AN ABSTRACT OF THE THESIS OF

<u>Renee H. Harkins</u> for the of degree <u>Master of Science</u> in <u>Horticulture</u> presented on <u>June 4, 2013</u>
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Abstract approved:

Bernadine C. Strik

The study was conducted in an organic trailing blackberry (*Rubus* L. subgenus *Rubus*, Watson) planting established at the North Willamette Research and Extension Center in Aurora, OR on 26 May 2010. Three weed management systems were compared for ‘Marion’ and ‘Black Diamond’: 1) non-weeded; 2) hand-hoed two to three times per year (hand weed); and 3) black landscape fabric mulch (weed mat). The planting was certified organic in May 2012, the first fruiting year. Aboveground weed dry weight (DW) increased from 2010 through 2012 in the non-weeded plots. Findings suggest that nitrogen (N) was the major nutrient affecting blackberry cane growth and fruit development. Other nutrients were considered sufficient as evidenced by soil and plant tissue testing, with the exception of calcium (Ca) and boron, which were at the low end of the sufficiency range in some soil and tissue samples. Soil nutrients fluctuated a small amount by distance and location relative to the emitter and sampling depth. However overall nutrient concentrations were adequate for good blackberry growth. Given some of the observed nutrient trends, soil sampling should be completed in-row, under the drip

emitters where fertilizer is applied, at a 0.15 cm depth, to ensure proper long-term soil management.

Total aboveground plant biomass increased from 0.3 and 2.0 t·ha^{-1} in the non-fruiting years (2010 and 2011, respectively) to 3.4 t·ha^{-1} in the fruiting year (2012). Primocane number and plant DW were not affected by cultivar or weed management in 2010. In 2011, ‘Black Diamond’ had shorter primocanes and less biomass and macro- and micro-nutrient accumulation than ‘Marion’. Plants grown without weed control produced fewer but longer primocanes with less biomass and lower nutrient content. In 2012, floricane biomass removed at pruning was greater for ‘Marion’ plants and was least for plants in non-weeded plots, and greatest for plants in weed mat plots. Floricanes had greater macro- and micronutrient concentrations than the primocanes, but less than when the floricane leaves were sampled in July, indicating nutrient loss to the fruit and possibly remobilization of some nutrients during cane senescence. Ultimately, floricanes were also a sink for nutrients, reducing primocane biomass in 2012. During the first harvest year (2012), the cultivars did not differ in the DW yield, however, ‘Black Diamond’ had a greater fresh yield than ‘Marion’ (6.0 kg·plant^{-1} and 5.2 kg·plant^{-1}, respectively). The proportion of above-ground DW biomass allocated to fruit in weed controlled plots averaged 40% in ‘Marion’ and 56% in ‘Black Diamond’, suggesting a greater yield efficiency of ‘Black Diamond’ plants. Non-weeded plots produced approx. half the fresh yield (3.65 kg·plant^{-1}), 39% of the fruit DW biomass as weed mat plots, and the treatment had fruit with lower moisture content, higher percent soluble solids, and lower Ca concentrations, than the other treatments.

Net gain of N averaged 41 $kg \cdot ha^{-1}$ with weed control compared to 25 $kg \cdot ha^{-1}$ without weed control. Both cultivars accumulated large quantities of N, potassium, and Ca for growth and yield. Nutrient gains may have exceeded fertilizer nutrients available in the fruit production year. Overall, cultivar and weed management strategies had inconsistent effects on tissue and soil nutrient status during the study, with the exception of N.

'Black Diamond' and 'Marion' performed similarly across all three weed management strategies and appeared well suited to organic production for high-value processed markets. Weed mat appeared best suited for organic systems, reducing labor required for weed control, enhancing nutrient uptake by plants, and producing the greatest amount of plant growth and yield. Weed management strategies affected nutrient accumulation and loss, indicating fertilization may need to be adjusted depending on the strategy used.

Weed, Water, and Nutrient Management Practices for
Organic Blackberry During Establishment

by

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Renee H. Harkins, Author

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CHAPTER 1: Introduction

In recent years, organic blackberries (*Rubus* L. subgenus *Rubus*, Watson) gained favor with consumers worldwide, creating a niche market for blackberry growers. As of 2005, approximately 8% of global blackberry production was organic and was expected to increase (Strik et al., 2007). Recent demand for organic blackberries coincides with a gap of knowledge; to date, there is no published research on organic blackberry production systems, and consequently growers do not know how to optimize yield and growth. The primary challenges to increased organic blackberry production include limited resources to control weeds, mitigate pests and disease, and fertilize plants (Larco et al., 2013). The long-term goal of this study is to compare various management strategies to develop a comprehensive understanding of how organic production of blackberries may be best achieved.

Blackberries are a high value, horticultural crop, and organic production has only intensified their value. The purpose of organic production is to generate premium products, using environmentally-conscious methods. Prices for organic goods, including blackberries, are generally higher than the conventional alternative, in order to offset more expensive management. Price per kg of processed, conventional ‘Marion’ blackberries in Oregon was $1.19, $1.52, and $1.72 for the years 2009, 2010, and 2011, respectively (NASS, 2012). In those same years, the price for the organic alternative was about 33% greater ("Category Spotlight", 2011).

Trailing-type blackberries are commonly grown in the Willamette Valley, Oregon where the winter climate is moderate and does not typically cause substantial cold damage to overwintering primocanes (Strik, 1992). ‘Marion’ is the most popular trailing blackberry cultivar grown worldwide, consisting of approximately 55% of harvested blackberries in Oregon in 2011 (NASS, 2012; Strik et al., 2007). ‘Black Diamond’ is a popular, new thornless trailing cultivar developed at the USDA Agricultural Research Service in Corvallis, Oregon (Finn et al., 2005). In 2004 and 2005 more ‘Black Diamond’ plants were sold than any other cultivar in Oregon, making this cultivar the second most important one grown (Finn et al., 2005; Strik et al., 2007). Trailing cultivars are predominately grown for the processed market and are typically harvested by machine to reduce harvest costs (Strik and Finn, 2012). ‘Marion’ and ‘Black Diamond’ are the leading cultivars in the processed-fruit market (Finn et al., 2005; Strik, 1992). It is unknown how these cultivars will behave in an organic production system. In particular, the physiological response of the plants to various cultural management tools suited for organic production and the nutritive response of the plant to those systems has yet to be explored.

Weed management is a fundamental component of organic production systems, and it is considered critical for good production in many berry crops (e.g. Barney and Miles, 2007; Bushway et al., 2008; Heiberg, 2002; Krewer et al., 2009; Pritts and Kelly, 2001; Zebarth et al., 1993). The use of pre-emergent and contact herbicides, while common in conventional systems, are limited in organic systems. Conventional herbicides contain synthetic compounds, thus only organic herbicides, such as those approved by the Organic Materials Review Institute (OMRI), may be used in organic systems in the United States. These constraints limit the breadth of available weed management tools for organic production, thereby necessitating alternative forms of weed control (Bond and Grundy, 2001). There are several cultural forms of weed management that are commonly incorporated in organic systems, these include weed mat (landscape fabric), hand-weeding, and integrated growth. However, the efficacy, cost effectiveness, and implications on plant and soil nutrient status and yield of these alternative forms of organic weed control are not well understood.

The long-term goal of this study is to develop an economical organic production system for machine-harvested, trailing blackberry which maximizes plant growth and fruit yield and is sustainable. During these establishment years, we studied 1) how soil samples are best collected in fertigated organic blackberry systems to manage for soil health, high yields, and vigorous plant growth; 2) whether cultural forms of weed management affect plant growth and early fruit production; and 3) the effects of weed management strategies on biomass and nutrient accumulation and losses in ‘Marion’ and ‘Black Diamond’.

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CHAPTER 2: Effects of Fertigation and Weed Management on Soil Nutrients and pH in Organic Trailing Blackberry During Establishment

Abstract

An organic blackberry (*Rubus* L. subgenus *Rubus* Watson.) system for processing, established in May 2010, was used to determine the effects of fertigation on soil nutrient availability. Two popular blackberry cultivars for processing, 'Marion' and 'Black Diamond', were planted by three cultural weed management treatments, 'non-weeded', 'hand weed', and 'weed mat'. During the planting year, tissue-culture propagated plants were fertilized with fish emulsion by hand. In successive years, all plots were spring fertigated with fish emulsion, using a single lateral of drip tubing. Findings suggest that nitrogen was the major nutrient affecting blackberry cane growth and fruit development. Other nutrients were considered sufficient as evidenced by soil and plant tissue testing, with the exception of calcium and boron which were at the low end of the sufficiency range in some soil samples. Ultimately, findings indicate that soil samples should be collected to the 0.15 m depth in-row, under the drip emitters, in fertigated systems, to ensure proper long term soil management.

Introduction

Soil testing is an important component of nutrient management and is often used as a diagnostic tool for crop production or to identify meaningful trends such as changes in soil pH or organic matter over time. For meaningful results, samples need to be collected correctly in both time and place and consistently from year to year. Tests results may vary with soil depth and location and often migrate over time and often differ depending on the management practices used, including those associated with tillage and weed control, fertilizer application, and irrigation (Hart et al., 2006; Kowalenko, 1991).

Tillage affects soil nutrient levels and frequently increases availability of many nutrients for plant uptake. No-till practices, on the other hand, often increase soil pH and availability of certain nutrients near the soil surface and leads to stratification of organic matter and nutrients in the soil profile (Agbede, 2010; Logan et al., 1991; Tebrugge and During, 1999). Because perennial cropping systems remain un-tilled for many years, the aforementioned effects on soil nutrient availability are likely evident in these systems. Of course, fertilizer application will also affect availability of soil nutrients, including those not applied. Availability often varies, however, depending on the amount and placement of the fertilizer as well as the source and time in which it is applied (Bryla, 2011; Gaskell et al., 2011; Mattson et al., 2011; Mikkelsen, 2011; Santos, 2011).

Fertigation, or the application of fertilizer through the irrigation system, is becoming a common method of applying fertilizer to many horticultural crops, primarily due to widespread adoption of drip irrigation in these crops, including many vegetable, tree fruit, and small fruit crops. When managed properly, fertigation offers the advantage of applying the fertilizer directly to the planting row, to areas of high root density, thereby reducing labor and loss of nutrients to the environment (Gardenas et al., 2005; Obreza and Sartain, 2010).

Organic blackberries are a relatively new commodity in the global marketplace and may be well adapted to popular forms of organic weed management such as hand-weeding, weed mat, and integrated weed growth (allowing weeds to grow in-row). Hand-weeding removes competitive weed biomass, eliminating nutrient competition by weeds (Bond and Grundy, 2001; Ram et al., 2004), but it is costly and time consuming (Olmstead et al., 2012). Weed mat (perforated landscape fabric) is considered an inert mulch (Granatstein and Mullinix, 2008); however, previous studies showed that weed mat increased soil temperature, triggering increased decomposition and mineralization of organic matter under the weed mat (Daugaard, 2008; Julian et al., 2012). Integrated weed growth, unlike the aforementioned forms of weed management, entails zero weed control. This may be perfectly suitable for vigorous, highly competitive crops (Clements et al., 1994).

Commonly used synthetic fertilizers are prohibited on certified organic acreage, therefore Organic Materials Review Institute (OMRI) approved organic fertilizers are necessary for good crop growth (Bond and Grundy, 2001; Kristiansen et al., 2008). One study of certified organic fertilizers showed that as much as 60% of organic N found in seabird guano, hydrolyzed fish powder, feather meal, and blood meal mineralized within two weeks, indicating organic fertilizers may be a reliable source of N for organic systems (Hartz and Johnstone, 2006). However, the broad spectrum of organic fertilizers available can be highly variable across N source, thus presenting management challenges depending on the particular organic fertilizer chosen (Gaskell and Smith, 2007).

A conventional caneberry management guide recommends applying 34-56 $kg \cdot ha^{-1}$ of N during establishment of trailing blackberries and 56-78 $kg \cdot ha^{-1}$ N, annually, thereafter (Hart et al., 2006). Split fertilizer applications are recommended (Hart et al., 2006), however some studies show there is no advantage to split fertilizer application in ‘Arapaho’ thornless blackberry (Naraguma and Clark, 2008). Caneberries, which require early spring fertilization, may be subject to nutrient leaching, particularly in the Pacific Northwest, because spring rains often extend into the growing season (Kowalenko et al., 2000). Hence the nutrient use efficiency is unknown for trailing blackberry.

Soil sampling is reccomended prior to planting and whenever visible problems appear, such as poor plant growth or nutrient deficiency symptoms in the leaves (Fernandez and Ballington, 1999; Hart et al., 2006). However, existing caneberry management guides do not address how soil management may differ in organic caneberry systems. Therefore, there remains a gap of knowledge, as the optimum depth and location for soil sampling, when cultural weed management is paired with fertigation of organic fertilizer, is not known.

The objective of the present study was to determine the effects of different organic weed management strategies, including hand weeding, weed mat, and no weeding, on soil nutrient availability during establishment of trailing blackberries for processing. The two most widely planted trailing varieties, ‘Black Diamond’ and ‘Marion’, were included in the study. All plants were fertilized each spring with hydrolyzed fish emulsion. The fertilizer was applied by hand around the base of the plants during the first year after planting, and was applied by fertigation through the drip irrigation system the following 2 years.

Materials and Methods

Study site. The study was conducted at the North Willamette Research and Extension Center in Aurora, OR (long. 45°17' N, lat. 122°45' W; USDA hardiness zone 8; elevation 46 m). Winter wheat (*Triticum* sp.) was planted at the site for at least 10 years prior to the study. The soil is mapped as a Willamette silt loam (fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll). It was sampled for analysis on 7 Aug. 2009 and had a soil pH of 5.3 and contained 3.6% organic matter, 1.5 ppm NO_3-N, 2.3 ppm NH_4-N, 188 ppm phosphorus (P; Bray P I test), 295 ppm exchangable potassium (K), 925 ppm calcium (Ca), and 104 ppm magnesium (Mg) in the top 0.2 m of the soil profile (Brookside Laboratories, Inc., New Knoxville, OH). The site was certified organic by Oregon Tilth (Salem, OR) in May 2012.

Site preparation. Cereal rye (*Secale cereal* L.) and common vetch (*Vicia sativa* L.) were seeded at the site on 18 May 2009 at a rate of 34 and 67 $kg \cdot ha^{-1}$, respectively, and incorporated on 27 Aug. 2009 using a power spader (Model 165, Series 205, Tortella, Ortona, Italy) and rototiller (Model TB 180, TerraAnova, Padova, Italy). Plant rows were marked 3.0-m apart (north-south direction) on 31 Aug. 2009 and sub-soiled 0.4-m deep using a two-shank ripper (Rankin Model R3-60, Yakima, WA). Pelletized lime [calcium carbonate (2242 $kg \cdot ha^{-1}$) and pelletized dolomite lime (4148 $kg \cdot ha^{-1}$)] and fertilizer

[KMag 0N-0P-22K-11Mg-22S ($MgSO_4 \cdot K_2SO_4$; 561 kg·ha^{-1}), 90% granular sulfur (S; 10 kg·ha^{-1}); 15% granular boron (B; 2 kg·ha^{-1}); copper sulfate (SO_4; 1 kg·ha^{-1}); and zinc sulfate (SO_4, 14 kg·ha^{-1})] were then broadcast and incorporated using the power spader and rototiller. Lime was applied because the preexisting soil pH in 2009 was below sufficiency for good blackberry growth (Hart et al., 2006). We fertilized because immobile nutrients are routinely incorporated prior to planting of perennial crops to ensure nutrient sufficiency of those nutrients for the longevity of the planting. Cereal rye was seeded within rows and hard-fine fescue (*Festuca longifolia* Thuill. ‘Aurora Gold’) was seeded between rows at a rate of 112 kg·ha^{-1} each on 7 Oct. 2009. The rye was flail mowed on 8 May 2010, and rows were sub-soiled (0.4-m deep) using a single-shank ripper and tilled using a 0.3-m wide strip tiller.

Experimental design. The study was planted on 26 May 2010. 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 subplots, and a combination of three weed management strategies (weed mat, hand-hoeing, and no weeding) and two primocane training dates (August and February) as sub-subplots. Each sub-subplot consisted of four plants spaced 1.5-m apart in-row and was separated from plants in adjacent plots by 3.0 m (to provide space for clearing the machine harvester). Between row spacing was 3.0 m (2,222 plants/ha). The planting also had a plot of four border plants at the end of each row, and a border row on each side. However, irrigation and training treatments were not initiated until Aug. 2012 (year 3), and therefore, only cultivar and weed management treatments assigned to postharvest irrigation and August training (30 plots in total) were measured during the first 2 years after planting and are included in the present study.

Planting establishment. A 1.4-m wide strip of black landscape fabric (water infiltration rate 6.8 L·h·m^2; 0.11 kg·m^2; TenCate Protective Fabrics, OBC Northwest, Inc. Canby, OR) was centered on the row of each weed mat plot and secured in place using 0.1-m long nails. Square openings (≈0.2 m x 0.2 m) were cut in the fabric for each plant. Plants propagated from tissue-culture, and weeds were removed by hand around each plant during the first year after planting, including those near plants (≈0.2 m diam.) in non-weeded plots to encourage growth. For additional information regarding the pre-plant establishment, see Chapter 3.

Primocanes were trained on a two-wire vertical trellis according to methods by Strik and Finn (2012) in the first two years after planting, but were cut to the crown and removed in February after the first season to increase growth and improve vigor the following year (standard commercial practice). By year 3, plants had both primocanes and floricanes (the previous year's primocanes). At this point, new primocanes were left on the ground alongside the row and, depending on the training date treatment, were tied to the trellis in either August or February. For more information regarding the plant establishment, see Chapter 3.

Irrigation. Irrigation was applied using a single lateral of drip tubing (UNIRAM, Netafim USA, Fresno, CA) installed in each treatment plot immediately after planting. The tubing had 1.9 $L \cdot h^{-1}$ in-line, pressure-compensating emitters spaced every 0.6 m and was placed under the landscape fabric, at the base of the plants, in weed mat plots, and was attached to a third wire on the steel posts, located at 0.3 m above the ground, in hand-weeded and non-weeded plots. Each weed management treatment was irrigated independently using a manifold with electric solenoid valves and an automatic timer. Irrigation was scheduled weekly based on estimates of crop evapotranspiration (ET). Crop ET was calculated by multiplying reference ET by a crop coefficient for caneberry and was downloaded daily along with weather data, including air temperature and precipitation, obtained from a Pacific Northwest Cooperative Agricultural Weather Network AgriMet weather station (http://usbr.gov/pn/agrimet/). The weather station was located in an irrigated field of tall fescue [*Lolium arundinacea* (Schreb.) S.J. Darbyshire] ≈0.5 km from the site. 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.

Fertilization. Plants were fertilized using pelletized, processed poultry litter (4N–3P–2K–7Ca; Nutri-Rich; Stutzman Environmental Products Inc., Canby, OR) and Fish-Agra (4N–1P–1K; Northeast Organics, Manchester-by-the-Sea, MA) in 2010 and TRUE 402 liquid fertilizer (4N–0P–2K; True Organic Products, Inc., Spreckels, CA) in 2011 and 2012 (Table 1.1). The Nutri-Rich was incorporated into the soil (≈0.45 m diam.) at a rate of 28 kg·ha^{-1} N just prior to planting. Fish-Agra was diluted with 10 parts water (v/v) and applied by hand, around the base of plants, in seven weekly applications of 4 kg·ha^{-1} N each from 14 July to 25 Aug. 2010 (28 kg·ha^{-1} total N). TRUE 402 was also diluted with 10 parts water but applied by fertigation (injection through the drip system) using a Mix-Rite TF10-002 fertilizer injector (DEMA, St. Louis, MO). Irrigation was run for 10 min prior to each injection to fully pressurize the system, and was run for an additional hour afterwards to flush the drip lines. Plants were fertigated with 8.0 kg·ha^{-1} N on 15 Apr. and 16 kg·ha^{-1} N each on 9 May and 1 and 20 June in 2011, and with 14 kg·ha^{-1} N each on 23 April, 8 May, and 7 and 13 June in 2012 (56 kg·ha^{-1} total N per year).

Weed management. Weeds were hoed from hand-weeded plots and pulled from weed mat plots on 20 Apr. and 8 June in 2011 and on 20 Mar., 8 May, and 25 June in 2012. The weeds were removed when relatively small, which is typical for commercial production. Weeds were allowed to decompose on the soil surface between-rows.

Fruit production. Ripe fruit were harvested twice weekly in July 2012, using an over-the-row rotary harvester (Littau Harvesters Inc., Stayton, OR). Floricanes were cut to the crown in August after harvest, placed between rows, and flail mowed (standard commercial practice).

