertilizer source on soil Ca in 'Marion' and 'Obsidian' (Table 3). There was no effect of fertilizer on soil Ca in 2012, nor was there any effect on soil Mg in either year. Fertilization with fish increased soil Na for all cultivars in 2011 and 2012. In 2011, soil in 'Black Diamond' plots fertilized with fish had a higher level of Mn than in 'Black Diamond' and 'Obsidian' fertilized with poultry and 'Marion' and 'Triple Crown' fertilized with soy. There was no fertilizer effect on soil Mn in 2012. The effects of fertilizer on soil Fe and Al were inconsistent among years (Table 3).

Fertilizer type did not significantly affect primocane tissue nutrient concentration in 2012 for any of the nutrients tested, but there was a significant fertilizer × cultivar interaction on tissue P concentration (Table 4). Plants fertilized with poultry, which was higher in P (Table 2), had higher levels of tissue P, especially in 'Obsidian'. However, cultivar effects on tissue P were larger than fertilizer effects.

**Cultivar effects.** There was a significant main effect of cultivar on yield and all fruit quality variables in 2011 and 2012. Interactions of cultivar and fertilizer are described above. 'Triple Crown', a semierect blackberry, had the greatest total and marketable yield in both years. Within the trailing types, 'Black Diamond' and 'Marion' had the lowest

**Table 4. Effect of cultivar and fertilizer source on primocane leaf tissue nutrient concentration in a new field of hand-picked organic blackberry at a grower collaborator site in Jefferson, OR on 3 Aug. 2012 as determined by analysis of variance for a split-plot design [cultivar as main plots and fertilizer as subplots (n = 3)].**

| | Macronutrients (%) | | | | | | | | Micronutrients (ppm)[y] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | P | | | | | | | | | | | | |
| Treatments | N[z] | Poultry[x] | Fish | Soy | K | Ca | Mg | S | Fe | B | Cu | Mn | Zn | Al |
| Cultivar | | | | | | | | | | | | | | |
| Black Diamond | 2.7 c[w] | 0.30 d | 0.31 d | 0.32 d | 1.4 c | 0.22 c | 0.25 c | 0.15 c | 91.6 b | 18.6 b | 8.6 c | 39.0 c | 28.5 c | 58.4 b |
| Marion | 3.0 b | 0.40 bc | 0.43 b | 0.41 b | 1.8 b | 0.26 b | 0.25 c | 0.16 c | 97.4 b | 18.0 b | 9.2 bc | 64.0 b | 42.8 b | 77.3 b |
| Obsidian | 3.7 a | 0.53 a | 0.49 a | 0.49 a | 2.1 a | 0.24 bc | 0.28 b | 0.20 b | 133.1 a | 23.2 a | 12.0 a | 64.2 b | 52.7 a | 84.3 b |
| Triple Crown | 3.1 b | 0.36 cd | 0.38 bcd | 0.36 cd | 1.4 c | 0.34 a | 0.33 a | 0.23 a | 150.8 a | 19.4 b | 9.8 b | 93.2 a | 49.9 a | 123.8 a |
| Significance[v] | | | | | | | | | | | | | | |
| Cultivar (C) | 0.01 | | 0.0001 | | 0.0001 | 0.001 | 0.0001 | 0.0001 | 0.004 | 0.02 | 0.001 | 0.0001 | 0.0001 | 0.01 |
| Fertilizer (F) | NS | | NS | | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| C × F | NS | | 0.04 | | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |

[z]N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, Na = sodium, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, Al = aluminum.
[y]1 ppm = $mg \cdot L^{-1}$.
[x]Fertilizer products used were pelletized, processed poultry litter ["poultry," 4N–1.3P–2.5K–7Ca (Nutri-Rich; Stutzman Environmental Products, Canby, OR)], a blend of fish hydrolysate and fish emulsion with added molasses ["fish," 4N–0P–1.7K (TRUE 402; True Organic Products, Spreckels, CA)], and pelletized soy meal ["soy," 8N–0.4P–1.7K (Phyta Grow Leafy Green Special; California Organic Fertilizers, Hanford, CA)]. The three fertilizer treatments were applied at an equivalent total rate of nitrogen of 50 lb/acre (56.0 $kg \cdot ha^{-1}$) in 2011 and 2012, based on the percent nitrogen in the product as stated on the label.
[w]Means followed by the same letter within the treatment or the interaction were not significantly different via least square means at $P > 0.05$.
[v]Probability value provided unless nonsignificant [NS ($P > 0.05$)].

yield in 2011 and 2012, respectively (Table 1). The proportion of nonmarketable fruit varied among cultivars and between years averaging 45% and 27% for 'Obsidian', 25% and 44% for 'Black Diamond', 17% and 25% for 'Marion', and 13% and 25% for 'Triple Crown' in 2011 and 2012, respectively [29% and 32% for the trailing cultivars, on average (data not shown)]. 'Obsidian' produced the most cull or nonmarketable fruit (4.8 $Mg \cdot ha^{-1}$) in 2011 and 'Black Diamond' (7.6 $Mg \cdot ha^{-1}$) in 2012 (data not shown). On average, 'Triple Crown' had the greatest berry weight and 'Marion' the least in both years (Table 1). 'Black Diamond' fruit had the lowest percent soluble solids in both years, whereas 'Triple Crown' fruit had the highest in 2012. 'Obsidian' had the firmest fruit, and 'Triple Crown' and 'Marion' fruit were the least firm in 2011 and 2012, respectively.

