AN ABSTRACT OF THE THESIS OF

Javier A. Fernandez-Salvador for the degree of Master of Science in Horticulture presented on May 20, 2014

Title: Nutrient Management of Blackberry Cultivars Grown in Organic Production Systems

Abstract approved:

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Bernadine C. Strik

The impact of fertilizer source and cultivar on growth, fruit quality, and yield was evaluated in organic blackberry (*Rubus* L. subgenus *Rubus* Watson) from 2011–2013 in three studies. In all studies, plants were drip irrigated, and weeds were managed using a woven polypropylene, permeable landscape fabric (weed mat). At a grower collaborator site, fertilizer source (liquid fish and molasses blend; soybean meal; pelletized, processed poultry litter) had little effect on yield or fruit quality and results were inconsistent among cultivars (‘Marion’, ‘Black Diamond’, ‘Obsidian’, ‘Triple Crown’) and years. Fertilizer source (corn steep liquor and fish waste digestion; fish solubles and molasses blend) also had little effect on the machine-harvested yield, plant growth, and fruit quality of ‘Marion’ and ‘Black Diamond’. When these fertilizers were applied through the drip system, emitter flow rates decreased an average of 4.5% in the first year and 19% in the second year, but system performance was not affected by fertilizer source or flushing. Primocane leaf tissue nutrient concentrations were within recommended levels for all nutrients, except for Ca and B which were below recommended standards, in all cultivars and Mg which was deficient in some. Cultivars differed in yield and fruit quality in all of the organic production trials. At the grower collaborator site, ‘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, while ‘Marion’ fruit were the least firm in 2012. ‘Black Diamond’ produced a greater machine-harvested total yield than ‘Marion’ in the second study, but also produced a greater proportion of unmarketable fruit. In the third study, all of the cultivars tested responded well to the organic production system used based on yield and plant growth, but ‘Onyx’ and ‘Metolius’ were considered to have a low yield for commercial production. In contrast, the higher yielding ‘Obsidian’ and ‘ORUS-2635-1’ appeared to be the best suited for fresh market, organic production due to their greater fruit size, firmness, and sugar to acid ratio and a low post-harvest percent moisture loss (‘ORUS-2635-1’) and a long number of marketable days of storage (‘Obsidian’). Plantings were successfully established and maintained using the organic sources of fertilizer studied. Supplemental fertilization with B, Mg, and Ca would be required with each fertilizer studied to maintain recommended soil and plant fertility levels. Since the cultivars responded similarly to the fertilizer sources studied, cost of the nitrogen (N) in the fertilizer should be taken into account, which varied from $5.60 to $18.00 per kg of N.

Nutrient Management of Blackberry Cultivars

Grown in Organic Production Systems

by

Javier A. Fernandez-Salvador

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Javier A. Fernandez-Salvador, Author

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Cultivar, Fertilizer Source, and Nutrient Management in Organic Blackberry Production Systems

CHAPTER 1: Introduction

Organic blackberry (*Rubus* L. subgenus *Rubus*, Watson) production has increased in the last ten years to nearly 162 hectares harvested in the U.S. in 2008 (NASS, 2010). Significant expansion in organic plantings is also expected to continue in the next ten years as consumer demand for organic products increases and growers become more interested in targeting higher-value niche markets (OTA, 2013). Such growth follows the overall trend of organic sales in the U.S., for which more targeted research is needed for the various specialty crops such as blackberries.

Guidelines for nutrient management in organic blackberry production have been developed, to date, from research done in conventional systems (Hart et al., 2006; Kuepper et al., 2003; Naraguma et al., 1999). Studies specific to organic blackberry, including response to organic fertilizer sources by various blackberry types and cultivars (e.g. erect, semi-erect and trailing types; Strik and Finn, 2012) are lacking.

Organic agriculture is a method of growing and producing food that focuses on cultural and biological practices to manage nutrients and pests. It is highly regulated in both cultural methods as well as sources for inputs. Specifically, mainly natural (non-synthetic) substances may be used for nutrient management, while only a few synthetic substances may be used in minor cases (such as micronutrients; OMRI, 2013). Consequently, a price premium is typically paid for organic analogs of most crops. For example, organic 'Marion' blackberry fruit in Oregon sold at a ~33% price premium per kg of fruit over conventional fruit in 2009–2011. In 2010–2011, value of organic blackberries increased 17% compared to a 5% growth in value of conventional blackberries ("Category Spotlight", 2011).

Blackberries are grown for either the fresh-market or for processing, and are commonly cultivated in the Willamette Valley, Oregon where the climate is ideal for overwintering primocanes (Strik, 1992). Growers who are focused on fresh market production systems are interested in growing blackberry cultivars that extend the fruiting season, while producing a high-quality, economical yield. There is however, a need for more information on cultivar adaptation to organic production systems. Cultivars have been found to differ in plant growth, yield, and fruit quality in conventional (Finn et al., 1997, 2005a, 2005b, 2005c, 2011; Strik, 1992; Strik and Finn, 2012) and organic production (Harkins et al., 2013). There are a number of trailing blackberry cultivars grown in Oregon. ‘Black Diamond’ (Finn et al., 2005b), grown predominantly for the processed market, and ‘Marion’ (Finn et al., 1997), grown for the processed market, account for >75% of the 7,200 acres of blackberries produced in 2012 (NASS, 2013). ‘Obsidian’ (Finn et al., 2005a) is the most widely grown trailing blackberry cultivar for fresh market. ‘Onyx’ is a relatively new cultivar (2011) producing vigorous canes and a moderate yield of uniform, firm, sweet, excellent-flavored fruit that are suited for the local and wholesale fresh market (Finn et al., 2011). ‘Metolius’ is characterized by vigorous plant growth, a good yield, and medium-sized, firm fruit with excellent flavor (Finn et al., 2005c). Erect and semi-erect blackberry types are also grown in the U.S. for fresh market (Strik and Finn, 2012). In Oregon, ‘Triple Crown’ (Galletta et al., 1998) is a fresh market, semi-erect cultivar desired for its relatively late fruiting season and good flavor. It would be important to understand how well these cultivars are adapted to organic management practices, and in particular, their response to organic fertilizer sources and the effect on yield and fruit quality.

Selecting appropriate fertilizers for maximizing yield and fruit quality is a challenging endeavor in organic production systems as sources are limited, application methods vary, and nutrient levels are relatively inconsistent compared to conventional chemical fertilizers. For example, natural sources of nitrogen (N) such as fish emulsion may vary in N content by 2–4 %, based on factors such as time of year for fishing, fish type, fat content, and processing methods (OMRI, 2013). Types of approved organic fertilizers include liquid products that are best applied using tank sprays (by hand or mechanically to canopy or soil) or fertigation (diluted through drip irrigation systems) or raw, unprocessed, pelletized and granular products for localized bed or broadcast application using mechanical fertilizer spreaders. The use of chemical fertilizers such as ammonium sulfate and urea is common in conventional berry production, but as these sources are not permitted in organic agriculture. Instead natural materials such as fish emulsion, vegetable hydrolysate, plant and animal by-products and minerals are used to supply fertility needs.

The current recommendation is to provide fertilizer N in split applications in the spring when using granular products (April to June in the northern hemisphere; Hart et al., 2006). Fertilizing through the irrigation system (fertigation) is an important tool as it targets the planting row directly and maximizes water and nutrient uptake while minimizing leaching of important nutrients (Gärdenäs et al., 2005). Fertigation techniques are gaining popularity as applying irrigation and fertilizer in one delivery method is more efficient, provided the product used does not clog the emitters (Schwankl and McGourty, 1992). Organic blackberry have been established successfully when fertigating using fish emulsion from spring to mid-summer (Harkins et al., 2013). Still, despite advancements in suitable sources and application methods for fertilizers, it is not well understood how the different sources perform in organic production systems or their effect on yield and fruit quality. In particular, more knowledge is needed on how different sources function in drip irrigation systems, at what rate they release N and other nutrients, and in general, their efficacy and cost effectiveness.

The overall goal of this study was to evaluate fertilizer source and cultivar adaptation to organic production systems for fresh and processed markets. Specifically, our objectives were to: 1) evaluate the impact of three organic fertilizer sources, including pelletized, processed poultry litter, pelletized soybean meal, and a fish hydrolysate and emulsion blend with added molasses, on yield and fruit quality of blackberry cultivars grown for fresh market at a grower collaborator site; 2) determine the impact of two organically-approved liquid fertilizer sources (fertigated) on plant growth, yield, fruit quality and soil and plant tissue nutrient status of ‘Marion’ and ‘Black Diamond’ grown in a machine-harvested system for processing; 3) assess the impact of fertilizer source on the performance of the drip irrigation/fertigation system; and 4) characterize the adaptation of fresh market blackberry cultivars to an organic management system considering plant growth and nutrient status, yield, fruit quality, and shelf-life. Studies were conducted at a grower collaborator site and at the North Willamette Research and Extension Center.

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CHAPTER 2: Response of Blackberry Cultivars to Fertilizer Source in an Organic Fresh Market Production System

Abstract

Blackberry (*Rubus* L. subgenus *Rubus* Watson) cultivars, three trailing types ('Marion', 'Black Diamond', and 'Obsidian') and one semi-erect type ('Triple Crown'), were studied from 2011-2012 at a certified organic, grower collaborator site located in Jefferson, OR. Plants were fertilized with 56 $kg \cdot ha^{-1}$ nitrogen (N) each spring using three different sources: 1) a liquid fish and molasses blend (4–0–2); 2) pelletized soybean meal (8–1–2); and 3) pelletized, processed poultry litter (4–3–3). Plants were drip irrigated, and weeds were managed using a polypropylene, permeable landscape fabric (weed mat). Marketable yield differed significantly between years, and total yield, berry weight, firmness, and percent soluble solids were affected significantly by a year x cultivar interaction. '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, while 'Marion' fruit were the least firm in 2012. Harvest date affected the fruit quality variables measured in all cultivars. The effect of fertilizer source on yield and fruit quality was relatively small and was inconsistent among cultivars and years. 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. Fruit weight differed more among the four cultivars, particularly when plants were fertilized with soy than with poultry or fish in 2011, but was not significantly different among the three fertilizers within each cultivar in either year. 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 source had no effect on soil nutrient levels other than fertilization with fish increased soil potassium (K) and sodium (Na). 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 two year study, the blackberry cultivars responded similarly to the three sources of organic fertilizer. The cost per kg N, however, varied from $18.00 ($8.16/lb) for the liquid fish and molasses blend, $11.80 ($5.35/lb) for the pelletized soybean meal, and $5.60 ($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.

Introduction

Organic blackberry production in the U.S. increased from 180 acres in 2005 (Strik et al., 2007) to 495 acres in 2008 (NASS, 2010), with west coast states accounting for 970 acres of certified or fully converted organic blackberries and raspberries in 2007 (Granatstein et al., 2010). Significant expansion in organic plantings is expected in the next ten years as consumer demand for organic products increases and growers become more interested in targeting higher-value niche markets (OTA, 2013).

Guidelines for fertilizer and nutrient management in organic blackberry production are presently limited to overarching recommendations for nitrogen (N) application rates and appropriate soil pH (Kuepper et al., 2003; Naraguma et al., 1999), and do not address different sources of N fertilizer or possible response differences among blackberry types (e.g. erect, semi-erect and trailing types; Finn and Strik, 2014).

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; Strik et al., 2008). Recommended rates of N application in conventional plantings vary with age and cultivar of blackberry grown, ranging from 25 to 70 lb N/acre (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 (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 new fertilizer N for 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 et al., 2008). The number of organically-approved N fertilizer sources for caneberries 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 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 steep liquor), and molasses, while dry fertilizers include animal manures (or manure derived products), plant and animal by-products (e.g. plant-based meals such as soybean meal and animal-based meals such as feather meal) or mineralized materials (e.g. sodium nitrate or bat and bird guano) (OMRI, 2013). The organic fertilizer source (e.g. manure, animal 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 lb 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 sources, including pelletized, processed poultry litter, pelletized soybean 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’ (semi-erect type), were chosen for the study. ‘Black Diamond’ (Finn et al., 2005b), 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 7,200 acres of blackberries produced in Oregon in 2012 (USDA, 2013). ‘Obsidian’ (Finn et al., 2005a) is the most widely grown trailing blackberry for fresh market in Oregon and other production regions. ‘Triple

Crown' (Galletta et al., 1998) is a fresh market semi-erect 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; hardiness zone 8b, average annual extreme min. temperature from 15 to 20 °F (USDA Plant Hardiness Zone Map, 2012; PRISM Climate Group, USDA ARS - Oregon State University, Corvallis, OR)].

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 (Fig. 1.1). Prior to planting blackberry, the site was farmed as a conventional grass seed crop, growing bentgrass (*Agrostis spp*) in rotation with other grass crops including Creeping Fescue (*Festuca rubra*) and Rye grass (*Lolium perenne*).

Site preparation. In September 2009, the farm was transitioned to organic production and the planting site was prepared by: 1) mowing the remnant grass seed crop; 2) sub soiling 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 prior to bed shaping.

Drip irrigation [one line of drip tubing (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. geo-textile cloth ("weed mat"; Hanes Geo Components model Terra Tex Woven, Winston-Salem, NC), which was centered and secured on the bed using 6-inch long landscaping staples. The grower then cut the weed mat at the center of the raised bed, to allow for it to be opened for fertilizer applications; the edges of the weed mat were patched with smaller sections of geotextile fabric and held in place by landscape staples. The grower chose weed mat as the in-row weed management strategy.

The area between rows (aisles) was seeded with fine fescue (50 lb/acre; a mixture of *Festuca longifolia, F. rubra* subp. *commutata, F. rubra* subp. *rubra, F. rubra* subp. *litoralis and F. ovina,* cultivars unknown) following the NRCS riparian area broadcast grass planting method (Brillion Model "Sure Stand" Seeder, Brillion, WI).

The grower divided the planting area into two 100 x 100 ft blocks with rows orientated in a north-south direction. The planting was established as an on-farm variety trial (0.46 total planted acres).

Planting establishment and management. The cultivars, 'Marion', 'Obsidian', and 'Triple Crown' were obtained as rooted cuttings and 'Black Diamond' as tissue-cultured, plug stock in spring and summer 2009. All plants were potted into 1 gal pots and grown at the farm until planting in October 2009 (north block) and May-June 2010 (south block). Plant spacing varied between cultivars/blocks ranging from 3 to 4.5 ft in the row with 11 ft between rows (880 to 1,320 plants/acre). A 3-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 'Triple Crown' trellis system 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 (2.7 lb N/acre per application; 3N–1P–5K 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 (Rears model SPF flail, Rears MFG Co. Eugene, OR) during the fall and winter as training occurred for all cultivars. In the trailing cultivars, primocanes were trained from August-September by looping half the canes in each direction down to the lower trellis wire and bringing them back towards 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 2 - 3 canes/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 to 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 (NOP) 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 hours, 4 times/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 December 2011 (REX lime sulfur solution, ORCAL Inc., Junction City, OR) at a rate of 2.4 gal/100 gal water. In 2011 and 2012, the fungicides *Bacillus subtilis* (Serenade MAX, AgraQuest, Inc. Davis, CA) and *Streptomyces lydicus* (Actinovate AG, Natural Industries, Inc. Houston, TX) were applied in mid-spring (2011) or early- and late-spring (2012) to help control *Botrytis cinerea* fruit rot, per label rate and recommendations. A spinosad insecticide (Entrust SC, Dow Agro Science LLC 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.

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 (‘Obsidian’, ‘Black Diamond’, ‘Marion’, and ‘Triple Crown’) as main plots and three fertilizer sources (pelletized, processed poultry litter [“poultry”], pelletized soybean 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 source treatments were applied at an equivalent total 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 re-closing the weed mat). The fish fertilizer used was a blend of fish hydrolysate and fish emulsion with added molasses (TRUE 402; 4N–0P–2K; True Organic Products, Inc., Spreckels, CA) 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 soybean meal (Phyta Grow Leafy Green Special 8N–1P–2K; California Organic Fertilizers Inc., Hanford, CA) was broadcast in the row area on 30 Apr. 2011 and 26 Apr. 2012. Pelletized, processed poultry litter (Nutri-Rich 4N–3P–3K–7Ca; Stutzman Environmental Products Inc., Canby, OR) was broadcast in the row area on 3 Apr. 2011 and 16 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 were calculated.

Fruit harvest. Fruit were hand-harvested approximately 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 sub-sample 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 (°Brix). The 25-berry sample was picked first, prior to 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 (Ametek Model LKG1, Feasterville, PA). 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 ¼-gal polyethylene re-sealable 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 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, Inc. (New Bremen, OH) for analysis of leaf tissue N, phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sulfur (S), boron (B), iron (Fe), manganese (Mn), Cu, Zn, and aluminium (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 to 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 4 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 1M KCl (Dahnke, 1990). Soil organic matter was measured using Loss-On-Ignition at 360 ºC (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 source as a sub-subplot. Due to significant year effects and plants maturing during the study period, data were re-analyzed by year as a split-plot (cultivar as main plot and fertilizer source as sub-plot) using the General Linear Model procedure in SAS (version 9.3; SAS Institute Inc., 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 ($P = 0.0193$), fruit firmness ($P < 0.0001$), total yield ($P < 0.0001$), and marketable yield ($P = 0.0009$). There was a significant year x cultivar interaction for fruit weight (P = 0.0001), fruit firmness (P < 0.0001), percent soluble solids (P = 0.0298), and total yield (P = 0.0335). Data for seasonal total and marketable yield and fruit quality variables were then analyzed and are presented by year (Table 1.1).