Soil sampling. Soil samples were collected on 7 Oct. 2010, 14 Oct. 2011, and 23 Oct. 2012 using a 1-inch diameter open-sided stainless-steel soil probe. The sample locations on each date are illustrated in Fig. 1.1. Three samples were collected 1) in-row, under the drip line, at a distance of 6 (I_1), 18 (I_2), and 30 (I_3) inches from one of the two center plants in a given plot and 2) perpendicular to the row, progressing into the alleyway, at a between-row distances of 6 (B_1), 18 (B_2), 30 (B_3), 42 (B_4), and 54 (B_5) inches from the plant. Samples were collected to a depth of 0-0.15 m at each location and at depths of 0.15-0.30 m and 0.30-0.45 m at locations I_1 and B_2. 'Marion' was the only cultivar sampled in 2010.

All soil samples were analyzed by Brookside Laboratories (New Knoxville, OH). Extractable soil P (Bray 1 extraction), K, Ca, Mg, SO_4-S, Na, B, Cu, Mn, and Zn were determined by ICP, after extraction of the nutrients using the Mehlich 3 method (Mehlich, 1984). Soil organic matter was measured using Loss-On-Ignition at 360 ºC (Nelson and Sommers, 1996). Soil NO_3-N and NH_4-N were determined using automated colorimetric methods after extraction with 1 M KCl (Dahnke, 1990). Soil pH was measured using the 1:1 soil:water method (McLean, 1982).

Statistical analysis. Statistical analyses were completed with SAS (SAS Institute Inc., Cary, N.C., USA). PROC MIXED was used to determine the main treatment effects of cultivar, weed management, location, and depth. Significant means or interactions were separated at the 5% significance level using Fisher's protected LSD test or Tukey's mean separation procedure when the number of means was greater than five.

Results

Weather conditions. Mean daily air temperatures were near normal each month, on average, and never differed by more than 3^{o}F within a given month amongst the three growing seasons (early April – late September) (Table 1.2). Mean daily soil temperatures, on the other hand, were 2-13 ^oF cooler than normal during each growing season. In the summer, mean daily soil temperatures at the site are normally 8-11 ^oF warmer than mean daily air temperatures, but in 2010-12, the soil and air temperatures were similar each month, including in the summer, and never differed by more than 4^oF in any month during each growing season.

Precipitation was 25% and 37% higher than normal during 2 years of the study, primarily due to more rain in late spring and early fall in 2010 and more rain in most months—except February and the dry period between early July and late September— in 2012. Precipitation was also 47% above normal in late winter and early spring in 2011 but near or below normal the rest of the year. Little rainfall occurred during most summer months, and plants mostly relied on irrigation at this time. Approximately 1-2 in. of water was applied per week from June to the end of September each year.

Wet soil was needed to insert the soil probe and collect intact soil samples, and therefore a period of rain was necessary prior to sampling. A total of 2.1 and 2.5 in. of rain was recorded during the 3 weeks prior to sampling in 2010 and 2011, and 3.5 in. was recorded during the 11 d prior to sampling in 2012. Almost no rain fell for 2-3 mos. prior to those dates.

Soil pH and organic matter. Soil pH was affected by a W x D interaction in 2010 (Table 1.3); Soil under weed mat had a lower pH than that under hand-weeded plots at the D_1 and D_2 depths, but was similar at the D_3 depth (Fig. 2). Additionally, soil pH was higher in-row in hand-weeded plots than weed mat plots at the D_1 depth (Fig. 2). In 2011, between-row pH behaved differently than in-row pH (Table 1.3). In 2012, soil pH at lower depths (D_2 and D_3) was higher in weed mat plots than in non-weeded and hand weeded plots (Table 1.3).

The effect of location on soil pH was complicated by a W x L interaction in 2010 (Table 1.3). The effect appeared to only be on in-row samples (I_1-I_3) of hand weeded plots, as locations I_1 and I_3 had the highest pH, and location I_2 had the lowest pH, when compared to the weed mat plots (Table 1.3). Additionally, in 2010, soil pH was found to be more acidic at sample locations between-row (B_1-B_5), compared to sample locations in-row, under the drip emitters (I_1-I_3) (Table 1.3). In 2011, soil pH was greatest nearest the plant (I_1, B_1) (Table 1.3). Findings from 2012 mirror some of those observed in 2010, as the pH of hand weeded and non-weeded plots were again greater in-row than between-row, however the particular location varied by weed management.

In all years, soil OM decreased with depth (Table 1.3). Soil OM in 2010 was impacted by a W x L interaction (Table 1.3). At location I_1 in the weed mat plots, there was more soil OM than at the same location in hand weed plots. In 2011, a C x L interaction indicated that at sample locations B_3 and I_2, plots with 'Black Diamond' plants had less OM than plots with 'Marion' plants, but at all other locations concentrations were similar (Table 1.3). In 2012, locations in the between-row, grass aisle (locations B_3-B_5), had more OM compared to all other sample locations (Table 1.3).

Soil mineral nitrogen, phosphorus, and sulfur. In 2010, soil NO_3-N and NH_4-N concentrations were affected by a W x L x D interaction (Fig. 1.2). There was a trend for greater in-row N, at the D_1 location, in weed mat plots (Fig. 1.2). In 2011, NH_4-N and NO_3-N concentration was not affected by treatments. While NH_4-N concentrations were again unaffected by treatments in 2012, NO_3-N concentration tended to decrease with depth (Table 4).

In 2010, at location I_1, total N concentration in the weed mat treatment was much higher than in the hand weeded treatment. Additionally, samples collected nearest the plant had the highest mean NO_3-N concentration in 2010 (Table 1.4). In 2011, soil NO_3-N and NH_4-N were not affected by treatments. In 2012, NH_4-N concentrations were again unaffected by treatments, but NO_3-N concentration varied by a C x L and a W x L (Table 1.4). The concentration of NO_3-N in plots with 'Black Diamond' plants was greater at locations B_1 and B_2 when compared to that location in plots with 'Marion' plants, but at all other locations NO_3-N concentration were similar between cultivars. With regards to the W x L interaction in 2012, NO_3-N concentration was greater in non-weeded plots at in-row locations (I_1-I_3) compared to hand weed or weed mat treatments at those same in-row locations.

Soil P concentrations were considered high for blackberry, in all study years (Table 1.4). In 2010, there was a significant W x D interaction for soil P. Weed mat plots had more soil P at D_1 than hand weeded plots, but P decreased with depth in both treatments. In 2011, P concentration in the soil decreased with depth (Table 1.4). An interaction of C x D in 2012 illustrated that 'Black Diamond' had higher concentrations of P at the D_1 depth and lower concentrations at the D_3 depth when compared to 'Marion' at those depths (Table 1.4).

Phosphorus was not affected by location in 2010. In 2011, there was a C x L interaction of P sampled by location (Table 1.4). At locations B_3, B_5 and I_2, plots with 'Black Diamond' plants had lower soil P concentrations than plots with 'Marion' plants; at all other sample locations, P concentrations were nearly equivalent across cultivars. Phosphorus concentrations varied by location in 2012, but there was a trend for higher P in row and near the plant.

From 2010-2012, SO_4-S concentrations were considered high (Table 1.4). In 2010 and 2011, SO_4-S concentrations by depth were impacted by a two-way interaction of L x D (Table 1.4). At D_1, in-row concentrations of SO_4-S were higher than that between-row; however at D_3, between-row concentrations of SO_4-S were greater than in-row concentrations. In 2012, SO_4-S concentration increased with depth in both hand weeded and non-weeded plots, but remained largely unchanged in weed mat plots (Table 1.4).

There was a location effect of SO_4-S in 2010, as SO_4-S concentrations were greatest nearest the plant, at locations I_1 and B_1 (Table 1.4). In 2011, SO_4-S concentrations were again affected by location, with the highest concentrations of SO_4-S at the grass aisle interface (location B_3) (Table 1.4). In 2012, SO_4-S concentrations tended to be greater in-row, under the drip emitters, than between-row (Table 1.4).

*Soil cations***.** For all study years, K concentrations were considered medium to high based on sufficiency standards for good blackberry growth (Table 1.5). In 2010 and 2011, there was a W x L x D interaction of soil K (Table 1.5; Fig. 1.3). In 2012, interactions affecting soil K expanded to a four-way interaction of C x W x L x D (Table 1.5; Fig. 1.3).

Potassium concentration in the soil was unaffected by location in 2010 (Table 1.3), but in 2011, there was a C x L interaction on soil K (Table 1.5). At locations B_3 and I_2, plots with 'Black Diamond' plants had less K than plots with 'Marion' plants, and at all other sample locations concentrations of K were similar. In 2012, there was a three-way interaction of C x W x L on soil K (Table 1.5). Regardless of cultivar, in-row concentrations of K were greater than between-row concentrations in non-weeded plots. In hand weeded plots, at D_1, in-row soil K was greater than between-row, but at lower depths, soil K varied by cultivar. In weed mat plots of 'Black Diamond' plants, in-row concentrations of K were greater than between-row concentrations at lower depths. In contrast, weed mat plots of 'Marion' plants had higher K concentrations in-row than between-row for all depths.

Recommended sufficiency standards for blackberries suggest that Ca concentrations were adequate in 2010 and 2011, but concentrations were low in 2012 (Table 1.5). Calcium concentrations in the soil increased with depth in 2010 (Table 1.5), but were also higher in hand weed plots than weed mat plots (data not shown). In 2011, there was a three-way C x L x D interaction for Ca concentrations in the soil (Table 1.5).

Plots with ‘Black Diamond’ plants had higher Ca concentrations in-row than between-row at the lower sample depths (D_2 and D_3). Similarly, in plots with ‘Marion’ plants, Ca concentrations were higher in-row than between-row, but at the D_1 and D_2 depths. In 2012, there was a C x D interaction on soil Ca (Table 1.5); At D_3, plots of ‘Black Diamond’ had a higher concentration of Ca in the soil than that of ‘Marion’.

Calcium concentrations by location were subject to a weed management by location interaction in 2010 (Table 1.5). Between-row Ca concentration of hand weeded plots tended to decrease with increased distance from the plant, but Ca concentrations of weed mat plots did not. In 2011, in-row Ca concentrations were greater than between-row (Table 1.5). In 2012, a W x L interaction of Ca indicated that Ca concentrations of hand weeded, non-weeded, and weed mat plots varied differently by sample location (Table 1.5).

Over the course of the study, Mg concentrations were considered high, based on soil sufficiency standards for blackberries (Table 1.5). In 2010, soil Mg increased with depth (Table 1.5). In 2011, soil Mg was higher in non-weeded plots of ‘Marion’ plants than in non-weeded plots of ‘Black Diamond’ plants (Table 1.5). In 2012, there was an interaction of C x D for soil Mg (Table 1.5). At D_3, plots with ‘Black Diamond’ plants had a higher concentration of Mg in the soil than plots with ‘Marion’ plants.

Location effects on Mg concentration in the soil were impacted by a W x L interaction in 2010 (Table 1.5). In-row locations I_1 and I_3 had greater Mg concentrations in the hand weeded treatment than in the weed mat treatment, and at location I_2, Mg concentrations were greater under the weed mat treatment. By 2011, Mg concentrations were higher in-row than between-row (Table 1.5). In 2012, a WxL interaction was again observed for Mg (Table 1.5). The effect was such that at location I_2, Mg concentrations were greatest in hand weeded plots.

Sodium concentrations by depth were unaffected by treatments in 2010 (Table 1.5). In 2011, there was a significant two-way interaction of L x D on soil Na (Table 1.5). Sodium concentrations were higher in-row than between-row at D_2 and D_3, but at the D_1 depth Na concentrations were similar across locations. Results from 2012 indicated that location was the only significant treatment effect observed in 2012, as in-row Na concentrations were again higher Na than between-row.

There were no treatment effects by location on soil Na concentrations in 2010 (Table 1.5). In 2011 and 2012, soil Na was higher in-row than between-row (Table 1.5).

Soil micronutrients. Soil B was below adequate sufficiency levels for blackberry (Table 1.6). During the first 2 years after planting (2010 and 2011), B concentrations were higher at D_1 than at D_3 (Table 1.6). Additionally, in 2011, B concentrations were greatest in non-weeded plots and least in weed mat plots (Table 1.6). In 2012, there was a W x L x D interaction on soil B which was greater between-row at the D_1 location in non-weeded plots (Table 1.6; Fig. 1.4).

The location of B in the soil was affected by a W x L interaction in 2010 (Table 1.6). Between-row B concentrations in weed mat plots trended downward with increased distance from the plant, however B concentrations in hand weeded plots behaved differently by location. In 2011 and 2012, B concentrations were higher in-row (I_1-I_3) than between-row (B_1-B_5) (Table 1.6).

Copper concentrations were satisfactory for blackberry plant growth in both 2010 and 2011, but by 2012, levels were considered low (Table 1.6). Copper concentrations by depth were unaffected by treatments in 2010, but in 2011 and 2012, Cu concentrations decreased with depth (Table 1.6).

2010 Cu concentrations by location were not affected by treatments (Table 1.6). In 2011, Cu concentrations varied by location, but with no discernible trend (Table 1.6). In 2012, like in 2010, there were no effects of treatments on Cu concentrations by location (Table 1.6).

Soil Mn was high based on blackberry sufficiency standards (Table 1.6). Manganese levels declined with soil depth each year but were also affected by interactions of L x D in 2011 and C x L x D in 2012 (Table 1.6). In 2011, soil Mn was similar at both in-row and between-row locations at D_1 but was higher in-row than between-rows at D_2 and D_3 (data not shown). In 2012, plots with ‘Black Diamond’ plants had higher Mn concentrations between-row at the D_1 depth and lower concentrations at the D_3 depth, when compared to in-row locations at those depths. Additionally, Mn concentrations in plots of ‘Marion’ plants were higher at D_1 and D_3 in-row, compared to between-row, at those depths.

In 2010 and 2011, Mn concentrations in the soil were greater between-row than in-row (Table 1.6). Specifically, the B_4 location (the grass interface) had the highest concentration of Mn each year (Table 1.6). In 2012, a C x L interaction showed that Mn concentrations sharply increased in ‘Black Diamond’ at B_3 and in ‘Marion’ at B_3 and B_4 (Table 1.6).

Soil Zn concentrations were largely adequate or above blackberry sufficiency standards, except in 2012, at location D_3, sufficiency was considered low (Table 1.6). Zinc concentrations decreased with depth in 2010, 2011, and 2012 (Table 1.6).

There was no effect of treatment on the concentration of Zn by location in 2010; however, in 2011 and 2012, Zn concentrations were varied by location, but with no distinct trends (Table 1.6).

Discussion

Adequate soil pH for blackberry production is between 5.6 and 6.5 (Hart et al., 2006). Because the preexisting soil pH at the study site was 5.3 in August 2009, maintaining a higher soil pH is a concern for vigorous plant growth. Pre-plant application of lime was completed to increase soil pH, but it often takes many months before the full extent of the effects of liming are evident (Peters and Kelling, 1998). It follows that the higher soil pH, at lower depths, in weed mat plots in 2010 and 2012 presumably facilitates blackberry growth. In contrast, the reduction in soil pH between-row in 2010 and 2011 indicates that roots extending into the alleyway may be subject to unfavorable conditions. Interactions of W x L in both 2010 and 2012 suggest that there may be increased soil pH, below emitters, where there was a concentrated region of fertilizer application. This is in contrast to the decreased pH that Parchomchuk et al. (1993), Haynes (1990), and Klein and Spieler (1987) found using conventional ammonium based fertilizers, however the location of pH change was similar between studies. Consequently, monitoring of soil pH at multiple depths is critical in regions where the natural soil pH is not adequate for good plant growth.

As is commonly observed, soil OM decreased with depth. Pre-plant incorporation of OM would not have affected the lower soil sample depths as clearly as those nearer the surface because the field was shanked to the 0.4 m depth, and soil samples were collected to a 0.45 m depth. Due to favorable summer soil conditions, such as increased soil temperature and frequent irrigation (Table 3), decomposition of the OM in years 2011 and 2012 was likely greater nearer the surface where the OM was artificially high (Yao et al., 2011). However expected reductions in OM, due to reduced nutrient cycling in weed mat plots were not observed, but longer term effects of weed mat on soil OM may become visible in future years (Neilsen et al., 2003). While OM tended to vary differently by cultivar, location, and weed management year to year, soil OM was greatest, and in some instances even increased, between-row from 2010 to 2012. OM increases were presumably because soil samples B_3-B_5 were collected from the grass aisle and likely retained a higher percentage of grass root biomass than samples collected within the planting row. Thus the amount of OM in these samples was dependent on the between-row management of the cereal rye cover crop.

The greater amount of between-row N, relative to in-row N, observed at depth D_1 in weed mat plots in 2010, may be linked to the timing and placement of fertilization as well as acidification in weed mat plots. Since fertilizer was applied from June to September in 2010 and plants were small compared to 2011 and 2012 (Chapter 4), there was likely more N remaining in the soil at fall soil sampling. Additionally, conditions in weed mat plots may have increased nitrification of soil NH_4-N, thereby increasing soil acidity. By 2011, fertilizer was applied via the irrigation system, thus N concentrations were more evenly distributed by depth and location. In 2012, the reduction of NO_3-N with depth may have been associated with leaching, possibly due to the greater amount of rain prior to soil sampling in 2012. Since others found that trailing 'Kotata' blackberry was able to uptake 45% of fertilizer N applied during the on-year (Mohadjer et al. 2001), it is likely that plant uptake accounts for much of the N applied, so long as the timing of application matched plant demand. Given that fertilizer application was later in 2012 than in 2011, and because it takes 1 to 4 weeks before the organic N mineralizes, some of the fertilizer N may have gone unused by plants and was leached downward with the fall rains (Hartz et al., 2010), resulting in a stratification of NO_3-N by depth. This may have been observed to a lesser extent in non-weeded plots because weed uptake of water, in row (I_1-I_3), may have minimized leaching of NO_3-N, explaining the higher surface NO_3-N concentrations in-row in 2012. It was also noted that NO_3-N levels were higher at the I_1 location in weed mat plots in both 2010 and 2012, suggesting that location I_1 may be located under a drip emitter where nitrification of NH_4-N may be faster due to increased soil temperature, greater soil moisture, and or higher soil pH associated with the use of weed mat (Sahrawat, 2008). Because trialing blackberry may remove as much as 73.4 $kg \cdot ha^{-1}$ (fruit and floricanes) in a fruiting year and annual N application was only 53 $kg \cdot ha^{-1}$ in 2012 (Chapter 4), soil N may become deficient without greater replacement during fertilization. Overall, the small amounts of NO_3-N left in the soil at the time of soil sampling in 2011 and 2012 suggest that blackberry plants are very efficient at obtaining soil NO_3-N.

Phosphorus concentrations in the soil were greatest at the D_1 depth regardless of WxD interactions in 2010 and cultivar effects in 2012. Because P is non-mobile in the soil, P applied during fertilization likely remains near the soil surface (Klein and Skedi, 1999). Even though there were interactions for both samples collected by depth and location, concentrations of P at the site were very high (Hart et al., 2006), possibly due to legacy effects of prior fertilization at the site.

Sulfate-sulfur concentrations were initially high at the study site but decreased from 2010 to 2012; high levels after planting may be a result of the mineralization of the pre-plant addition 90% granular S, copper sulfate, and zinc sulfate. In general, at the lower sample depths, there was a higher concentration of SO_4-S between-row than in-row, possibly due to between-row leaching of SO_4-S, as opposed to plant uptake in-row. By 2012, SO_4-S concentrations still increased with depth, but some of the losses at the upper soil depths appear to be mitigated by the weed mat, as has been observed with the use of polyethylene mulches (Jones and Jones 1978). At surface locations, in-row concentrations of SO_4-S were higher than between-row concentrations, likely because the fertilizer contained SO_4-S, and it was applied in the planting row during fertigation (Hart et al., 2006). But, because we do not have record of S concentrations in the fertilizers applied, the exact cause of higher in-row SO_4-S cannot be confirmed.

