AN ABSTRACT OF THE THESIS OF

Emily K. Dixon for the degree of Master of Science in Horticulture presented on October 15, 2015.

Title: Weed Management, Training, and Irrigation Practices for Organic Production of Trailing Blackberry: Plant Growth, Yield, and Nutrients.

Abstract approved:

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There is limited information available on production of trailing blackberry, particularly certified organic plantings, which are of interest to growers as there is increased consumer demand and a price premium over conventionally-produced fruit. Various production strategies were evaluated for their effect on yield, biomass production, carbon (C), and nutrient concentrations and content in a certified organic trailing blackberry field grown at the North Willamette Research and Extension Center in Aurora, OR. The planting was irrigated by drip and fertigated with an Organic Materials Review Institute-listed fish hydrolysate and fish emulsion fertilizer. The study was conducted over two complete years and the planting was machine-harvested for the processed market. Treatments used in the study were: cultivar (‘Marion’ and ‘Black Diamond’), irrigation strategy [no irrigation after the final fruit harvest in July (no postharvest) and continuous summer irrigation (postharvest)], weed management strategy [nonweeded (weeds left to grow in the row), hand-weeded (weeds hoed as needed

throughout the season), and weed mat (a porous landscape fabric)], and primocane training time (August and February).

The best performing organic production systems did not depend on irrigation strategy, utilized weed mat, and used February-training (for ‘Marion’ only). When the plantings were mature, ‘Marion’ and ‘Black Diamond’ yielded as much as 9 and 11 $t{\cdot}ha^{-1}$, respectively; similar to what would be expected in conventional production. The use of weed mat consistently increased yield and vegetative growth, even when compared to hand-weeded (13% increase). ‘Black Diamond’ plants did not compete as effectively with weeds as ‘Marion’ and were more readily infested by raspberry crown borer (*Pennisetia marginata* Harris) which likely reduced yield. Unlike ‘Black Diamond’, ‘Marion’ was negatively affected by an unusually cold winter in 2014. In that year, August-trained ‘Marion’ plants had 1 kg/plant less yield than February-trained plants, as well as less biomass.

Soil pH, organic matter content, and soil ammonium-nitrogen (NH_4-N), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), copper (Cu), manganese (Mn), and zinc (Zn) concentrations were greater under weed mat than in hand-weeded plots. Several nutrients were below recommended standards in both the soil or primocane leaf tissue, including soil K, soil boron (B), and primocane leaf N, phosphorus (P), K, Ca, Mg, S, B, and Zn concentrations in at least one year or cultivar. ‘Black Diamond’ tended to have higher floricane and fruit nutrient concentrations than ‘Marion’. Use of weed mat often led to the highest nutrient concentrations in the soil, leaves, and fruit, while withholding irrigation postharvest had limited effects, and the impact of primocane training time varied among years, nutrients, and plant parts.

Aboveground dry biomass production in the planting averaged 5.75 t·ha^{-1}, approximately 50% of which was comprised of C. Floricanes, primocanes, and fruit comprised 45%, 30%, and 25% of aboveground plant biomass, respectively. The average aboveground C stock of the planting was 0.75 t·ha^{-1} in late winter. The treatment with the largest impact on dry biomass and nutrient content was weed management. Weeds reduced aboveground plant dry biomass, primocane, floricane, and fruit nutrient content, and annual gain. Using weed mat for weed control generally led to the largest dry biomass and nutrient content. February-trained 'Marion' plants lost more of most nutrients in 2014 than the year prior, although nutrient gain was not affected by cultivar. Both cultivars lost the most N in harvested fruit when weed mat was used (22 t·ha^{-1}, as compared with 18 t·ha^{-1} with hand weeding and 12 t·ha^{-1} with weeds present in 2013), although 'Black Diamond' with weed mat lost 6 t·ha^{-1} more N through fruit removal than 'Marion' in 2014. Continuous summer irrigation resulted in plants that gained more dry biomass, N, K, Mg, S, B, and Cu than those that received no irrigation after fruit harvest in one or both years. Nitrogen, K, and B were lost at higher rates than what was applied through fertilization, which would eventually lead to the depletion of those nutrients in the planting.

Both cultivars appear to be well suited for organic production, although each had their own challenges. Allowing weeds to grow in the row reduced yield, dry biomass, and nutrient concentrations and content, while both hand weeding and the use of weed mat resulted in increased growth and yield. Weed mat improved production even over hand weeding and reduced labor, making it an ideal choice in this organic system. Withholding irrigation after harvest reduced water use by an average of 44% each year without adversely affecting yield or nutrient concentrations in either cultivar, although it did reduce dry biomass and some nutrient gains. Training time mainly affected ‘Marion’, which had reduced growth and yield when primocanes were trained in August.

Weed Management, Training, and Irrigation Practices for Organic Production of Trailing Blackberry: Plant Growth, Yield, and Nutrients.

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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.

Emily K. Dixon, Author

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Dedicated to my dad
Alfred R. Dixon
1943 – 2000

Weed Management, Training, and Irrigation Practices for Organic Production of Trailing Blackberry: Plant Growth, Yield, and Nutrients.

CHAPTER 1: Introduction

Oregon produced approximately half of the almost 6000 ha of blackberry harvested in the United States in 2012 [U.S. Department of Agriculture (USDA), 2014]. Worldwide production of organic blackberries was 2500 ha in 2008 (Strik et al., 2008). Only 8% of that was harvested from certified or exempt organic farms in the United States in the same year, but consumer demand for organic products and interest in organic production systems has been steadily increasing (USDA, 2010). Oregon primarily grows trailing types for the processed market, which are typically harvested by machine (Strik and Finn, 2012; USDA, 2014). The two most popular cultivars grown are 'Marion' and 'Black Diamond', which together accounted for more than 75% of the blackberry produced in Oregon in 2012 (USDA, 2013).

While blackberry research has been ongoing (e.g., Strik and Finn, 2012), published research on the organic production of blackberries is relatively recent (e.g., Fernandez-Salvador et al., 2015a; 2015b; Harkins et al., 2013; 2014). There is an organic guide for small-scale production for the fresh market (Kuepper et al., 2003), but there is limited information on the production of trailing types for the processed market. In addition, information about mature production is limited, and it is unknown how cultivars other than 'Marion', which was used to develop the Oregon caneberry nutrient management guide (Hart et al., 2006), respond to various production practices or utilize and allocate nutrients. It is also unknown how organic fertilizers, which contain many nutrients in varying quantities, could interact with other management practices to affect blackberry growth and yield over time.

Blackberry has a growth pattern typical of *Rubus* species, with biennial aboveground canes that are produced from a perennial crown and root system. Vegetative primocanes emerge in the spring and grow throughout the summer. They go dormant and overwinter in the autumn. During their second year, they are called floricanes and produce fruiting laterals, which flower and produce fruit. After fruiting, the floricanes senesce and are removed from the plant. Primocanes and floricanes will exist on the plant at the same time in an annual or every-year production system (Strik and Finn, 2012). This partitioning of the plant into reproductive and vegetative parts allows for convenient study of differential resource allocation and utilization. Primocanes primarily acquire nutrients from the soil, while floricanes rely on stored nutrients during early fruiting lateral growth and production (Malik et al., 1991; Mohadjer et al., 2001; Naraguma et al., 1999; Whitney, 1981). The nutrient concentration and content of blackberry plant parts (especially nutrients other than nitrogen) have not been examined during mature fruit production and the carbon content of blackberry is unknown.

Trailing blackberry primocanes are trained onto a wire trellis sometime after floricane removal in summer and before budbreak in the spring, typically in either August or February (Strik and Finn, 2012). The benefits of August training include increased light exposure, flower bud initiation, and yield (Bell et al., 1995a); however there is a significant increase in the risk of cold injury in cold-sensitive cultivars such as ‘Marion’ (Bell et al., 1995b; 1992).

Controlling weeds can be very challenging in organic systems, as tools available to conventional producers, such as herbicides, are unavailable, while hand labor, which can be very effective, is also expensive. Allowing weeds to grow is one option, however, weeds compete with blackberry and significantly reduce plant growth and yield (Harkins et al., 2013; Meyers et al., 2014). Perforated landscape fabric, or “weed mat”, has been used as an effective barrier to weeds in blueberry (*Vaccinium corymbosum* L.) and in blackberry plantings during establishment (Harkins et al., 2013; Larco et al., 2013; Makus, 2011; Meyers et al., 2014).

Oregon has a Mediterranean climate with relatively hot, dry summers (U.S. Department of Interior, 2013). Blackberry plants have a high water demand during fruit production, which coincides with high air temperatures in the Pacific Northwest (Bryla and Strik, 2008; U.S. Department of Interior, 2013). Irrigation demand drops off rapidly after fruit production (Bryla and Strik, 2008), which may allow for a reduction in water use. Grower irrigation practices are varied, from drip to overhead sprinklers, and from continuous summer irrigation to no irrigation at all (Strik and Finn, 2012; B.C. Strik, personal observation). There is potential for drip irrigation to be particularly effective in organic blackberry production by reducing weed presence outside of the drip zone, decreasing canopy disease presence, and allowing for fertilization through the drip lines (fertigation). Fertigation has previously been found to be effective at delivering Organic Materials Review Institute-listed liquid materials in blackberry (Fernandez-Salvador et al., 2015a; Harkins et al., 2013).

The objective of this study was to continue the work of Harkins et al. (2013; 2014) and assess the effects of organic production practices (weed management, training time, and irrigation) on mature ‘Black Diamond’ and ‘Marion’ trailing blackberry that were machine-harvested for the organic processed market. The treatments studied were three weed management practices (nonweeded, hand-weeded, and weed mat), two primocane training times (August and February), and two irrigation strategies (continuous summer irrigation and no irrigation after fruit harvest). Treatment effects on plant growth and yield; soil pH, organic matter, and nutrients; plant nutrient status; and aboveground nutrient, carbon, and dry biomass allocation, accumulation, and removal were evaluated.

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WEED MANAGEMENT, TRAINING, AND IRRIGATION PRACTICES FOR ORGANIC PRODUCTION OF TRAILING BLACKBERRY: I. MATURE PLANT GROWTH AND FRUIT PRODUCTION

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CHAPTER 2: Weed Management, Training, And Irrigation Practices For Organic Production Of Trailing Blackberry: I. Mature Plant Growth And Fruit Production

Abstract

Weed management, training time, and irrigation practices were evaluated from 2013–2014 in a mature field of trailing blackberry (*Rubus* L. subgenus *Rubus* Watson) established in western Oregon. The field was planted in 2010 and certified organic in 2012, before the first harvest season. Treatments included two cultivars (‘Marion’ and ‘Black Diamond’), three weed management practices [nonweeded, hand-weeded or bare soil, and weed mat (black landscape fabric)], two irrigation strategies (irrigation throughout the growing season and no postharvest irrigation), and two primocane training dates (August and February). When averaged over the other treatments, ‘Marion’ and ‘Black Diamond’ had similar yields in both years. However, the presence of weeds reduced vegetative growth and yield, especially in ‘Black Diamond’, while weed mat increased growth and yield over hand-weeded plots by 13%. Withholding irrigation after harvest reduced water use by an average of 44% each year without adversely affecting yield in either cultivar. The effects of training time were primarily seen in 2014 after a cold winter. August-trained ‘Marion’ plants had more cold damage than February-trained plants and, consequently, had fewer and shorter canes, less biomass, fewer nodes, and 1kg/plant less yield than February-trained plants. ‘Black Diamond’ was cold hardier than ‘Marion’, but was more readily infested by raspberry crown borer (*Pennisetia marginata* Harris). As the planting reached maturity, yields in the best performing organic production systems (both cultivars under weed mat and ‘Marion’ that was February-

trained) averaged 11 and 9 $t \cdot ha^{-1}$, for ‘Black Diamond’ and ‘Marion’ respectively, similar to what would be expected in conventional production.

Introduction

Approximately 6000 ha of blackberry (*Rubus* L. subgenus *Rubus*, Watson) were harvested in the United States in 2012 (U.S. Department of Agriculture, 2014). Oregon was the leading producer with 2500 ha, most of which were trailing types grown predominantly for the processed market (Strik and Finn, 2012; U.S. Department of Agriculture, 2014). There were only 200 ha of organic blackberries harvested from certified and exempt organic farms in the United States in 2008, although worldwide production was 2500 ha (Strik et al., 2008; U.S. Department of Agriculture, 2010). Consumer demand for organic products has been steadily increasing, creating a price premium for organic fruit and strong interest in organic production systems.

There is a growing body of research dedicated to blackberry growth and production (e.g., Strik and Finn, 2012), but there has been relatively little published on organic production of blackberries. The Appropriate Technology Transfer for Rural America (ATTRA) has published a general organic production guide that is mainly focused on small-scale production of erect and semi-erect types of blackberry for the fresh market with little information on the production of trailing types for the processed market (Kuepper et al., 2003). In organic trailing blackberry systems, Harkins et al. (2013, 2014) studied weed management and cultivar impacts during establishment, and Fernandez-Salvador et al. (2015a, 2015b) investigated several cultivar and fertilizer options.

Weed management can be one of the most challenging and expensive issues to address in organic production, as OMRI (Organic Materials Review Institute) listed materials for weed control are limited, and removing weeds by hand is expensive. Therefore, some growers allow weeds to grow in organic blackberry plantings and only remove them prior to harvest. However, weeds compete with blackberry plants and can significantly reduce yield when left unmanaged (Harkins et al. 2013; Meyers et al., 2014). Use of a perforated landscape fabric, or “weed mat”, as a barrier to weeds within the blackberry row has been successful in blackberry plantings during establishment (Harkins et al., 2013; Makus, 2011; Meyers et al., 2014).

Most of the research published to date on trailing blackberry has been in ‘Marion’ or other older cultivars (Bell et al., 1995a, 1995b; Cortell et al., 1997a, 1997b; Julian et al., 2009; Mohadjer et al., 2001; Sheets et al., 1972; Takeda et al., 2002). However, many newer thornless cultivars, such as ‘Black Diamond’, are desirable to producers because they reduce training time and cane damage and eliminate the risk of finding thorny petioles in the machine-harvested processed end product (Strik and Buller, 2002). Thornless cultivars of trailing blackberry are also reported to be cold hardier (Finn et al., 2005). ‘Marion’ and ‘Black Diamond’ together accounted for >75% of the 2914 ha of blackberry produced in Oregon in 2012 (U.S. Department of Agriculture, 2013).

Trailing blackberry canes are typically trained onto a two-wire trellis in either late summer or late winter. Bell et al. (1995a) found that ‘Marion’ plants trained in August produced 46% greater yield than those trained in February. Despite the potential increase in yield, many growers still train in February, as canes left on the ground through the colder winter months are better protected from cold damage (Bell et al., 1992).

Irrigation practices in blackberry are varied. Most fresh market plantings are irrigated by drip, while blackberry grown for processed markets is most commonly irrigated using moveable pipe with overhead sprinklers or big gun systems (Strik and Finn, 2012; B.C. Strik, personal observation). Some growers in Oregon do not irrigate at all, even though blackberry plants have high water demands during fruit production (Bryla and Strik, 2008; Strik and Finn, 2012) and there is relatively little precipitation in summer (U.S. Department of Interior, 2013). There may be an option for an intermediate solution of turning off irrigation to blackberry after harvest instead of irrigating throughout the summer because irrigation demand drops off after fruit production (Bryla and Strik, 2008). Drip irrigation may be especially beneficial in organic production by reducing weed presence outside of the drip zone and disease problems in the canopy when compared with overhead systems. Applying fertilizers through the drip irrigation system (fertigation) has worked well using OMRI-approved products in organic blackberry (Fernandez-Salvador et al., 2015a).

The objective of the present study was to evaluate various production practices (cultivar, weed management, training time, and irrigation) for their effect on growth and organic production of mature trailing blackberry that were machine-harvested for the processed market. Two cultivars, ‘Marion’ and ‘Black Diamond’, were included in the study, along with three weed management strategies, nonweeded, hand-weeded, and weed mat. Two training dates, August and February, and two irrigation strategies, continuous summer irrigation and no irrigation after fruit harvest, were also included.

Materials and Methods

Study site. The study was carried out in 2013 and 2014 in a mature trailing blackberry planting at the North Willamette Research and Extension Center in Aurora, OR [lat. 45°16’47”N, long. 122°45’23”W; USDA hardiness zone 8b (U. S. Department of Interior, 2013); elevation 56 m]. The soil is a Willamette silt loam, classified as a fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll. The site was certified organic by a USDA accredited agency (Oregon Tilth, Certified Organic, Corvallis, OR).

The field was planted with tissue-cultured plug plants on 26 May 2010. Annual development of the planting during establishment was described by Harkins et al. (2013). Plants were trained on a two-wire vertical trellis system in each row with the wires attached to steel posts at 1.0 m and 1.6 m above the ground. Primocanes that grew in year 1 (2010, the planting year) were removed the following winter (Feb. 2011) to increase subsequent growth and promote plant establishment, as per standard commercial practice (Strik and Finn, 2012). In year 2 (2011), primocanes were trained to the trellis wires as they grew. By year 3 (2012, the first fruiting season) through year 5 (2014), plants had primocanes and floricanes (the previous year’s primocanes). New primocanes were bundled and tied to the bottom trellis wire, below the floricane canopy, until August each year. Primocanes were then trained to the upper trellis wires in late August or February, depending on treatment (see below), by dividing the primocanes produced by each plant into two bundles and looping half in one direction from the upper to middle trellis wire and bringing it back towards the plant with one or two twists; the other half was looped in the opposite direction. An every-year production system was chosen because it is the predominant production method used by growers (Strik and Finn 2012). See Harkins et al. (2013) for further details on site preparation and establishment.

Experimental design. Treatments were arranged as a 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 split-plots, and a combination of three weed management strategies (weed mat, hand-weeded, and nonweeded) and two primocane training dates (August and February) as split-split plots. Each split-split 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 (2222 plants/ha). The planting also had a plot of four border plants at the end of each row, and a border row on each side. Overall, there were 12 rows of 104 m each (0.4 ha) and a total of 120 treatment plots.

Weed management. The three weed management strategies were applied to each plot individually. Weeds were only removed from the nonweeded plots during the first year after planting (2010) to aid in plant establishment. In subsequent years, weeds in the nonweeded plots were cut to soil level just prior to machine harvest (early July) to avoid any interference with the catcher plates. The biomass removed was left in the row except for a 0.25 m^2 section located between the center plants in each plot and on the west side of the row that was collected, dried, and weighed to calculate biomass/m^2. In hand-weeded plots, weeds were removed by hand hoeing throughout the establishment years (2010–2012) and on 22 Mar., 10 May, and 19 June in 2013 and 28 Mar., 28 May, 8 July, and 8 Aug. in 2014. The extra day of hoeing in 2014 was needed to compensate for increased weed presence. The weed mat treatment 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 and secured using 0.1-m long nails. According to the manufacturer, the weed mat had a density of 0.11 $kg \cdot m^{-2}$ and a water flow rate 6.8 $L \cdot h \cdot m^{-2}$. The weed mat was placed on top of the row just prior to planting, and openings were cut for each plant ("planting hole"). Weeds were removed from the planting hole area and seams in the weed mat, as required, on 31 May 2013 and 10 June and 8 Aug. 2014. Any weeds removed from the hand-weeded and weed mat plots were left between the rows. Labor hours required to maintain the three weed management treatments were recorded.

Irrigation. Each treatment was irrigated with a single lateral of drip tubing (UNIRAM; Netafim USA, Fresno, CA). The tubing had pressure-compensating emitters (1.9 $L \cdot h^{-1}$ in-line) spaced every 0.6 m and was placed along the ground at the base of the plants under the weed mat or was attached to a third trellis wire located 0.3 m above the ground in the nonweeded and hand-weeded plots. The cultivar, irrigation, and weed management treatment combinations were irrigated independently using a manifold with electric solenoid valves and an automatic timer.

Irrigation was scheduled weekly based on estimates of crop evapotranspiration (ET) but was adjusted as needed each week to maintain similar leaf water potentials (LWP) among treatments. Crop ET was calculated by multiplying reference ET by a crop coefficient for blackberry that was downloaded daily along with weather data, including air temperature and precipitation, obtained from a Pacific Northwest Cooperative Agricultural Weather Network AgriMet weather station (U.S. Department of the Interior, 2013; Table 2.1). The weather station was located in a field of tall fescue [*Lolium arundinacea* (Schreb.) S.J. Darbyshire] approx. 0.5 km from the site. Leaf water potential was measured weekly throughout the 2012–2014 seasons after irrigation was initiated, using a pressure chamber (Model 1000, PMS Equipment, Albany, OR). The measurements were made between 12:00 and 15:00 HR on one recent fully-expanded primocane leaf in three replicate plots per treatment before the postharvest irrigation treatment was implemented and in four replicates thereafter. Irrigation was increased by 10% above the previous week's rate when mean weekly water potential in a given weed management treatment was lower than the mean of any other weed management treatment in the cultivar. In 2012, LWP was measured only on primocane leaves. Harkins et al. (2013) speculated that a cane type by weed management interaction was responsible for treatment differences seen in fruit characteristics in 2012 so floricane LWP were added in 2013. The interaction was not observed in 2013, so in 2014, only primocane LWP data were collected. Water applications were measured in each treatment using turbine water meters (model 36M201T; Netafim USA, Fresno, CA) installed in the irrigation manifold. There was no evidence of water runoff during irrigation in any treatment.

Soil water content was measured weekly, beginning after the final fruit harvest and continuing until the rainy season, using a Trase I time domain reflectometry (TDR) system (Soilmoisture Equipment Corp., Santa Barbara, CA). The TDR system was equipped with a pair of 0.4-m stainless-steel waveguides and a waveguide connector. The waveguides were installed vertically in the middle of the row between two plants in three replicates of 'Marion' plots receiving no postharvest irrigation, which included all of the training time and weed management combinations. The waveguides were located underneath or next to the drip line and 0.75 m from the adjacent two plants.

Irrigation was applied in the postharvest irrigation treatment from 9 May to 8 Oct. 2012, 17 May to 27 Sept. 2013, and 28 May to 23 Sept. 2014. In the no postharvest irrigation treatment, irrigation was initiated on the same dates but withheld after the last fruit harvest on 30 July 2012, 19 July 2013, and 15 July 2014. Thus these latter plots received no effective water until the rainy season began on 12 Oct. 2012, 21 Sept. 2013, and 23 Sept. 2014 (Table 2.1).

Primocane training. Primocanes in the August-trained treatment were trained to the upper trellis wires on 13–14 Aug. 2012, 27–29 Aug. 2013, and 14 Aug. 2014 using the method described above. In the February-trained treatment, primocanes were left on the wire for the drip lines, just above ground level, throughout the growing season and subsequent winter until they were wrapped and tied to the upper two trellis wires on 21–25 Feb. 2013 and 21–28 Feb. 2014. Primocane training was done by replicate to avoid any possible date effects within treatment over the days required to train.

Fertilization. An OMRI-approved fish hydrolysate and fish emulsion blend was diluted 1:3 (v/v) with water and applied through the drip 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). While only one injector was needed, the electric pump was installed to reduce injection time (≈ 1.5 h per application compared to ≈ 4.5 h per application with the water-driven pump). Converted Organics 421 (4N–0.8P–0.8K; True Organic Products Inc., Spreckels, CA) was used for the first four applications in 2013 and True Organics 512

(5N–0.4P–1.7K) was used for the last four applications in 2013 and all applications in 2014. The fertilizer(s) was split into eight equal applications (approximately every 2 weeks from 5 Apr. to 12 July 2013 and 19 Mar. to 25 June 2014) and applied at a total rate of 90 $kg \cdot ha^{-1}$ N per year (based on percentage of N as stated on the label). Irrigation was run for 30 min prior to injection to fully pressurize the system to 303.4 kPa and run for 2 h after injection to flush the drip lines.

Plant growth and fruit production. Primocanes (at 0.3 m height) were counted on two separate plants in each four-plant plot on 24 Jan. 2013 (for growth in 2012), 20 Feb. 2014 (for growth in 2013), and 18 Dec. 2014 (for growth in 2014) and average primocanes/plant was calculated. Individual primocanes were defined as originating at the crown or at a branch below 0.3 m and extending at least to the lower training wire (1.0 m).

Ripe fruit were harvested twice weekly from 24 June to 18 July in both years, using an over-the-row rotary harvester (Littau Harvesters Inc., Stayton, OR). 'Black Diamond' was harvested on every date in both years whereas 'Marion' was not harvested on the first or last date in either year. Marketable yield and unmarketable fruit ("culls", including overripe, damaged, rotten, or under-ripe fruit) were weighed separately. A subsample of 25 berries was randomly selected from the machine-harvested, marketable yield of each plot and weighed; a weighted average individual fruit weight was calculated for the fruiting season. The subsample was used to measure percent soluble solids (TSS; °Brix) on 5, 8, and 11 July in 2013 and 3, 10, and 15 July in 2014. The subsamples were crushed by hand in a 1-L polyethylene re-sealable bag, and the juice was used to measure TSS with a temperature-compensated digital refractometer (Atago, Bellevue, WA). A 25-

berry subsample per treatment plot was shipped overnight to Brookside Laboratories (New Bremen, OH) for analysis of fruit percent moisture on 8 July 2013 and 7 July 2014.

Senescing floricanes were removed by pruning at the base of the plant (approx. 0.1-m high) after fruit harvest on 29 July to 5 Aug. in 2013 and 30 July to 1 Aug. in 2014, per standard commercial practice (Strik and Finn, 2012). Two floricanes were randomly selected per plot, and floricane length was measured, and number of nodes/cane, laterals/cane, and fruit/lateral (subsample of 10 laterals) were counted. The number of nodes/plant was calculated by multiplying the canes/plant by the nodes/cane. Percent bud break was calculated from the nodes/cane and the laterals/cane. The total fresh biomass of the pruned floricanes was determined per plot. A subsample of the pruned canes in each plot was shipped overnight to Brookside Laboratories for analysis of percent moisture content. Dry weight was then calculated. After pruning and data collection, the floricanes were left between the rows and flail-mowed (chopped), per standard commercial practice.

During August training in 2013, primocanes were wilted or “flagging” at the cane tip. These canes broke at the crown easily. Larvae were found in these affected canes and identified as raspberry crown borer (*Pennisetia marginata* Harris). The presence of crown borer was assessed in August of both years by counting the number of plots in which at least one infested primocane was discovered when training (broken at base with larval presence identified) or a cane showed symptoms of flagging. The percentage of crown borer infestation was then calculated for each treatment.

An unusually early and extreme cold event for the region occurred in Dec. 2013 (Table 2.1). Following relatively warm autumn temperatures, the air temperature dropped to -12.4 ºC on 9 Dec. By spring 2014, cold damage was evident, based on reduced and delayed bud break and primocane necrosis. All plots were surveyed for damage on 21 Apr. using a rating system, where 1 indicated 100% of normal bud break (no visible damage) and 5 indicated extreme damage (<5% of normal bud break). Plots were rated as an average of the four plants.

Data analysis: Data were analyzed by year due to large differences in the annual weather conditions (Table 2.1). Within year, data were analyzed as a split-split-split plot design with cultivar as the main plot factor, postharvest irrigation as the split-plot factor, and weed management and training time as split-split-plots, using PROC MIXED in SAS (version 9.3; SAS Institute Inc., Cary, NC). Residuals were plotted to assess homogeneity of variance (residual by fitted value plot). When strong fanning was observed in the residual plots, the data were log-transformed prior to analysis to improve homogeneity of variance and to assess proportional effects. Data were back-transformed for presentation. Normality was assessed using a histogram of the residuals. Means from significant main effects were compared using a Tukey's honestly significant difference test with $\alpha = 0.05$. Mean comparisons from significant interactions were compared using Least Square Means (LS Means) with $\alpha = 0.05$.

Results and Discussion

This study was a continuation of the work done by Harkins et al. (2013) to assess the impact of weed management and cultivar during the establishment years. Our study was conducted in the same planting and implemented the additional treatments of no postharvest irrigation and training time.

Fruit production in 2013. ‘Black Diamond’ tended (P = 0.08) to have greater yield than ‘Marion’ in 2013 (Table 2.2). Harkins et al. (2013) also found that ‘Black Diamond’ had greater yield than ‘Marion’ during the first year of production in 2012. Total yield declined approximately 30% from the first (Harkins et al., 2013) to the second fruiting year (2013; Table 2.2). Yield was relatively high in 2012 because this was the first year in which the plants were cropped, and thus, primocanes grew without competition from floricanes in 2011 (Harkins et al., 2013). In contrast, the primocanes that grew in 2012 competed with a high number of fruiting canes (Harkins et al., 2013), which has been shown to reduce primocane growth (Cortell and Strik, 1997b; Mohadjer et al., 2001). Consequently, 2013 was expected to be a recovery year, in which fruit production on the floricanes would be lower as the planting transitioned to full production every year (Strik and Finn, 2012). Average yield from both cultivars was comparable to what would be expected from a mature, conventionally managed field grown in an every-year production system (Julian et al., 2009).

The nonweeded plots had 100% weed coverage during the course of this study (data not shown), and the aboveground weed biomass in late June was 25.3 $g \cdot m^{-2}$. The hand labor required to control weeds was 81, 412, and 95 h/ha in the weed mat, hand-weeded, and nonweeded (to cut off the aboveground biomass prior to machine harvest) management strategies, respectively. Weed management, on average, improved yield by 54% over nonweeded plots (Table 2.2). The weeds in the nonweeded plots were predominantly grasses (E. Dixon, unpublished data), which may have had a more negative impact on the blackberry plants than an intentionally planted nitrogen-fixing cover crop such as clover. Plants grown with weed mat produced a 13% greater yield than those in hand-weeded plots (Table 2.2), similar to the positive impact of weed mat reported by Harkins et al. (2013) and found in erect blackberry and blueberry (*Vaccinium corymbosum* L.) (Krewer et al., 2009; Makus, 2011; Meyers et al., 2014). Increasing the width of the weed-free strip within the row from 0 to 2 m also increased yield in erect blackberry (Meyers et al., 2014). Since hand-weeded plots were hoed several times during the season, it is possible that even the relatively young weeds present before each hoeing event competed with the blackberry plants, leading to a reduction in yield.

‘Black Diamond’ fruit were heavier and contained relatively more water than ‘Marion’ fruit (Table 2.2). Average fruit weight was 6% and 12% greater for plants grown with weed control than those grown in nonweeded plots for ‘Marion’ and ‘Black Diamond’, respectively. Weeds also reduced fruit water content, particularly in ‘Black Diamond’. Other studies have demonstrated the negative impact of weeds on fruit weight and fruit water content (Harkins et al., 2013; Meyers et al., 2014). Through 4 years after planting, ‘Black Diamond’ was not able to compete as effectively with weeds as ‘Marion’.

There was a cultivar by training time interaction on fruit water content and soluble solids (TSS). Fruit from February-trained plants contained higher TSS than fruit from plants trained in August, which was likely a concentration effect, as the fruit from the February-trained treatment also had lower water content (Table 2.2). Fruit TSS was also affected by a three-way interaction among cultivar, irrigation, and weed management (Fig. 2.1). ‘Marion’ fruit had higher TSS than ‘Black Diamond’ for all of the treatment combinations, as reported by others (Fernandez-Salvador et al., 2015a; Harkins et al., 2013). Fruit from both cultivars had the highest TSS in the nonweeded plots, consistent with the findings of Harkins et al. (2013). Meyers et al. (2014) also found that increasing the width of a weed-free strip within the row decreased TSS in erect blackberry. In our study, fruit from the nonweeded plots were smaller and had lower water content, and thus TSS may thus have been more concentrated; this effect was more pronounced in ‘Black Diamond’ than in ‘Marion’ (Fig. 2.1).

Weeds had a negative effect on many yield components. Plants grown in nonweeded plots had fewer primocanes than those grown with weed control, but there was no effect of weed management on primocane length or the number of nodes per plant, similar to what was observed by Harkins et al. (2013; Table 2.2). Meyers et al. (2014) found no effect of weeds on primocane length or number in erect blackberry. When primocanes became floricanes, their dry weight at pruning in August was significantly less in nonweeded plots, particularly in ‘Black Diamond’ (Table 2.2). There was no significant difference between weed mat and hand-weeded plots for primocane vigor or floricane dry weight (Table 2.2). Makus (2011) observed increased vigor when erect blackberry were grown with weed mat as compared to bare soil. In our study, there was a cultivar by weed management interaction effect on floricane dry weight because there was a greater reduction in dry weight in nonweeded plots compared to weed mat in ‘Marion’ (38%) than in ‘Black Diamond’ (24%). Since floricanes were more than twice as long in ‘Marion’ as in ‘Black Diamond’ (Table 2.2), and ‘Marion’ has thorny canes, there likely was more cane breakage when primocanes were pulled up and trained in the weedy plots. Our findings were similar to those reported by Harkins et al. (2013).

‘Black Diamond’ typically has a compact growth habit with densely spaced, short laterals (Fernandez-Salvador et al., 2015a; Finn et al., 2005; Harkins et al., 2013).

‘Marion’ tends to have more of a sprawling habit with very long canes, low percent bud break, and long laterals (Fernandez-Salvador, et al. 2015a; Finn et al., 1997; Harkins et al., 2013). In our study, cane length was affected by a cultivar x irrigation x training time interaction (Fig. 2.2). Cane length in ‘Black Diamond’ was not affected by training time or postharvest irrigation, whereas ‘Marion’ canes were shorter when grown without postharvest irrigation and when August-trained. August training caused visible signs of stress on the plants, such as wilting, likely a result of the primocanes (next year’s floricanes) being sometimes bent or kinked when they were wrapped around the trellis wires and from leaves being torn or ripped off when the primocanes were untangled (E. Dixon, personal observation). Furthermore, August training was done when temperatures were warm (Table 2.1). More kinking and cane damage would be expected when training the longer, thorny canes of ‘Marion’ as compared to the shorter, thornless canes of ‘Black Diamond’. A significant amount of primocane growth occurs postharvest (Cortell and Strik, 1997b). Not irrigating coupled with the stress of August training led to a shorter cane length in ‘Marion’ plants in this treatment (Fig. 2.2; Table 2.2). In contrast, plants that were irrigated after harvest produced canes of similar length, regardless of training time (Fig. 2.2).

Percent bud break on the floricanes was affected by a cultivar x irrigation x weed management interaction (Fig. 2.2). ‘Marion’ had less bud break than ‘Black Diamond’ across all irrigation and weed management treatments. Within a cultivar, long canes tend to have lower bud break, likely a result of resource limitation in trailing blackberry (Bell et al., 1995a; Cortell and Strik, 1997b). ‘Marion’ floricanes had the lowest percent bud break when the primocanes (in the previous year) grew in hand-weeded or weed mat plots with postharvest irrigation, which was likely a response to increased cane length (Fig. 2.2). Primocanes that were trained in August had greater bud break the following spring than those trained in February (Table 2.2). August-trained primocanes receive better light exposure during fruit bud development (Takeda et al., 2002), which leads to greater bud break the following spring relative to February training (Bell et al., 1995a). The opposing effects of the cultivar, irrigation, and training time treatments on floricane length and bud break led to no differences in yield, except for the effect of weed management.

Fruit production in 2014. Yield was affected by every treatment, except irrigation in 2014 (Table 2.3).'Black Diamond' produced a similar yield in both years of the study, whereas the yield of 'Marion' increased 24% from 2013 to 2014 when primocanes were February-trained, but declined 12% for August-trained plants (Tables 2.2 and 2.3). Consistent yield from year to year is expected in every-year production systems (Julian et al., 2009), barring any adverse environmental effects such as cold injury. The training time effect in 'Marion' (Table 2.3) was likely a result of a treatment effect on winter cold damage to canes (see "winter cold injury" below). August-trained 'Marion' plants yielded approximately 1 kg/plant less than the other cultivar and training time treatment combinations. Commercial producers in Oregon also experienced low 'Marion' yields—there was a 37% reduction in total 'Marion' yield from 2013 to 2014, while all other cultivars experienced an 8% increase (U.S. Department of Agriculture, 2015). The low yield in August-trained 'Marion' plants was reflected in a training time effect on several yield components, including fewer primocanes/plant and shorter primocanes relative to those on February-trained plants.