Fertilizer source. There was no significant main effect of fertilizer source on yield (marketable and total) or fruit quality in 2011 or 2012. However there was a significant fertilizer x cultivar interaction on fruit weight in 2011, total yield in 2011 and 2012, and marketable yield in 2012 (Table 1.1). There was a trend (P = 0.0847) for a fertilizer x cultivar interaction on marketable yield in 2011 (data not shown).

The effects of fertilizer source on total yield varied with cultivar, but results were inconsistent among the two years (Table 1.1). 'Triple Crown' produced the highest 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 of all other cultivars in 2011 and 2012. Fertilizer source had no effect on marketable yield in 2011, but in 2012 'Obsidian' had a greater marketable yield when fertilized with soy as compared to fish. In 2011, there was no effect of fertilizer source 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 1.1). There was no effect of fertilizer source on berry weight in 2012 or fruit soluble solids and firmness in either year (Table 1.1).

The fertilizers applied in 2011 and 2012 came from the same batch. The calculated rate of all nutrients applied is shown in Table 1.2 for 2012 only, as the laboratory results for the samples sent in 2011 and 2012 were very similar. While 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 N/acre for the poultry, fish, and soy products, respectively (Table 1.2). Poultry litter contained more than 70 fold the Ca, four-fold the P, and more than three-fold the Mg, Fe, Mn, and Zn than the fish and soy fertilizers. The fish fertilizer contained four- to twenty-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 1.2).

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 1.3). The soil organic matter content was unaffected by fertilizer source and would be considered high for blackberry production 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 recommended levels (P-Bray, 20 to 40 ppm; K, 150 to 350 ppm; Ca, 1000 ppm; and Mg, 120 ppm) in both years (Table 1.3). 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 1.3).

Fertilizer source affected soil K in 2011 and there was a fertilizer x cultivar interaction on soil Ca, Na, Mn, and Al (Table 1.3). In 2012, fertilizer source affected soil K, Na, Fe, and Al. There was no effect of fertilizer source on available soil nitrate- and ammonium-N in either year. Fertilization with fish increased soil K in both years compared to 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 1.3). There was no effect of fertilizer on soil Ca in 2012, nor was there an 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 source on soil Fe and Al were inconsistent among years (Table 1.3).

There was no significant main effect of fertilizer source on primocane tissue nutrient concentration in 2012 for any of the nutrients tested, but there was a significant fertilizer source x cultivar interaction on tissue P concentration (Table 1.4). Plants fertilized with poultry, which was higher in P (Table 1.2), 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 source are described above. ‘Triple Crown’, a semi-erect blackberry, had the greatest total and marketable yield in both years. Within the trailing types, ‘Black Diamond’ and ‘Marion’ had the lowest yield in 2011 and 2012, respectively (Table 1.1). The proportion of non-marketable 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 non-marketable fruit (4.8 $t{\cdot}ha^{-1}$) in 2011 and ‘Black Diamond’ (7.6 $t{\cdot}ha^{-1}$) in 2012 (data not shown).

On average, ‘Triple Crown’ had the greatest berry weight and ‘Marion’ the least in both years (Table 1.1). ‘Black Diamond’ fruit had the lowest percent soluble solids in both years, while ‘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 1.3). Soil in the ‘Triple Crown’ and ‘Black Diamond’ plots tended to have the lowest level of nitrate-N in 2011. In contrast, soil in ‘Black Diamond’ plots had the highest level of nitrate-N in 2012.

Cultivar affected all of the measured primocane tissue nutrient concentrations (Table 1.4). 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 was highest in ‘Obsidian’ and tended to be lowest in ‘Black Diamond’; there were relatively few differences between ‘Marion’ and ‘Triple Crown’. 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 = 0.0054) for ‘Obsidian’; firmness (P = 0.0003) and total yield (P = 0.0104) for ‘Black Diamond’; firmness (P = 0.0127) and berry weight (P = 0.0434) for ‘Marion’; and berry weight (P = 0.002) for ‘Triple Crown’.

There were very different weather patterns in 2011 and 2012 (Fig.1.2 and 1.3). For example precipitation in the month of June 2011 was 0.9 inches while in 2012 the same month had 2.5 inches of rain; and 1.1 inches in July 2011, in contrast to 0.2 inches 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 temperature were higher in 2011 than in 2012 (Fig. 1.3). The harvest season in 2012 was approx. two weeks earlier than in 2011 (Fig. 1.4).

‘Obsidian’ had the earliest fruiting season, followed by ‘Marion’ and ‘Black Diamond’ (trailing types) and the semi-erect 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. 1.4).

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. 1.5). 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. 1.6). 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 (Fig. 1.7). In contrast, the percent soluble solids of ‘Triple Crown’ fruit were relatively consistent through the season in both years.

Discussion

Total yield increased considerably from 2011 to 2012 in all cultivars except ‘Marion’, likely a result of the planting maturing. The effect of fertilizer source on yield and fruit quality was relatively small and was inconsistent among cultivars and years for all variables within each cultivar. 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, had different levels of all macro- and micro-nutrients. 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 source on soil pH, but mean values declined the least from 2011 to 2012 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 to 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 sources, increased soil K and Na in both years. 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) suggest that blackberry is a crop very susceptible to excess B and possibly other salts, with injury appearing at concentrations above 0.5 ppm ($mg \cdot L^{-1}$) 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 prior to 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, while the K applied in the fish fertilizer increased soil K, there was no effect on primocane leaf K, Mg, or Ca levels. 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 and the effect of the additional K applied in fish fertilizer.

Fertilizer source 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 Northwest 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 (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 in sodium tetraborate (OMRI, 2013).

The growth of primocanes in blackberry is mainly dependent upon nutrients available in the soil or from newly applied fertilizer, in contrast to floricanes where a large portion of the initial growth is dependent upon reserves stored in the plant from previous growing seasons (Cortell and Strik, 1997; Malik et al., 1991; Mohadjer et al., 2001). In conventional production in Oregon, N, P, K and B are the main fertilizer nutrients applied to blackberry, and Hart et al. (2006) recommends 31-49 lb·acre^{-1} (35-55 kg·ha^{-1}) of N during year one or two of establishment and 49-71 lb·acre^{-1} (55-80 kg·ha^{-1}) of N once the planting matures; 80 lb·acre^{-1} (90 kg·ha^{-1}) of P (P_2O_5); 40-98 lb·acre^{-1} (45-110 kg·ha^{-1}) of K (K_2O); and 1-3 lb·acre^{-1} (1-3 kg·ha^{-1}) 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 by 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 micro-nutrients 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'. 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, while 'Black Diamond' had over two-fold greater levels. Cultivars may thus utilize varying rates of N fertilizer. Nitrogen uptake in the blackberry plant is commonly related to canopy size (Strik, 2008). 'Triple Crown', a vigorous semi-erect cultivar, may have taken up more N fertilizer as measured by lower soil nitrate 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 by 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 ammonium-N which 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 nitrate-N is available for early primocane growth (Malik et al., 1991; Mohadjer et al., 2001) as well as fertilizer cost. The cost per lb of N, varied from $8.16 ($18.00/kg) for the liquid fish and molasses blend, $5.35 ($11.80/kg) for the pelletized soybean meal, and $2.54 ($5.60/kg) 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.

Total yield increased considerably from 2011 to 2012 in all cultivars except 'Marion', likely a result of the planting maturing. Fruit quality and marketable yield improved from 2011 to 2012, possibly due to the implementation of timely preventative fungicide applications for control of *Botrytis* and other fungi, to which the early ripening cultivars are more sensitive if weather conditions are conducive for the spread of the disease. In general, 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'. Siriworhan et al. (2004) showed that percent soluble solids (°Brix) varied both with cultivar ('Marion' and 'Evergreen Thornless') and at three maturity stages (under ripe, ripe, overripe), as confirmed in the present study, as all cultivars differed in percent soluble solids of fruit, particularly in 2012, perhaps due to weather conditions. While fruit firmness has been shown to decline with fruit maturity (Stiles and Tilson, 1998), we also found that firmness generally declined through the harvest season for many cultivars as temperatures increased.

Strik et al. (1996) found that there were significant effects of year, date of harvest and genotype on berry weight, drupelet and ovary number and percent drupelet set and determined that the weight of a blackberry fruit is a function of the number of drupelets, the weight of each drupelet, and the receptacle weight. Additional studies should be conducted to determine the relationship between berry weight fluctuation across a harvest season and the causes for such variability in a conventional or organic production systems.

‘Obsidian’ is an early ripening, high-yielding, fresh market cultivar producing uniformly shaped fruit (Finn and Strik, 2014). 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., 2005a). 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 inches and over 0.1 inches 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 than has been previously reported in conventional production (Finn et al., 2005b), or organic, machine-harvested production (Harkins et al., 2013), but had a lower total yield when compared to a three-year-old conventional planting (Finn et al., 2005b) and a greater yield than an organic, machine-harvested trial (Harkins et al., 2013). ‘Black Diamond’ fruit had a lower percent soluble solids than the other cultivars, agreeing with findings by 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 (Finn, et al. 2005a; 2005b).

‘Marion’ is considered a processing cultivar, because fruit are too soft for fresh market, as was confirmed in this study. 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 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, while harvest by machine selects mostly ripe fruit at a more uniform stage of maturity. In an organic machine-harvested study, ‘Marion’ fruit also had a higher percent soluble solids (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 percent soluble solids 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 air temperatures can be high, this cultivar can produce fruit that vary in firmness. Fruit were also found to be prone to sunburn, which reduced the proportion of marketable fruit in 2012. The high maximum temperatures (above 90 ºF and 85 ºF in 2011 and 2012, respectively) are commonly related to increased UV damage (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 have been reported as undesirable traits of this cultivar by fresh market blackberry growers.

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 lb of N was higher for the liquid fish and molasses blend than for the pelletized soybean 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 had the greatest firmness, but were more sensitive to botrytis indicating the importance of a good pest management program. ‘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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Table 1.1. Effect of cultivar and fertilizer source on fruit weight, percent soluble solids (°Brix), fruit firmness, and total and marketable fruit yield in hand-picked organic blackberry, 2011-2012 (n=3).

Treatments	Fruit weight (g)			Soluble solids (%)	Firmness (g-f)[z]	Total yield (t·ha^{-1})			Marketable yield (t·ha^{-1})		
2011											
	Poultry	Fish	Soy			Poultry	Fish	Soy			
Cultivar											
Black Diamond	7.27 b[y]	7.03 b	6.70 bc	10.4 b	411.7 a	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	235.6 b	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	466.8 c	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	208.2 d	13.8 b	15.9 ab	18.6 a		14.0 a	
Significance[x]											
Fertilizer(F)[w]		ns		ns	ns		ns			ns	
Cultivar(C)		<.0001		<.0001	<.0001		<.0001			<.0001	
C x F		0.0202		ns	ns		0.0360			ns	
2012											
						Poultry	Fish	Soy	Poultry	Fish	Soy
Cultivar											
Black Diamond		6.89 b		10.1 d	268.6 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	175.8 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	329.3 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 a	195.6 c	26.6 a	26.6 a	27.8 a	20.0 a	20.0 a	21.1 a
Significance											
Fertilizer(F)		ns		ns	ns		ns			ns	
Cultivar(C)		<.0001		<.0001	<.0001		<.0001			<.0001	
C x *F*		ns		ns	ns		0.009			0.0034	

[z]g-f: gram-force [1 gram-force (gf) = 0.00980665 Newtons (1N)].
[y] Means followed by the same letter within the treatment or the interaction were not significantly different ($P \geq 0.05$).
[x]P value provided unless non-significant (ns; $P \geq 0.05$).
[w]Fertilizer products used were: pelletized, processed poultry litter ("poultry", Nutri-Rich 4N–3P–3K–7Ca,; Stutzman Environmental Products Inc., Canby, OR), a blend of fish hydrolysate and fish emulsion with added molasses ("fish", TRUE 402; 4N–0P–2K; True Organic Products, Inc., Spreckels, CA)and pelletized soybean meal ("soy",
Phyta Grow Leafy Green Special 8N–1P–2K; California Organic Fertilizers Inc., Hanford, CA). The three fertilizer source treatments were applied at an equivalent total rate of N of 50 lb/acre in 2011 and 2012, based on the percent N in the product as stated on the label.

Table 1.2. Total nutrients applied in organic fertilizer treatments in blackberry, 2012.

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

[z]Fertilizers were analyzed by Brookside Laboratories, Inc. (New Bremen, OH). The pelletized, processed poultry litter was applied as a band application on top of the soil at the center of the raised bed in spring. The fish hydrolysate and fish emulsion with added molasses mixture was diluted with water (1:10, v/v) prior to application as a directed spray to the bed surface in four equal portions in spring. The pelletized soybean meal was applied as a band on top of the soil in the center of the raised bed in spring. Nutri-Rich 4–3–3 had a pH of 8.3, TRUE 4–0–2 had a pH of 5.5 and Leafy Green 8–1–2 had a pH of 6.2.

Table 1.3. Effect of cultivar and fertilizer source on soil pH, organic matter (OM), and nutrient content in organic blackberry on 3 Nov. 2011 and 5 Nov. 2012 (n=3).

	pH	OM	NO_3-N	NH_4-N	P	K	Ca			Mg	Na			B	Fe	Mn			Cu	Zn	Al		
Treatments		(%)	(ppm)	(ppm)	Bray I									(mg·kg^{-1})									
2011							Poultry	Fish	Soy		Poultry	Fish	Soy			Poultry	Fish	Soy			Poultry	Fish	Soy
Cult.(C)																							
Black D.	6.4	4.7	6.82 bc[z]	1.80	130.0	386.6	4595.3 a	4422.3 ab	4038.0 ab	785.0	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	1103.0 cd	1097.7 d	1187.3 abcd
Marion	6.3	4.1	13.19 a	1.86	151.0	404.8	4266.3 ab	4260.0 ab	4156.3 ab	806.0	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	1247.7 ab	1272.3 ab	1219.7 abc
Obsidian	6.2	4.2	9.41 ab	2.39	157.0	496.0	4397.7 ab	3833.0 ab	4308.3 ab	785.1	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	1258.3 ab	1277.3 a	1194.3 abcd
Triple C.	6.1	4.7	3.67 c	1.17	125.0	430.0	3720.7 b	3732.0 b	4332.0 ab	735.4	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	1119.3 cd	1160.3 bcd	1173.0 abcd
Fert.(F)[y]																							
Poultry	6.3	4.3	8.19	1.70	139.0	398.4 b	-	-	-	760.6	-	-	-	0.68	344.7	-	-	-	4.80	6.90	-	-	-
Fish	6.1	4.5	9.55	2.40	148.0	550.6 a	-	-	-	757.8	-	-	-	0.65	359.8	-	-	-	4.80	6.50	-	-	-
Soy	6.3	4.4	7.08	1.40	135.0	339.0 b	-	-	-	815.3	-	-	-	0.66	356.7	-	-	-	5.20	7.10	-	-	-
Signif.[x]																							
C	ns	ns	0.0483	ns	ns	ns		ns		ns		<.0001		0.0256	ns		ns		ns	ns		0.0052	
F	ns	ns	ns	ns	ns	<.0001		ns		ns		0.0041		ns	ns		0.0007		ns	ns		ns	
C x F	ns	ns	ns	ns	ns	ns		0.0094		ns		0.0033		ns	ns		0.0087		ns	ns		0.0145	
2012																							
Cult.(C)																							
Black D.	5.6	4.7	17.9 a	4.62	204.2	592.4	-	3654.9	-	613.3	-	71.6	-	0.46	352	-	27.3	-	5.19	6.39	-	1138	-
Marion	5.7	4.7	10.4 b	3.78	172.9	578.2	-	3376.1	-	545.6	-	68.1	-	0.45	346	-	25.6	-	4.15	4.81	-	1096	-
Obsidian	5.7	4.8	10.4 b	5.19	184.1	619.1	-	3342.1	-	540.4	-	77.3	-	0.45	345	-	28.0	-	4.32	5.30	-	1087	-
Triple C.	5.9	4.6	10.5 b	5.71	180.4	509.0	-	3587.8	-	602.9	-	73.7	-	0.44	336	-	26.8	-	4.76	6.08	-	1047	-
Fert.(F)																							
Poultry	5.8	4.6	12.7	4.60	192.1	532.4 b	-	3534.3	-	568.4	-	60.7 b	-	0.45	329.1 b	-	25.6	-	4.32	5.87	-	1051.0 c	-
Fish	5.7	4.8	12.1	4.28	200.2	665.0 a	-	3453.1	-	571.4	-	104.4 a	-	0.45	348.4 a	-	28.2	-	4.97	6.19	-	1090.3 b	-
Soy	5.6	4.7	12.1	5.60	164.0	526.7 b	-	3483.3	-	586.8	-	52.9 b	-	0.46	356.3 a	-	27.0	-	4.53	4.88	-	1135.3 a	-
Signif.																							
C	ns	ns	0.0095	ns	ns	ns		ns		ns		ns		ns	ns		ns		ns	ns		ns	
F	ns	ns	ns	ns	ns	0.0325		ns		ns		0.0001		ns	0.0113		ns		ns	ns		0.0007	
C x F	ns	ns	ns	ns	ns	ns		ns		ns		ns		ns	ns		ns		ns	ns		ns	

[z]Means followed by the same letter within the treatment or interaction or in a given column were not significantly different ($P \geq 0.05$).
[y]Fertilizer products used were: pelletized, processed poultry litter ("poultry"), a blend of fish hydrolysate and fish emulsion with added molasses ("fish")and pelletized soybean meal ("soy"). The three fertilizer source treatments were applied at an equivalent total rate of N of 50 lb/acre in 2011 and 2012, based on the percent N in the product as stated on the label.
[x]P value provided unless non-significant (ns; $P \geq 0.05$).