Cultivar affected soil nutrient levels, but the effect varied by year for many nutrients (Table 3). Soil in the 'Triple Crown' and 'Black Diamond' plots tended to have the lowest level of $NO_3$-N in 2011. In contrast, soil in 'Black Diamond' plots had the highest level of $NO_3$-N in 2012.

The measured primocane tissue nutrient concentrations varied among cultivars (Table 4). Primocane tissue N, P, K, S, Fe, Cu, and Zn concentration were within or above the recommended standards, depending on cultivar [2.3% to 3.0% N, 0.19% to 0.45% P, 1.3% to 2.0% K, 0.1% to 0.2% S, 60 to 250 ppm Fe, 6 to 20 ppm Cu, and 15 to 50 ppm Zn (Hart et al., 2006)]. Tissue Mn and Mg were within or below the recommended range depending on cultivar (50 to 300 ppm Mn, 0.3% to 0.6% Mg). Primocane Ca and B concentration were below the recommended standards in all cultivars (0.6% to 2.0% Ca, 30 to 70 ppm B).

Primocane tissue N, P, K, B, Cu, and Zn concentration were highest in 'Obsidian' and tended to be lowest in 'Black Diamond'; there were relatively few differences between 'Marion' and 'Triple Crown' (Table 4). Tissue Ca, Mg, S, Fe, Mn, and Al were highest in 'Triple Crown' and tended to be lowest in 'Black Diamond'.

Harvest date had a significant effect on yield and all fruit quality variables (berry weight, percent soluble solids, and firmness) in all cultivars, which were analyzed separately ($P < 0.0001$ for all cultivars and variables), in 2011 and 2012 (data not shown). There was also a significant effect of year on fruit firmness ($P = 0.002$) and marketable yield ($P = 0.005$) for 'Obsidian', firmness ($P = 0.0003$) and total yield ($P = 0.01$) for 'Black Diamond', firmness ($P = 0.01$) and berry weight ($P = 0.04$) for 'Marion', and berry weight ($P = 0.002$) for 'Triple Crown' (data not shown).

There were very different weather patterns in 2011 and 2012 (Figs. 1 and 2). For example, precipitation in the month of June 2011 was 0.9 inch, whereas in 2012 the same

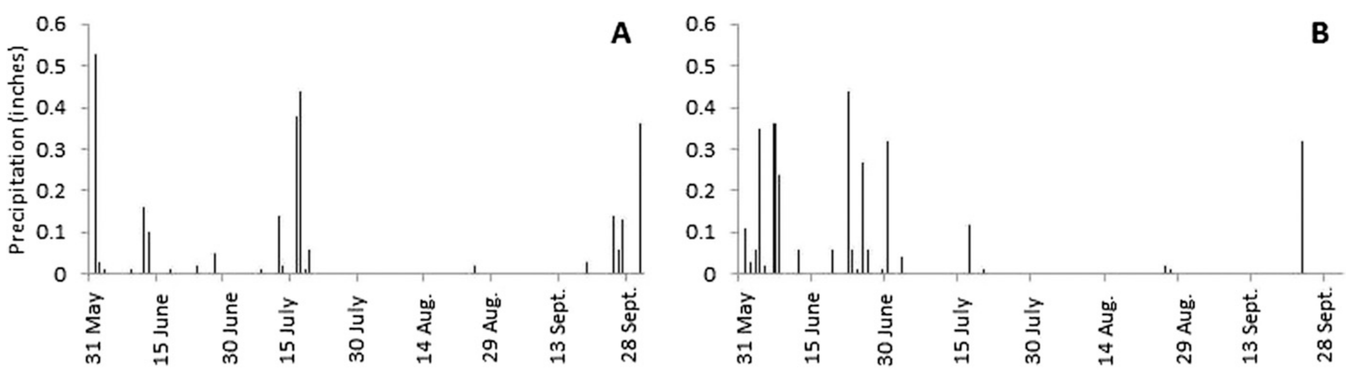


**Fig. 1. Total daily precipitation from 1 June to the end of harvest on 30 Sept. (A) 2011 and (B) 2012 at Oregon State University's Hyslop Field Laboratory in Corvallis, OR (U.S. Department of the Interior, 2013); 1 inch = 2.54 cm.**