‘Black Diamond’ produced 60% of the floricane dry weight of ‘Marion’ (Table 2.3), likely a result of ‘Marion’ producing very long fruiting laterals with large leaves, as discussed previously. ‘Black Diamond’ floricane dry weight at pruning was not affected by training time, while ‘Marion’ floricane dry weight was almost 2 kg less in August-trained plots than in February-trained plots. ‘Marion’ also produced fruit that weighed less when August-trained compared to February-trained, contributing to the low yield of this treatment. Training time had an effect on fruit per lateral, with February-trained ‘Black Diamond’ producing fewer fruit/lateral than the other cultivar and training time combinations. Previous studies have reported between 4.1 and 7.4 fruit/lateral in ‘Marion’ (Bell et al., 1995a; Cortell and Strik, 1997b; Harkins et al., 2013) and between 5.5 and 10.9 fruit/lateral in ‘Black Diamond’ (Fernandez-Salvador et al., 2015a). Bell et al. (1995a) found that ‘Marion’ had fewer fruit per lateral when February-trained (5.1) than when August-trained (6.5), and berry weight was inversely correlated with the number of fruit per lateral. In our study, February-trained ‘Black Diamond’ plants produced fewer but larger fruit/lateral than the other treatments. However, we did not find a similar relationship between fruit/lateral and fruit weight across or within cultivars in 2013 (Table 2.2) or during the establishment years (Harkins et al., 2013).

There was a cultivar by training time interaction on fruit TSS (Table 2.3). ‘Black Diamond’ fruit had less TSS than ‘Marion’ fruit. While there was no effect of training time on ‘Marion’ fruit TSS, August training resulted in lower fruit TSS than February training in ‘Black Diamond’. ‘Marion’ produced small fruit with low fruit water content, resulting in concentrated TSS. ‘Black Diamond’ August-trained plants produced smaller fruit than February-trained plants with no effect on fruit water content. This response to

August training could be a disadvantage for fresh market growers, as many small fruit could reduce hand harvest efficiency. However, this is less of an issue for the machine-harvest, processed market.

‘Black Diamond’ had a longer fruiting season than ‘Marion’, consistent with what was observed in the prior year (data not shown) and during the establishment year (Harkins et al., 2013), as well as with findings of others (Fernandez-Salvador et al., 2015a). There was also a cultivar by weed management interaction on yield (Table 2.3). The response of ‘Black Diamond’ to weed management was similar to what was observed in 2013 and during establishment (Harkins et al. 2013), but the magnitude of the response was greater in 2014. Weed control increased yield by 61% compared to nonweeded plots in ‘Black Diamond’ (Table 2.3). In ‘Marion’, weed control improved yield by 19% (Table 2.3), which was also more than what was observed in 2013 (Table 2.2). The high yield in weed mat plots was mainly a result of more canes/plant (particularly with February training), a high number of nodes/plant, greater fruit weight (compared to nonweeded), and more floricane biomass per plot (Table 2.3). Archbold et al. (1989) also found that high plant biomass resulted in larger fruit size in semi-erect blackberry. Interestingly, high yields have been related to a number of yield components in trailing blackberry, including cane number, cane diameter, cane length, node number, berry size, fruit/lateral, and internode length (Bell et al., 1995a; Cortell et al., 1997b; Fernandez-Salvador et al., 2015a; Harkins et al., 2013). The most common factors associated with high yield across these studies and in both years of our study appear to be berry weight and cane number per plant. The high yield in our study occurred despite a lower percent bud break in weed mat plots when primocanes were trained in February.

Weeds reduced fruit weight and percent water content and increased TSS in 2014 (Table 2.3), as was observed in 2013 (Table 2.2). Irrigation and training time had an effect on the amount of weed biomass removed from the nonweeded plots prior to harvest in late June. Plots with postharvest irrigation (in 2013) that were not trained until February 2014 had 10 $g \cdot m^{-2}$ less weed biomass than those that were August trained (P = 0.013; data not shown). Weed pressure was significantly reduced in February-trained plots because the primocanes lying along the ground from August to February reduced weed growth through shading. This effect was also noticed, although no data were collected, in the hand-weeded plots during the early hoeing dates (E. Dixon, personal observation).

Plots that received no irrigation postharvest for two consecutive years (2012–2013) had significantly shorter canes in early 2014, but this had no effect on yield (Table 2.3). In contrast, in machine-harvested erect blackberry and raspberry, grown in Fayetteville, AR and Kent, U.K. respectively, plants that were not irrigated postharvest produced lower yields of smaller berries than plants that were irrigated (Goode and Hyrycz, 1968; Morris et al., 1978). Similar results were found in Arkansas when plants were not irrigated at all in erect blackberry (Morris and Sims, 1985; Sims and Morris, 1982). Morris et al. (1978) also found that irrigation postharvest was necessary for good fruit production the following year. Raspberry plants in Pullman, WA that received postharvest irrigation produced more fruit per lateral than those that did not, although total yield was not presented (Crandall et al., 1974). In our study, the number of fruit per lateral was not affected by irrigation. A similar cultivar x irrigation x weed management interaction was seen for fruit TSS in 2014 (data not shown) as was described for 2013

(Fig. 2.1). ‘Marion’ fruit had a greater TSS than ‘Black Diamond’ fruit, but TSS in ‘Marion’ was not affected by irrigation or training time. In contrast, ‘Black Diamond’ fruit from nonweeded plots that received no postharvest irrigation had higher TSS than the other treatment combinations. It is not clear why the fruit TSS from nonweeded, postharvest irrigated plots did not follow the same pattern as seen in 2013. Makus (2011) found that erect blackberry grown with weed barriers had higher TSS than those grown on bare soil, a response not observed in our study.

Irrigation. Primocane LWP averaged -0.84 MPa prior to fruit harvest when all treatments were being irrigated, but after harvest LWP averaged -0.87 and -0.96 MPa in the postharvest and no postharvest irrigation treatments, respectively (average of 2012–2014; data not shown). This reduction was not significant enough to warrant concern about the water status of the plants. ‘Black Diamond’ grown without postharvest irrigation had primocanes with lower LWP than those that were irrigated in 2012 and 2013, and there was a larger difference between irrigated and non-irrigated plants than was measured in ‘Marion’ (Fig. 2.3). The same trend was seen in 2014, but it was not significant (data not shown). The magnitude of the difference in primocane LWP between ‘Marion’ and ‘Black Diamond’ decreased from 2012–2014 with no significant difference among cultivars in 2014 (Fig. 2.4). Although there were some significant differences in primocane LWP between cultivars, weed management treatments, and training times, the differences were < 0.1 MPa, and no treatment resulted in a primocane LWP less than -1.00 MPa in 2013 or 2014.

In 2013, floricane LWP was compared with primocane LWP during the periods before and during fruit harvest when all plots were being irrigated. From 24 May through

19 July, primocane LWP averaged -0.81 MPa and was higher than floricane LWP (*P* < 0.0001), which averaged -0.92 MPa. Over that same period, there was a time x cultivar x cane type interaction that is shown in Fig. 2.5. Primocane and floricane LWP diverged further once fruit harvest began, especially in ‘Marion’. ‘Black Diamond’ floricane LWP dipped at the onset of harvest, but recovered more than in ‘Marion’. These results are consistent with those of Bryla and Strik (2008) and support their hypothesis that primocanes and floricanes are hydraulically independent. Harkins et al. (2013) speculated that competition from weeds may have limited water more in floricanes than in primocanes, resulting in lower fruit water content and higher TSS. However, our study did not find an interaction between cane type and weed management.

Postharvest irrigation did not have a large effect on aboveground vegetative growth. In 2013, the cultivars differed in their response to the postharvest irrigated treatment. ‘Black Diamond’ floricanes were longer when they had been trained in February (as primocanes), but in ‘Marion’, primocane training in August resulted in longer floricanes (Table 2.2). In 2014, plants that received irrigation postharvest tended to have longer floricanes and had a higher floricane dry weight than those that were not irrigated after harvest (Table 2.3). The greater growth in irrigated plants did not lead to greater yield, indicating that these plants did not require irrigation after harvest for good fruit production. Both cultivars were deeply rooted at the site, and with no irrigation after harvest, the plants extracted water down to a soil depth of at least 1.8 m (L. Valenzuela-Estrada, unpublished data). Peak water use in blackberry occurs during fruit development and declines sharply after harvest (Bryla and Strik, 2008), a response that also occurs in raspberry (Kongsrud, 1976) and blueberry (Bryla and Strik, 2007), and may help explain why such a limited response was seen to no postharvest irrigation in our study.

Soil water content was measured only to a depth of 0.4 m, which was not deep enough to accurately represent blackberry access to water (L. Valenzuela-Estrada, unpublished data). Soil water content in the no postharvest irrigation plots was similar under the three weed management treatments in both years, decreasing throughout the season until it was replenished by a rain event (Table 2.1; Fig. 2.6). In 2013, there were significant rain events in August and September. Soil water content tended to be higher under weed mat than the other weed management treatments in both years, but soil water content did not increase as quickly under weed mat after rainfall, indicating that the perforated, polyethylene ground cover is somewhat of a barrier to rain water. Weed mat plots were also much drier than the other treatments when soil samples were collected in October after significant rain (E. Dixon, personal observation). In a study conducted on raspberry establishment, Trinka and Pritts (1992) found that weed mat increased soil moisture compared to hand-weeded or nonweeded treatments, resulting in better growth and higher yield, especially in regards to the nonweeded treatments. They hypothesized that the higher moisture found under the weed mat led to the development of larger root systems and greater growth during establishment, which would then carry over into following years. Further work is needed to determine if there were larger root systems under the weed mat in our study. If so, they may have been responsible for the increased biomass measured aboveground.

Winter cold injury. Many of the treatment effects observed in 2014, which were not present in 2013, were caused by an extreme cold event that occurred in Dec. 2013

(Table 2.1). 'Marion' is not very cold hardy (Finn et al., 1997) and winter cold injury has been documented in the cultivar during previous cold winters (Bell et al., 1992). 'Marion' buds have been shown to have an LT_{50} of -5 to -23 ºC, depending on the primocane growing conditions and management (Bell et al., 1995b; Cortell and Strik, 1997a). The air temperature dropped to -12 ºC in 2013, within the range of temperatures known to cause damage. The average damage rating for 'Black Diamond' as a result of this cold event was 1.1, essentially no injury (data not shown). In the Pacific Northwest, 'Black Diamond' is considered to be cold hardy, and there have been few reports of winter cold injury since its release (Finn et al., 2005). The yield of 'Black Diamond' was similar in 2013 and 2014 (Tables 2.2 and 2.3), confirming there was no winter cold injury. In contrast, 'Marion' plants in all treatments experienced some level of damage (Table 2.4). 'Marion' plants grown without postharvest irrigation had less damage than those that received irrigation, an effect also seen in raspberry, where plants experiencing a water deficit in the fall had the best winter survival (Hoppula and Salo, 2006). Plants with postharvest irrigation grew later into the fall than those without irrigation and may have not been fully dormant at the time they were exposed to the cold temperature (9 Dec. 2013). However, Bell et al. (1995b) found that sampling date had no effect on hardiness in controlled freezing experiments. Factors that increase vegetative growth in the autumn, such as excessive irrigation, have been found to negatively affect winter survival in raspberry (Hoppula and Salo, 2006; Jennings and Cormack, 1969; Jennings et al., 1972; Säkö and Hiirsalmi, 1980). In our study, 'Marion' plants had the most cold injury when grown in non- and hand-weeded plots and when August-trained. However, when February trained, weed mat plots showed more cold injury. Primocanes of plants in

February-trained, hand-weeded or weed mat plots may have been more vigorous, delaying acclimation relative to those in weedy plots; this may also have increased cold injury. August training stresses the primocanes, as described previously, which may increase risk of cold injury. However, in contrast to February training, where canes are left near the soil surface (a warmer microclimate), August-trained canes are on the trellis throughout the winter and exposed to wind and colder air temperatures. This effect of training time on winter cold injury would explain the yield decline observed in August-trained 'Marion' from 2013 to 2014 compared to the increase that occurred in February-trained plots, as described above. The effect of cold damage on yield of August-trained 'Marion' plots can clearly be seen in Fig. 2.7, where these plots lagged behind the February-trained plots for the entire harvest season. In contrast, 'Black Diamond' had the same progression in yield and cumulative yield, regardless of training time. Bell et al. (1992) observed cold damage in 'Marion' after air temperatures dropped to -18 ºC in Dec. 1991. Fields that had been trained in August that year had twice the number of dead canes as those trained in February. In addition, yield declined by 43% in August-trained fields compared to 36% in February-trained fields (Bell et al., 1992).

Crown borer. Raspberry crown borer has a 2-year life cycle in Oregon. Eggs are laid singularly on the underside margins of leaves during August and September and hatch in 40 to 60 d, at which point, the larvae crawl down the cane and bore into the crown of the plant and overwinter. They spend the next growing season tunneling through the crown and the base of the new primocanes and, then, overwinter again, to emerge as adults the next summer (Breakey, 1963; Raine, 1962). Because of their 2-year lifecycle, an infestation may go unnoticed in the field until it is relatively severe. Crown borer can be a serious pest in blackberry. In severe infestations, 30% of plants may be lost (Lovett, 1921). 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 of Teasdale et al. (2013). However, no adult crown borers were captured, despite the presence of the larvae in the field.

While statistical analysis for this damage was not possible with these data, clear trends were apparent (Table 2.5). ‘Black Diamond’ was affected by this insect pest during the study and ‘Marion’ was not. It is possible that the thornless canes and dark green foliage found in this cultivar are more attractive to the pest than the thorny canes and lighter green leaves found in ‘Marion’. Interestingly, Breakey (1963) found that crown borer had no cultivar preference in several studies done in red raspberry in Washington. Although August-trained plots appeared to be more heavily infested than February-trained plots (Table 2.5), data were collected during August training, which probably caused bias (as the plots that were to be February-trained still had canes on the ground, making it more difficult to observe canes for symptoms of crown borer infestation). Plots receiving postharvest irrigation had about half the incidence of crown borer as those that were not irrigated. The reason for this positive response to postharvest irrigation is unclear. Nonweeded plots also had a reduced presence of crown borer when compared with plots receiving weed control. Weed cover may provide habitat for beneficial insects or predators of the crown borer.

Based on our results, it is not clear what effect the crown borer infestation had on growth and yield of ‘Black Diamond’. The infestation may have been present in the field earlier but was not discovered, which may have also had an effect on the relatively low numbers of crown borer seen in 2014. The low temperatures in Dec. 2013 probably also had an effect on the crown borer, but the cold tolerance of this pest is not known. Alternate-year production should be considered as a cultural method of reducing crown borer pressure, as all canes would be removed every 2 years, perhaps disrupting the lifecycle of the pest.

Conclusions

Withholding irrigation after harvest saved an estimated 1 million $L \cdot ha^{-1}$ over the 2 years of the study (Table 2.1). Goode and Hyrycz (1968) also found that deficit irrigation after harvest was an effective method to reduce water requirements in raspberry. In this case, raspberry plants irrigated only once during fruit expansion performed just as well as those irrigated throughout the season. Such reductions in irrigation after harvest in blackberry could result in considerable water and energy savings, as well as in environmental benefits. However, additional research is needed to verify that the plants in non-irrigated plots were not getting water from irrigated plots in adjacent rows (although this was unlikely as plants were drip irrigated and there was no relationship between sub-plot location in the field and yield) and to ensure that similar effects would be seen in a heavy cropping year or in other cultivars and soil types.

The impacts of weed management, when considered across the mature years of this study and the establishment years (Harkins et al., 2013), indicate that weed control is critically important for good blackberry production, and no weeding is a poor management option. Blackberry plants in the nonweeded treatment consistently produced fewer canes, less biomass, and a lower yield of lighter fruit than in either weed control treatment. In addition, plants grown with weed mat often produced more biomass and had a greater yield than those that were hand-weeded, consistent with Harkins et al. (2013). Weed mat is, thus, an effective and economical (Harkins et al., 2013) method of weed control in this type of blackberry.

Although August training has been shown to increase yield in 'Marion' (Bell et al., 1995a; Sheets et al., 1972), this response was not observed in our study. August-trained plants produced the same yield as February-trained plants in 2013. In 2014, while training time did not affect yield in 'Black Diamond', there was more cold injury and less yield when 'Marion' was August-trained. The results of training time may not be conclusive in the present study because 2013 was a low-yield year, and 2014 was unusual because of winter injury. However, August training appears to be risky in 'Marion' and is, thus, not recommended for organic production. Additionally, February training was an advantage in both cultivars for reduced weed pressure in the hand-weeded plots. Our study also showed that production systems that promote late-season growth such as weed mat and postharvest irrigation increased winter cold injury.

Further study is needed to develop effective organic control of the raspberry crown borer. Since there seems to be significant differences in cultivar attractiveness or susceptibility, cultivar selection might be one of the most important tools. Other cultural tools, such as alternate-year production and early scouting, may also be effective. There has been some work done with biological control agents, although complete control was not achieved (Capinera et al., 1986; McKern et al., 2007). There is also a need for further work with pheromone trapping, as the available lure was ineffective in our study. Contrary to previous work (Fernandez-Salvador et al., 2015a; Harkins et al. 2013), ‘Black Diamond’ did not produce a higher yield than ‘Marion’ in 2013, and in 2014, only produced higher yield under optimal weed management and when ‘Marion’ had been damaged by winter cold injury. Weeds caused a much greater reduction in yield in ‘Black Diamond’ than in ‘Marion’, so it is possible that ‘Black Diamond’ grown under ideal conditions in this production system (i.e. with weed mat) would outperform ‘Marion’ over time. Interestingly, conventional blackberry fields are expected to yield 3.5 kg/plant (Julian et al., 2009). In our study, the best treatment combinations yielded between 4 and 5 kg of fruit per plant in both years, indicating that high yields are possible in organic blackberry production, provided the weeds are controlled.

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Table 2.1. Mean daily air temperature, reference evapotranspiration (ET_{ref}), precipitation, and irrigation applied to mature organic trailing blackberry grown at the North Willamette Research and Extension Center, Aurora, OR in 2013–14.[z]

Month	Mean air temp (°C)		Minimum air temp (°C)[y]		Maximum air temp (°C)		Et_{ref} (mm)		Precipitation total (mm)		Irrigation (mm)[x]			
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013		2014	
											+Irrig.[w]	-Irrig.[v]	+Irrig.	-Irrig.
January	2.7	5.1	-4.6	-3.3	13.4	14.2	8	15	56	74	0	0	0	0
February	6.6	5.1	-0.9	-7.7	17.0	18.1	20	21	36	145	0	0	0	0
March	8.8	9.4	-1.2	-1.2	25.5	20.6	50	53	60	196	0	0	0	0
April	11.2	11.6	0.0	2.0	26.7	30.1	86	87	54	88	0	0	0	0
May	14.6	15.6	1.3	2.7	29.3	33.2	126	152	110	65	342	342	173	173
June	17.7	16.7	6.5	7.1	34.6	29.8	161	162	33	36	237	237	173	173
July	20.6	21.8	8.8	10.8	34.0	37.1	219	212	0	18	304	218	258	258
August	20.7	21.9	10.2	10.0	34.2	34.8	158	174	14	3	419	0	258	0
September	17.1	19.1	6.5	7.9	35.2	36.1	86	129	191	28	233	0	147	0
October	10.8	14.7	-0.8	6.8	25.0	29.9	44	55	26	172	0	0	0	0
November	7.3	8.0	-4.4	-6.3	17.3	17.7	19	28	90	67	0	0	0	0
December	2.1	7.1	-12.4	-3.8	13.1	17.8	9	16	48	173	0	0	0	0
Total/avg	11.7	13.0	0.8	2.1	25.4	26.6	986	1105	719	1065	1535	797	1009	604

[z]Weather data were obtained from a nearby AgriMet weather station (Aurora, OR) (US Department of the Interior, 2013).
[y]Minimum recorded temperature is given for each winter month while maximum recorded temperature is given for each summer month.
[x]Irrigation in May and June includes the time the system was used for fertigation.
[w]"+Irrig." = Postharvest irrigated plots received irrigation from 17 May to 27 Sept. 2013 and 28 May to 23 Sept. 2014.
[v]"-Irrig." = No postharvest irrigated plots received irrigation from 17 May to 19 July 2013 and 28 May to 29 July 2014.

Table 2.2. Impacts of cultivar, postharvest irrigation, weed management, and training time on growth, yield, and fruit quality in mature organic trailing blackberry grown at the North Willamette Research and Extension Center, Aurora, OR in 2013.

Treatment	No. of primocanes per plant[z]	Dry wt of the floricanes (kg/plot)		Avg floricane length (m)	No. of nodes per plant[y]	Bud break (%)	No. of fruit/lateral	Total yield (kg/plant)[x]	Fruit wt (g)		Fruit water content (%)		Fruit soluble solids (%)	
Cultivar (C)														
											Aug.	*Feb.*	*Aug.*	*Feb.*
Black Diamond (B. Dia.)	4.2	2.7 b[v]		3.0 b	320	74 a	10.2 a	4.0	5.9 a		84.8 a	84.7 a	10.0 d	10.2 c
Marion	3.8	5.0 a		7.3 a	372	46 b	7.1 b	3.3	5.3 b		82.7 b	82.1 c	12.9 b	13.5 a
Irrigation (I)														
Postharvest	3.9	4.0		5.4	383	58 b	8.6	3.7	5.5		83.6		11.6	
No postharvest	4.1	3.7		5.0	309	62 a	8.7	3.7	5.7		83.6		11.8	
Weed management (W)														
		B. Dia.	*Marion*						*B. Dia.*	*Marion*	*B. Dia.*	*Marion*		
Nonweeded	3.4 b	2.1 c	3.7 b	4.8	294	61	8.5	2.7 c	5.5 b	5.1 c	83.6 b	81.8 d	12.4 a	
Hand-weeded	4.3 a	2.8 b	5.5 a	5.1	367	61	8.6	3.9 b	6.1 a	5.4 b	85.2 a	82.7 c	11.4 b	
Weed mat	4.3 a	3.3 b	6.0 a	5.7	376	59	8.8	4.4 a	6.2 a	5.4 b	85.4 a	82.8 c	11.3 b	
Training (T)														
August (Aug.)	4.2	3.7		4.8	350	63 a	8.7	3.7	5.5 b		83.7 a		11.5 b	
February (Feb.)	3.7	4.0		5.5	342	58 b	8.6	3.7	5.8 a		83.4 b		11.9 a	
Significance[w]														
C	NS	0.0057		<0.0001	NS	0.0012	0.0005	NS	0.0019		0.0002		<0.0001	
I	NS	NS		NS	NS	0.0189	NS	NS	NS		NS		NS	
W	0.0235	<0.0001		NS	NS	NS	NS	<0.0001	<0.0001		<0.0001		<0.0001	
T	NS	NS		NS	NS	0.0016	NS	NS	<0.0001		0.01		<0.0001	
C × I	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS	
C × W	NS	0.0087		NS	NS	NS	NS	NS	0.0133		0.0291		<0.0001	
I × W	NS	NS		NS	NS	NS	NS	NS	NS		NS		0.0171	
C × T	NS	NS		NS	NS	NS	NS	NS	NS		0.0424		0.0044	
I × T	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS	
W × T	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS	
C × I × W	NS	NS		NS	NS	0.021	NS	NS	NS		NS		0.0274	
C × I × T	NS	NS		0.0221	NS	NS	NS	NS	NS		NS		NS	
C × W × T	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS	
I × W × T	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS	
C × I × W × T	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS	

[z]Determined in Feb. 2013.
[y]Nodes per plant was calculated by multiplying nodes per primocane by primocane number per plant.
[x]Total yield includes both marketable and cull (non-marketable) fruit.
[w]NS = non-significant; *P*-values provided for significant factors.
[v]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$; Tukey's honestly significant difference test).

Table 2.3. Impacts of cultivar, postharvest irrigation, weed management, and training time on growth, yield, and fruit quality in mature organic trailing blackberry grown at the North Willamette Research and Extension Center, Aurora, OR in 2014.

Treatment	No. of primocanes per plant[z]		Dry wt of the floricanes (kg/plot)		Avg. floricane length (m)	No. of nodes per plant[y]	Bud break (%)			No. of fruit/lateral		Total yield (kg/plant)[x]		Fruit wt (g)		Fruit water content (%)	Fruit soluble solids (%)	
Cultivar (C)																		
			Aug.	*Feb.*						*Aug.*	*Feb.*	*Aug.*	*Feb.*	*Aug.*	*Feb.*		*Aug.*	*Feb.*
Black Diamond (B. Dia.)	5.8		4.6 c[v]	5.0 c	7.2	874 a	56 a			6.9 a	6.2 b	3.9 a	4.0 a	5.2 bc	6.0 a	85.0 a	9.5 c	10.1 b
Marion	5.8		6.1 b	7.9 a	7.5	595 b	44 b			7.3 a	7.4 a	2.9 b	4.1 a	5.0 c	5.2 b	82.8 b	13.2 a	13.1 a
Irrigation (I)																		
Postharvest (+Irrig.)	6.1		6.2 a		7.6	802 a	48			7.0		3.7		5.3		83.9	11.4	
No postharvest (-Irrig.)	5.5		5.6 b		7.0	666 b	52			6.9		3.8		5.4		83.8	11.5	
Weed management (W)																		
	Aug.	*Feb.*	*Aug.*	*Feb.*			*+Irrig.*	*-Irrig.*				*B. Dia.*	*Marion*					
Nonweeded	4.5 c	4.6 c	3.9 c	5.2 b	7.2	603 b	53 a	54 a		7.1		2.8 e	3.1 de	5.1 b		83.5 b	11.7 a	
Hand-weeded	6.0 b	6.1 b	4.6 bc	6.8 a	6.8	702 b	50 a	50 a		6.9		3.7 bc	3.4 cd	5.4 a		83.8 b	11.4 b	
Weed mat	6.0 b	7.7 a	7.4 a	7.5 a	8.0	900 a	42 b	53 a		6.8		5.3 a	4.0 b	5.5 a		84.3 a	11.2 c	
Training (T)																		
							Non-weeded	*Hand-weeded*	*Weed mat*									
August (Aug.)	5.5 b		5.3 b		6.8 b	676 b	55 a	55 a	55 a	7.1 a		3.4 b		5.1 b		83.8	11.3 b	
February (Feb.)	6.1 a		6.5 a		7.9 a	791 a	52 a	44 b	40 b	6.8 b		4.1 a		5.6 a		84.0	11.6 a	
Significance[w]																		
C	NS		0.0007		NS	0.0162	0.0088			NS		0.0049		0.0019		0.001	<0.0001	
I	NS		0.0148		NS	0.0231	NS			NS		NS		NS		NS	NS	
W	<0.0001		<0.0001		NS	<0.0001	0.0205			NS		<0.0001		0.0002		0.0022	0.0001	
T	0.0185		<0.0001		0.0309	0.0291	<0.0001			0.048		<0.0001		<0.0001		NS	0.0036	
C × I	NS		NS		NS	NS	NS			NS		NS		NS		NS	NS	
C × W	NS		NS		NS	NS	NS			NS		0.0003		NS		NS	0.0059	
I × W	NS		NS		NS	NS	0.027			NS		NS		NS		NS	0.0186	
C × T	NS		0.0116		NS	NS	NS			0.0084		0.0016		<0.0001		NS	0.0006	
I × T	NS		NS		NS	NS	NS			NS		NS		NS		NS	NS	
W × T	0.0145		0.0088		NS	NS	0.0102			NS		NS		NS		NS	NS	
C × I × W	NS		NS		NS	NS	NS			NS		NS		NS		NS	0.0016	
C × I × T	NS		NS		NS	NS	NS			NS		NS		NS		NS	NS	
C × W × T	NS		NS		NS	NS	NS			NS		NS		NS		NS	NS	
I × W × T	NS		NS		NS	NS	NS			NS		NS		NS		NS	NS	
C × I × W × T	NS		NS		NS	NS	NS			NS		NS		NS		NS	NS	

[z]Determined in Feb. 2014.
[y]Nodes per plant was calculated by multiplying nodes per primocane by primocane number per plant.
[x]Total yield includes both marketable and cull (non-marketable) fruit.
[w]NS = non-significant; *P*-values provided for significant factors.
[v]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$; Tukey's honestly significant difference test).

Table 2.4. Impact of postharvest irrigation, weed management, and training time (August or February) on cold injury sustained in mature 'Marion' organic trailing blackberry grown at the North Willamette Research and Extension Center, Aurora, OR after exposure to damaging cold temperatures in Dec. 2013.

	Rating[z]	
Treatment		
Irrigation (I)		
Postharvest	2.5 a[x]	
No postharvest	1.9 b	
Weed management (W)		
	August	*February*
Nonweeded	3.1 a	1.5 c
Hand-weeded	2.7 a	1.9 bc
Weed mat	1.9 bc	2.1 b
Training (T)		
August	2.5 a	
February	1.8 b	
Significance[y]		
I	0.0007	
W	NS	
T	<0.0001	
I × W	NS	
I × T	NS	
W × T	0.0001	
I × W × T	NS	

[z]A higher rating indicates more cold damage. 1 = normal bud break (no visible damage), 2 = light damage (75% of normal bud break), 3 = moderate damage (50% of normal), 4 = heavy damage (25% of normal), 5 = extreme damage (<5% of normal bud break). Plots were rated based on the average damage of the 4 plants on 21 Apr. 2014.
[y]NS = non-significant; *P*-values are provided for significant factors.
[x]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$; Tukey's honestly significant difference test).

Table 2.5. Impact of cultivar, postharvest irrigation, weed management, and training time on raspberry crown borer (*Pennisetia marginata* Harris) infestation in mature organic trailing blackberry grown at the North Willamette Research and Extension Center, Aurora, OR.[z]

	Plots infested by crown borer (%)[y]		
	2013	**2014**	**Total**
Treatment			
Cultivar			
Black Diamond	30	7	37
Marion	0	0	0
Irrigation			
Postharvest	8	3	11
No postharvest	22	3	25
Weed management			
Nonweeded	10	0	10
Hand-weeded	20	5	25
Weed mat	15	5	20
Training			
August	17	7	24
February	13	0	13

[z]Data collected during August training. Plots found during training in Feb. 2013 indicate equal presence in August and February-trained plots.
[y]Percent of plots in each treatment where crown borer larvae were discovered or suspected in at least one cane during August training.

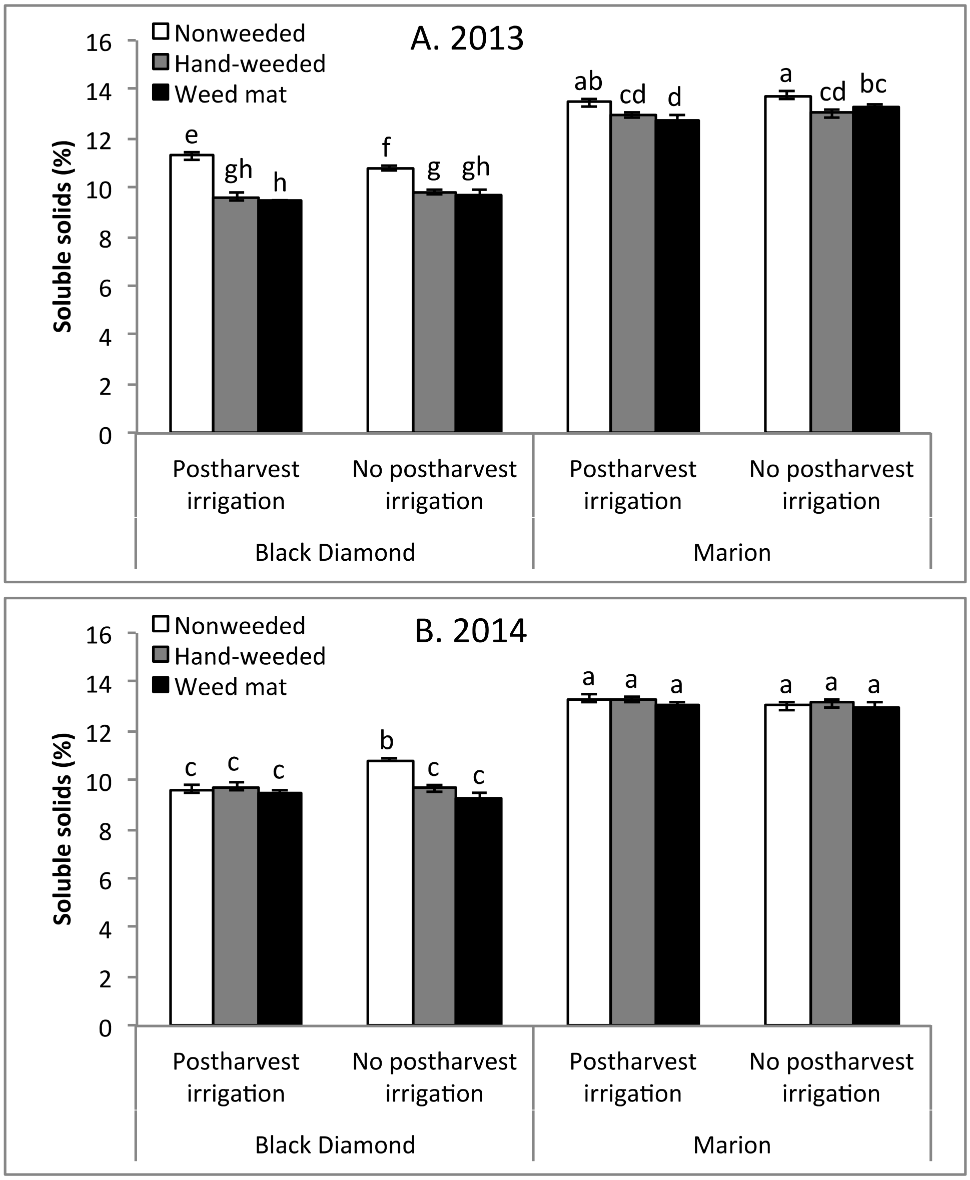

Fig. 2.1. Effects of cultivar, irrigation, and weed management on fruit soluble solids of ‘Black Diamond’ and ‘Marion’ in 2013 (**A**) and 2014 (**B**) in mature organic trailing blackberry grown at the North Willamette Research and Extension Center, Aurora, OR. Mean ± SE; means followed by the same letter within the interaction presented are not significantly different (*P* > 0.05).

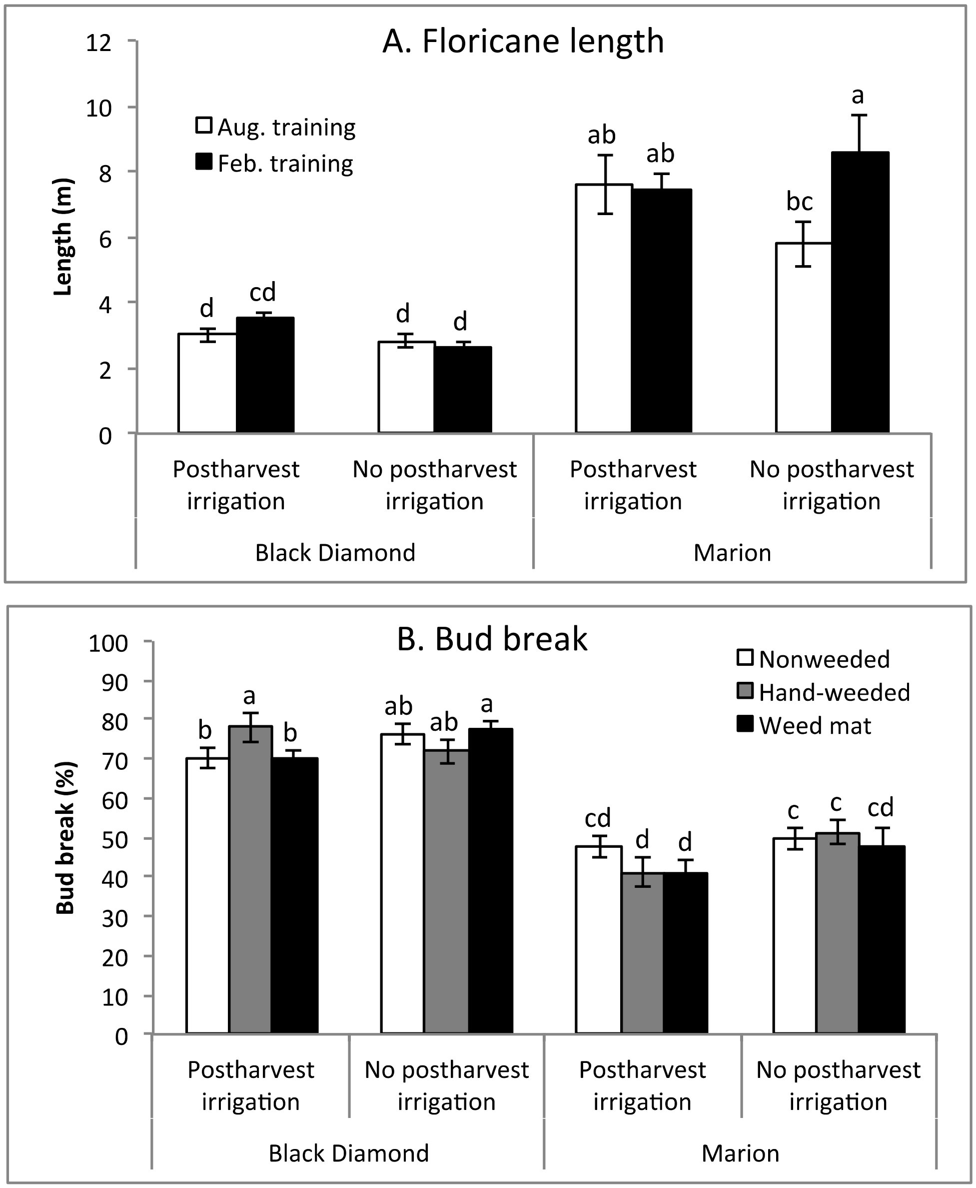

Fig. 2.2. Effects of cultivar, irrigation, and weed management on floricane length of ‘Black Diamond’ and ‘Marion’ (**A**) and percent bud break of ‘Black Diamond’ and ‘Marion’ (**B**) in mature organic trailing blackberry grown at the North Willamette Research and Extension Center, Aurora, OR, 2013. Mean ± SE; means followed by the same letter within the interaction presented are not significantly different ($P > 0.05$).

