A review of optimal systems for organic production of blueberry and blackberry for fresh and processed markets in the northwestern United States

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ABSTRACT

Various production systems have been evaluated in blackberry (*Rubus* L. subgenus *Rubus* Watson) and northern highbush blueberry (*Vaccinium corymbosum* L.) in certified organic research trials for 5 and 8 years, respectively, in Aurora, OR, USA (lat. 45°16'47"N, long. 122°45'23"W) and are reviewed here. Treatments included cultivar, weed management, and fertilizer source in both crops; planting system, use of municipal yard debris compost, and fertilizer rate in blueberry; and effectiveness of liquid sources of fertilizer through the drip irrigation system, training time, and impact of withholding irrigation after fruit harvest in blackberry. In blueberry, cumulative yield per plant (2008-2014) averaged 21% greater on raised beds than on flat ground. A black, woven polyethylene ground cover (weed mat) offered the most economical method of weed control, as compared to a mulch of municipal yard debris

compost topped with sawdust or sawdust alone. Mulching with weed mat increased cumulative yield compared to the organic mulches, but there was little effect of mulch type on fruit quality. Plants grown with weed mat had a higher shoot-to-root ratio during establishment and required more irrigation water be applied. Addition of yard debris compost to the mulch increased soil and leaf potassium (K), but had little effect on plant nitrogen (N). However, when this compost was used as an amendment prior to planting, soil pH increased to levels above the recommended range for blueberry. Some cultivars were less adapted to the various fertilizer sources and production systems tested. Trailing blackberry plants grown with weed mat produced 25% and 100% higher yield than plants grown with hand-weeding and without weed control, respectively, making this the most economical weed management option. We found no effect of post-harvest deficit irrigation on yield over 2 years. There was little effect of fertilizer source on blackberry yield or fruit quality in processed or fresh production systems. Cultivar differences in adaptation to organic production systems and susceptibility to insect pests were noted. Organic sources of fertilizer contain high levels of nutrients other than N, particularly phosphorus, K, and calcium. The addition of these nutrients when using organic fertilizers, even when they are not required by the plants, must be considered in these production systems. The cost of organic fertilizers tested ranged from \$US5.60 to \$17.95 per kg of N and varied by method of application. Liquid sources of fish and grain blends were successfully fertigated during the study with little impact on emitter performance. Since our research began, weed mat has become very common in organic as well as conventional blueberry fields in the Pacific northwestern United States thus reducing costs of herbicides and hand weeding.

1. Introduction

The Pacific northwestern United States is an important region for production of cultivated blueberry (*Vaccinium* spp.) and blackberry (*Rubus* L. subgenus *Rubus* Watson) accounting for 20% and 45% of the total U.S. harvested area in 2012, respectively (U.S. Department of Agriculture, 2014). Most of the blueberries grown in Oregon and Washington are northern highbush cultivars (*Vaccinium corymbosum* L.; e.g., ‘Duke’, ‘Draper’, ‘Liberty’, ‘Aurora’) harvested by hand or machine for fresh (~50% of production) and processed markets. In contrast, most of the blackberry production in this region is in Oregon with trailing blackberry cultivars (e.g., Marion, Black Diamond) accounting for over 95% of the planted area, and erect (e.g., Navaho, Ouachita) and semi-erect (e.g., Chester Thornless, Triple Crown) cultivars grown on the remaining area (Strik and Finn, 2012). Trailing types are predominantly grown for processed markets (individually quick frozen, bulk frozen, puree, and juice) and are harvested by machine, whereas those grown for fresh market are harvested by hand.

The proportion of total U.S. blueberry and blackberry production grown on certified organic and exempt organic (less than \$US5,000/year gross income and not requiring certification) farms was relatively small at 3% for each crop in 2008 (U.S. Department of Agriculture, 2010). However within the U.S., the Pacific northwestern region accounted for 39% and 49% of the total blackberry and blueberry organic area planted in 2008, respectively. The certified organic area has grown considerably since the last survey was conducted in 2008, particularly in blueberry where the certified area increased to an estimated 915 ha in Oregon and Washington in 2011, 55% of total U.S. organic blueberry area (Strik, 2014). By 2014, the organic blueberry area in Oregon and Washington accounted for about 20% of total blueberry area planted.

Growth in organic blueberry and blackberry production continues as consumer demand for organic products remains strong, creating a 20% to 200% price premium for organic fruit. This region is also considered to have advantages for organic production, including reduced weed and disease management costs in the dry, low-humidity summers, and the absence of some important diseases and insect pests that cause losses in other production regions (Strik et al., 2015, 2007; Strik and Yarborough, 2005).

Research on organic production systems in this region was strongly influenced by the industries, who requested trials on organic production, helped fund the studies through grants, and guided the research through advisory boards (Strik et al., 2015). When the research studies were initiated (2006 and 2010 for organic blueberry and blackberry, respectively) there were two production guides for organic highbush blueberry and one for organic blackberry in North America (Krewer and Walker, 2006; Kuepper and Diver, 2004; Kuepper et al., 2003). The recommendations in these guides, however, were based on anecdotal information with little research to compare methods. Furthermore, there was no information on organic production systems available for trailing blackberry specifically grown for high-value processed markets, particularly whether machine harvest could be used (as is common in conventional production). Growers interested in the processed blackberry market had questions as to whether labor-saving machine harvesting technology can be used in organic systems where even “beneficial” insects could become harvest contaminants. Key challenges to rapid expansion of certified organic blueberry and blackberry production were thus identified including greater production costs and/or inputs (particularly for fertilization and weed management), limited options for disease and insect control associated with greater risk, and reduced yields of organic plantings (whether

perceived or real). Growers were concerned about whether returns would be enough to more than offset the expected higher costs of organic production (Strik, 2014).

The objectives of the research trials were to evaluate crop-relevant production systems and assess their impact on plant growth and nutrient status, yield, fruit quality, and economics of production from establishment through maturity in blueberry and blackberry. In blueberry, the impact of planting method, cultivar, mulch, and fertilizer source and rate were evaluated. In blackberry, weed management options, training time, and deficit irrigation were evaluated in two important cultivars grown for the machine-harvested, processed market. In addition, cultivar adaptation and fertilizer source were evaluated.

This manuscript is intended to be a review of the organic production systems research conducted on blueberry and blackberry in Oregon, USA. I will first describe the key methodologies used in the various organic trials conducted over the last decade; the original studies, where more information is provided on methodology and statistical analyses used, are cited where appropriate. Key results and discussion items are provided.

2. Materials and methods

Long-term organic systems trials were established at Oregon State University's North Willamette Research and Extension Center (NWREC; Aurora, OR, USA; lat. 45°16'47"N, long. 122°45'23"W) for blueberry in 2006 and for blackberry in 2010. Each planting was certified organic prior to the first fruit harvest year by a USDA-accredited agency (Oregon Tilth, Certified Organic, Corvallis, OR). The soil is mapped as a Willamette silt loam (a fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll) with an organic matter content of 3 to 4%. In

addition, a grower-collaborator trial evaluating the effect of fertilizer source in fresh market blackberry cultivars was included and is described below.