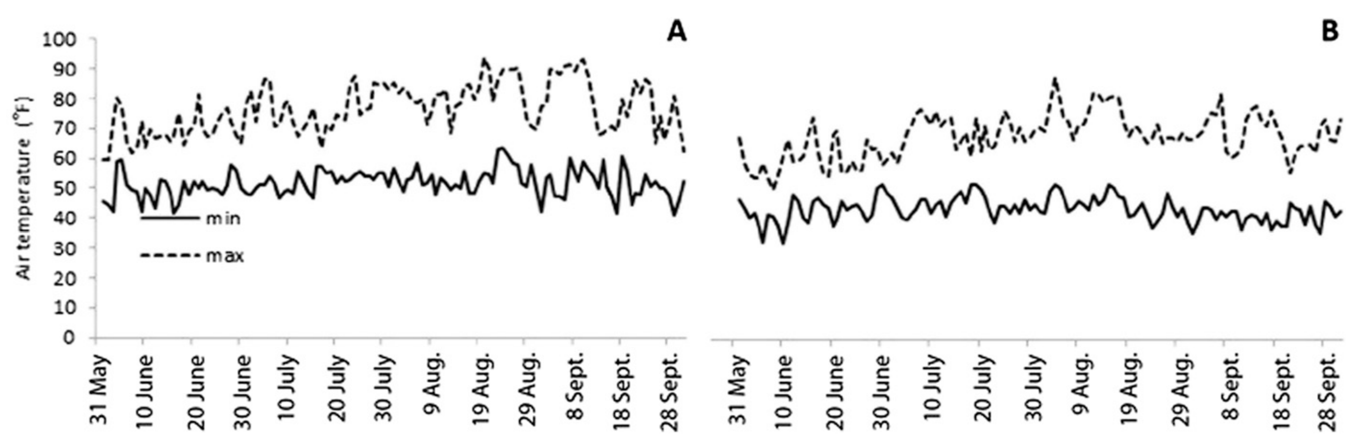


**Fig. 2. Maximum ("max") and minimum ("min") daily air temperature (hourly, 24 h) from 1 June to the end of harvest on 30 Sept. (A) 2011 and (B) 2012 at Oregon State University's Hyslop Field Laboratory in Corvallis, OR (U.S. Department of the Interior, 2013); (°F − 32) ÷ 1.8 = °C.**

month had 2.5 inches of rain; in addition, there were 1.1 inches in July 2011, in contrast to 0.2 inch during the same month in 2012 (data not shown). Although the average air temperature was similar in 2011 and 2012 (data not shown), the daily maximum and minimum temperatures were higher in 2011 than in 2012 (Fig. 2). The harvest season in 2012 was ≈2 weeks earlier than in 2011 (Fig. 3).

'Obsidian' had the earliest fruiting season, followed by 'Marion' and 'Black Diamond' (trailing types) and the semierect type 'Triple Crown'. Marketable yield was considerably lower than total yield on certain harvest dates, particularly for 'Obsidian' in 2011, 'Triple Crown' in 2012, and some mid and late harvests of 'Black Diamond' in 2012 (Fig. 3).

Berry weight increased through most of the fruiting season for 'Obsidian' in 2011, but remained stable or declined for most of the harvest season in the other cultivars (Fig. 4). Fruit firmness declined somewhat during the fruiting season for all cultivars in 2011, while in 2012, fruit firmness declined considerably during the fruiting season, particularly in the trailing blackberry cultivars (Fig. 5). Percent soluble solids of the trailing blackberry cultivars varied throughout the fruiting season, particularly in Obsidian and Black Diamond in 2011 and Marion in 2012 (Fernandez-Salvador, 2014). In contrast, the percent soluble solids of 'Triple Crown' fruit were relatively consistent through the season in both years.

## Discussion

The effect of fertilizer type on yield and fruit quality was relatively small and was inconsistent among cultivars and years for the variables tested. Soy meal produced the greatest total yield in 'Triple Crown' in 2011 and in 'Obsidian' in both years. In contrast, poultry and fish produced the greatest total yield in 'Black Diamond' in 2011, and fish produced the greatest yield in 'Black Diamond' and 'Marion' in 2012. A longer-term study would be needed to determine whether continued use of any of these fertilizers would have effects over time.

The three organic fertilizers compared in this study, as is the case with most organically approved fertilizers available (e.g., Fernandez-Salvador et al., 2015a; Harkins et al., 2014), had different levels of all macro- and micronutrients. The additional amount of P, Ca, Mg, Fe, Mn, and Zn present in the poultry fertilizer did not result in measureable increases in the soil level of these nutrients in Autumn 2011 and only in a higher level of Ca in 2012. The additional calcium carbonate in the poultry fertilizer, originating from lime added during the product manufacturing process, may make this fertilizer of benefit in maintaining the soil pH in an appropriate range for blackberry (between 5.6 and 6.5) or in mitigating the decline in pH that occurs with repeated fertilization in conventional (Chaplin and Dixon, 1979; Chaplin and Martin, 1980) or organic production systems (Fraser et al., 1988; Tester, 1990). In our study, there was no effect of fertilizer type on soil pH in a given year, but mean values declined the least in plots fertilized with poultry. Longer-term studies would be needed to determine whether the additional calcium in the poultry fertilizer would be significant in maintaining soil pH in the desired range for blackberry (Hart et al., 2006). The use of organic fertilizers in horticultural production systems seems to be of benefit in maintaining a higher soil pH when compared with synthetic fertilizers applied in conventional systems (Bulluck et al., 2002; Clark et al., 1998; Fraser et al., 1988; Liu et al., 2007; Tester, 1990).