Table 1.4. Effect of cultivar and fertilizer source on primocane leaf tissue nutrient concentration in organic blackberry on 3 Aug. 2012 (n=3).

	Macronutrients (%)								Micronutrients (ppm)					
Treatments	N		P		K	Ca	Mg	S	Fe	B	Cu	Mn	Zn	Al
		Poultry	Fish	Soy										
Cultivar														
Black Diamond	2.7 c[z]	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[y]														
Cultivar	0.0118		0.0001		0.0001	0.0014	0.0001	0.0001	0.0037	0.0171	0.0012	0.0001	0.0001	0.0118
Fertilizer[x]	ns		ns		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cult. x Fertilizer	ns		0.0393		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[z] Means followed by the same letter within the treatment or the interaction were not significantly different ($P \geq 0.05$).

[y]P value provided unless non-significant (ns; $P \geq 0.05$).

[x]Fertilizer products used were: pelletized, processed poultry litter (“poultry”), a blend of fish hydrolysate and fish emulsion with added molasses (“fish”)and pelletized soybean meal (“soy”). The three fertilizer source treatments were applied at an equivalent total rate of N of 50 lb/acre in 2011 and 2012, based on the percent N in the product as stated on the label.

Fig. 1.1. A) Satellite photography of the study site. Jefferson, OR [lat. 44°43´ N, 123°0´ W; elevation 230ft]. Overview of the entire caneberry research block at the grower cooperator location: the area delimited in white is the organic blackberry section. Fig 1.1. B) Enlarged satellite photography of the organic blackberry section: the two sections delimited in white are the north and south blocks of the study area respectively. The National Soil Survey: Web Soil Survey (WSS) produced by the National Cooperative Soil Survey and operated by the USDA Natural Resources Conservation Service (NRCS), classifies the study site as (numbers shown on Figure 1.1, A and B): 18 Camas gravelly sandy loam, 51.4% of the are in study area; 25 Cloquato silt loam, 33.9% of the study area; and 73 Newberg fine sandy loam, 14.7%of the study area (USDA-NRCS-NSSC. Lincoln, NE). See Materials and Methods for further details.

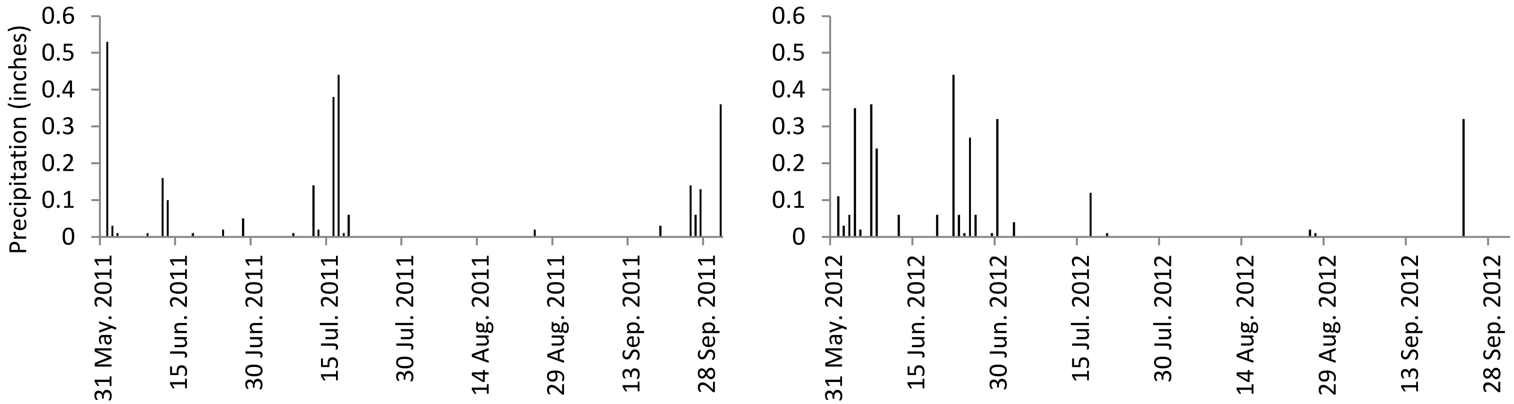

Fig. 1.2. Total daily precipitation from 1 June to the end of harvest on 30 Sept. 2011 and 2012 at Oregon State University's Hyslop Field Lab in Corvallis, OR; 1 inch = 2.54 cm.

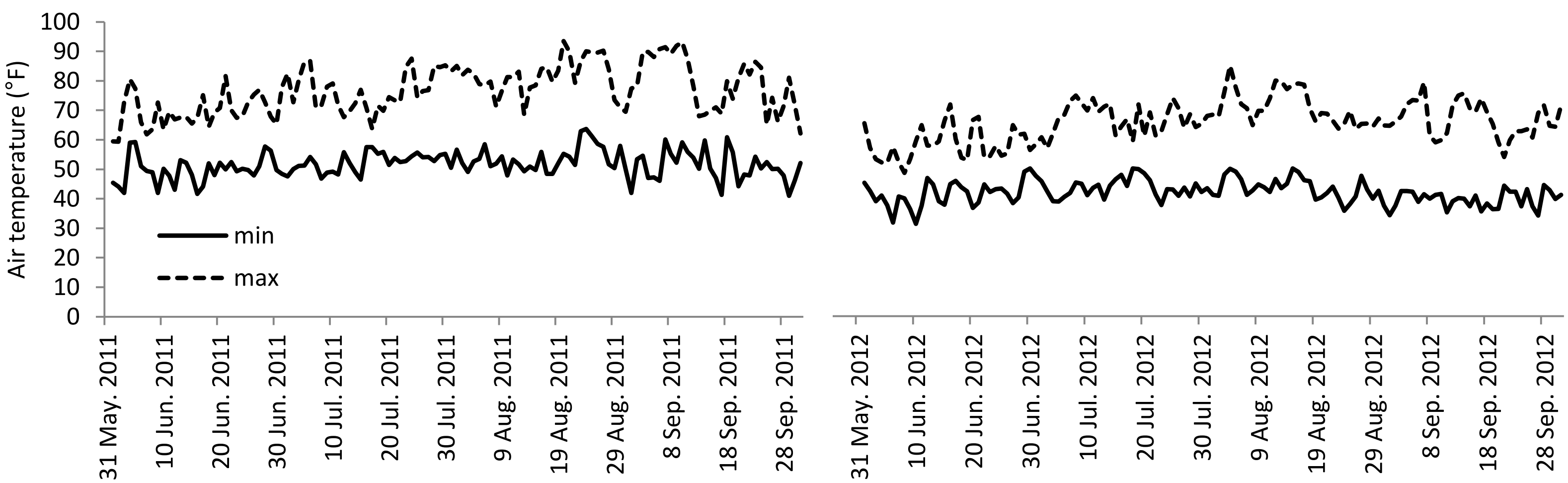

Fig. 1.3. Maximum and minimum daily air temperature (hourly, 24 h) from 1June to the end of harvest on 30 Sept. 2011 and 2012 at Oregon State University's Hyslop Field Lab in Corvallis, OR; (°F - 32) ÷ 1.8 = °C.

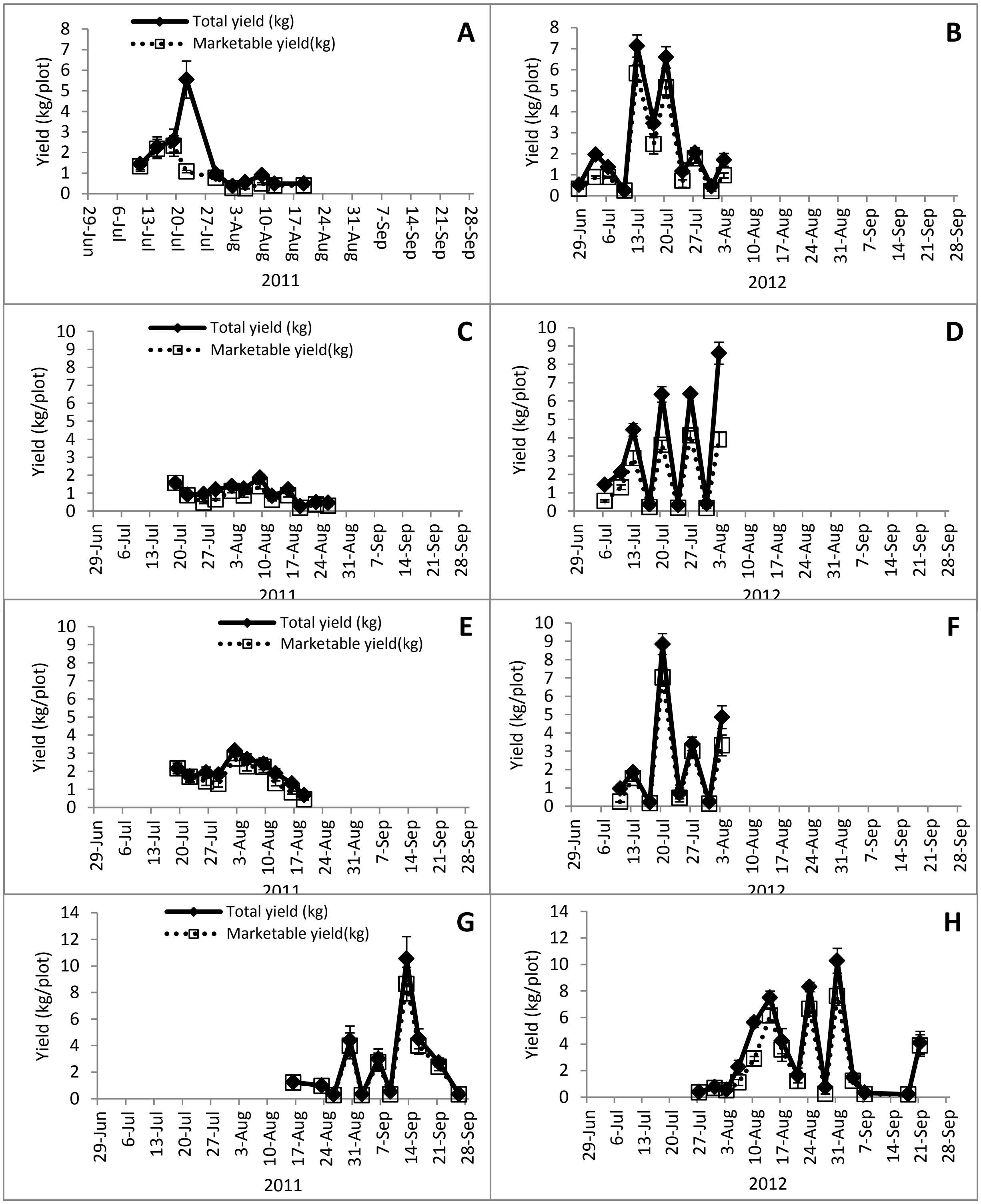

Fig. 1.4. Seasonal average blackberry total and marketable yield (kg/plot) during the two growing seasons for the four hand-harvested cultivars in the study: 'Obsidian' A) 2011, B) 2012, 'Black Diamond' C) 2011, D) 2012, 'Marion' E) 2011, F) 2012, 'Triple Crown' G) 2011 H) 2012.

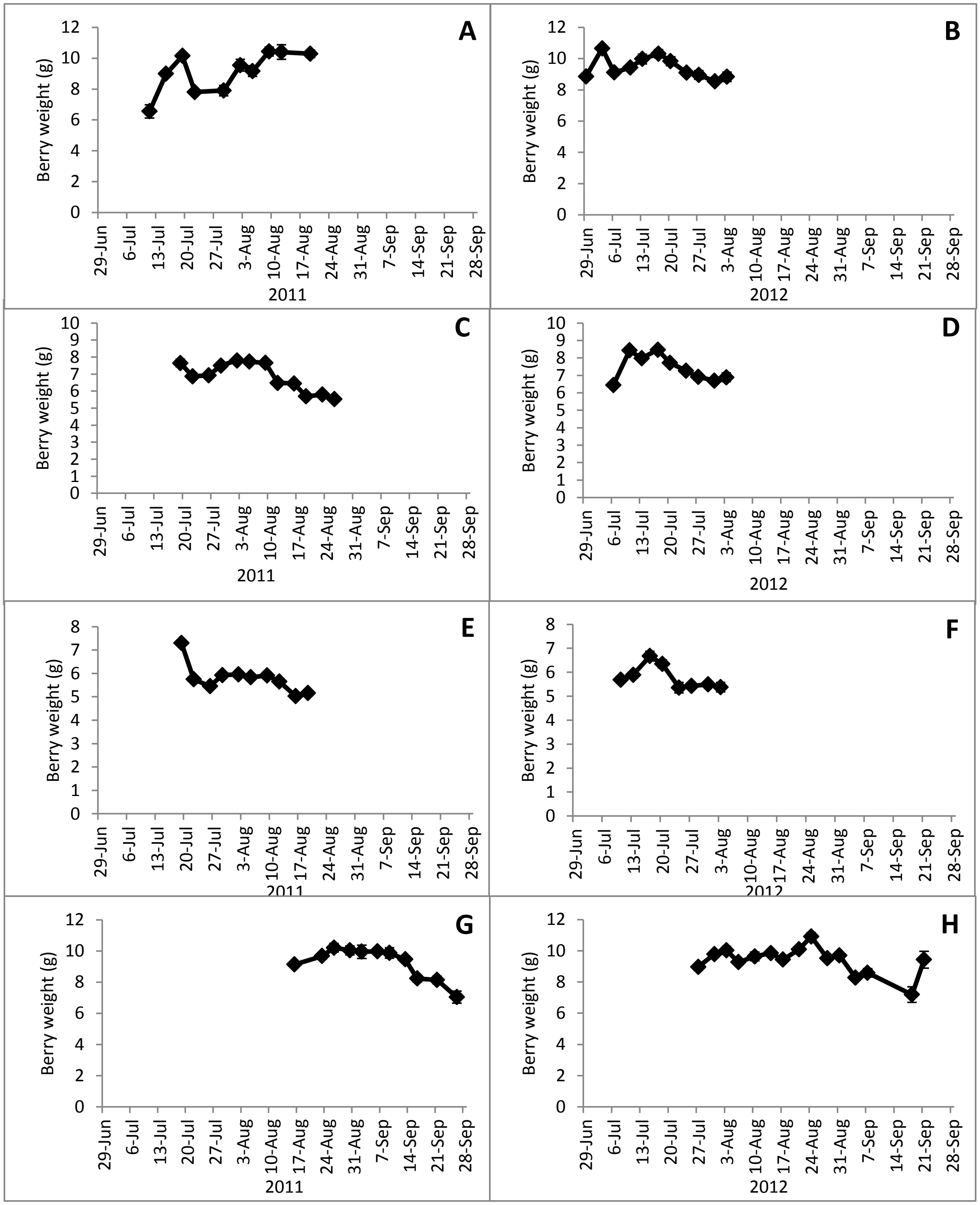

Fig. 1.5. Seasonal average blackberry fruit weight (g) during the two growing seasons for the four hand-harvested cultivars in the study: ‘Obsidian’ A)2011, B)2012, ‘Black Diamond’ C) 2011, D) 2012, ‘Marion’ E) 2011, F) 2012, ‘Triple Crown’ G) 2011 H) 2012.