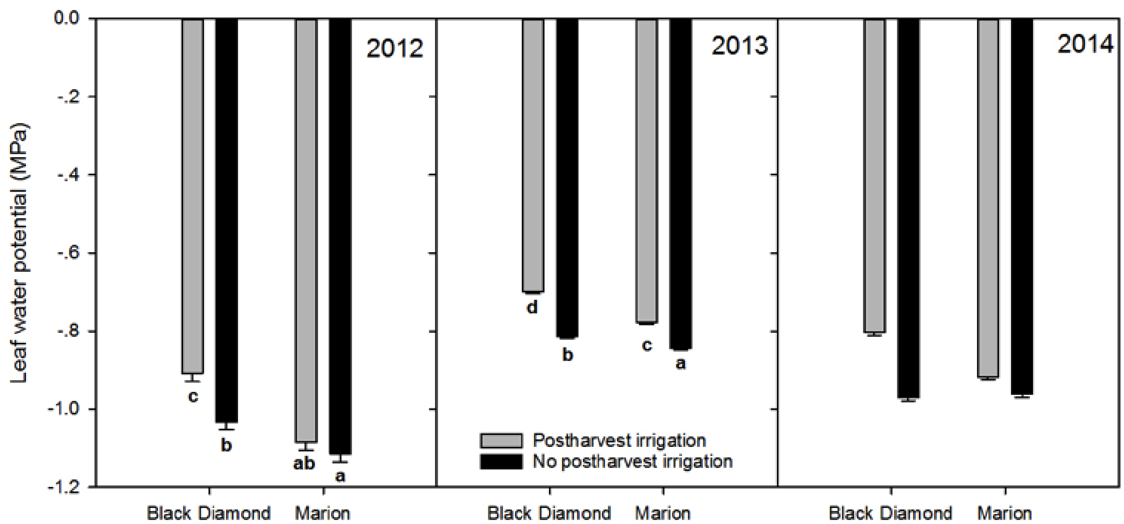

Fig. 2.3. Effect of cultivar and irrigation on average seasonal primocane leaf water potential of mature organic trailing blackberry grown at the North Willamette Research and Extension Center, Aurora, OR, 2012–2014. Mean ± SE. Means followed by the same letter within year are not significantly different ($P > 0.05$).

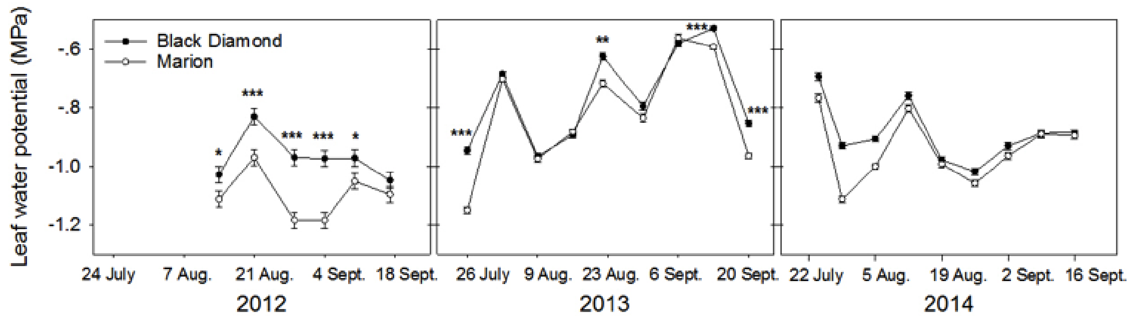

Fig. 2.4. Effect of cultivar and sample date on primocane leaf water potential of mature organic trailing blackberry grown at the North Willamette Research and Extension Center, Aurora, OR, 2012–2014. Mean ± SE. Significance provided by sample date ("*" = $P < 0.05$; "**" = $P < 0.01$; "***" = $P < 0.001$).

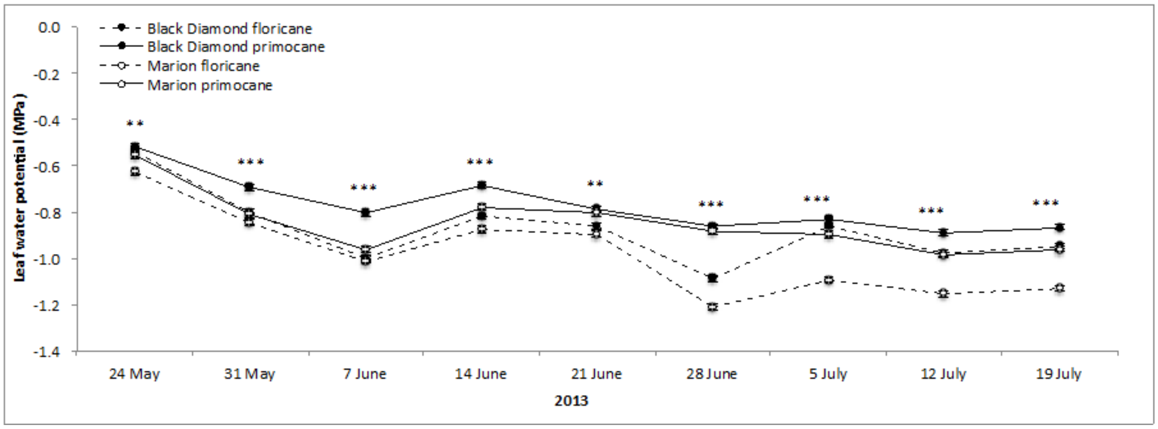

Fig. 2.5. Effect of cultivar and sample date on primocane and floricane leaf water potential of mature organic trailing blackberry grown at the North Willamette Research and Extension Center, Aurora, OR, 2013. Mean ± SE. Significance provided by sample date ("*" = $P < 0.05$; "**" = $P < 0.01$; "***" = $P < 0.001$).

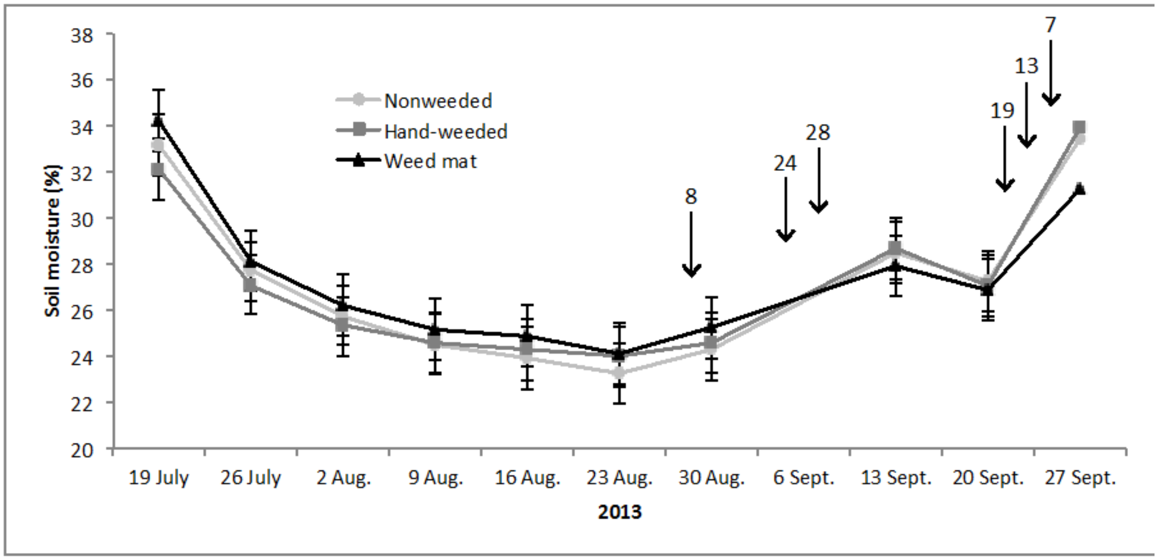

Fig. 2.6. Effect of weed management and sample date on soil water content in mature organic trailing blackberry not irrigated postharvest and grown at the North Willamette Research and Extension Center, Aurora, OR in 2013. Measurements were taken weekly (beginning after fruit harvest and continuing until the rainy season) at a depth of 0–0.4 m in plots with no postharvest irrigation. Rain events that resulted in > 5 mm of accumulation are indicated with arrows and the volume (mm) of the event. Mean ± SE.

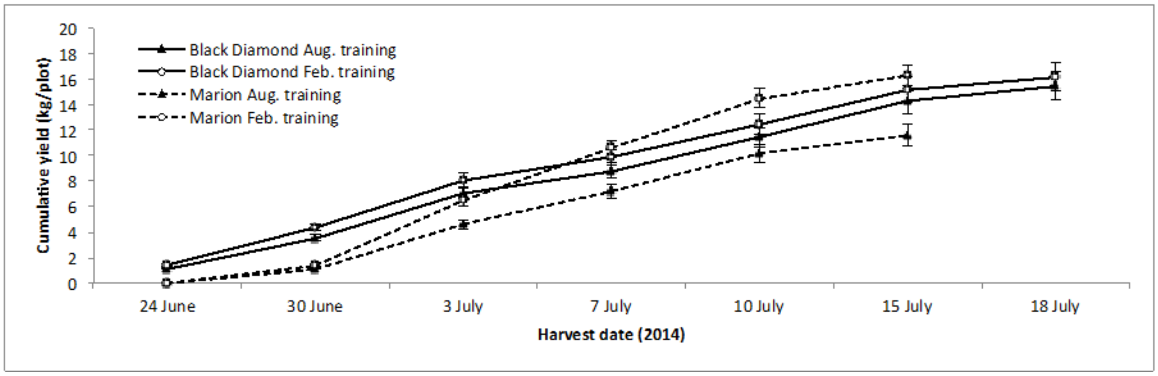

Fig. 2.7. Effect of cultivar and training time on cumulative yield of mature organic trailing blackberry grown at the North Willamette Research and Extension Center, Aurora, OR, 2014. Mean ± SE.

WEED MANAGEMENT, TRAINING, AND IRRIGATION PRACTICES FOR ORGANIC PRODUCTION OF TRAILING BLACKBERRY: II. SOIL AND ABOVEGROUND PLANT NUTRIENT CONCENTRATIONS

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CHAPTER 3: Weed Management, Training, and Irrigation Practices for Organic Production of Trailing Blackberry: II. Soil and Aboveground Plant Nutrient Concentrations

Abstract

Organic production of blackberries is increasing, but there is relatively little known about how production practices affect plant and soil nutrient status. The impact of cultivar (‘Black Diamond’ and ‘Marion’), weed management (nonweeded, hand-weeded, and weed mat), primocane training time (August and February), and irrigation (throughout the summer and none postharvest) on plant nutrient status and soil pH, organic matter, and nutrients was evaluated from Oct. 2012–Dec. 2014 in a mature trailing blackberry (*Rubus* L. subgenus *Rubus* Watson) production system. The study site was certified organic and machine-harvested for the processed market. The planting was irrigated by drip and fertigated with fish hydrolysate and fish emulsion fertilizer. Soil pH, organic matter content, and concentrations of soil nutrients, including ammonium-nitrogen (NH_4-N), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), copper (Cu), manganese (Mn), and zinc (Zn), were greater under weed mat than in hand-weeded plots. Soil K and boron (B) were below recommended standards during the study, despite a high content of K in the fish fertilizer and supplemental B applications. Primocane leaf nutrient concentrations were below the N, K, Ca, and Mg sufficiency standards in ‘Black Diamond’ and were lower than in ‘Marion’ for N, phosphorus (P), Ca, Mg, S, B, and Zn in at least one year. In contrast, floricane leaves and fruit tended to have higher nutrient concentrations in ‘Black Diamond’ than in ‘Marion’. Weed management strategy affected many nutrients in the soil, leaves, and fruit. Often, use of weed mat led to the

highest concentrations. Withholding irrigation postharvest had limited effects on plant nutrient concentrations. The impact of primocane training time varied among years, nutrients, and plant parts.

Introduction

Organic blackberry (*Rubus* L. subgenus *Rubus,* Watson) production is becoming an important niche market in Oregon, where almost 50% of the U.S. hectarage (organic or conventional) is located [U.S. Department of Agriculture (USDA), 2014]. Oregon primarily grows trailing types used for the processed market, and nearly all of the fruit is harvested by machine (Strik and Finn, 2012; USDA, 2014). Although there is an increasing body of knowledge about organic blackberry production (e.g. Fernandez-Salvador et al., 2015a; 2015b; Harkins et al., 2013; 2014; Kuepper et al., 2003), some gaps still remain, such as how cultivars other than ‘Marion’, which was used to develop the Oregon caneberry nutrient management guide (Hart et al., 2006), utilize and allocate nutrients.

Blackberry plants have perennial crowns and roots, with biennial aboveground canes. In the spring, vegetative primocanes emerge and grow throughout the summer until the autumn, when they go dormant and overwinter. The following spring they are called floricanes and produce lateral shoots (fruiting laterals), which flower and produce fruit. Later in the summer the floricanes senesce and are removed from the plant. In an annual or every-year production system (Strik and Finn, 2012), primocanes are growing simultaneously with the floricanes and during fruit production. Because of this unique growth habit, the nutrient status of the vegetative and reproductive plant parts may be quite different as plants could be allocating resources independently to the different cane types (Malik et al., 1991; Mohadjer et al., 2001; Naraguma et al., 1999; Whitney, 1981). For example, primocanes primarily acquire nutrients from the soil, so adequate fertilization during primocane growth is important (Malik et al., 1991; Mohadjer et al., 2001; Naraguma et al., 1999; Whitney, 1981). Floricanes, on the other hand, rely on stored nutrients during early fruiting lateral growth and fruit production (Malik et al., 1991; Mohadjer et al., 2001; Naraguma et al., 1999; Whitney, 1981).

Primocanes are typically trained onto a wire trellis to facilitate management and harvest, usually in late summer or late winter (Strik and Finn, 2012). Summer training of the primocanes has been shown to increase light exposure and flower bud initiation and therefore yield in some cases (Bell et al., 1995). However, in other cases, training time did not affect yield or even decreased yield when primocane training in August was followed by a particularly cold winter (Bell, et al., 1992; Chapter 2).

Weed control is one of the most difficult management problems in organic production because there are few Organic Materials Review Institute (OMRI)-listed products and labor for hand weeding can be expensive. Some blackberry growers allow weeds to grow in the row (B.C. Strik, personal observation), although this has been shown to be detrimental to blackberry plant growth and yield (Chapter 2; Harkins et al., 2013; Meyers et al., 2014). Weed mat, or porous landscape fabric, has been used successfully to manage weeds in various production systems (Chapter 2 Harkins et al., 2013; Makus, 2011; Meyers et al., 2014). It is particularly well suited to trailing blackberry because, unlike many other types of caneberry, trailing types only produce canes from the crown of the plant, so only a small hole in the weed mat is needed for the plant.

Withholding irrigation after harvest has been shown to have little effect on blackberry plant growth and fruit production in Oregon, which has a Mediterranean climate with relatively dry summers and continuous summer irrigation is typical (Chapter 2; US. Department of Interior, 2013). Blackberry can be irrigated by a variety of methods, from drip to overhead sprinklers, depending on the desired market (Strik and Finn, 2012). However, drip irrigation is usually used in organic production systems because it has the potential to decrease weeds outside of the drip zone, reduce disease presence in the canopy, and can be used to apply fertilizers (fertigation). Fertigation has been used effectively with OMRI-listed materials in blackberry (Chapter 2; Fernandez-Salvador et al., 2015a; Harkins et al., 2013).

Soil in the Willamette Valley, where most Oregon blackberries are grown, tends to be sufficient in phosphorus (P), but nitrogen (N), potassium (K), and boron (B) frequently need to be applied to sustain good growth (Hart et al., 2006). Organic fertilizers are often applied for a certain N rate [55 to 80 $kg \cdot ha^{-1}$ for mature blackberry (Hart et al., 2006)], but unlike many conventional fertilizers, they contain varying levels of other macro- and micronutrients. The effect of organic fertilizers on blackberry growth and soil properties was studied by Harkins et al. (2013) during establishment and Fernandez-Salvador et al. (2015a; 2015b), although effects over a longer time period and combined with other management practices are still unknown.

The objective of this study was to evaluate several production practices (cultivar, weed management, training time, and irrigation) for their effect on the nutrient status of primocane and fruiting lateral leaves, and fruit as well as on soil pH, organic matter, and nutrients in a mature, organic planting of trailing blackberry. The planting was machine-harvested for the processed market. ‘Marion’ and ‘Black Diamond’ were the cultivars used, along with nonweeded, hand-weeded, and weed mat management strategies, August and February primocane training times, and two irrigation strategies (continuous summer irrigation and no irrigation after fruit harvest).

Materials and Methods

Study site. The study was conducted at the North Willamette Research and Extension Center in Aurora, OR [lat. 45°16’47”N, long. 122°45’23”W; USDA plant hardiness zone 8b (U. S. Department of Interior, 2013); elevation 56 m] in 2013 and 2014. The soil type at the site is mapped as a Willamette silt loam (fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll). The field was planted with tissue-cultured plugs in 2010 and was certified organic by Oregon Tilth (Corvallis, OR), a USDA accredited agency, in 2012 during the first year of fruit production. When the planting was approaching maturity in autumn 2012, the soil pH was 5.7 and contained 2.8% organic matter, 0.8 ppm nitrate-N (NO_3-N), 2.8 ppm ammonium-N (NH_4-N), 419 ppm P (Bray II), and 234 ppm K. See Harkins et al. (2013; 2014) for detailed information on site preparation and establishment and Chapter 2 for details on production once the planting matured.

Experimental design. Four management treatments were included in this study: cultivar (‘Marion’ and ‘Black Diamond’), irrigation (postharvest and no postharvest), weed management [nonweeded, hand-weeded, and weed mat (a porous, polyethylene ground cover)], and primocane training time (August and February). Treatments were arranged in a split-split-split plot design with five replicates. The main plot factor was cultivar with one row each of 'Marion' and 'Black Diamond' per replicate. The rows were spaced 3-m apart and split into the two irrigation treatments as subplots, which were further divided into sub-subplots of the weed management and training time combinations. The sub-subplots consisted of four plants spaced 1.5-m apart within the row and were separated from adjacent plots by 3.0 m to allow for clearing of the machine harvester. The in-row and between-row plant spacing was equivalent to a planting density of 2222 plants/ha. Four border plants at the end of each row and a border row on each side completed the planting.

Weed management. In nonweeded plots, weeds were allowed to grow after the first year (2010) and were cut to soil level just prior to machine harvest (early July) to avoid any interference with the catcher plates; the cut weeds were left in the row. In hand-weeded plots, weeds were removed by hand hoeing on several dates through each growing season. The weed mat treatment plots were covered in a 1.4-m wide strip of black, woven, polyethylene ground cover (TenCate Protective Fabrics; OBC Northwest Inc., Canby, OR), which was centered on the row and secured using 0.1-m long nails. According to the manufacturer, the weed mat had a density of 0.11 $kg \cdot m^{-2}$ and a water flow rate of 6.8 $L \cdot h^{-1}$ per m^2. Weeds were removed from the planting hole area and from the seams in the weed mat as required. More information on weed management strategies is provided in Chapter 2.

Irrigation. Each treatment was irrigated with a single lateral of drip tubing (UNIRAM; Netafim USA, Fresno, CA). The tubing had pressure-compensating emitters

(1.9 L·h^{-1} in-line) spaced every 0.6 m and was placed along the ground at the base of the plants under the weed mat, or was attached to a third wire on the steel trellis posts (located ≈0.3 m above the ground) in the nonweeded and the hand-weeded plots. The cultivar, irrigation, and weed management treatment combinations were irrigated independently using a manifold with electric solenoid valves and an automatic timer.

Irrigation was scheduled weekly based on estimates of crop evapotranspiration (ET) but was adjusted as needed each week to maintain similar leaf water potentials (LWP) among treatments (Chapter 2). Irrigation was applied from 9 May to 8 Oct. 2012, 17 May to 27 Sept. 2013, and 28 May to 23 Sept. 2014 in the postharvest irrigation treatment. In the no postharvest irrigation treatment, irrigation was initiated on the same dates but was withheld after the last fruit harvest on 30 July 2012, 19 July 2013, and 15 July 2014. These non-irrigated plots received no effective water after harvest until the rainy season began on 12 Oct. 2012, 21 Sept. 2013, and 23 Sept. 2014.

Fertilization. An OMRI-approved fish hydrolysate and fish emulsion blend was diluted 1:3 (v/v) with water and applied through the drip 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). While only one injector was needed, the electric pump was installed to reduce injection time (≈1.5 h per application compared to ≈4.5 h per application with the water-driven pump). The fertilizer was split into eight equal applications (approximately every 2 weeks from 5 Apr. to 12 July 2013 and 19 Mar. to 25 June 2014) and applied at a total rate of 90 kg·ha^{-1} N per year (based on percentage of N as stated on the label). Converted Organics 421 (4N–0.8P–0.8K; True Organic Products Inc., Spreckels, CA) was used for the first four applications in 2013, and True Organics 512 (5N–0.4P–1.7K) was used for the last four applications in 2013 and all applications in 2014. Irrigation was run for 30 min prior to injection to fully pressurize the system to 303.4 kPa and run for 2 h after injection to flush the drip lines. The fertilizers applied were analyzed for total nutrient content (Brookside Laboratories, New Bremen, OH), and the rate of all macro- and micronutrients applied was calculated (Table 3.1).

Additional granular fertilizers were applied in 2013 and 2014, based on results from soil and primocane leaf tissue analyses. They included Pro-Pell-It lime and dolomite (Marion Ag Service Inc., Aurora, OR), which was applied in 2013 to increase soil pH, and solubor (U.S. Borax Inc., Valencia, CA), which was applied both years to increase the concentration of B in the plants. Lime sulfur (Or-Cal Inc., Junction City, OR) was also applied to plants in the spring of both years to control for septoria leaf spot (*Septoria rubi* Westend) and copper (Cu; Nu-Cop 50 DF; Albaugh Inc., Ankeny, IA) was applied in 2014 to control for purple blotch [*Septocyta ruborum* (Lib.) Petr.] and cane rust [*Kuehneola uredines* (Link) Arthur].

Primocane training. In the August-trained treatment, primocanes were trained to the upper trellis wires on 13–14 Aug. 2012, 27–29 Aug. 2013, and 14 Aug. 2014 using the method described in Chapter 2. In the February-trained treatment, primocanes were left on the lower trellis wire used for the drip lines until they were wrapped and tied to the upper two trellis wires on 21–25 Feb. 2013 and 21–28 Feb. 2014. Primocane training was done by replicate to avoid any possible date effects within treatment over the days required to wrap and tie the canes.

Data collection. Soil was analyzed to evaluate treatment effects over time. Soil samples were collected on 23 Oct. 2012 and 2013, and 27 Oct. 2014. Samples were aggregates of two soil cores taken per plot. The cores were collected using a 2.4–cm diameter, 0.5–m long, slotted, open-side, chrome-plated steel probe (Soil Sampler Model Hoffer; JBK Manufacturing, Dayton, OH). The probe was inserted 0.3-m deep at a distance of 0.3 m from the crown in the middle of the row of two different plants in each plot. Soil samples were shipped to Brookside Laboratories for analysis of pH using the 1:1 soil:water method (McLean, 1982), organic matter using Loss-On-Ignition at 360 °C (Nelson and Sommers, 1996), NO_3-N and NH_4-N using automated colorimetric methods after extraction with 1 M KCl (Dahnke, 1990), and Bray II P, K, calcium (Ca), magnesium (Mg), sulfur (S), sodium (Na), iron (Fe), B, Cu, manganese (Mn), zinc (Zn), and aluminum (Al) using ICP after extraction of the nutrients using the Mehlich 3 method (Mehlich, 1984).

Leaf samples were collected from the primocanes on 26 July 2013 and 25 July 2014 per standard recommendations for tissue analysis (Hart et al., 2006) and from the floricanes (choosing leaves on the fruiting laterals) on 20 June 2013 and 19 June 2014 (first black fruit stage). Ten recent fully expanded leaves were collected from each plot on each sample date. The leaf samples were analyzed for macro- and micronutrient concentration by Brookside Laboratories. Total N content was determined in each sample using a combustion analyzer, and P, K, Ca, Mg, S, Fe, B, Cu, Mn, Zn, and Al were determined using an inductively-coupled plasma (ICP) spectrophotometer after wet ashing the samples in nitric/perchloric acid (Gavlak et al., 1994).

Ripe fruit were harvested twice weekly from 24 June to 18 July in both years, using an over-the-row rotary harvester (Littau Harvesters Inc., Stayton, OR). 'Black Diamond' was harvested on every date in both years whereas 'Marion' was not harvested on the first or last date in either year. A 25-berry subsample per treatment plot was shipped overnight to Brookside Laboratories on 8 July 2013 and 7 July 2014 and analyzed for macro- and micronutrient concentration, as described previously.

Floricanes and primocanes were also collected and analyzed for nutrients in the course of the study, see Appendix Tables 1.1–1.4. Primocane tissue samples were collected in late winter during the dormant period, while floricane tissue samples were collected during floricane removal in late summer (August).

Data analysis. Plant nutrient data were analyzed by year due to large differences in weather and to winter damage observed in Dec. 2013 (Chapter 2). Soil data were analyzed across years to examine treatment effects over time. Within year, data were analyzed for a split-split-split plot design with cultivar as the main plot factor, postharvest irrigation as the subplot factor, and weed management and training time as sub-subplots, using PROC MIXED in SAS (version 9.3; SAS Institute Inc., Cary, NC). The soil data were analyzed using a split-split-split-split plot design as above except year was the highest order factor. Residuals were plotted to assess homogeneity of variance (residual by fitted value plot) and normality (histogram of the residuals). When strong fanning was seen in the residual plots, the data were log transformed for analysis to improve homogeneity of variance and to assess proportional effects. Data were back transformed for presentation. Means were compared for treatment effects using Tukey's honestly significant difference test with $\alpha = 0.05$. Mean comparisons within significant interactions were done for treatments using Least Square Means (LS Means) with α = 0.05.

Results

Soil conditions. Soil pH, organic matter content, and macronutrient concentrations were mainly affected by sample year and weed management strategy (Table 3.2). Soil organic matter increased in the last year of the study. Soil NO_3–N and NH_4–N were higher in 2013 than in 2012 and 2014. Soil K was greater in 2014 than in 2013. Soil P decreased each year from 2012 to 2014. Soil pH increased over the study period, but only with weed mat. The effects of weed management strategy on soil macronutrients were mixed. In general, soil under the weed mat had the highest pH, organic matter content, and concentration of several macronutrients, including NH_4-N, K, Ca, Mg, and S. The hand-weeded treatment had lower concentrations of several soil macronutrients than the nonweeded treatment, including soil NO_3-N (in February-trained plots only), K, and Ca.

Cultivar had a limited effect on soil macronutrient concentration. Irrigation affected most soil macronutrients, although mostly through interactions with other treatments. For example, 'Marion' plots that were trained in February had a lower concentration of soil K when they were irrigated after harvest than when they were not (P = 0.0031; Fig. 3.1A). August-trained plots had higher soil pH and Mg than February-trained plots, while February-trained plots had higher NO_3-N, P, and S in some treatment combinations (P = 0.0213; Table 3.2; Fig. 3.1B).

The concentration of soil micronutrients such as Na, Fe, and Cu tended to increase during the study period, while soil B decreased over time, and soil Zn and Mn were not affected by year (Table 3.3). Soil B was higher in 'Black Diamond' plots than in 'Marion' plots, but only in 2012. 'Black Diamond' plots also had higher soil Fe than 'Marion', but only when weed mat was used. 'Black Diamond' plots irrigated after harvest had higher soil Zn with weed mat than when hand-weeded, whereas plots that received no postharvest irrigation had higher Zn with hand weeding than no weeding (P = 0.0086; Fig. 3.1C). Soil Zn in 'Marion' plots was not affected by irrigation or weed management. Soil Cu was lowest in hand-weeded plots, whereas weed mat plots had higher soil Mn and Zn than the other weed management strategies. Soil under weed mat in 'Black Diamond' plots was especially high in Mn in 2013 and 2014, but in 'Marion', it was only higher in 2014 than in 2012 (P = 0.0041; Fig. 3.2A). A similar pattern was seen under weed mat in the different irrigation treatments (P = 0.0006; Fig. 3.2B). In both cultivars, soil Mn was higher in weed mat than in nonweeded or hand-weeded plots when the plots were irrigated after harvest; however, when plots were not irrigated after harvest, those with weed mat had higher soil Mn than other weed management treatments in 'Black Diamond', but were only higher than hand-weeded in 'Marion' (P = 0.0145; Fig. 3.2C). In plants receiving no irrigation postharvest, soil Fe was higher with February training than when trained in August (Table 3.3).

Primocane leaf nutrient concentration. 'Marion' had higher concentrations of N, P, S, and Zn in the primocane leaves than 'Black Diamond' in 2013 (Table 3.4), as well as higher concentrations of Ca, Mg, and B the following year (Table 3.5). 'Black Diamond', on the other hand, only had a higher concentration of Fe and Al in the primocane leaves and only in 2013. The concentration of many of the nutrients in the primocane leaves of 'Black Diamond' were near the bottom of or below the recommended leaf tissue standards for caneberry in Oregon (Hart et al., 2006). For example, N, K, Ca, Mg, and B were below the standards in at least one year and P dropped to the very bottom of the sufficiency range in 2014. ‘Marion’ had leaf B concentrations below the sufficiency range in 2013.

The irrigation treatments had no direct effect on primocane leaf nutrient concentrations in 2013, but in 2014, plots with postharvest irrigation resulted in higher primocane leaf Fe and Al than those without (Tables 3.4 and 3.5). In 2013, plots with weed control (i.e., hand weeding or weed mat) had higher primocane leaf S than nonweeded plots. Plots with weed mat had higher leaf K than nonweeded plots in 2013 within training time. Plots without postharvest irrigation had higher leaf Mg when nonweeded than with weed mat in 2013. Use of weed mat as a mulch led to higher primocane leaf Cu and Zn and lower Fe and Al than found with the other weed management treatments. In 2014, the hand-weeded plots had the highest primocane leaf Fe and Al compared to the other weed management treatments, while the nonweeded plots had higher primocane leaf Ca than hand-weeded plots, and higher primocane leaf Mg than the plots with either method of weed control.

As far as primocane training was concerned, February-trained plots had higher primocane leaf P, K, S, B, Cu, Mn, and Zn than August-trained plots in 2013 (Table 3.4). A similar training-time effect was observed for primocane leaf K in 2014, whereas the opposite effect was found for leaf Mg and Zn (Table 3.5). In 2013, there was an irrigation × training time effect on primocane leaf Ca and Mg with February-trained plants having a higher concentration of both nutrients in the primocane leaves than the August-trained plants only when the plants were not irrigated after harvest (Table 3.4). August-trained plants had primocane leaves with leaf K and B concentrations below the sufficiency range in 2013.

Floricane leaf nutrient concentration. The treatments had variable effects on the nutrient concentrations in the floricane fruiting lateral leaves (Tables 3.6 and 3.7). The nutrients in these leaves often differed between cultivars or were affected by cultivar interactions. For example, ‘Black Diamond’ had greater floricane leaf N than ‘Marion’ in 2013, and greater leaf N, P, Ca, Mg, S, Fe, Cu (with postharvest irrigation only), Mn, Zn, and Al than ‘Marion’ in 2014.

Weed management effects on floricane leaf nutrient concentration were complicated by interactions with cultivar and irrigation. In both years, the presence of weeds in the nonweeded plots reduced floricane leaf P. Leaf Zn was higher in the weed mat plots than in the other weed management strategies in both years, while leaf Al was lower in the weed mat plots than the other two weed management treatments in 2014. In 2013, ‘Black Diamond’ had lower floricane leaf N in the nonweeded treatment than with weed control, whereas weed management strategy had no effect on floricane leaf N in ‘Marion’. However, in 2014, both cultivars grown in nonweeded plots had a lower floricane leaf N than in weed mat plots. ‘Black Diamond’ had higher leaf Ca than ‘Marion’ when the weeds were controlled (Table 3.6).

Training affected floricane leaf nutrient concentrations directly only in 2014, when August-trained plants had higher floricane leaf N, P, Ca, Mg, S, B, and Zn than those trained in February. In 2013, August-training ‘Black Diamond’ increased floricane leaf Ca compared to ‘Marion’, whereas there was no difference between cultivars when they were trained in February. Training time only affected leaf Mn in ‘Marion’ plants that were irrigated postharvest, where February training resulted in higher Mn than August training (*P* = 0.031; Fig. 3.3A). In 2014, ‘Black Diamond’ trained in August had a higher floricane leaf Ca, B, and Zn than when trained in February, whereas there was no effect in ‘Marion’. In 2014, floricane leaf Ca was affected by a cultivar × irrigation × training interaction (*P* = 0.0106; Fig. 3.3B). In ‘Marion’, floricane leaf Ca was unaffected by irrigation or training time but was lower than in ‘Black Diamond’, whereas in ‘Black Diamond’, floricane leaf Ca was lowest in plants that received no postharvest irrigation and were February-trained. Irrigation did not have a direct effect on any floricane leaf nutrient in either year.

Fruit nutrient concentration. The concentration of nutrients in the fruit was mostly affected by cultivar and weed management (Tables 3.8 and 3.9). For example, ‘Black Diamond’ had higher concentrations of many nutrients in the fruit than ‘Marion’, including N, P (in 2014 and only with August training), K, S, Fe (2013 only), B, Cu (August-trained plants only in 2014), Mn (in 2014 and with postharvest irrigation only), and Al. ‘Marion’, on the other hand, often had higher concentrations of Ca (August-trained plants only in 2013 and with weed mat only in 2014), Mn (in 2014 and only with postharvest irrigation or weed mat) and Zn (2013 and only in nonweeded) in the fruit than ‘Black Diamond’.

The effects of weed management were varied. In some cases, plants grown with weed control produced fruit with higher concentrations of N (with weed mat in August-trained plants only in 2014), P (with weed mat only in 2014), K (2103 only; in ‘Marion’ only with weed mat), Mg (2013 only), S (only in ‘Black Diamond’ in 2013 and with weed mat only in 2014), Fe (2013 only), B (2013 only), Cu (only in ‘Black Diamond’ in

2013), Mn (only in 2014 in hand weeded ‘Marion’), and Zn (only ‘Black Diamond’ in 2013 and with weed mat only in 2014) than those in nonweeded plots. Sometimes plants grown with weed mat also had higher concentrations of fruit N (in 2014 only for February-trained plants), P, S (2014 only), and Cu (2014 only) than with hand weeding but had lower concentrations of Ca (‘Black Diamond’ only in 2014) and Mn (only in 2013 when August-trained).

Only a few nutrients in the fruit were affected directly by training time (Tables 3.8 and 3.9). August-trained plants had higher concentrations of Ca (‘Marion’ in 2013 only) and Mg (‘Black Diamond’ only in 2014). A significant three-way interaction among cultivar, irrigation, and training time in 2013 revealed that August-trained plants also had a higher concentration of K in the fruit than February-trained plants when ‘Black Diamond’ was irrigated after harvest ($P = 0.047$; Fig. 3.4).