The additional K and Na applied with the fish fertilizer, relative to the other fertilizer types, increased soil K and Na in both years, in contrast to what we found in a separate study (Fernandez-Salvador et al., 2015a). Since soil Na also varied by cultivar, Marion and Black Diamond plants may have taken up more Na than Obsidian and Triple Crown. The use of liquid fish by-products as fertilizers may limit the number of applications to the soil due to the high Na content (Teuber et al., 2005).

The sensitivity of blackberry plants to Na is not entirely known, but Horneck et al. (2007) suggested that blackberry plants are very susceptible to excess B and possibly other salts, with injury appearing at concentrations above 0.5 ppm in a saturated paste extract. In 'Shawnee' blackberry, leaf Na was positively correlated with rate of Na fertilization, with plants showing tolerance at low to moderate Na rates but reduced plant growth at high (6.5 mM) Na levels (Spiers, 1993). We did not measure leaf Na in our study, as this is not a common nutrient analyzed in commercial laboratories. Continuous applications of fish fertilizer may thus not be a viable option in an organic blackberry production system unless the applied Na is leached through irrigation or by rainfall. The use of fish fertilizers should be evaluated before doing continuous applications in drier or saline and sodic soils as well as in regions with less annual precipitation as suggested in various studies regarding plant response to salinity (Grattan and Grieve, 1999; Munns and Termaat, 1986; Parida and Das, 2005).

Research on the response of caneberries to K fertilization is rather limited and results have been inconsistent. When soil and plants are deficient in K, growth is often limited and excessive application of N may lead to K deficiency (Ljones, 1966). In the current study, although the K applied in the fish fertilizer increased soil K, there was no effect on primocane leaf K, Mg, or Ca levels. In contrast, fertigation with fish increased primocane leaf K but had no effect on soil K in our other study (Fernandez-Salvador et al., 2015a). Shoemaker (1978) also reported the lack of a consistent relationship between leaf tissue K and soil K. Nelson and Martin (1986) found that leaf Ca of 'Thornless Evergreen' blackberry decreased with increased rates of N and K fertilization. Spiers (1987) also found that increased K fertilization raised tissue K but decreased leaf P, Mg, and Ca concentration and that after two growing seasons an increased rate of K decreased plant growth in 'Cheyenne' blackberry. Primocane tissue Ca and Mg may become deficient with excessive K fertilization in 'Cheyenne', 'Boysen', and 'Youngberry' (Ljones, 1966; Spiers, 1987). In contrast, Kowalenko (1981a) found a positive correlation between soil and tissue Mg and K concentration and K fertilization in 'Willamette' red raspberry. As we did not vary the rate of K applied in our study, additional research would be needed to determine possible correlations in an organic production system