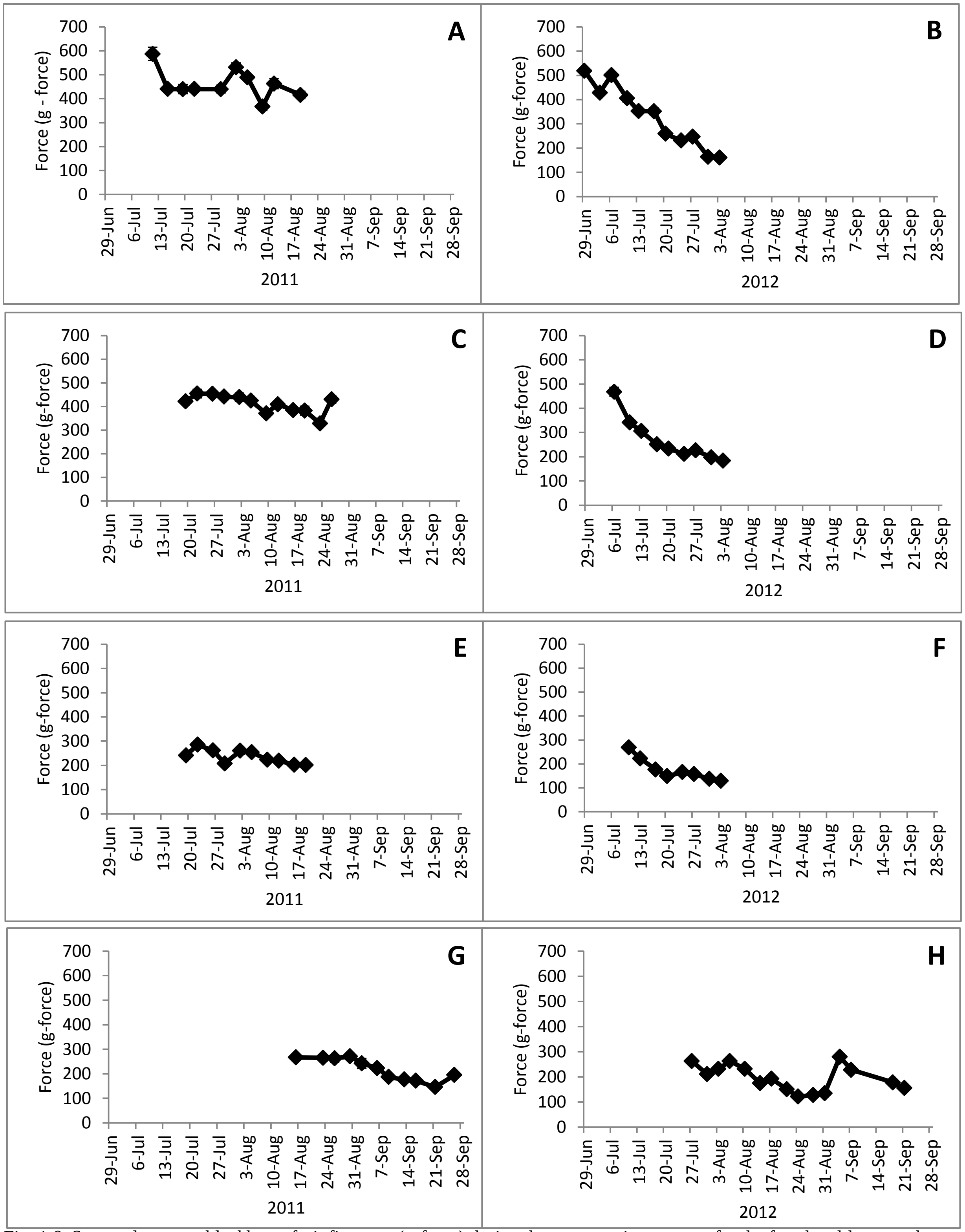

Fig. 1.6. Seasonal average blackberry fruit firmness (g-force) during the two growing seasons for the four hand-harvested cultivars in the study: ‘Obsidian’ A) 2011, B) 2012, ‘Black Diamond’ C) 2011, D) 2012, ‘Marion’ E) 2011, F) 2012, ‘Triple Crown’ G) 2011, H) 2012. [1 gram-force (gf) = 0.00980665 Newtons (1N)]

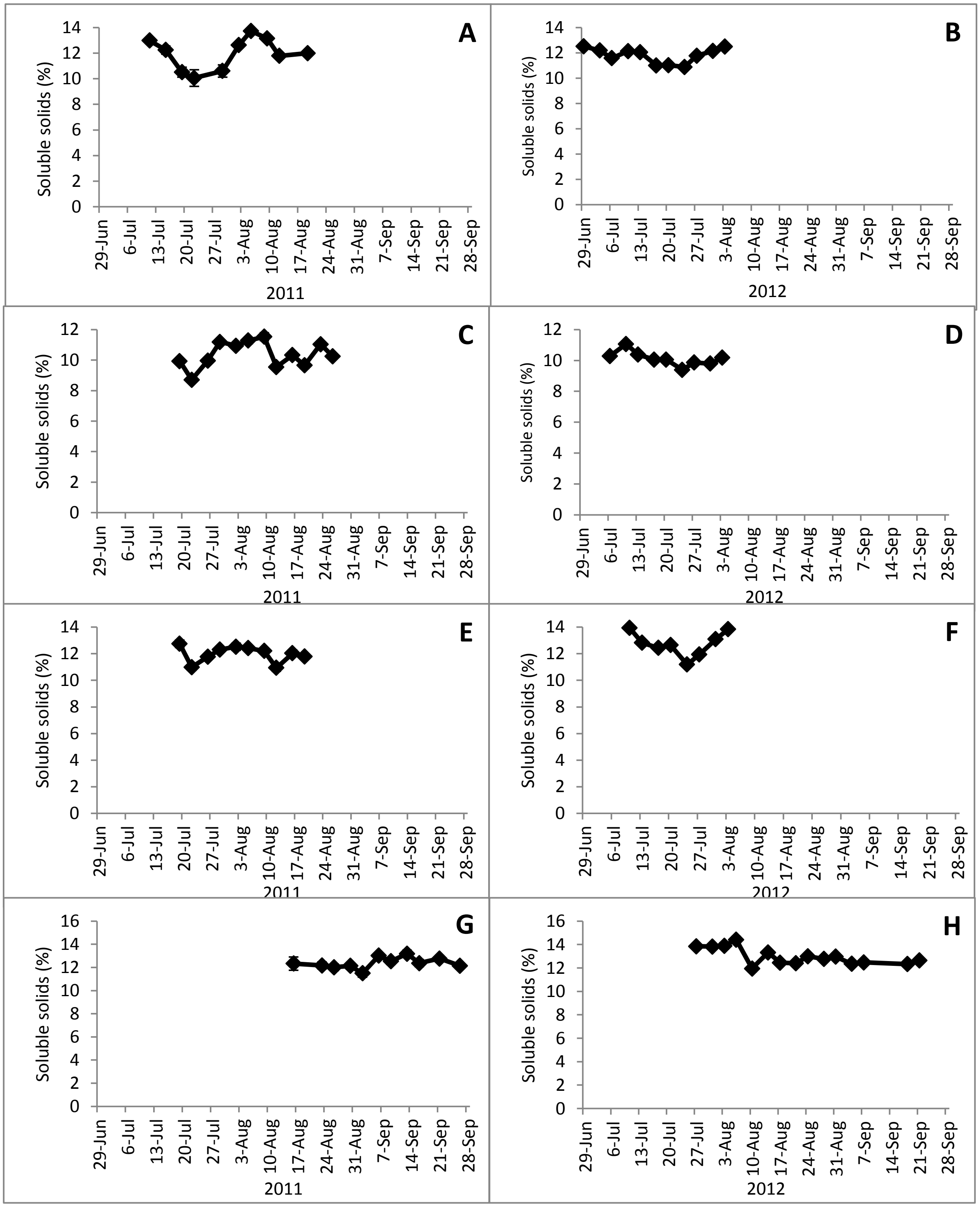

Fig. 1.7. Seasonal average blackberry fruit percent soluble solids (%) during the two growing seasons for the four hand harvested cultivars in the study: 'Obsidian' A)2011, B)2012, 'Black Diamond' C)2011, D)2012, 'Marion' E)2011, F)2012, 'Triple Crown' G)2011 H)2012.

CHAPTER 3: Liquid Corn and Fish Fertilizers are Good Options for Fertigation in Blackberry Cultivars Grown in an Organic Production System

Abstract

The impact of organic fertilizer source on the growth, fruit quality and yield of blackberry (*Rubus* L. subgenus *Rubus* Watson) cultivars (‘Marion’ and ‘Black Diamond’) grown in a machine-harvested, organic production system for the processed market was evaluated from 2011–2013. The planting was established in spring 2010 using approved practices for organic production and was certified in 2012. Plants were irrigated using a drip line under a woven polyethylene ground cover (weed mat) installed for weed management. Two sources of liquid fertilizer were evaluated: 1) a corn steep liquor and fish waste digestion (2.5–2.5–1.5); and 2) a fish solubles and molasses blend (4–0–2). Fertilizers were applied by fertigation through the drip system at rates of 56 $kg{\cdot}ha^{-1}$ N per year in 2011–2012 and 90 $kg{\cdot}ha^{-1}$ N in 2013. The impact of fertigation on drip system performance was evaluated with two maintenance options, “flushing” and “no flushing” of the drip lines. Total yield differed among years, while fruit soluble solids concentration and firmness, and floricane biomass dry weight at pruning were affected by year x cultivar. ‘Black Diamond’ had greater total yield and average fruit weight than ‘Marion’, but produced the most unmarketable fruit. There was no effect of fertilizer source on yield, fruit quality, primocane length, or primocanes/plant in any year, with the exception of fruit weight, which was greater with corn than with fish. ‘Marion’ had a greater floricane biomass when fertilized with fish than with corn. Soil nutrients were within the recommended range, except for B, which was below recommended levels; and only soil nitrate-N was affected by fertilizer source, which was greater in ‘Marion’ than in ‘Black Diamond’ when fertilized with fish. Primocane leaf tissue nutrient concentrations were within recommended levels for all nutrients,

except for Ca and B which were below recommended standards in both cultivars. Primocane leaf K and Zn concentrations were greater with fish than with corn. There was no fertilizer source or maintenance effect on emitter flow rate of the drip system in either year. However, flow rates decreased an average of 4.5% in the first year and 19% in the second year. Overall, there were no differences between the fertilizers on plant growth, yield, or fruit quality, and both fertilizers were suitable for planting establishment.

Introduction

Fertilizer practices in blackberry are routinely adjusted based on leaf tissue analysis (Hart et al., 2006). Nitrogen (N) is the predominant nutrient applied to trailing blackberry, and the best growth and yield is usually achieved with ≈ 28–56 $kg \cdot ha^{-1}$ N during the establishment year and ≈ 45–84 $kg \cdot ha^{-1}$ N during the subsequent years in conventional and organic systems (Bushway et al., 2008; Hart et al., 2006; Kuepper et al., 2003). The most common N fertilizers applied to blackberry are calcium nitrate, urea, and ammonium sulfate in conventional systems and OMRI-listed (Organic Materials Review Institute) fish emulsion, pelletized chicken litter, soybean meal, or feather meal in organic systems (Chapter 2; Harkins et al., 2013). In blackberry, N must be available in early spring for sufficient primocane growth (Malik et al., 1991; Mohadjer et al., 2001; Naraguma and Clark, 1998). The current recommendation is to apply N in split applications in the spring when using granular fertilizers (April to June in the northern hemisphere; Hart et al., 2006). Fertilizing through the irrigation system (fertigation) is an important tool as it targets the planting row directly and maximizes water and nutrient uptake while minimizing leaching of important nutrients (Gärdenäs et al., 2005). Organic blackberry have been established successfully when fertigating using fish emulsion from spring to midsummer (Harkins et al., 2013).

Blackberry plant nutrient status and fruit quality are affected by N fertilization (Archbold, et al., 1989; Naraguma and Clark, 1998; Nelson and Martin, 1986). The chapter 2 study found relatively little effect of fertilizer source on yield and quality of hand-harvested blackberry. In their study, fertilizer was applied by hand to the soil surface. Little is known, however, about the influence of fertilizer sources of N that can be injected and fertigated on fruit yield and quality in organic blackberry. In ‘Arapaho’, fertilizer N rate had little effect on yield, berry weight, or primocane number, but leaf N, phosphorus (P), potassium (K), calcium (Ca), sulfur (S), and manganese (Mn) levels were influenced by N application rate and timing. Spiers and Braswell (2002) found that varying rates of N, P, K and Mg influenced leaf macronutrient concentration, where an increased rate of N led to higher leaf N and P, and reduced leaf K and Mg. In red raspberry (*Rubus idaeus* L.), applications of fertilizer N increased leaf N and fruit size, but had no effect on yield (Chaplin and Martin, 1980).

In organic production systems, many factors must be taken into account in nutrient management programs, including availability and release rate of N from the fertilizer, ease of application, and cost. In addition, many nutrients other than N are present in organic fertilizers and are thus applied to the planting whether required or not (Harkins et al., 2014; Larco et al., 2013). Common organic sources of N range from cover crops to green manure for on-farm sources and fish byproducts, vegetable hydrolysate (e.g. corn steep liquor), molasses, animal manures (or manure-derived products), plant and animal by-products (e.g. plant-based meals such as soybean meal and animal-based meals such as feather, bone, and meat meals) or mineralized materials (e.g. sodium nitrate or bat and bird guano) for off-farm sources (Gaskell and Smith, 2007; Kuepper, 2003; Mikkelsen and Hartz, 2008; OMRI, 2013; Sideman, 2007). Manure, for example, is a relatively inexpensive and abundant source of N, however, the USDA organic regulations only permit manure use with a restriction on pre-harvest interval (90 d for blackberry; OMRI, 2013). Organic compliant, OMRI listed liquid fertilizer sources are limited and are believed to clog emitters reducing fertilizer and water application efficiency (Schwankl and McGourty, 1992).

Liquid fertilizer sources allowed in organic production include fish emulsions and hydrolysates, microbial digestions of vegetable byproducts (corn steep liquor), molasses, soy derived amino acids, manure slurries and soluble guanos, and in some cases soluble mined minerals such as sodium nitrate, and combinations of all of the above (OMRI, 2013). Corn steep liquor has been studied as a nitrogen source in fertigation studies in tomato (*Solanum lycopersicum* L.) and muskmelon (*Cucumis melo* L.) (Nakano et al., 2001, 2003; Nakano and Uehara, 2003) while fish emulsion has widely been studied in various vegetables and fruits (Chapter 2; Fonte et al., 2009; Harkins et al., 2013; Larco et al., 2013; Strik et al., 2012; Young et al., 2005; Zhao et al., 2007). Corn steep liquor utilizes a high-volume byproduct of the corn syrup and starch industries, and has been reviewed by the United States National Organic Standards Board (NOSB) for its compliance for use in organic production (NOSB Crops Committee, 2011). Corn steep liquor is comprised of the solubilized protein components of the corn endosperm, and is relatively high in N and other minerals necessary for good plant growth (Keller and Heckman, 2006). Fish emulsion is also a readily available N source, and is a byproduct of the fishing industry primarily in Alaska and Mexico (OMRI, 2013). For example, over 1,000,000 metric tons of fish waste are produced in Alaska every year and must be utilized for fertilizer or animal feed (Zhang et al., 2007). Schwankl and McGourty (1992) found that spray-dried fish protein and poultry protein performed well in fertigation systems with minimal clogging. Corn steep liquor has not been specifically studied for its performance in drip fertigation systems; however, it is known to be soluble in water (Keller and Heckman, 2006). Corn steep liquor and fish emulsion fertilizers are valued as rapid-release N sources with no pre-harvest interval restriction as for manure fertilizer sources. Management of fertigation through the drip system is important. Less optimal fertigation management can lead to uneven distribution of nutrients and water, a reduction in nutrient availability, and may reduce yield (Hanson et al., 2006). It is thus important for organic growers to have information regarding fertilizer options suited for use in fertigation systems.

The objectives of this study were to 1) determine the impact of two organically-approved liquid fertilizer sources (fertigated) on plant growth, yield, fruit quality and soil and plant tissue nutrient status of 'Marion' and 'Black Diamond' grown in an organic production system and 2) assess the impact of fertilizer source on the performance of the drip irrigation/fertigation system. 'Marion' and 'Black Diamond' are predominantly harvested by machine for high-value processed markets and together account for >75% of the 2,914 ha of blackberries produced in Oregon in 2012 (NASS, 2013). Like all trailing types, the cultivars are perennial but the shoots are biennial, producing primocanes the first year, which then become floricanes with flowers and fruit the following year and then senesce after harvest. Mature plants will have both primocanes and floricanes in the same year in a typical annual or every-year production system (Julian et al., 2009; Strik and Finn, 2012).

Materials and methods

Study site. The study was conducted at the 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); elevation 46 m]. Soil at the site is a Willamette silt loam (fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll) that 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 $kg \cdot ha^{-1}$) and dolomite (4148 $kg \cdot ha^{-1}$)] and K-Mag fertilizer (102 $kg \cdot ha^{-1}$ K, 62 $kg \cdot ha^{-1}$ Mg, 102 $kg \cdot ha^{-1}$ S) + micronutrients [2 $kg \cdot ha^{-1}$ B (H_3BO_3), 1 $kg \cdot ha^{-1}$ Cu ($CuSO_4$), and 14 $kg \cdot ha^{-1}$ Zn ($ZnSO_4$)] were broadcast and incorporated into each row before planting. See Harkins et al. (2013) for further information on site preparation. 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 ground cover ("weed mat"; water flow rate 6.8 $L \cdot h \cdot m^{-2}$; 0.11 $kg \cdot m^{-2}$; 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 $L \cdot h^{-1}$ 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 (ET) 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) in May 2012 and even though approved practices were conducted during the three years prior to planting and in the establishment year, organic certification was not obtained until the first fruit harvest year.