Overall, soil K concentrations were of the medium recommended sufficiency standards for good blackberry growth, suggesting applications of K were adequate. For example, annual K removal (fruit and floricanes) in an every-year organic trailing blackberry production system is 49 $kg \cdot ha^{-1}$, however application of K in 2011 and 2012 exceeded uptake (Chapter 4; Table 1.1). It is possible that in 2013 soil K could become deficient, particularly since there was an observed annual decline in soil K from the pre-plant KMag application (Neilsen and Neilsen, 2011). Soil K concentrations by both location and depth varied distinctly year to year, and were influenced by many interactions among treatments. As K is an immobile soil nutrient, it follows that fertilizer application of K likely resulted in the higher K concentrations in-row near surface levels (Klein et al., 1999); indeed this is what we observed with a few exceptions; most noteworthy was K concentration by depth in 2012. In 2012, K decreased from the D_1 to D_2 depth, with the exception of in-row soil K from weed mat plots with 'Black Diamond' plants; in these plots, soil K increased from the D_2 to D_3 depth. Because weed mat plots with 'Black Diamond' plants received the most irrigation in 2011 and 2012 (800 $L \cdot plant^{-1}$ and 721 $L \cdot plant^{-1}$), K may have leached to lower depths, causing increased K concentrations there (Sharpley, 1991).

Calcium concentrations were below recommended levels by 2012. Leaching may have in part caused the decreased Ca concentrations (Ehret et al., 2012; Sharpley, 1991). Additionally, the reduction in Ca in 2012 may also be attributed to the removal of Ca in the harvested fruit, which was found to be 5.0 $kg \cdot ha^{-1}$ in 2012 (Chapter 4). Because Ca is a component of blackberry fruit cell walls, plants likely required more Ca in 2012, when plants were fruiting, possibly further reducing soil Ca (Tosun et al., 2008). In 2010, Ca concentrations were greatest nearest the plant, likely due to the application of 0.4 $lbs \cdot acre^{-1}$ of Ca, which was applied by hand, around base of plant during fertilization (Ca; Table 5). Then, in 2011, Ca concentrations were greater in-row relative to between-row likely because Ca was applied, in the hydrolyzed fish emulsion fertilizer, during fertigation, increasing in-row but not between-row Ca concentrations. It was also found that plots with ‘Black Diamond’ plants had more Ca at lower sample depths than plots with ‘Marion’ plants. Because ‘Black Diamond’ plants were irrigated more than ‘Marion’ plants in 2011 and 2012 (data not shown), Ca in plots with ‘Black Diamond’ plants may have percolated to deeper soil depths due to increasing pH in-row (Ernani et al., 2012).

Because Mg concentrations ranged from the medium to high for blackberry sufficiency, there was no indication that Mg concentrations triggered possible negative effects on plant growth. However, if soil pH continues to decline, Mg availability in to blackberries may become limited (Havlin et al., 2010; Staugaitis and Rutkauskiene, 2010). In general, Mg concentrations were greater in-row than between-row, but at what location, in-row, the nutrient was most concentrated varied by year and the particular weed management strategy. Even though Mg is a non-mobile soil nutrient, Mg concentrations increased with depth in 2010, and by 2012, plots with ‘Black Diamond’ plants had a higher concentration of Mg than plots of ‘Marion’ plants at D_3. Evidence suggests that one, or a combination of the following, resulted in higher Mg concentrations at D_3: 1) lower soil pH in ‘Black Diamond’ plots induced cation leaching (Staugaitis and Rutkauskiene, 2010) or 2) higher irrigation of plots with ‘Black Diamond’ plants caused Mg to percolate downward (Neilsen and Neilsen, 2011; Parchomchuk, 1993).

Soil Na was not greatly affected by treatments, however in-row soil Na was higher than between-row. Since Na is a component of the fertilizers applied (Table 1.1), we suggest there was a direct effect of location of fertilizer placement on Na soil concentrations. We also observed that Na concentration in-row were greater at lower depths in 2011, possibly because Na moved to the edge of the wetting front during irrigation (Zhang et al., 2008). Spiers (1993) showed that ‘Shawnee’ blackberries are not tolerant to high levels of Na application, thus it is likely advantageous that soil concentrations of Na are low at our study site.

There was a trend of greater soil B in-row compared to between-row from 2010 to 2012. Because interactions of treatments on depth were inconsistent from year to year, there was no overriding effect of one or more treatments on soil B. In all study years, soil B concentrations were low, based on sufficiency standards for blackberry (Hart et al., 2006). This is likely an artifact of the study site, as B levels are characteristically low

(Strik, personal observation). Additionally, we found that as much as 26.9 $g{\cdot}ha^{-1}$ of B may be removed in the harvested fruit of trailing blackberry, suggesting that B applied during fertilization and that existing in the soil is likely not sufficient to sustain B losses in fruit (Chapter 4). Because soil B is necessary for good yield and fruit set in many berry crops, it is critical that there is sufficient B available to obtain adequate yield (Blevins et al., 1996; Wojcik, 2005a, 2005b).

Since Cu is an immobile soil nutrient, it follows that Cu would be greater in-row, at surface levels where it is applied as a constituent of the fertilizer. Kowalenko et al. (2005) noted that in red raspberries a considerable amount of Cu is lost in the berries at harvest. We found that removal of Cu was as much as 12.4 $g{\cdot}ha^{-1}$, exceeding what was replaced by fertilizer applications. Given the above, Cu should be monitored to ensure that it does not become depleted in the soil.

Because soil Mn concentrations did not respond to treatments similarly across study years, it is difficult to determine the particular effects of the cultivar and weed management treatments. High rates of Mn fertilization in 2010 may have increased soil Mn that year. Mn concentrations were often greater between-row than in-row, which is contrary to all other nutrients in this study. Additionally, Mn levels were distinctly greater at the grass interface, in 2011 and 2012, where there also happened to be a great deal of dandelions (*Taraxacum officinale* F.H. Wigg). Thus the dandelions may have altered the soil environment to cause the high Mg levels observed.

Since Zn is an immobile soil nutrient and its concentration decreased with depth in all study years, we suggest that surface applied Zn, through fertilization, created the declining trend in soil Zn with depth. Soil Zn concentration by location was extremely variable year to year, and thus there were no discernible trends associated with the treatments.

Conclusions

Findings suggest that N was the major nutrient affecting blackberry cane growth and fruit development. Other nutrients were considered sufficient, with the exception of Ca and B, which were at the low end of the sufficiency range in some soil samples. We found that despite trends of soil nutrients by location and depth, differences in nutrient concentrations were not so great as to require different management decisions by treatment, possibly due to large blanket additions of pre-plant fertilizer and soil amendments. However, the long term effects of the treatments are not well understood, thus, where and to what depth soil samples are collected may be more critical in future years. It is our recommendation that even though blackberry roots are believed to extend beyond the in-row area, soil samples should be collected in-row where the fertigated nutrients are applied and the roots are most concentrated (Zebarth et al., 2002). Additionally, sampling to the 0.15 m depth targets the zone of fertilziation, and thus is most pertinent to nutrient management. Ultimately, results indicate that successful soil sampling in blackberries should be completed carefully, especially on fertigated plantings where there may be localized zones of plant available nutrients.

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Table 1.1. Total nutrients in organic fertilizers applied to trailing blackberry plants during the first three growing seasons (2010–2012).

	Macronutrients (kg·ha^{-1})						Micronutrients (g·ha^{-1})			
Fertilizer[z]	**N**	**P**	**K**	**Ca**	**Mg**	**Na**	**B**	**Cu**	**Mn**	**Zn**
2010										
Nutra-Rich	26	16	18	80	5	3	24	38	314	274
Fish-Agra	28	7	7	6	1	N/A	2	38	4	20
2011 & 2012										
TRUE 402	53	7	62	1	1	26	11	6	18	79

[z]Nutra-Rich and TRUE 402 were analyzed by Brookside Laboratories, Inc. (New Knoxville, OH). Values for Fish-Agra were obtained from the product label. Nutra-Rich was a pelletized poultry liter product broadcast and then incorporated in the soil just prior to planting, The product had a pH of 8.3. Fish-Agra and True 402 were hydrolyzed fish products mixed 1:10 (v/v) with water prior to application. Nutra-Rich had a pH of 7.3 and TRUE 402 had a pH of 5.5. Nutra-Rich was applied by hand around the base of the plants in eight equal applications of ≈4 kg·ha^{-1} N each. TRUE 402 was applied by fertigation through the drip system and was injected in four equal applications of ≈14 kg·ha^{-1} N each per year.

N/A – not available.

Table 1.2. Mean daily air and soil temperature and precipitation at the site during the first three growing seasons (2010–2012). Data were obtained from an AgriMet weather station in, approx. 0.5 km from the planting site, Aurora, OR.

	Mean daily air temp. (ºF)				**Mean daily soil temp. (ºF)**				**Precipitation (in.)**			
Month	**Normal**	**2010**	**2011**	**2012**	**Normal**	**2010**	**2011**	**2012**	**Normal**	**2010**	**2011**	**2012**
January	41	46	42	41	43	45	42	41	6.3	6.4	5.1	8.8
February	43	47	40	44	46	46	42	44	3.6	3.5	4.8	4.0
March	47	47	46	45	50	48	47	45	4.7	5.2	6.9	8.9
April	50	49	47	52	56	50	51	54	2.8	3.1	4.8	4.2
May	57	53	53	56	63	55	57	57	2.5	4.9	3.5	3.1
June	62	60	60	60	70	60	62	61	1.5	3.4	1.0	2.6
July	68	67	65	67	78	66	65	66	0.3	0.2	1.1	0.5
August	68	67	68	69	79	69	68	70	0.6	0.0	0.1	0.0
September	63	62	65	64	72	66	66	66	1.2	2.2	0.7	0.1
October	53	54	54	55	59	57	57	58	3.4	5.2	2.4	6.7
November	46	45	44	48	50	47	47	50	6.5	6.7	5.9	8.9
December	41	44	38	42	44	44	40	44	7.1	9.9	3.4	8.0
Avg./Total	53	53	52	53	59	54	54	55	40.6	50.8	39.9	55.7

[z]Measured at 2 in. depth.

Table 1.3. Effects of soil depth and sampling location on soil pH and organic matter content in organic plots of trailing blackberry following the first 3 years after planting (Oct. 2010–12). Each value represents the mean of the three replicates and includes the average of two cultivars (‘Black Diamond’ and ‘Marion’).[z]

	pH			Organic matter content (%)		
Source of variation	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**
Soil depth[y]						
Location						
I_1 (6 in.)	5.6	5.7	5.7	2.9	2.6	2.5
B_2 (18 in.)	5.5	5.8	5.5	2.8	2.7	2.5
Significance	NS	**	**	NS	NS	NS
Depth						
D_1 (0-0.15 m)	5.6	5.8 a	5.8 a	3.3 a	2.8 a	2.8 a
D_2 (0.15-0.30 m)	5.6	5.8 a	5.4 c	3.2 a	2.7 a	2.7 a
D_3 (0.30-0.45 m)	5.5	5.6 b	5.7 b	2.1 b	2.4 b	2.0 b
Significance	NS	***	***	***	***	***
Interactions						
$W \times L$	**	NS	NS	NS	NS	NS
$W \times D$	*	NS	**	NS	NS	NS
$L \times D$	NS	*	NS	NS	NS	NS
$W \times L \times D$	NS	NS	NS	NS	NS	NS
Sampling location[x]						
Location						
In-row distance from plant						
I_1 (6 in.)	5.6 bc[v]	6.0 a	5.9 a	3.3	2.8 a	2.9 b
I_2 (18 in.)	5.9 ab	5.7 bc	5.7 a-c	3.2	1.9 b	2.9 b
I_3 (30 in.)	5.9 a	5.8 a-c	5.8 a-c	3.3	2.8 a	2.8 b
Between-row distance from plant						
B_1 (6 in.)	5.5 c	5.9 ab	5.6 c	3.3	2.7 a	3.0 ab
B_2 (18 in.)	5.5 c	5.7 bc	5.7 bc	3.3	2.8 a	2.8 b
B_3 (30 in.)	5.7 ab	5.6 c	5.7 bc	3.3	1.9 b	3.2 a
B_4 (42 in./grass)	5.5 c	5.9 a-c	5.8 ab	3.3	2.9 a	3.2 a
B_5 (54 in./grass)	5.7 ab	6.0 a	5.7 bc	3.3	2.9 a	3.1 ab
Significance	*	***	***	NS	***	***
Interactions						
$C \times L$	--	NS	NS	--	*	NS
$W \times L$	***	NS	***	*	NS	NS
Recommended level[w]		pH			Organic matter	
Low		<5.6			--	
Medium		5.6–6.5			--	
High		>6.5			--	

[z]Only weed mat and hand-weeded plots of ‘Marion’ were measured in 2010. Soil was collected from three depths (D_{1-3}) at two locations (I_1 and B_2) and one depth (D_1) at nine locations (I_{1-3} and B_{1-5}) (see Fig. 1). Sample locations B_4 and B_5 were located in the grass alleyway.

[y]Cultivar, weed management, $C \times W$, $C \times L$, $C \times D$, $C \times W \times L$, $C \times W \times D$, $C \times L \times D$, and $C \times W \times L \times D$ had no significant effect each year on pH or organic matter content in soil samples collected at three depths at the I_1 and B_2 locations.

[x]Cultivar, weed management, $C \times W$, and $C \times W \times L$ had no significant effect each year on pH or organic matter content in soil samples collected at different in-row and between-row locations at the D_1 depth.

[w]Recommended levels for soil pH are from Hart et al. (2006).

[v]Means followed by the same letter in a given column are not significantly different at 0.05 level.

C – cultivar; *W* – weed management; *L* – location; *D* – depth; and NS, *, **, *** – nonsignificant.and significant at $P \leq 0.05$, 0.01, and 0.001, respectively.

Table 1.4. Effects of soil depth and sampling location on soil mineral N, P, and S in organic plots of trailing blackberry following the first 3 years after planting (Oct. 2010-12). Each value represents the mean of the three replicates.[z]

	NO_3-N (mg·kg^{-1})			NH_4-N (mg·kg^{-1})			P (mg·kg^{-1})			SO_4-S (mg·kg^{-1})		
Source of variation	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**
Soil depth[y]												
Weed management												
Weed mat	30	0.7	0.8	5	1.2	2.1	158	177	189	33	14	15
Hand-weeded	5	1.2	0.8	2	1.1	2.2	154	172	178	24	16	18
Non-weeded	--	1.2	0.8	--	1.2	2.3	--	171	203	--	13	16
Significance	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Location												
I_1 (6 in.)	28	1.4	0.7	5	1.1	2.2	159	174	188	30	14	15
B_2 (18 in.)	7	0.7	0.9	2	1.3	2.1	154	172	192	27	15	18
Significance	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
Depth												
D_1 (0-0.15 m)	36 a[v]	1.2	0.9 a	7 a	1.3	2.3	206 a	186 a	221 a	27 ab	13 b	15 b
D_2 (0.15-0.30 m)	13 b	1.0	0.9 a	2 ab	1.1	2.0	185 b	178 a	214 a	23 a	14 b	15 b
D_3 (0.30-0.45 m)	4 b	0.9	0.6 b	1 b	1.1	2.2	78 c	155 b	134 b	35 b	17 a	20 a
Significance	**	NS	***	*	NS	NS	***	***	***	*	***	***
Interactions												
C x *D*	--	NS	NS	--	NS	NS	--	NS	*	--	NS	NS
W x *L*	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
W x *D*	**	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	**
L x *D*	**	NS	NS	*	NS	NS	NS	NS	NS	**	**	NS
W x *L* x *D*	**	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS
Sampling location[x]												
Location												
In-row distance from plant												
I_1 (6 in.)	59 a	0.6	0.7 bc	11 a	1.3	2.5	204	183 a	223 ab	36 ab	11 b	17 a
I_2 (18 in.)	9 b	1.1	0.8 bc	2 b	1.5	2.1	196	100 b	223 ab	19 bc	26 a	15 ab
I_3 (30 in.)	12 b	1.6	0.7 bc	2 b	1.6	2.1	197	180 a	220 ab	17 c	13 b	16 a
Between-row distance from plant												
B_1 (6 in.)	41 a	1.0	1.0 ab	4 b	1.3	2.4	205	184 a	228 a	44 a	14 b	16 a
B_2 (18 in.)	12 b	1.7	1.1 a	3 b	1.3	2.2	208	190 a	206 ab	19 bc	14 b	12 bc
B_3 (30 in.)	5 b	0.7	0.5 c	3 b	1.0	1.9	193	86 b	203 ab	18 bc	24 a	11 c
B_4 (42 in./grass)	1 b	0.5	0.6 c	2 b	1.7	2.0	209	169 a	199 b	20 bc	11 b	11 c
B_5 (54 in./grass)	1 b	0.5	0.6 c	2 b	1.4	1.9	208	186 a	224 ab	18 bc	12 b	10 c
Significance	***	NS	***	**	NS	NS	NS	***	**	***	***	***
Interactions												
C x *L*	--	NS	**	--	NS	NS	--	*	NS	--	NS	NS

W x *L*	***	NS	*	**	NS	NS	NS	NS	NS	NS	NS	NS
C x *W* x *L*	NS	NS	NS	NS	NS	NS	NS	NS	***	NS	NS	*
Recommended level[w]		NO_3-N			NH_4-N			P			SO_4-S	
Low		-			--			<20			<2	
Medium		-			--			20–40			2–10	
High		-			--			>40			>10	
Excessive		-			--			--			--	

[z]Only weed mat and hand-weeded plots of ‘Marion’ were measured in 2010. Soil was collected from three depths (D_{1-3}) at two locations (I_1 and B_2) and one depth (D_1) at nine locations (I_{1-3} and B_{1-5}) (see Fig. 1). Sample locations B_4 and B_5 were located in the grass alleyway.

[y]Cultivar, *C* x *W*, *C* x *L*, *C* x *W* x *L*, *C* x *W* x *D*, *C* x *L* x *D*, and *C* x *W* x *L* x *D* had no significant effect each year on mineral N, P, or S in soil samples collected at three depths at the I_1 and B_2 locations.

[x]Cultivar, weed management, and *C* x *W* had no significant effect each year on mineral N, P, or S in soil samples collected at different in-row and between-row locations at the D_1 depth.

[w]Recommended levels for SO_4-S are from Marx et al. (1997) and levels for P are from Hart et al. (2006). Fertilizer application of any given nutrient is not recommended when the soil level is high or excessive.

[v]Means followed by the same letter in a given column are not significantly different at 0.05 level.

C – cultivar; *W* – weed management; *L* – location; *D* – depth; and NS, *, **, *** – nonsignificant.and significant at $P \leq 0.05$, 0.01, and 0.001, respectively.