Aluminum was the only nutrient in the fruit affected directly by postharvest irrigation (Table 3.8). In this case, the concentration of Al was greater with than without postharvest irrigation (2013 only).

Discussion

In fall 2012, soil pH was 5.7, and the only nutrients below the recommended levels (Hart et al., 2006) were K and B (Harkins, 2013). Supplemental lime and B were broadcast in early 2013, and K was applied by fertigation (Table 3.1). Soil pH increased to an average of 5.8 by fall 2013, but soil B and K were still low. Additional B and K fertilizer were applied in spring 2014, which resulted in a slight increase in soil levels by fall 2014. In blueberry (*Vaccinium corymbosum* L.), soil K also increased over time when plants were fertilized with fish emulsion (Larco et al., 2013). Primocane leaf B concentration was below the sufficiency range throughout the study, including during the establishment years (Harkins et al., 2014).

Soil K under weed mat was higher than the other weed management treatments, although still below the recommended threshold (Hart et al., 2006). Primocane leaf %K was also below the sufficiency range. Interestingly, ‘Black Diamond’ had higher floricane leaf %K in the nonweeded treatment than the weed mat treatment in 2014. However, it is not clear from these data if the nutrient content (as opposed to concentration) was actually different, and this effect was not observed during the establishment years (Harkins et al., 2014) or in 2013. Harkins et al. (2014) found that the amount of K removed from the field in fruit and floricane prunings during the first fruiting year ranged from 36–82 $kg \cdot ha^{-1}$, depending on the weed management treatment. If K removal was similar in the current study, it would have exceeded the amount of K that was applied (Table 3.1), implying that K would not be replenished in the soil at the rate it was being removed. Primocane leaf K concentrations were highest in 2012 (Harkins et al., 2014) and lowest in 2014, indicating that this may have indeed been taking place. Even though soil K increased over the study period, additional fertilizer K or use of another fertilizer source with a higher K content appeared necessary to provide enough K in this production system since soil and primocane leaf levels were consistently low.

Plant tissue nutrient concentrations did not appear to be consistently related to soil nutrient level across treatments. For instance, while soil Ca was highest under weed mat, Ca concentration was actually lower in plant tissues grown with weed mat than those with at least one of the other weed management treatments, including the fruit in 2013, floricane tissue sampled during caning out at the end of July in 2013 (Appendix Table 1.3), 'Black Diamond' floricane leaves and fruit in 2014, and primocane tissue from plants without postharvest irrigation sampled at the end of the year during the dormant period (Appendix Table 1.2). The only plant tissue grown with weed mat that had higher Ca than the nonweeded treatment was 'Marion' floricane leaves in 2014.

Soil Ca increased over the three years in the nonweeded and weed mat treatments and was higher under weed mat than the other weed management strategies. Soil Mg was higher with weed mat than with hand weeding. Increases in these nutrients were likely due to the lime applied during the study period. Differences in soil Ca and Mg did not translate into similar patterns in primocane leaves, floricane leaves, or fruit. Fruit and floricane leaf concentrations of Ca and Mg tended to be slightly higher in 2014 than 2013, although this was not seen in primocane leaves.

The soil in the weed mat plots was drier during soil sampling than in the other weed management plots (E. Dixon, personal observation) and had a higher organic matter content, likely due to increased root growth over the study (Chapter 2). There may have been less leaching of soil cations in the drier treatments (i.e. no postharvest irrigation and weed mat). Lime and B were applied by broadcasting the products on top of the weed mat. Due to the weed management treatment response observed, it is clear that nutrients are able to pass through the weed mat to the soil with relative ease. Landscape fabrics have previously been shown to be permeable to organically derived N and P (Zibilske, 2010). Interestingly, although the soil pH increased from 2012–2014 in the weed mat treatment, the hand-weeded and nonweeded plots saw no change in soil pH.

Primocane leaf nutrient analysis is an important tool used by growers to develop and modify nutrient management programs. The nutrient concentrations of primocane leaves sampled in late July to early August are compared to published standards (Hart et al., 2006) with the goal of improving the nutrient status of the subsequent floricanes (the following year) through fertilization in autumn or spring (Strik and Bryla, 2015). In our study, primocane leaf concentrations of N, K, Ca, Mg, and B were low or below the recommended sufficiency ranges in one or both years, similar to what Harkins et al. (2014) found during the establishment years, although in their case, K was sufficient in the planting. In the 4 years of primocane leaf testing included in that study and the present one, 'Black Diamond' always had a lower leaf N than 'Marion' and was at the very bottom or below the sufficiency range, a response also observed by Fernandez-Salvador et al. (2015a). In another study, 'Black Diamond' had the lowest primocane leaf N among six cultivars tested, not including 'Marion' (Fernandez-Salvador et al., 2015b). It is unclear whether 'Black Diamond' requires less N than 'Marion' or if the N content of the plants was in balance relative to yield, with less N allocated to primocane leaves, but more to other plant parts such as fruit, floricane leaves, and floricane tissue (Appendix Tables 1.3 and 1.4). 'Black Diamond' produced 2 $t{\cdot}ha^{-1}$ more fruit than 'Marion' in 2012 (Harkins et al., 2013). In 2013 and 2014, the cultivars did not significantly differ in yield (Chapter 2). Although some of the primocane leaf nutrients were at the low end of the sufficiency range, or even below the range for some treatments, yield was generally in the expected range, except in nonweeded plots and in August-trained 'Marion' plants in 2014, which experienced cold damage (Chapter 2). It is possible that the two cultivars were allocating N differently, as 'Black Diamond' had a higher %N in floricane leaves and fruit during the first year of production (Harkins et al., 2014) and the following 2 years. ‘Black Diamond’ also had higher floricane %N and tended to have higher primocane %N than ‘Marion’ (Appendix Tables 1.2–1.4). Nelson and Martin (1986) found that the rate of applied fertilizer N and K were better predictors of yield in ‘Thornless Evergreen’ blackberry than primocane leaf or soil nutrient concentrations, although they still considered primocane leaf nutrient samples as the best indicator for plant nutrient needs in the following year. Since the recommended nutrient standards were primarily developed using data from ‘Marion’ (Hart et al., 2006), it is possible that other cultivars are not well represented by these sufficiency ranges. Primocane tissues (cane and non-senescent leaves) were also higher in ‘Marion’ for %P, while floricane tissues had a higher %P in ‘Black Diamond’ (Appendix Tables 1.2–1.4).

Leaves were not washed prior to analysis (a standard sampling practice, Hart et al., 2006), so nutrients such as Fe and Al may be highly variable due to soil contamination. Copper fungicide applied in March and April 2014 resulted in an order of magnitude increase of Cu in the 2014 floricane fruiting lateral leaves compared to the prior year. Soil Cu levels were also almost doubled from 2013 to 2014. Despite increased soil and floricane leaf Cu, primocane leaf Cu did not increase in 2014 and was again at the low end of the sufficiency range.

The cultivar by weed management interaction on floricane leaf %N suggested that ‘Black Diamond’ was less effective at competing with weeds for N than ‘Marion’. In both years, there was a much larger reduction in floricane leaf %N when plants were grown without weed control in ‘Black Diamond’ than in ‘Marion’. This cultivar response to weeds was consistent with the effects seen on yield (Chapter 2) in the mature planting, although there was no cultivar response to weed presence on leaf %N or yield during the establishment years (Harkins et al., 2014). While ‘Black Diamond’ had a higher concentration of N in each part of the floricane than ‘Marion’, including in the leaves, canes (Appendix Tables 1.3 and 1.4), and fruit, it had a lower concentration of N in the primocane leaves, which is consistent with what was reported by Harkins et al. (2014).

Training effects seen in 2014 on the nutrient concentration of floricane fruiting lateral leaves were probably due to the treatment effects on winter hardiness documented in Chapter 2. Floricane leaves in 2014 had higher concentrations of most nutrients than they did in 2013, most likely due to the increase in fertilizer rate from 56 $kg{\cdot}ha^{-1}$ of N in 2012 (Harkins et al., 2013) to 90 $kg{\cdot}ha^{-1}$ of N in 2013; this also led to an increase in the other nutrients present in the organic fertilizers used (Table 3.1). Floricanes use primarily stored nutrients for new growth in the spring (those taken up when these canes were primocanes in the prior year), whereas primocane growth is supported by newly taken up nutrients (Malik et al., 1991; Mohadjer et al, 2001; Naraguma et al., 1999; Whitney, 1981). Therefore, the primocanes that grew in 2013 (and became floricanes in 2014) would have had access to the increased fertilizer application as compared with the primocanes that grew in 2012.

‘Black Diamond’ had a higher concentration of many nutrients in the fruit than ‘Marion’ in both years, despite producing larger fruit with a higher water content than ‘Marion’ (Chapter 2). Our results are similar to what was found by Harkins et al. (2014) in 2012. The only nutrient consistently higher in ‘Marion’ than ‘Black Diamond’ was Ca, which is known to be important for good fruit quality and storage life in other species (Jones et al., 1932; Léchaudel et al., 2005; Simmons et al., 1998). Interestingly, ‘Black

Diamond' has been found to have firmer fruit than 'Marion' (Fernandez-Salvador et al., 2015a; Finn et al., 2005). It is possible that low Ca concentrations in 'Black Diamond' fruit still resulted in higher Ca content than 'Marion' considering 'Black Diamond's larger fruit weight and higher water content (Chapter 2) as Ca is mobile in the xylem (Jones et al, 1983). It is also possible that the compact growth habit (Fernandez-Salvador et al., 2015a; Finn et al., 2005; Harkins et al., 2013), and perhaps a lower leaf:fruit ratio, found in 'Black Diamond' was responsible for the higher fruit nutrients, although mango (*Mangifera indica* L.) had higher Ca with lower leaf:fruit ratios (Léchaudel et al., 2005; Simmons et al., 1998). Leaf:fruit ratio had no effect on the accumulation of cations in grape (*Vitis vinifera* L.) (Etchebarne et al., 2010).

Conclusions

Plant and soil nutrient levels were affected by the treatments studied. While the cultivars had limited effects on soil nutrients, they differed in the concentration of many nutrients in the plant tissues studied. 'Black Diamond' had higher concentrations of some nutrients in floricane tissues than in primocane leaves, including N and P. Since the sufficiency standards (Hart et al., 2006) were developed primarily with data from 'Marion', they may need to be adjusted for other cultivars, including 'Black Diamond'. Withholding irrigation after harvest affected most soil nutrients, although effects on plant tissue nutrients were limited. Since the impact of postharvest irrigation on plant growth and yield were also limited after 3 years (Chapter 2), deficit irrigation seems to be an effective strategy for water conservation. Organic matter, pH, NH_4–N, K, Ca, Mg, S, Cu, Mn, and Zn were all higher in soil under weed mat than in hand-weeded plots, as were nutrient concentrations in many plant parts. These results combined with the increased plant growth, yield, and profit (Chapter 2; Dixon and Strik, 2015; Harkins et al., 2013) gained from using weed mat rather than hand weeding or no weeding indicate that weed mat is a very effective management tool in this organic system. The effects of primocane training time were variable. Training primocanes in August increased the concentration of some nutrients in the aboveground plant, but August training is not recommended in 'Marion' due to the greater risk of cold damage in winter (Chapter 2). While our study provides information on the impact of these organic production systems on aboveground nutrient concentration, further study is needed to assess treatment effects on blackberry crowns and roots as they comprise a significant portion of the plant and root and crown storage could impact nutrient concentrations in aboveground plant parts.

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Table 3.1. Total nutrients applied to mature organic trailing blackberry plants during two growing seasons (2013–2014).

	Macronutrients (kg▪ha^{-1})						Micronutrients (g▪ha^{-1})			
Fertilizer[zy]	N	P	K	Ca	Mg	Na	B	Cu	Mn	Zn
2013										
Converted Organics 4-2-1	31	15	18	2	4	<1	9	5	24	61
True Organics 5-1-2	42	9	13	<1	3	32	8	2	17	50
Solubor	–	–	–	–	–	–	2200	–	–	–
Pro-Pell-It lime	–	–	–	762	–	–	–	–	–	–
Pro-Pell-It dolomite	–	–	–	112	58	–	–	–	–	–
2014										
True Organics 5-1-2	90	10	40	<1	2	28	10	2	25	32
Solubor	–	–	–	–	–	–	2200	–	–	–
Nu-Cop 50	–	–	–	–	–	–	–	4400	–	–

[z]Analyzed by Brookside Laboratories, Inc. (New Bremen, OH). Values for Solubor, Pro-Pell-It lime and dolomite, and Nu-Cop 50 were obtained from the product label.
[y]The two products were fish derivatives mixed 1:3 (v/v) with water before application by fertigation through the drip system and were injected in four equal applications at a rate of 90 kg·ha^{-1} total N (based on percentage of N as stated on the label) per year.

Table 3.2. Soil pH, organic matter (OM) content, and macronutrient concentrations in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center, in Aurora, OR.[z]

	pH (1:1 soil:water)			OM (%)		Macronutrients (ppm) NO$_3$			NH$_4$			P		K	Ca			Mg		S
Treatment																				
Year (Y)																				
	non-weeded	*hand-weeded*	*weed mat*						*non-weeded*	*hand-weeded*	*weed mat*				*non-weeded*	*hand-weeded*	*weed mat*			
2012	5.6 cd[x]	5.6 cd	5.7 bcd	2.8 b			0.7 b		3 de	3 e	3 de	419 a		234 ab	988 cd	971 d	1000 bcd	131		16
2013	5.7 cd	5.6 d	6.0 ab	2.8 b			1.5 a		11 b	10 b	13 a	376 b		222 b	1241 bc	1066 bcd	1628 a	138		17
2014	5.9 abc	5.6 cd	6.1 a	3.2 a			0.8 b		5 cd	5 cde	7 c	261 c		252 a	1258 b	1095 bcd	1572 a	165		18
Cultivar (C)																				
Black Diamond (B. Dia.)		5.8		3.0			1.0			7		354		246 a		1219		149		17
Marion		5.8		2.9			1.0			6		350		226 b		1185		140		17
Irrigation (I)																				
	non-weeded	*hand-weeded*	*weed mat*			*non-weeded*	*hand-weeded*	*weed mat*												
Postharvest (+Irrig.)	5.7 bc	5.6 c	6.1 a	2.9		0.9 bc	0.8 c	0.9 bc		6		350		230 b		1215		149		18 a
No postharvest (-Irrig.)	5.7 bc	5.6 c	5.8 b	2.9		1.3 a	0.9 c	1.2 ab		7		354		242 a		1189		141		16 b
Weed management (W)																				
						Aug.		*Feb.*										*+Irrig.*	*-Irrig.*	
Nonweeded		5.7 b[x]		2.9 b		0.9 b		1.2 a		6 b		342		233 b		1162 b		137 bc	139 bc	16 b
Hand-weeded		5.6 b		2.9 b		0.9 b		0.8 b		6 b		347		211 c		1044 c		130 c	130 c	16 b
Weed mat		6.0 a		3.0 a		1.0 ab		1.0 ab		8 a		367		264 a		1400 a		179 a	153 b	18 a
Training (T)																				
				+Irrig.	*-Irrig.*	*+Irrig.*		*-Irrig.*				*+Irrig.*	*-Irrig.*							
August (Aug.)		5.8 a		3.0 a	2.8 b	0.9 b		0.9 b		7		353 ab	329 b	236		1222		151 a		16 b
February (Feb.)		5.7 b		2.9 ab	3.0 a	0.8 b		1.3 a		6		348 ab	379 a	237		1182		138 b		18 a
Significance[y]																				
Y		NS		0.0234			0.0177			0.0035		0.0002		0.025		0.0405		NS		NS
C		NS		NS			NS			NS		NS		0.038		NS		NS		NS
I		NS		NS			0.0193			NS		NS		0.025		NS		NS		0.0125
W		<0.0001		0.0013			0.0033			<0.0001		NS		<0.0001		<0.0001		<0.0001		0.0004
T		0.0303		NS			NS			NS		0.0275		NS		NS		0.0015		0.0004
Y x C		NS		NS			NS			NS		NS		NS		NS		NS		NS
Y x I		NS		NS			NS			NS		NS		NS		NS		NS		NS
Y x W		0.0099		NS			NS			0.0237		NS		NS		<0.0001		NS		NS
Y x T		NS		NS			NS			NS		NS		NS		NS		NS		NS
C x I		NS		NS			NS			NS		NS		NS		NS		NS		NS
C x W		NS		NS			NS			NS		NS		NS		NS		NS		NS
C x T		NS		NS			NS			NS		NS		NS		NS		NS		NS
I x W		0.0425		NS			0.0379			NS		NS		NS		NS		0.0041		0.0463
I x T		NS		0.0001			0.0002			NS		0.0069		NS		NS		NS		NS
W x T[w]		NS		NS			0.026			NS		NS		NS		NS		NS		0.0133

[z]Samples were collected from the top 30 cm of soil in Oct. 2012–2014.
[y]NS = non-significant; *P*-values provided for significant factors.
[x]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[w]All other higher order interactions are mentioned in the text or were non-significant and are not shown.

Table 3.3. Soil micronutrient concentrations in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR.[z]

	Micronutrients (ppm)												
	Na		Fe		B		Cu			Mn	Zn	Al	
Treatment													
Year (Y)													
					B. Dia.	*Marion*	*non-weeded*	*hand-weeded*	*weed mat*				
2012	29 b[x]		305 ab		0.61 a	0.47 b	0.7 c	0.7 c	0.8 c	20	2.4	1368 a	
2013	31 ab		289 b		0.30 c	0.28 c	0.8 c	0.8 c	0.8 c	22	2.1	1255 b	
2014	38 a		325 a		0.38 bc	0.42 bc	1.5 ab	1.2 b	1.7 a	23	2.0	1349 a	
Cultivar (C)													
Black Diamond (B. Dia.)	33		307		0.43		1.0			23 a	2.3	1323	
Marion	33		306		0.39		1.0			20 b	2.0	1325	
Irrigation (I)													
Postharvest (+Irrig.)	34		307		0.41		1.0			22	2.1	1337	
No postharvest (-Irrig.)	32		306		0.41		1.1			22	2.3	1311	
Weed management (W)													
	B. Dia.	*Marion*	*B. Dia.*	*Marion*	*Aug.*	*Feb.*						*B. Dia.*	*Marion*
Nonweeded	32 ab	32 ab	301 b	307 ab	0.43 ab	0.43 ab	1.0 ab			19 b	2.0 b	1336 ab	1314 bc
Hand-weeded	34 ab	30 b	305 ab	310 ab	0.39 ab	0.38 b	0.9 b			17 b	2.1 b	1347 ab	1376 a
Weed mat	33 ab	36 a	314 a	301 b	0.38 b	0.45 a	1.1 a			29 a	2.4 a	1287 c	1284 c
Training (T)													
			+Irrig.	*-Irrig.*									
August (Aug.)	32		310 a	299 b	0.40		1.0			21 b	2.2	1324	
February (Feb.)	34		304 ab	313 a	0.42		1.0			23 a	2.2	1324	
Significance[y]													
Y	0.0492		0.0168		0.0023		0.0037			NS	NS	0.0234	
C	NS		NS		NS		NS			0.0038	NS	NS	
I	NS		NS		NS		NS			NS	NS	NS	
W	0.023		NS		0.0053		0.0036			<0.0001	0.0039	<0.0001	
T	NS		NS		NS		NS			0.0111	NS	NS	
Y x C	NS		NS		0.0216		NS			NS	NS	NS	
Y x I	NS		NS		NS		NS			NS	NS	NS	
Y x W	NS		NS		NS		0.0106			<0.0001	NS	NS	
Y x T	NS		NS		NS		NS			NS	NS	NS	
C x I	NS		NS		NS		NS			NS	NS	NS	
C x W	0.0247		0.0082		NS		NS			0.0106	NS	0.0448	
C x T	NS		NS		NS		NS			NS	NS	NS	
I x W	NS		NS		NS		NS			<0.0001	0.0045	NS	
I x T	NS		0.0007		NS		NS			NS	NS	NS	
W x T[w]	NS		NS		0.0135		NS			NS	NS	NS	

[z]Samples were collected from the top 30 cm of soil in Oct. 2012–2014.
[y]NS = non-significant; *P*-values provided for significant factors.
[x]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[w]All other higher order interactions are mentioned in the text or were non-significant and are not shown.

Table 3.4. Primocane leaf nutrient concentrations in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR. The leaves were collected in July 2013.

	Macronutrients (%)									Micronutrients (ppm)								
Sufficiency range[z]	2.3-3.0	0.19-0.45	1.3-2.0		0.6-2.0		0.3-0.6		0.1-0.2	60-250		30-70		6-20	50-300	15-50	na	
	N	P	K		Ca		Mg		S	Fe		B		Cu	Mn	Zn	Al	
Treatment																		
Cultivar (C)																		
Black Diamond (B. Dia.)	2.1 b[x]	0.23 b	1.2		0.6		0.30		0.141 b	151 a		28.5		7.2	161	27 b	110 a	
Marion	2.8 a	0.28 a	1.3		0.7		0.34		0.156 a	131 b		29.8		6.9	157	35 a	96 b	
Irrigation (I)																		
					Aug.	*Feb.*	*Aug.*	*Feb.*		*B. Dia.*	*Marion*	*B. Dia.*	*Marion*				*B. Dia.*	*Marion*
Postharvest (+Irrig.)	2.5	0.26	1.2		0.7 ab	0.6 ab	0.33 ab	0.33 ab	0.149	160 a	125 b	29.4 a	28.8 ab	7.0	166	31	119 a	90 b
No postharvest (-Irrig.)	2.5	0.25	1.3		0.6 b	0.7 a	0.32 b	0.34 a	0.148	142 ab	136 b	27.5 b	30.9 a	7.1	152	31	101 ab	102 ab
Weed management (W)																		
			Aug.	*Feb.*			*+Irrig.*	*-Irrig.*										
Nonweeded	2.4	0.26	1.1 c	1.2 bc	0.6		0.32 ab	0.33 a	0.144 b	144 a		30.5		6.8 b	165	29 c	107 a	
Hand-weeded	2.5	0.25	1.3 ab	1.2 ab	0.7		0.33 ab	0.33 ab	0.149 a	147 a		28.6		7.0 b	161	31 b	109 a	
Weed mat	2.5	0.26	1.2 b	1.3 a	0.6		0.34 a	0.32 b	0.152 a	131 b		28.3		7.4 a	151	32 a	93 b	
Training (T)																		
August (Aug.)	2.5	0.25 b	1.2 b		0.6		0.30		0.145 b	137		28.2 b		6.9 b	150 b	30 b	100	
February (Feb.)	2.5	0.26 a	1.3 a		0.7		0.30		0.152 a	145		30.1 a		7.2 a	168 b	31 a	106	
Significance[y]																		
C	<0.0001	0.0095	NS		NS		NS		0.0006	0.0007		NS		NS	NS	<0.0001	0.0097	
I	NS	NS	NS		NS		NS		NS	NS		NS		NS	NS	NS	NS	
W	NS	NS	<0.0001		NS		NS		0.0045	0.0464		NS		0.0001	NS	0.0003	0.0183	
T	NS	0.0295	0.0191		NS		NS		0.0004	NS		0.0321		0.0100	0.0354	0.0258	NS	
C x I	NS	NS	NS		NS		NS		NS	0.0196		0.0426		NS	NS	NS	0.0148	
C x W	NS	NS	NS		NS		0.0148		NS	NS		NS		NS	NS	NS	NS	
I x W	NS	NS	NS		NS		0.0213		NS	NS		NS		NS	NS	NS	NS	
C x T	NS	NS	NS		NS		NS		NS	NS		NS		NS	NS	NS	NS	
I x T	NS	NS	NS		0.0342		0.0104		NS	NS		NS		NS	NS	NS	NS	
W x T	NS	NS	0.0152		NS		NS		NS	NS		NS		NS	NS	NS	NS	
C x I x W	NS	NS	NS		NS		NS		NS	NS		NS		NS	NS	NS	NS	
C x I x T	NS	NS	NS		NS		NS		NS	NS		NS		NS	NS	NS	0.0474	
C x W x T	NS	NS	NS		NS		0.0154		NS	NS		NS		NS	NS	NS	NS	
I x W x T[w]	NS	NS	NS		NS		NS		NS	NS		NS		NS	NS	NS	NS	

[z]Recommended sufficiency range for caneberry crops (Hart et al., 2006); no sufficiency levels are available for aluminum (Al).
[y]NS = non-significant; *P*-values provided for significant factors.
[x]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[w]All other higher order interactions were non-significant and are not shown.

Table 3.5. Primocane leaf nutrient concentrations in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR. The leaves were collected in July 2014.

	Macronutrients (%)								Micronutrients (ppm)						
Sufficiency range[z]	2.3-3.0	0.19-0.45	1.3-2.0		0.6-2.0	0.3-0.6	0.1-0.2		60-250		30-70	6-20	50-300	15-50	na
	N	P	K		Ca	Mg	S		Fe		B	Cu	Mn	Zn	Al
Treatment															
Cultivar (C)															
							Aug.	*Feb.*							
Black Diamond	2.0 b[x]	0.2 b	1.12		0.56 b	0.29 b	0.13 b	0.12 c	136		30 b	7.6	129	26 b	107
Marion	2.5 a	0.3 a	1.16		0.81 a	0.34 a	0.14 ab	0.14 a	142		32 a	6.9	150	31 a	120
Irrigation (I)															
Postharvest (+Irrig.)	2.2	0.3	1.13		0.71	0.32	0.13		151 a		31	7.2	143	29	124 a
No postharvest (-Irrig.)	2.2	0.3	1.15		0.66	0.31	0.13		128 b		30	7.3	136	29	103 b
Weed management (W)															
			Aug.	*Feb.*					*+Irrig.*	*-Irrig.*					
Nonweeded	2.2	0.3	1.11 b	1.11 b	0.72 a	0.33 a	0.13		101 c	104 c	32	7.2	138	29	77 b
Hand-weeded	2.2	0.3	1.14 ab	1.17 ab	0.66 b	0.30 b	0.13		252 a	183 b	30	7.2	141	28	190 a
Weed mat	2.2	0.3	1.10 b	1.20 a	0.68 ab	0.31 b	0.13		110 c	95 c	30	7.3	139	29	76 b
Training (T)															
August (Aug.)	2.2	0.3	1.12 b		0.71	0.32 a	0.13		140		32	7.2	138	29 a	115
February (Feb.)	2.2	0.3	1.16 a		0.67	0.31 b	0.13		138		30	7.3	141	28 b	112
Significance[y]															
C	0.0013	0.0048	NS		0.0054	0.0033	0.0149		NS		0.0481	NS	NS	0.001	NS
I	NS	NS	NS		NS	NS	NS		0.0151		NS	NS	NS	NS	0.0083
W	NS	NS	NS		0.0284	0.0014	NS		<0.0001		NS	NS	NS	NS	<0.0001
T	NS	NS	0.0072		NS	0.0416	NS		NS		NS	NS	NS	0.0488	NS
C x I	NS	NS	NS		NS	NS	NS		NS		NS	NS	NS	NS	NS
C x W	NS	NS	0.0032		NS	NS	NS		NS		NS	NS	NS	NS	NS
I x W	NS	NS	0.0405		NS	NS	NS		0.0111		NS	NS	NS	NS	NS
C x T	NS	NS	NS		NS	NS	0.0181		NS		NS	NS	NS	NS	NS
I x T	NS	NS	NS		NS	NS	NS		NS		NS	NS	NS	NS	NS
W x T	NS	NS	0.031		NS	NS	NS		NS		NS	NS	NS	NS	NS
C x I x W	NS	NS	0.0292		NS	0.03040	NS		NS		NS	NS	NS	NS	0.0241
C x I x T	NS	NS	NS		NS	NS	NS		NS		NS	NS	NS	NS	NS
C x W x T	NS	NS	NS		NS	NS	NS		NS		NS	NS	NS	NS	NS
I x W x T[w]	NS	NS	NS		NS	NS	NS		NS		NS	NS	NS	NS	NS

[z]Recommended sufficiency range for caneberry crops (Hart et al., 2006); no sufficiency levels are available for aluminum (Al).
[y]NS = non-significant; *P*-values provided for significant factors.
[x]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[w]All other higher order interactions were non-significant and are not shown.

Table 3.6. Floricane leaf nutrient concentrations in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR. The leaves were collected from the fruiting laterals in June 2013.

	Macronutrients (%)											Micronutrients (ppm)								
	N		P	K		Ca		Mg		S		Fe		B	Cu		Mn	Zn	Al	
Treatment																				
Cultivar (C)																				
						Aug.	*Feb.*													
Black Diamond (B. Dia.)	2.8 a[y]		0.19	1.28		1.3 a	1.2 ab	0.28		0.14		197		52	6.1		273	26	155	
Marion	1.9 b		0.19	1.26		1.1 b	1.1 b	0.26		0.13		174		55	5.7		243	25	136	
Irrigation (I)																				
Postharvest (+Irrig.)	2.3		0.19	1.27		1.2		0.27		0.14		181		54	5.9		259	25	143	
No postharvest (-Irrig.)	2.3		0.19	1.27		1.2		0.27		0.14		190		53	6.0		257	26	149	
Weed management (W)																				
	B. Dia.	*Marion*		*B. Dia.*	*Marion*	*B. Dia.*	*Marion*	*B. Dia.*	*Marion*	*B. Dia.*	*Marion*	*+Irrig.*	*-Irrig.*		*B. Dia.*	*Marion*			*+Irrig.*	*-Irrig.*
Nonweeded	2.4 b	1.8 c	0.18 b	1.32 a	1.24 b	1.2 abc	1.2 bc	0.27 abc	0.26 abc	0.13 c	0.13 bc	164 b	201 a	53	5.7 b	5.7 b	244	24 b	132 b	157 a
Hand-weeded	2.9 a	1.9 c	0.19 a	1.25 ab	1.27 ab	1.3 ab	1.1 c	0.28 ab	0.25c	0.155 ab	0.13 c	191 a	193 a	53	6.3 a	5.6 b	265	25 b	149 ab	151 ab
Weed mat	3.0 a	1.9 c	0.20 a	1.26 ab	1.27 ab	1.3 a	1.1 c	0.29 a	0.26 bc	0.15 a	0.13 c	187 ab	177 ab	55	6.4 a	5.8 b	265	27 a	147 ab	137 ab
Training (T)																				
August (Aug.)	2.3		0.19	1.26		1.2		0.27		0.14		187		54	5.9		249	26	145	
February (Feb.)	2.3		0.19	1.27		1.2		0.26		0.14		184		53	5.9		268	25	146	
Significance[z]																				
C	<0.0001		NS	NS		NS		NS		NS		NS		NS	NS		NS	NS	NS	
I	NS		NS	NS		NS		NS		NS		NS		NS	NS		NS	NS	NS	
W	<0.0001		0.0074	NS		NS		NS		0.0033		NS		NS	0.0138		NS	0.0055	NS	
T	NS		NS	NS		NS		NS		NS		NS		NS	NS		NS	NS	NS	
C x I	NS		NS	NS		NS		NS		NS		NS		NS	NS		NS	NS	NS	
C x W	<0.0001		NS	0.0147		0.0067		0.0237		0.0016		NS		NS	0.0265		NS	NS	NS	
I x W	NS		NS	NS		NS		NS		NS		0.0402		NS	NS		NS	NS	0.0492	
C x T	NS		NS	NS		0.0208		NS		NS		NS		NS	NS		NS	NS	NS	
I x T	NS		NS	NS		NS		NS		NS		NS		NS	NS		NS	NS	NS	
W x T[x]	NS		NS	NS		NS		NS		NS		NS		NS	NS		NS	NS	NS	

[z]NS = non-significant; *P*-values provided for significant factors.
[y]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[x]All other higher order interactions are mentioned in the text or were non-significant and not shown.

Table 3.7. Floricane leaf nutrient concentrations in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR. The leaves were collected from the fruiting laterals in June 2014.

	Macronutrients (%)									Micronutrients (ppm)								
	N		P	K		Ca		Mg	S	Fe	B		Cu		Mn	Zn		Al
Treatment																		
Cultivar (C)																		
						Aug.	*Feb.*				*Aug.*	*Feb.*	*+Irrig.*	*-Irrig.*		*Aug.*	*Feb.*	
Black Diamond (B. Dia.)	2.8 a[y]		0.28 a	1.41		1.7 a	1.5 b	0.36 a	0.171 a	183 a	64 a	56 b	71 a	57 ab	368 a	35 a	29 b	147 a
Marion	2.2 b		0.20 b	1.37		1.1 c	1.1 c	0.27 b	0.128 b	136 b	63 ab	64 a	53 b	64 ab	222 b	23 c	21 c	110 b
Irrigation (I)																		
Postharvest (+Irrig.)	2.5		0.24	1.39		1.4		0.32	0.150	161	63		61		300	27		130
No postharvest (-Irrig.)	2.5		0.23	1.38		1.3		0.31	0.149	158	60		60		291	27		128
Weed management (W)																		
	B. Dia.	*Marion*		*B. Dia.*	*Marion*								*+Irrig.*	*-Irrig.*				
Nonweeded	2.6 b	2.1 d	0.23 b	1.46 a	1.31 c	1.3		0.31	0.140 c	162	60		83 a	62 ab	287	26 b		133 a
Hand-weeded	2.9 a	2.2 dc	0.24 a	1.41 abc	1.37 abc	1.4		0.31	0.151 b	162	61		49 b	63 ab	303	27 b		132 a
Weed mat	3.0 a	2.3 c	0.25 a	1.35 bc	1.43 ab	1.4		0.32	0.157 a	155	64		51 b	56 ab	296	29 a		122 b
Training (T)																		
													B. Dia.	*Marion*				
August (Aug.)	2.6 a		0.25 a	1.39		1.4 a		0.32 a	0.153 a	159	63 a		67 a	47 b	303	29 a		128
February (Feb.)	2.4 b		0.23 b	1.39		1.3 b		0.31 b	0.146 b	160	60 b		60 ab	69 a	287	25 b		129
Significance[z]																		
C	<0.0001		<0.0001	NS		0.0002		<0.0001	<0.0001	0.0142	NS		NS		0.0002	<0.0001		0.032
I	NS		NS	NS		NS		NS	NS	NS	NS		NS		NS	NS		NS
W	<0.0001		0.0043	NS		NS		NS	<0.0001	NS	NS		0.0042		NS	0.0022		0.0406
T	0.0001		0.0004	NS		<0.0001		0.0153	0.0002	NS	0.018		NS		NS	<0.0001		NS
C x I	NS		NS	NS		NS		NS	NS	NS	NS		0.0329		NS	NS		NS
C x W	0.0098		NS	<0.0001		NS		NS	NS	NS	NS		NS		NS	NS		NS
I x W	NS		NS	NS		NS		NS	NS	NS	NS		0.0199		NS	NS		NS
C x T	NS		NS	NS		0.0024		NS	NS	NS	0.0031		0.0006		NS	0.004		NS
I x T	NS		NS	NS		NS		NS	NS	NS	NS		NS		NS	NS		NS
W x T[x]	NS		NS	NS		NS		NS	NS	NS	NS		NS		NS	NS		NS

[z]NS = non-significant; *P*-values provided for significant factors.
[y]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[x]All other higher order interactions are mentioned in the text or were non-significant and are not shown.

Table 3.8. Fruit nutrient concentrations in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR. The fruit were machine-harvested in July 2013.