Primocane training. Annual development of the planting is illustrated by Harkins et al. (2013). Plants were trained on a three-wire vertical trellis system in each row that was installed prior to planting. The lower trellis wire was attached to steel posts at 0.3 m above the ground, the middle wire at 1.0 m, and the upper wire was attached at 1.6 m. Primocanes that grew in year 1 (2010, the planting year), were removed the following 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 towards the plant with one or two twists, and the other half was looped in the opposite direction. By year 3 (2012) and 4 (2013), plants had primocanes and floricanes (the previous year's primocanes). At this point, new primocanes were bundled and tied to the bottom wire below the floricane canopy to avoid cane damage and were trained to the trellis in late August, after the senescing floricanes were removed by pruning.

Experimental design. The study was conducted from 2011 to 2013 and included the first and second fruiting seasons, years 3 and 4, respectively. Treatments were arranged as a randomized block design with five replicates and included cultivar ('Marion' and 'Black Diamond') and fertilizer source [corn steep liquor and fish waste digestion ("corn"; 2.5N–2.5P–1.5K); and fish solubles and molasses blend ("fish"; 4N–0P–2K)]. Each plot consisted of four plants spaced 1.5 m apart in-row and was separated from plants in adjacent plots by 3.0 m (to provide space for clearing the machine harvester). Between row spacing was 3.0 m (2,222 plants/ha). The impact of fertigation on drip system performance was evaluated using a split plot design with two maintenance options, "flushing" and "no flushing" of the drip lines, as the main plot and the two fertilizer sources (corn and fish) as the subplots with three replicates.

Fertilizer applications. Prior to planting in year 1, pelletized, processed poultry litter (4N–3P–2K–7Ca; Nutri-Rich; Stutzman Environmental Products Inc., Canby, OR) was incorporated into the soil (~0.45 m diam.) at a rate of 28 kg·ha^{-1} N. In addition, Fish Agra (4N–1P–1K; 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).

The two fertilizer source treatments were applied at an equivalent rate of N (56 kg·ha^{-1} in 2011-2012 and 90 kg·ha^{-1} in 2013) based on the percent N in the product as stated on the label. The fish fertilizer used was a fish hydrolysate and fish emulsion blend combined with molasses (TRUE 402; 4N–0P–2K; True Organic Products, Inc., Spreckels, CA) that was diluted with five parts water (v/v) prior to injection through the drip system (fertigation). The corn fertilizer used was a natural microbial digestion of corn steep liquor and ground fish waste (AgroThrive 2.5N–2.5P–1.5K) produced by a Progressive Digestion Process (PDP, patent pending by the manufacturer, AgroThrive, Inc., Morgan Hill, CA) and stabilized by thermophilic fermentation; the corn fertilizer was diluted with two parts water (v/v) prior to fertigation. The fertilizers were injected through the drip irrigation system using a combination of a water-driven pump fertilizer injector (Mix-Rite 571 CW, DEMA, St. Louis, MO) and an electric, low volume chemigation pump system (Insectigator III, Agri-Inject, Inc., Yuma, CO). Irrigation was run for 10 min prior to each injection to fully pressurize the system to 103.4 kPa and was also run for an additional 4 h after injection to flush the drip lines. In 2011 and 2012, the fish was fertigated in equal portions on 18 Apr., 13 May, and 3 and 24 June 2011, and 25 Apr., 11 May, and 1 and 15 June 2012 (56 kg·ha^{-1} total N). In 2013, the fish was fertigated in equal portions on 10 and 17 Apr., 1, 15, and 30 May, 13 and 27 June, and 11 July (90 kg·ha^{-1} total N). The corn fertilizer was fertigated in four equal portions on 22 Apr., 17 May, and 7 and 24 June 2011 and 27 Apr., 15 May, and 4 and 18 June 2012 (56 kg·ha^{-1} total N) and in eight equal portions on 12 and 20 Apr., 8 and 23 May, 6 and 20 June, and 2 and 17 July 2013 (90 kg·ha^{-1} total N). The fertilizers studied were analyzed for total nutrient content (Brookside Laboratories, New Bremen, OH), and the rate of all macro- and micronutrients applied were calculated. Additionally, 2.2 kg·ha^{-1} of boron (B; Solubor, 20 Mule Team Borax, Englewood, CO) were applied on 28 Feb. 2013, and 560 kg·ha^{-1} of pelletized dolomitic lime [62 kg·ha^{-1} Magnesium (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., St Paul, OR) were applied as a broadcast 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 and fruit production. Primocanes (at 0.3 m height) were counted on each of two plants/plot in Mar. 2012, Feb. 2013, and Mar. 2014 to assess treatment effects on primocane number in 2011–2013, respectively. In Mar. 2012, a primocane from each of two plants per plot was then randomly selected and measured for length, weighed, oven-dried at 70 °C, re-weighed and average percent primocane dry weight (DW) and total primocane DW/plant calculated.

Ripe fruit were harvested twice weekly from 5 July to 30 July in 2012 and from 24 June to 19 July in 2013, using an over-the row rotary harvester (Littau Harvesters Inc., Stayton, OR). Total marketable and un-marketable fruit (“culls” including overripe, dropped, sunburned, damaged, rotten, or under-ripe fruit) were weighed on each harvest date and total yield calculated. A sample of 25 berries was hand-picked just prior to each machine harvest date, 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: fruit weight (seasonal, weighted average calculated), fruit firmness, and percent soluble solids (°Brix).

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 (Ametek Model LKG1, Feasterville, PA). 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-L polyethylene re-sealable bag and crushed by hand to obtain a homogeneous mixture for measuring percent soluble solids, on a temperature-compensated digital refractometer (Atago, Bellevue, WA).

Senescing floricanes were removed by pruning at the base of the plant (approx. 0.1 m high) after fruit harvest on 6 Aug. 2012 and 15 Aug. 2013, per standard commercial practice (Strik and Finn, 2012). The total fresh biomass of the floricanes was determined per plot. In 2012 and 2013, one floricane was randomly sampled from each of two plants per plot, weighed, oven-dried at 70 °C, re-weighed, and average floricane fresh and DW calculated. Total floricane DW/plot and DW/plant were estimated based on the number of floricanes/plot and plants/plot, respectively. Additionally in 2013, each sampled floricane was measured for length 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 previously described.

Tissue and soil analysis. Tissue samples were collected from the primocane leaves on 17 Aug. 2012 and 16 Aug. 2013 per standard recommendations (Hart et al., 2006). Samples consisted of ten recent fully-expanded leaves selected from both sides of the row on each plot and were sent to Brookside Laboratories. Total N content was determined in each sample using a combustion analyzer, and P, K, Ca, Mg, S, iron (Fe), B, copper (Cu), Mn, zinc (Zn), and aluminium (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 to published standards (Hart et al., 2006).

Soil samples were collected on 2 Nov. 2012 and 23 Oct. 2013 using a 2.4-cm diam., 0.5-m long, slotted, open-side, chrome plated steel soil probe (Soil Sampler Model Hoffer, JBK Manufacturing, Dayton, OH). One sample was collected per treatment plot with each sample composed of four cores collected to 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 cores were combined in a bucket and a sub-sampled sent for analysis to Brookside Laboratories and extractable soil P (Bray I), K, Ca, Mg, sulphate-sulfur (SO_4-S), 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 1M KCl (Dahnke, 1990). Soil organic matter was measured using Loss-On-Ignition at 360 ºC (Nelson and Sommers, 1996) and soil pH using the 1:1 soil:water method (McLean, 1982).

Fertigation and drip system performance. Water volume from the emitters was measured in plots with the “flush” treatment, after opening the valve at the end of the drip line, flushing with irrigation water for one minute, and then re-closing the valve. In the “no flush” treatment plots, the flushing valve at the end of the drip line remained closed during the study. To evaluate emitter flow, approx. 5 m of each treatment plot’s drip line was raised onto metallic stakes of approx. 0.3m tall, until each of six emitters was dripping directly into 0.25 L beakers. Water volume from the emitters was measured after 5 min. using graduated cylinders. Flow measurements were taken on three occasions in each year: during or after the fertigation season was completed (7 May 2012, 29 Jul. 2013), during or after harvest (25 Jul. 2012, 9 Aug. 2013), and after the floricanes were pruned out (13 Sept. 2012, 12 Sept. 2013). The average volume per plot was calculated for all 2012 and 2013 measurements.

Data analysis. Data were analyzed for a split-plot design with year as the main plot factor and cultivar and fertilizer as subplots using the General Linear Model procedure in SAS (version 9.3; SAS Institute Inc., Cary, NC). Residuals were tested for normality using the Shapiro-Wilk test and data were log transformed and analyzed where necessary, 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 drip water flow data were analyzed for a split-plot design using year as the main plot factor and fertilizer and maintenance of the drip system as a subplots, using the same statistical procedures as previously described.

Results and Discussion

Fertilizer source. The fertilizer applied in 2011 came from different batches than that applied in 2012 and 2013. While the rate of product applied for each fertilizer was calculated based on the percentage of N, as stated on the label for a target rate of N (56 $kg \cdot ha^{-1}$ total N in 2011 and 2012, and 90 $kg \cdot ha^{-1}$ in 2013), the actual rate of N applied was 50 $kg \cdot ha^{-1}$ and 62 $kg \cdot ha^{-1}$ total N in 2011–2012; and 80 and 99 $kg \cdot ha^{-1}$ total N in 2013 for the fish and corn products, respectively (Table 2.1). Plants fertilized with corn had approximately 25% more N unintentionally applied than plants fertilized with fish as the source. The corn fertilizer contained more than three-fold the P and Ca, eight-fold the Mg, and two-fold the B, Mn, Cu and Zn than the fish fertilizer, while the fish fertilizer contained more than 22-fold the Na, and more than seven-fold the Fe than the corn fertilizer (Table 2.1). The N content of corn steep liquor may vary with levels as high as 7.5%, and it is considered a relatively complete fertilizer source (Keller and Heckman, 2006).

Plant growth and yield. Cultivar and fertilizer source had no significant effect on primocane length or biomass in 2011, the “off year” (primocanes growing without the presence of floricanes), but there was a significant effect of cultivar (P = 0.0004) on primocane number per plant. ‘Black Diamond’ produced more primocanes in 2011 (12.9 canes/plant) than ‘Marion’ (9.0 canes/plant; data not shown). In 2012 and 2013 (years with primocanes and floricanes growing simultaneously), there were inconsistent treatment effects on primocane growth. There was no fertilizer or cultivar effect on primocane number in 2012 (averaging 3.3 primocanes/plant), but ‘Marion’ produced longer canes (7.6 m) than ‘Black Diamond’ (4.9 m) (P =0.0463). In 2013, ‘Black Diamond’ produced more primocanes (9.8 canes/plant) than ‘Marion’ (6.6 canes/plant) (P <.0001; data not shown). Our results showing ‘Black Diamond’ produced more canes/plant, but shorter canes than ‘Marion’ agree with those of Harkins et al., (2013). Primocane growth was likely reduced in 2012 due to the high yield in this first fruiting season (Table 2.2) as is typical following an off-year (Strik and Finn, 2012). The presence of floricanes has been shown to reduce primocane number and length (Bell et al., 1995; Cortell and Strik, 1997). Under conditions of limited available N, as may occur under a high floricane sink strength, primocane growth may be reduced (Malik et al., 1991; Mohadjer et al., 2001). In 2013, the observed increase in primocane number may have been a result of the increased rate of N applied (Table 2.1) and/or the reduced sink strength of the floricanes as yield was lower in 2013 than in 2012 (Table 2.2).

Machine harvest of ‘Black Diamond’ began 5 d earlier and lasted 5 d longer than ‘Marion’ in both years and the 2013 harvest season was 12 d earlier than in 2012 for both cultivars (data not shown). Total yield was affected by year and cultivar, but not fertilizer source in the two fruiting seasons of the study (Table 2.2). Total yield was 29% greater in 2012 than in 2013 (Table 2.2), as is typical when a fruiting season follows an “off year” or primocane-only growth year (Bell et al., 1995; Cortell and Strik, 1997; Strik and Finn, 2012). ‘Black Diamond’ had a 25% and 21% greater average total and marketable yield, respectively, than ‘Marion’. The proportion of non-marketable fruit varied among cultivars in 2012 and 2013, averaging 17% for ‘Black Diamond’ and 14% for ‘Marion (data not shown). Our findings disagree with those of Harkins et al. (2013) who reported that ‘Marion’ produced more cull fruit than ‘Black Diamond’; however, the cull fruit in their study was limited to machine-sorted cull, whereas our cull included fruit dropped during machine harvest. ‘Black Diamond’ may have a lower machine-harvest efficiency than ‘Marion’. In a separate study, we found than ‘Marion’ also produced less cull fruit than ‘Black Diamond’ when hand-harvested (Chapter 2). The greater yield of ‘Black Diamond’ was likely a result of the cultivar having a higher percent budbreak and more fruit/lateral than found in ‘Marion’ (Table 2.3), as has been reported previously (Chapter 2; Harkins et al., 2013). ‘Marion’ floricanes were 3.8 m longer, on average, than in ‘Black Diamond’, but ‘Marion’ had a lower percent budbreak (Table 2.3). While these might be cultivar differences, percent budbreak has been shown to increase with shorter canes (Bell et al., 1995).

Fruit weight was significantly affected by cultivar and fertilizer in both years (Table 2.2). Plants fertilized with corn produced 5% heavier fruit than those fertilized with fish, on average. ‘Black Diamond’ produced 7% larger fruit, on average, than ‘Marion’, as has been reported previously in organic blackberry production (Chapter 2; Harkins et al., 2013). Fruit weight declined over the harvest seasons in both cultivars (data not shown), as has been reported previously (Chapter 2). ‘Marion’ fruit had a higher percent soluble solids than ‘Black Diamond’, especially in 2013, as found by Harkins et al. (2013). However, Siriwoharn et al. (2004) reported a similar sucrose content of ‘Black Diamond’ and ‘Marion’ fruit. In our study, mid-season fruit had a lower percent soluble solids than early- or late-season fruit in both cultivars, particularly in 2013 (data not shown), as has been reported previously (Chapter 2). Fruit harvested in the early-season were more firm than late-season fruit in both cultivars (data not shown). ‘Black Diamond’ fruit were more firm than ‘Marion’ fruit, particularly in 2012 (Table 2.2), similar to previous reports (Chapter 2; Finn et al., 2005). There was no effect of fertilizer source on the percent soluble solids or fruit firmness in either year.

There was a significant year × cultivar and cultivar × fertilizer interaction on floricane fresh biomass (data not shown) and DW/plant at pruning time (Table 2.4). ‘Marion’ produced 53% and 43% greater floricane DW biomass per plant than ‘Black Diamond’ in 2012 and 2013, respectively (Table 2.4). Additionally, ‘Marion’ had greater floricane DW biomass when fertilized with corn than with fish, whereas there was no effect of fertilizer source in ‘Black Diamond’ (Table 2.4). Greater canopy growth in ‘Marion’ compared to ‘Black Diamond’ was also reported by Harkins et al. (2013; 2014).

Soil and tissue nutrients. Soil pH was within the recommended range for blackberry production (5.6 to 6.5; Hart et al., 2006) (Table 2.5). The soil organic matter (OM) content was significantly higher in 2013 than in 2012, even though OM was not added underneath the weed mat. The increase in OM was likely due to the presence of fine blackberry roots in the soil sample, the presence of which likely increased during these establishment years. Most of the nutrient levels in the soil were within or above the recommended range for blackberry in Oregon (Hart et al., 2006). Soil P, K, Ca, and Mg were considerably above recommended levels (P-Bray, 20 to 40 ppm; K, 150 to 350 ppm; Ca, 1000 ppm; and Mg, 120 ppm) in both years (Table 2.6). Soil B was below the recommended level (0.5 to 1.0 ppm) in both years (Table 2.5).

The level of soil P decreased and Ca increased significantly from 2012 to 2013. The increase in Ca was likely due to the application of lime the prior winter. There was no effect of cultivar on soil nutrient level, but there was a cultivar × fertilizer interaction on soil NO_3-N (Table 2.5). Fertilization with fish increased soil NO_3-N in 'Marion' plots relative to 'Black Diamond' plots, whereas there was no difference among cultivars when corn was the fertilizer source. Soil NH_4-N was not affected by cultivar or fertilizer source but was significantly higher in 2013 than 2012. Nakano et al. (2003) and Nakano and Uehara (2003) suggested that the N in corn steep liquor takes longer to be available to the plant, due to the high amounts of organic N and small amounts of NO_3-N and NH_4-N. The higher soil NH_4-N level in 2013 may have been in response to the increased rate of N applied and because the mostly organic N applied in both fertilizers takes longer to go undergo nitrification (Burger and Jackson, 2003; Vanotti et al., 1995), 12.8 ± 2.2 weeks as estimated by Standford and Smith (1972), depending on various soil factors.