Table 1.5. Effects of soil depth and sampling location on soil cations in organic plots of trailing blackberry following the first 3 years after planting (Oct. 2010-12). Each value represents the mean of the three replicates.[z]

	K (meq/100 g soil)			Ca (meq/100 g soil)			Mg (meq/100 g soil)			Na (meq/100 g soil)		
Source of variation	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**
Soil depth[y]												
Weed management												
Weed mat	0.65	0.58 b	0.49	4.89	5.11	4.94	1.15	1.08	1.14	0.24	0.16	0.14
Hand-weeded	0.60	0.63 a	0.56	5.80	5.29	4.61	1.61	1.13	1.10	0.21	0.16	0.13
Non-weeded	--	0.65 a	0.54	--	5.29	4.58	--	1.20	0.99	--	0.15	0.12
Significance	NS	**	NS	**	NS	NS	*	NS	NS	NS	NS	NS
Location												
I_1 (6 in.)	0.60	0.63	0.49	5.30	5.00	4.42	1.55	1.05	0.95	0.27	0.14	0.10
B_2 (18 in.)	0.64	0.61	0.57	5.39	5.46	5.00	1.22	1.22	1.20	0.18	0.18	0.16
Significance	NS	NS	***	NS	**	**	NS	**	***	NS	***	***
Depth												
D_1 (0-0.15 m)	0.69 a[v]	0.64 a	0.58 a	5.13 b	5.25	4.89 a	1.28 b	1.13	1.14 a	0.25	0.14 b	0.13
D_2 (0.15-0.30 m)	0.60 b	0.64 a	0.48 c	4.92 b	5.22	4.42 b	1.17 b	1.14	0.92 b	0.22	0.16 a	0.13
D_3 (0.30-0.45 m)	0.58 b	0.58 b	0.52 b	5.99 a	5.22	5.04 a	1.69 a	1.15	1.17 a	0.21	0.16 a	0.13
Significance	**	***	***	**	NS	***	***	NS	***	NS	**	NS
Interactions												
C x *W*	--	*	NS	--	**	NS	--	*	NS	--	NS	NS
C x *D*	--	NS	NS	--	NS	**	--	NS	**	--	NS	NS
L x *D*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	***	NS
C x *L* x *D*	--	NS	NS	--	*	NS	--	NS	NS	--	NS	NS
W x *L* x *D*	*	**	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
C x *W* x *L* x *D*	--	NS	*	--	NS	NS	--	NS	NS	--	NS	NS
Sampling location[x]												
Weed management												
Weed mat	0.68	0.61	0.55	5.09	5.07	4.96	1.16	1.17	1.12	0.23	0.14	0.11
Hand-weeded	0.64	0.66	0.61	5.22	5.55	4.79	1.34	1.29	1.15	0.21	0.16	0.13
Non-weeded	--	0.66	0.61	--	5.49	4.82	--	1.35	1.10	--	0.15	0.12
Significance	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Location												
In-row distance from plant												
I_1 (6 in.)	0.69	0.63 b	0.65 ab	5.28	5.48 a-c	5.12	1.54 a	1.22 ab	1.28 a	0.31 ab	0.13 b	0.15
I_2 (18 in.)	0.63	0.65 ab	0.61 a-c	5.22	6.06 a	5.12	1.56 a	1.51 a	1.26 a	0.21 bc	0.20 a	0.16
I_3 (30 in.)	0.60	0.64 ab	0.54 cd	5.35	5.41 a-c	4.88	1.55 a	1.25 ab	1.15 ab	0.21 bc	0.16 ab	0.14
Between-row distance from plant												
B_1 (6 in.)	0.68	0.63 b	0.61 a-c	5.82	5.33 a-c	4.67	1.18 b	1.27 ab	1.01 b	0.35 a	0.18 ab	0.12
B_2 (18 in.)	0.68	0.66 ab	0.52 d	4.99	5.02 bc	4.65	1.02 b	1.05 b	1.00 b	0.19 c	0.15 ab	0.11

B_3 (30 in.)	0.64	0.61 b	0.67 a	5.08	5.90 ab	4.77	1.06 b	1.48 a	1.14 ab	0.17 c	0.12 b	0.12
B_4 (42 in./grass)	0.69	0.71 a	0.57 b-d	4.67	4.88 c	4.58	1.08 b	1.16 ab	1.09 ab	0.16 c	0.12 b	0.08
B_5 (54 in./grass)	0.68	0.63 b	0.54 d	4.83	4.90 c	5.07	1.02 b	1.21 ab	1.05 b	0.16 c	0.12 b	0.07
Significance	NS	**	***	NS	***	NS	***	**	***	***	***	NS
Interactions												
W x *L*	**	**	***	*	NS	**	***	NS	***	NS	NS	NS
Recommended level[w]		K			Ca			Mg			Na	
Low		<0.4			<5			<0.5			--	
Medium		0.4–0.9			5–10			0.5–1.5			--	
High		>0.9			>10			>1.5			--	

[z]Only weed mat and hand-weeded plots of 'Marion' were measured in 2010. Soil was collected from three depths (D_{1-3}) at two locations (I_1 and B_2) and one depth (D_1) at nine locations (I_{1-3} and B_{1-5}) (see Fig. 1). Sample locations B_4 and B_5 were located in the grass alleyway.
[y]Cultivar, *C* x *L*, *W* x *L*, *W* x *D*, *C* x *W* x *L*, and *C* x *W* x *D* had no significant effect each year on cations in soil samples collected at three depths at the I_1 and B_2 locations.
[x]Cultivar, *C* x *W*, and *C* x *W* x *L* had no significant effect each year on cations in soil samples collected at different in-row and between-row locations at the D_1 depth.
[w]Recommended levels for K and Ca are from Hart et al. (2006) and levels for Mg are from Marx et al. (1997). Fertilizer application of any given nutrient is not recommended when the soil level is high.
[v]Means followed by the same letter in a given column are not significantly different at 0.05 level.
C – cultivar; *W* – weed management; *L* – location; *D* – depth; and NS, *, **, *** – nonsignificant.and significant at $P \leq 0.05$, 0.01, and 0.001, respectively.

Table 1.6. Effects of soil depth and sampling location on soil micronutrients in organic plots of trailing blackberry following the first 3 years after planting (Oct. 2010-12). Each value represents the mean of the three replicates and includes the average of two cultivars (‘Black Diamond’ and ‘Marion’).[z]

	B (mg·kg^{-1})			Cu (mg·kg^{-1})			Mn (mg·kg^{-1})			Zn (mg·kg^{-1})		
Source of variation	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**
Soil depth[y]												
Weed management												
Weed mat	0.42	0.47 b	0.50	1.2	0.9	0.7	20	23	15	1.9	2.1	1.4
Hand-weeded	0.43	0.50 ab	0.51	1.0	1.1	0.6	27	24	17	2.3	2.3	1.5
Non-weeded	--	0.54 a	0.55	--	0.9	0.6	--	25	16	--	2.0	1.6
Significance	NS	*	NS	NS	NS	NS	**	NS	NS	NS	NS	NS
Location												
I_1 (6 in.)	0.36	0.53	0.51	1.0	0.8	0.6	26	27	16	1.8	2.0	1.3
B_2 (18 in.)	0.49	0.47	0.53	1.3	1.1	0.7	21	21	16	2.3	2.3	1.8
Significance	NS	**	NS	NS	NS	*	NS	***	NS	NS	NS	**
Depth												
D_1 (0-0.15 m)	0.50 a[v]	0.51 ab	0.53	1.6	1.1 a	0.7 a	30 a	24 ab	20 a	3.0 a	2.6 a	2.3 a
D_2 (0.15-0.30 m)	0.38 b	0.52 a	0.51	1.0	1.0 ab	0.6 ab	26 a	27 a	14 b	2.5 a	2.3 a	1.6 b
D_3 (0.30-0.45 m)	0.39 b	0.48 b	0.52	0.7	0.8 b	0.5 b	14 b	20 b	14 b	0.6 b	1.5 b	0.7 c
Significance	**	*	NS	NS	*	**	***	*	***	***	***	***
Interactions												
C x *D*	--	NS	*	--	NS	NS	--	NS	NS	--	NS	NS
C x *L*	--	NS	**	--	NS	NS	--	NS	NS	--	NS	NS
W x *D*	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS
L x *D*	NS	NS	NS	NS	NS	NS	NS	*	**	NS	NS	NS
C x *L* x *D*	--	NS	NS	--	NS	NS	--	NS	**	--	NS	NS
W x *L* x *D*	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sampling location[x]												
Location												
In-row distance from plant												
I_1 (6 in.)	0.44 a-c	0.48 bc	0.53	1.2	1.4 a	0.7	34 c	23 c	18 cd	3.0	2.6 a	2.7 ab
I_2 (18 in.)	0.47 a-c	0.45 c	0.48	1.3	0.7 b	1.5	28 c	16 c	17 cd	3.9	1.2 bc	2.8 ab
I_3 (30 in.)	0.42 bc	0.49 ab	0.50	1.1	1.0 ab	0.8	29 c	20 c	15 d	2.1	2.8 a	2.4 ab
Between-row distance from plant												
B_1 (6 in.)	0.55 ab	0.48 bc	0.52	1.1	0.9 ab	0.7	25 c	20 c	16 cd	3.6	2.9 a	3.2 a
B_2 (18 in.)	0.57 a	0.54 ab	0.54	2.1	0.9 ab	1.6	27 c	24 c	22 cd	3.1	2.5 a	1.8 b
B_3 (30 in.)	0.44 a-c	0.44 c	0.60	1.6	0.6 b	0.8	98 b	23 c	56 a	2.9	0.8 c	2.4 ab
B_4 (42 in./grass)	0.50 a-c	0.57 a	0.60	2.4	1.3 a	0.7	115 a	64 a	48 b	2.3	2.1 ab	2.4 ab
B_5 (54 in./grass)	0.38 c	0.55 ab	0.52	1.6	1.0 ab	1.2	38 c	39 b	23 c	2.4	2.5 a	2.4 ab
Significance	**	***	NS	NS	***	NS	***	***	***	NS	***	*

Interactions												
C x *L*	--	NS	NS	--	NS	NS	--	NS	***	--	NS	NS
W x *L*	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C x *W* x *L*	--	NS	NS	--	NS	NS	--	NS	*	--	NS	**
Recommended level[w]		B			Cu			Mn			Zn	
Low		<0.5			--			--			--	
Medium		0.5–1.5			--			--			--	
High		>1.5			--			--			--	

[z]Only weed mat and hand-weeded plots of ‘Marion’ were measured in 2010. Soil was collected from three depths (D_{1-3}) at two locations (I_1 and B_2) and one depth (D_1) at nine locations (I_{1-3} and B_{1-5}) (see Fig. 1). Sample locations B_4 and B_5 were located in the grass alleyway.

[y]Cultivar, *C* x *W*, *W* x *L*, *C* x *W* x *L*, *C* x *W* x *D*, and *C* x *W* x *L* x *D* had no significant effect each year on micronutrients in soil samples collected at three depths at the I_1 and B_2 locations.

[x]Cultivar, weed management, and *C* x *W* had no significant effect each year on micornutrients in soil samples collected at different in-row and between-row locations at the D_1 depth.

[w]Recommended levels for B are from Hart et al. (2006). Fertilizer application of B is not recommended when the soil level is high.

[v]Means followed by the same letter in a given column are not significantly different at 0.05 level.

C – cultivar; *W* – weed management; *L* – location; *D* – depth; and NS, *, **, *** – nonsignificant.and significant at $P \leq 0.05$, 0.01, and 0.001, respectively.

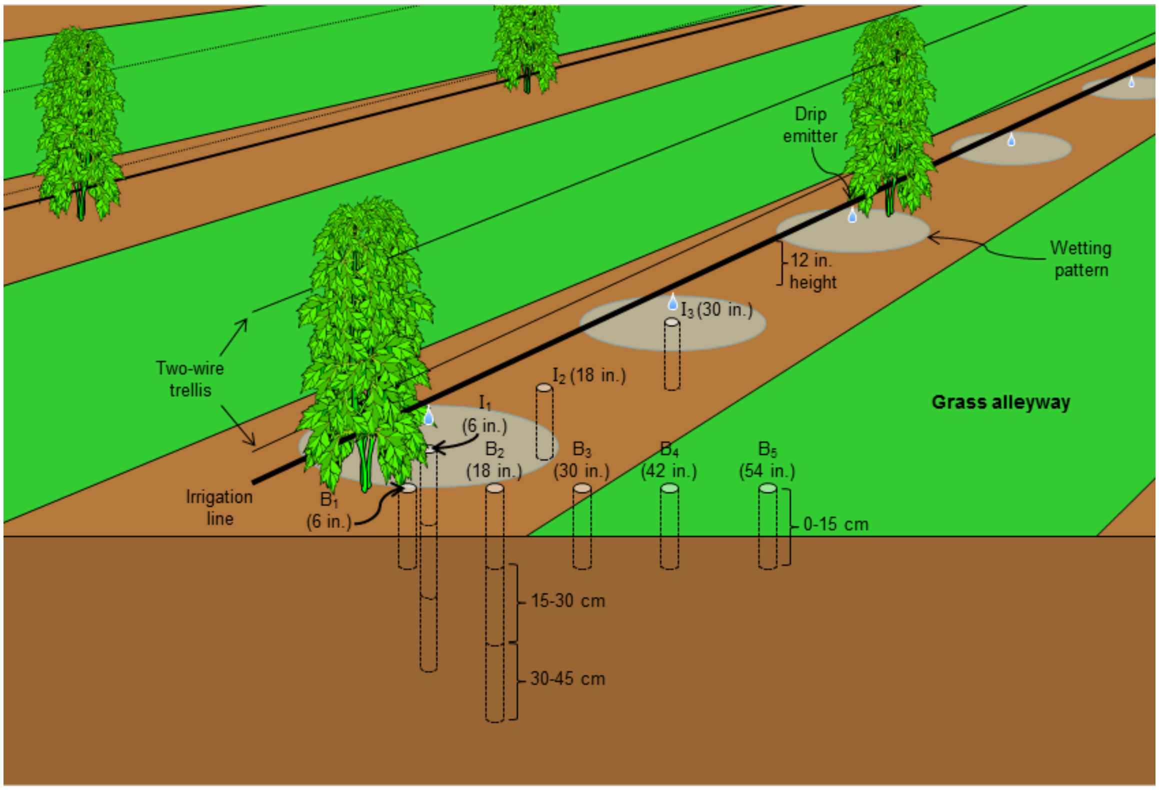

Fig. 1.1. Schematic diagram of the sampling locations used to measure the distribution of soil nutrients in an organic planting of 'Black Diamond' and 'Marion' trailing blackberry. Plants were spaced 5-feet apart within rows and 10-feet apart between rows and were tied to a two-wire trellis system. A grass alleyway was seeded and maintained between the rows. Irrigation was applied using a single lateral of drip tubing that was either suspended on a third trellis wire, ≈12 inches above the ground, or was placed on the soil surface under the middle of a 5-foot-wide strip of weed mat centered in the row (not shown). Fish emulsion fertilizer diluted to 10% with water was applied by hand, around the base of the plants, during the first year after planting (2010), and was injected through the drip system (fertigation) the following 2 years. Soil samples were collected each fall: in-row, under the drip line, at a distance of 6 (I_1), 18 (I_2), and 30 (I_3) inches from the base of a plant; and between rows, progressing into the alleyway, at a distance of 6 (B_1), 18 (B_2), 30 (B_3), 42 (B_4), and 54 (B_5) inches from the plant. The samples were collected to a depth of 0-0.15 m at each location, and to depths of 0.15-0.3 and 0.3-0.45 m at locations I_1 and B_2. See Materials and Methods for further details.

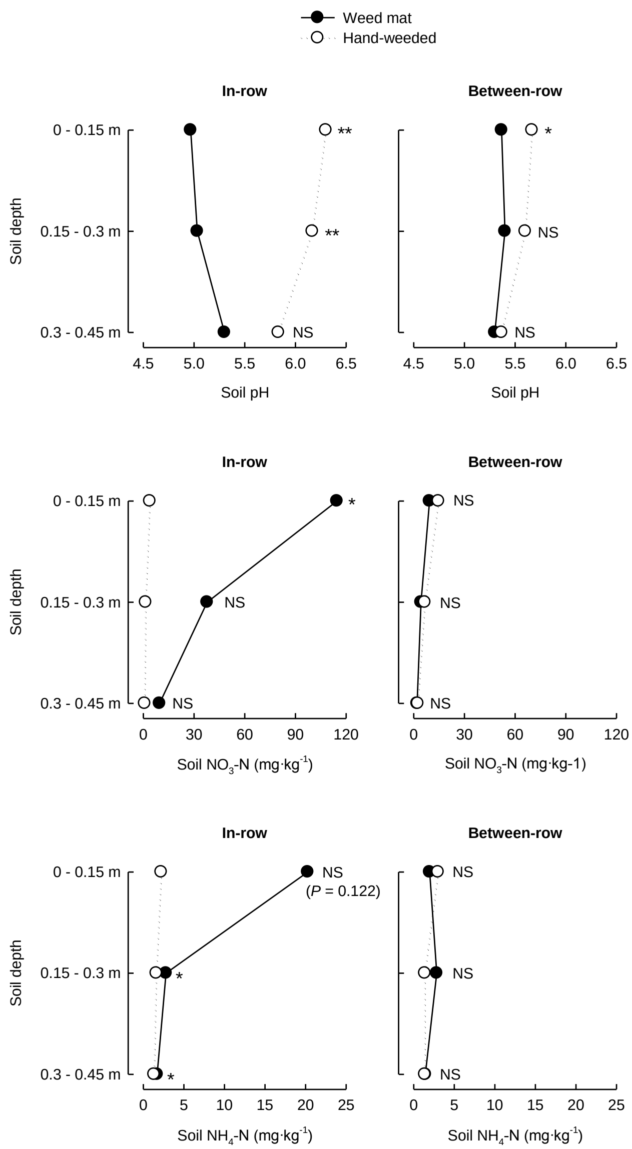

Fig. 1.2. Soil pH and mineral N in weed mat and hand-weeded plots of organic 'Marion' trailing blackberry following the first year after planting (Oct. 2010). Soil was sampled in-row at a distance of 6 inches from the plants (I_1) and between-row at a distance of 18 inches from the plants (B_2) (see Fig. 1). Each symbol represents the mean of the three replicates. Fertilizer was applied by hand around the base of the plant in 2010.

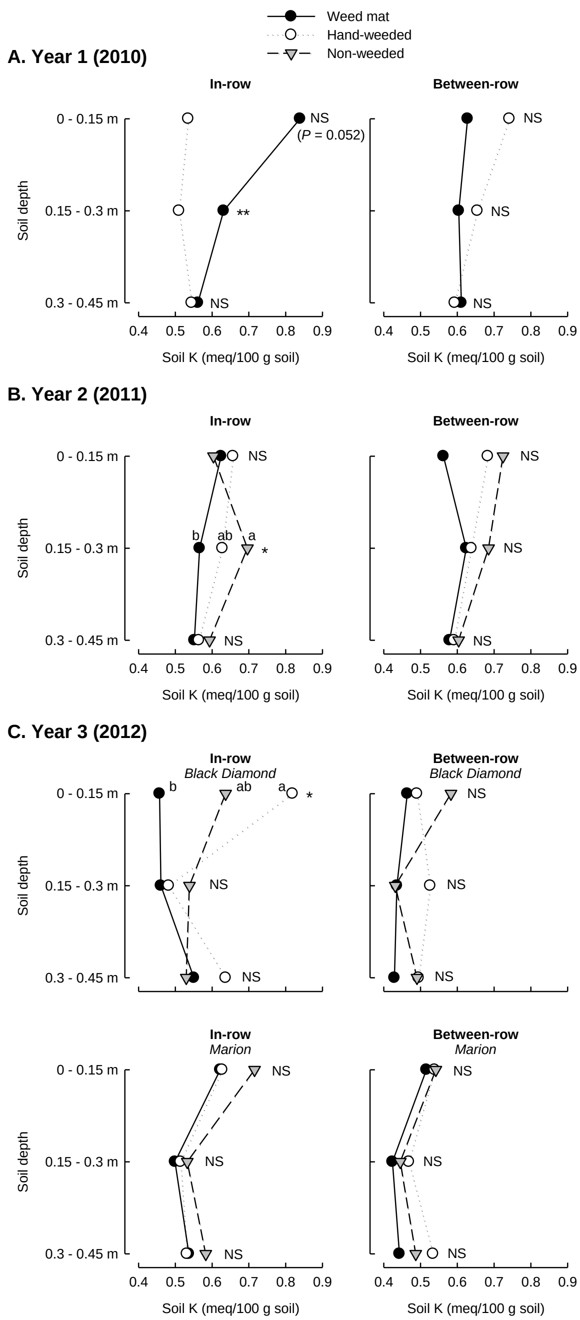

Fig. 1.3. Soil K in weed mat, hand-weeded, and non-weeded plots of organic ‘Black Diamond’ and ‘Marion’ trailing blackberry following the first 3 years after planting (Oct. 2010-2012). Soil was sampled in-row at a distance of 6 inches from the plants (I_1) and between-row at a distance of 18 inches from the plants (B_2) (see Fig. 1). Each symbol represents the mean of the three replicates and includes ‘Marion’ only in 2010 and the average of both cultivars in 2011.

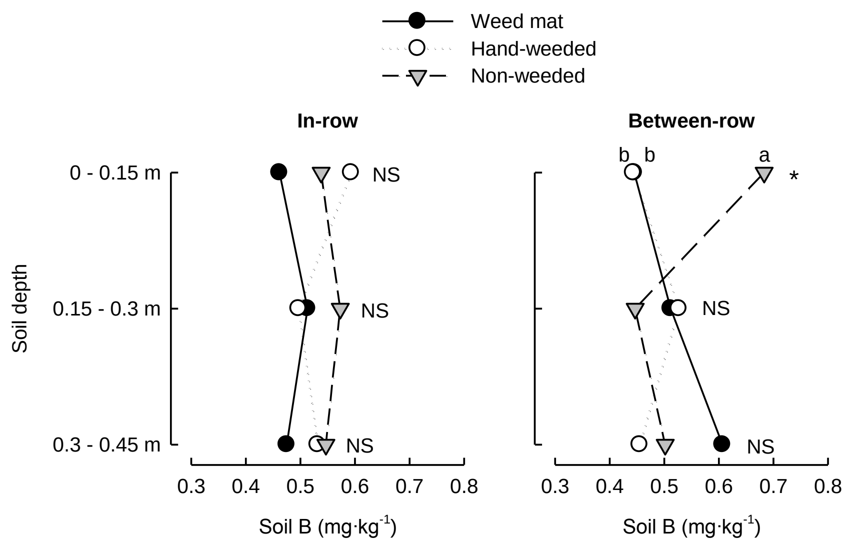

Fig. 1.4. Soil B in weed mat, hand-weeded, and non-weeded plots of organic trailing blackberry following the first 3 years after planting (Oct. 2010-2012). Soil was sampled in-row at a distance of 6 inches from the plants (I_1) and between-row at a distance of 18 inches from the plants (B_2) (see Fig. 1). Each symbol represents the mean of the three replicates and includes the average of two cultivars (‘Black Diamond’ and ‘Marion’).