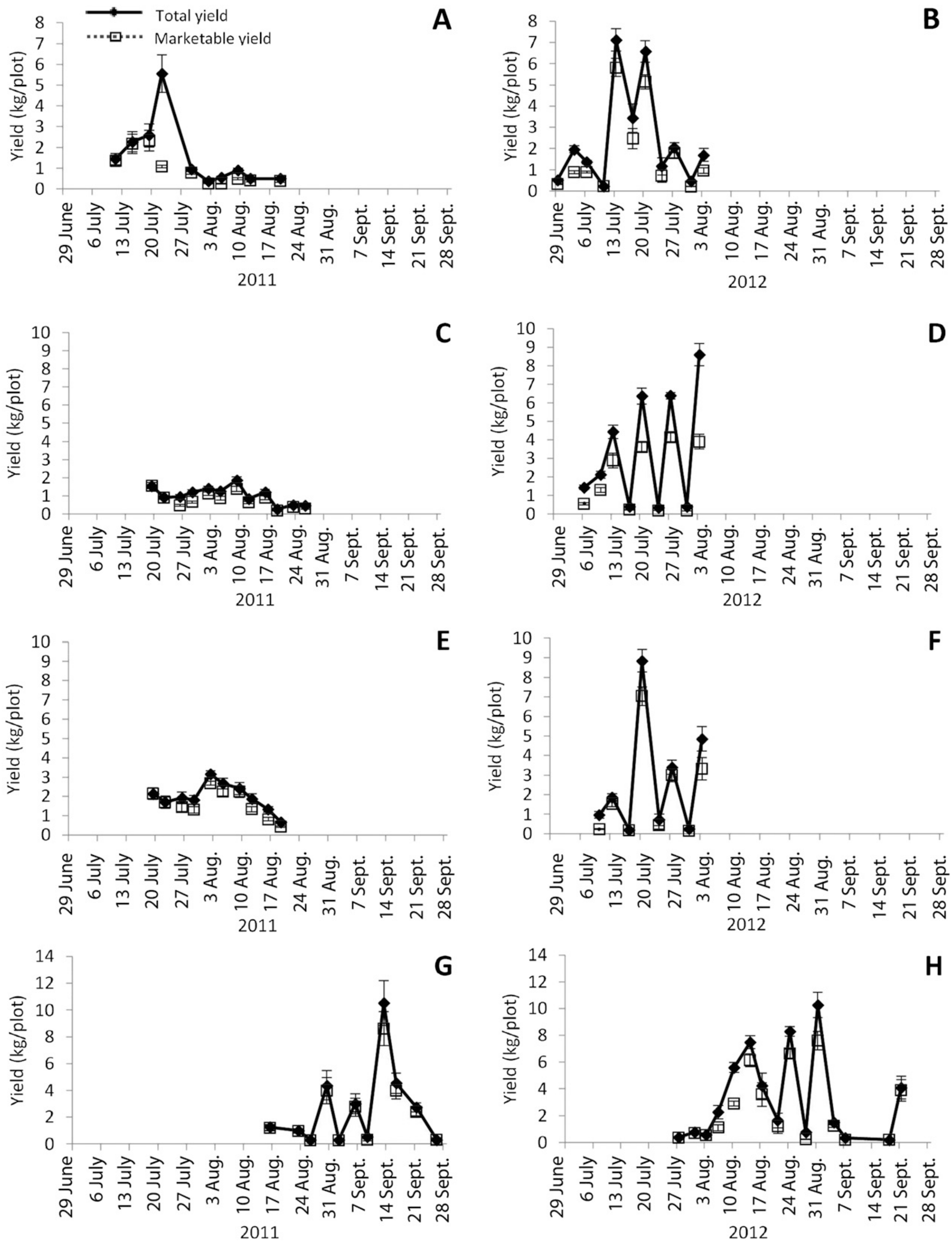


**Fig. 3. Seasonal average blackberry total and marketable yield [11 × 17-ft (3.4 × 5.2 m) plot] during the two growing seasons for the four hand-harvested cultivars in the study: Obsidian (A) 2011 and (B) 2012, Black Diamond (C) 2011 and (D) 2012, Marion (E) 2011, and (F) 2012, Triple Crown (G) 2011 and (H) 2012. Bars indicate SE; 1 kg per 187-ft² (17.4 m²) plot = 57.5610 g·m⁻² = 0.1886 oz/ft².**