Most primocane tissue nutrient concentrations were within the recommended levels (Hart et al., 2006) for blackberry in Oregon (Table 2.6). In 2012 and 2013, tissue N, P, K, S, Fe, Mn, Cu, and Zn concentration were within 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, 50 to 300 ppm Mn, 6 to 20 ppm Cu, and 15 to 50 ppm Zn). Tissue Mg was within or below the recommended standards depending on year and cultivar (0.3 to 0.6% Mg). Tissue Ca and B were below the recommended standard (0.6 to 2.0% Ca, 30 to 70 ppm B). Soils in the Pacific Northwest are often deficient in B (Hart et al., 2006). Boron deficiency in blackberry may result in a reduction in percent bud break (Hart et al., 2006) and fruit weight (Kowalenko, 1981). Although B was applied in 2013, soil and tissue B concentrations declined. Additional studies are necessary to determine the efficacy of soil applications of B. Approved foliar B applications may be an alternative for organic blackberry production.

Primocane tissue nutrient concentration was not affected by year for any of the nutrients tested (Table 2.6), even though the yield was much greater in 2012 than in 2013 (Table 2.2). Although the high yield in 2012 reduced primocane growth, as mentioned previously, fertilization appeared to be adequate. There was a year x cultivar interaction for primocane leaf S, Cu and Zn which did not differ among years in 'Marion', but were higher in 2013 than in 2012 in 'Black Diamond' (Table 2.6). Primocane leaf K and Zn concentration was higher in plants fertilized with fish than plants fertilized with corn. Additionally there was a significant cultivar x fertilizer source interaction on leaf tissue Mg, S, and B concentration (Table 2.6). Primocane leaf Mg, S, and B tended to be higher in 'Marion' when fertilized with fish compared to corn, whereas the opposite was found in 'Black Diamond'. The application of fish fertilizer, which had higher K content (Table 2.1), increased leaf K, while the 25% greater rate of N applied when using corn fertilizer had no significant effect on soil or tissue N content, possibly due to most of the additional N being in the organic-N form. The higher rate of N applied also had no effect on yield, likely indicating that the lower rate of N applied with the fish was sufficient for blackberry. Additional studies are required to determine if there is a need for cultivar specific nutrient recommendations and the relations of organic-N in the plant and soil.

Fertigation and drip system performance. Drip emitter flow rate was significantly affected by year, but not by fertilizer source or drip maintenance treatment (Table 2.7). When the system was tested, prior to starting the fertigation treatments in 2011, the average water flow rate of the emitters was 2.2 $L \cdot h^{-1}$ (data not shown). In 2012, flow rate was reduced an average of 4.5% (0.1 $L \cdot h^{-1}$) compared to 2011 and in 2013 there was an additional 19.0% (0.3 $L \cdot h^{-1}$) reduction in emitter flow rate from the prior year (Table 2.7). Schwankl and McGourty (1992) found that flow rates were not drastically reduced after various applications of organic fertilizers (fish and poultry protein) in one fertigation season, similar to what we observed in our first season. However, we found that over a longer fertigation period (3 years), reduction in emitter performance was cumulative over time. There was a trend (P = 0.067) for flow rates to be higher when the fish fertilizer was fertigated in comparison to the corn fertilizer. The main reasons for drip emitter clogging are physical (particles), chemical (mineral interactions and solubility), and biological (growth of organisms), which are governed by a variety of factors (Boman and Ontermaa, 1994; Haman, 2011; Schwankl et al., 2008; Schwankl, 1992). Gilbert et al. (1982) suggested that bacteria in water may be affected by mineral and organic particles that contribute to population reproduction and growth, but they also concluded that biological clogging was minimal in four years of operation and that the main reasons for drip clogging were physical and biological slime deposits, which could also be possible reasons for the water volume reduction in the present study. Additional research is needed to determine the possible causes for clogging in organically managed fertigated systems.

Conclusions

Using the current standards for blackberry (Hart et al., 2006), the liquid corn and fish organic fertilizers applied, although differing in macro- and micronutrient content, supplied sufficient nutrients to meet plant needs with the exception of Ca and B. Both fertilizers could be applied through the drip, but emitter performance was reduced over time. For perennial organic caneberry crops, flushing of the fertigation system should be conducted on a regular basis to reduce the possibility of residue accumulation at the end of the lines and to prevent emitter clogging over time. Further research is needed to determine the cause of the reduction in emitter flow performance and the relation to organic fertilizers and possible causes for clogging. As expected, ‘Black Diamond’ had greater total yield and average fruit weight than ‘Marion’. Fertilizer source had no effect on yield, although there were some minor effects on fruit quality.

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Table 2.1. Total nutrients applied in organic fertilizer treatments in blackberry, 2011─2012 and 2013

		Macronutrients (kg·ha^{-1})						Micronutrients (g·ha^{-1})				
Fertilizer[z]	Treatment name	N	P	K	Ca	Mg	Na	B	Fe	Mn	Cu	Zn
2011–2012												
TRUE 402	Fish	50	8	60	1	1	27	12	307	19	4	48
Agrothrive LF	Corn	62	30	40	3	8	1	23	40	49	9	97
2013												
TRUE 402	Fish	80	14	98	1	1	44	20	496	30	6	77
Agrothrive LF	Corn	99	47	63	4	13	2	37	63	78	15	154

[z]Fertilizers were analyzed by Brookside Laboratories, Inc. (New Bremen, OH). The fish hydrolysate and fish emulsion blend combined with molasses fertilizer was diluted with water (1:5, v/v) prior to injection in four equal portions in spring 2011 and 2012 and eight equal portions in spring 2013. The corn steep liquor and ground fish waste fertilizer was diluted with water (1:2, v/v) prior to injection in four equal portions in spring 2011 and 2012 and eight equal portions in spring 2013. TRUE 402; 4N–0P–2K had a pH of 5.5 and Agrothrive LF 2.5N–2.5P–1.5K had a pH of 3.98.

Table 2.2 Effect of cultivar and fertilizer source on total and marketable fruit yield, fruit weight, percent soluble solids (°Brix), fruit firmness in machine-picked organic blackberry, 2012–2013 (n=5).

Treatments	Total yield (kg/plant)	Marketable yield (kg/plant)	Fruit weight (g)	Soluble solids (%)		Fruit firmness (N)	
Year							
2012	7.1 a[z]	6.3	5.9	11.6		2.1	
2013	5.5 b	4.4	5.8	11.4		2.0	
Cultivar				2012	2013	2012	2013
Black Diamond	7.0 a	5.8 a	6.0 a	10.3 b	9.8 c	2.5 a	2.2 b
Marion	5.6 b	4.8 b	5.6 b	12.9 a	13.0 a	1.6 c	1.7 c
Fertilizer[y]							
Fish	6.3	5.4	5.7 b	11.5		2.0	
Corn	6.2	5.3	6.0 a	11.5		2.0	
Significance[w]							
Year(Y)	0.0484	ns	ns	ns		ns	
Cultivar(C)	<.0001	0.0006	0.0063	<.0001		<.0001	
Fertilizer(F)	ns	ns	0.0470	ns		ns	
Y x C	ns	ns	ns	<.0001		<.0001	
C x F	ns	ns	ns	ns		ns	
Y x C x F	ns	ns	ns	ns		ns	

[z]Means followed by the same letter within the treatment or interaction are not significantly different ($P \geq 0.05$).

[y]Fertilizer products used were: a blend of fish hydrolysate and fish emulsion combined with molasses (“fish”, TRUE 402; 4N–0P–2K; True Organic Products, Inc., Spreckels, CA) and corn steep liquor (“corn”, Agrothrive LF; 2.5N-2.5P-1.5K; Agrothrive Inc., Morgan Hill, CA). The two fertilizer source treatments were applied at an equivalent total rate of N (56 kg·ha^{-1} in 2012 and 90 kg·ha^{-1} in 2013) based on the percent N in the product as stated on the label.

[x]*P* value provided unless non-significant (ns; $P \geq 0.05$).

Table 2.3. Effects of cultivar and fertilizer source on floricane traits (yield components) in organic blackberry in 2013 (n=5).

Treatments	Floricane length (m)	No. of nodes	Internode length (cm)	Budbreak (%)	Fruit/lateral
Cultivar					
Black Diamond	4.8 b[z]	116.4	4.2 b	67.0 a	11.1 a
Marion	8.6 a	117.1	7.3 a	53.0 b	8.0 b
Fertilizer[y]					
Fish	6.9	120.5	5.9	59.8	9.8
Corn	6.5	113.1	5.7	60.2	9.3
Significance[x]					
Cultivar(C)	<.0001	ns	<.0001	0.0029	<.0001
Fertilizer(F)	ns	ns	ns	ns	ns
C x F	ns	ns	ns	ns	ns

[z]Means followed by the same letter within the treatment or interaction are not significantly different ($P \geq 0.05$).
[y]Fertilizer products used were: a blend of fish hydrolysate and fish emulsion combined with molasses ("fish", TRUE 402; 4N–0P–2K; True Organic Products, Inc., Spreckels, CA) and corn steep liquor ("corn", Agrothrive LF; 2.5N-2.5P-1.5K; Agrothrive Inc., Morgan Hill, CA). The two fertilizer source treatments were applied at an equivalent total rate of N (56 $kg \cdot ha^{-1}$ in 2012 and 90 $kg \cdot ha^{-1}$ in 2013) based on the percent N in the product as stated on the label.
[x]*P* value provided unless non-significant (ns; $P \geq 0.05$).

Table 2.4. Effects of year, cultivar and fertilizer source on floricane biomass dry weight (DW) per plant in organic blackberry in the years, 2012–2013 (n=5).

Treatments	Floricane biomass DW (kg/plant)	
Year		
2012	1.7	
2013	0.8	
Cultivar	2012	2013
Black Diamond (BD)	1.3 b[z]	0.7 d
Marion (M)	2.0 a	1.0 c
Fertilizer[y]	BD	M
Fish	1.1 c	1.4 b
Corn	0.8 c	1.6 a
Significance[x]		
Year(Y)	ns	
Cultivar(C)	<.0001	
Fertilizer(F)	ns	
Y x C	0.0015	
C x F	0.0004	
Y x C x F	ns	

[z]Means followed by the same letter within the treatment or interaction are not significantly different ($P \geq 0.05$).

[y]Fertilizer products used were: a blend of fish hydrolysate and fish emulsion combined with molasses (“fish”, TRUE 402; 4N–0P–2K; True Organic Products, Inc., Spreckels, CA) and corn steep liquor (“corn”, Agrothrive LF; 2.5N-2.5P-1.5K; Agrothrive Inc., Morgan Hill, CA). The two fertilizer source treatments were applied at an equivalent total rate of N (56 $kg \cdot ha^{-1}$ in 2012 and 90 $kg \cdot ha^{-1}$ in 2013) based on the percent N in the product as stated on the label.

[x]*P* value provided unless non-significant (ns; $P \geq 0.05$).

Table 2.5. Effects of year, cultivar and fertilizer on soil pH, organic matter (OM), and nutrient content in organic blackberry on 2 Nov. 2012 and 23 Oct. 2013 (n=5).

Treatments	pH	OM (%)	NO_3-N (ppm)		NH_4-N (ppm)	P Bray I	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Na (mg/kg)	B (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Al (mg/kg)
Year (Y)																
2012	5.9	2.4 b[z]	1.27		0.74 b	238.9 a	239.3	1146.1 a	153.2	25.8	0.39	328.6	20.4	1.11	2.29	1432.4
2013	6.0	2.9 a	1.30		6.19 a	205.8 b	223.0	1260.8 b	172.1	28.3	0.37	314.6	20.8	0.84	2.16	1342.5
Cultivar (C)			Corn	Fish												
Black Diamond	6.0	2.7	1.52 a	0.84 b	3.31	228.2	222.4	1173.8	162.2	27.4	0.39	321.8	21.1	1.03	2.08	1385.9
Marion	5.9	2.6	1.25 ab	1.52 a	3.63	216.6	239.9	1233.1	163.1	26.8	0.37	321.4	20.1	0.92	2.37	1389.1
Fertilizer (F)[y]																
Corn	5.9	2.7	1.39		3.70	227.7	225.6	1181.2	163.3	25.9	0.40	323.8	21.0	1.10	2.37	1372.8
Fish	6.0	2.6	1.18		3.23	217.1	236.7	1225.6	162.0	28.2	0.36	319.4	20.2	0.85	2.08	1402.2
Significance[x]																
Year (Y)	ns	0.027	ns		0.0023	0.0499	n.s.	0.0144	ns	ns	ns	ns	ns	ns	ns	ns
Cultivar (C)	ns	ns	ns		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Fertilizer(F)	ns	ns	ns		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Y x C	ns	ns	ns		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
C x F	ns	ns	0.0372		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Y x C x F	ns	ns	ns		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[z]Means followed by the same letter within the treatment or interaction are not significantly different ($P \geq 0.05$).
[y]Fertilizer products used were: a blend of fish hydrolysate and fish emulsion combined with molasses ("fish", TRUE 402; 4N–0P–2K; True Organic Products, Inc., Spreckels, CA) and corn steep liquor ("corn", Agrothrive LF; 2.5N-2.5P-1.5K; Agrothrive Inc., Morgan Hill, CA). The two fertilizer source treatments were applied at an equivalent total rate of N (56 $kg{\cdot}ha^{-1}$ in 2012 and 90 $kg{\cdot}ha^{-1}$ in 2013) based on the percent N in the product as stated on the label.
[x]P value provided unless non-significant (ns; $P \geq 0.05$).

Table 2.6. Effect of year, cultivar and fertilizer source on primocane leaf tissue nutrient concentration in organic blackberry on 17 Aug. 2012 and 16 Aug. 2013 (n=5).

Treatments	Macronutrients (%)								Micronutrients (ppm)								
	N	P	K	Ca	Mg		S		B		Fe	Mn	Cu		Zn		Al
Year (Y)																	
2012	2.41	0.34	1.66	0.31	0.27		0.14		19.2		106.9	95.3	8.21		32.2		79.5
2013	2.62	0.36	1.43	0.36	0.30		0.15		17.1		97.8	104.9	9.04		36.0		59.3
Cultivar (C)							2012	2013					2012	2013	2012	2013	
Black Diamond	2.11 b[z]	0.30 b	1.42 b	0.31 b	0.27		0.13 c	0.14 b	20.0 a		115.5 a	105.1	8.9 b	10.3 a	26.9 c	33.5 b	81.6 a
Marion	2.92 a	0.40 a	1.67 a	0.35 a	0.30		0.16 a	0.16 a	16.3 b		89.2 b	95.1	7.5 c	7.7 c	37.5 a	38.5 a	57.2 b
Fertilizer(F)[y]					BD	M	BD	M	BD	M							
Corn	2.50	0.35	1.50 b	0.34	0.28 b	0.29 a	0.14 c	0.15 b	20.5 a	15.6 b	98.4	102.0	8.47		33.1 b		67.6
Fish	2.53	0.35	1.59 a	0.33	0.26 b	0.30 a	0.13 c	0.16 a	19.6 a	17.1 b	106.3	98.2	8.78		35.1 a		71.3
Significance[x]																	
Year (Y)	ns	ns	ns	ns	ns		ns		ns		ns	ns	ns		ns		ns
Cultivar (C)	<.0001	<.0001	<.0001	0.0202	<.0001		<.0001		<.0001		0.0075	ns	<.0001		<.0001		0.0225
Fertilizer(F)	ns	ns	0.0044	ns	ns		ns		ns		ns	ns	n.s.		0.0467		ns
Y x C	ns	ns	ns	ns	ns		0.0007		ns		ns	ns	0.0087		0.0073		ns
C x F	ns	ns	ns	ns	0.0205		0.0167		0.0075		ns	ns	ns		ns		ns
Y x C x F	ns	ns	ns	ns	ns		ns		ns		ns	ns	ns		ns		ns

[z]Means followed by the same letter within the treatment or interaction are not significantly different ($P \geq 0.05$).
[y]Fertilizer products used were: a blend of fish hydrolysate and fish emulsion combined with molasses ("fish", TRUE 402; 4N–0P–2K; True Organic Products, Inc., Spreckels, CA) and corn steep liquor ("corn", Agrothrive LF; 2.5N-2.5P-1.5K; Agrothrive Inc., Morgan Hill, CA). The two fertilizer source treatments were applied at an equivalent total rate of N (56 $kg \cdot ha^{-1}$ in 2012 and 90 $kg \cdot ha^{-1}$ in 2013) based on the percent N in the product as stated on the label.
[x]*P* value provided unless non-significant (ns; $P \geq 0.05$).

Table 2.7. Effects of fertigation with organic fertilizers and maintenance of the drip system on average drip emitter flow rates during the third and fourth year after planting (2012–2013; n=3).[z]

Year/treatments	Drip emitter flow rate ($L \cdot h^{-1}$)
Year (Y)	
2012	2.08
2013	1.74
Organic fertilizer (F)[y]	
Corn steep liquor	1.87
Fish hydrolysate/emulsion	1.94
Drip maintenance (D)[x]	
Flush	1.89
No flush	1.93
Significance[w]	
Year (Y)	0.0068
Organic fertilizer (F)	ns
Drip maintenance (D)	ns
Y x F	ns
F x D	ns
Y x F x D	ns

[z]The drip system was designed using drip tubing with 2 $L \cdot h^{-1}$ integral pressure-compensating, continuously self-cleaning emitters spaced every 0.6 m. The emitters had an average flow rate of 2.21 $L\ h^{-1}$ on 13 Apr. 2011 (prior to any fertigation).