2.1. Blueberry

2.1.1. Blueberry organic systems trial

A 0.4-ha research trial was planted in October 2006 and was transitional in the establishment years, but was certified organic in the first cropping year (2008) – a typical scenario for commercial growers. The planting was considered mature in the eighth growing season (2014). There were 48 treatment combinations arranged in a balanced factorial ($2 \times 4 \times 2 \times 3$) split-split plot design with five replicates. The main plots were bed configuration (raised beds of ~ 0.3 m high or flat ground), the subplots were fertilizer rate and source (2 rates $\times$ 2 sources), and the sub-subplots were cultivar (the early-season ‘Duke’ and mid-season ‘Liberty’) and mulch treatment (‘compost + sawdust’, sawdust, or weed mat). Sub-subplots were 4.6 m long with six plants each. Plant spacing was 0.76 m by 3 m (4385 plants/ha). The plants were drip irrigated, and irrigation rate was adjusted to maintain soil water content at similar values across treatments. Details on planting establishment are provided elsewhere (Larco et al., 2013a, 2013b). Treatments are briefly described here.

Mulch treatments were: a) Douglas fir (*Pseudotsuga menziesii* M.) sawdust mulch (9 cm deep; $360 \text{ m}^3 \cdot \text{ha}^{-1}$); b) compost (municipal yard debris, 4 cm deep; $152 \text{ m}^3 \cdot \text{ha}^{-1}$) plus Douglas fir sawdust (5 cm deep; $200 \text{ m}^3 \cdot \text{ha}^{-1}$) mulch on top (compost + sawdust); and c) weed mat [black, woven polyethylene ground cover (TenCate Protective Fabrics; OBC Northwest Inc., Canby, OR)] with sawdust mulch (5 cm) in the 20-cm diameter planting hole ($1.4 \text{ m}^3 \cdot \text{ha}^{-1}$). The intent of the compost + sawdust treatment was to have the sawdust mulch act as a barrier to weed seed

germination in the more nutrient-rich compost layer. The two organic mulches were initially applied in 2006 just after planting and were replenished in Jan. 2011 and 2013 as needed to maintain mulch depth. The solid 1.5-m-wide piece of weed mat, centered over the row, was installed just prior to planting and was replaced with “zippered” weed mat (overlapping pieces stapled in place) in the winter of 2010-2011 allowing the weed mat to be opened and granular fertilizers to be applied underneath. The mulches are further characterized for their properties in Sullivan et al. (2015). Weeds were removed by hand-weeding from plots mulched with sawdust and weed mat (i.e., the planting hole area) and were controlled using OMRI-approved (Organic Materials Review Institute) post-emergent acetic acid (20%; WeedPharm[®], Pharm Solutions, Inc., Port Townsend, WA), lemon grass oil or d-limonene (GreenMatch EX[®] and Avenger[®], respectively, Cutting Edge Formulations, Inc., Buford, GA), and propane flaming in addition to hand-weeding in plots mulched with compost + sawdust. Labor and product costs were recorded (Julian et al., 2012).

Fertilizer rate and source treatments were granular feather meal (ranging from 11% to 13% N, depending on product or batch) or fish emulsion (4% to 5% N) applied initially at “low” and “high” rates of 29 and 57 kg·ha⁻¹ N, respectively, during the first few years of establishment (2007-2009) and then increased incrementally as the planting matured to 73 and 140 kg·ha⁻¹ N, respectively, by 2013. In 2007-14, feather meal was broadcast on top of the organic mulches or under the weed mat (around plants from 2007-2010 and opened for application to the in-row area from 2011-2014) with half of the total nitrogen (N) applied in March and the other half in May. Fish emulsion was diluted (1 part to 10 parts water v/v) and was applied by hand as a drench around the base of the plants in 2007-2009, side-dressed with a sprayer on each side of the row

in 2010, and injected through the drip system (fertigated) in 2011-14 in seven equal applications every 2 weeks from mid-April to early July.

From the first (2008) through the eighth (2014) fruiting seasons, ripe fruit were harvested by hand approximately every 7 days. In 2011-2014, the planting was sprayed weekly with a spinosad (metabolites of *Saccharopolyspora spinosa*) insecticide (Entrust[®] SC; Dow Agro Science, Indianapolis, IN), from the time when ‘Liberty’ fruit first turned blue through harvest, to help control Spotted Wing Drosophila [*Drosophila suzukii* (Matsumura)]; applications to the early-season ‘Duke’ were not required as insect populations were very low. In 2013-2014, the fungicide *Bacillus subtilis* (Serenade[®] MAX; AgraQuest, Davis, CA) was applied in spring for control of gray mold (*Botrytis cinerea* Pers.) per label rate and recommendations. No other pesticides were required during the study period. Scare alarms (Bird Gard LLC, Sisters, OR) were used for bird control. To determine the returns per treatment, fruit were sold to a commercial organic berry packer (fresh and processed markets). Additional information on data collection is provided in Larco et al. (2013a, 2013b). Analysis of all treatment effects on measured variables was done as a complete factorial for a split-split plot design using the PROC MIXED procedure in SAS software package version 8 (SAS Institute, Cary, NC). Contrasts were used to compare the effect of fertilizer rate and source and compost type on measured variables. Means were separated at the 5% level using Fisher’s protected LSD test.

2.1.2. Blueberry, cultivar adaptation

Ten cultivars (Duke, Bluecrop, Reka, Bluejay, Bluegold, Draper, Legacy, Liberty, Ozarkblue, and Aurora) were established in October 2006 at the certified organic planting site described above (2.1.1.). Plants were either grown with a) pre-plant amendment (a combination of municipal yard debris compost and Douglas fir sawdust), incorporated prior to forming the

183 raised beds and planting, topped with a mulch of the same yard debris compost and sawdust or b)
184 no pre-plant amendment, but including a mulch of Douglas fir sawdust topped with weed mat (as
185 described in 2.1.1.). Each experimental unit consisted of a 5-m plot containing seven plants. The
186 experimental design was a balanced split-plot with amendment–mulch treatment as the main plot
187 and cultivar as the split plot with two replicates. Data were collected on yield and fruit quality
188 [berry weight, firmness, and total soluble solids (TSS)] from 2008-2013. In six of the cultivars
189 (Duke, Bluecrop, Draper, Legacy, Liberty, and Aurora) leaves were sampled every 2 weeks
190 throughout the growing season in 2013-2014 to determine changes in tissue nutrient
191 concentration over time. Further information on planting establishment and data collection are
192 provided in Strik and Vance (2015). Analysis of all treatment effects on measured variables was
193 done using the PROC MIXED procedure in SAS software package version 8 (SAS Institute,
194 Cary, NC). Mean comparison was performed using LSMEANS.

196 2.2. *Blackberry*

197 2.2.1. *Blackberry organic systems trials for processing*

198 The ~0.4-ha research trial was planted in May 2010 using tissue-cultured plug plants.
199 Plant spacing was 1.5 m in the row and 3 m between rows (2222 plants/ha). Weeds around the
200 small plants were removed by hand in the planting year. Any primocanes that grew in 2010 were
201 pruned off to crown height in the following winter such that only primocanes grew in 2011 per
202 standard commercial practice (Harkins et al., 2013; Strik and Finn, 2012). The plants were drip
203 irrigated, and irrigation rate was adjusted to maintain soil water content at similar values across
204 treatments. An OMRI-approved fish hydrolysate and fish emulsion blend was diluted (1 part to
205 10 parts water v/v) and applied through the drip system (4% to 5% N, depending on product and

batch). The fertilizer was divided into eight equal applications (approximately every 2 weeks from early April to late-June or early July) and applied at a total rate of 56 kg·ha⁻¹ N in 2010-2012 and 90 kg·ha⁻¹ N in 2013-2014 (based on percentage of N as stated on the label). The planting was certified organic in the first cropping year (2012).