CHAPTER 3: Weed Management Practices for Organic Production of Trailing Blackberry. I. Plant Growth and Yield

Abstract

Weed management practices were evaluated in a new field of trailing blackberry (Rubus L. subgenus Rubus Watson) established in western Oregon. The field was planted in May 2010 and certified organic in May 2012. Treatments included two cultivars, ‘Marion’ and ‘Black Diamond’, grown in 1) non-weeded plots, where weeds were cut to the ground just prior to harvest, 2) hand-weeded plots, hoed two to three times per year, and 3) weed mat plots, covered with black landscape fabric. Each treatment was fertilized with fish emulsion and irrigated by drip. Weeds increased from 2010 through 2012 in both non-weeded and hand-weeded plots and required 38 and 90 h·ha-1 of labor to remove the weeds in the latter treatment in 2011 and 2012, respectively. Weeds in weed mat plots, in comparison, were confined primarily to the planting holes in the fabric and required only 1 h·ha-1 of labor for weed removal each year. Blackberry growth, in terms of number and dry weight of the primocanes, was similar among treatments during the first year after planting but differed with cultivar and weed management the following season. In 2011, ‘Black Diamond’ produced shorter but an average of three more primocanes per plant than ‘Marion’, while plants in hand-weeded and weed mat plots produced nearly twice as many primocanes as non-weeded plots. Hence, when fruit were produced on floricanes (the previous year’s primocanes) for the first time in 2012, ‘Black Diamond’ had 15% more yield than ‘Marion’, and weed control increased yield by 67% with hand-weeding

and 100% with weed mat. ‘Black Diamond’ and weed control also produced larger berries (measured as average individual fruit weight) with a greater water content but a lower soluble solids concentration. So far, of the three practices studied, weed mat was best suited to organic production of blackberries. The initial cost of the weed mat was far less than the cost of hand-weeding during the first 3 years following planting, and after only one season of fruit production, the yield benefit of weed mat provided enough profit to warrant its use over no weeding or hand weeding.

Introduction

Commercial production of blackberries (*Rubus* L. subgenus *Rubus*, Watson) has increased rapidly in recent years from a total of 13,960 ha worldwide in 1995 to 20,035 ha in 2005 (Strik et al., 2007). Approximately 6,000 ha are currently produced in the United States (U.S. Department of Agriculture, 2010a). More than half of the U.S. total is processed fruit [IQF (individually quick frozen), bulk frozen, puree, freeze-dried, canned, juice, and juice concentrate] produced primarily in Oregon and Washington (Strik et al., 2007). Organic production has also increased to >2,500 ha worldwide, but there was only 200 ha in the United States in 2008 (U.S. Department of Agriculture, 2010b; Strik and Finn, 2012). However, significant expansion in organic plantings is expected in the next 10 years as consumer demand for organic products increase and growers become more interested in targeting higher-value niche markets (Strik and Finn, 2012).

Guidelines for organic blackberry production are limited at the moment. General information is available for erect and semi-erect types used for fresh market production

(Kuepper et al., 2003), but most of it is anecdotal and does not necessarily apply to organic production of trailing types used for production of processed fruit. Trailing blackberries ripen in midsummer in Oregon and Washington and are usually machine-harvested (Strik and Finn, 2012).

Weed management is considered critical for good production in berry crops (Barney et al., 2007; Bushway et al., 2008; Heiberg, 2002; Krewer et al., 2009; Pritts and Kelly, 2001; Zebarth et al., 1993). Blackberry plants are relatively vigorous, however, and therefore may tolerate more competition from weeds. A few commercial operations grow organic blackberries with no weed control and achieve reasonable yields (Strik, personal observations). The strategy is considered a holistic approach to weed management—maintaining good soil properties, providing habitat for beneficial insects, and favoring healthy crop growth and high yield (Buhler, 2002; Marshall et al., 2003; Swanton and Weise, 1991)—but weeds left uncontrolled may interfere with machine harvest and produce seeds that become fruit contaminants.

Pre-emergent and contact herbicides are commonly used in conventional blackberry plantings (Barney et al., 2007; Bushway et al., 2008), but chemical options are limited for organic production. Perforated landscape fabric, often referred to as weed mat, is an alternative option and has been approved for use as weed barrier in organic plantings (U.S. Department of Agriculture, 2011). Trailing blackberry may be well suited to weed mat because, unlike erect and semi-erect types, new canes, referred to as primocanes, emerge only from the crown or the base of the plants. Weed mat is currently used with success in other perennial cropping systems, including conventional and organic tree fruit orchards (Granatstein and Mullinix, 2008) and blueberry (*Vaccinium corymbosum* L.) fields (Julian et al., 2012).

The objective of the present study was to evaluate the effects of three different organic weed management strategies, including weed mat, hand weeding, and no weeding, on growth and early production of trailing blackberry. Two popular cultivars, 'Marion' and 'Black Diamond', were included in the study. Both are predominantly harvested by machine for high-value processed markets and together account for >75% of the 2,914 ha of blackberries produced in Oregon in 2012 (U.S. Department of Agriculture, 2013). Like all trailing types, the cultivars are perennial but the shoots are biennial, producing primocanes the first year, which then become floricanes with flowers and fruit the following year and then senesce after harvest. Mature plants will have both primocanes and floricanes in the same year in a typical annual or every-year production system (Julian et al., 2009; Strik and Finn, 2012).

Materials and Methods

Study site. The study was conducted at the North Willamette Research and Extension Center in Aurora, OR (long. 45°17' N, lat. 122°45' W; USDA hardiness zone 8; elevation 46 m). Winter wheat (*Triticum* sp.) was planted at the site for at least 10 years prior to the study. The soil is mapped as a Willamette silt loam (fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll). It was sampled for analysis on 7 Aug. 2009 and had a soil pH of 5.3 and contained 3.6% organic matter, 1.5 ppm NO_3-N, 2.3 ppm NH_4-N, 188 ppm phosphorus, and 295 ppm potassium (K) in the top 0.2 m of the soil profile (Brookside

Laboratories, Inc., New Knoxville, OH). The site was certified organic by Oregon Tilth (Salem, OR) in May 2012.

Site preparation. Cereal rye (*Secale cereal* L.) and common vetch (*Vicia sativa* L.) were seeded at the site on 18 May 2009 at a rate of 34 and 67 $kg \cdot ha^{-1}$, respectively, and incorporated on 27 Aug. 2009 using a power spader (Model 165, Series 205, Tortella, Ortona, Italy) and rototiller (Model TB 180, TerraAnova, Padova, Italy). Plant rows were marked 3.0-m apart (north-south direction) on 31 Aug. 2009 and sub-soiled 0.4-m deep using a two-shank ripper (Rankin Model R3-60, Yakima, WA). Pelletized lime [calcium carbonate (2242 $kg \cdot ha^{-1}$) and pelletized dolomite lime (4148 $kg \cdot ha^{-1}$)] and fertilizer [561 kg(KMag 0N-0P-22K-11Mg-22S)ha^{-1}, 90% granular sulfur (S, 10 $kg \cdot ha^{-1}$), 15% granular boron (B, 2 $kg \cdot ha^{-1}$), copper sulfate, (Cu, 1 $kg \cdot ha^{-1}$), and zinc sulfate (Zn, 14 $kg \cdot ha^{-1}$)] were then broadcast and incorporated using the power spader and rototiller. Lime was applied because the preexisting soil pH in 2009 was below sufficiency for good blackberry growth (Hart et al., 2006). We fertilized because immobile nutrients are routinely incorporated prior to planting of perennial crops to ensure nutrient sufficiency of those nutrients for the longevity of the planting. Cereal rye was seeded within rows and hard-fine fescue (*Festuca longifolia* Thuill. 'Aurora Gold') was seeded between rows at a rate of 112 $kg \cdot ha^{-1}$ each on 7 Oct. 2009. The rye was flail mowed on 8 May 2010, and rows were sub-soiled (0.4-m deep) using a single-shank ripper and tilled using a 0.3-m wide strip tiller.

Experimental design. The study was planted on 26 May 2010. 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 subplots, and a combination of three weed management strategies (weed mat, hand-hoeing, and no weeding) and two primocane training dates (August and February) as sub-subplots. Each sub-subplot consisted of four plants spaced 1.5-m apart in-row and was separated from plants in adjacent plots by 3.0 m (to provide space for clearing the machine harvester). Between row spacing was 3.0 m (2,222 plants/ha). The 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. Since irrigation and training treatments were not initiated until Aug. 2012 (year 3), only cultivar and weed management treatments assigned to postharvest irrigation and August training (30 plots in total) were measured during the first 2 years after planting and are therefore included in the present study.

A 1.4-m wide strip of black landscape fabric (water flow rate 6.8 $L \cdot h \cdot m^2$; 0.11 $kg \cdot m^2$; TenCate Protective Fabrics, OBC Northwest, Inc. Canby, OR) was centered on the row of each weed mat plot and secured in place using 0.1-m long nails. Square openings (≈0.2 m x 0.2 m) were cut in the fabric for each plant. Cost of the weed mat was estimated at \$366$\cdot ha \cdot y^{-1}$, amortized over an expected 5 year life, with an additional \$741 and \$494/ha for installation and cutting holes for planting, respectively.

Plants propagated from tissue-culture were obtained from a commercial nursery as plugs and were planted in each treatment plot along with the rooted potting media. Twelve plants died after planting and were replaced with new plugs at 60 days after planting. All but one dead plant were ‘Marion’; five were in weed mat plots and seven were in hand-weeded plots. To encourage growth, weeds were removed by hand around each plant during the first year after planting, including those near plants (≈0.2 m diam.) in non-weeded plots.

Plants were trained on a two-wire vertical trellis in each row installed prior to planting. The lower trellis wire was attached to steel posts at 1.0 m above the ground, and the upper wire was attached at 1.6 m. The posts were located between each plot and directly in the center of the row. Primocanes were tied to the trellis as they grew during first 2 years after planting, using bailing twine, but were cut to the crown and removed in February after the first season to increase growth and improve vigor the following year (standard commercial practice). Once the primocanes grew above the upper trellis wire in the second year, half the canes were looped in one direction down to the lower trellis wire and brought back towards the plant with one or two twists, and the other half was looped in the opposite direction (Strik and Finn, 2012). By year 3, plants had both primocanes and floricanes (the previous year’s primocanes). At this point, new primocanes were tied to the lowest trellis wire, underneath the floricane canopy, and, depending on the training date treatment, were tied to the trellis in either August or February.

Irrigation and fertilizer applications. Irrigation was applied using a single lateral of drip tubing (UNIRAM, Netafim USA, Fresno, CA) installed in each treatment plot immediately after planting. The tubing had 1.9 $L \cdot h^{-1}$ in-line, pressure-compensating emitters spaced every 0.6 m and was placed under the landscape fabric, at the base of the plants, in weed mat plots, and was attached to a third wire on the steel posts, located at

0.3 m above the ground, in hand-weeded and non-weeded plots. Each weed management treatment was irrigated independently using a manifold with electric solenoid valves and an automatic timer. Irrigation was scheduled weekly based on estimates of crop evapotranspiration (ET). Crop ET was calculated by multiplying reference ET by a crop coefficient for caneberry 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 (http://usbr.gov/pn/agrimet/). The weather station was located in a field of tall fescue [*Lolium arundinacea* (Schreb.) S.J. Darbyshire] ≈0.5 km from the site. 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 on 28 July 2010 using a Trase I time domain reflectometry (TDR) system (Soilmoisture Equipment Corp., Santa Barbara, CA) to determine the distribution of water between drip emitters following irrigation and to ensure that soil moisture was adequate (>20%) near the young plants. The TDR system was equipped with a pair of 0.15-m stainless steel waveguides and a waveguide connector. The waveguides were installed vertically—in the middle of the row, at each 0.1 m location between two plants—in five hand-weeded 'Marion' plots.

To monitor plant water status in each treatment, leaf water potential was measured weekly after irrigation was initiated, beginning the second week after planting, using a pressure chamber (Model 1000, PMS Equipment, Albany, OR). The measurements were made between 11:00 and 13:30 HR on one recent fully-expanded primocane leaf in three replicate plots per treatment. Irrigation was adjusted as needed each week to maintain similar leaf water potentials among treatments. 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.

Plants were fertilized using pelletized, processed poultry litter (4N–3P–2K–7Ca; Nutri-Rich; Stutzman Environmental Products Inc., Canby, OR) and Fish Agra (4N–1P–1K; Northeast Organics, Manchester-by-the-Sea, MA) in 2010 and TRUE 402 liquid fertilizer (4N–0P–2K; True Organic Products, Inc., Spreckels, CA) in 2011 and 2012. The Nutri-Rich was incorporated into the soil (~ 0.45 m diam.) at a rate of 28 $kg{\cdot}ha^{-1}$ N just prior to planting. Fish Agra was diluted with 10 parts water (v/v) and applied by hand, around the base of plants, in seven weekly applications of 4 $kg{\cdot}ha^{-1}$ N each from 14 July to 25 Aug. 2010 (28 $kg{\cdot}ha^{-1}$ total N). TRUE 402 was also diluted with 10 parts water but applied by fertigation (injection through the drip system) using a Mix-Rite TF10-002 fertilizer injector (DEMA, St. Louis, MO). Irrigation was run for 10 min prior to each injection to fully pressurize the system, and was also run for an additional hour afterwards to flush the drip lines. In 2011, plants were fertigated with 8.0 $kg{\cdot}ha^{-1}$ N on 15 Apr. and then 16 $kg{\cdot}ha^{-1}$ N each on 9 May and 1 and 20 June (56 $kg{\cdot}ha^{-1}$ total N). In 2012, 14 $kg{\cdot}ha^{-1}$ N was fertigated on each of the following dates: 23 April, 8 May, and 7 and 13 June (56 $kg{\cdot}ha^{-1}$ total N).

Weed management. Weeds were hoed from hand-weeded plots and pulled from weed mat plots on 20 Apr. and 8 June in 2011 and on 20 Mar., 8 May, and 25 June in 2012, and the labor required to weed each treatment was recorded. Labor was valued at $15/h. The weeds were removed when relatively small, which is typical for commercial production. The most common weed species present in the field were identified in six non-weeded plots (three 'Marion' and three 'Black Diamond') on 20 June 2011 and 25 June 2012, and percent weed cover was estimated visually using a 1-m^2 grid randomly located in each plot. Weeds in the grid were cut at the soil surface on 25 July 2011 and 27 June 2012 (just prior to fruit harvest) and oven-dried at 70 °C and weighed; remaining weeds were then mowed to the ground in each plot using a string trimmer.

Plant growth and fruit production. Primocanes were counted at 0.3 m height in each plot in Feb. 2011 and Jan. 2012 and 2013. A primocane from two plants per plot was then randomly selected and measured for length (Feb. 2011 and Jan. 2012 only), oven-dried at 70 °C, and weighed. In Jan. 2013, a regression equation of primocane number to DW in 2011 was used to estimate DW in 2012 ($DW_{2011}=-6.46x^2 +178.16x-305.6$; $R^2=0.53$; $P <0.0001$).

Ripe fruit were harvested twice weekly in July 2012, using an over-the-row rotary harvester (Littau Harvesters Inc., Stayton, OR). Total marketable fruit and culls (sunburned, damaged, or under-ripe fruit) were weighed on each harvest date, and a subsample of 25 berries were randomly selected from each plot and weighed to determine average individual fruit weight. A weighted average berry weight was calculated for the fruiting season. The subsamples were also measured for percent soluble solids on three dates (early-, mid-, and late-season in each cultivar), using a digital refractometer (Atago, Bellevue, WA). At mid-harvest, a 60 g sub-sample of ripe fruit per plot was shipped overnight to Brookside Laboratories to determine percent water content.

A floricane was sampled from two plants per plot in Aug. 2012 (after harvest) and measured for length and the total number of nodes, fruiting laterals, and fruiting sites per cane. The remaining floricanes were then cut to the crown, placed between rows, and flail mowed (standard commercial practice).

Data analysis. Data were analyzed for a split-plot design using PROC GLM in SAS (SAS Institute Inc., Cary, NC), and means were separated at the 5% level using Fisher's protected LSD test. Due to variations in management, ANOVA calculations were completed within year, and not across years.

Results and Discussion

Weather and irrigation. Weather conditions were cool and wet in the spring and warm and dry in the summer at the site, which is normal for western Oregon (Table 2.1). Mean daily air temperatures ranged from 5.4-21.1 °C in April and May and 10.8-29.0 °C in June through August each year. The lowest temperature in any growing season was -1.7 °C (8 Apr. 2011) and the highest was 39.6 °C (4 Aug. 2012). Most rain occurred from October to March, when plants were dormant (Table 2.1).

Irrigation was needed from May or June to the end of September each year (Table 2.1). Water was applied frequently in the first year after planting (four 15-30 min applications per day with 2 h between applications) to ensure the young plants were well watered during establishment. Soil water content ranged from 22% to 35% between emitters (Fig. 2.1) and was within the limits considered available for plant water uptake in silty loam soil (Saxton and Rawls, 2006). A total of 230 mm of irrigation was applied in year 1. Irrigation was increased to 367 mm the following year but scheduled in three to four single applications per week. By 2012, a total of 548 mm was applied. Once again, irrigation was scheduled three to four times per week, except in July, when it was applied daily during harvest. Water requirements are generally highest during harvest in berry crops (Bryla and Strik, 2007; 2008).

To maintain similar leaf water potentials among treatments, additional water was added to weed mat plots compared to hand-weeding or no weeding, particularly in 'Marion' in 2011 (Table 2.1, footnote 'x'). Plastic mulches such as weed mat increase canopy temperatures during the day and therefore often result in more plant water use (Allen et al., 1998; Larco, 2010). The effect was probably lower in 2012 because plants were larger (shaded more weed mat). However, it was not clear why the cultivars differed. Leaf water potential was often lower in 'Marion' than in 'Black Diamond' (eight out of twelve dates in 2011 and four dates out of twelve dates in 2012), but values were always > -1.0 MPa in both cultivars and only differed by 0.1 MPa when averaged over 12 measurement dates in 2011 and 11 measurement dates in 2012 (data not shown). Water potentials were also similar among weed management treatments each year and, within a cultivar, never differed by more than 0.3 MPa.

Weeds. In non-weeded plots, weeds increased from ≈30% cover in 2010 to nearly 100% cover the following 2 years. About 2 $h \cdot ha^{-1}$ (\$30) of labor was required to hand pull weeds around the blackberry plants in 2010. Dominant weed species included *Stellaria media* (L.) Vill., *Taraxacum officinale* F.H. Wigg, *Euphorbia esula* L., *Poa annua* L., *Sonchus oleraceus* L., *Anthemis cotula* L., and *Avena fatua* L. Total weed biomass (aboveground) averaged 2.1 kg/plot (dry wt.) in year 2 and 2.2 kg/plot in year 3. Weed biomass was not affected by cultivar in either year. Weeds were mowed prior to harvest in 2012 and therefore did not interfere with the rotary harvester.

Weeds also increased in hand-weeded plots. A total of 9 $h{\cdot}ha^{-1}$ ($135), 38 $h{\cdot}ha^{-1}$ ($570) and 90 $h{\cdot}ha^{-1}$ ($1,350) of hand labor was required to hoe the plots in 2010 through 2012, respectively. The higher labor requirements in 2012 may have been due, at least in part, to the high number of weed seeds produced in nearby non-weeded plots (Koochek et al., 2009). In contrast, only 1 $h{\cdot}ha^{-1}$ ($15) of labor was required per year to remove weeds from the planting hole area in weed mat plots. Similar labor requirements were noted with weed mat in organic blueberry and orchard systems (Julian et al., 2012; Neilsen et al, 2003). In our study, use of weed mat increased costs by $2,347 and $322/ha relative to non-weeded and hand-weeded systems, respectively, over the 3 years of establishment.