[y]Both fertilizers were applied by fertigation through the drip system at an annual rate of 56.0 $kg\ ha^{-1}$ N in 2011 and 2012, and 89.7 $kg\ ha^{-1}$ N in 2013.

[x]Drip lines with flush treatment were rinsed with water by opening a valve installed at the end of each tube section before each fertilization and flushed with water for 1 minute before each volume measurement was taken during the season and also at the beginning and end of the irrigation period in 2012 and 2013.

[w]P value provided unless non-significant (ns; $P > 0.05$).

CHAPTER 4: Trailing Blackberry Cultivars Differ in Yield and Post-harvest Fruit Quality During Establishment in an Organic Production System

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 drip line under a woven polyethylene ground cover (weed mat) installed for weed management. Liquid fertilizers injected through the drip system were used at a rates of 56 $kg{\cdot}ha^{-1}$ total N in 2011-2012 and 90 $kg{\cdot}ha^{-1}$ total N in 2013. Cultivars differed in the level of nutrients measured in primocane leaves. Tissue P, K, S, Fe, Mn, Cu, and Zn concentrations were within the recommended standards, but tissue Ca, Mg, and B were deficient in some or all cultivars. All of the cultivars tested responded well to the organic production system used based on yield and plant growth, but 'Onyx' and 'Metolius' were considered to have a low yield for commercial production. In contrast, the higher yielding 'Obsidian' and 'ORUS-2635-1' appeared to be the best suited for fresh market, organic production due to their greater fruit size, firmness, and sugar to acid ratio and a low post-harvest percent moisture loss (ORUS-2635-1) and the longest number of marketable days of storage ('Obsidian').

Introduction

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 2008, organic blackberry were harvested on a reported 348 farms in the United States for a crop value of $4.6 million (Geisler, 2012). In Oregon, 52.8 million pounds (23.9 million kg) of blackberries were produced on 7,300 acres (2,954 ha) in 2011 (NASS, 2013). Given the 12% growth of organic sales from 2009 to 2010 (OTA, 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 mainly natural fertilizer sources of animal, plant or of mined origin for nutrient management (USDA, 2011). In the present study, organically-approved liquid fertilizers that could be applied using the drip irrigation system ("fertigated") were selected. Liquid fish emulsion, molasses derived, and soluble mined products are commonly used in organic production because they provide adequate levels of nitrogen (N), are relatively cost effective, and are soluble in water, making them ideal for application through the drip irrigation system ("fertigation") (Gaskell and Smith, 2007). In organic production, fertigation is becoming more common (Chapter 3; Harkins et al., 2013; Schwankl and McGourty, 1992). System design and costs need to be considered when adopting irrigation/fertigation systems. Blackberry fields have been successfully established using drip irrigation and fertigation (Harkins et al., 2013), but fertilizer source may affect emitter clogging over time (Chapter 3).

Weed management during planting establishment is important for maximizing plant growth and yield (Harkins et al., 2013). The use of woven polyethylene ground covers ("weed mat") has been an effective weed management strategy in blackberry plants that do not produce primocanes from roots buds (e.g. trailing and semi-erect types) (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. Well-adapted cultivars have good post-harvest 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). However, there is relatively little information available on cultivar adaptation to organic production systems. Cultivars have been found to differ in plant growth, yield, and fruit quality in conventional (Finn et al., 1997, 2005a, 2005b, 2005c, 2011; Strik, 1992; Strik and Finn, 2012) and organic (Chapter 2; Chapter 3; Harkins et al., 2013) production.

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. Cultivars were compared for plant growth and yield and post-harvest 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 Pacific Northwest (Finn and Strik, 2014; Finn et al., 2005b). Under conventional management, yield and berry weight for ‘Obsidian’ ranged from 19-28 $t{\cdot}ha^{-1}$, and 5.5-6.8 g, respectively (Finn et al., 2005b). ‘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 and Strik, 2014; Finn et al., 2005b). Yield has been as high as 21 $t{\cdot}ha^{-1}$ in conventional production (Finn et al., 2005b) and 13 to 17 $t{\cdot}ha^{-1}$ in organic production systems (Chapter 2; Chapter 3; Harkins et al., 2013). ‘Black Diamond’ may also be hand-harvested for fresh market, as fruit are large, firm, uniformly shaped and have good flavor (Finn et al., 2005b). ‘Onyx’ is a relatively new cultivar (2011) producing vigorous canes and a moderate yield of uniform, firm, sweet, and excellent flavored fruit that are suited for local and wholesale fresh market (Finn et al., 2011). 'Onyx' yield averaged 14 $t \cdot ha^{-1}$ under conventional management (Finn et al., 2011). 'Metolius' is characterized by vigorous plant growth, a good yield, and medium-sized, firm fruit with excellent flavor (Finn et al., 2005c). In conventional production trials, the advanced selection,'ORUS 1939-4' had high yields with medium to large, firm, sweet fruit with excellent flavor. 'ORUS 2635-1' is considered a high-yielding selection that produces high-quality, large fruit (Strik et al., 2011).

Materials and methods

Study site. The study was conducted at the 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); elevation 46 m]. Soil at the site is a Willamette silt loam (fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll) that 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 $kg \cdot ha^{-1}$) and dolomite (4148 $kg \cdot ha^{-1}$)] and K-Mag fertilizer (102 $kg \cdot ha^{-1}$ K, 62 $kg \cdot ha^{-1}$ Mg, 102 $kg \cdot ha^{-1}$ S) + micronutrients [2 $kg \cdot ha^{-1}$ B (H_3BO_3), 1 $kg \cdot ha^{-1}$ Cu ($CuSO_4$), and 14 $kg \cdot ha^{-1}$ 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 ground cover ("weed mat"; water flow rate 6.8 $L \cdot h \cdot m^{-2}$; 0.11 $kg \cdot m^{-2}$; 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 $L \cdot h^{-1}$ 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 (ET) 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) in May 2012 and even though approved practices were conducted during three years prior to planting and in the establishment year, organic certification was not obtained until the first fruit harvest year.

Experimental design. The study was conducted from 2011 to 2013, years 2 through 4 and included the first and second fruiting years, years 3 and 4, respectively. The study was arranged as a randomized block design with four replicates with the treatment including four cultivars (‘Obsidian’, ‘Black Diamond’, ‘Onyx’, ‘Metolius’) and two advanced selections (‘ORUS 1939-4’, ‘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 un-planted space. 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). Plants were trained on a two-wire vertical trellis system that was installed prior to 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 following 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 towards the plant with one or two twists, and the other half was looped in the opposite direction. In year 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 N fertilizer applications were based on the percent N in the product as stated on the label. Prior to planting in year 1, pelletized, processed poultry litter (4N–3P–2K–7Ca; Nutri-Rich; Stutzman Environmental Products Inc., Canby, OR) was incorporated into the soil (~0.45 m diam.) at a rate of 28 $kg{\cdot}ha^{-1}$ N. In addition, Fish Agra (4N–1P–1K; 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 $kg{\cdot}ha^{-1}$ N each from 14 July to 25 Aug. 2010 (28 $kg{\cdot}ha^{-1}$ total N). In 2011-2012 a fish hydrolysate and fish emulsion blend combined with molasses (TRUE 402; 4N–0P–2K; True Organic Products, Inc., Spreckels, CA) was diluted with five parts water (v/v) prior to fertigation and was applied in four equal applications (total of 56 $kg{\cdot}ha^{-1}$ N) on 18 Apr., 13 May, and 3 and 24 June 2011, and 25 Apr., 11 May, and 1 and 15 June 2012. In 2013, a soluble grain fermentation and nitrate of soda blend (4N–2P–1K; Converted Organics of California, LLC, Gonzales, CA) was diluted with four parts water (v/v) prior to fertigation and applied at a target rate of 45 $kg{\cdot}ha^{-1}$ of N; and a fish hydrolysate and fish emulsion blend combined with molasses (TRUE 512 ; 5N–1P–2K; True Organic Products, Inc., Spreckels, CA) was diluted with two parts water (v/v) prior to fertigation. The fertilizers were each applied in four equal portions – on 5 and 19 Apr., 3, 17 May for the grain source and 7, 14 and 28 June, and 7 July for the fish source for 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 prior to each injection to fully pressurize the system to 103.4 kPa and was also run for an additional hour afterwards to flush the drip lines. The fertilizers applied 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 boron (B; Solubor, 20 Mule Team Borax, Englewood, CO), 560 kg·ha^{-1} of pelletized dolomitic lime [62 kg·ha^{-1} magnesium (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., St Paul, OR) were broadcast applied to the plots and aisles on 8 Mar. 2013.

Plant growth. Primocanes were counted at 0.3m height in each plot in Mar. 2012, Feb. 2013, and Mar. 2014 to assess treatment effects on primocane number in 2011–2013, respectively.

Senescing floricanes were removed by pruning at the base of the plant (approx. 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, re-weighed, and average floricane fresh and dry weight (DW) calculated. 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 specified 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 ten recent fully-expanded leaves cut from both sides of the row on each plot and were sent to Brookside Laboratories. Total N content was determined in each sample using a combustion analyzer, and P, K, Ca, Mg, S, iron (Fe), B, copper (Cu), Mn, zinc (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 to published standards (Hart et al., 2006).

Soil was sampled on 2 Nov. 2012 and 23 Oct. 2013 using a 2.4-cm diam., 0.5-m long, slotted, open-side, chrome plated steel soil probe (Soil Sampler Model Hoffer, JBK Manufacturing, Dayton, OH). One sample was collected per block (repetition) with each sample composed of one core per plot (six plots per repetition) 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 cores were combined in a bucket and a subsample sent for analysis to Brookside Laboratories and extractable soil P (Bray I), K, Ca, Mg, sulphate-sulfur (SO_4-S), 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 1M KCl (Dahnke, 1990). Soil organic matter was measured using Loss-On-Ignition at 360 ºC (Nelson and Sommers, 1996) and soil pH 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 plastic buckets. Total marketable and un-marketable fruit ("culls" including overripe, deformed, dropped, sunburned, damaged, rotten, or under-ripe fruit) were harvested, separated and weighed on each harvest date and total yield calculated. A sample of 25 berries was hand-picked just prior to 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); sugar to acid ratio was calculated. 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 (Ametek Model LKG1, Feasterville, PA). 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 (Atago, Bellevue, WA). The remaining crushed, bagged fruit was used to determine titratable acidity using an automatic titrator (DL 12, Mettler-Toledo, LLC, Columbus, OH) with Sodium Hydroxide 0.1 normal (BDH brand, VWR International LLC., Radnor, PA) as a reagent.

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 plastic clamshells (dimensions: 11.4 cm × 11.4 cm × 4.5 cm) 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 2–4 h prior to transport (~1.5 h) to the OSU campus. Clamshells were then stored at 4 +/- 1 °C for 14–21 d depending on cultivar and harvest year. Clamshells were weighed on a 0.01g readability scale (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 calculated (n=4) 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 analysis. Data for yield, plant growth, and plant nutrient status were analyzed for a split-plot design with year as the main plot factor and cultivar 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 due to large differences in weather (data not shown) and observed marketable days at 5°C. The effects of cultivar and harvest date were analyzed using a split plot design. Residuals were tested for normality using the Shapiro-Wilk test and data were log transformed and analyzed where necessary, 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 $\alpha = 0.05$.

Results and Discussion

Fertilizers applied. The fertilizers applied came from a different batch each year, which would not be unusual in commercial production. While the rate of product applied was calculated based on the percentage of N, as stated on the label, for a target rate of 56 $kg \cdot ha^{-1}$ total N in 2011 and 2012 and 90 $kg \cdot ha^{-1}$ N in 2013, the actual rate of N applied was 50, 52, and 75 $kg \cdot ha^{-1}$ total N in 2011, 2012, and 2013, respectively (Table 3.1). 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 3.1). The TRUE 402 fish fertilizer had more than three-fold the K and twenty-fold the Na than the Converted Organics 4–2–1 fermented grain and ten-fold the Fe as the TRUE 512 fish and molasses blend. In 2013, the Converted Organics 4–2–1had more than two-fold the Ca, ten-fold the Fe, and over a thirty-fold less Na than the TRUE 512 (Table 3.1).

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 3.2). Soil organic matter (OM) content decreased during the study, confirming what has been observed when using weed mat as a mulch in organic blueberry production (Sullivan et al., 2014). 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 3.2). 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 the second year, 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 mulch.

There was an effect of cultivar on all primocane tissue nutrient levels except for Al (Table 3.3). 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 cultivars. ‘Obsidian’ also had higher leaf K (except for ‘Metolius’), B, and Fe (except for ‘Black Diamond’) than the other cultivars studied (Table 3.3). ‘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 cultivars 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 cultivars, with measured values just below the recommended level (0.3 to 0.6% Mg). While tissue B was highest in ‘Obsidian’ and lowest in ‘ORUS 1939-4’ and ‘Onyx’, all cultivars were deficient in B (30 to 70 ppm B). Cultivars 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 while K, B, and Mn decreased from 2012 to 2013 (Table 3.3). 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 Pacific Northwest are often deficient in B (Hart et al., 2006), as confirmed at the present study site and even though B fertilizer was applied in early 2013, soil and tissue B concentrations declined. Additionally all fertilizers applied through the drip had a relatively low B content. 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. Cultivars produced an average cane length of 3.6 m in 2011 (data not shown). There was a significant year and cultivar effect on the number of primocanes/plant (Table 3.4). Plants produced the most primocanes/plant in 2011, the "off year" (no floricanes growing simultaneously with the primocanes) and the fewest in 2012, the first fruiting year as expected (Bell et al., 1995; Cortell and Strik, 1997; Mohadjer et al., 2001; Strik and Finn, 2012). Cane number increased from 2012 to 2013, both fruiting years, perhaps in response to the increased rate of N applied. 'Onyx' produced the greatest primocanes/plant and 'Metolius' and 'ORUS 2635-1' the least (Table 3.4).

Total and marketable yield were affected by cultivar, but did not differ among the first and second fruiting seasons (Table 3.5). Yield of 'Marion' trailing blackberry was greater following 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" relative to an "on year". While there was no cultivar by year interaction on yield in our study, the cultivars may not have responded similarly to the alternate year production method used during the establishment years here – slight differences among cultivars may have masked any treatment effects.

‘The proportion of non-marketable yield varied among cultivars, averaging 19% for ‘Black Diamond’, 16% for ‘Metolius’, 13% for ‘ORUS 2635-1’, 12% for ‘Obsidian’ and ‘ORUS 1939-4’, and 11% for ‘Onyx’ (see Table 3.5). Blackberry cultivars differing in marketable yield has been documented in organic production systems (Chapter 2; Chapter 3; Harkins et al., 2013).

There was a significant year × cultivar interaction on all of the fruit quality parameters measured at harvest (Table 3.5). ‘Obsidian’ and ‘ORUS 2635-1’ produced the largest fruit, particularly in 2013, while ‘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. Cultivars have been shown to differ in fruit weight in both organic (Chapter 2; Harkins et al., 2013) and conventional blackberry production (Finn et al., 2005b, 2005c).

‘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 cultivar where fruit TSS increased from 2012 to 2013 (Table 3.5). ‘Black Diamond’ had the lowest fruit TSS in both years. Although we did not include ‘Marion’, a processing cultivar, in our study, the low fruit TSS in ‘Black Diamond’, particularly in 2013, agrees with previous reports (Chapter 2; Harkins et al., 2013).

Fruit firmness declined from 2012 to 2013 in ‘Black Diamond’ and ‘Metolius’, but was not affected by year in the other cultivars (Table 3.5). The firmest fruit were harvested from ‘Metolius’ in 2012, but there was relatively little difference among the other cultivars studied. The relatively low fruit firmness observed in ‘Black Diamond’, particularly in 2013, agrees with subjective firmness measurements reported by Finn et al. (2005b), but contradict those of

Chapter 2, where 'Black Diamond' had similar to or greater fruit firmness than the other fresh market cultivars studied.

Fruit pH increased from 2012 to 2013 in 'Black Diamond', 'Metolius', 'ORUS 1939-4', and 'Onyx', while there was no difference between years in the other cultivars (Table 3.5). Fruit total acidity (TA) tended to be lowest in 'Onyx' and 'ORUS 1939-4', agreeing with other reports for 'Onyx' (Finn et al., 2011). The cultivars differed in perceived sweetness, as indicated by the sugar to acid ratio (Table 3.5). 'Onyx' fruit had the highest sugar to acid ratio, while 'Black Diamond', 'Metolius', and 'Obsidian' had the lowest, depending on year. Cultivars 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, cultivars with a high TSS had a relatively low TA and vice versa (Table 3.5).