There were 24 treatment combinations arranged in a balanced factorial ($2 \times 2 \times 3 \times 2$) split-split-split plot design with five replicates and included a row of ‘Marion’ and a row of ‘Black Diamond’ blackberry as main plots, two irrigation strategies (postharvest and no postharvest irrigation) as subplots, and a combination of three weed management strategies (weed mat, hand-weeded, and non-weeded) and two primocane training dates (August and February) as sub-subplots. Each sub-subplot consisted of four plants and was separated from plants in adjacent plots by 3.0 m to provide space for clearing the machine harvester. Treatments are briefly described here but more information is provided by Dixon et al. (2015). Data were analyzed using PROC GLM in SAS (SAS Institute Inc., Cary, NC), and means were separated at the 5% level using Fisher’s protected LSD test.

The three weed management treatments were: 1) “non-weeded” where weeds were not removed from 2011-2014, but were cut to soil level just prior to machine harvest (early July) to avoid any interference with the catcher plates; 2) “hand-weeded” where weeds were removed by hand hoeing on three to four dates per year (2010-2014); and c) “weed mat” where plots were covered in a 1.4-m-wide strip of black, woven polyethylene ground cover (TenCate Protective Fabrics; OBC Northwest Inc., Canby, OR) centered on the row just prior to planting; openings were cut for each plant, creating a planting hole. Weeds were removed from the planting hole area and seams in the weed mat, as required annually.

Plants were irrigated with a single lateral of drip tubing (UNIRAM; Netafim USA, Fresno, CA; 1.9 L·h⁻¹ in-line every 0.6 m), placed along the ground at the base of the plants under the weed mat or attached to a trellis wire at 0.3 m above the ground in the non-weeded and hand-weeded plots. The cultivar, irrigation, and weed management treatment combinations were irrigated independently based on estimates of crop evapotranspiration (ET), plant water status, and soil water content (Dixon et al., 2015). Irrigation was applied in the postharvest irrigation treatment the entire dry season from early May through late-September to early October in 2012-2014. In the “no postharvest irrigation” treatment, irrigation was initiated on the same dates in spring but withheld after the last fruit harvest (in mid- to late-July 2012-2014). Thus the latter plots received no additional water until the rainy season began in late September to early October depending on the year.

Primocanes in the August-trained treatment were trained to two upper trellis wires (at 1.0 m and 1.6 m) in mid- to late August of 2012-2014, after pruning out the senescent floricanes, using the method described by Dixon et al. (2015). In the February-trained treatment, primocanes were left in a bundle near the ground throughout the growing season and subsequent winter until they were trained to the upper trellis wires in late February 2013-2014.

In 2012-2013, the efficacy of fertigation with an OMRI-approved fish hydrolysate and fish emulsion blend (TRUE 402; 4N–0P–1.7K; True Organic Products, Inc., Spreckels, CA) and a natural microbial digestion of corn steep liquor and ground fish waste (AgroThrive 2.5N–1.1P–1.2K; AgroThrive, Inc., Morgan Hill, CA) was evaluated based on drip emitter performance with or without flushing of the system (Fernandez-Salvador et al., 2015a). Additional information on fertilization and planting maintenance can be found in Harkins et al. (2014, 2013), Dixon et al. (2015) and Fernandez-Salvador (2015a). Data were analyzed using PROC GLM in SAS (SAS

Institute Inc., Cary, NC), and means were separated at the 5% level using Fisher's protected LSD test.

Ripe fruit were harvested twice weekly from late June to mid-July (2012-2014), using an over-the-row rotary machine harvester (Littau Harvesters Inc., Stayton, OR). Data were collected on yield, berry weight, percent fruit moisture and TSS as well as plant growth and biomass (Dixon et al., 2015; Fernandez-Salvador et al., 2015a; Harkins et al., 2013).

2.2.2. Blackberry organic trials for fresh market

Four trailing blackberry cultivars (Obsidian, Black Diamond, Metolius, Onyx) and two advanced selections (ORUS 1939-4 and ORUS 2635-1) were evaluated from 2010-2013 in a certified organic blackberry planting at the North Willamette Research and Extension Center, described above in 2.2.1. 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·ha⁻¹ N in 2010-2012 and 90 kg·ha⁻¹ N in 2013. Fruit were hand harvested in 2012 and 2013, the first and second fruiting seasons, respectively. The study was arranged as a balanced randomized complete block design with four replicates each of the six blackberry genotypes. Plant spacing was 1.5 m in the row and 3 m between rows (2222 plants/ha). Data were collected on plant growth, yield, and fruit quality. More information on planting establishment, maintenance and data collection may be found in Fernandez-Salvador et al. (2015c). Data were analyzed using PROC GLM in SAS (SAS Institute Inc., Cary, NC), and means were separated at the 5% level using Fisher's protected LSD test.

A separate trial was conducted from 2011-2012 at a certified organic site of a grower-collaborator located in Jefferson, OR. Three trailing blackberry cultivars (Marion, Black Diamond, and Obsidian) and one semi-erect cultivar (Triple Crown) were studied for their

response to different types of fertilizer from 2011-12. Plants were drip irrigated, and weeds were managed using a polypropylene, permeable landscape fabric (weed mat). All cultivars were fertilized at a target rate of 56 kg·ha⁻¹ N in spring 2011 and 2012 using three different sources: 1) a liquid fish and molasses blend (“TRUE 402”; 4N–0P–1.7K; True Organics, Spreckels, CA); 2) pelletized soy (*Glycine max*) meal (8N–0.4P–1.7K; Phyta-Grow[®] Leafy Green Special[™]; California Organic Fertilizers, Hanford, CA); and 3) pelletized, processed poultry litter (4N–1.3P–2.5K–7Ca; Nutri-Rich[®], Stutzman Environmental Products, Canby, OR). All fertilizers were applied under the weed mat (by opening, applying the product and then re-closing the weed mat). The fish fertilizer was diluted (1 part to 10 parts water v/v) prior to applying in four equal portions from late April to early June. The granular soy meal and poultry litter were applied in late April.

Treatments were arranged in a balanced split-plot design with three replicates and included the four cultivars as main plots and three fertilizer sources as subplots (Fernandez-Salvador et al., 2015b) for more information. Data were analyzed using PROC GLM in SAS (SAS Institute Inc., Cary, NC), and means were separated at the 5% level using Fisher’s protected LSD test.