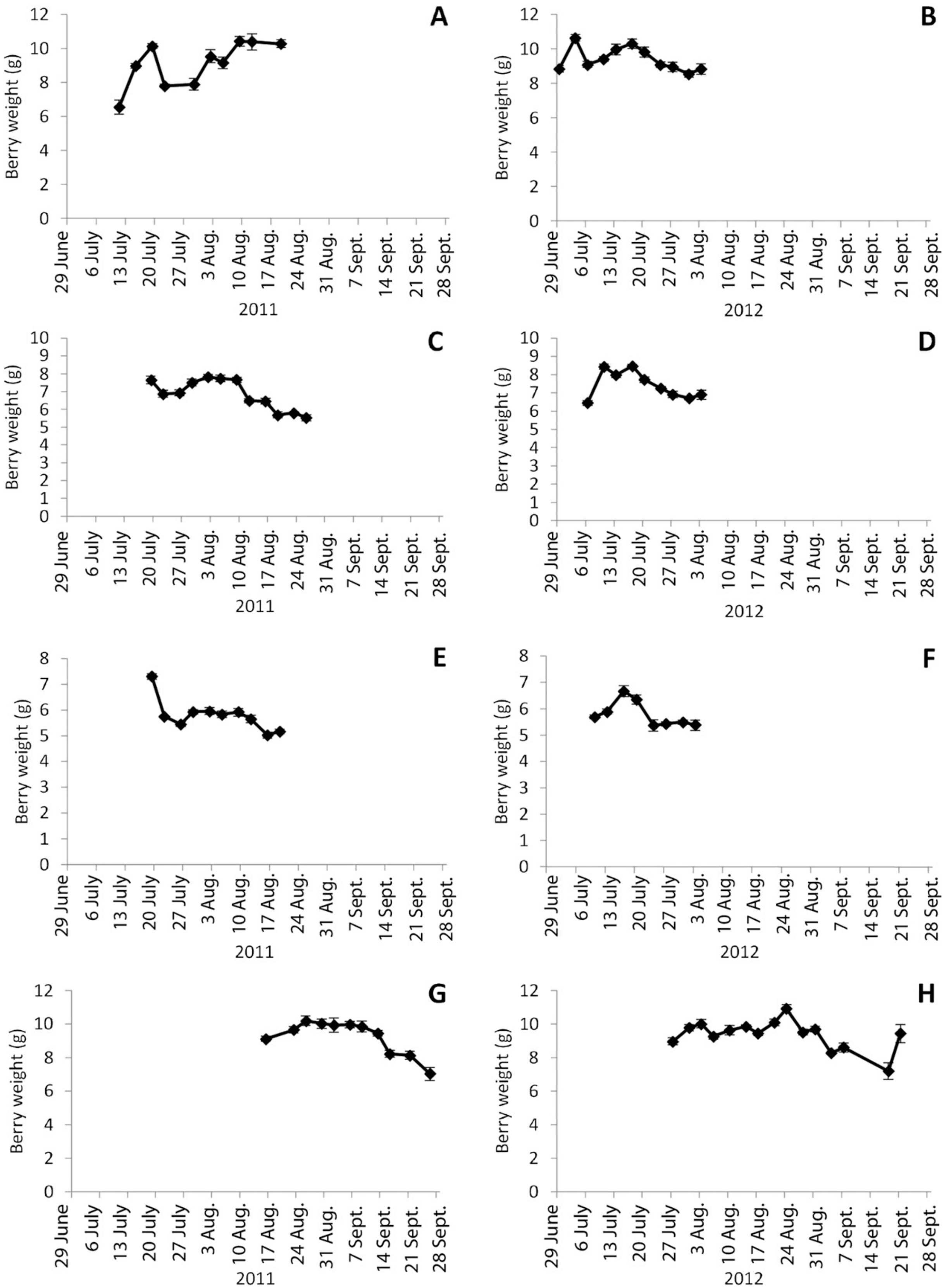


**Fig. 4. Seasonal average blackberry fruit weight during the two growing seasons for the four hand-harvested cultivars in the study: Obsidian (A) 2011 and (B) 2012, Black Diamond (C) 2011 and (D) 2012, Marion (E) 2011 and (F) 2012, Triple Crown (G) 2011, and (H) 2012. Bars indicate SE; 1 g = 0.0353 oz.**

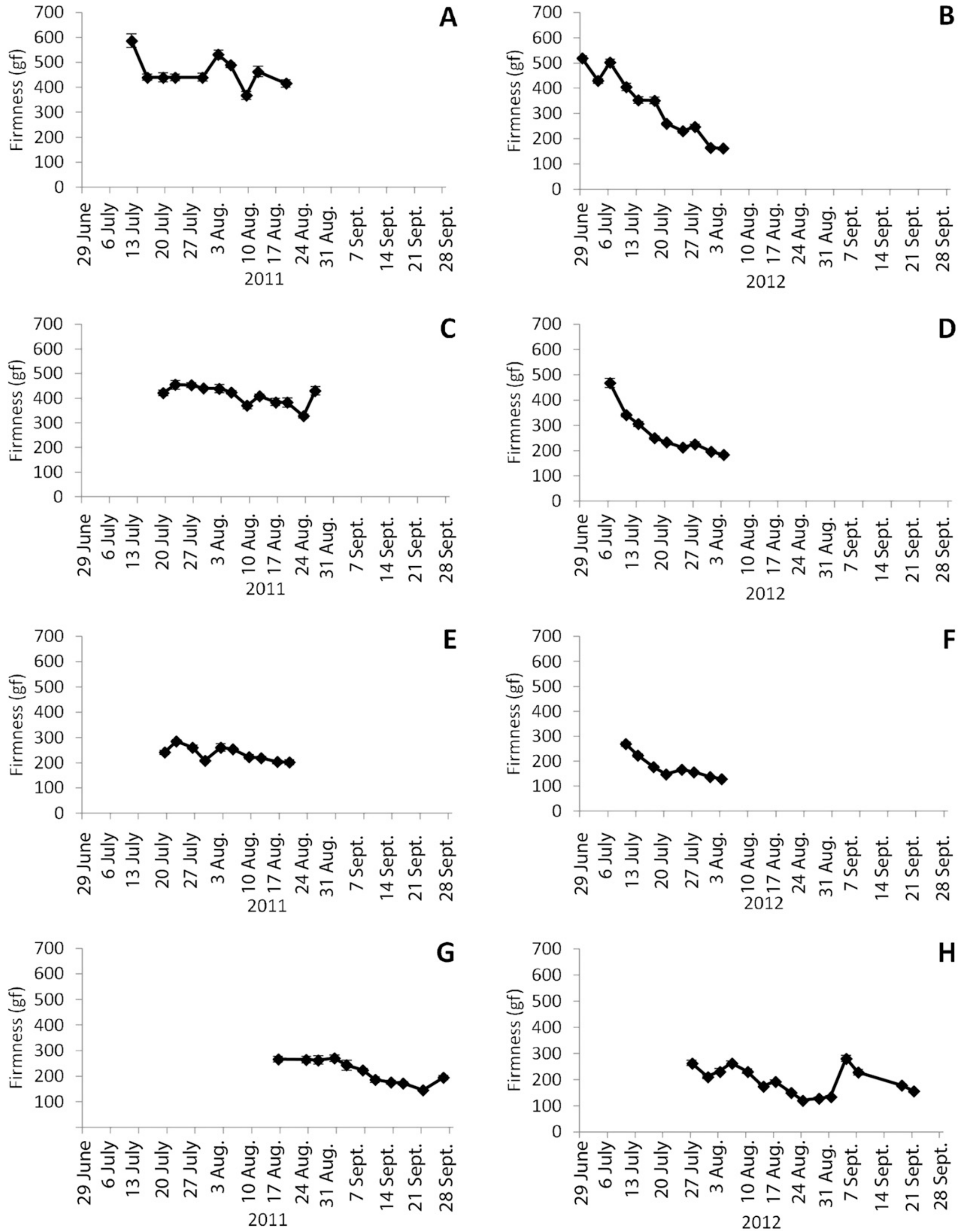


**Fig. 5. Seasonal average blackberry fruit firmness during the two growing seasons for the four hand-harvested cultivars in the study: Obsidian (A) 2011 and (B) 2012, Black Diamond (C) 2011 and (D) 2012, Marion (E) 2011, and (F) 2012, Triple Crown (G) 2011, and (H) 2012. Bars indicate SE; 1 g-force (gf) = 0.0098 N = 0.0022 lbf.**

and the effect of the additional K applied in fish fertilizer.