There was a significant year and cultivar effect on floricane DW biomass/plant at pruning time. Biomass was 44% greater in 2012 than 2013 (Table 3.6), 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. While 'Metolius' had amongst the lowest floricane DW, this cultivar produced longer floricanes than 'ORUS 1939-4' and 'ORUS 2635-1' and had amongst the highest nodes/cane and longest internode length (Table 3.6).

The percent budbreak on the floricanes was lower in 2012 than in 2013 likely related to the higher biomass produced in 2012 (Table 3.6). A higher biomass in alternate year production systems has been related to a reduction in percent budbreak as reported previously in conventional 'Marion' blackberry production (Bell et al., 1995; Cortell and Strik, 1997). Percent budbreak was higher in ‘Black Diamond’ than any of the other cultivars studied (Table 3.6); this cultivar also had a high percent budbreak in other studies (Chapter 3; Harkins et al., 2013). ‘Metolius’ floricanes had the lowest percent budbreak, despite this cultivar having amongst 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 3.6). This may have been a result of greater intra-canopy shading in the relatively dense canopies produced in 2011–2012. Bell et al. (1995) found that ‘Marion’ primocanes trained in August produced more fruit/lateral than those trained in February, likely due to increased light exposure during the flower bud initiation and differentiation period. There was a year x cultivar interaction on the number of fruit/lateral as ‘Black Diamond’ produced amongst the fewest fruit/lateral in 2012, but had more fruit/lateral than the other cultivars in 2013 (Table 3.6). ‘Obsidian’ had amongst 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 size.

The number of marketable days of fruit storage was affected by cultivar, but not harvest date in the 2012; there was no treatment effect on fruit shelf life (marketable days at 5°C) in 2013 (Table 3.7). 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 storage observed. Marketable storage days averaged 13.4 and 15.5 d in 2012 and 2013, respectively. Cultivars with the most marketable days at 5 °C in our study, ‘Obsidian’ and ‘Black Diamond’, had a similar number of days 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., 1999; 1996). Shelf-life might be longer if these cultivars were stored at the lower temperature (~ 1.5 °C) commonly used commercially. However, 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 packaged commercially.

In 2012 and 2013, percent moisture loss of fruit was affected by cultivar on all evaluation dates during storage, but not by harvest date within season (Fig. 3.1 and 3.2). 'Metolius' fruit lost the most moisture during storage in both years, while the two advanced selections 'ORUS 1939-4' and 'ORUS 2635-1' lost the least. Differences in percent moisture loss of fruit (Fig. 3.1 and 3.2) did not appear to be related to the number of marketable days at 5°C (Table 3.7), but may be related to storage temperature, use of adequate packaging (clamshells) which reduces fruit injury and subsequent pathogen growth as suggested by Perkins-Veazie et al (1999).

Conclusions

All of the cultivars tested, responded well to the organic production system used based on yield and plant growth, with the exception of 'Onyx' and 'Metolius' which were considered to have a low yield for commercial production. Within the higher yielding cultivars, 'Obsidian' and 'ORUS 2635-1' appeared to be the best suited for fresh market, organic production due to 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 establishment, had varying levels of macro- and micro-nutrients and produced or maintained acceptable levels of soil and plant nutrients with the exception of soil and plant B and plant Ca and Mg. Cultivars differed considerably in many tissue nutrients reinforcing that tissue sampling should be done by cultivar (Hart et al., 2006) and suggesting that the current standards, developed for ‘Marion’, may need to be further studied for other popular commercial cultivars.

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Table 3.1. Total nutrients applied in organic blackberry in 2011–2013

	Macronutrients ($kg \cdot ha^{-1}$)						Micronutrients ($g \cdot ha^{-1}$)				
Fertilizer[z]	N	P	K	Ca	Mg	Na	B	Fe	Mn	Cu	Zn
2011											
TRUE 402 (4–0–2)	50	8	61	1	1	27	12	310	19	4	48
2012											
TRUE 402 (4–0–2)	52	7	62	1	1	26	12	354	18	6	38
2013											
TRUE 512 (5–1–2)	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]Fertilizers were 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 four equal portions in spring 2013 in combination with Converted Organics 4–2–1 (grain fermentation soluble and sodium nitrate) which was also injected in four equal portions in spring 2013. TRUE 402; 4N–0P–2K had a pH of 5.5, TRUE 512; 5N–1P–2K had a pH of 3.7 and Converted Organics 4–2–1; 4N–2P–1K had a pH of 4.1.

Table 3.2. Soil pH, organic matter (OM), and nutrient content in organic blackberry on 3 Nov. 2012 and 21 Oct. 2013 (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[x]																
Year (Y)	0.043	0.0439	ns	0.0011	0.0259	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.0299

[x]P value provided unless non-significant (ns; $P > 0.05$).

Table 3.3. Effect of year and cultivar on primocane leaf tissue nutrient concentration in organic blackberry on 8 Aug. 2012 and 15 Aug. 2013 (n=4).

Treatments	N	P	K	Ca	Mg	S	B	Fe	Mn	Cu	Zn	Al
	%	%	%	%	%	%	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
Year (Y)												
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
Cultivar (C)												
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)	n.s.	0.0383	0.0024	n.s.	0.0203	0.0035	0.0024	n.s.	0.0388	0.0006	0.0075	n.s.
Cultivar (C)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0111	0.0109	<.0001	<.0001	n.s.
C x Y	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

[z]Means followed by the same letter in a given column were not significantly different ($P \geq 0.05$).
[y]P value provided unless non-significant (ns; $P \geq 0.05$).

Table 3.4. Effect of year and cultivar on number of primocanes per plant in organic blackberry in the years 2011–2013 (n=4).

Treatments	Primocanes /plant
Year	
2011	11.2 a
2012	7.6 c
2013	9.4 b
Cultivar	
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	0.0055
Cultivar	<.0001
Year x cultivar	ns

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

Table 3.5. Effect of year and cultivar 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, 2012-2013 (n= 4).

Treatments	Total yield (kg/plant)	Marketable yield (kg/plant)	Fruit weight (g)		Soluble solids (%)		Firmness (N)		pH		Titratable acidity (%) or (g/100ml)		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	
Cultivar			2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Black Diamond	8.74 a	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	1.1 a	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[w]														
Year(Y)	ns	ns	ns		ns		ns		0.0061		ns		ns	
Cultivar(C)	0.0059	0.0045	<.0001		<.0001		<.0001		<.0001		<.0001		<.0001	
YxC	ns	ns	0.0151		0.0003		<.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).
[x]P value provided unless non-significant (ns; *P* > 0.05).

Table 3.6. Effect of year and cultivar on floricane traits in organic blackberry, 2012-2013 (n=4).

Treatments	Floricane biomass DW (kg/plant)[z]	Floricane length (m)	No. of nodes	Internode length (cm)	Bud break (%)	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 a	7.42 a	
Cultivar						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	
Cultivar(C)	0.0012	0.0393	0.0195	<.0001	0.0002	<.0001	
CxY	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 non-significant (ns; $P > 0.05$).

Table 3.7. Effect of cultivar and harvest date on fruit shelf life (marketable days at 5 °C) in handpicked organic blackberry in the years 2012 and 2013.

Treatments	Fruit marketable days	
	2012	2013
Cultivar		
Black Diamond	14.6 a	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]		
Cultivar	0.0227	ns
Harvest date	ns	ns
Cultivar x harvest date	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 non-significant (ns; $P > 0.05$).

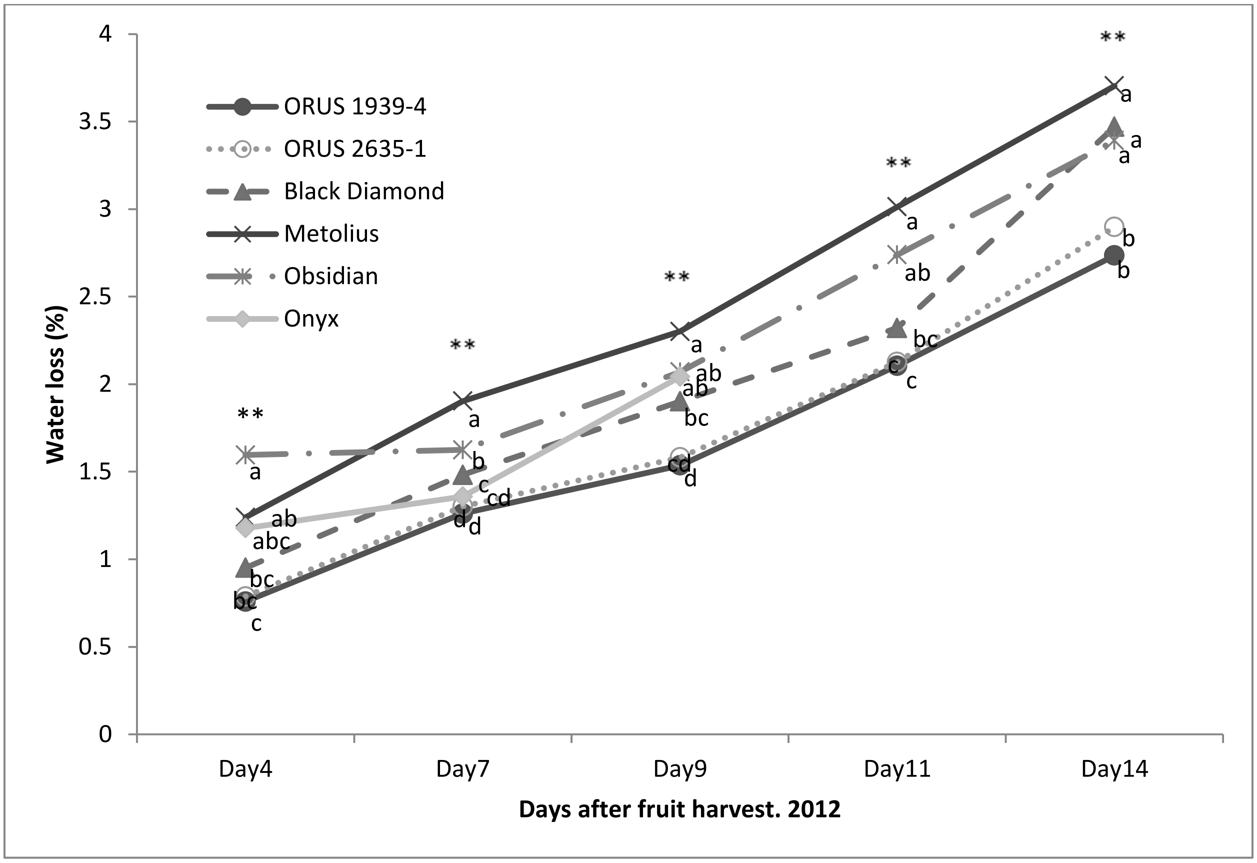

Fig. 3.1. Seasonal average blackberry fruit percent moisture loss in 2012 for the six hand-harvested cultivars in the study: 'ORUS 1939-4', 'ORUS 2635-1', 'Black Diamond', 'Metolius', 'Obsidian', 'Onyx'. Cultivars were separated by Fisher's protected least significant difference on each date at the 5% level. NS, ** Nonsignificant and significant at $P \leq 0.05$, respectively.

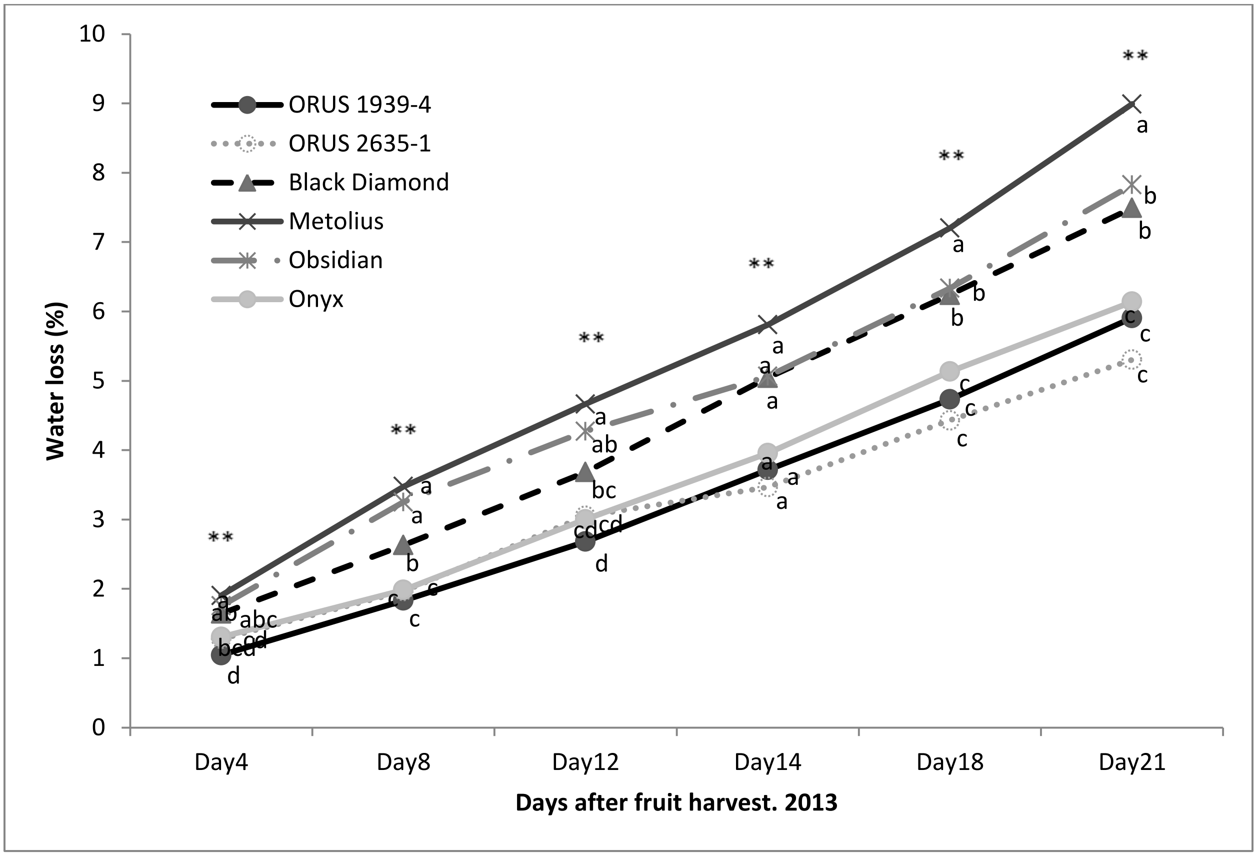

Fig. 3.2. Seasonal average blackberry fruit percent moisture loss in 2013 for the six hand-harvested cultivars in the study: 'ORUS 1939-4', 'ORUS 2635-1', 'Black Diamond', 'Metolius', 'Obsidian', 'Onyx'. Cultivars were separated by Fisher's protected least significant difference on each date at the 5% level. NS, ** Nonsignificant and significant at $P \leq 0.05$, respectively.

CHAPTER 5: General Conclusions

All fertilizer sources evaluated in these studies were suitable to maintain adequate plant nutrition in organic blackberry production, with the exception of soil and plant B and plant Ca and Mg. Each organic fertilizer source had varying levels of macro- and micro-nutrients which may lead to the need for rate adjustments over time. Supplemental applications of B, Ca, and Mg may be needed in deficient soils when the organic fertilizer sources studied are used. Poultry litter may offer advantages in blackberry production to help mitigate the decline in soil pH that occurs when fertilizing due to the added calcium carbonate in its composition. The fish fertilizer contributed relatively large amounts of sodium to the soil with no adverse effects observed during the study. Application method and cost should be considered when determining which fertilizer source to use, as liquid fertilizers may clog emitters when fertigating over time, thereby reducing system performance. Fertilizer source had no effect on yield, although there were some minor effects on fruit quality. A comprehensive cost benefit analysis of organic fertilizer options considering plant availability and mineralization rate of N is needed and a longer term study is suggested to follow up on present findings.

All cultivars performed adequately and would be considered suitable for commercial organic production with the exception of 'Onyx' and 'Metolius' which were considered to have a low yield. Within the higher yielding cultivars, 'Obsidian' and 'ORUS 2635-1' appeared to be the best suited for fresh market due to their greater fruit size, firmness, sugar to acid ratio, low weight loss ('ORUS 2635-1') and longer shelf life ('Obsidian'). 'Triple Crown' produced the highest yield and largest fruit weight, but was considered soft for a fresh market, shipping cultivar. In contrast, 'Obsidian' fruit had the greatest firmness, but were more sensitive to botrytis indicating the importance of a good pest management program. ‘Marion’ and ‘Black Diamond’ had traits that make these cultivars less suitable for fresh market than for the processed market. ‘Black Diamond’ had a greater yield and average fruit weight than ‘Marion’.

Fertilizer source had little to no effect on yield and other fruit quality factors during this study, indicating that all sources are suitable for establishing organic blackberries. However, evidence shows that cost and application method are influential factors when determining which fertilizer source to use, as liquid fertilizers may present advantages and disadvantages when compared with solid fertility options. Cultivars differed in the level of many tissue nutrients reinforcing that tissue sampling should be done by cultivar and suggesting that the current standards developed for ‘Marion’ may need to be further studied before being applied to other popular commercial cultivars.

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