3. Key results and discussion

3.1 Bed configuration in blueberry

Blueberry plants may be grown on flat ground or on raised beds, which improve drainage and soil aeration thus reducing the incidence of root rot (Bryla and Linderman, 2007; Bryla et al., 2008) and improve root growth (Larco et al., 2013a). Raised beds also increase machine-harvest

efficiency (Strik and Buller, 2002). Prior to our study, there had been no long-term comparison of flat ground to raised-bed production and we hypothesized that mechanical methods of weed control might be possible in flat ground production (Sciarappa et al., 2008) that were not possible with raised beds. However, we quickly observed that during establishment (the first 2 years), blueberry plants grown on raised beds produced 33% higher yields than those on flat ground (Larco et al., 2013a), warranting the added establishment costs and leading to greater economic returns (Julian et al., 2012). In addition, cumulative yield per plant (2008-2014) averaged 21% higher on raised beds than on flat ground, likely due to increased root growth (Valenzuela-Estrada et al., 2011b). The majority of blueberry growers in this region now establish blueberry fields on raised beds.

3.2 Impacts of weed management systems on yield, quality, and costs

3.2.1 Blueberry

For the weed management strategies evaluated in the organic blueberry production systems trial, we used various methods to control weeds, because judicious weed control is critical for good growth and yield in blueberry (Krewer et al., 2009). We found an effect of mulch type on yield, despite weeds being controlled in all treatments. In the first fruiting year (2008), yield per plant was highest with weed mat and lowest with sawdust mulch (Larco et al., 2013a). Plants grown on weed mat had a higher shoot-to-root ratio (Larco et al., 2013a) perhaps a result of higher soil temperatures measured under weed mat than under the sawdust mulches (Larco, 2010; Valenzuela-Estrada et al., 2011a). However, more irrigation water was required in the weed mat mulch, relative to the organic mulches, particularly for plants grown on raised beds during establishment (Larco, 2010) and through maturation (Strik et al., unpublished). There was

no significant main effect of mulch (averaged over planting method, cultivar, fertilizer source and rate) on cumulative yield per hectare (2008-2014), but the contrast comparing weed mat to the organic mulches (sawdust and compost + sawdust) indicated the 4% greater yield for weed mat was significant ($P < 0.05$). There were also some interaction effects of mulch when the cultivars were grown on raised beds and fertilizer source was considered (3.4.1).

When plants were young, berry weight was lower when ‘Duke’ was grown with weed mat compared to the organic mulches. However, the opposite was found in ‘Liberty’ (Larco et al., 2013a). While weed mat did reduce average berry weight over the seven fruiting seasons, the range of 2.19 g (weed mat) to 2.23 g (sawdust) found was not commercially relevant (data not shown). Mulch type had no consistent effect on fruit firmness or TSS through the study period and no average effect over the 7 years (data not shown). In Georgia, rabbiteye blueberry (*V. virgatum* Ait.) established with organic mulches had a similar yield to those with weed mat in the first 2 years of establishment, but higher yields in years 3 - 5 (Krewer et al., 2009).

More weeds were found in the compost + sawdust mulch than the sawdust mulch alone throughout the study period (Julian et al., 2012) as also reported by others in blueberry (Burkhard et al., 2009). While the compost was initially free of weed seeds, the upper layer of dry sawdust eroded through wind and hand-pulling of weeds, thus bringing the nutrient rich, moist compost to the surface. Weed seeds that blew into the planting appeared to germinate readily in this compost layer.

In certified organic systems, chemical options for weed control are limited to directed applications of acetic acid (20% vinegar), lemon grass oil or d-limonene, and hand removal. The approved organic burn-down herbicides performed poorly on established weeds in our study (Larco, 2010; Julian et al., 2012) and others in Georgia (Tertuliano et al., 2012). Propane flaming

worked reasonably well on smaller weeds (Julian et al., 2012; Larco, 2010), but may damage the crop plant (Granatstein and Mullinix, 2008) or be a fire hazard in plantings mulched with organic materials such as sawdust. We found almost complete weed control with weed mat in the row although weeds did appear in the cut planting hole area thus requiring hand removal (Julian et al., 2012; Larco, 2010). Sciarappa et al. (2008) also found almost complete control of weeds when using weed mat plus a mulch of coffee grounds around the planting hole in organic blueberry in New Jersey, USA.

In an economic analysis of the weed management strategies studied, we noted the costs of installation (product and labor) were \$US3065/ha, \$4497/ha, and \$5652/ha for the weed mat (when amortized over 5 years), sawdust, and compost + sawdust mulches, respectively (Julian et al., 2012). Cumulative net returns for 2006 (planting establishment) through 2009 (second fruiting season) averaged -\$36,874 for weed mat, -\$41,568 for sawdust, and -\$44,068 per hectare for compost + sawdust (net loss during establishment years); losses were greater for compost + sawdust due to the high weed management costs associated with this mulching strategy (Julian et al., 2012).

Weed mat has become very common in organic as well as conventional blueberry fields in the Pacific northwestern United States, thus reducing costs of herbicides and hand weeding. The costs of producing organic and conventional blueberry were estimated by Julian et al. (2011a, 2011b). The cash costs to establish a new planting of conventional blueberry can surpass \$US30,165/ha and result in return of -\$9995/ha (a net loss) during the first 6 years (Julian et al., 2011a). In contrast, the cash costs required to establish a “typical” organic blueberry field were higher at \$32,520/ha, but the net return through year 6 was \$6,930/ha (Julian et al., 2011b). In plantings yielding 18 t·ha⁻¹ per year, the break-even price (to cover total costs for the year) was

estimated to be \$3.08/kg for organic blueberries produced in Oregon (Julian et al., 2011b) and \$10/kg in southern California (Takele et al., 2007). In Georgia, net returns were estimated to be higher for organic than conventional rabbiteye production over a 6-year period despite a lower yield in organic plots (Tertuliano et al., 2012). However, net returns are impacted greatly by the production system used, yield, and fruit prices (Julian et al., 2012).

3.2.2 *Blackberry*

The possibility of ceasing irrigation of blackberry plants after harvest in our dry summers (for August and September) was appealing as this would aid in weed control. Some blackberry growers in Oregon do not irrigate at all and some use this practice to try to increase winter cold hardiness, especially in the cold-sensitive cultivar Marion (Bell et al., 1995, 1992). In our trial, we found no effect of deficit irrigation after fruit harvest on yield, saving an estimated 1 million L·ha⁻¹ over the 2 years of the study (Dixon et al., 2015). In addition, ‘Marion’ plants that were deficit irrigated had less cold damage than those that received irrigation all summer (Dixon et al., 2015). ‘Marion’ plants also had more cold injury when grown in non- and hand-weeded plots and when trained in August versus February. However, when weed mat was used as a mulch, training in February resulted in greater cold injury perhaps because the canes were more vigorous, delaying acclimation relative to those in weedy plots (Dixon et al., 2015). August training has been shown to increase risk of cold injury in grower fields in susceptible cultivars (Bell et al., 1992).

In non-weeded plots, the tall weeds did not interfere with machine harvesting as they were cut to soil level just prior to harvest using a scythe. There were no obvious treatment effects on the presence or absence of insect harvest contaminants.