	Macronutrients (%)									Micronutrients (ppm)								
	N	P	K		Ca		Mg	S		Fe	B	Cu		Mn		Zn		Al
Treatment																		
Cultivar (C)																		
					Aug.	*Feb.*												
Black Diamond (B. Dia.)	1.4 a[y]	0.20	1.08 a		0.15 b	0.15 b	0.10	0.078 a		27 a	11 a	4.8 a		32		14 b		238 a
Marion	1.2 b	0.20	0.88 b		0.19 a	0.17 b	0.11	0.064 b		23 b	9 b	4.5 b		31		16 a		173 b
Irrigation (I)																		
Postharvest	1.3	0.20	0.99		0.16		0.11	0.070		25	10	4.5		33		15		221 a
No postharvest	1.3	0.20	0.97		0.17		0.11	0.071		24	10	4.7		31		15		189 b
Weed management (W)																		
			B. Dia.	*Marion*				*B. Dia.*	*Marion*			*B. Dia.*	*Marion*	*Aug.*	*Feb.*	*B. Dia.*	*Marion*	
Nonweeded	1.2 b	0.19 c	1.00 b	0.85 d	0.17 a		0.10 b	0.070 b	0.061 c	24 b	9 b	4.3 c	4.3 c	33 ab	30 ab	12 c	15 ab	201
Hand-weeded	1.3 a	0.20 b	1.11 a	0.88 cd	0.17 a		0.11 a	0.080 a	0.065 c	25 a	10 a	4.9 ab	4.5 c	33 a	31 ab	14 b	15 ab	206
Weed mat	1.4 a	0.21 a	1.13 a	0.92 c	0.16 b		0.11 a	0.083 a	0.066 bc	25 a	10 a	5.2 a	4.6 bc	30 b	33 a	15 ab	16 a	209
Training (T)																		
August (Aug.)	1.3	0.20	1.01 a		0.17 a		0.11	0.071		25	10	4.6		32		15		209
February (Feb.)	1.3	0.19	0.95 b		0.16 b		0.10	0.070		25	10	4.7		32		15		202
Significance[z]																		
C	0.0057	NS	0.0007		0.0152		0.0053	<0.0001		0.0095	0.0003	0.0012		NS		0.0023		0.0257
I	NS	NS	NS		NS		NS	NS		NS	NS	NS		NS		NS		0.0172
W	<0.0001	<0.0001	<0.0001		0.0023		0.0001	<0.0001		0.0225	0.0006	<0.0001		NS		<0.0001		NS
T	NS	NS	<0.0001		0.0289		<0.0001	NS		NS	NS	NS		NS		NS		NS
C x I	NS	NS	NS		NS		NS	NS		NS	NS	NS		NS		NS		NS
C x W	NS	NS	0.0467		NS		NS	0.0021		NS	NS	0.0453		NS		0.0493		NS
I x W	NS	NS	NS		NS		NS	NS		NS	NS	NS		NS		NS		NS
C x T	NS	NS	NS		0.008		NS	NS		NS	NS	NS		NS		NS		NS
I x T	NS	NS	NS		NS		NS	NS		NS	NS	NS		NS		NS		NS
W x T[x]	NS	NS	NS		NS		NS	NS		NS	NS	NS		0.0421		NS		NS

[z]NS = non-significant; *P*-values provided for significant factors.
[y]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[x]All other higher order interactions are mentioned in the text or were non-significant and are not shown.

Table 3.9. Fruit nutrient concentrations in mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR. The fruit were machine-harvested in July 2014.

	Macronutrients (%)						Micronutrients (ppm)					
	N	P	K	Ca	Mg	S	Fe	B	Cu	Mn	Zn	Al
Treatment												
Cultivar (C)												
		Aug. / *Feb.*			*Aug.* / *Feb.*	*Aug.* / *Feb.*			*Aug.* / *Feb.*	*+Irrig.* / *-Irrig.*		
Black Diamond (B. Dia.)	1.3 a[y]	0.24 a / 0.23 ab	1.2 a	0.19 b	0.132 a / 0.125 b	0.102 a / 0.098 a	34	12 a	8.7 a / 8.5 ab	33 b / 35 ab	18	94 a
Marion	1.2 b	0.21 c / 0.22 bc	1.0 b	0.23 a	0.130 ab / 0.130 ab	0.078 b / 0.081 b	32	10 b	7.2 c / 7.8 bc	37 a / 33 b	18	68 b
Irrigation (I)												
Postharvest (+Irrig.)	1.2	0.23	1.1	0.21	0.130	0.089	33	11	8.0	35	18	81
No postharvest (-Irrig.)	1.3	0.23	1.1	0.21	0.129	0.090	34	11	8.1	34	18	81
Weed management (W)												
	Aug. / *Feb.*			*B. Dia.* / *Marion*						*B. Dia.* / *Marion*		
Nonweeded	1.2 c / 1.3 abc	0.22 b	1.1	0.20 ab / 0.23 a	0.129	0.089 b	33	11	8.1 a	35 abc / 32 bc	17 b	73
Hand-weeded	1.3 abc / 1.2 bc	0.22 b	1.1	0.19 b / 0.23 ab	0.128	0.088 b	32	11	7.6 b	34 abc / 37 a	18 ab	91
Weed mat	1.3 ab / 1.3 a	0.23 a	1.1	0.16 c / 0.22 ab	0.131	0.092 a	34	11	8.4 a	31 c / 36 ab	19 a	80
Training (T)												
August (Aug.)	1.2	0.23	1.1	0.21	0.131 a	0.090	33	11	8.0	35	18	81
February (Feb.)	1.3	0.22	1.1	0.21	0.127 b	0.089	33	11	8.1	34	18	81
Significance[z]												
C	0.0005	0.0128	0.0002	0.0152	NS	0.0002	NS	0.0006	0.0129	NS	NS	0.0266
I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
W	0.0013	0.018	NS	<0.0001	NS	0.0339	NS	NS	0.0005	NS	<0.0001	NS
T	NS	NS	NS	NS	0.0378	NS	NS	NS	NS	NS	NS	NS
C x I	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0076	NS	NS
C x W	NS	NS	NS	0.0138	NS	NS	NS	NS	NS	0.0286	NS	NS
I x W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C x T	NS	0.0024	NS	NS	0.0146	0.0045	NS	NS	0.0199	NS	NS	NS
I x T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
W x T[x]	0.0385	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]NS = non-significant; *P*-values provided for significant factors.
[y]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[x]All other higher order interactions were non-significant and are not shown.

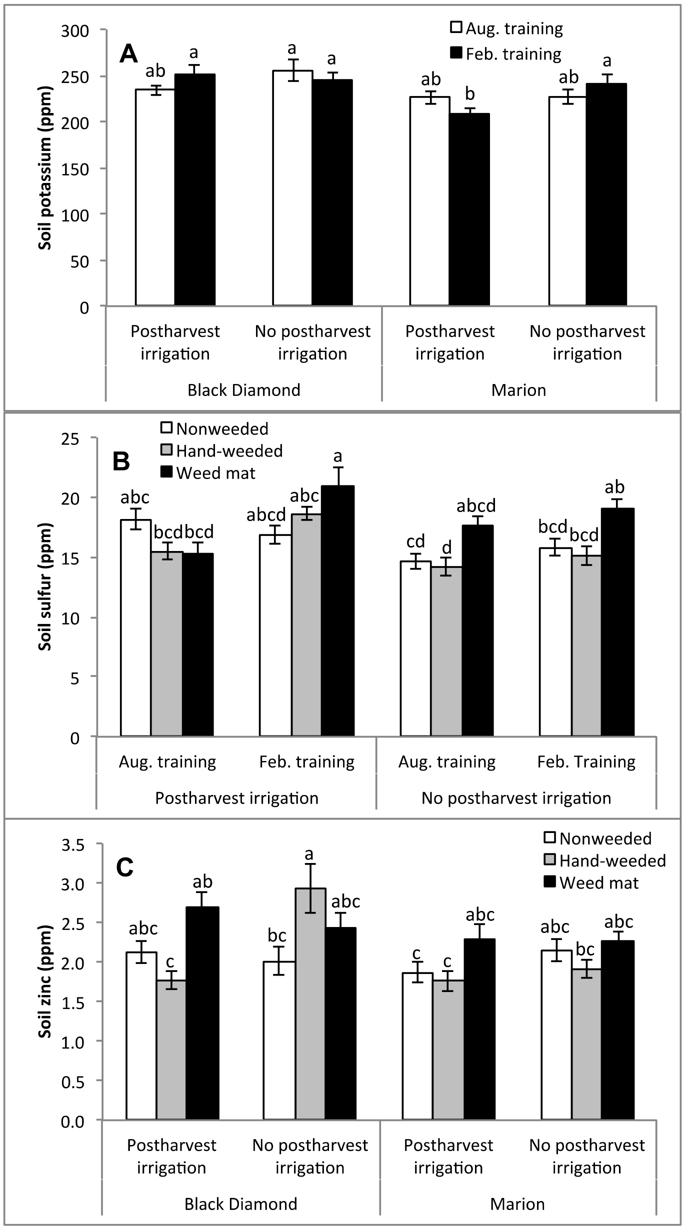

Fig. 3.1. Soil concentrations of potassium (**A**), sulfur (**B**), and zinc (**C**) in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR. Potassium was significantly affected by a three-way interaction among cultivar, irrigation, and trailing time (P = 0.0031). Sulfur was significantly affected by a three-way interaction among irrigation, weed management, and training (P = 0.0213). Zinc was significantly affected by a three-way interaction among cultivar, irrigation, and weed management (P = 0.0086). Each bar represents the mean (± 1 SE) of 3 years. Bars with the same letter within a given interaction are not significantly different (P > 0.05).

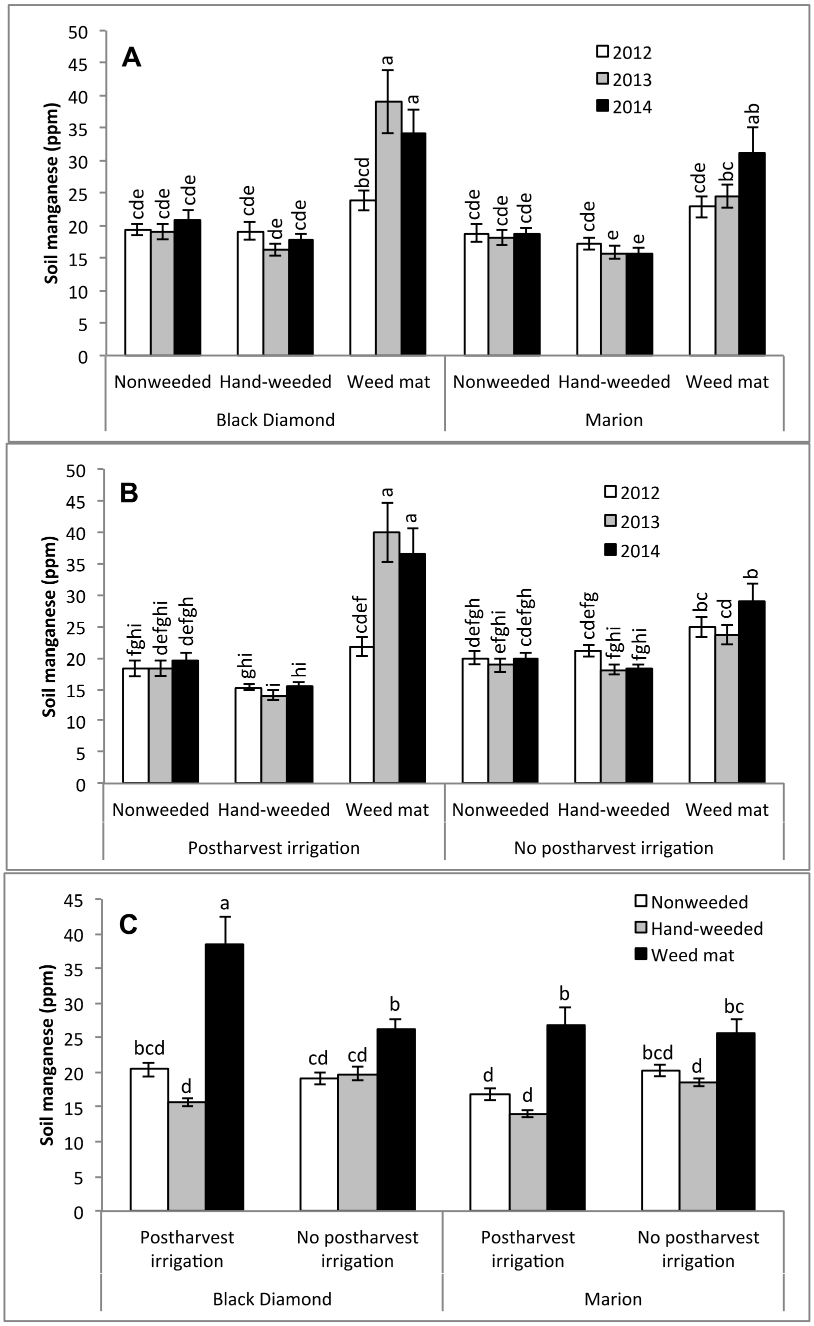

Fig. 3.2. Soil manganese concentration in mature organic 'Black Diamond' and 'Marion' trailing blackberry as affected by (**A**) weed management strategy and sample year (P = 0.0041), each bar represents the mean (± 1 SE); (**B**) irrigation strategy, weed management strategy, and sample year (P = 0.0006), each bar represents the mean (± 1 SE) of the two cultivars; and (**C**) weed management and irrigation strategies (P = 0.0145), each bar represents the mean (± 1 SE) of 3 years. Mean ± SE; means followed by the same letter within a given interaction are not significantly different (P > 0.05).

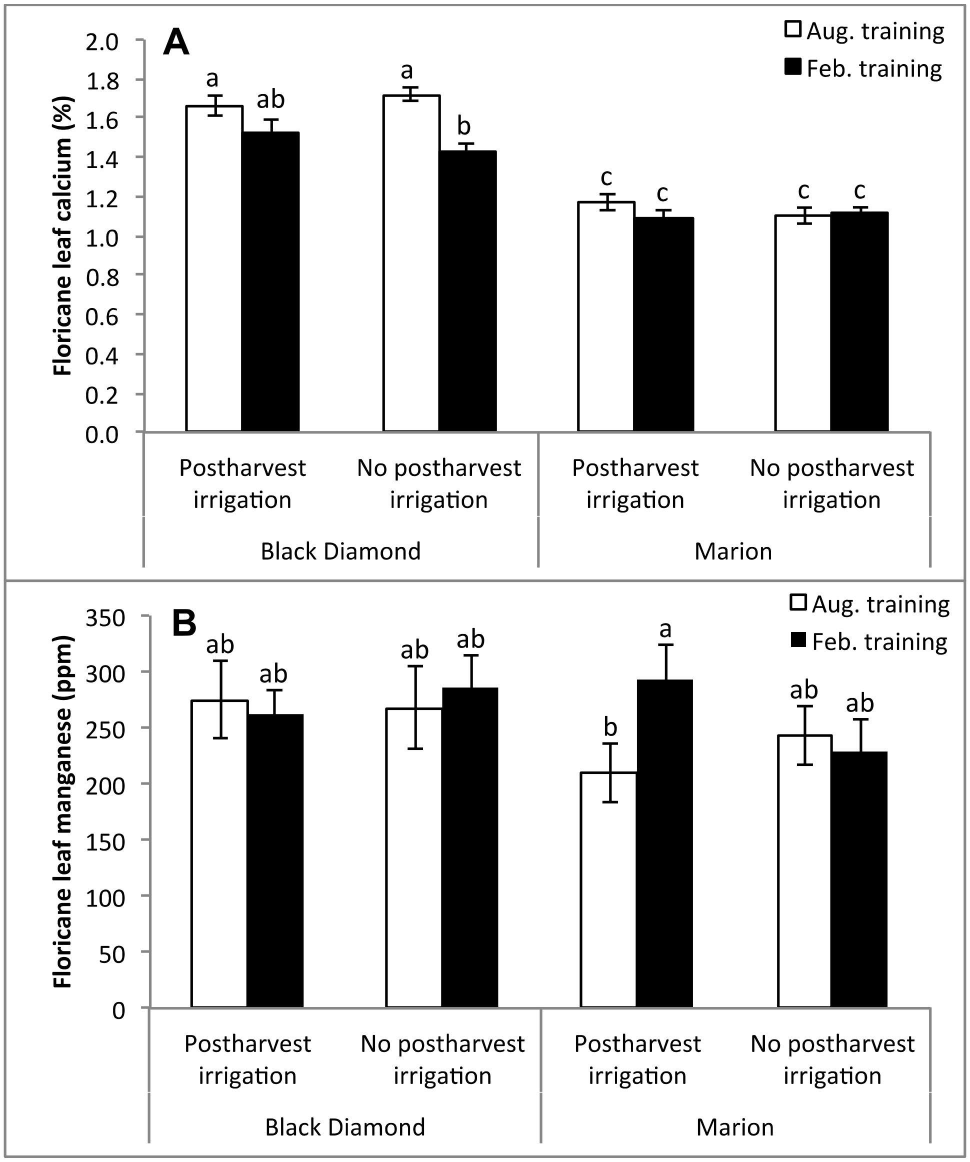

Fig. 3.3. Effects of irrigation strategy and training time on (**A**) floricane fruiting lateral leaf calcium concentration in 2014 (P = 0.031) and (**B**) floricane fruiting lateral leaf manganese concentration in 2013 (P = 0.0106) in mature organic 'Black Diamond' and 'Marion' trailing blackberry grown at the North Willamette Research and Extension Center in Aurora, OR. Mean ± SE; means followed by the same letter within the interaction presented are not significantly different (P > 0.05).

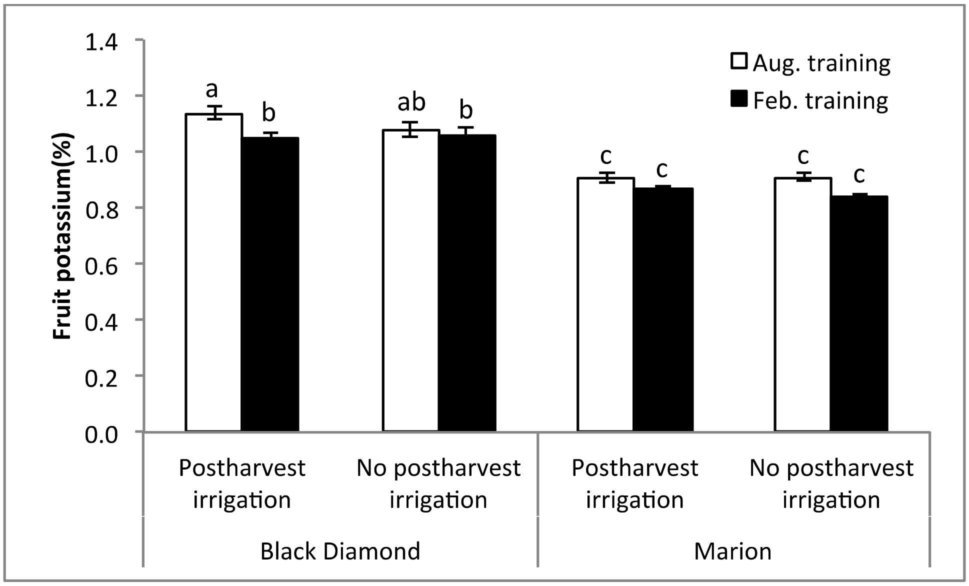

Fig. 3.4. Effects of irrigation strategy and training time on fruit potassium concentration in 2013 (P = 0.047) in mature organic ‘Black Diamond’ and ‘Marion’ trailing blackberry grown at the North Willamette Research and Extension Center in Aurora, OR. Mean ± SE; means followed by the same letter within the interaction presented are not significantly different (P > 0.05).

WEED MANAGEMENT, TRAINING, AND IRRIGATION PRACTICES FOR ORGANIC PRODUCTION OF TRAILING BLACKBERRY: III. ACCUMULATION AND LOSS OF ABOVEGROUND BIOMASS, CARBON, AND NUTRIENTS

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CHAPTER 4: Weed Management, Training, And Irrigation Practices For Organic Production Of Trailing Blackberry: III. Accumulation And Loss Of Aboveground Biomass, Carbon, And Nutrients

Abstract

Relatively little is known about aboveground nutrient content of organic blackberry, and there is no published work on total carbon (C) content. Treatment effects on biomass, C, and nutrient content, accumulation, and loss were assessed over 2 years in a mature organic trailing blackberry (*Rubus* L. subgenus *Rubus*, Watson) production system that was machine-harvested for the processed market. Treatments included two irrigation options (no irrigation after harvest and continuous summer irrigation), three weed management strategies (weed mat, hand-weeded, and nonweeded), and two primocane training times (August and February) in two cultivars (‘Black Diamond’ and ‘Marion’). Floricanes comprised an average of 45% of the total aboveground plant dry biomass, while primocanes and fruit comprised 30% and 25%, respectively. Depending on the treatment, the total aboveground dry biomass gain over the course of the season was 5.0–6.5 $t \cdot ha^{-1}$ per year, while C stock of the planting was an estimated 0.4–1.1 $t \cdot ha^{-1}$ in late winter. Carbon accounted for approximately 50% of the dry biomass of each aboveground plant part, including primocanes, floricanes, and fruit. Weed management had the largest impact on plant biomass and nutrient content. No weed control reduced aboveground dry biomass, the content of nutrients in the primocanes, floricanes, and fruit, and the annual gain of dry biomass and nutrients, whereas use of weed mat resulted in the most dry biomass and nutrient content. Nutrient accumulation was similar between the cultivars, although February-trained ‘Marion’ plants had a greater loss of most

nutrients in 2014 than the year prior. The amount of nitrogen (N) removed in the fruit was 22, 18, and 12 $kg \cdot ha^{-1}$ for weed mat, hand-weeded, and nonweeded plots, respectively, in 2013. In 2014, ‘Marion’ and ‘Black Diamond’ differed in N removed in harvested fruit when grown with weed mat at 18 and 24 $kg \cdot ha^{-1}$, respectively, while there was no cultivar effect when plants were grown in hand-weeded or nonweeded plots. Plots with weed mat tended to lose the most nutrients through harvested fruit in both years. In 2014, August-trained ‘Marion’ lost 5 $kg \cdot ha^{-1}$ N less than the other training time and cultivar combinations. Plants that were irrigated throughout the summer gained more dry biomass, N, potassium (K), magnesium, sulfur, boron (B), and copper in one or both years than those that received no irrigation after fruit harvest. The irrigation treatment had inconsistent effects on nutrient content of each individual plant part between the two years. Nutrient losses were often higher than what was applied through fertilization, especially for N, K, and B, which would eventually lead to depletion of those nutrients in the planting.

Introduction

Organic blackberry (*Rubus* L. subgenus *Rubus*, Watson) production is an important niche market in Oregon, which produces a significant portion of the organic and conventional crop in the United States [U.S. Department of Agriculture (USDA), 2014; USDA, 2010]. Blackberry is a perennial plant that produces biennial canes from the crown. When canes emerge the first year, they are vegetative and called primocanes. In their second year, they produce fruiting laterals and fruit on what are then called floricanes. Following fruit production, the floricanes senesce and are removed. In an annual or every-year fruit production system, primocanes and floricanes exist on the plant at the same time (Strik and Finn, 2012).

Nitrogen (N) allocation has been studied in several blackberry types (Malik et al., 1991; Mohadjer et al., 2001; Naraguma et al., 1999; Whitney, 1982). Primocanes have been found to utilize new fertilizer N for early growth (Malik et al., 1991; Mohadjer et al., 2001; Naraguma et al., 1999), while both stored N and new fertilizer N are allocated to floricane growth and fruit production (Mohadjer et al., 2001). Blackberry has relatively low accumulation of biomass and N compared with other perennial crops due to the low planting density and relatively small size of the plants (Mohadjer et al., 2001). Annual N accumulation ranged from 37 to 44 $kg \cdot ha^{-1}$ in alternate-year production (Mohadjer et al., 2001), while N loss ranged from 34 to 79 $kg \cdot ha^{-1}$ in the first year of trailing blackberry fruit production (Harkins et al., 2014). The nutrient content of different blackberry plant parts and nutrients other than N have only been examined during the establishment years (Harkins et al., 2014), but not during mature production. It is important to understand the gains and losses of each nutrient as their rates of soil mineralization and plant uptake differ. Because of this, fertilizer requirements may be over- or underestimated.

Aboveground dry biomass production in red raspberry (*Rubus idaeus* L.) ranges from 0.3 to 7.8 $t \cdot ha^{-1}$ depending on planting age, location, and production practices (Alvarado-Raya et al., 2007; Darnell et al., 2008; Dean et al., 2000; Rempel et al., 2004; Whitney, 1982). There has not been as much work done in blackberry, but Mohadjer et al. (2001) reported 4.8 to 5.3 $t \cdot ha^{-1}$ of dry biomass in an alternate-year production system of ‘Kotata’ trailing blackberry, and Harkins et al. (2014) measured 3.3 $t \cdot ha^{-1}$ of aboveground dry biomass in 2012, in the first fruiting season of an organic trailing blackberry planting.

A high percentage of plant dry biomass is composed of C (Appendix Table 1.5), but the C content and allocation of blackberry has not been studied. There has been work in other *Rubus* species on photosynthetic rate (Bowen and Freyman, 1995; Fernandez and Pritts, 1993; Percival et al., 2001), radiolabeling of $^{14}CO_2$ (Fernandez and Pritts, 1994; Gauci et al., 2009; Privé et al., 1994), and reduction in C supply (Fernandez and Pritts, 1996). Mature blueberry (*Vaccinium corymbosum* L.) were found to contain 8.3 $t{\cdot}ha^{-1}$ C during dormancy (Nemeth, 2013), while mature grape (*Vitis vinifera* L.) was estimated to have 1.9 $t{\cdot}ha^{-1}$ of C (Keightley, 2011). Carbon sequestration has become increasingly important in light of climate change and the ability to estimate the C stock of agricultural land could be important for gauging offsets to C emissions.

The objective of this study was to continue the work by Harkins et al. (2013; 2014) and Chapters 2 and 3 and examine the effects of cultivar (‘Black Diamond’ and ‘Marion), postharvest irrigation, weed management (weed mat, hand-weeded, and nonweeded), and primocane training time (August and February) on aboveground gains and losses of dry biomass, C, and nutrients in a mature planting of organic trailing blackberry.

Materials and Methods

Study site. The study was conducted in a mature planting at the North Willamette Research and Extension Center in Aurora, OR [lat. 45°16’47”N, long. 122°45’23”W; USDA plant hardiness zone 8b (U. S. Department of Interior, 2013)] in 2013 and 2014.

The soil type at the site is Willamette silt loam (fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll). The field was certified organic by Oregon Tilth (Corvallis, OR), a USDA accredited agency, in 2012 (first fruiting year). See Harkins et al. (2013; 2014) for detailed information on site preparation and establishment and Chapters 2 and 3 for details on mature production.

Experimental design. Treatments included cultivar (‘Marion’ and ‘Black Diamond’), irrigation (postharvest and no postharvest), weed management [nonweeded, hand-weeded, and weed mat (a porous, polyethylene ground cover)], and primocane training time (August and February). Treatments were arranged in a split-split-split plot design with five replicates. See Chapter 2 for details of experimental plot layout. Plots were 1.5 by 3 m in size and contained 4 plants.

Weed management. The three weed management strategies were applied to each plot individually. In nonweeded plots, weeds were allowed to grow after the first year (2010) and cut to soil level just prior to machine harvest (early July) during each harvest year (2012–2014) to avoid any interference with the catcher plates on the machine harvester; the biomass removed was left in the row. In hand-weeded plots, weeds were removed by hoeing throughout each growing season. The weed mat plots were covered with a 1.4-m-wide strip of black, woven, polyethylene ground cover (TenCate Protective Fabrics; OBC Northwest Inc., Canby, OR) centered on the row. Weeds were removed from the planting hole area and seams in the weed mat as required. More information on weed management strategies is provided in Chapter 2.

Irrigation. Each treatment was irrigated with a single lateral of drip tubing (UNIRAM; Netafim USA, Fresno, CA). The tubing had pressure-compensating emitters

(1.9 L·h^{-1} in-line) spaced every 0.6 m and was placed along the ground at the base of the plants under the weed mat, or was attached on a third wire on the steel posts, located 0.3 m above the ground in nonweeded and hand-weeded plots. The cultivar, irrigation, and weed management treatment combinations were irrigated independently using a manifold with electric solenoid valves and an automatic timer.

Irrigation was scheduled weekly based on estimates of crop evapotranspiration (ET) but was adjusted as needed each week to maintain similar leaf water potentials (LWP) among treatments (Chapter 2). Irrigation was applied from 9 May to 8 Oct. 2012, 17 May to 27 Sept. 2013, and 28 May to 23 Sept. 2014 in the postharvest irrigation treatment. In the no postharvest irrigation treatment, irrigation was initiated on the same dates but withheld after the last fruit harvest date on 30 July 2012, 19 July 2013, and 15 July 2014. Thus, these plots received no effective water until the rainy season began on 12 Oct. 2012, 21 Sept. 2013, and 23 Sept. 2014.

Fertilization. An OMRI-approved fish hydrolysate and fish emulsion blend was diluted 1:3 (v/v) with water and applied through the drip system. Converted Organics 421 (4N–0.8P–0.8K; True Organic Products Inc., Spreckels, CA) was used for the first four applications in 2013, and True Organics 512 (5N–0.4P–1.7K) was used for the last four applications in 2013 and all applications in 2014. The fertilizer(s) was split into eight equal applications (approximately every 2 weeks from 5 Apr. to 12 July 2013 and 19 Mar. to 25 June 2014) and applied at a total rate of 90 kg·ha^{-1} N per year (based on the percentage of N listed on the label). Additional boron (B) fertilizer, and lime and dolomite amendments were applied in 2013 and 2014 to correct nutritional deficiencies seen in soil tests and primocane leaf analyses (Chapter 3). The total amount of nutrients applied to the planting is presented in Chapter 3.

Primocane training. Primocanes in the August-trained treatment were trained to the upper trellis wires on 13–14 Aug. 2012, 27–29 Aug. 2013, and 14 Aug. 2014, using the method described in Chapter 2. In the February-trained treatment, primocanes were left on the wire for the drip irrigation lines, just above ground level, throughout the growing season and the subsequent winter, until they were wrapped and tied to the upper two trellis wires on 21–25 Feb. 2013 and 21–28 Feb. 2014. Primocane training was done by replicate to avoid any possible date effects within treatment over the days required to train.

Data collection. Primocanes (at 0.3 m height) were counted on two plants in each plot on 24 Jan. 2013, 20 Feb. 2014, and 18 Dec. 2014 (to assess primocane growth in 2012 to 2014, respectively). Individual primocanes were defined as originating at the crown or at a branch below 0.3 m and extending at least 1.0 m or to the first training wire.

One primocane was randomly cut from two plants per plot in Dec. 2014, weighed to determine the average individual fresh weight per cane, and then multiplied by cane number to estimate the total primocane fresh weight per plant in each plot. Subsamples that included tissue from the base, middle, and tip of the canes were analyzed for moisture content, C, N, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), B, copper (Cu), manganese (Mn), zinc (Zn), and aluminum (Al) concentration (Appendix Tables 1.1 and 1.2). A set of subsamples were also collected and analyzed for nutrients in Feb. 2014. The 2013 primocane nutrient concentrations were estimated as the average of the Feb. and Dec. 2014 values. Percent moisture content was used to estimate dry biomass of the primocanes. The relationship between primocane number and dry biomass was determined at the end of the study in Dec. 2014: [primocane dry biomass = 0.13 x (no. of primocanes per plant) – 0.043; $r^2 = 0.36$; $P < 0.0001$]. Primocane dry biomass was then calculated from the number of primocanes counted in Feb. 2013 and 2014. Primocane C and nutrient content was calculated from primocane nutrient concentrations and dry biomass in late winter. 2013 primocane nutrient content refers to primocanes that then fruited as floricanes in 2013; 2014 primocane nutrient content refers to primocanes that fruited as floricanes in 2014; and primocane nutrient content was calculated a final time in Dec. 2014 for primocanes that would have fruited as floricanes in 2015.

Ripe fruit were harvested twice weekly from 24 June to 18 July in 2013 and 2014, using an over-the-row rotary harvester (Littau Harvesters Inc., Stayton, OR). Total yield was calculated from the weight of machine-harvested fruit on each date. A 25-berry subsample per treatment plot was shipped overnight to Brookside Laboratories (New Bremen, OH) on 8 July 2013 and 7 July 2014 and analyzed for C and nutrient concentrations and for percent moisture (Chapter 3).

Senescing floricanes were removed by pruning at the base of the plant (approx. 0.1 m high) after fruit harvest on 29 July–5 Aug. 2013 and 30 July–1 Aug. 2014, per standard commercial practice (Strik and Finn, 2012). The total fresh biomass of the pruned floricanes was determined per plot, and a subsample of the pruned canes was shipped overnight to Brookside Laboratories for analysis of total nutrient concentration and percent moisture content (Chapter 3). Floricane dry biomass and C and nutrient content were then calculated. After pruning and data collection, the floricanes were left between the rows and flail-mowed (chopped), per standard commercial practice.

Dry biomass, C, and nutrient content data from the primocanes, fruit, and floricanes were used to calculate total aboveground plant nutrient content per hectare and gains and losses as affected by treatments in each year. Annual nutrient gains were calculated by subtracting primocane dry biomass (dormant weight) from the floricane dry biomass (to estimate floricane growth), then adding the dry biomass of harvested fruit and new primocane growth. Annual nutrient losses were defined as the floricane prunings and fruit, while net change in aboveground nutrient content was defined as the nutrient gains minus the nutrient losses.

Data analysis. Data were analyzed by year due to large differences in weather and winter damage observed in Dec. 2013 (Chapter 2). Within year, data were analyzed for a split-split-split plot design with cultivar as the main plot factor, postharvest irrigation as the subplot factor, and weed management and training time as sub-subplots, using PROC MIXED in SAS (version 9.3; SAS Institute Inc., Cary, NC). Normality was assessed using a histogram of the residuals. Residuals were plotted to assess homogeneity of variance (residual by fitted value plot). Strong fanning or skewedness in the residual plots led to the data being log transformed for analysis to improve homogeneity of variance and to assess proportional effects. Data were back transformed for presentation. Means were compared for treatment effects using a Tukey's honestly significant difference test at $\alpha = 0.05$. Mean comparisons within significant interactions were done for treatments using Least Square Means (LS Means) at $\alpha = 0.05$.

Results

Dry biomass production. There were no main effects of cultivar or irrigation on the dry biomass of the dormant primocanes during the study. However, primocane dry biomass was significantly affected by an interaction between cultivar and irrigation in 2015, as well as by weed management each year, and by interactions between irrigation and training date in 2013 and cultivar and training date in 2015 (Table 4.1–4.3). In 2013, the plants from the postharvest irrigation treatment had more dry biomass in the primocanes when the primocanes were trained in August than when they were trained in February. The plants also had more dry biomass in the primocanes with hand weeding than with no weeding in 2 out of 3 years (2014 and 2015) and with weed mat each year. In 2015, 'Marion' had more primocane dry biomass than 'Black Diamond', particularly with postharvest irrigation, while 'Black Diamond' produced more primocane dry biomass when the primocanes were trained in February rather than in August.

'Marion' produced more floricane dry biomass than 'Black Diamond' in 2013, regardless of weed management strategy (Table 4.4). In 'Marion', however, both weed control strategies increased floricane dry biomass compared to no weed control, whereas in 'Black Diamond', there was no difference between hand-weeded and no weed control. In 2014, floricane dry biomass was affected by all treatments (Table 4.5). Plants produced more floricane dry biomass when grown with postharvest irrigation than with no postharvest irrigation the previous year. 'Marion' continued to produce more floricane dry biomass than 'Black Diamond', but it was especially greater in 'Marion' when the primocanes were trained in February. In addition, training time only had an effect on floricane dry biomass in 'Marion'. Weed control led to greater floricane dry biomass compared to no weeding when plants were trained in February. However, when plants were August-trained there was no difference between hand-weeded and no weed control plots.

In 2013, ‘Black Diamond’ produced more fruit dry biomass without than with postharvest irrigation the previous year, whereas the opposite was found in ‘Marion’ (Table 4.6). The plants also produced more fruit dry biomass with weed mat than with hand weeding that year, and the least amount of fruit dry biomass without weed control. In 2014, ‘Marion’ produced more fruit dry biomass when the plants were trained in February rather than in August, while ‘Black Diamond’ produced the same amount of fruit dry biomass with either training treatment (Table 4.7). Both cultivars produced more fruit dry biomass with weed mat than with no weed control, although there was a larger difference between the weed mat treatment and the nonweeded treatment in ‘Black Diamond’ than ‘Marion’ (Table 4.7). Similarly to what was observed in 2013, ‘Black Diamond’ plants grown with weed mat produced the most fruit dry biomass, but August-training resulted in a larger difference between weed control treatments. Fruit dry biomass was greater in weed mat than in hand-weeded plots only when plants were trained in August.

In 2013, the annual gain in total aboveground plant dry biomass (new primocane growth and floricane and fruit growth) was greatest, on average, in both cultivars with postharvest irrigation, weed mat, and February training (Table 4.8). In 2014, February training still led to the greatest gain in dry biomass, on average (Table 4.9). However, weed management only had an effect on dry biomass gain in August-trained plants, where plants grown with weed mat gained more than with other weed management strategies. The two cultivars gained similar amounts of dry biomass, averaging 4.1 and 4.7 $t{\cdot}ha^{-1}$ in 2013 and 2014, respectively.