Primocane production. Primocanes were longer in ‘Marion’ than in ‘Black Diamond’, beginning the first year of planting but were unaffected by weed management until the following season (Table 2.2). By the end of 2011, the number of primocanes per plant increased in all treatments from the previous year, but ‘Black Diamond’ had more primocanes than ‘Marion’, and weed control with either weed mat or hand-weeding nearly doubled primocane production relative to non-weeded plots. The number of primocanes in ‘Marion’ was similar to the number produced previously by young plants grown under conventional conditions (Bell et al. 1995) but was less than the 16 to 20 primocanes produced by mature plants during an “off year” (i.e., all floricanes removed in a given year to increase production the following year) (Cortell and Strik, 1997a). In general, ‘Black Diamond’ was less vigorous than ‘Marion’, producing shorter primocanes and less biomass aboveground, agreeing with observations reported by Finn et al. (2005). Primocane vigor, however, was increased by weed control in both cultivars, although interestingly the length of individual primocanes was longer in non-weeded than in weed mat plots (Table 2). Weed control also increased primocane production in red raspberry but, in this case, had no effect on primocane length (Bowen and Freyman, 1995).

Primocane production declined when plants were harvested for the first time in 2012, and neither primocane number nor dry weight were affected by cultivar or weed management (Table 2.2). However given the previously described differences in plant growth by cultivar in 2011, future work may expect to see a greater nutrient efficiency of ‘Black Diamond’ plants over ‘Marion’ plants during plant maturity. Cortell and Strik (1997a) also observed lower primocane production in ‘Marion’ when floricanes were present. Floricanes reduce light penetration into the canopy and may compete with primocanes during fruit production for carbon and nutrients (Cortell and Strik, 1997b; Mohadjer et al., 2001).

Early fruit production. ‘Marion’ produced longer floricanes (or longer primocanes the previous year) with more nodes and shorter internode lengths than ‘Black Diamond’ and therefore had greater fruit production potential per floricane (Table 2.3). ‘Black Diamond’, however, produced more floricanes/plant and more flowers/lateral than

'Marion', which, when combined with a higher average individual fruit weight, resulted in a higher total yield in 'Black Diamond' (Tables 2.2 and 2.3). 'Black Diamond' also had a longer and more consistent fruit production season than 'Marion' (Fig. 2.2A). Total marketable yield averaged 13.3 $t \cdot ha^{-1}$ in 'Black Diamond' and 11.6 $t \cdot ha^{-1}$ in 'Marion', which is similar to mature conventional, machine-harvested, commercial fields in Oregon and surpassed yields expected for 'Marion' during establishment (Julian et al., 2009). In this early fruit production year, 'Black Diamond' produced an average of $3,751/ha greater income from fruit harvest than 'Marion' (at $2.11/kg).

Plants also had higher yields with weed control, particularly when weed mat was used (Table 3; Fig. 2.2B). Plants with weed mat produced twice as much fruit as those in non-weeded plots (added fruit income of $16,878/ha) but also produced 20% more fruit (added income of $5,626/ha) than hand-weeded plants. Even though weeds were removed with hand-weeding, the timing of removal may have led to weed competition in the plants (Everaarts, 1992; Van Heemst, 1985). Net income (fruit harvest minus weed management costs over the 3 years), not including other management costs which were assumed to be equivalent among weed management treatments, was $31,380/ha in the weed mat, 86% and 20% greater than in the non-weeded and hand-weeded systems, respectively.

Weed control also increased berry weight and fruit water content but reduced percent soluble solids in the fruit (Table 2.3). It is not known whether increased berry weight was due to more drupelets/fruit, higher drupelet weight, or a combination of both, and whether the reduction in soluble solids was due to fewer solids or a dilution of the solids (Strik et al., 1996). Although primocane leaf water potentials were similar among treatments, primocanes and floricanes appear to be hydraulically independent (Bryla and Strik, 2008). Competition from weeds may have limited water more in floricanes than in primocanes and therefore resulted in less fruit water content and weight and a higher concentration of soluble solids. However, berry weight, fruit water content, and soluble solids also differed between cultivars in a similar manner [i.e., water content was higher and soluble solids were lower in ‘Black Diamond’ with larger fruit; Table 2.3], suggesting that fruit water content was not necessarily a function of plant water relations. Water measurements on floricanes and further quantification of fruit components will be determined in the treatments in later studies.

Weed management had no effect on any of the floricane traits measured, including internode number and length, percent bud break, and number of flowers/lateral, and only 0.5% to 0.8% of the fruit harvested in any treatment were non-marketable (culls) (Table 2.3). Nonetheless, weeds clearly reduced plant growth, fruit production, and income during the first few years after planting. Similar results were found in other fruit crops (Burkhard et al., 2009; Sanguankeo et al., 2009; Tworkoski and Glenn, 2001).

Conclusions. The results of the study indicate that weed control is beneficial during establishment of trailing blackberry and can be done successfully in organic plantings using hand-weeding or weed mat. Of the two, weed mat led to the highest yield and net returns in the study and required only 1 $h \cdot ha^{-1}$ of labor for weed control each year. Weeds reduced primocane number and dry weight per plant and ultimately resulted in lower yield. Weeds likely compete with the young blackberry plants for both light and soil resources, but further work is needed to determine whether floricane water status was also impacted by weeds and whether plant and soil nutrients were limited. Both ‘Black Diamond’ and ‘Marion’ appeared well-suited to organic production in the present study and produced early yields that equaled or surpassed conventional production. The study will continue for at least 3 more years to determine sustainability of each practice.

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Table 2.1. Mean daily air temperature, reference evapotranspiration (ET_{ref}), precipitation, and irrigation applied to organic blackberry plants in 2010–12.[z]

	Mean daily air temperature (°C)			ET_{ref} (mm)			Precipitation (mm)			Irrigation (mm)[y]		
Month	2010	2011	2012	2010	2011	2012	2010	2011	2012	2010	2011[x]	2012[x]
January	7.7	5.4	5.1	21	15	17	163	129	223	--	0	0
February	8.3	4.3	6.4	32	25	28	90	121	101	--	0	0
March	8.6	7.7	7.1	53	40	38	131	176	226	--	0	0
April	9.7	8.3	11.0	70	64	65	80	123	106	--	0	0
May	11.9	11.4	13.5	89	85	106	125	88	78	6	0	19
June	15.3	15.8	15.4	99	102	108	86	26	67	32	51	115
July	19.4	18.4	19.3	148	129	138	6	29	13	60	119	181
August	19.2	19.9	20.4	128	127	141	0	2	0	67	124	121
September	16.9	18.5	17.6	72	90	93	55	19	3	65	73	112
October	12.2	12.0	12.8	42	35	53	133	61	169	0	0	0
November	7.4	6.5	8.8	19	17	20	171	151	227	0	0	0
December	6.4	3.1	5.6	18	11	14	251	87	204	0	0	0
Total/Avg.	11.9	10.9	11.9	790	739	821	1290	1013	1416	230	367	548

[z]Weather data were obtained from a nearby AgriMet weather station (Aurora, OR).
[y]Irrigation was applied 26 May (planting) to 30 Sept. 2010, 13 June to 30 Sept. 2011, and 18 May to 30 Sept. 2012.
[x]To maintain similar primocane leaf water potentials among treatments, ‘Marion’ plants with weed mat were irrigated with an additional 103 mm of water in July–Sept. 2011 and 21 mm in July–Sept. 2012, while ‘Black Diamond’ plants with weed mat were irrigated with an additional 34 mm of water in Aug.–Sept. 2011 but with no additional water in 2012.

Table 2.2. The effects of cultivar and weed management strategies on primocane growth in ‘Black Diamond’ and ‘Marion’ trailing blackberry following the first 3 years after planting (2010-2012 growing seasons).[z]

	Avg. primocane length (m)		Primocane no./plant			Primocane dry weight (kg/plant)		
Treatment	2010	2011	2010	2011	2012	2010	2011	2012
Cultivar (*C*)								
Black Diamond	1.8	3.3	3.4	11.6	4.2	0.1	0.8	0.1
Marion	3.0	6.9	3.4	8.6	4.3	0.1	1.0	0.1
Significance	0.0003	< 0.0001	NS	< 0.0001	NS	NS	0.05	NS
Weed management (*W*)								
Non-weeded	-	5.8 a[y]	-	6.5 b	3.7	-	0.6 b	0.1
Hand-weeded	2.5	5.4 ab	3.4	11.6 a	4.7	0.1	1.0 a	0.1
Weed mat	2.2	4.1 b	3.4	12.2 a	4.3	0.1	1.1 a	0.1
Significance	NS	0.04	NS	< 0.0001	NS	NS	< 0.0001	NS
Interaction *C* x *W*	NS	NS	NS	NS	NS	NS	NS	NS

[z]Primocanes were counted and weighed following each growing season on 22 Feb. 2011, 24 Jan. 2012, and 23 Jan. 2013.
[y]Means followed by the same letter within a column were not significantly different at the 0.05 level.
[NS]Nonsignificant.

Table 2.3. The effects of cultivar and weed management strategies on floricane traits, yield, and fruit quality in ‘Black Diamond’ and ‘Marion’ trailing blackberry during the first year of fruit production (July 2012).

	Floricanes									
Treatment	Avg. length (m)	No. of nodes	Internode length (m)	Bud break (%)	No. of flowers/lateral	Total marketable yield (kg/plant)	Culls (g/plant)	Average individual fruit wt. (g/berry)	Fruit water content (%)	Fruit soluble solids (%)
Cultivar (*C*)										
Black Diamond	3.1	103.8	0.05	40.1	5.7	6.0	28.8	5.5	86.5	10.6
Marion	4.9	130.8	0.02	37.8	4.1	5.2	30.3	4.9	83.9	13.2
Significance	0.0007	0.04	0.01	NS	0.002	< 0.0001	< 0.0001	< 0.0001	0.0001	< 0.0001
Weed management (*W*)										
Non-weeded	3.9	111.1	0.04	41.9	5.0	3.6 c[z]	29.1 b	4.9 b	84.3 b	12.4 a
Hand-weeded	3.9	106.8	0.04	40.7	5.2	6.0 b	31.5 b	5.4 a	85.7 a	11.7 b
Weed mat	4.2	134.1	0.03	34.3	4.5	7.2 a	35.2 a	5.5 a	85.8 a	11.7 b
Significance	NS	NS	NS	NS	NS	< 0.0001	< 0.0001	< 0.0001	0.02	< 0.0001
Interaction										
C x *W*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]Means followed by the same letter within a column were not significantly different at the 0.05 level.
[NS]Nonsignificant.

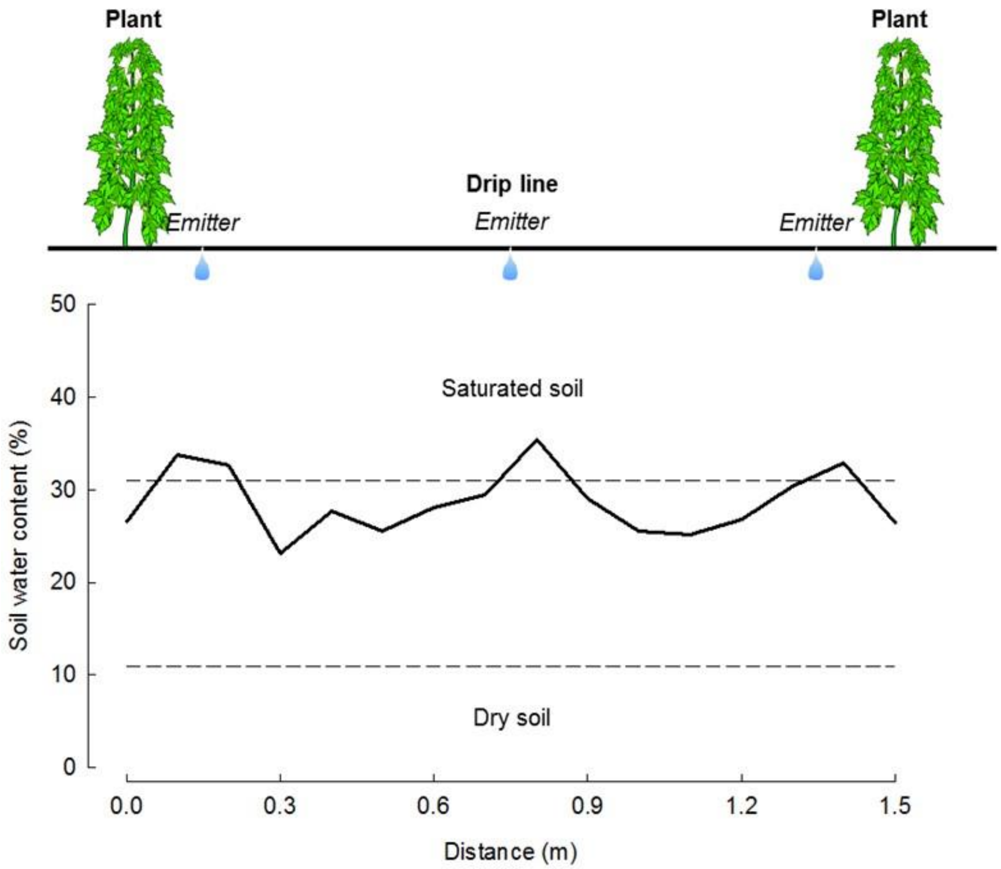

Fig. 2.1. Soil water content measured in the middle of the row between two hand-weeded blackberry plants. Plants were irrigated using a single lateral of drip tubing, with 1.9 L h^{-1} in-line emitters every 0.6 m, located near the base of the plants. Measurements were taken on 28 July 2010 (year 1), using a 0.15-m TDR probe, inserted vertically, at each 0.1-m increment between the plants. The data represent the mean of four plots and have a pooled SE of 3.3%. The lower dashed line represents the permanent wilting point, as defined by Saxton and Rawls (2006), and the upper dashed line represents field capacity.

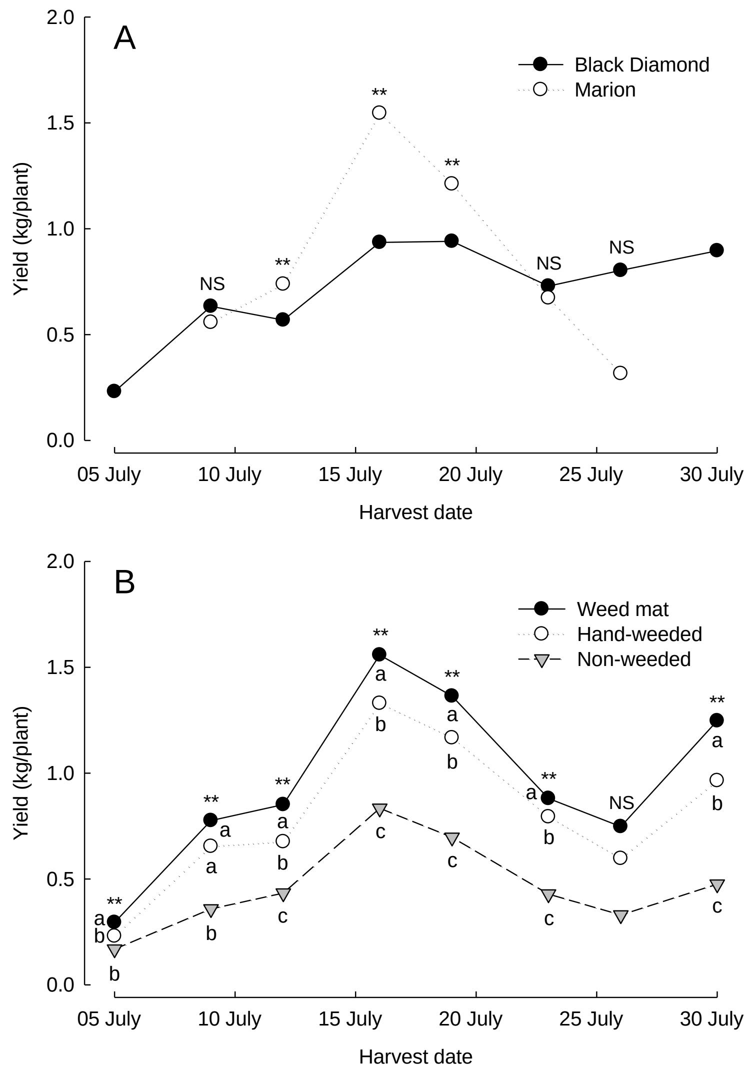

Fig. 2.2. Effects of cultivar (**A**) and weed management strategies (**B**) on marketable yield in 'Black Diamond' and 'Marion' trailing blackberry during the first year of fruit production in 2012. 'Black Diamond' was harvested from 5 July to 30 July, and 'Marion' was harvested from 9 July to 26 July. Each symbol represents the mean of five replicates. Weed management treatments were separated by Fisher's protected LSD on each date at the 5% level. ^{NS,**}Nonsignificant and significant at $P \leq 0.01$, respectively.

CHAPTER 4: Weed Management Practices for Organic Production of Trailing Blackberry. II. Plant Biomass and Nutrient Accumulation and Losses

Abstract

Weed management practices were evaluated in a new field of trailing blackberry (*Rubus* L. subgenus *Rubus* Watson) established in western Oregon. The field was planted in May 2010 and certified organic in May 2012. Treatments included two cultivars, 'Marion' and 'Black Diamond', grown in 1) non-weeded plots, 2) hand-weeded plots, hoed two to three times per year, and 3) weed mat plots, covered with black landscape fabric. Each treatment was fertilized with fish emulsion and irrigated by drip. Total biomass production of primocanes increased from 0.3 $t \cdot ha^{-1}$ in the planting year (2010) to 2.0 $t \cdot ha^{-1}$ the following year. Total above-ground biomass gain in 2012, the first fruiting year, averaged 4.0 $t \cdot ha^{-1}$. The dry weight (DW) biomass of harvested fruit was 1.4 $t \cdot ha^{-1}$ in non-weeded plots compared to 1.9 and 2.3 $t \cdot ha^{-1}$ in hand weeded and weed mat plots, respectively, and was not affected by cultivar. The proportion of above-ground DW biomass allocated to fruit averaged 40% in 'Marion' and 56% in 'Black Diamond' in weed-free plots, suggesting greater production efficiency in 'Black Diamond'. Floricane biomass removed at pruning was greatest in the weed mat plots and least in the non-weeded plots. Cultivars differed in tissue nutrient concentration, nutrient accumulation and loss. The primocanes of 'Marion' accumulated more N, P, K, Mg, S, Fe, Cu and Al per hectare than in 'Black Diamond'. Weeds reduced nutrient accumulation in primocanes. The accumulation of macro- and micronutrients was greater in the floricanes

than the primocanes. ‘Black Diamond’ had a greater %N, P, Mg, Ca and a lower %B in floricane leaves than did ‘Marion’, perhaps a result of nutrient concentration with less vigor. ‘Marion’ fruit had a greater concentration of Mg, Ca, and Zn and a lower %S and %B than ‘Black Diamond’ fruit. Plants grown with weed mat had a greater %Ca than those in non-weeded or hand-weeded plots. Nutrient concentration declined from June to August in the floricane tissue through loss in harvested fruit and remobilization during senescence. The net gain of N averaged 41 $kg \cdot ha^{-1}$ with weed control compared to 25 $kg \cdot ha^{-1}$ without weed control. The blackberry cultivars studied accumulated relatively high quantities of N, K, and Ca for growth and fruit production. Accumulation and loss of macro- and micro-nutrients of plants grown in hand weeded plots was intermediate to that of non-weeded and weed mat plots. Weed management strategies had inconsistent effects on soil and tissue nutrient concentration with the exception of %N which was reduced in the primocane and floricane leaves of non-weeded plots. Weed control increased biomass production and nutrient accumulation and losses in trailing blackberry.

Introduction

Recent surveys show a shift towards more organic blackberry (*Rubus* L. subgenus *Rubus*, Watson) production worldwide (Strik et al., 2007). In the United States, 74% of the 200 ha of organic blackberry area is planted in the coastal west (NASS, 2010). Some of the challenges to increased organic blackberry production include limited options for weed, insect, and disease management and fertilization. Because many organic management tools are often more expensive than their conventional counterparts, there tends to be a greater cost associated with organic production (e.g. Julian et al., 2011a and 2011b). Therefore management practices that minimize inputs and sustain good plant growth and yield are ideal for continued expansion of organic blackberry area.

Weed management is considered one the more difficult aspects of organic production. For example, in establishing plantings of ‘Black Diamond’ and ‘Marion’ trailing blackberry, the presence of weeds in the plant row reduced yield 40% compared to hand-weeded bare soil (Harkins et al., 2013), possibly due to competition for soil nutrients. Weed mat was an effective weed management tool in blueberry, increasing yield and net economic returns relative to plants mulched with sawdust (Larco et al., 2013a; Julian et al., 2012). In establishing blackberry, weed mat reduced weed management costs and increased yield 20% and 100% relative to plants grown in hand-weeded or non-weeded plots, respectively (Harkins et al., 2013). However, it not well understood why weed mat increased growth and yield in blackberry. Previous studies suggest the use of weed mat may improve soil temperature, increasing root growth or enhancing nutrient availability (Andersen and Crocker, 2008; Harkins et al., 2013; Julian et al., 2012; Larco et al., 2013a; Percival et al., 1998; Strik et al., 2006; Willard and Valenti, 2008).