Trailing blackberry plants grown with weed mat were more vigorous than those grown in hand-weeded (bare soil) plots and with no weed control producing 25% and 100% higher yields, respectively (Dixon and Strik, 2015). There was an interaction between cultivar and weed management strategy on cumulative machine-harvested yield (2012-2014), mainly because there was a greater positive effect of weed control on yield of ‘Black Diamond’ than of ‘Marion’ (Fig. 1A). Also, ‘Black Diamond’ had a higher yield when grown with weed mat than when hand-weeded, whereas there was no difference between these weed control methods in ‘Marion’. In addition, weed control (either by hand-weeding or weed mat) increased average berry weight (5.65 g versus 5.20 g) and fruit water content (data not shown), but reduced fruit TSS in ‘Black Diamond’ (Fig. 1B). The latter is likely a function of concentration compared to the non-weeded plots (Dixon et al., 2015; Harkins et al., 2013). The reason for the higher yield with weed mat than bare soil in ‘Black Diamond’ is not known at this time. It is possible, that the small weeds that were present prior to hoeing may still have competed with the blackberry plants and ‘Black Diamond’ and ‘Marion’ may differ in root system architecture or ability to access soil water (Valenzuela-Estrada et al., unpublished). While there was little effect of weed mat on soil temperature, this mulch may have influenced root growth (data not shown). It is possible that plants in the non-weeded plots could have benefitted from additional fertilizer applications relative to those in the weed-controlled plots. However, based on measurements of plant water status and soil water content, plants were not stressed for water (data not shown). It is clear that judicious weed control is needed to maximize yield in blackberry, as has been confirmed by others (Makus, 2011; Meyers et al., 2014).

Weed mat required a high initial investment to install (Harkins et al., 2013), but only 16 h·ha⁻¹ of labor to maintain over the 5-year study period (Dixon and Strik, 2015). The non-weeded

and hand-weeded treatments required 25 and 215 h·ha⁻¹ of labor to mow tall weeds prior to harvest and hand hoe, respectively. Total cumulative costs, including materials and installation (weed mat) over the 5 years were \$3302/ha for weed mat, \$3231/ha for hand weeding, and \$370/ha for no weeding (labor was valued at \$US15/h). However, when cumulative yield and returns were factored in, the hand-weeded and weed mat management strategies increased net returns by 40% and 71% compared to non-weeded plots, respectively. In addition, weed mat had a 22% higher cumulative net return than the hand-weeded treatment (Dixon and Strik, 2015). It is clear from our studies to date that organic growers should seriously consider using weed mat for weed management in machine-harvested organic trailing blackberry.

3.3 Impacts of weed management systems on soil and plant nutrients

3.3.1 Blueberry

We analysed the organic mulch materials used in our organic research trials for nutrient content (Table 1). The municipal yard debris compost was added as a component of one of the mulch treatments because of hypothesized organic matter, nutrient, microbiological benefits (e.g., Forge et al., 2003), and a low soluble salt (EC), as blueberry plants are sensitive to high levels of salt (Larco et al., 2014). Yard debris compost is produced by Oregon municipal composting programs and typically costs 1.5 to 2 times more than sawdust. While we have not yet measured impacts of mulches on soil microbiology, we have noted differences in soil properties and nutrients. Because organic sources of N are expensive and often laborious to apply, the potential for a slow-release N benefit from compost is of great economic significance. The slow-release N provided by the yard debris compost was estimated at roughly 25 kg·ha⁻¹·yr⁻¹

(3% of total compost-N applied), based on experience with similar composts applied before planting in grass (Sullivan et al., 2003) and sweet corn (Gale et al., 2006).

The sawdust used had a high carbon-to-nitrogen ratio ($C:N > 495$) and thus likely contributed few nutrients to the soil during the study period (Table 1). In contrast, the yard debris compost contained high N, P, K, Ca, and Mg and with the low C:N ratio (24) was likely a significant contributor to soil and/or plant nutrient status (Sullivan et al., 2015).

Although compost supplied a high rate of total N, estimated at $25 \text{ kg} \cdot \text{ha}^{-1}$ N per year of the study, it apparently supplied low amounts of plant-available N. The addition of compost to the mulch had no effect on blueberry leaf N concentration in 2007-2008 (Larco et al., 2014, 2013b), but did increase leaf N compared to sawdust alone in 2009 and 2013 (data not shown). Leaf N concentrations, on the other hand, were below published sufficiency levels (1.76–2.0%; Hart et al., 2006b) in all treatments in 2012-2014, despite reaching commercially acceptable yields of $10\text{--}18 \text{ t} \cdot \text{ha}^{-1}$.

Compost contained $5.6 \text{ g} \cdot \text{kg}^{-1}$ K on a dry-weight basis compared to $0.05 \text{ g} \cdot \text{kg}^{-1}$ K for sawdust (Larco et al., 2014), leading to a 60% increase in soil K compared to sawdust alone by the sixth year (Sullivan et al., 2015). Leaf K concentration was higher in 5 of 7 years when compost was added to the mulch compared to sawdust alone (data not shown). Our previous research demonstrated a potential long-term problem with too much K in compost (Costello, 2011) and high soil K has been observed to induce Mg deficiency in blueberry plants (Eck, 1988; Krewer and Ruter, 2012).

Addition of compost in the mulch increased soil Ca, Mg, and pH relative to the sawdust mulch alone. However, differences in soil nutrient levels were not always reflected in leaf nutrient concentrations (Sullivan et al., 2015). Adding compost to the mulch also increased soil

organic matter, averaging 3.9% compared to 3.3% with sawdust alone. In contrast, soil organic matter under the weed mat was significantly lower averaging 3.1%. Weed mat also increased soil nitrate- and ammonium-N ($\text{NH}_4\text{-N}$), Ca, and Mg in autumn, compared to sawdust mulch alone (Larco et al., 2013b; Sullivan et al., 2015) likely a result of a reduction in soil nutrients at the sampling depth from leaching with rainfall. Soil pH remained within the recommended range for blueberry (4.5 to 5.5; Hart et al., 2006b) during the course of the study for all mulches, and the use of a high-pH compost (e.g. pH 7 for the mulch used) as part of a mulching program may help mitigate the decline in soil pH that occurs with long-term fertilization. We continue to evaluate whether sustained compost use as part of a fertilization and mulching program may adversely affect soil and blueberry plant health.

While including a high-pH compost as part of a mulching program may be of benefit, we found that incorporating a yard debris compost (pH of 7.5; $\text{EC } 0.7 \text{ dS}\cdot\text{m}^{-1}$) prior to planting followed by adding a small amount of the same compost to the surface mulch increased soil pH significantly compared to no pre-plant amendment and sawdust topped with weed mat as a mulch. Soil pH was 6.2 and above the recommended range for blueberry (Hart et al., 2006b) in the amended plots compared to 5.3 in the weed mat mulched plots, leading to differences in plant leaf nutrient concentration, growth, and yield from establishment through plant maturity (Strik and Vance, 2015).