In 2013, ‘Marion’ lost more dry biomass (harvested fruit and floricane prunings) than ‘Black Diamond’ when the plants were irrigated postharvest but not when there was no postharvest irrigation (Table 4.10). In addition, plants grown with weed mat lost the most dry biomass whereas those grown without weed control lost the least. In 2014, there was no effect of training time on dry biomass lost in ‘Black Diamond’, whereas ‘Marion’ lost more dry biomass when February-trained (Table 4.11). ‘Marion’ also lost more dry biomass than ‘Black Diamond’ within each training time. Plants grown with weed mat had the greatest loss in dry biomass with August training; however, when plants were trained in February, there was no difference between dry biomass loss for weed mat and the hand-weeded treatment. The average loss in dry biomass was 3.5 $t{\cdot}ha^{-1}$ in 2013 and 4.6 $t{\cdot}ha^{-1}$ in 2014.

In 2013, net change in aboveground dry biomass ranged from 0.4 to 0.7 $t{\cdot}ha^{-1}$ among the treatments, with the greatest increase observed in plants that were irrigated postharvest (P = 0.0156) and those that were February-trained (P = 0.0168; Appendix Table 1.6). In 2014, net change ranged from -0.3 to 0.3 $t{\cdot}ha^{-1}$, although there were no significant treatment effects (Appendix Table 1.7).

Primocane nutrient content. Treatment effects and interactions on dormant primocane macro- and micronutrient content varied among years (Tables 4.1–4.3). Cultivar and irrigation had limited direct effects on primocane nutrient content. In 2013, ‘Marion’ primocanes trained in February had less Cu in the tissue than those trained in August, or than ‘Black Diamond’ primocanes trained at either time (Table 4.1). In 2014, ‘Black Diamond’ primocanes contained less P and more S and Zn than ‘Marion’ primocanes (Table 4.2). In 2015, ‘Black Diamond’ primocanes had less K and B than ‘Marion’ primocanes trained in August, and less Mg, Fe, Cu, and Al than ‘Marion’ primocanes trained on either date (Table 4.3).

The impact of withholding irrigation after fruit harvest on primocane nutrient content often was affected by training time. In 2013, plants that received irrigation postharvest had less Ca and Zn in the primocanes trained in February as compared to August, whereas there was no effect of training time when the plants received no irrigation after fruit harvest (Table 4.1). In 2015, ‘Black Diamond’ plants that received postharvest irrigation had less S and Al in the primocanes than those that were not irrigated after harvest, while there was no difference in S or Al between the irrigation treatments in ‘Marion’.

In 2013, plants grown with weed mat had more primocane N, K (only when February-trained), Ca, S, and Cu than the nonweeded treatment. Plants in hand-weeded plots also contained more primocane Ca and Cu than the nonweeded treatment (Table 4.3). In 2014 and 2015, weed management affected all measured primocane nutrients. In both years, the plants with weed mat had a higher content of most nutrients in the primocanes than those in nonweeded plots, except for N and K in 2014 when the primocanes were August-trained, and a higher content of N and K (in February-trained only), P, and S than those in hand-weeded plots in 2014, but not in 2015 (Tables 4.4 and 4.5). In addition to the interactions mentioned previously, the 2013 primocanes that were trained in August had higher N, P, Ca, Mg, S, B, Cu, Mn, and Zn than when trained in February, while the opposite was found for Fe and Al content. In 2014, direct training effects were more limited, with only a similar response to training in the Fe and Al content. In addition, primocanes trained in February had a higher K content than those trained in August (Table 4.2). Only primocane Al was directly affected by training time in 2015, with a similar pattern as was seen in the previous 2 years.

Floricane nutrient content. The nutrient content in the pruned floricanes was mostly affected by cultivar and weed management in 2013 (Table 4.4) and by cultivar, weed management, and training time in 2014 (Table 4.5). In both years, floricane nutrient content was higher in 'Marion' than 'Black Diamond' (except for P) and generally greater with weed control, although in 2014, plants in nonweeded and hand-weeded plots did not differ in floricane N and S (when August-trained), Zn (February-trained), Fe and Al (in 'Black Diamond'), Cu (when irrigated postharvest), and P, Ca, Mg, and B. Use of weed mat led to higher floricane N, P, S, and Zn content than hand weeding in 2013 and all nutrients in 2014, although only when August-trained for N, S, B, Zn, and Al, only when irrigated postharvest for Cu, and only in 'Black Diamond' for Fe.

The effect of training time, on average, was limited in 2013, with Mn content in floricane prunings only being higher when plants were trained in February (Table 4.4). However, in 2014, February training increased the content of all nutrients in the subsequent floricane prunings (Fe and Al only in hand-weeded plots) (Table 4.5). Floricane N, K, Ca, S, B, and Mn content were particularly high in 'Marion' for canes that were trained in February.

Fruit nutrient content. Treatment effects on fruit nutrient content varied between 2013 and 2014 (Tables 4.6 and 4.7). In 2013, there was a direct effect of weed management on every nutrient. In general, plants growing in nonweeded plots had the lowest content of each nutrient in the harvested fruit, whereas plants in weed mat plots had the greatest, although hand-weeded and weed mat plots were not different for Ca, Mn, or Al. No other treatment had a direct effect on any nutrient in 2013 except plants that received postharvest irrigation had more fruit Al than those that did not. However, there was a cultivar × irrigation interaction on all fruit nutrients except N, Ca, Fe, and Cu. When plants received no postharvest irrigation, 'Black Diamond' fruit contained more P, K, Mg, S, B, Mn, and Al than did 'Marion'. In plants irrigated postharvest, either the opposite was found (i.e., Mg, Mn, and Zn) or there was no difference between the cultivars (Table 4.6).

In 2014, there was no effect of irrigation on fruit nutrient content, but there was an effect of cultivar or a cultivar × training time interaction on the fruit content of each nutrient (Table 4.7). Fruit produced by August-trained 'Marion' plants had particularly low N, P, K, S, B, and Cu content than the other training time and cultivar combinations, whereas February-trained 'Marion' had a high P, Ca, Mg, Fe, Mn, and Zn content in the fruit. 'Marion' plants trained in February had a greater content of all nutrients, except for Al.

'Black Diamond' grown with weed mat in 2014 had a greater content of N, P, K, S, Zn, and Al in the fruit than in nonweeded plots and more content than hand-weeded plots in all nutrients except for Al. 'Marion' plants with weed mat only produced greater fruit N, P, K, and Zn than with no weed control. In both cultivars, use of weed mat increased fruit Ca, Mg, Fe, B, Cu, and Mn than no weed control and hand-weeded (except for Ca). February training increased fruit N, S, Fe, Mn, and Al content compared to August training. Fruit from plants in both training treatments had the highest P, K, Ca, Mg, B, Cu, and Zn when grown with weed mat, but August-trained plants tended to have a particularly low fruit nutrient content in the nonweeded treatment as compared to plants that were February-trained (with the exception of K and Mg). Plants in the hand-weeded treatment only had lower fruit P, K, Mg, B, Cu, and Zn content than the weed mat treatment when trained in August. In contrast, there was no difference in fruit nutrient content between the two methods of weed control when plants were trained in February.

A three-way interaction among irrigation, weed management, and training time revealed that fruit Ca content in 2014 was particularly low when the plants were not weeded, not irrigated after harvest, and trained in August when compared to those that were irrigated postharvest, trained in February, and had weed mat, or those that were not irrigated postharvest and were either trained in February and hand-weeded or trained in August and grown with weed mat (P = 0.0347; Fig. 4.1A). Fruit Fe content was particularly high in plants trained in February and either grown with weed mat and irrigated postharvest or hand-weeded and not irrigated postharvest when compared to plants that were not weeded and trained in August with either irrigation treatment or those that were hand-weeded and trained in August with postharvest irrigation (P = 0.0429; Fig. 4.1B).

Nutrient gains and losses. In 2013, the annual gain (new primocane and floricane growth and fruit harvest) in macronutrients per hectare was affected mostly by irrigation and weed management whereas training time also affected micronutrient gain (Table 4.8). Postharvest irrigation increased the total gain of N in ‘Marion’ and of K, Mg, and S in both cultivars relative to no irrigation after harvest (Table 4.8). Weed control, particularly with weed mat, also increased the gain of many nutrients relative to no weeding, including N, P (weed mat only), K, Ca, Mg, S, Fe, B, Cu, Mn, Zn, and Al. Finally, February training increased the gain of Fe (particularly in plants that were irrigated postharvest), Cu, Mn, and Al relative to August training.

In 2014, 'Marion' plants gained more Mg, B, Cu, and Mn than 'Black Diamond' (Table 4.9). Plants grown with weed mat gained more Ca, Mg, Mn, and Zn than the other weed management strategies, regardless of training time. However, plants with weed mat only gained more N, P, K, S, and B than the other weed management treatments when August-trained; weed management did not affect nutrient gain in February-trained plants. Plants that were irrigated after harvest gained more B and Cu than those that were not irrigated.

'Marion' lost more N, Ca, Mg, Fe, B, Cu, and Zn as a result of fruit harvest and floricane pruning than 'Black Diamond' in 2013 (Table 4.10). 'Marion' plants irrigated after harvest also lost more P and Al than 'Black Diamond' or than 'Marion' plants that were not irrigated after harvest. Plants grown with weed mat lost the most N, P, K, S, Cu, and Zn, and those in nonweeded plots lost the least. In addition, either method of weed control increased the annual loss of Ca, Mg, Fe, B, Mn, and Al compared to nonweeded plants.

In 2014, 'Marion' plants that were trained in February lost more N, K, Ca, S, B, and Mn than the other cultivar and training time combinations (Table 4.11). 'Marion' also lost more P when February-trained than when August-trained, although it did not lose more P than 'Black Diamond' for either training time. There was no effect of training time on nutrient loss of 'Black Diamond', which lost less Mg, Fe, B, Zn, and Al (except in nonweeded plots) than 'Marion', irrespective of training time. Withholding irrigation after harvest decreased loss of N in both cultivars and of Cu in ‘Black Diamond’.

‘Black Diamond’ plants lost less N and S than ‘Marion’ when grown in nonweeded and hand-weeded plots, but there was no difference among cultivars when weed mat was used (Table 4.11). Plants grown with weed mat had a greater loss of Ca, Mg, and Mn than those in nonweeded and hand-weeded plots in both cultivars. Weed mat also led to greater loss of P, K, B, Zn, and Al when primocanes were trained in August, whereas there was generally no difference between weed mat and hand-weeded plots in the loss of these nutrients when primocanes were trained in February. In general, plants grown without weed control had the least loss of nutrients.

In 2013, net change in aboveground nutrient content (annual gains minus annual losses) was 11–15 $kg{\cdot}ha^{-1}$ N, 1–2 $kg{\cdot}ha^{-1}$ P, 5–10 $kg{\cdot}ha^{-1}$ K, 0–2 $kg{\cdot}ha^{-1}$ Ca, 1–2 $kg{\cdot}ha^{-1}$ Mg, 0–1 $kg{\cdot}ha^{-1}$ S, 94–289 $g{\cdot}ha^{-1}$ Fe, 6–11 $g{\cdot}ha^{-1}$ B, 2–4 $g{\cdot}ha^{-1}$ Cu, 33–68 $g{\cdot}ha^{-1}$ Mn, 13–28 $g{\cdot}ha^{-1}$ Zn, and 94–292 $g{\cdot}ha^{-1}$ Al, depending on treatment (Appendix Table 1.6). Net nutrient content change was affected by irrigation and training time in 2013, but not by cultivar or weed management. Plots receiving postharvest irrigation gained more dry biomass and N, K, Ca, Mg, S, B, and Zn than those not receiving postharvest irrigation. February-trained plots gained more dry biomass, N, P, K, Ca, S, Fe, Cu, Mn, and Al than August-trained plots. There was a significant cultivar × irrigation effect on gain in aboveground Ca (P = 0.0428). All ‘Marion’ plots and postharvest irrigated ‘Black Diamond’ plots gained an average of 1.7 $kg{\cdot}ha^{-1}$ of Ca in 2013 while ‘Black Diamond’ plots without postharvest irrigation lost 0.4 $kg{\cdot}ha^{-1}$ Ca.

There were few treatment effects on change in aboveground nutrients in 2014 (Appendix Table 1.7). The net aboveground change of K and S was greater in ‘Black Diamond’ (-8 $kg{\cdot}ha^{-1}$ and -0.6 $kg{\cdot}ha^{-1}$, respective losses) than ‘Marion’ (-3 $kg{\cdot}ha^{-1}$ and -0.2 $kg{\cdot}ha^{-1}$, respective losses). In addition, there was a net gain of Cu (8 $g{\cdot}ha^{-1}$) in ‘Marion’, whereas there was a loss in ‘Black Diamond’ (-4 $g{\cdot}ha^{-1}$). Plants that were trained in February lost more Fe and Al (-390 and -389 $g{\cdot}ha^{-1}$, respectively) than those trained in August (-112 and -114 $g{\cdot}ha^{-1}$, respectively). Aboveground net nutrient change ranged from -8 to -13 $kg{\cdot}ha^{-1}$ N, 0 to -1 $kg{\cdot}ha^{-1}$ P, -3 to -8 $kg{\cdot}ha^{-1}$ K, 0 to 2 $kg{\cdot}ha^{-1}$ Ca, 0 to -1 $kg{\cdot}ha^{-1}$ Mg, 0 to -1 $kg{\cdot}ha^{-1}$ S, -112 to -390 $g{\cdot}ha^{-1}$ Fe, -9 to 4 $g{\cdot}ha^{-1}$ B, -4 to 8 $g{\cdot}ha^{-1}$ Cu, -38 to 8 $g{\cdot}ha^{-1}$ Mn, -25 to 10 $g{\cdot}ha^{-1}$ Zn, and -114 to -478 $g{\cdot}ha^{-1}$ Al, depending on treatment.

Carbon. Carbon content of the primocanes and floricanes varied between years and followed the same pattern as dry biomass (Tables 4.1–4.5). There was no effect of cultivar on primocane C content in 2013 or 2014 (Tables 4.1 and 4.2), but in 2015 ‘Marion’ had greater primocane C, particularly when August-trained (Table 4.2). ‘Marion’ had a higher floricane C content than ‘Black Diamond’ in 2013 (Table 4.4) and when February-trained in 2014 (Table 4.5). Irrigation did not affect C content directly except for plants that received irrigation after harvest in 2013 produced a higher C content in floricanes the following year than those without postharvest irrigation (Table 4.5).

Irrigation interacted with training time in 2013 (Table 4.1) and cultivar in 2015 (Table 4.3) to affect C content of the primocanes. In 2013, plants with postharvest irrigation had a lower primocane C content only if they were trained in February. In

2015, there was no effect of postharvest irrigation in either cultivar, but withholding irrigation postharvest reduced primocane C more in ‘Marion’ than in ‘Black Diamond’.

Weed management affected C content of the primocanes and floricanes similarly throughout the study. Plants grown with weed mat always produced more primocane and floricane C than in nonweeded plots, while hand weeding often led to the production of more primocane and floricane C than in nonweeded plots (Tables 4.1–4.5). Training time affected primocane C content in 2013 and 2015 and floricane C content in 2014. Training in August increased primocane C content in 2013, but not in 2014–2015. ‘Marion’ plants had a higher primocane C content than ‘Black Diamond’ in 2015 when trained in ‘August’ (Table 4.3). ‘Marion’ plants had a greater floricane C than ‘Black Diamond’ in 2013 (Table 4.4) and in 2014, particularly when they had been trained in February (as primocanes) (Table 4.5).

Treatment effects on fruit C content were variable (Tables 4.6 and 4.7). In 2013, fruit from plants grown with weed mat contained more C than those in hand-weeded plots; the lowest fruit C was from plants grown without weed control. ‘Black Diamond’ plants grown without postharvest irrigation produced greater fruit C than those with irrigation, whereas the opposite was found in ‘Marion’ in 2013 (Table 4.6). In 2014, cultivar × training time, cultivar × weed management, and weed management × training time interactions all affected fruit C content (Table 4.7). Training time had no effect on ‘Black Diamond’ fruit C, whereas ‘Marion’ produced more fruit C when trained in February (Table 4.7). ‘Black Diamond’ grown with weed mat produced more fruit C than any other weed management strategy. However, there was no effect of weed management strategy on ‘Marion’ fruit C. There was no effect of training time on fruit C when plants were grown with weed mat (Table 4.7). However, fruit C was greater when February-trained than August-trained when plots were hand-weeded or grown without weed control.

Aboveground gain in C content was similar in 2013 (Table 4.8) and 2014 (Table 4.9), although treatment effects differed. February-trained plants gained more C in both years than August-trained plants. In 2013, irrigation only affected ‘Marion’ plants, which gained more C with postharvest irrigation than without. Also, plants grown with weed mat gained more C than when hand-weeded or grown without weed control. In 2014, ‘Marion’ gained more C than ‘Black Diamond’, and there was no effect of irrigation. In addition, weed management did not have an effect on C gain in February-trained plants; however, August-trained plants grown with weed mat gained more C than in the other weed management treatments.

The measured loss in aboveground plant C followed similar patterns to those seen in C gain (Tables 4.10 and 4.11). In 2013, ‘Marion’ lost more C than ‘Black Diamond’ when it was irrigated postharvest, while there was no difference when irrigation was withheld postharvest. Plants grown with weed mat lost the most C and those grown with weeds lost the least (Table 4.10). In 2014, ‘Marion’ lost more C than ‘Black Diamond’. However, there was no effect of training time on C lost in ‘Black Diamond’, while February training led to greater C loss in ‘Marion’ (Table 4.11). Plants grown with weed mat lost the most C regardless of training time, whereas August-trained plants from weedy plots lost less C than those that were trained in February.

In 2013, irrigation and training time had direct effects on net change in aboveground C (Appendix Table 1.6). Plots that received irrigation after harvest gained

0.4 t·ha^{-1} C compared to 0.2 t·ha^{-1} C when not irrigated postharvest. The net gain of February-trained plots was 0.4 t·ha^{-1} C while August-trained plots gained 0.2 t·ha^{-1} C. There were no treatment effects on net aboveground C in 2014, with an average measured net loss of 0.03 t·ha^{-1} of C (Appendix Table 1.7).

The aboveground C stock of the treatments averaged 0.4−1.1 t·ha^{-1} during dormancy in late winter. The greatest C stock was measured in ‘Black Diamond’ grown without postharvest irrigation, with weed mat, and when trained in February, while the lowest was measured in ‘Black Diamond’ grown without postharvest irrigation, without weed control, and when trained in August. In ‘Marion’, the highest aboveground C stock occurred when plants received no irrigation after harvest, were grown with weed mat, and were August-trained, while the lowest occurred with postharvest irrigation, no weed control, and February training.

Discussion

Total aboveground dry biomass of the planting (primocanes, floricanes, and fruit) was 5.2 t·ha^{-1} in 2013 and 6.3 t·ha^{-1} in 2014, almost half of which was comprised of C. This dry biomass production was above the range reported by Mohadjer et al. (2001) for a conventional planting of ‘Kotata’ trailing blackberry that was managed as an alternate-year production system. Harkins et al. (2014) measured an aboveground dry biomass of 3.3 t·ha^{-1} in 2012, the first fruiting season, for this planting. The low dry biomass production in 2012 was primarily due to a low primocane dry biomass, 0.2 t·ha^{-1} (Harkins et al., 2014), compared with the 1.7 t·ha^{-1} of primocane dry biomass produced per year during the present study. Harkins et al. (2014) noted that the primocane dry biomass produced in 2011, a year when they grew without the presence of floricanes, was 2.0 $t \cdot ha^{-1}$ dry biomass, similar to what was produced by ‘Kotata’ in an “off year” of an alternate year production system (Mohadjer et al., 2001). The dry biomass production pattern we observed, where the low primocane dry biomass in 2012 followed a year of high dry biomass production and consequently led to low floricane dry biomass in 2013, is characteristic of a planting transitioning from alternate-year production to every-year production, where primocanes and floricanes compete for resources.

Differences in primocane dry biomass among the treatments tended to equate to similar differences in nutrient content. Weed management most consistently affected primocane dry biomass and nutrient content, which was also seen by Harkins et al. (2014) during the establishment years of this planting. Weeds reduced nutrient uptake or availability for primocane growth. A similar response was seen in raspberry plants when perennial ryegrass (*Lolium perenne* L.) was grown as a between row cover crop (Bowen and Freyman, 1995). While blackberry roots extending into the row middles (L. Valenzuela, unpublished data), which were planted to a grass cover crop in the present study, this occurred in all treatments, the grass went dormant in summer, and grass is shallow-rooted and, therefore, would not compete very much with a deeply rooted crop such as blackberry. However, the nonweeded treatment was the only one where weeds were competing with plants within the row. There was also an impact of weed management on soil organic matter, pH, and nutrient levels, which were lowest in the nonweeded and hand-weeded plots and higher under the weed mat (Chapter 3).

‘Black Diamond’ and ‘Marion’ did not differ in primocane N content despite the former having a lower primocane leaf N concentration (Chapter 3), leading to the possibility that the lower leaf %N was sufficient in this cultivar. Perhaps ‘Black Diamond’ was allocating more newly acquired N to primocane tissue than to primocane leaf tissue, leading to the appearance of N deficiency in leaf tissue samples. Leaf samples were taken in midsummer, while the primocane tissue was sampled in winter, so N may also have been remobilized from leaves to cane tissue between the two sample dates.

August-trained ‘Black Diamond’ plants produced half as much primocane dry biomass as ‘Marion’ plants with the same training treatment, whereas February-trained plants produced the same dry biomass in the two cultivars. This response was unexpected, as only August-trained ‘Marion’ plants were negatively affected by cold winter weather the previous year (Chapter 2). Despite the similar primocane dry biomass production seen in 2014 and 2015, nutrient content was lower in 2015 for N, K, Mg, S, Fe, and Al. Canes were sampled in early winter 2015 compared to late winter 2014, perhaps causing the differences found, although plants should be dormant throughout the winter season. However, Whitney (1982) found that carbohydrate reserves stopped accumulating in red raspberry in early November in northern New Hampshire. Plants may become dormant later in the more temperate climate found in western Oregon.

Fruit dry biomass was 0.4–0.7 $t{\cdot}ha^{-1}$ lower in each year of the present study than what was measured during the first fruiting year by Harkins et al. (2014). Consequently, nutrient content removed in the fruit was also lower for most macro- and micronutrients. However, N removal in fruit was approximately the same, and fruit Al content was much higher in 2013, although values in 2014 were similar to 2012. Fruit from weed mat plots contained more N, K, Mg, S, Mn, and Zn in 2013 or 2014 than either the hand-weeded or nonweeded plots, a response that may have been due to the higher soil nutrient levels under the weed mat (Chapter 3). However, soil Ca was also higher under weed mat than in hand-weeded plots, but Ca was not higher in the fruit. In contrast, other nutrients, such as P, were higher in the fruit from weed mat plots and not in the soil (Chapter 3). Fertilizer studies in raspberry and blackberry have shown that higher rates of N, P, K, Ca, and Mg increased plant levels of those nutrients; however, often this response did not result in an increase in yield (Kowalenko, 1981a; Kowalenko, 1981b; Nelson and Martin, 1986; Spiers and Braswell, 2002).

Floricane dry biomass at floricane senescence or pruning in 2014 was similar to that reported by Harkins et al. (2014) in 2012, but it was approximately 1 $t{\cdot}ha^{-1}$ less in 2013; a response that reflected the planting's transition into mature every-year production from 2013 to 2014. Despite the higher floricane dry biomass in 2014, fruit production did not increase from 2013 to 2014, so it appears that floricane dry biomass is not directly related to yield. An infestation of crown borer (*Pennisetia marginata* Harris) was discovered in 2013 that affected 'Black Diamond' primarily. There was also an extreme cold event in Dec. 2013 that caused cold injury to 'Marion' (Chapter 2). Either of these problems could have reduced fruit production the following year. In fact, yield did appear to increase from 2013 to 2014 in February-trained 'Marion', which had much less winter cold damage than August-trained 'Marion' (Chapter 2). 'Black Diamond' also had almost 20% lower bud break in 2014 than was seen in 2013 (Chapter 2), which may have been the reason that we did not see an increase in fruit dry biomass during this study.

The higher dry biomass of ‘Marion’ floricanes compared to ‘Black Diamond’ in our study was also seen by Fernandez-Salvador et al. (2015a). As in the primocanes, floricane nutrient content tended to be related to dry biomass production. In general, nutrient content of the floricanes in 2013 was similar to what was reported by Harkins et al. (2014) for the first fruiting year. Floricanes contained at least twice as much N as the fruit, and the N content in the floricanes was almost twice as high in ‘Marion’ as it was in ‘Black Diamond’ in 2013. Floricane N content for plants grown in the three weed management treatments progressively increased from nonweeded to hand-weeded to weed mat. Floricane N content was much higher in 2014 than in 2013. This response was expected as 2014 floricanes (which were primocanes in 2013) received a higher rate of N fertilizer than was applied in 2012, both when they were growing as primocanes in 2013 and when they were producing laterals and fruit in 2014. Primocane growth in blackberry is supported almost exclusively by newly acquired N, while floricanes primarily use stored nutrients for growth in the early spring, and only later begin taking up nutrients from the soil (Malik et al., 1991; Mohadjer, 2001).

Both fruit and floricanes were removed from the plants and were considered nutrient losses. Between 40% and 55% of the aboveground N was lost by floricane pruning and fruit harvest in semi-erect blackberry, trailing blackberry, and red raspberry (Malik et al., 1991; Mohadjer et al., 2001; Rempel et al., 2004). Delaying floricane removal reduced N losses in ‘Kotata’ blackberry by almost 65% (Mohadjer et al., 2001) and in red raspberry by almost 40% (Rempel et al., 2004). Growers could use this tactic to reduce N fertilizer applications in the spring. Because the floricanes in our study were placed in the aisles after pruning and were chopped, their nutrients would have returned to the soil and would thus not represent a true loss from the system. Strik et al. (2006) found that the organic form of N in red raspberry prunings left in the row was as readily taken up as a granular, inorganic form applied at the same time.

In many cases, in both years of our study, nutrient losses were higher than what was applied in fertilizer, which would eventually lead to depletion in the soil. In 2013, K fertilizer application (31 $kg \cdot ha^{-1}$) (Chapter 3) was notably lower than the loss seen in the field (33–58 $kg \cdot ha^{-1}$, depending on the treatment). Calcium, Mg, and B applications were also lower than the amount lost for some treatments, but lime, dolomite lime, and B fertilizers were applied in addition to the fertigation treatments (Chapter 3). Despite fertilization, soil Ca, Mg, and B did not increase from 2013 to 2014. Similar results were seen in 2014, except in that year, N was also lost at a higher rate than it was applied for the most vigorous treatments, e.g. February-trained ‘Marion’ and weed mat plots, irrespective of cultivar or training time. Withholding irrigation after harvest reduced aboveground plant gain of B. Thus, plants in fields receiving no irrigation postharvest over many seasons might eventually be deficient in B if availability is limited during primocane growth and uptake. If we assume that floricane nutrients were actually returning to the system through uptake by blackberry roots in the row middles, true nutrient losses through fruit harvest were not higher than the fertilizer applied. However, it is unknown if nutrients other than N become readily available for plant uptake through this same pathway.

The treatment effects on C content were a direct response to the treatment effects on dry biomass production for the primocanes, floricanes, and fruit. Cultivar differences in C accumulation have been observed in red raspberry (Percival et al., 2001) and were also apparent in this study, especially for floricane C. Floricanes represented a much higher proportion of total aboveground plant C in 2014 (52%) than in 2013 (41%). Carbon gains were similar between the 2 years, although C losses were much higher in 2014 than 2013, due to the higher dry biomass production in that year, which was reflected in the net change of C. Interestingly, primocane tissues comprise a much higher portion of the plant dry biomass than floricanes in semi-erect and erect blackberry (Malik et al., 1991; Naraguma et al., 1999). In our study, primocanes represented approximately 30% of the aboveground dry biomass, or slightly less than the floricanes (45%). Our findings are similar to what has been reported for 'Kotata', another trailing cultivar (Mohadjer et al., 2001).

Cane C content increased in both years from when primocanes were sampled in late winter until they were removed and sampled as floricanes in August. Research in raspberry has shown that roots are a strong sink of C, which is remobilized into the floricanes for lateral and fruit production the following year (Fernandez and Pritts, 1996; Waister and Wright, 1989). Studies with ^{14}C in red raspberry have shown that fruit is the largest sink for C produced in floricane leaves whereas the new primocane growth is the strongest sink for primocane leaves, and both types of canes send C to the roots as a secondary sink (Fernandez and Pritts, 1994; Privé et al., 1994; Waister and Wright, 1989). In blackberry, greater dry matter accumulation in the floricanes seems to suggest floricanes and fruit are the largest sink (Mohadjer et al., 2001). Floricanes and primocanes do not share fixed C products in other *Rubus* species (Fernandez and Pritts, 1993; Gauci et al., 2009), so it is probable that vegetative and reproductive canes in blackberry are also independent. The floricanes and fruit in our study would then have been receiving C from floricane leaves or root remobilization, not primocanes.

Aboveground C stock of the planting during dormancy was between 0.4–1.1 $t \cdot ha^{-1}$ and was negatively affected by weeds, postharvest irrigation, and February-training. The C stock of a mature blueberry planting, which included prunings, senesced leaves, the crown, and roots, was 8.3 $t \cdot ha^{-1}$ (Nemeth, 2013). The C stock of a mature, trailing blackberry planting in this study was underestimated because the crown and root C were not included. In ‘Kotata’, the crown dry biomass was 1.4 $t \cdot ha^{-1}$ (Mohadjer et al., 2001) and in red raspberry, large amounts of carbohydrate were found to be stored in the roots (Fernandez and Pritts, 1996). In addition, blackberry plants have much less woody growth aboveground and are planted at a lower density (2222 plants/ha) than blueberry (4300 plants/ha).

While aboveground nutrient content and dry biomass and the changes observed are interesting, our results do not include belowground plant tissue (the roots and crown of the plant) and probably grossly underestimate the dry biomass and nutrient capture of blackberry. Blackberry roots extend deep into the soil and spread laterally (L. Valenzuela-Estrada et al., unpublished) and probably constitute a significant portion of the whole-plant dry biomass. Roots have been found to constitute between 26% and 41% of the dry biomass of other blackberry types grown in the field or in containers, respectively (Malik et al., 1991; Naraguma et al., 1999).

Conclusions

Dry biomass production in organic trailing blackberry was negatively affected by weeds, and often by training the primocanes in August. The aboveground C stock of the planting in winter reached a maximum of 1.1 $t \cdot ha^{-1}$ and was negatively impacted by weeds, postharvest irrigation, and February training. While this C stock is relatively low compared to what has been reported in some other crops, this value does not include the roots or crowns. Nutrient content gains and losses in the aboveground portions of the plants were directly related to dry biomass accumulation. The use of weed mat led to a particularly high fruit nutrient content, even when compared with hand weeding. ‘Black Diamond’ had lower floricane nutrient content than ‘Marion’, but a similar primocane nutrient content. The nutrient deficiencies found in Chapter 3 in ‘Black Diamond’ primocane leaf N concentrations may have reflected only a difference in allocation between the two cultivars, not a true plant deficiency in N. The current caneberry nutrient standards (Hart et al., 2006) may need to be revised for cultivars other than ‘Marion’. The organic fertilizer applied to the planting often contained less nutrients than what was removed from the planting in floricane prunings and fruit. Although, since the floricanes were left in the field, true losses in the fruit were lower than the fertilizers applied. Fertilization rates may also need to be adjusted for some of these organic production systems, and it is unknown if other less mobile nutrients would be as readily available to plants as N is in the floricane prunings.

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Table 4.1 Dry biomass and total nutrient content in the dormant primocanes in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, 2013.[z]

	$(t \cdot ha^{-1})$		Macronutrients $(kg \cdot ha^{-1})$						Micronutrients $(g \cdot ha^{-1})$					
	Dry biomass	C	N	P	K	Ca	Mg	S	Fe	B	Cu	Mn	Zn	Al
Treatment														
Cultivar (C)														
											Aug. *Feb.*			
Black Diamond	1.2	0.6	17	3	11	7	2	1.0	149	18	9 a 9 a	122	51	142
Marion	1.1	0.5	13	2	8	5	2	0.7	144	16	9 a 7 b	96	36	136
Irrigation (I)														
	Aug. *Feb.*	*Aug.* *Feb.*				*Aug.* *Feb.*							*Aug.* *Feb.*	
Postharvest	1.3 a[x] 0.9 b	0.6 a 0.4 b	15	2	9	7 a 4 b	2	0.9	124	16	9	98	56 a 29 b	118
No postharvest	1.2 ab 1.2 ab	0.6 ab 0.5 ab	15	3	10	6 ab 6 ab	2	0.9	169	16	9	118	49 a 40 ab	164
Weed management (W)														
					Aug. *Feb.*									
Nonweeded	1.0 b	0.5 b	13 b	2	9 ab 7 b	5 b	1	0.7 b	120	13	7 b	93	38	111
Hand-weeded	1.2 ab	0.5 ab	15 ab	2	11 ab 8 ab	6 a	2	0.9 ab	164	18	9 a	118	47	160
Weed mat	1.3 a	0.6 a	17 a	3	10 ab 12 a	6 a	2	1.0 a	156	18	9 a	113	47	149
Training (T)														
August (Aug.)	1.2 a	0.6 a	17 a	3 a	10	7 a	2 a	1.0 a	118 b	18 a	9 a	124 a	51 a	107 b
February (Feb.)	1.0 b	0.5 b	14 b	2 b	9	5 b	1 b	0.8 b	173 a	13 b	7 b	93 b	33 b	169 a
Significance[y]														
C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
W	0.0398	0.0399	0.0353	NS	0.0275	0.0367	NS	0.0435	NS	NS	0.0461	NS	NS	NS
T	0.0343	0.0349	0.0229	0.0317	NS	0.0021	0.0032	0.0223	0.0192	0.0019	0.0048	0.0095	0.0001	0.0142
C x I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C x W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I x W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C x T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0291	NS	NS	NS
I x T	0.0447	0.0424	NS	NS	NS	0.0453	NS	NS	NS	NS	NS	NS	0.0181	NS
W x T[w]	NS	NS	NS	NS	0.0262	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]Primocane dry biomass was estimated using the relationship found between primocane number and dry biomass at the end of the study in Dec. 2014 [primocane biomass = 0.13 x (primocane number) – 0.043; $r^2 = 0.36$; $P < 0.0001$]. Because of particularly low cane number in 2013, primocanes were not sampled for nutrient content and the values presented here are an average of the subsequent 2 years.

[y]NS = non-significant; *P*-values provided for significant factors.

[x]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).

[w]All other higher order interactions were non-significant and are not shown.