Fertilizer type had no effect on primocane tissue nutrient levels, perhaps because soil nutrient levels were within the recommended range for all treatments (Hart et al., 2006), except for soil B, which declined to deficient levels in the second year. Soils in the Pacific northwestern United States are often deficient in B (Hart et al., 2006). Boron deficiency in caneberries may reduce percent budbreak (Chaplin and Martin, 1980) and fruit weight (Kowalenko, 1981b). Application of B fertilizer has been shown to increase leaf tissue B concentration and improve yield in primocane-fruiting 'Polana' red raspberry and black currant [*Ribes nigrum* (Wojcik, 2005a, 2005b)] or may reduce initial yield and have no effect on leaf B concentration (Chaplin and Martin, 1980). In organic production systems, B could be supplied using approved chelated or diluted B in foliar applications or with soil-applied granular products based on sodium tetraborate (OMRI, 2013).

The growth of primocanes in blackberry is mainly dependent on nutrients available in the soil or from newly applied fertilizer, in contrast to floricanes where a large portion of the initial growth is dependent on reserves stored in the plant from previous growing seasons (Cortell and Strik, 1997; Malik et al., 1991; Mohadjer et al., 2001; Naraguma et al., 1999). In conventional production in Oregon, N, P, K, and B are the main fertilizer nutrients applied to blackberry, and Hart et al. (2006) recommend 31–49 lb/acre of N during year one or two of establishment and 49–71 lb/acre of N once the planting matures; 80 lb/acre of P [as phosphate ($P_2O_5$)]; 40–98 lb/acre of K [as potash ($K_2O$)]; and 1–3 lb/acre of B, for conventional plantings, based on soil and leaf tissue tests. The current primocane leaf nutrient standards (Hart et al., 2006) are based on 'Marion', but optimum nutrient levels may differ among cultivars as found in the present study and others (Fernandez-Salvador et al., 2015a; Harkins et al., 2013). In organic production, application of the recommended rates of N may lead to higher than recommended rates of other macro- and micronutrients as the commonly used organic fertilizers contain a broad range of nutrients. Primocane leaf N concentration was above recommended standards in 'Obsidian' and lowest (although within recommended standards) in 'Black Diamond', similar to our findings by Fernandez-Salvador et al. (2015b). Harkins et al. (2013) found that 'Marion' and 'Black Diamond' differed in leaf N and speculated that 'Black Diamond' may require more N fertilizer than 'Marion' to maintain adequate plant tissue levels, plant growth, and yield.

The level of soil $NO_3$-N in 2011 was greatest in 'Marion' and least in 'Triple Crown'. In 2012, 'Marion', 'Obsidian', and 'Triple Crown' plots did not differ in soil $NO_3$-N, whereas 'Black Diamond' had over 2-fold greater levels. Cultivars may thus have different N requirements and vary in the rate of fertilizer used. Nitrogen uptake in the blackberry plant is commonly related to canopy size (Strik, 2008). 'Triple Crown', a vigorous semierect cultivar, may have taken up more N fertilizer as measured by lower soil $NO_3$ in autumn and higher leaf N concentration of primocanes in summer. In contrast, 'Black Diamond' was observed to have the least vegetative growth in this study, as has been reported elsewhere (Fernandez-Salvador et al., 2015a, 2015b; Harkins et al., 2013), and had the greatest soil $NO_3$-N and lowest primocane leaf N concentration. This cultivar may be more efficient in N use and allocation than other cultivars (Harkins et al., 2014). The largest proportion of N in the organic fertilizer sources used in this study is $NH_4$-N that first needs to be mineralized to be available to the blackberry plant (Gaskell and Smith, 2007; Gutser et al., 2005). Blackberry growers thus need to consider timing of fertilizer application to ensure $NO_3$-N is available for early primocane growth (Malik et al., 1991; Mohadjer et al., 2001) as well as fertilizer cost. The cost of N, varied from $8.16/lb for the liquid fish and molasses blend, $5.35/lb for the pelletized soy meal, and $2.54/lb for the pelletized, processed poultry litter. A more comprehensive cost analysis including delivery method and/or application cost should be conducted to determine actual costs of using different types of organic fertilizers. Liquid sources of fertilizer can be applied through the drip irrigation system (fertigated) in organic blackberry production (Fernandez-Salvador et al., 2015a, 2015b; Harkins et al., 2013), reducing cost of application compared with the method used in this study.

Total yield increased considerably from 2011 to 2012, as the planting matured in all cultivars except Marion. Fruit quality and marketable yield improved from 2011 to 2012, possibly due to the implementation of timely preventative fungicide applications for control of botrytis gray mold and other fungi, to which the early ripening cultivars are more sensitive if weather conditions are conducive for the spread of the disease. The season for these cultivars varies with Obsidian ripening earliest, followed by Black Diamond and Marion with Triple Crown ripening the latest. 'Obsidian' is typically exposed to the most rainy wet, rot-inducing weather and 'Triple Crown' the least.