3.3.2 Blackberry

In organic trailing blackberry, the use of weed mat as an in-row mulch increased soil K, Mg, Mn, and Al when measured in autumn of each of the study years (2012-2014) and increased soil Ca, $\text{NH}_4\text{-N}$, pH, and organic matter content in 2013 and 2014 compared to the hand-weeded or bare soil treatment (Dixon et al., unpublished; Harkins, 2013). The increased organic matter

content under the weed mat is in contrast to what we found in blueberry, when compared to sawdust mulch (Strik et al., unpublished; Sullivan et al., 2015), and others have found in apple (*Malus x domestica* Borkh.) (Choi et al., 2011) and may have been a result of greater root growth in the sampled region in weed mat than in the bare soil treatment (Valenzuela-Estrada et al., unpublished). In blackberry, as much as 84 kg·ha⁻¹ K is removed from the plant in harvested fruit and pruned floricanes, and removal of K was 41% and 24% greater in weed mat than in the non- and hand-weeded treatments, respectively (Harkins et al., 2014). Despite the greater losses with weed mat, the soil K level was still higher than in the hand-weeded plots. Other than higher Al concentration in primocanes, there was no consistent effect of soil nutrient content on primocane leaf nutrient concentration (Dixon et al., unpublished; Harkins et al., 2014). Weed mat did increase fruit Ca concentration (0.21 %) compared to hand-weeded and non-weeded (0.19%) treatments (Harkins et al., 2014).

3.4 Impacts of fertilizer source

We analysed all of the organic fertilizers used in our research trials for nutrient content (Table 1). Even though all of the fertilizers were applied at a similar target rate of nitrogen (based on the percentage of N as stated on the product label), there were still differences in the actual rate of N applied because the nutrient concentration in the product did not exactly match the stated concentration on the label. In addition to N, most of the organic fertilizers studied also contained high amounts of P (poultry litter, grain fermentation, and corn steep liquor), K (poultry litter, fish emulsion, grain fermentation, and corn steep liquor) and Ca and Mg (poultry litter). The impacts of addition of these nutrients when using organic fertilizer materials or products,

even when they are not required by the plants, must be considered in these organic production systems.

The available fertilizer sources differed in cost of application. For example, feather meal, soy meal and other pelletized products are applied as granular products on top of the organic mulch or under the weed mat, whereas fish emulsion and other liquid blends may be fertigated (Fernandez-Salvador et al., 2015a). However, these products also differ greatly in cost per unit of N, ranging from \$US5.60/kg for the pelletized, processed poultry litter, \$10.00/kg for the feather meal, \$11.77/kg for the soy meal, and \$17.95/kg for the fish blends (Fernandez-Salvador et al., 2015b; Julian et al., 2012; Larco et al., 2014).

3.4.1 Blueberry

Nitrogen is the predominant nutrient routinely applied to blueberry, and the best growth and yield is usually achieved with 25–100 kg·ha⁻¹ N in conventional as well as organic systems (e.g., Bañados et al., 2012; Cummings et al., 1971; Eck, 1988; Hanson, 2006; Hart et al., 2006b). The most common OMRI-approved products used as nitrogen sources in organic blueberry are fish emulsion or feather meal. Nitrogen uptake increases throughout the growing season in young plants but primarily occurs during shoot and early fruit development in the spring in mature plants (Bañados et al., 2012; Retamales and Hanson, 1989; Throop and Hanson, 1997). The current recommendation is to apply N in split applications in the spring when using granular fertilizers (April to June; Hart et al., 2006b) or to fertigate with frequent applications of low rates of N from spring to midsummer when using liquid fertilizers (Bryla and Machado, 2011). However, organic farmers commonly apply liquid fish emulsion to the soil directly, especially in young plantings. Granular feather meal and grain-based products are also commonly applied directly to the in-row area, after opening the weed mat, if present.

The rates of N and other macro- and micronutrients applied to blueberry are routinely adjusted based on leaf tissue analysis. While the patterns of nutrient changes in sampled leaves over the growing season were similar among conventional- and organically-managed blueberry cultivars, Strik and Vance (2015) speculated that tissue nutrient standards may need to be adjusted for some nutrients when plants are grown in organic systems.

We have observed cultivar differences in plant growth and yield response to fertilizer source and rate during establishment and maturation in blueberry. When plants were establishing, fish emulsion increased growth compared to feather meal, likely because N in the fish was more available to plants when needed (Larco et al., 2013b; Valenzuela-Estrada et al., unpublished). In later years, when the first application of feather meal was made earlier to improve N availability, there was little effect of fertilizer source and rate in ‘Liberty’, on average, whereas ‘Duke’ had higher yields when fertilized with feather meal than with fish emulsion. When we began our research, the most common production system used in organic fields was growing blueberry on raised beds, mulching with sawdust and fertilizing with the higher rate of fish emulsion. When we compared cumulative yield in our study to this industry standard, there was no significant effect of any other mulching or fertilizer source treatment on yield of ‘Liberty’ (Fig. 2). However, in ‘Duke’ use of feather meal increased yield in all mulch types compared to when fish emulsion was used as the fertilizer source.

In ‘Duke’, fertilization with the low rate of fish emulsion led to greater cumulative yield than with the high rate of fish emulsion (data not shown). High rates of fertilizer, particularly of fish emulsion, have reduced soil pH over time (Strik et al., unpublished), which is a concern because soil pH management is critical in blueberry (Hart et al., 2006b).

3.4.2 Blackberry

Nitrogen is the predominant nutrient routinely applied to blackberry, and the best growth and yield is usually achieved with 28–56 kg·ha⁻¹ N during the establishment year and 45–84 kg·ha⁻¹ N during subsequent years in conventional and organic systems (Bushway et al., 2008; Hart et al., 2006a; Kuepper et al., 2003). The most common OMRI-listed fertilizers applied to organic blackberry are fish emulsion, pelletized chicken litter, soybean meal, and feather meal (Table 1). 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 divide the total recommended rate of N into equal, “split” applications, generally from April through June (Hart et al., 2006a).

In trailing blackberry grown for processing, we evaluated two sources of organically-approved liquid fertilizer – a corn steep liquor and fish waste digestion as well as a fish solubles and molasses blend (Table 1; Fernandez-Salvador et al., 2015a). While ‘Marion’ and ‘Black Diamond’ differed in plant growth and yield during the study, there was little effect of fertilizer source on plant performance. Primocane leaf tissue nutrient concentrations were within recommended levels for all nutrients, except for a low Ca and B, and primocane leaf K and Zn were greater with fish emulsion than with corn as the fertilizer source, likely a result of the higher rate of K and Zn applied with fish emulsion (Table 1). When pelletized, processed poultry litter, soybean meal, and fish emulsion were compared at an organic, grower-collaborator site, no differences in the performance of ‘Obsidian’, ‘Marion’, ‘Black Diamond’, and ‘Triple Crown’ blackberry cultivars were noted (Fernandez-Salvador et al., 2015b).

A liquid fish emulsion was successfully used to establish the organic blackberry planting from 2011-2013 (Harkins et al., 2013) and during maturation (Dixon et al., 2015) with no noted adverse effects on drip system emitter performance. While Fernandez-Salvador et al. (2015a)

noted no difference among fertigated corn- and fish-based liquid fertilizers on emitter flow rate of the drip system during the 2 years of study, the flow rates did decline an average of 4.5% in the first year and 19% in the second year. It is clear that judicious cleaning of the drip system in spring and fall would be necessary to try to maintain performance over the life of the irrigation system for efficient irrigation and fertigation.