Table 4.2. Dry biomass and total nutrient content in the dormant primocanes in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, 2014.[z]

	(t•ha^{-1})		Macronutrients (kg•ha^{-1})						Micronutrients (g•ha^{-1})					
	Dry biomass	C	N	P	K	Ca	Mg	S	Fe	B	Cu	Mn	Zn	Al
Treatment														
Cultivar (C)														
Black Diamond	1.7	0.8	28	3.8 b	18	8	3	1.6 a	375	27	13	165	71 a	317
Marion	1.7	0.8	26	4.2 a	16	6	3	1.3 b	427	24	10	166	56 b	412
Irrigation (I)														
														Aug. *Feb.*
Postharvest	1.8	0.9	29	4.2	18	7	3	1.5	391	26	12	169	68	153 b 611 a
No postharvest	1.6	0.8	25	3.8	16	7	3	1.3	412	24	12	162	58	273 b 424 a
Weed management (W)														
			Aug. *Feb.*		*Aug.* *Feb.*									
Nonweeded	1.3 b	0.6 b	22 b[x] 21 b	3.2 b	13 b 14 b	5 b	2 b	1.1 c	250 b	20 b	9 b	126 b	53 b	247 b
Hand-weeded	1.8 a	0.9 a	27 b 26 b	3.9 b	16 b 16 b	8 a	3 a	1.4 b	517 a	27 a	12 a	183 a	68 a	421 a
Weed mat	2.0 a	1.0 a	28 b 38 a	4.8 a	17 b 26 a	8 a	3 a	1.7 a	437 a	28 a	14 a	187 a	69 a	429 a
Training (T)														
August (Aug.)	1.6	0.8	26	3.9	15 b	7	3	1.4	226 b	25	11	168	70	213 b
February (Feb.)	1.8	0.9	28	4.1	19 a	7	3	1.5	576 a	25	12	163	57	521 a
Significance[y]														
C	NS	NS	NS	0.034	NS	NS	NS	0.0122	NS	NS	NS	NS	0.0196	NS
I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
W	0.0001	<0.0001	<0.0001	0.0005	<0.0001	0.0003	0.0007	0.0001	0.0079	0.0011	0.0002	0.0009	0.0062	0.019
T	NS	NS	NS	NS	0.026	NS	NS	NS	<0.0001	NS	NS	NS	NS	<0.0001
C x I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C x W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I x W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C x T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I x T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.017
W x T	NS	NS	0.0264	NS	0.021	NS	NS	NS	NS	NS	NS	NS	NS	NS
C x I x W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C x I x T	NS	NS	NS	NS	NS	NS	NS	NS	0.0189	NS	NS	NS	NS	0.0428
C x W x T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I x W x T[w]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]Primocane dry biomass was estimated using the relationship found between primocane number and dry biomass at the end of the study in Dec. 2014 [primocane biomass = 0.13 x (primocane number) – 0.043; $r^2 = 0.36$; $P < 0.0001$]. Primocanes were sampled in Feb. 2014.
[y]NS = non-significant; P-values provided for significant factors.
[x]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[w]All other higher order interactions were non-significant and are not shown.

Table 4.3 Dry biomass and total nutrient content in the dormant primocanes in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, 2015.[z]

	($t \cdot ha^{-1}$)				Macronutrients ($kg \cdot ha^{-1}$)								Micronutrients ($kg \cdot ha^{-1}$)								
	Dry biomass		C		N	P	K		Ca	Mg	S		Fe	B		Cu	Mn		Zn	Al	
Treatment																					
Cultivar (C)																					
	Aug.	*Feb.*	*Aug.*	*Feb.*			*Aug.*	*Feb.*						*Aug.*	*Feb.*					*Aug.*	*Feb.*
Black Diamond (B. Dia.)	1.1 c[x]	1.7 bc	0.5 c	0.8 bc	16	3	8 b	12 ab	9	1 b	1.01		91 b	16 b	22 ab	9.8 b	130		48	51 c	109 b
Marion	2.1 a	1.9 ab	1.0 a	0.9 ab	18	4	13 a	13 a	10	3 a	1.11		174 a	29 a	24 a	18.2 a	174		61	149 a	171 a
Irrigation (I)																					
	B. Dia.	*Marion*	*B. Dia.*	*Marion*			*B. Dia.*	*Marion*			*B. Dia.*	*Marion*		*B. Dia.*	*Marion*		*Aug.*	*Feb.*		*B. Dia.*	*Marion*
Postharvest	1.3 b	2.1 a	0.6 b	0.9 a	16	3	10 b	14 a	9	2	0.98 c	1.14 a	128	19 b	26 a	13.6 b	127 b	182 a	51	51 c	169 a
No postharvest	1.4 b	1.9 a	0.7 b	0.9 a	17	3	10 b	12 ab	10	2	1.05 ab	1.07 abc	139	18 b	28 a	14.4 a	160 ab	140 b	58	104 b	151 a
Weed management (W)																					
Nonweeded	1.2 b		0.6 b		12 b	2 b	8 b		7 b	1 b	0.75 b		88 b	17 b		10.0 b	116 b		41 b	74 b	
Hand-weeded	1.7 a		0.8 a		18 a	3 ab	12 a		10 a	2 a	1.09 a		148 a	24 a		14.4 a	160 ab		58 a	138 a	
Weed mat	2.1 a		1.0 a		20 a	4 a	15 a		12 a	2 a	1.34 a		169 a	28 a		17.6 a	182 a		64 a	149 a	
Training (T)																					
August (Aug.)	1.6		0.7		15	3	11		9	2	1.00		117	22		13.3	143		51	100 b	
February (Feb.)	1.8		0.8		18	3	13		9	2	1.12		151	23		14.7	162		57	141 a	
Significance[y]																					
C	0.0177		0.0125		NS	NS	NS		NS	0.0347	NS		0.021	0.0217		0.0089	NS		NS	0.0004	
I	NS		NS		NS	NS	NS		NS	NS	NS		NS	NS		0.0116	NS		NS	0.0003	
W	0.0007		0.0006		0.0004	0.0027	0.0003		0.0046	0.0034	0.0007		0.0127	0.0035		0.0038	0.0126		0.0049	0.0037	
T	NS		NS		NS	NS	NS		NS	NS	NS		NS	NS		NS	NS		NS	0.0101	
C x I	0.0238		0.024		NS	NS	0.0146		NS	NS	0.041		NS	0.029		NS	NS		NS	0.0001	
C x W	NS		NS		NS	NS	NS		NS	NS	NS		NS	NS		NS	NS		NS	NS	
I x W	NS		NS		NS	NS	NS		NS	NS	NS		NS	NS		NS	NS		NS	NS	
C x T	0.0288		0.0231		NS	NS	0.0456		NS	NS	NS		NS	0.0317		NS	NS		NS	0.0144	
I x T	NS		NS		NS	NS	NS		NS	NS	NS		NS	NS		NS	0.0357		NS	NS	
W x T[w]	NS		NS		NS	NS	NS		NS	NS	NS		NS	NS		NS	NS		NS	NS	

[z]Primocanes were sampled in Dec. 2014, but these values represent the primocanes that would have flowered and fruited as floricanes in 2015.
[y]NS = non-significant; *P*-values provided for significant factors.
[x]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[w]All other higher order interactions were non-significant and are not shown.

Table 4.4. Dry biomass and total nutrient content in the floricane prunings in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, July, 2013.

	($t{\cdot}ha^{-1}$)				Macronutrients ($kg{\cdot}ha^{-1}$)							Micronutrients ($g{\cdot}ha^{-1}$)								
	Dry biomass		C		N	P	K		Ca	Mg	S	Fe	B	Cu		Mn		Zn	Al	
Treatment																				
Cultivar (C)																				
Black Diamond (B. Dia.)	1.5 b		0.7 b		29 b	3.1	27 b		25 b	4 b	1.9 b	620 b	87 b	9 b		744 b		56 b	487 b	
Marion	2.8 a		1.3 a		45 a	3.8	41 a		40 a	8 a	2.9 a	889 a	273 a	16 a		978 a		84 a	735 a	
Irrigation (I)																				
																Aug.	*Feb.*			
Postharvest	2.2		1.0		39	3.6	35		34	7	2.5	769	191	13		749 b	1055 a	73	620	
No postharvest	2.1		0.9		35	3.2	33		31	6	2.3	740	171	13		815 b	815 b	67	600	
Weed management (W)																				
	B. Dia.	*Marion*	*B. Dia.*	*Marion*			*B. Dia.*	*Marion*						*B. Dia.*	*Marion*				*B. Dia.*	*Marion*
Nonweeded	1.1 c[y]	2.0 b	0.5 c	0.9 b	26 c	2.5 c	20 d	27 cd	24 b	5 b	1.7 c	571 b	131 b	7 c	11 b	604 b		49 c	382 c	533 bc
Hand-weeded	1.5 bc	3.0 a	0.7 bc	1.4 a	40 b	3.6 b	27 cd	45 ab	36 a	7 a	2.6 b	815 a	198 a	10 b	18 a	1002 a		73 b	502 bc	833 a
Weed mat	1.8 b	3.3 a	0.8 b	1.5 a	45 a	4.2 a	33 bc	51 a	37 a	7 a	2.9 a	878 a	213 a	12 b	19 a	973 a		87 a	575 b	840 a
Training (T)																				
August (Aug.)	2.1		1.0		37	3.4	34		32	6	2.4	751	180	13		782 b		69	602	
February (Feb.)	2.2		1.0		37	3.4	34		33	6	2.4	758	182	13		935 a		71	620	
Significance[z]																				
C	0.0057		0.0045		0.0117	NS	0.0283		0.0211	0.0100	0.0159	0.0234	0.0004	0.0126		0.0500		0.0339	0.0131	
I	NS		NS		NS	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS	NS	
W	<0.0001		<0.0001		<0.0001	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		<0.0001		<0.0001	<0.0001	
T	NS		NS		NS	NS	NS		NS	NS	NS	NS	NS	NS		0.0055		NS	NS	
C x I	NS		NS		NS	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS	NS	
C x W	0.0087		0.0095		NS	NS	0.0071		NS	NS	NS	NS	NS	0.0134		NS		NS	0.041	
I x W	NS		NS		NS	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS	NS	
C x T	NS		NS		NS	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS	NS	
I x T	NS		NS		NS	NS	NS		NS	NS	NS	NS	NS	NS		0.0051		NS	NS	
W x T[x]	NS		NS		NS	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS	NS	

[z]NS = non-significant; *P*-values provided for significant factors.
[y]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[x]All other higher order interactions were non-significant and are not shown.

Table 4.5. Dry biomass and total nutrient content in the floricanes prunings in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, July, 2014.

	($t \cdot ha^{-1}$)				Macronutrients ($kg \cdot ha^{-1}$)										
	Dry biomass		C		N		P		K		Ca		Mg	S	
Treatment															
Cultivar (C)															
	Aug.	*Feb.*	*Aug.*	*Feb.*	*Aug.*	*Feb.*			*Aug.*	*Feb.*	*Aug.*	*Feb.*		*Aug.*	*Feb.*
Black Diamond (B. Dia.)	2.5 c[y]	2.8 c	1.1 c	1.2 c	48 b	50 b	5.8		48 b	51 b	37 b	38 b	7 b	2.7 b	2.8 b
Marion	3.4 b	4.4 a	1.5 b	2.0 a	56 b	73 a	5.6		49 b	65 a	47 b	63 a	11 a	3.2 b	4.2 a
Irrigation (I)															
Postharvest (+Irrig.)	3.4 a		1.5 a		60 a		5.9		55		49		10	3.4	
No postharvest (-Irrig.)	3.1 b		1.4 b		54 b		5.5		52		43		9	3.1	
Weed management (W)															
	Aug.	*Feb.*	*Aug.*	*Feb.*	*Aug.*	*Feb.*	*Aug.*	*Feb.*						*Aug.*	*Feb.*
Nonweeded	2.2 b	2.9 b	1.0 b	1.3 b	37 b	50 b	3.9 d	5.1 bcd	41 c		39 b		8 b	2.1 b	2.8 b
Hand-weeded	2.6 b	3.8 a	1.1 b	1.7 a	45 b	63 a	4.5 cd	6.3 abc	50 b		43 b		9 b	2.6 b	3.6 a
Weed mat	4.1 a	4.1 a	1.8 a	1.8 a	75 a	72.a	7.3 a	6.8 ab	69 a		57 a		12 a	4.2 a	4.0 a
Training (T)															
August (Aug.)	3.0 b		1.3 b		52 b		5.2 b		49 b		42 b		8 b	3.0 b	
February (Feb.)	3.6 a		1.6 a		61 a		6.1 a		58 a		50 a		10 a	3.5 a	
Significance[z]															
C	0.0007		0.0005		0.0036		NS		NS		0.0131		0.0043	0.0049	
I	0.0146		0.0283		0.0139		NS		NS		NS		NS	NS	
W	<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001	<0.0001	
T	<0.0001		<0.0001		0.001		0.0213		0.0021		0.002		0.0009	0.0008	
C x I	NS		NS		NS		NS		NS		NS		NS	NS	
C x W	NS		NS		NS		NS		NS		NS		NS	NS	
I x W	NS		NS				NS		NS		NS		NS	NS	
C x T	0.0116		0.0106		0.0044		NS		0.0312		0.0082		NS	0.0107	
I x T	NS		NS		NS		NS		NS		NS		NS	NS	
W x T	0.0088		0.0073		0.0033		0.0334		NS		NS		NS	0.0082	
C x I x W	NS		NS		NS		NS		NS		NS		NS	NS	
C x I x T	NS		NS		NS		NS		NS		NS		NS	NS	
C x W x T	NS		NS		NS		NS		NS		NS		NS	NS	
I x W x T[x]	NS		NS		NS		NS		NS		NS		NS	NS	

	Micronutrients($g \cdot ha^{-1}$)													
	Fe			B		Cu		Mn		Zn		Al		
Treatment														
Cultivar (C)														
				Aug.	*Feb.*	*+Irrig.*	*-Irrig.*	*Aug.*	*Feb.*					
Black Diamond (B. Dia.)	701 b			156 c	158 c	252 a	166 b	900 b	962 b	87 b		612 b		
Marion	887 a			302 b	396 a	366 a	348 a	987 b	1424 a	104 a		814 a		
Irrigation (I)														
Postharvest (+Irrig.)	807			268 a		309 a		1145		100		729		
No postharvest (-Irrig.)	781			238 b		257 b		991		91		697		
Weed management (W)														
	B. Dia.	*Marion*		*Aug.*	*Feb.*	*+Irrig.*	*-Irrig.*			*Aug.*	*Feb.*	*B. Dia.*	*Marion*	
Nonweeded	491 b	658 b		171 c	258 ab	324 ab	134 c	828 c		56 d	93 bc	431 b	604 b	
Hand-weeded	669 b	1027 a		200 bc	269 a	237 bc	241 ab	1035 b		80 c	109 abc	587 b	940 a	
Weed mat	944 a	980 a		316 a	304 a	366 a	397 a	1342 a		120 a	111 ab	818 a	898 a	
Training (T)														
	Non-weeded	*Hand-weeded*	*Weed mat*									*Non-weeded*	*Hand weeded*	*Weed mat*
August (Aug.)	493 d	735 bc	987 a	229 b		251		943 b		86 b		449 d	655 bc	875 a
February (Feb.)	655 cd	960 a	935 ab	277 a		316		1193 a		105 a		587 cd	871 a	840 ab
Significance[z]														
C	0.0059			0.0001		0.0408		0.0026		0.0248		0.0023		
I	NS			0.0486		0.0014		NS		NS		NS		
W	<0.0001			<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		
T	0.0106			0.0005		NS		0.0016		0.0027		0.006		
C x I	NS			NS		0.0336		NS		NS		NS		
C x W	0.0106			NS		NS		NS		NS		0.0139		
I x W	NS			NS		0.001		NS		NS		NS		
C x T	NS			0.0007		NS		0.0173		NS		NS		
I x T	NS			NS		NS		NS		NS		NS		
W x T	0.0247			0.0096		NS		NS		0.0062		0.0226		
C x I x W	NS			NS		NS		NS		NS		NS		
C x I x T	NS			NS		NS		NS		NS		NS		
C x W x T	NS			NS		NS		NS		NS		NS		
I x W x T[x]	0.0251			NS		NS		NS		NS		0.0374		

[z]NS = non-significant; *P*-values provided for significant factors.
[y]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[x]All other higher order interactions are non-significant and not shown.

Table 4.6. Dry biomass and total nutrient content in the fruit of a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, 2013.

	($t \cdot ha^{-1}$)				Macronutrients ($kg \cdot ha^{-1}$)										Micronutrients ($g \cdot ha^{-1}$)									
	Dry biomass		C		N	P		K		Ca	Mg		S		Fe	B		Cu	Mn		Zn		Al	
Treatment																								
Cultivar (C)																								
	+Irrig.	*-Irrig.*	*+Irrig.*	*-Irrig.*		*+Irrig.*	*-Irrig.*	*+Irrig.*	*-Irrig.*		*+Irrig.*	*-Irrig.*	*+Irrig.*	*-Irrig.*		*+Irrig.*	*-Irrig.*		*+Irrig.*	*-Irrig.*	*+Irrig.*	*-Irrig.*	*+Irrig.*	*-Irrig.*
Black Diamond	1.2 bc[y]	1.4 a	0.56 bc	0.63 a	19	2.5 bc	2.8 a	14 ab	15 a	2.0	1.3 b	1.5 a	1.0 ab	1.1 a	36	13 ab	15 a	7	40 b	44 a	18 b	20 ab	320 a	320 a
Marion	1.4 ab	1.2 c	0.61 ab	0.54 c	16	2.7 ab	2.4 c	12 ab	11 b	2.3	1.5 a	1.3 b	0.9 ab	0.8 b	29	12 ab	11 b	6	47 a	36 b	22 a	20 b	260 b	193 c
Irrigation (I)																								
Postharvest (+Irrig.)	1.3		0.58		17	2.6		13		2.1	1.4		0.9		33	13		6	42		20		289 a	
No postharvest (-Irrig.)	1.3		0.59		17	2.6		13		2.2	1.4		1.0		33	13		6	40		20		256 b	
Weed management (W)																								
Nonweeded	1.0 c		0.45 c		12 c	1.9 c		10 c		1.7 b	1.1 c		0.7 c		24 c	9 c		4 c	33 b		13 c		207 b	
Hand-weeded	1.4 b		0.61 b		18 b	2.7 b		14 b		2.3 a	1.5 b		1.0 b		36 b	13 b		6 b	44 a		20 b		284 a	
Weed mat	1.6 a		0.69 a		22 a	3.2 a		16 a		2.4 a	1.7 a		1.2 a		40 a	16 a		8 a	49 a		24 a		329 a	
Training (T)																								
August	1.3		0.58		17	2.6		13		2.2	1.4		0.9		33	13		6	40		20		273	
February	1.3		0.59		17	2.6		13		2.1	1.4		0.9		33	13		6	42		20		273	
Significance[z]																								
C	NS		NS		NS	NS		NS		NS	NS		NS		NS	NS		NS	NS		NS		NS	
I	NS		NS		NS	NS		NS		NS	NS		NS		NS	NS		NS	NS		NS		0.0425	
W	<0.0001		<0.0001		<0.0001	<0.0001		<0.0001		<0.0001	<0.0001		<0.0001		<0.0001	<0.0001		<0.0001	<0.0001		<0.001		<0.0001	
T	NS		NS		NS	NS		NS		NS	NS		NS		NS	NS		NS	NS		NS		NS	
C x I	0.0234		0.023		NS	0.0489		0.0447		NS	0.0277		0.0257		NS	0.0356		NS	0.0245		0.0223		0.0174	
C x W	NS		NS		NS	NS		NS		NS	NS		NS		NS	NS		NS	NS		NS		NS	
I x W	NS		NS		NS	NS		NS		NS	NS		NS		NS	NS		NS	NS		NS		NS	
C x T	NS		NS		NS	NS		NS		NS	NS		NS		NS	NS		NS	NS		NS		NS	
I x T	NS		NS		NS	NS		NS		NS	NS		NS		NS	NS		NS	NS		NS		NS	
W x T[x]	NS		NS		NS	NS		NS		NS	NS		NS		NS	NS		NS	NS		NS		NS	

[z]NS = non-significant; *P*-values provided for significant factors.

[y]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).

[x]All other higher order interactions were non-significant and are not shown.

Table 4.7. Dry biomass and total nutrient content in the fruit of a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, 2014.

	(t$\cdot$ha^{-1})						Macronutrients (kg$\cdot$ha^{-1})				
	Dry biomass			C			N		P		
Treatment											
Cultivar (C)											
	Aug.	*Feb.*		*Aug.*	*Feb.*		*Aug.*	*Feb.*	*Aug.*	*Feb.*	
Black Diamond (B. Dia.)	1.3 b[y]	1.3 b		0.6 b	0.6 b		17 a	18 a	3.1 ab	2.9 b	
Marion	1.1 b	1.5 a		0.5 b	0.7 a		13 b	18 a	2.4 c	3.4 a	
Irrigation (I)											
Postharvest	1.3			0.6			16		2.9		
No postharvest	1.3			0.6			17		3.0		
Weed management (W)											
	B. Dia.	*Marion*		*B. Dia.*	*Marion*		*B. Dia.*	*Marion*	*B. Dia.*	*Marion*	
Nonweeded	1.0 d	1.2 cd		0.4 c	0.5 bc		12 c	14 c	2.2 c	2.5 c	
Hand-weeded	1.2 bcd	1.3 bc		0.5 bc	0.6 b		16 bc	15 bc	2.8 bc	2.8 bc	
Weed mat	1.7 a	1.5 ab		0.7 a	0.6 ab		24 a	18 b	3.9 a	2.2 ab	
Training (T)											
	Non-weeded	*Hand-weeded*	*Weed Mat*	*Non-weeded*	*Hand-weeded*	*Weed Mat*			*Non-weeded*	*Hand-weeded*	*Weed Mat*
August (Aug.)	0.9 d	1.1 cd	1.6 a	0.4 d	0.5 cd	0.7 a	15 b		2.0 d	2.5 dc	3.7 a
February (Feb.)	1.2 bc	1.5 ab	1.6 a	0.5 bc	0.6 ab	0.7 a	18 a		2.7 bc	3.2 ab	3.6 a
Significance[z]											
C	NS			NS			NS		NS		
I	NS			NS			NS		NS		
W	<0.0001			<0.0001			<0.0001		<0.0001		
T	0.0004			0.0005			0.0058		0.0018		
C x I	NS			NS			NS		NS		
C x W	0.0191			0.0071			0.0075		0.0306		
I x W	NS			NS			NS		NS		
C x T	0.0004			0.0004			0.0134		<0.0001		
I x T	NS			NS			NS		NS		
W x T[x]	0.0237			0.011			NS		0.0207		

	Macronutrients (kg$\cdot$ha^{-1})										
	K			Ca			Mg			S	
Treatment											
Cultivar (C)											
	Aug.	*Feb.*		*Aug.*	*Feb.*		*Aug.*	*Feb.*		*Aug.*	*Feb.*
Black Diamond (B. Dia.)	16 a	16 a		2.4 b	2.3 b		1.7 b	1.6 b		1.3 a	1.3 a
Marion	11 b	16 a		2.5 b	3.5 a		1.4 b	2.0 a		0.9 b	1.3 a
Irrigation (I)											
Postharvest	15			2.6			1.7			1.2	
No postharvest	15			2.7			1.7			1.2	
Weed management (W)											
	B. Dia.	*Marion*								*B. Dia.*	*Marion*
Nonweeded	12 c	11 c		2.3 b			1.4 c			1.0 b	0.9 b
Hand-weeded	15 b	13 bc		2.7 a			1.6 b			1.2 b	1.0 b
Weed mat	20 a	15 b		3.0 a			2.0 a			1.7 a	1.2 b
Training (T)											
	Non-weeded	*Hand-weeded*	*Weed Mat*	*Non-weeded*	*Hand-weeded*	*Weed Mat*	*Non-weeded*	*Hand-weeded*	*Weed Mat*		
August (Aug.)	10 c	12 c	18 a	2.0 b	2.4 ab	3.0 a	1.2 c	1.4 c	2.1 a	1.1 b	
February (Feb.)	13 bc	16 ab	17 a	2.7 a	3.1 a	2.9 a	1.6 bc	1.8 ab	2.0 a	1.3 a	
Significance[z]											
C	0.0164			0.0157			NS			0.0088	
I	NS			NS			NS			NS	
W	<0.0001			0.0021			<0.0001			<0.0001	
T	0.0038			0.0024			0.0029			0.0052	
C x I	NS			NS			NS			NS	
C x W	0.0274			NS			NS			0.0044	
I x W	NS			NS			NS			NS	
C x T	0.0004			0.0002			<0.0001			0.0005	
I x T	NS			NS			NS			NS	
W x T[x]	0.0101			0.0182			0.011			NS	

	Micronutrients (g$\cdot$ha^{-1})														
	Fe		B			Cu			Mn		Zn			Al	
Treatment															
Cultivar (C)															
	Aug.	*Feb.*	*Aug.*	*Feb.*		*Aug.*	*Feb.*		*Aug.*	*Feb.*	*Aug.*	*Feb.*			
Black Diamond (B. Dia.)	43 bc	45 ab	16 a	16 a		11 a	11 a		43 b	42 b	24 b	22 b		123 a	
Marion	36 c	52 a	11 b	16 a		8 b	12 a		39 b	53 a	20 b	28 a		88 b	
Irrigation (I)															
Postharvest	42		14			10			44		23			106	
No postharvest	46		15			11			44		24			105	
Weed management (W)															
											B. Dia.	*Marion*		*B. Dia.*	*Marion*
Nonweeded	36 c		12 c			9 b			36 c		16 d	20 dc		76 c	76 c
Hand-weeded	43 b		14 b			10 b			46 b		22 dc	24 bc		131 ab	96 bc
Weed mat	53 a		18 a			13 a			52 a		31 a	29 ab		162 a	96 bc
Training (T)															
			Non-weeded	*Hand-weeded*	*Weed Mat*	*Non-weeded*	*Hand-weeded*	*Weed Mat*			*Non-weeded*	*Hand-weeded*	*Weed Mat*		
August (Aug.)	40 b		10 c	12 bc	18 a	7 c	8 bc	13 a	41 b		16 c	20 bc	30 a	96 b	
February (Feb.)	48 a		14 ab	16 a	18 a	10 ab	11 a	13 a	48 a		21 b	25 ab	30 a	115 a	
Significance[z]															
C	NS		NS			NS			NS		NS			0.0373	
I	NS		NS			NS			NS		NS			NS	
W	<0.0001		<0.0001			<0.0001			<0.0001		<0.0001			<0.0001	
T	0.0006		0.0006			0.001			0.0114		0.0035			0.0299	
C x I	NS		NS			NS			NS		NS			NS	
C x W	NS		NS			NS			NS		0.0397			0.0127	
I x W	NS		NS			NS			NS		NS			NS	
C x T	0.0042		0.0008			0.0001			0.0056		0.0002			NS	
I x T	NS		NS			NS			NS		NS			NS	
W x T[x]	NS		0.0298			0.0186			NS		0.0451			NS	

[z]NS = non-significant; *P*-values provided for significant factors.
[y]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[x]All other higher order interactions are mentioned in the text or were non-significant and are not shown.

Table 4.8. Annual dry biomass and nutrient gain in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center, Aurora in OR, in 2013.

	(t•ha^{-1})			Macronutrients (kg•ha^{-1})							Micronutrients (g•ha^{-1})						
	Dry biomass	C		N		P	K	Ca	Mg	S	Fe		B	Cu	Mn	Zn	Al
Treatment																	
Cultivar (C)																	
Black Diamond (B. Dia.)	3.4	1.6		60		7	52	30	7	3.6	822		120	21	871	102	991
Marion	4.7	2.2		74		8	62	47	11	4.4	1084		316	24	1199	131	1099
Irrigation (I)																	
		B. Dia.	*Marion*	*B. Dia.*	*Marion*						*Aug.*	*Feb.*					
Postharvest	4.4 a	1.7 bc[y]	2.4 a	64 b	84 a	8	60 a	42	10 a	4.4 a	820 b	1140 a	233	24	1085	127	1081
No postharvest	3.7 b	1.5 c	1.9 b	56 b	65 b	7	53 b	35	8 b	3.7 b	929 ab	922 ab	203	21	984	106	1009
Weed management (W)																	
Nonweeded	3.3 c	1.5 c		52 c		6 b	43 c	30 b	8 c	3.1 c	750 b		169 b	17 c	790 b	89 c	826 b
Hand-weeded	4.1 b	1.9 b		67 b		7 b	56 b	41 a	9 b	4.0 b	1053 a		227 a	23 b	1191 a	119 b	1126 a
Weed mat	4.8 a	2.2 a		82 a		10 a	71 a	44 a	11 a	4.9 a	1055 a		258 a	27 a	1124 a	142 a	1183 a
Training (T)																	
August (Aug.)	3.8 b	1.7 b		64		7	55	37	9	3.8	874 b		209	21 b	915 b	115	950 b
February (Feb.)	4.4 a	2.0 a		70		8	58	39	9	4.2	1032 a		227	24 a	1155 a	119	1139 a
Significance[z]																	
C	NS	NS		NS		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS
I	0.0074	0.01		0.0079		NS	0.0247	NS	0.0218	0.0267	NS		NS	NS	NS	NS	NS
W	<0.0001	<0.0001		<0.0001		<0.0001	<0.0001	0.0006	0.0003	<0.0001	0.0004		<0.0001	<0.0001	0.0062	0.0002	0.0008
T	0.0087	0.0115		NS		NS	NS	NS	NS	NS	0.0143		NS	0.0399	0.0213	NS	0.0121
C x I	NS	0.042		0.0425		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS
C x W	NS	NS		NS		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS
I x W	NS	NS		NS		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS
C x T	NS	NS		NS		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS
I x T	NS	NS		NS		NS	NS	NS	NS	NS	0.012		NS	NS	NS	NS	NS
W x T	NS	NS		NS		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS
C x I x W	NS	NS		NS		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS
C x I x T	NS	NS		NS		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS
C x W x T	NS	NS		NS		NS	NS	NS	NS	NS	NS		0.0235	NS	NS	NS	NS
I x W x T[x]	NS	NS		NS		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS

[z]NS = non-significant; *P*-values provided for significant factors.
[y]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[x]All other higher order interactions were non-significant and are not shown.

Table 4.9. Annual dry biomass and nutrient gain in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, in 2014.

	(t•ha^{-1})				Macronutrients (kg•ha^{-1})											Micronutrients (g•ha^{-1})						
	Dry biomass		C		N		P		K		Ca	Mg	S		Fe	B		Cu		Mn	Zn	Al
Treatment																						
Cultivar (C)																						
Black Diamond	3.8		1.6 b		57		8		63		43	8 b	4		539	179 b		160 b		1017 b	98	522
Marion	5.6		2.4 a		75		9		70		64	13 a	5		736	380 a		187 a		1301 a	147	721
Irrigation (I)																						
Postharvest (+Irrig.)	4.8		2.1		69		9		68		58	11	4		693	297 a		242 a		1241	125	679
No postharvest (-Irrig.)	4.6		2.0		64		8		65		50	10	4		582	263 b		205 b		1077	120	564
Weed management (W)																						
	Aug.	*Feb.*	*Aug.*	*Feb.*	*Aug.*	*Feb.*	*Aug.*	*Feb.*	*Aug.*	*Feb.*			*Aug.*	*Feb.*		*Aug.*	*Feb.*	*+Irrig.*	*-Irrig.*			
Nonweeded	3.4 c[y]	4.1 bc	1.4 c	1.8 bc	44 d	59 bcd	6 b	8 ab	47 c	61 bc	47 b	9 b	3 d	4 bcd	519	209 c	271 abc	290 a	157 b	978 b	94 b	488
Hand-weeded	3.6 c	5.6 ab	1.5 c	2.3 ab	50 cd	77 ab	6 b	10 ab	50 bc	75 ab	49 b	10 b	3 cd	5 abc	601	222 bc	300 abc	170 ab	219 ab	1098 b	116 b	604
Weed mat	6.1 a	5.6 ab	2.6 a	2.4 ab	93 a	74 abc	12 a	9 ab	91 a	75 ab	65 a	13 a	6 a	5 ab	791	362 a	316 ab	267 a	238 ab	1401 a	157 a	772
Training (T)																						
August (Aug.)	4.3 b		1.9 b		62		8		63		51	10	4		699	264		201		1054	105 b	687
February (Feb.)	5.1 a		2.2 a		70		9		71		57	11	4		575	295		246		1264	140 a	557
Significance[z]																						
C	NS		0.0437		NS		NS		NS		NS	0.0458	NS		NS	0.0099		0.0477		0.0364	NS	NS
I	NS		NS		NS		NS		NS		NS	NS	NS		NS	0.024		0.0487		NS	NS	NS
W	<0.0001		<0.0001		<0.0001		0.0033		<0.0001		0.0003	0.0097	<0.0001		NS	0.0007		NS		0.0059	0.0074	NS
T	0.0384		0.0448		NS		NS		NS		NS	NS	NS		NS	NS		NS		NS	0.0321	NS
C x I	NS		NS		NS		NS		NS		NS	NS	NS		NS	NS		NS		NS	NS	NS
C x W	NS		NS		NS		NS		NS		NS	NS	NS		NS	NS		NS		NS	NS	NS
I x W	NS		NS		NS		NS		NS		NS	NS	NS		NS	NS		0.0086		NS	NS	NS
C x T	NS		NS		NS		NS		NS		NS	NS	NS		NS	NS		NS		NS	NS	NS
I x T	NS		NS		NS		NS		NS		NS	NS	NS		NS	NS		NS		NS	NS	NS
W x T	0.0221		0.0236		0.0021		0.0054		0.0048		NS	NS	0.0154		NS	0.0311		NS		NS	NS	NS
C x I x W	NS		NS		NS		NS		NS		NS	NS	NS		NS	NS		NS		NS	NS	NS
C x I x T	NS		NS		NS		NS		NS		NS	NS	NS		0.004	NS		NS		NS	NS	0.0049
C x W x T	NS		NS		NS		NS		NS		NS	NS	NS		NS	NS		NS		NS	NS	NS
I x W x T[x]	NS		NS		NS		NS		NS		NS	NS	NS		NS	NS		NS		NS	NS	NS

[z]NS = non-significant; *P*-values provided for significant factors.
[y]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[x]All other higher order interactions were non-significant and are not shown.

Table 4.10. Annual dry biomass and nutrient loss in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, in 2013.

	($t\cdot ha^{-1}$)				Macronutrients ($kg\cdot ha^{-1}$)							Micronutrients ($g\cdot ha^{-1}$)						
	Dry biomass		C		N	P		K	Ca	Mg	S	Fe	B	Cu	Mn	Zn	Al	
Treatment																		
Cultivar (C)																		
Black Diamond (B. Dia.)	2.8 b		1.3 b		48 b	6		41	27 b	6 b	2.9	657 b	102 b	16 b	786	73 b	807	
Marion	4.1 a		1.9 a		61 a	6		53	42 a	9 a	3.8	919 a	286 a	22 a	1047	105 a	961	
Irrigation (I)																		
	B. Dia.	*Marion*	*B. Dia.*	*Marion*		*B. Dia.*	*Marion*										*B. Dia.*	*Marion*
Postharvest	2.7 c[y]	4.3 a	1.2 c	2.0 a	56	6 b	7 a	48	36	8	3.4	801	204	19	977	92	789 b	1033 a
No postharvest	2.9 bc	3.8 ab	1.3 bc	1.7 ab	53	6 b	6 b	46	33	7	3.2	775	183	19	856	86	824 b	889 b
Weed management (W)																		
Nonweeded	2.6 c		1.2 c		38 c	4 c		33 c	26 b	6 b	2.4 c	595 b	141 b	14 c	638 b	62 c	664 b	
Hand-weeded	3.7 b		1.7 b		58 b	6 b		50 b	38 a	8 a	3.6 b	851 a	211 a	20 b	1047 a	93 b	951 a	
Weed mat	4.1 a		1.9 a		66 a	8 a		58 a	40 a	9 a	4.1 a	919 a	229 a	23 a	1065 a	112 a	1036 a	
Training (T)																		
August	3.4		1.5		54	6		47	34	8	3.3	785	193	19	856	88	875	
February	3.5		1.6		55	6		47	35	8	3.4	791	195	19	977	90	892	
Significance[z]																		
C	0.0139		0.0125		0.0486	NS		NS	0.0209	0.0122	NS	0.0262	0.0006	0.0335	NS	0.0355	NS	
I	NS		NS		NS	NS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
W	<0.0001		<0.0001		<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	
T	NS		NS		NS	NS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
C x I	0.0228		0.0246		NS	0.0386		NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0254	
C x W	NS		NS		NS	NS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
I x W	NS		NS		NS	NS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
C x T	NS		NS		NS	NS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
I x T	NS		NS		NS	NS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
W x T[x]	NS		NS		NS	NS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	

[z]NS = non-significant; *P*-values provided for significant factors.
[y]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[x]All other higher order interactions were non-significant and are not shown.

Table 4.11. Annual dry biomass and nutrient loss in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, in 2014.