According to Hart et al. (2006), the recommended rate of nitrogen (N) fertilizer application for conventionally grown trailing blackberry ranges from 34-56 $kg \cdot ha^{-1}$ during establishment, and 56-78 $kg \cdot ha^{-1}$ in mature plantings. The recommended rate of application for all other nutrients varies by soil type or soil nutrient concentration. Leaf tissue samples of the most recent, fully-expanded primocane leaves or soil samples can be used to determine nutrient sufficiency for blackberry plants (Hart et al., 2006). It is important to note that OMRI-approved (Organic Materials Review Institute) organic fertilizers are comprised of many nutrients, depending on the source of N. As a result, an array of macro- and micronutrients are applied during fertilization with N, regardless of plant and soil nutritive requirements.

Previous studies in caneberries have shown that changes in biomass and nutrient content vary by cultivar and cane management. Mohadjer et al. (2001) found that when ‘Kotata’ trailing blackberry was grown in a conventional, alternate year (AY) system, total plant biomass, excluding roots, reached 4,944 $kg{\cdot}ha^{-1}$ (1,389 $plants{\cdot}ha^{-1}$) in the off-year. In the on-year of their study, 2,222 $kg{\cdot}ha^{-1}$ of dry weight fruit biomass was removed at harvest and 3,430 $kg{\cdot}ha^{-1}$ of floricane biomass was removed at caning-out (pruning in August), consequently removing 37% and 58% of newly accumulated nitrogen (N), respectively (Mohadjer et al., 2001). ‘Meeker’ red raspberry (*Rubus idaeus* L.), accumulated 5,500 $kg{\cdot}ha^{-1}$ dry weight biomass in the aboveground plant (4,444 $plants{\cdot}ha^{-1}$), when grown in a conventional every-year (EY) production system, with 13% of the total N present removed in the harvested fruit and 17% in the prunings (Rempel et al., 2004). Biomass and N accumulation and losses in EY trailing blackberry and in organic production systems are not known.

Nutrient allocation in blackberry may also be a function of competition within plants. Floricane growth of ‘Chester Thornless’ and ‘Kotata’ blackberry was dependent on nutrient reserves, while fertilizer applications of N were integral to growth of the new primocanes (Malik et al., 1991; Mohadjer et al., 2001). Vegetative and reproductive components in blackberry compete for resources (Cortell and Strik, 1997) and thus the partitioning and accumulation of nutrients are likely related to sink strength. There has been no research to date on the partitioning, gains, and losses of macro- and micro-nutrients in organic blackberry systems.

The objective of the present study was to evaluate the effects of three different organic weed management strategies, including weed mat, hand weeding, and no weeding, on plant biomass and nutrient accumulation and losses during the establishment of organic trailing blackberry. Two popular cultivars for processing, ‘Marion’ and ‘Black Diamond’, were included in the study. Like all trailing types, the cultivars are perennial but the shoots are biennial, producing primocanes the first year, which then become floricanes with flowers and fruit the following year and then senesce after harvest. Mature plants will have both primocanes and floricanes in the same year in a typical annual or every-year production system (Julian et al., 2009; Strik and Finn, 2012).

Materials and Methods

Study site. The study was conducted at the North Willamette Research and Extension Center in Aurora, OR (long. 45°17' N, lat. 122°45' W; U.S. Dept. of Agriculture hardiness zone 8; elevation 46 m). The planting was established 26 May 2010 (Fig. 3.1). Soil at the site is mapped as a Willamette silt loam (fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll). It was sampled for analysis on 7 Aug. 2009 and had a soil pH of 5.3 and contained 3.6% organic matter, 1.5 ppm NO_3-N, 2.3 ppm NH_4-N, 188 ppm phosphorus (P), and 295 ppm potassium (K) in the top 0.2 m of the soil profile (Brookside Laboratories, Inc., New Knoxville, OH). The site was certified organic by Oregon Tilth (Salem, OR) in May 2012. More information regarding site preparation and planting can be found in Harkins et al., 2013.

Experimental design. The study was planted on 26 May 2010 using plants propagated from tissue-culture. 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 subplots, and a combination of three weed management strategies (weed mat, hand-hoeing, and no weeding) and two primocane training dates (August and February) as sub-subplots. Each sub-subplot consisted of four plants spaced 1.5-m apart in-row and was separated from plants in adjacent plots by 3.0 m (to provide space for clearing the machine harvester). Between row spacing was 3.0 m (2,222 plants/ha). The 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. However, irrigation and training treatments were not initiated until Aug. 2012 (year 3), and therefore, only cultivar and weed management treatments assigned to postharvest irrigation and August training (30 plots in total) were measured during the first 2 years after planting and are included in the present study.

A 1.4-m wide strip of black landscape fabric (water flow rate 6.8 L·h·m^2; 0.11 kg·m^2; TenCate Protective Fabrics, OBC Northwest, Inc. Canby, OR) was centered on the row of each weed mat plot and secured in place using 0.1-m long nails. Square openings (≈0.2 m x 0.2 m) were cut in the fabric for each plant.

Plants were trained on a two-wire vertical trellis in each row installed prior to planting. The lower trellis wire was attached to steel posts at 1.0 m above the ground, and the upper wire was attached at 1.6 m. Primocanes were tied to the trellis as they grew during first 2 years after planting, using paper twine, but were cut to the crown and removed in February after the first season to increase growth and improve vigor the following year (standard commercial practice; Fig. 3.1). Once the primocanes grew above the upper trellis wire in the second year, half the canes were looped in one direction down to the lower trellis wire and brought back towards the plant with one or two twists, and the other half was looped in the opposite direction (Strik and Finn, 2012). By year 3, plants had both primocanes and floricanes (the previous year's primocanes; Fig. 3.1). At this point, new primocanes were left on the ground alongside the row and, depending on the training date treatment, were tied to the trellis in either August or February.

Irrigation and fertilizer applications. Irrigation was applied using a single lateral of drip tubing (UNIRAM, Netafim USA, Fresno, CA) installed in each treatment plot immediately after planting. The tubing had 1.9 L·h^{-1} in-line, pressure-compensating emitters spaced every 0.6 m and was placed under the landscape fabric, at the base of the plants, in weed mat plots, and was attached to a third wire on the steel posts, located at 0.3 m above the ground, in hand-weeded and non-weeded plots. Each weed management treatment was irrigated independently using a manifold with electric solenoid valves and an automatic timer. Irrigation was scheduled weekly based on estimates of crop evapotranspiration (ET) and measurements of soil water content (Trase I time domain reflectometry [TDR] system, Soilmoisture Equipment Corp., Santa Barbara, CA), and primocane leaf water potential (Model 1000, PMS Equipment, Albany, OR) (Harkins et al., 2013). Weather conditions were cool and wet in the spring and warm and dry in the summer at the site, which is normal for western Oregon (Harkins et al., 2013).

Plants were fertilized using pelletized, processed poultry litter (4N–3P–2K–7Ca; Nutri-Rich; Stutzman Environmental Products Inc., Canby, OR) and Fish Agra (4N–1P–1K; Northeast Organics, Manchester-by-the-Sea, MA) in 2010 and TRUE 402 liquid fertilizer (4N–0P–2K; True Organic Products, Inc., Spreckels, CA) in 2011 and 2012. The Nutri-Rich was incorporated into the soil (~ 0.45 m diam.) at a rate of 28 kg·ha^{-1} N just prior to planting. Fish Agra was diluted with 10 parts water (v/v) and applied by hand, around the base of plants, in seven weekly applications of 4 kg·ha^{-1} N each from 14 July to 25 Aug. 2010 (28 kg·ha^{-1} total N). TRUE 402 was also diluted with 10 parts water but applied by fertigation (injection through the drip system) using a Mix-Rite TF10-002 fertilizer injector (DEMA, St. Louis, MO). Irrigation was run for 10 min prior to each injection to fully pressurize the system, and was run for an additional hour afterwards to flush the drip lines. Plants were fertigated with 8.0 kg·ha^{-1} N on 15 Apr. and 16 kg·ha^{-1} N each on 9 May and 1 and 20 June in 2011, and with 14 kg·ha^{-1} N each on 23 April, 8 May, and 7 and 13 June in 2012 (56 kg·ha^{-1} total N per year). Nutrient content of the fish emulsion fertilizer was analyzed at Brookside Laboratories and the nutrients applied each year calculated. The fish fertilizer contained 90%, 8%, and 2% organic-N, ammonium (NH_4-N), and nitrate (NO_3-N), respectively (data not shown).

Weed management. Weeds were hoed from hand-weeded plots and pulled from the planting hole area of weed mat plots on 20 Apr. and 8 June in 2011 and on 20 Mar., 8 May, and 25 June in 2012. The weeds were removed when relatively small, which is typical for commercial production. On 25 July 2011 and 27 June 2012 (just prior to fruit harvest) weeds were mowed to the ground in each plot using a string trimmer and the weed biomass left in the row. Information on weed cover and main species present is provided in Harkins et al., 2013.

Plant biomass. In Feb. 2011 and Jan. 2012 and 2013 a primocane from two plants per plot was randomly selected and oven-dried at 70 °C, and weighed. In Jan. 2013, a regression equation of primocane number (counted at 0.3 m height) to DW in 2011 was used to estimate DW in 2012 (Harkins et al., 2013).

Ripe fruit were harvested twice weekly in July 2012, using an over-the-row rotary harvester (Littau Harvesters Inc., Stayton, OR). At mid-harvest, a 60 g sub-sample of ripe fruit per treatment was shipped overnight to Brookside Laboratories to determine percent dry weight. The dry weight biomass of total harvested fruit per treatment was calculated.

A floricane was sampled from two plants per plot in Aug. 2012 (after harvest) and oven-dried at 70 °C, and weighed. The remaining floricanes were then cut to the crown, placed between rows, and flail mowed (standard commercial practice) and the new primocanes were then trained to the trellis wires (Fig. 3.1).

Effect of cultivar and weed management on tissue nutrient concentration. The tissue nutrient concentration of plant parts was determined by sending samples to Brookside Laboratories for analysis of N, phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sulfur (S), boron (B), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), and aluminum (Al). Total leaf N was determined by a combustion analyzer using an induction furnace and a thermal conductivity detector (Gavlak et al., 1994). All other nutrient concentrations were determined via inductively coupled plasma spectrophotometer (ICP) after wet ashing in nitric/perchloric acid (Gavlak et al., 1994). A sample of 10 of the most-recent fully expanded primocane leaves/plot was collected on 18 Aug. 2011 and 31 July 2012 (n=3) per standard recommendation (Hart et al., 2006). On 3 July 2012 (at first black stage of fruit), recent fully expanded leaves on fruiting laterals (floricanes) were sampled (10 leaves/plot). Ripe fruit (approx. 60 g fresh weight) were sub-sampled from a mid-harvest date for each treatment (n=3). Senescing floricanes, just before pruning (caning out) were sub-sampled (approx. 75 g/plot) to include cane and lateral tissue on 9 Aug. 2012 (n=3). Dormant primocane tissue was sub-sampled (75 g/plot) to include cane and any non-senescent leaves or petioles in Jan. 2011 and 2012. Nutrient concentrations in the primocane leaves were compared to standards (Hart et al., 2006) and primocanes and other tissues were analyzed for treatment effects.

Biomass and nutrient gains and losses. Total biomass (DW) for the above-ground plant and biomass per hectare (2,222 plants/ha) were calculated. Nutrient content of plant parts was calculated using nutrient concentration and DW data and a total nutrient content per plant and per hectare calculated. Nutrient gains are the total amount of a nutrient accumulated in the aboveground biomass in one year. Nutrient losses are the total amount of nutrients removed in the aboveground biomass in one year.

Soil analysis. Soil samples were collected on 7 Oct. 2011 and 23 Oct. 2012 using a 2.5 cm diameter stainless-steel soil probe. Soil collected for each treatment plot consisted of a pooled sample of two cores/plot. Soil cores were taken on each side of the row approx. 0.3 m from the crown of the two center plants. Soil was sampled from a depth of 0-0.3 m and was sent to Brookside Laboratories for analysis. Extractable soil sulfur (S), Ca, Mg, K, sodium (Na), B, Fe, Mn, Cu, Zn, Al, and P (Bray II extraction) were determined via ICP after extraction via the Mehlich 3 method (Mehlich, 1984). Soil organic matter was measured using Loss-On-Ignition at 360 ºC (Nelson and Sommers, 1996). Soil NO_3-N and NH_4-N were measured via automated colorimetric methods after extraction with 1 M KCl (Dahnke, 1990) and soil pH via the 1:1 soil:water method (McLean, 1982).

Data analysis. Analysis of all treatment effects was done as a complete factorial for a split-split plot design using the PROC GLM procedure in the SAS software package version 9.2 (SAS Institute, Cary, NC). The analysis was done by year due to differences in planting age and cane management. Means were separated at the 5% level using Fisher's protected LSD test.

Results

Effects of cultivar and weed management on tissue nutrients. In winter 2010-11, nutrient concentration of N, K, Ca, S, Mn, Zn, and Al in dormant primocane tissue (canes and non-senescent leaves) was greater in 'Black Diamond' than 'Marion', whereas the opposite was found for tissue Mg concentration (%Mg) (Table 1). Additionally, the %Fe, Cu, and Al were greater and the %K was less in the primocanes of plants grown in hand weed plots compared to weed mat (Table 2). These canes were removed in winter (Fig. 3.1) to encourage greater primocane growth in 2011. These primocanes, when sampled in the winter of 2011-12, had a greater %N, P, K, Mg, B, Fe, Cu, and Al, but a lower %Ca in 'Marion' than in 'Black Diamond' (Table 1). Plants growing in the non-weeded plots had a lower %N, K, S, Fe, and Al and greater %Cu and Zn in the dormant primocane tissue than plants grown in the hand weed plots. In weed mat plots, the %P was greater and the %Ca tended ($P = 0.062$) to be lower in dormant primocanes compared to those in the hand weeded plots (Table 1).

During the growing season of both years, ‘Marion’ primocane leaves had a greater %N, P, K, Mg, Ca, and S and a lower %Cu than in ‘Black Diamond’ (Table 2). The %B in primocane leaves was greater in ‘Marion’ than in ‘Black Diamond’ in 2011, but the opposite was found in 2012. While there was no effect of cultivar on %Fe, Mn, and Al in 2011, these nutrients were in greater concentration in ‘Black Diamond’ than in ‘Marion’ in 2012.

Weed management treatment affected primocane leaf nutrient concentration in both years (Table 2). In 2011, %N, P, K, S, Cu, and Zn were least and %Mn was greatest when plants were grown in the presence of weeds (non-weeded) compared to hand weed plots. In 2012, plants in non-weeded plots continued to have the lowest primocane leaf %N and S, but also had the lowest %Fe and Al. There was a significant cultivar by weed management interaction in 2012 for %Fe, because ‘Black Diamond’ had a greater %Fe than ‘Marion’ when grown in non-weeded or hand weed plots, but there was no difference between the cultivars in the weed mat plots (data not shown). Plants grown with weed mat had greater primocane leaf %P (2011), S, Cu (2011), and Zn (2011) and a lower %Al (2012) than when grown in hand weed plots (Table 2).

In July 2012, floricane leaf %N, P, Mg, Ca, S, Fe, Mn, Cu, Zn, and Al were greater and %B was lower in ‘Black Diamond’ than in ‘Marion’ (Table 3). Plants in non-weeded plots had a lower %N, P, Mg, Ca, S, and Cu than plants grown in hand weed plots (Table 3). There was a significant interaction of cultivar and weed management for floricane leaf %P and S, because ‘Black Diamond’ had a much greater leaf %P and S than ‘Marion’ when grown in the hand weed plots (Table 3). ‘Marion’ plants grown in the non-weeded plots had a higher floricane leaf %B than did ‘Black Diamond’; however cultivars did not differ in %B when grown in the hand weed or weed mat plots (data not shown).

By the time floricanes were pruned out in Aug. 2012, cane tissue (senescing cane and fruiting laterals) had greater %P, K, S, and Mn and lower %Mg and B in ‘Black Diamond’ than in ‘Marion’ (Table 1). There was no effect of weed management on nutrient concentration of floricanes at time of pruning.

Cultivar had more of an effect on fruit nutrient concentration than weed management (Table 1). ‘Marion’ had a greater ripe fruit %Mg, Ca, and Zn and a lower %S and B than ‘Black Diamond’. The %Ca of fruit was greater from plants grown with weed mat than from those in non-weeded or hand weed plots (Table 1). There was a cultivar by weed management interaction on fruit %Ca, because differences among cultivars were less in hand weed plots than in the non-weeded or weed mat plots (data not shown).

Differences in soil conditions associated with cultivar and weed management. Cultivar and weed management did not affect soil pH or organic matter content during the establishment years (Table 4). There was an inconsistent effect of cultivar on soil nutrient concentration. The soil in ‘Marion’ plots had a lower concentration of Mg in 2011 and B in 2012 and a higher concentration of Na in 2012 (Table 4).

The effects of the weed management treatments on soil nutrient concentration differed by year. Soil NH_4-N was greatest in the weed mat treatment in 2011, but weed management had no effect in 2012 (Table 4). The soil under weed mat had a greater P concentration in 2011 than in the non-weeded plots (Table 4). Soil Mg was greater in weed mat plots than in non-weeded or hand weed plots in both years, and weed mat had greater soil Ca in 2011 and soil K in 2012 (Table 4). There was relatively little effect of weed management on the concentration of micronutrients in the soil. Soil Mn was higher under weed mat than the other weed management treatments in both years and soil Al was lower under weed mat in 2012 (Table 4).

Effects of weed management and cultivar on biomass. The main effects of cultivar and weed management on DW and nutrient accumulation and losses are shown in Tables 6 and 7.

In the planting year (2010), primocanes on plants grown in weed mat plots had a greater %DW than those in hand weed plots (Table 1), but there was no effect of weed mat on total gain in biomass (Table 5). In 2011, ‘Marion’ primocanes had a greater %DW than ‘Black Diamond’ canes, but there was no effect of weed management (Table 2). The gain in primocane biomass per hectare was greater in ‘Marion’ than ‘Black Diamond’, and was least in the non-weeded plots (Table 5). In 2012, when primocanes grew in the presence of floricanes, primocane biomass at the end of the season was unaffected by cultivar or weed management, but was considerably less than what was produced the previous year.

The biomass of dormant primocanes (winter 2011-12) increased an average of 55% and 61% in ‘Marion’ and ‘Black Diamond’, respectively, as these canes grew as floricanes in their second year, 2012, and produced fruit (Table 5). Floricane biomass (canes plus fruit) was greater for ‘Marion’ plants of hand weed and weed mat plots, but floricane biomass was similar in non-weeded plots (Table 5). Total gain in biomass in 2012 was greater in weed mat plots ‘Marion’ plants than ‘Black Diamond’ plants, however both cultivars had similar, decreasing biomass gains in hand weed and non-weeded plots, respectively (Table 5). The DW biomass of fruit harvested per hectare was not affected by cultivar (Table 6), but ‘Black Diamond’ fruit had a lower %DW than ‘Marion’ fruit (Table 1). Harvested fruit biomass was significantly greater on plants grown with weed mat and least in non-weeded plots (Table 6). Fruit produced on plants growing with weeds (non-weeded) had a greater %DW than those grown with bare soil or with weed mat (Table 4). ‘Marion’ floricanes at pruning had a greater %DW and biomass than those of ‘Black Diamond’ (Table 1; Table 6). Additionally, weed management effect on floricane biomass which was least in non-weeded plots and greatest in weed mat plots (Table 6).

Effects of weed management and cultivar on nutrient gains and losses. In the planting year, there were few effects of weed management on nutrient accumulation in primocanes (Table 5). Plants in hand weeded plots accumulated more Fe and Al than those in weed mat plots. The nutrients accumulated in the above-ground plant in 2010 were removed at pruning prior to the 2011 growing season (Fig. 1).

In 2011, nutrient accumulation in the primocanes was significantly lower for plants grown in non-weeded plots than those grown with weed mat or in hand weeded plots (Table 5). More nutrients were accumulated in 'Marion' primocanes than in 'Black Diamond' primocanes, except for Ca, Mn, and Zn (Table 5). The above-ground accumulation of N was more than two-fold higher in plants grown with weed mat than those in non-weeded plots. Nutrient losses from leaf senescence in fall 2011 were not estimated; note that not all leaves senesce in this type of blackberry in the temperate climate of Oregon's Willamette Valley.