3.5 Cultivar adaptation

3.5.1 Blueberry

A wide range of cultivars are grown in this region for the fresh and processed markets (Strik et al., 2014). When evaluating ten northern highbush blueberry cultivars in two certified organic production systems, all cultivars responded well from establishment through maturation, but cultivars differed in their apparent tolerance to the higher soil pH resulting from yard debris compost as a pre-plant amendment and as part of the mulching program (see 3.3.1). For example, ‘Aurora’, ‘Bluejay’, ‘Duke’, ‘Legacy’, and ‘Ozarkblue’ had lower yield when yard debris compost was incorporated prior to planting (compared to no pre-plant amendment), likely due to the higher soil pH (6.2). In contrast, ‘Bluecrop’, ‘Bluegold’, ‘Draper’, ‘Liberty’, and ‘Reka’ did not differ in yield between these planting systems. It is clear that maintaining soil pH within the current recommended standard of 4.5 to 5.5 is important for many cultivars for optimal growth and production (Hart et al., 2006b; Strik and Vance, unpublished). Cultivars also differed in their growth and yield response to fertilizer source in our trials (see 3.4.1). The differences among cultivars in the measured fruit quality parameters were similar to what has been observed in conventional production systems (data not shown). In southern highbush blueberry, fruit from plants fertilized with 11 different organic fertilizer treatments within the same field showed little

difference in post-harvest fruit quality parameters as compared to unfertilized and conventionally fertilized plants (Echeverría et al., 2009). In contrast, Wang et al. (2008) reported that ‘Bluecrop’ fruit harvested from different organic blueberry farms had higher TSS, malic acid, total phenolics, total anthocyanins, and antioxidant activity (ORAC) than fruit from conventionally managed farms. In contrast, rabbiteye cultivars differed in total phenolics, anthocyanins, and ORAC values, but no consistent difference between organic and conventional production systems was found (You et al., 2011).

3.5.2 *Blackberry*

Trailing blackberry cultivars are predominantly grown for machine-harvested processed markets in Oregon, but some are also hand-picked for the fresh market. In addition to a few trailing cultivars, erect and semi-erect cultivars are also grown to extend the fresh market fruiting season in Oregon (Finn and Strik, 2014, 2012).

In an evaluation of trailing cultivars at the North Willamette Research and Extension Center and of trailing and semi-erect cultivars at a grower collaborator site all cultivars responded well (based on yield and plant growth) to the organic production systems used, with the exception of ‘Onyx’ and ‘Metolius’, which were considered to have a low yield for commercial production (Fernandez-Salvador et al., 2015b, 2015c). Within the higher yielding genotypes, ‘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’) (Fernandez-Salvador et al., 2015c). ‘Obsidian’ and ‘Triple Crown’ fruit were sensitive to gray mold (*Botrytis cinerea*) and sun burn, respectively, depending on the year and weather (Fernandez-Salvador et al., 2015b), as has been observed in conventional production.

In the fourth year of a 5-year trial of ‘Marion’ and ‘Black Diamond’ trailing blackberries grown in various organic production systems, an infestation of raspberry crown borer [*Pennisetia marginata* (Harris)] was observed and treatment effects noted (Dixon et al., 2015). The larvae of this insect bore into and damage lower canes and the crown of raspberry (*Rubus idaeus* L.) and blackberry plants. Symptoms of infestation were evident during training in August where affected primocanes were wilted or “flagging” at the cane tip. These canes broke at the crown easily. In organic production, where options for pest control are limited, the recommended control method for raspberry crown borer is removing and burning infested plants (DeFrancesco et al., 2015). A sex pheromone component for raspberry crown borer has recently been developed and was successful in capturing males in wing traps (Judd et al., 2012; Teasdale et al., 2013). In our study, wing traps with the pheromone bait (Evergreen Growers Supply, Clackamas, OR) were deployed during the second year, as per the recommendations by Teasdale et al. (2013). However, no adult crown borers were captured, despite the presence of the larvae in the field (Dixon et al., 2015). While cultivar differences in susceptibility to this insect pest have not been noted in red raspberry (Breakey, 1963), we found that ‘Black Diamond’ was affected by this insect in 2013-2014, while ‘Marion’ was not (Dixon et al., 2015). It is possible that the thornless canes and dark green foliage found in ‘Black Diamond’ are more attractive to the pest than the thorny canes and lighter green leaves found in ‘Marion’.

4. Conclusions

Certified organic research trials over 5 and 8 years in blackberry and blueberry, respectively, affirmed that these crops may be successfully grown in long-term systems for

processed or fresh markets, but the production system can greatly affect plant growth, yield, and economic returns.

The various mulches tested for weed control in blueberry resulted in relatively little difference in yield or fruit quality over the 8-year study. However, mulch type impacted weed control costs, root growth and soil and plant nutrient status. Weeds became more prevalent in the mulch that included yard debris compost, thus increasing hand removal costs because the organically-approved herbicides were of limited effectiveness. Mechanical methods of weed control would not be effective in plantings on raised beds which were shown to produce a significantly higher yield than plantings on flat ground. Use of weed mat as a barrier to weeds was the most cost effective weed management strategy in our study.

Weed mat led to increased soil temperature and an increase in the shoot-to-root ratio of blueberry plants during establishment relative to sawdust mulch; we are currently assessing the impact of these mulches on biomass allocation in mature plants. More irrigation was required to maintain the same soil water content when weed mat was used relative to sawdust mulch.

The municipal yard debris compost used in the study as part of a mulching program was nutrient rich, increased soil organic matter and helped mitigate the decline in soil pH that occurred with fertilization over the 8-year study. However, the estimated 25 kg·ha⁻¹ N per year released by the compost was either not available to the plants or was in excess of the N required, even at the lower rate of fertilizer N applied. The compost in the mulch increased soil and leaf K in most years. We continue to evaluate whether sustained compost use as part of a fertilization and mulching program may lead to an imbalance in soil cations and adversely affect blueberry plant health. When unmodified yard debris compost (not acidified) was added as a pre-plant amendment, soil pH increased above the recommended range for blueberry, reducing plant

growth and yield in some cultivars. Yard debris compost must thus be used with caution in blueberry production systems considering the possible increase in weed management costs when used as a mulch and the possible impacts on soil pH (unless first acidified), when used as an amendment, and K content.

The blueberry cultivars studied responded differently to fertilizer source and rate during establishment and maturation suggesting that cultivar-specific trials would be of benefit in this crop. In our study, ‘Duke’ which is considered a more difficult cultivar to grow in conventional systems, was also the more sensitive to fertilizer source and rate and soil pH in the organic systems trials we studied.

When we began our blueberry research, the most common production system used in organic fields was growing plants on raised beds, mulching with sawdust and fertilizing with high rates of fish emulsion. Our research results have confirmed that growing on raised beds is advised. However, organic production systems including weed mat and feather meal as the fertilizer source (at the low or high rate of N) performed better and had greater economic returns than the industry standard of sawdust mulch and fish emulsion. Based in large part on our findings, weed mat has become the most common mulch used since 2009 in organic and conventional plantings. However, organic growers continue to predominantly use fish emulsion, which may be economically applied by fertigation. In our study, yield in the best-performing organic systems has been comparable to those observed in well-managed conventional fields.