	(t·ha⁻¹)				Macronutrients (kg·ha⁻¹)												
	Dry biomass		C		N			P		K		Ca		Mg	S		
Treatment																	
Cultivar (C)																	
	Aug.	*Feb.*	*Aug.*	*Feb.*	*Aug.*	*Feb.*		*Aug.*	*Feb.*	*Aug.*	*Feb.*	*Aug.*	*Feb.*		*Aug.*	*Feb.*	
Black Diamond (B. Dia.)	3.8 c[y]	4.1 bc	1.7 c	1.8 bc	66 b	67 b		9 ab	9 ab	64 b	67 b	39 b	40 b	9 b	4 b	4 b	
Marion	4.5 b	6.0 a	2.0 b	2.6 a	70 b	91 a		7 b	10 a	60 b	81 a	49 b	66 a	13 a	4 b	5 a	
Irrigation (I)																	
Postharvest (+Irrig.)	4.7		2.1		76 a			9		69		52		12	5		
No postharvest (-Irrig.)	4.5		2.0		71 b			8		67		46		10	4		
Weed management (W)																	
	Aug.	*Feb.*	*Aug.*	*Feb.*	*B. Dia.*	*Marion*		*Aug.*	*Feb.*	*Aug.*	*Feb.*				*B. Dia.*	*Marion*	
Nonweeded	3.1 c	4.1 b	1.4 c	1.8 b	46 d	67 bc		6 c	8 bc	46 c	60 bc	41 b		9 b	3 d	4 bc	
Hand-weeded	3.7 bc	5.2 a	1.6 bc	2.3 b	60 dc	79 ab		7 c	10 ab	53 c	75 ab	46 b		10 b	4 cd	5 ab	
Weed mat	5.7 a	5.7 a	2.5 a	2.5 a	94 a	95 a		11 a	10 a	87 a	86 a	60 a		14 a	6 a	6 a	
Training (T)																	
					Non-weeded	*Hand-weeded*	*Weed mat*								*Non-weeded*	*Hand-weeded*	*Weed mat*
August (Aug.)	4.2 b		1.8 b		48 e	59 de	96 a	8 b		62 b		44 b		10 b	3 c	4 c	6 a
February (Feb.)	5.0 a		2.2 a		65 cd	80 bc	93 ab	9 a		74 a		53 a		12 a	4 bc	5 ab	5 a
Significance[z]																	
C	0.0013		0.0011		0.0109			NS		NS		0.0117		0.0044	0.022		
I	NS		NS		0.0337			NS		NS		NS		NS	NS		
W	<0.0001		<0.0001		<0.0001			<0.0001		<0.0001		<0.0001		<0.0001	<0.0001		
T	<0.0001		<0.0001		0.0007			0.0101		0.0014		0.0017		0.0007	0.0006		
C x I	NS		NS		NS			NS		NS		NS		NS	NS		
C x W	NS		NS		0.0285			NS		NS		NS		NS	0.0438		
I x W	NS		NS		NS			NS		NS		NS		NS	NS		
C x T	0.0032		0.0028		0.0029			0.0472		0.0109		0.006		NS	0.0027		
I x T	NS		NS		NS			NS		NS		NS		NS	NS		
W x T	0.0082		0.0056		0.0057			0.0262		0.0382		NS		NS	0.01		
C x I x W	NS		NS		NS			NS		NS		NS		NS	NS		
C x I x T	NS		NS		NS			NS		NS		NS		NS	NS		
C x W x T	NS		NS		NS			NS		NS		NS		NS	NS		
I x W x T[x]	NS		NS		NS			NS		NS		NS		NS	NS		

	Micronutrients (g·ha⁻¹)													
	Fe			B		Cu		Mn		Zn		Al		
Treatment														
Cultivar (C)														
				Aug.	*Feb.*	*+Irrig.*	*-Irrig.*	*Aug.*	*Feb.*			*Non-weeded*	*Hand-weeded*	*Weed mat*
Black Diamond (B. Dia.)	745 b			171 c	173 c	264 a	178 b	942 b	1004 b	110 b		507 c	718 b	978 a
Marion	934 a			313 b	413 a	376 a	360 a	1027 b	1478 a	128 a		678 bc	1035 a	993 a
Irrigation (I)														
Postharvest (+Irrig.)	852			282		320 a		1189		122		835		
No postharvest (-Irrig.)	827			253		268 b		1036		115		802		
Weed management (W)														
	B. Dia.	*Marion*		*Aug.*	*Feb.*	*+Irrig.*	*-Irrig.*			*Aug.*	*Feb.*	*+Irrig.*	*-Irrig.*	
Nonweeded	524 b	702 b		182 c	271 ab	334 ab	142 c	864 c		73 d	116 bc	649 cd	537 d	
Hand-weeded	711 b	1069 a		213 bc	284 a	246 bc	252 ab	1080 b		100 c	133 abc	815 bc	938 ab	
Weed mat	1000 a	1029 a		333 a	322 a	379 a	410 a	1394 a		151 a	140 ab	1041 a	931 ab	
Training (T)														
	Non-weeded	*Hand-weeded*	*Weed mat*			*B. Dia.*	*Marion*					*Non-weeded*	*Hand-weeded*	*Weed mat*
August (Aug.)	524 d	771 bc	1038 a	242 b		216 b	304 b	984 b		108 b		513 c	755 b	1000 a
February (Feb.)	704 cd	1009 a	989 ab	293 a		224 b	429 a	1241 a		130 a		673 bc	998 a	971 a
Significance[z]														
C	0.0056			0.0001		0.0438		0.0028		0.0263		0.0036		
I	NS			NS		0.0014		NS		NS		NS		
W	<0.0001			<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		
T	0.0063			0.0004		NS		0.0016		0.0017		0.0028		
C x I	NS			NS		0.0306		NS		NS		NS		
C x W	0.0114			NS		NS		NS		NS		0.0128		
I x W	NS			NS		0.0009		NS		NS		0.0295		
C x T	NS			0.0005		0.0437		0.0158		NS		NS		
I x T	NS			NS		NS		NS		NS		NS		
W x T	0.0219			0.0089		NS		NS		0.0048		0.0235		
C x I x W	NS			NS		NS		NS		NS		NS		
C x I x T	NS			0.0496		NS		NS		NS		NS		
C x W x T	NS			NS		NS		NS		NS		NS		
I x W x T[x]	0.022			NS		NS		NS		NS		0.0458		

[z]NS = non-significant; *P*-values provided for significant factors.
[y]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[x]All other higher order interactions were non-significant and are not shown.

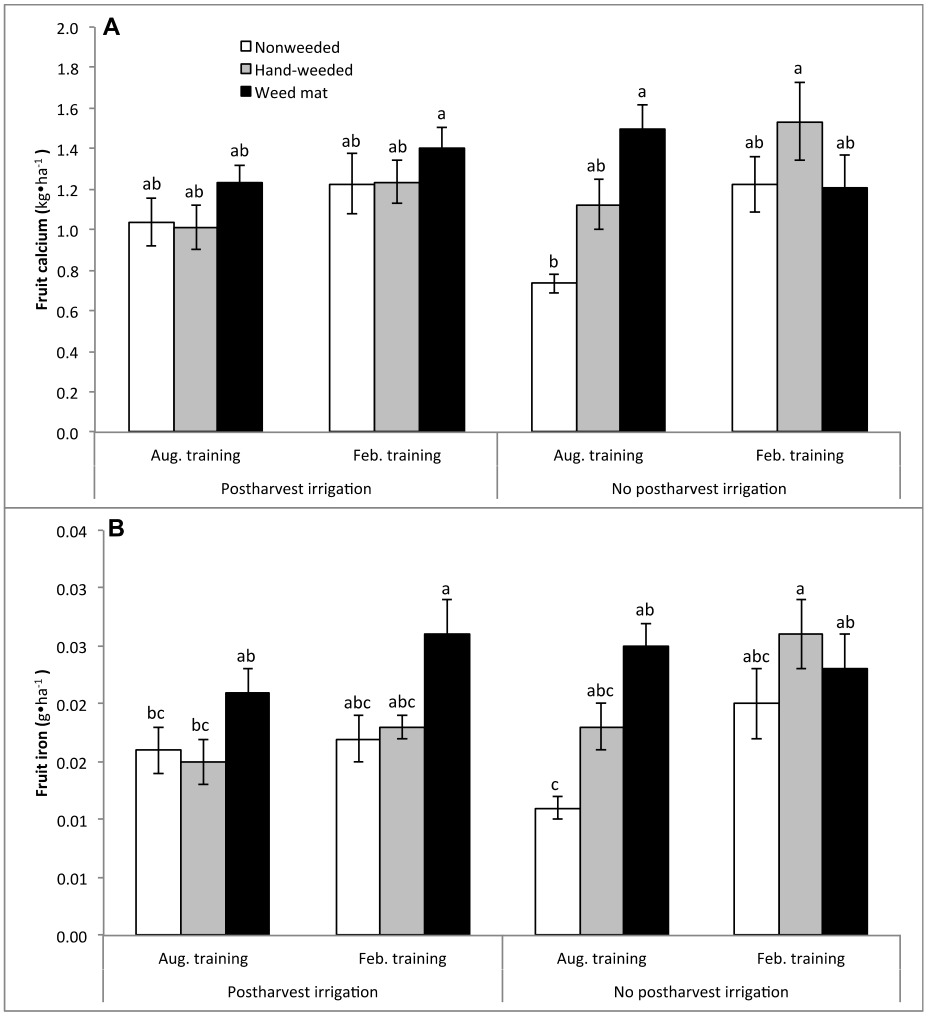

Fig. 4.1. Effects of irrigation, weed management strategy, and training time on mature organic ‘Black Diamond’ and ‘Marion’ trailing blackberry fruit (**A**) calcium (P = 0.0347) and (**B**) iron (P = 0.0429) grown at the North Willamette Research and Extension Center in Aurora, OR in 2014. Mean ± SE; means followed by the same letter within the interaction presented are not significantly different (P > 0.05).

CHAPTER 5: General Conclusions

Based on our study, 'Black Diamond' and 'Marion' appear to both be suited for organic blackberry production. The best treatment combinations yielded between 4 and 5 kg of fruit per plant, which is comparable to or greater than what might be produced in a conventional system. Although the two cultivars did not differ in yield when averaged over the other treatments, 'Black Diamond' with weed mat produced more fruit than 'Marion' in 2014. The low primocane leaf nutrient concentrations in 'Black Diamond' compared with 'Marion' did not seem to negatively affect yield, perhaps because the two cultivars did not differ in actual primocane nutrient content. Floricane nutrient content was lower in 'Black Diamond' than 'Marion', but possibly this reflected only a difference in allocation, not a true plant deficiency. Cultivar had minimal effects on soil nutrient concentrations.

Withholding irrigation after harvest had very few effects on plant growth, yield, or nutrient status, saving an estimated 1 million $L \cdot ha^{-1}$ over the 2 years of the study. The potential monetary and environmental benefits of this irrigation strategy should not be overlooked. However, further study is necessary to ensure that there are not any long-term negative effects and whether results would be similar for other cultivars and soil types in this region.

Weeds negatively affected blackberry biomass, yield, fruit weight, and aboveground plant nutrient content and annual gain. Additionally, plants grown with weed mat often outperformed those with hand weeding, especially in yield, biomass production, soil nutrient status, and fruit nutrient content. Weeds caused a significant reduction in yield in 'Black Diamond' in the last year of the study while 'Marion' in hand-weeded and nonweeded plots actually did not differ in yield. Weed management was thus critical in the organic production systems tested, especially for ‘Black Diamond’. Additionally, the consistent increase in yield from using weed mat as a mulch to control weeds over hand weeding affirmed that weed mat is the most economical method of weed management in this study.

While August training has been shown to increase yield of ‘Marion’ compared to February training in other studies, there was no effect of training time on yield of either cultivar here. August training actually decreased biomass production and yield in ‘Marion’, due to winter injury. ‘Black Diamond’ did not appear to be damaged by the cold temperatures. The particularly cold winter experienced in one of the two years of this study illustrated that February training has a distinct advantage, both in preventing winter injury and for reducing weed pressure in the hand-weeded plots. In addition, weed mat and postharvest irrigation, which promoted late-season growth, increased winter cold injury.

There are several management problems that still need to be addressed for organic blackberry production. Organic control of raspberry crown borer, which readily infested the ‘Black Diamond’ plants in this study, needs to be explored. There are management options, such as cultivar selection and alternate-year production, that may be effective tools against the pest. New sufficiency standards for primocane leaf nutrient concentration may need to be developed for cultivars other than ‘Marion’. ‘Black Diamond’ produced relatively high yields in this study while consistently testing below the primocane leaf N standard developed for ‘Marion’. While mobile nutrients like N may become available to blackberry relatively rapidly after floricane prunings are mulched in the field, it is still unknown whether other, and less mobile, nutrients become available in the same time frame. Further work is also needed on whole plant nutrient concentrations, content, carbon, and biomass, as belowground nutrient concentrations, allocation, and biomass are still unknown. The aboveground carbon stock of blackberry was relatively low compared with other perennial berry crops. Its capacity as a strong carbon sink appears to be low, as the canes cycle biennially. However, the perennial crown and large root system may add significantly to the total carbon sequestration potential and were not included in this study.

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APPENDIX

Table 1.1. Primocane tissue subsample nutrient concentrations in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR in 2014.[z]

	Macronutrients (%)										Micronutrients (ppm)								
	N		P		K		Ca	Mg	S		Fe		B	Cu		Mn	Zn	Al	
Treatment																			
Cultivar (C)																			
Black Diamond (B. Dia.)	1.7		0.23		1.0		0.5 a	0.18	0.10 a		189		16 a	8 a		101	45 a	188	
Marion	1.5		0.25		1.0		0.3 b	0.17	0.07 b		220		14 b	6 b		99	32 b	215	
Irrigation (I)																			
Post-harvest (+Irrig.)	1.6		0.24		1.0		0.4	0.18	0.09		207		15	7		97	39	203	
No post-harvest (-Irrig.)	1.6		0.24		1.0		0.4	0.18	0.08		202		15	7		102	38	200	
Weed management (W)																			
	+Irrig.	*-Irrig.*	*B. Dia.*	*Marion*	*B. Dia.*	*Marion*													
Nonweeded	1.7 ab[x]	1.6 bc	0.23 ab	0.25 a	1.0 b	1.0 b	0.4	0.18	0.09 a		188		15	7		97	40	186	
Hand-weeded	1.5 c	1.5 bc	0.21 b	0.24 ab	0.9 b	0.9 b	0.5	0.17	0.08 b		228		15	7		107	39	224	
Weed mat	1.8 a	1.6 abc	0.25 a	0.24 ab	1.2 a	0.9 b	0.4	0.18	0.09 a		200		15	7		96	36	196	
Training (T)																			
	+Irrig.	*-Irrig.*			*+Irrig.*	*-Irrig.*			*+Irrig.*	*-Irrig.*	*+Irrig.*	*-Irrig.*		*B. Dia.*	*Marion*			*+Irrig.*	*-Irrig.*
August	1.6 a	1.7 a	0.24 a		0.9 b	1.0 ab	0.5 a	0.19 a	0.09 ab	0.09 a	100 b	142 b	16 a	9 a	6 c	108 a	44 a	93 b	138 b
February	1.7 a	1.5 b	0.23 b		1.1 a	1.0 b	0.4 b	0.16 b	0.09 ab	0.08 b	314 a	262 a	14 b	8 b	6 c	92 b	33 b	312 a	262 a
Significance[y]																			
C	NS		NS		NS		0.0163	NS	0.0203		NS		0.015	0.0044		NS	0.0107	NS	
I	NS		NS		NS		NS	NS	NS		NS		NS	NS		NS	NS	NS	
W	0.0006		0.0168		0.0229		NS	NS	0.0119		NS		NS	NS		NS	NS	NS	
T	0.0423		0.0459		NS		0.0023	<0.0001	0.0207		<0.0001		<0.0001	0.0352		0.0136	<0.0001	<0.0001	
C x I	NS		NS		NS		NS	NS	NS		NS		NS	NS		NS	NS	NS	
C x W	NS		0.046		0.0097		NS	NS	NS		NS		NS	NS		NS	NS	NS	
I x W	0.041		NS		NS		NS	NS	NS		NS		NS	NS		NS	NS	NS	
C x T	NS		NS		NS		NS	NS	NS		NS		NS	0.0229		NS	NS	NS	
I x T	0.0011		NS		0.0392		NS	NS	0.005		0.0271		NS	NS		NS	NS	0.0209	
W x T	NS		NS		NS		NS	NS	NS		NS		NS	NS		NS	NS	NS	
C x I x W	0.0047		NS		NS		NS	NS	NS		NS		NS	NS		NS	NS	NS	
C x I x T	0.0271		NS		NS		NS	NS	0.0493		0.0334		NS	NS		NS	NS	0.0481	
C x W x T	NS		NS		NS		NS	NS	NS		NS		NS	NS		NS	NS	NS	
I x W x T	NS		NS		NS		NS	NS	NS		NS		NS	NS		NS	NS	NS	
C x I x W x T	0.0089		NS		NS		NS	NS	NS		NS		NS	NS		NS	NS	NS	

[z]Primocane subsamples were collected during February training on 22 Feb. 2014.
[y]NS = non-significant; *P*-values provided for significant factors.
[x]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).

Table 1.2. Primocane tissue subsample nutrient concentrations in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR in 2015.[z]

	Macronutrients (%)										Micronutrients (ppm)									
	N	P		K		Ca		Mg	S		Fe		B	Cu		Mn	Zn		Al	
Treatment																				
Cultivar (C)																				
		Aug.	*Feb.*	*Aug.*	*Feb.*				*Aug.*	*Feb.*	*+Irrig.*	*-Irrig.*							*+Irrig.*	*-Irrig.*
Black Diamond (B. Dia.)	1.2	0.194 b[x]	0.187 b	0.74 a	0.74 a	0.65 a		0.11	0.08 a	0.07 a	50 b	77 a	13.8	7		99	36.3		39 b	69 a
Marion	0.9	0.193 b	0.206 a	0.63 b	0.68 a	0.49 b		0.13	0.06 b	0.06 b	92 a	85 a	13.4	9		86	32.4		83 a	76 a
Irrigation (I)																				
																	Aug.	*Feb.*		
Post-harvest (+Irrig.)	1.1	0.194		0.72		0.55		0.11 b	0.07		71 b		13.7	8		92	35.2 a	29.2 b	61 b	
No post-harvest (-Irrig.)	1.0	0.196		0.67		0.60		0.12 a	0.07		81 a		13.5	8		94	36.4 a	36.3 a	73 a	
Weed management (W)																				
		B. Dia.	*Marion*	*B. Dia.*	*Marion*	*+Irrig.*	*-Irrig.*		*B. Dia.*	*Marion*				*+Irrig.*	*-Irrig.*					
Nonweeded	1.0	0.203 a	0.195 bc	0.75 a	0.62 c	0.52 b	0.63 a	0.12 ab	0.08 a	0.05 b	73		13.8 a	8 ab	9 a	98 a	35.5 a		61	
Hand-weeded	1.1	0.190 c	0.199 ab	0.75 a	0.66 bc	0.56 ab	0.60 ab	0.12 a	0.08 a	0.06 b	78		13.9 a	7 b	8 ab	94 ab	35.2 ab		71	
Weed mat	1.0	0.179 d	0.203 ab	0.71 ab	0.68 ab	0.56 ab	0.56 b	0.11 b	0.07 a	0.06 b	77		13.1 b	8 ab	8 ab	86 b	32.2 b		70	
Training (T)																				
August (Aug.)	1.1	0.193		0.69 b		0.60 a		0.12 a	0.07		67 b		14.0 a	8		94	35.8 a		57 b	
February (Feb.)	1.0	0.196		0.71 a		0.54 b		0.11 b	0.07		85 a		13.2 b	8		92	32.9 b		78 a	
Significance[y]																				
C	NS	NS		NS		0.0399		NS	0.0175		0.0215		NS	NS		NS	NS		0.032	
I	NS	NS		NS		NS		0.0228	NS		0.0336		NS	NS		NS	0.0057		0.0351	
W	NS	NS		NS		NS		0.0496	NS		NS		0.0172	NS		NS	NS		NS	
T	NS	NS		0.0424		0.0014		0.0308	NS		0.0021		0.0019	NS		NS	0.0246		0.0006	
C x I	NS	NS		NS		NS		NS	NS		0.0094		NS	NS		NS	NS		0.0198	
C x W	NS	0.0116		0.0008		NS		NS	0.0076		NS		NS	NS		NS	NS		NS	
I x W	NS	NS		NS		0.0494		NS	NS		NS		NS	0.0351		NS	NS		NS	
C x T	NS	0.024		0.0493		NS		NS	0.0176		NS		NS	NS		NS	NS		NS	
I x T	NS	NS		NS		NS		NS	NS		NS		NS	NS		NS	0.0222		NS	
W x T	NS	NS		0.0014		NS		NS	NS		NS		NS	NS		NS	NS		NS	
C x I x W	NS	NS		NS		NS		NS	NS		NS		NS	NS		0.0055	NS		NS	
C x I x T	NS	NS		0.0178		0.019		NS	NS		NS		NS	NS		NS	NS		NS	
C x W x T	NS	NS		NS		NS		NS	NS		NS		NS	NS		NS	NS		NS	
I x W x T	NS	NS		0.035		NS		NS	NS		NS		NS	NS		NS	NS		NS	
C x I x W x T	NS	0.0351		0.0072		NS		NS	0.0204		NS		NS	NS		NS	NS		NS	

[z]Primocane subsamples were collected at the end of the study period on 16 Dec. 2014.
[y]NS = non-significant; *P*-values provided for significant factors.
[x]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).

Table 1.3. Floricane tissue subsample nutrients in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR in 2013.[z]

	Macronutrients (%)							Micronutrients (ppm)						
	N	P	K	Ca	Mg		S	Fe	B		Cu	Mn	Zn	Al
Treatment														
Cultivar (C)														
					Aug.	*Feb.*								
Black Diamond (B. Dia.)	1.9 a[x]	0.20 a	1.8 a	2 a	0.29 a	0.30 a	0.12 a	417 a	58 b		6.4 a	485 a	36 a	328 a
Marion	1.6 b	0.14 b	1.5 b	1 b	0.29 ab	0.27 b	0.11 b	331 b	97 a		5.7 b	358 b	30 b	273 b
Irrigation (I)														
Post-harvest	1.8	0.18	1.6	2	0.30		0.12	370	78		6.1	435	32	296
No post-harvest	1.8	0.16	1.6	2	0.28		0.11	377	76		6.1	408	33	304
Weed management (W)														
									B. Dia.	*Marion*				
Nonweeded	1.7 b	0.17	1.6 b	1 b	0.29		0.11 b	386	53 b	99 a	5.9	397	31 b	309
Hand-weeded	1.8 a	0.17	1.6 ab	2 a	0.30		0.12 a	371	59 b	101 a	6.2	450	32 b	300
Weed mat	1.8 a	0.18	1.7 a	1 b	0.28		0.12 a	363	61 b	93 a	6.1	418	35 a	292
Training (T)														
August (Aug.)	1.8 a	0.18 a	1.7 a	2	0.29		0.12 a	375	80 a		6.2 a	405	33	300
February (Feb.)	1.7 b	0.16 b	1.6 b	2	0.29		0.11 b	372	74 b		5.9 b	437	32	301
Significance[y]														
C	<0.0001	0.001	0.0017	<0.0001	0.0114		<0.0001	0.0021	<0.0001		0.0038	0.0002	0.0013	0.0076
I	NS	NS	NS	NS	NS		NS	NS	NS		NS	NS	NS	NS
W	0.0018	NS	0.0055	0.0076	NS		0.0036	NS	NS		NS	NS	0.0032	NS
T	0.0062	0.0086	0.0038	NS	NS		0.0079	NS	0.0057		0.0049	NS	NS	NS
C x I	NS	NS	NS	NS	NS		NS	NS	NS		NS	NS	NS	NS
C x W	NS	NS	NS	NS	NS		NS	NS	0.0147		NS	NS	NS	NS
I x W	NS	NS	NS	NS	NS		NS	NS	NS		NS	NS	NS	NS
C x T	NS	NS	NS	NS	0.0268		NS	NS	NS		NS	NS	NS	NS
I x T	NS	NS	NS	NS	NS		NS	NS	NS		NS	NS	NS	NS
W x T	NS	NS	NS	NS	NS		NS	NS	NS		NS	NS	NS	NS
C x I x W	NS	NS	NS	NS	NS		NS	NS	NS		NS	NS	NS	NS
C x I x T	NS	NS	NS	NS	NS		NS	NS	0.0102		0.0379	0.0121	0.0010	NS
C x W x T	NS	NS	NS	NS	NS		NS	NS	NS		NS	NS	NS	NS
I x W x T	NS	NS	NS	NS	NS		NS	NS	NS		NS	NS	NS	NS
C x I x W x T	NS	NS	NS	NS	NS		NS	NS	NS		NS	NS	NS	NS

[z]Floricane subsamples were collected during caning out on 29 and 30 July and 1 and 5 Aug. 2013.
[y]NS = non-significant; *P*-values provided for significant factors.
[x]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).

Table 1.4. Floricane tissue subsample nutrients in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR in 2014.[z]

	Macronutrients (%)							Micronutrients (ppm)								
	N	P	K		Ca	Mg	S	Fe	B	Cu		Mn		Zn		Al
Treatment																
Cultivar (C)																
Black Diamond (B. Dia.)	1.8 a[x]	0.2 a	1.9 a		1.4	0.3	0.103 a	265 a	59 b	73		348 a		30 a		231 a
Marion	1.7 b	0.1 b	1.5 b		1.4	0.3	0.095 b	226 b	90 a	90		303 b		27 b		205 b
Irrigation (I)																
												B. Dia.	*Marion*	*B. Dia.*	*Marion*	
Post-harvest (+Irrig.)	1.8	0.2	1.6		1.4	0.3	0.099	238	76	85		316 ab	338 a	28 b	28 b	214
No post-harvest (-Irrig.)	1.7	0.2	1.7		1.4	0.3	0.098	253	74	78		381 a	269 b	32 a	25 b	222
Weed management (W)																
			B. Dia.	*Marion*						*+Irrig.*	*-Irrig.*			*Aug.*	*Feb.*	
Nonweeded	1.7 b	0.2	2.0 a	1.4 b	1.5	0.3	0.096	235 b	79	109 a	56 b	316		27 b	31 a	210 b
Hand-weeded	1.7 ab	0.2	1.8 a	1.4 b	1.4	0.3	0.100	269 a	72	62 b	75 ab	330		29 ab	28 ab	237 a
Weed mat	1.8 a	0.2	1.8 a	1.5 b	1.4	0.3	0.100	235 b	74	85 ab	103 a	330		29 ab	26 b	208 b
Training (T)																
August (Aug.)	1.8	0.2	1.7		1.4	0.3	0.100	251	76	80		322		29		221
February (Feb).	1.7	0.2	1.7		1.4	0.3	0.097	241	73	83		328		28		215
Significance[y]																
C	0.0003	0.0011	0.0002		NS	NS	0.0053	0.0005	0.0004	NS		0.0288		0.0104		0.0021
I	NS	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS		NS
W	0.0495	NS	NS		NS	NS	NS	0.001	NS	NS		NS		NS		0.0006
T	NS	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS		NS
C x I	NS	NS	NS		NS	NS	NS	NS	NS	NS		0.0025		0.0035		NS
C x W	NS	NS	0.0395		NS	NS	NS	NS	NS	NS		NS		NS		NS
I x W	NS	NS	NS		NS	NS	NS	NS	NS	0.0016		NS		NS		NS
C x T	NS	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS		NS
I x T	NS	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS		NS
W x T	NS	NS	NS		NS	NS	NS	NS	NS	NS		NS		0.0237		NS
C x I x W	NS	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS		NS
C x I x T	0.0125	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS		NS
C x W x T	NS	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS		NS
I x W x T	NS	NS	NS		NS	NS	NS	NS	0.0031	NS		NS		NS		NS
C x I x W x T	NS	NS	NS		NS	NS	NS	NS	NS	NS		NS		NS		NS

[z]Floricane subsamples were collected during caning out on 30 and 31 July and 1 Aug. 2014.
[y]NS = non-significant; *P*-values provided for significant factors.
[x]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).

Table 1.5. Carbon concentrations in plant tissues of a mature organic trailing blackberry planting located at the North Willamette Research and Extension Center in Aurora, OR in 2013–2014.

	Carbon (%)															
	Floricane leaves[z]			Fruit[y]			Primocane leaves[x]			Floricane tissue[w]				Primocane tissue[v]		
	2013	2014		2013		2014	2013		2014	2013		2014		2014	2015	
Treatment																
Cultivar (C)																
		Aug.	*Feb.*	*Aug.*	*Feb.*										*Aug.*	*Feb.*
Black Diamond (B. Dia.)	46	44.9 c[t]	45.4 b	44.3 ab[x]	44.6 a	43	48.4		47	45.5 b		43.8 b		49 a	46 ab	46 a
Marion	47	46.5 a	46.4 a	44.6 a	43.9 b	43	48.4		46	46.2 a		44.7 a		48 b	46 a	45 b
Irrigation (I)																
							Aug.	*Feb.*				*Aug.*	*Feb.*			
Postharvest (+Irrig.)	46	45.6		44.6		43	48.6 a[x]	48.1 b	46	45.8		44.0 b	44.2 ab	49	46	
No postharvest (-Irrig.)	47	45.9		44.2		43	48.4 ab	48.5 ab	47	46.0		44.6 a	44.1 b	48	46	
Weed management (W)																
		+Irrig.	*-Irrig.*							*B. Dia.*	*Marion*				*Aug.*	*Feb.*
Nonweeded	47	45.8 ab	45.7 ab	44.3		43	48.6		47	45.5 c	46.5 a	44.1		48	46 ab	46 ab
Hand-weeded	47	45.5 b	45.9 ab	44.5		43	48.3		46	45.4 c	46.1 ab	44.4		48	46 ab	45 b
Weed mat	47	45.7 ab	46.1 a	44.3		43	48.4		47	45.7 bc	46.1 ab	44.2		48	45 ab	46 a
Training (T)																
August (Aug.)	46	45.7 b		44.5		43	48.5		47	45.8		44.3		49	46	
February (Feb.)	47	45.9 a		44.3		43	48.3		47	45.9		44.2		48	46	
Significance[u]																
C	NS	0.0006		NS		NS	NS		NS	0.007		0.007		0.0076	NS	
I	NS	NS		NS		NS	NS		NS	NS		NS		NS	NS	
W	NS	NS		NS		NS	NS		NS	NS		NS		NS	NS	
T	NS	0.0233		NS		NS	NS		NS	NS		NS		NS	NS	
C x I	NS	NS		NS		NS	NS		NS	NS		NS		NS	NS	
C x W	NS	NS		NS		NS	NS		NS	0.0332		NS		NS	NS	
I x W	NS	0.0323		NS		NS	NS		NS	NS		NS		NS	NS	
C x T	NS	0.0019		0.0472		NS	NS		NS	NS		NS		NS	0.017	
I x T	NS	NS		NS		NS	0.0277		NS	NS		0.0173		NS	NS	
W x T	NS	NS		NS		NS	NS		NS	NS		NS		NS	0.0259	
C x I x W	NS	NS		0.0484		NS	NS		NS	NS		NS		NS	NS	
C x I x T	NS	NS		NS		NS	NS		NS	NS		NS		0.0279	NS	
C x W x T	NS	NS		NS		NS	NS		NS	NS		NS		NS	NS	
I x W x T	NS	NS		NS		NS	0.0207		NS	NS		NS		NS	NS	
C x I x W x T	NS	NS		NS		NS	NS		NS	NS		NS		NS	NS	

[z]Floricane leaf samples were collected in June each year.
[y]Fruit samples were collected from the machine-harvested fruit in July each year.
[x]Primocane leaf samples were collected in July each year.
[w]Floricane tissue subsamples were collected during pruning out each year in July–Aug each year.
[v]Primocane tissue subsamples were collected during February training in 2014 and at the end of the study period in Dec. 2014 (2015 samples).
[u]NS = non-significant; P-values provided for significant factors.
[t]Means followed by the same letter within a column or interaction are not significantly different (P > 0.05).

Table 1.6. Annual dry biomass and nutrient net change in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR in 2013.

	(t·ha^{-1})		Macronutrients (kg·ha^{-1})							Micronutrients (g·ha^{-1})					
	Dry biomass	C	N	P	K	Ca		Mg	S	Fe	B	Cu	Mn	Zn	Al
Treatment															
Cultivar (C)															
						+Irrig.	*-Irrig.*								
Black Diamond	0.4	0.2	11	1	7	1.9 a	-0.4 b	1	0.5	147	8	4	33	21	154
Marion	0.7	0.3	13	2	8	2.0 a	1.1 a	1	0.6	236	9	2	68	19	232
Irrigation (I)															
Postharvest (+Irrig.).	0.7 a[y]	0.4 a	14 a	2	9 a	1.9 a		2 a	0.7 a	220	11 a	4	63	28 a	222
No postharvest (-Irrig.)	0.4 b	0.2 b	9 b	1	6 b	0.3 b		1 b	0.4 b	164	6 b	2	37	13 b	165
Weed management (W)															
Nonweeded	0.5	0.2	10	1	7	0.5		1	0.5	162	8	2	36	17	165
Hand-weeded	0.5	0.3	10	1	6	1.4		1	0.5	218	8	3	54	22	215
Weed mat	0.7	0.3	15	2	9	1.5		2	0.7	195	10	4	61	22	200
Training (T)															
August	0.4 b	0.2 b	9 b	1 b	5 b	0.5 b		1	0.4 b	94 b	7	2 b	37 b	20	94 b
February	0.7 a	0.4 a	14 a	2 a	10 a	1.8 a		1	0.7 a	289 a	11	4 a	64 a	20	292 a
Significance[z]															
C	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS	NS
I	0.0156	0.0168	0.0368	NS	0.0288	0.0103		0.037	0.0348	NS	0.044	NS	NS	0.0119	NS
W	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS	NS
T	0.0168	0.0193	0.0304	0.0478	0.0075	0.0475		NS	0.0461	0.0018	NS	0.0432	0.0422	NS	0.0014
C x I	NS	NS	NS	NS	NS	0.0428		NS	NS	NS	NS	NS	NS	NS	NS
C x W	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS	NS
I x W	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS	NS
C x T	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS	NS
I x T	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS	NS
W x T[x]	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS	NS

[z]NS = non-significant; *P*-values provided for significant factors.
[y]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).
[x]All other higher order interactions were non-significant and are not shown.

Table. 1.7. Annual dry biomass and nutrient net change in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR in 2014.

	($t\cdot ha^{-1}$)		Macronutrients ($kg\cdot ha^{-1}$)						Micronutrients ($g\cdot ha^{-1}$)						
	Dry biomass[z]	C	N	P	K	Ca	Mg	S	Fe	B	Cu	Mn	Zn	Al	
Treatment															
Cultivar (C)															
Black Diamond	-0.3	-0.2	-13	-1.3	-8 b[x]	0.2	-1.6	-0.6 b	-262	-9	-4 b	-38	-25	-266	
Marion	0.3	0.1	-8	-0.3	-3 a	4.0	-0.5	-0.2 a	-240	4	8 a	8	10	-236	
Irrigation (I)															
Postharvest (+Irrig.)	-0.1	-0.1	-12	-0.9	-6	1.6	-1.2	-0.5	-226	-3	2	-14	-12	-228	
No postharvest (-Irrig.)	0.1	0.0	-8	-0.7	-5	2.6	-0.8	-0.3	-276	-2	2	-17	-3	-274	
Weed management (W)															
														+Irrig.	*-Irrig.*
Nonweeded	-0.1	-0.1	-10	-0.9	-5	1.2	-0.9	-0.4	-162	-4	1	-10	-12	-180 a	-167 a
Hand-weeded	0.0	-0.1	-9	-0.7	-5	1.2	-1.0	-0.4	-337	-4	2	-30	-12	-171 a	-478 b
Weed mat	0.1	0.0	-12	-0.8	-7	3.8	-1.1	-0.4	-254	0	4	-5	1	-331 ab	-180 a
Training (T)															
August	0.0	0.0	-10	-0.8	-5	2.0	-1.1	-0.4	-112 a	-3	2	-25	-14	-114 a	
February	0.0	-0.1	-11	-0.8	-6	2.2	-0.9	-0.4	-390 b	-2	2	-6	-2	-389 b	
Significance[y]															
C	NS	NS	NS	NS	0.002	NS	NS	0.0305	NS	NS	0.0366	NS	NS	NS	
I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
T	NS	NS	NS	NS	NS	NS	NS	NS	0.0012	NS	NS	NS	NS	0.0007	
C x I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
C x W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
I x W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0483	
C x T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
I x T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
W x T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
C x I x W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
C x I x T	NS	NS	NS	NS	NS	NS	NS	NS	0.0041	NS	NS	NS	NS	0.0055	
C x W x T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
I x W x T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
C x I x W x T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	

[z]Because of the calculations, rounding, and estimation involved, nutrients may add up to greater than dry biomass (e.g. the postharvest irrigation treatment).
[y]NS = non-significant; *P*-values provided for significant factors.
[x]Means followed by the same letter within a column or interaction are not significantly different ($P > 0.05$).