Total and marketable yield were comparable to the yield of hand-harvested fruit in conventional systems, in particular for the fresh market cultivars Obsidian and Triple Crown (B.C. Strik, personal observation). Siriwoharn et al. (2004) showed that percent soluble solids varied with cultivar (Marion and Thornless Evergreen) and with stage of maturity (underripe, ripe, overripe). The present study confirms such findings, as all cultivars differed in percent soluble solids, particularly in 2012, perhaps due to weather conditions. Although fruit firmness has been shown to decline with fruit maturity (Stiles and Tilson, 1998), we also found that firmness declined through the harvest season for many cultivars as temperatures increased.

'Obsidian' is an early ripening, high-yielding, fresh market cultivar producing uniformly shaped fruit (Finn et al., 2005b). In our study, 'Obsidian' was the earliest to harvest, being 6 to 10 d earlier than 'Black Diamond' and 'Marion'. 'Obsidian' had a similar yield, but a greater average fruit weight greater than what has been reported in conventional production (Finn et al., 2005b). However, marketable yield in our study was lower in 2011 than in 2012, likely because of a higher incidence of fruit rot. Weather events may have influenced marketable yield, as precipitation on 15 July (over 0.4 inch and over 0.1 inch in 2011 and 2012, respectively) preceded 'Obsidian' harvest in both years increasing the incidence of fruit rot. In 2012, the grower responded by applying preventative, OMRI-listed fungicides in anticipation of precipitation events likely reducing the quantity of cull fruit.

'Black Diamond' produced larger fruit in this study as well as in Fernandez-Salvador et al. (2015a) than had been previously reported in conventional production (Finn et al., 2005a), or organic, machine-harvested production (Harkins et al., 2013). Total yield was lower in 'Black Diamond' when compared with a 3-year-old conventional planting (Finn et al., 2005a) and a greater yield than reported in an organic, machine-harvested trial (Harkins et al., 2013). 'Black Diamond' fruit had lower percent soluble solids than the other cultivars, agreeing with other studies (Fernandez-Salvador et al., 2015a, 2015b; Harkins et al., 2013), but contrasting those reported by Siriwoharn et al. (2004). 'Black Diamond' fruit were similar in firmness to those of 'Obsidian', agreeing with previous reports (Fernandez-Salvador et al., 2015b; Finn et al., 2005a; 2005b).

This study confirmed that 'Marion' fruit are too soft for the fresh market. Fruit weight was similar, but yield was lower than what has been reported in other hand-picked studies (Finn et al., 1997). Fruit percent soluble solids was lower in our study (12.4% on average) than what has been reported in conventional machine-harvested fruit for individually quick-frozen (IQF) in Oregon [13.6% (Finn et al., 1997)], likely because hand-harvested fruit are picked at all stages of ripeness, thus reducing average percent soluble solids, whereas harvest by machine selects mostly ripe fruit at a more uniform stage of maturity. In an organic machine-harvested system, 'Marion' fruit had higher percent soluble solids (Fernandez-Salvador et al., 2015a; Harkins et al., 2013) than in the current study.

'Triple Crown' produced the largest fruit, heavier than what has been previously reported for conventional production (Galletta et al., 1998), and had the greatest yield. Fruit soluble solids content was similar to what has been previously reported (Galletta et al., 1998), but fruit firmness ranked near the lowest of the cultivars studied, an undesirable trait for a fresh market cultivar. As 'Triple Crown' ripens in the latest part of the summer in Oregon, when the weather is warm and dry, this cultivar can produce fruit that vary in firmness. Fruit were prone to sunburn, which reduced the proportion of marketable fruit in 2012. The high maximum temperatures (above 90 and 85 °F in 2011 and 2012, respectively) are commonly related to increased damage from ultraviolet light (sunburn) and preceded harvest dates of 'Triple Crown' in both years. The sensitivity of 'Triple Crown' to sunburn and its shorter shelf life due to fruit softness has been reported as undesirable traits of this cultivar by fresh market blackberry growers (J.A. Fernandez-Salvador and B.C. Strik, personal observation).

## Conclusions

The three organic fertilizers compared in this study were suitable to maintain adequate nutrition in organic blackberry production, but supplemental applications of B may be needed in deficient soils. Poultry litter may offer advantages in blackberry production to help mitigate the decline in soil pH that occurs when fertilizing. The fish fertilizer contributed relatively large amounts of sodium to the soil with no adverse effects observed. Of the three fertilizers, the cost per pound of N was higher for the liquid fish and molasses blend than for the pelletized soy meal, and the pelletized, processed poultry litter, but a comprehensive cost benefit analysis of organic fertilizer options considering plant availability and mineralization rate of N is needed. All cultivars performed well and would be considered suitable for commercial organic production. 'Triple Crown' produced the highest yield and largest fruit weight, but was considered soft for a fresh market, shipping cultivar. In contrast, 'Obsidian' fruit was the firmest, but were more sensitive to gray mold indicating the importance of a good organic disease management program in the early season. 'Marion' and 'Black Diamond' had traits that make these cultivars more suitable, as expected, for processing. Yield and fruit quality variables were influenced by harvest date and seasonal changes where weather conditions from year to year are important considerations for successful commercial organic production.

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