Some of the trailing blackberry cultivars we evaluated did not achieve commercially acceptable yields in the organic production systems tested. The trailing blackberry cultivars studied had significantly more growth and yield during establishment and maturity when weed control was used. Weed mat was an effective and economical method of weed control in this

type of blackberry which does not produce new primocanes from root buds (only from the crown). In addition, plants grown with weed mat performed better than those in hand-weeded plots. While weed mat did affect soil nutrient content, there was no consistent relationship with leaf nutrient concentration. Blackberry plants grown in non-weeded plots had a higher TSS, likely a result of reduced water content, but produced smaller berries and had about half the yield of plants grown with weed mat.

Withholding irrigation starting after fruit harvest had no impact on yield over two years offering savings in water use, irrigation costs, and reduced weed pressure. In addition, deficit irrigation increased cold hardiness in ‘Marion’. More information is needed on root system depth and whether there are differences among cultivars in the ability to access water from deeper parts of the soil profile. In addition, the longer-term impact of deficit irrigation needs to be assessed.

Our studies confirmed that trailing blackberry can be grown successfully in organic production systems for the machine-harvested processed market. However, economical yields were only achieved with use of weed mat in our research. At present, there is relatively little weed mat used in blackberry production in Oregon.

Risks in organic production are higher than in conventional production. For example, infestation with raspberry crown borer would have reduced the longevity of the blackberry trial planting as there are few organically-approved control methods. Our findings show promise for finding cultivars that are more tolerant to this pest.

In contrast to our findings in blueberry, there was little effect of the diverse sources of fertilizer on blackberry plant growth, yield, and fruit quality. However, in addition to N, most of the organic fertilizers studied also contained high amounts of P, K, Ca and Mg, depending on the source and this was often reflected in soil and leaf nutrient concentration. When organic

fertilizers are used, these other nutrients are added whether they are needed by the plants or not. In addition, growers should compare fertilizer sources for the cost per unit of N applied, as the sources we studied ranged from \$US5.60 to \$17.95/kg. Cost of application may also be a factor as some products are granular and would need to be applied to the in-row area under a weed mat mulch, if used, for most efficient uptake. Application through the drip irrigation was effective for the liquid fish emulsion and corn steep liquor blends we evaluated. However, we did measure a decline in emitter performance over the 2 years of study indicating that drip system flushing and good maintenance would be critical for fertilizer and irrigation efficiency.

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924

925 Table 1. Total nutrients applied in various sources of fertilizer and mulches used in organic blackberry and blueberry research trials
 926 conducted at Oregon State University's North Willamette Research and Extension Center, Aurora, Oregon, USA.

Product	Macronutrients (kg·ha ⁻¹)						Micronutrients (kg·ha ⁻¹)					
	N ^z	P	K	Ca	Mg	Na	B	Fe	Mn	Cu	Zn	Al
Fertilizer products^y												
Poultry litter ^x	53	31	36	161	10	6	0.1	0.2	0.6	0.1	0.6	0.4
Soybean meal ^{x,w}	49	4	17	2	2	0	0	0.1	0	0	0.1	0.1
Fish emulsion ^{x,w}	53	8	63	1	1	26	0	0.4	0	0	0.1	0.1
Grain fermentation ^x	40	22	27	3	6	1	0	0.7	0	0	0	-
Corn Steep liquor ^x	62	30	40	3	8	1	0	0	0	0	0	-
Feather meal ^w	50	1	2	3	0	0	0	0.4	0	0	0.3	-
Mulch products^v												
Sawdust	69	5	22	30	6	-	2.2	-	1.4	0.1	0.3	-
Yard-debris compost	615	97	342	613	143	-	2.0	-	27.1	0.2	6.6	-

927

928 ^zN = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; Na = sodium; B = boron; Fe = iron; Mn =
 929 manganese; Cu = copper; Zn = zinc; Al = aluminum.

930 ^yAll products were applied at the same target rate of N (56 kg·ha⁻¹) based on the product label. Fertilizers were analyzed for elemental
 931 content by Brookside Laboratories (New Bremen, OH), and actual calculated rate of elements applied is presented here. "Poultry
 932 litter": pelletized and processed, Nutri-Rich 4-3-3 (4N-1.3P-2.5K-7Ca; Stutzman Environmental Products, Canby, OR). "Soybean

933 meal”: pelletized, Leafy Green 8–1–2 (“soy”; 8N–0.4P–1.7K; California Organic Fertilizers, Hanford, CA). “Fish emulsion”: fish
 934 hydrolysate and fish emulsion with added molasses mixture (fertigated after diluting with water 1:10 v/v), TRUE 4–0–2 (4N–0P–
 935 1.7K; True Organic Products, Spreckels, CA). “Grain fermentation”: grain fermentation soluble and sodium nitrate (fertigated after
 936 diluting with water 4:1 v/v), 4–2–1 (Converted Organics of California, LLC, Gonzales, CA). “Corn steep liquor”: corn steep liquor
 937 and ground fish waste blend (fertigated after diluting with water 1:2, v/v), Agrothrive LF (2.5N–1.1P–1.2K; AgroThrive, Inc., Morgan
 938 Hill, CA). “Feather meal”: Phyta-Grow Super “N” (12N–0P–0K; California Organic Fertilizers, Hanford, CA). Nutri-Rich 4–3–3 had
 939 a pH of 8.3, TRUE 4–0–2 had a pH of 5.5, Leafy Green 8–1–2 had a pH of 6.2, Converted organics 4–2–1 had a pH of 4.1, Agrothrive
 940 LF 2.5N–1.1P–1.2K had a pH of 3.98, and Phyta-Grow super “N” had a pH of 7.0. Adapted from Fernandez-Salvador et al. (2015b,
 941 2015c) and Strik and Vance (unpublished).
 942 ^xUsed successfully in organic blackberry research trials.
 943 ^wUsed successfully in organic blueberry research trials.
 944 ^yNutrients for the volume applied in 2013 as follows: “Sawdust”: Douglas fir (*Pseudotsuga menziesii* M.) applied to the in-row area
 945 at a depth of 9 cm (360 m³·ha⁻¹), pH 4.1. “Yard-debris compost”: municipal waste from yards, composted, applied to a depth of 4 cm
 946 to the in-row area (152 m³·ha⁻¹), pH 7.5. Strik and Vance (unpublished).

Fig. 1. Impact of three weed management strategies on **A.** cumulative yield (2012-2014) and **B.** fruit total soluble solids (TSS) of trailing blackberry cultivars Black Diamond and Marion grown in a certified organic machine-harvested research trial at Oregon State University's North Willamette Research and Extension Center, Aurora, Oregon, USA. Averaged over training time and post-harvest irrigation treatments. Letters above bars indicate mean comparison ($P < 0.05$; $n = 10$) using a protested LSD test.

Fig. 2. Effect of mulch type (sawdust, compost + sawdust, and weed mat) and fertilizer source (fish emulsion or feather meal applied at the same “high” rate of N) on cumulative yield (2008-2014) of ‘Duke’ and ‘Liberty’ grown on raised beds. Yield is shown as the proportion of each treatment combination (%) relative to the industry standard (sawdust mulch and fish fertilizer; 100%). Letters above bars indicate mean comparison within cultivar ($P < 0.05$; $n = 5$), using a protected LSD test.