Estimated nutrient gain in the floricanes in 2012 (these were primocanes in 2011) was significantly greater in 'Marion' than 'Black Diamond' for Mg and B and less in 'Marion' for Ca (Table 5). Nutrient gain in the floricanes was affected by weed management for all nutrients except Mn and, in general, was greatest in the weed mat and least in the non-weeded plots.

The estimated gain in nutrients in the primocanes in 2012 was relatively low (e.g. 2.4 to 2.8 $kg \cdot ha^{-1}$ of N). 'Marion' accumulated greater P, Mg, B, Fe, Cu, and Al and less

Ca than ‘Black Diamond’. Weed management affected only the accumulation of micro-nutrients (Table 5). On average, the net nutrient gain of Mg, Ca, and B were greater in ‘Marion’ than in ‘Black Diamond’ in 2012. Nutrient gains were greatest in weed mat plots and least in the non-weeded plots (Table 5).

Above-ground plant nutrient losses in 2012 occurred in harvested fruit and floricanes at pruning in August (Table 6). ‘Marion’ plants lost more Ca and Zn and less S and B per hectare in harvested fruit than ‘Black Diamond’. The content of all nutrients in harvested fruit was least when plants were grown without weed control and greatest when plants were grown with weed mat (Table 6). In ‘Marion’, Ca in fruit at harvest was much greater with weed mat than in ‘Black Diamond’. In senescing floricanes, more N and Ca were removed at pruning in ‘Marion’, particularly when grown with weed mat, than in ‘Black Diamond’. In ‘Marion’, an additional 12.9 and 16.0 $kg \cdot ha^{-1}$ of N was removed in weed mat and hand weed plots, respectively, than in ‘Black Diamond’. These cultivars did not differ in N removed at pruning when grown in non-weeded plots. Nutrient removal at pruning was intermediate when plants were grown in hand weeded plots (Table 6). Net nutrient losses in 2012 were greater in ‘Marion’ for N, Mg, Ca, S, B, Fe, Cu, and Zn (Table 6). There was no difference in net loss of N and Ca between ‘Marion’ and ‘Black Diamond’ when plants were grown in non-weeded plots, but ‘Marion’ had greater losses of N with weed control (data not shown). Losses for all nutrients were least in the non-weeded and greatest in the weed mat plots. The estimated net nutrient “gain” for above-ground plant growth for 2012 was negative, as losses exceeded gains in both cultivars.

Discussion

Cultivar effects. Biomass. Total biomass production increased during establishment. In the planting year, plants produced an average of 0.3 $t \cdot ha^{-1}$ in primocane biomass with no cultivar effect; this biomass was removed the following winter, per standard commercial practice. The following year, ‘Marion’ plants produced an average of 22% more primocane biomass than ‘Black Diamond’. Plants grown with weed control produced slightly less biomass (2.2 to 2.5 $t \cdot ha^{-1}$) than mature ‘Kotata’ trailing blackberry grown in the “off year” (primocanes only), 3.3 $t \cdot ha^{-1}$ (Mohadjer et al., 2001).

Above-ground plant DW biomass increased an average of 2.4 $t \cdot ha^{-1}$ in plots with weed control as primocanes (in 2011) became floricanes (in 2012) and produced fruit in both cultivars. This value likely underestimates biomass gain in floricanes, because we measured floricane biomass after canes had started to senesce and there is evidence that stored reserves are translocated from senescing canes into the crown and roots (Mohadjer et al., 2001; Rempel et al., 2004). The resources for the gain in biomass as plants transitioned from primocane to floricane production would have been derived from stored reserves in the crown and roots and nutrients available in the soil and from fertilizer applied.

In 2012, the presence of floricanes and the associated fruit production reduced primocane DW biomass at the end of the season to 10% of what was produced in 2011. Mohadjer et al. (2011) reported that primocane biomass in the "on year" of AY production was only 30% of what was produced in the primocane growth only year. Primocanes, when growing in the presence of floricanes, had a lower leaf %N than in 2011, as has been shown by others (Mohadjer et al., 2001). Floricanes are a competing sink in trailing blackberry production systems and have been shown to reduce primocane growth (Cortell and Strik, 1997) and be a competing sink for nutrients (Malik et al., 1991; Mohadjer et al., 2001; Naraguma et al., 1999; Rempel et al., 2004). In biennial or alternate year cropping systems, primocane biomass has been greater than in annual cropping systems (Bell et al., 1995; Mohadjer et al., 2001; Wright and Waister, 1982).

The DW biomass of harvested fruit ranged from 1.9 to 2.3 $t{\cdot}ha^{-1}$ in plots with weed control and was not affected by cultivar. However, 'Black Diamond' produced fruit with a lower %DW and thus had a greater fresh fruit yield per hectare (Harkins et al., 2013). 'Black Diamond' plants required greater irrigation to maintain similar primocane leaf water potentials as 'Marion' plants (Harkins et al., 2013) and may have allocated more water to developing fruit. The proportion of above-ground DW biomass allocated to fruit averaged 40% in 'Marion' and 60% in 'Black Diamond' in weed-free plots, suggesting greater production efficiency in 'Black Diamond'.

The floricane biomass of 'Black Diamond' removed at pruning, averaged 3.2 $t{\cdot}ha^{-1}$, similar to what was reported for 'Kotata' in August (Mohadjer et al., 2001). Removal in ‘Marion’ was greater than previously observed, possibly due to a larger allocation of DW to the floricanes than fruit. At the end of the first fruiting year (2012), estimated above-ground net gain in weed-free plots in our study ranged from 4.3 to 5.5 $t{\cdot}ha^{-1}$ when subtracting primocane biomass produced in 2011 from the floricane, fruit and new primocane biomass produced in 2012. In mature ‘Kotata’ trailing blackberry grown in a conventional, alternate year production system, the gain in biomass in the fruiting year averaged 3.4 $t{\cdot}ha^{-1}$ (Mohadjer et al., 2001). Differences in DW removal in the floricanes may be attributed to plant spacing.

Nutrients. Primocane leaf tissue analysis during the growing season (Aug. 2011 and July 2012) indicated that leaves of ‘Black Diamond’ had a lower %N, P, K, Mg, and Ca than those of ‘Marion’. Others have also found that blackberry cultivars differ in primocane tissue nutrient concentration (Clark et al., 1985). Only the %B of primocane leaves was considered below the sufficiency level in both cultivars (Hart et al., 2006). In our study, ‘Black Diamond’ may have had a lower requirement for N, P, K, Mg and Ca for primocane growth than ‘Marion’. When nutrient concentration was coupled with biomass production, there was a lower accumulation of all of these nutrients, except for Ca, in the 2011 primocane growth year in ‘Black Diamond’.

Differences among cultivars in primocane tissue nutrient concentration continued through development as the dormant primocanes (2011-12) of ‘Black Diamond’ had a lower %N, P, K, and Mg, and also had a lower %B and greater %Ca than ‘Marion’ canes. However, when these canes transitioned to floricanes in 2012, the fruiting lateral leaves in ‘Black Diamond’ had a greater %N, P, Mg, Ca and a lower %B than those of ‘Marion’. These nutrients may have become more concentrated in ‘Black Diamond’ because of the reduced growth or vigor observed in this cultivar relative to ‘Marion’. In both cultivars, the mean concentration of Ca, B, Fe, Mn, and Al increased in the 2012 floricane lateral leaves compared to the 2011 primocane leaves, possibly because these nutrients are not mobile in plants. Previous studies in blackberry have only addressed N allocation; because N is mobile in plants, remobilization has been observed between floricanes and primocanes (Malik et al., 1991; Mohadjer et al., 2001; Naraguma et al., 1999). Remobilization may thus occur between floricanes and primocanes for other mobile nutrients. However, because Ca is immobile (Hanger, 1979), the greater %Ca in the 2012 floricane leaves than the 2011 primocane leaves in both cultivars may be a reflection of Ca accumulation in the fruiting lateral leaves.

The nutrient concentration of fruiting lateral leaves was not necessarily indicative of the fruit nutrient status. ‘Black Diamond’ fruit had a lower concentration of Mg, Ca, and Zn and a greater %S and %B than ‘Marion’ fruit, the opposite of what was found in the fruiting lateral leaves. There may have been a greater translocation of Ca to the fruit in ‘Marion’ than ‘Black Diamond’, for example. In apricot (*Prunus armeniaca* L.) as much as 55% of Ca accumulation in fruit was driven by transpiration (Montanaro, et al., 2010). The greater canopy biomass in ‘Marion’ relative to ‘Black Diamond’ likely increased transpiration and Ca uptake. The importance of fruit transpiration and the relative Ca uptake of fruit are not known in blackberry.

In 2012, the tissue nutrient concentration was higher in primocane leaves than in the floricane leaves for N (in 'Marion' only), P, K, S ('Marion'), Cu, and Zn, whereas Ca, B, Fe, Mn, and Al were more concentrated in the floricane leaves than the primocane leaves. Differences in leaf nutrient concentrations by cane were the result of nutrient movement within plants, differential uptake, or accumulation. During fruiting, the floricanes of 'Marion' may have had a greater demand for N because this cultivar is more vigorous than 'Black Diamond'; thus N may have been deficient in this cultivar.

The greater biomass accumulation in the 2011 primocanes of 'Marion' coupled with higher primocane nutrient concentrations led to a greater accumulation of N, P, K, Mg, S, Fe, Cu and Al per hectare than in 'Black Diamond'. The N accumulated in the 2011 primocanes (26 $kg \cdot ha^{-1}$ in 'Marion'), was similar to what was reported for mature 'Kotata' in the off-year (Mohadjer et al., 2001).

In all treatments in 2012, the accumulation of macro- and micronutrients was greater in the floricanes than the primocanes, indicating floricanes are a greater nutrient sink than primocanes. In a situation where a critical nutrient is limiting, preferential allocation to the floricane sink, would reduce primocane growth. Nutrient limitations may have been the result of an insufficient quantity of fertilizer applied and or poor timing of fertilization application.

There was no significant effect of cultivar on fruit N concentration which averaged 1.0%. However, because of differences in DW content, removal of N with fruit harvest tended to be greater in 'Black Diamond' than 'Marion' (19.9 and 17.1 $kg \cdot ha^{-1}$, respectively). Mohadjer et al. (2001) found that 32.8 $kg \cdot ha^{-1}$ of N was removed in harvested fruit of 'Kotata', likely a combination of the higher yield in their study (9.7 $kg \cdot plant^{-1}$ compared to 5.2 to 6.0 $kg \cdot plant^{-1}$; Harkins et al., 2013) and the higher %N of the ripe 'Kotata' fruit (averaged 1.7 %N). In our study, there was no effect of cultivar on the amount of N removed per ton of fresh fruit yield (averaged 1.5 $kg \cdot t^{-1}$ FW). However, when expressed per unit DW yield, more N tended to be removed in 'Black Diamond' (10.5 $kg \cdot t^{-1}$ DW) than in 'Marion' (8.9 $kg \cdot t^{-1}$ DW).

The mean concentration of N, Mg, Ca, S, B, Mn, and Cu declined from June in the floricane leaf tissue to August in the senescing floricane tissue, indicating a loss of nutrients. Some of this loss could be attributed to nutrient gains in the fruit. 'Black Diamond' foricanes had a greater concentration of P, K, S, and Mn and a lower %Mg and %B at pruning than 'Marion' canes.

The N removed when pruning the senescing floricanes was greater in 'Marion' (averaged 50.9 $kg \cdot ha^{-1}$ in plots with weed control) than 'Black Diamond' (36.4 $kg \cdot ha^{-1}$), due to differences in biomass as there was no cultivar effect on N concentration. Mohadjer et al. (2001) found that the N content of 'Kotata' floricanes declined from 36.5 $kg \cdot ha^{-1}$ in August (our pruning time) to October as N was remobilized from senescing floricanes to the crown and roots. In our study, we could not delay pruning as the new primocanes needed to be trained to the trellis by the end of August. While the N removed at pruning was called a "loss" to the plant in this study, commercial growers typically flail (chop) the prunings in the row middles; the nutrients in the spent floricanes would thus ultimately be returned to the soil and be available to the plant (Ledgard et al., 1992; Rempel et al., 2004). The net gain in N averaged 41 kg·ha^{-1} in 2012 with weed control, slightly less than what was reported for ‘Kotata’ in the fruiting year (Mohadjer et al., 2001).

Even though ‘Marion’ had a lower fresh yield (Harkins et al., 2013) and an equivalent DW yield than ‘Black Diamond’, ‘Marion’ had a greater accumulation of Mg, Ca, and B and a greater net loss of N, Mg, Ca, S, B, Fe, Cu and Al per hectare than ‘Black Diamond’. These findings suggest more growth and nutrient accumulation (and subsequent loss) was required per unit DW biomass of fruit production in ‘Marion’ than in ‘Black Diamond’.

Weed management effects. Biomass. There was no effect of weed management on primocane biomass in the planting year (2010), because weeds around plants were controlled to enhance establishment (Harkins et al., 2013). In 2011, plants grown in the presence of weeds produced 40 to 50% less primocane DW biomass than those grown in hand weed plots or with weed mat.

In 2012, plants in the non-weeded plots produced 26% to 39% less fruit biomass than plants grown in hand weed or weed mat plots, respectively. Treatment effects on DW biomass were similar to treatment effects on growth and yield (Harkins et al., 2013). Weed control was found to increase fresh yield 67% with hand-weeding and 100% with weed mat (Harkins et al., 2013). The proportion of above-ground DW biomass allocated to fruit was greatest for plants grown with no weed control (50%) and least for plants grown in with weed mat (43%), even though fresh weight yield was least in non-weeded plots (Harkins et al., 2013). Previous studies on berries similarly found that fresh yield was reduced by weeds (Burkhard et al. (2009) in blueberries, Bowen and Freyman (1995) in raspberries, and Forcella et al. (2003) in strawberries), but the proportion of DW allocated to the fruit is unknown.

Weed management strategy similarly affected primocane biomass in 2011 and floricane biomass the following year at pruning in 2012, with the exception of floricane biomass in weed mat plots which was significantly greater than that in hand weed plots. At the end of the first fruiting year (2012), estimated above-ground DW gain and loss was least in the non-weeded plots and greatest in the weed mat plots.

<u>Nutrients.</u> In 2011, lack of weed control reduced the %N, P, and K in primocane leaves in August and leaf %N was below recommended sufficiency levels only in non-weeded plots (Hart et al., 2006). Plants growing with weed mat had a higher primocane leaf %P than those in hand weed plots, perhaps because of the higher soil P under weed mat or enhanced root growth. Weed mat also decreased primocane %Ca, possibly a dilution effect as plants grown with weed mat had increased growth. In the following winter, the primocanes in the non-weeded plots continued to have the lowest %N and %K.

The greater growth and yield observed on plants grown with weed mat is similar to what has been reported for blueberry (*Vaccinium corymbosum* L.) and apple (*Malus x domestica* Borkh.) (Larco et al., 2013a; Nielsen et al., 2003). However, even though greater growth and fresh yield was observed in plants grown with weed mat than in hand weeded plots, there was no difference in DW biomass and little difference in nutrient gain or loss between weed mat and hand weeded plots. While the concentrations of NH_4-N, P, K, Ca, Mg, S, Mn, and Zn were greater in soil under the weed mat, findings were inconsistent across years. In addition, nutrients that were in a higher concentration under weed mat were not necessarily in a greater concentration in the primocane or floricane tissues. Weed mat has been shown to increase soil temperatures compared to organic mulches (Cox, 2009; Larco, 2010) and increase canopy temperatures during the day, often resulting in more plant water use (Allen et al., 1998; Harkins et al., 2013; Larco, 2010). Also soil porosity or water infiltration rates in blueberry (Cox, 2009) or apple (*Malus domestica* Borkh.; Neilsen et al., 2003) declined under weed mat. Blueberry plants grown with weed mat had reduced root growth but larger canopies (Larco et al., 2013a); all of these factors may affect soil nutrient availability and plant nutrient status. In contrast to our findings, weed mat has been found to reduce soil cation availability (Choi et al, 2011; Hostetler et al., 2007; Larco et al., 2013b; Neilsen et al., 2003). The weed management strategies being studied here may have a more dramatic impact on soil nutrients and plant growth over time as has been found by others (e.g. Choi et al., 2011; Neilsen et al., 2003). With the exception of soil B, no soil nutrients were below recommended sufficiency levels during this study and soil pH was with the range suggested for caneberries (Hart et al., 2006).

In 2011, plants growing with weed control accumulated an average of 27 $kg \cdot ha^{-1}$ of N in the primocanes compared to 12 $kg \cdot ha^{-1}$ without weed control. These plants also accumulated higher quantities of other macro- and micronutrients in the 2011 primocanes than those grown in non-weeded plots, mainly as a result of differences in DW biomass. There was little effect of weed management on the amount of accumulated N in the primocanes in 2012 even though primocanes growing in plots without weed control had a lower %N than those with weed control. Since new primocane growth is more dependent on new fertilizer N than stored N (Malik et al., 1991; Mohadjer et al., 2001; Naraguma et al., 1999), competition from weeds likely reduced the amount of N available at critical times for primocane growth in 2011 and 2012.

In June, the concentration of N, P, Mg, Ca, S, and Cu in the fruiting lateral leaves of plants growing in non-weeded plots was less than those grown in hand-weeded plots. Since stored N is used predominantly for floricane growth rather than new primocane growth (Malik et al., 1991; Mohadjer et al., 2001; Naraguma et al., 1999), the stored N in roots, crown, and over-wintering primocanes may have been low in non-weeded plots leading to lower fruiting lateral leaf %N. However, by the time floricanes were removed in August, there was no effect of weed management on nutrient concentration. In fruit, %Ca was the only nutrient affected by weed management strategy and was greater when plants were grown with weed mat. Again, the greater biomass in plants grown with weed mat likely increased transpiration and Ca uptake. Even though irrigation was managed such that the primocane leaf water potential in the different weed management strategies did not differ, floricane leaf water potential was not measured and canes appear to be hydraulically independent in blackberry (Bryla and Strik, 2008). The floricanes in the non-weeded plots may have been stressed for water as a result of weed competition, also reducing nutrient uptake.

There was no effect of weed management on fruit %N, but differences in fruit DW biomass led to 12.6 $kg \cdot ha^{-1}$ of N removed in fruit harvested from plants in non-weeded plots compared to 17.8 $kg \cdot ha^{-1}$ and 25.2 $kg \cdot ha^{-1}$ of N in hand weeded and weed mat plots, respectively. The amount of N removed in fresh fruit was lower in hand weed plots (averaged 1.3 $kg \cdot t^{-1}$ FW) than in the other treatments (averaged 1.6 $kg \cdot t^{-1}$ FW) (Harkins et al., 2013). However, when expressed per unit DW yield, more N was removed in weed mat treatments (10.8 $kg \cdot t^{-1}$ DW) than in the other weed management strategies (9.2 $kg \cdot t^{-1}$ DW). The net gain of N averaged 41 $kg \cdot ha^{-1}$ with weed control compared to 25 $kg \cdot ha^{-1}$ without weed control.

There was a lower net accumulation of all nutrients, except Mn, in plants grown in non-weeded plots in 2012 than those grown with weed control and as a result net losses (from fruit harvest and pruning) was significantly lower for all macro- and micronutrients in non-weeded plots. Accumulation and loss of macro- and micro-nutrients of plants grown in hand weeded plots was intermediate to that of non-weeded and weed mat plots. Based on our findings, to date, it is not clear why plants grown with weed mat had a greater nutrient accumulation and loss than those in hand weeded plots. There were few consistent effects of weed mat on soil nutrient availability during these establishment years. More research is needed on the impact of weed mat on soil temperature, root growth, and nutrient availability. In the hand weeded plots, weeds were managed when they were of sufficient size to hoe; it is possible that there was some level of weed competition in these plots also (Harkins et al., 2013).

Plants grown with weed mat, which had the greatest biomass production and yield, had a net accumulation (in 2012) of 47 kg·ha^{-1} of N, 9 kg·ha^{-1}of P; 66 kg·ha^{-1} of K; and 40 kg·ha^{-1} of Ca. Nutrient requirements of 'Marion' plants were generally similar to 'Black Diamond' except 'Marion' plants accumulated 9 kg·ha^{-1} and 36 kg·ha^{-1} of Mg and Ca, respectively (compared to 5 and 25 kg·ha^{-1} in 'Black Diamond') and 192 g·ha^{-1} of B compared to 85 g·ha^{-1} in 'Black Diamond'.

Net biomass or nutrient gain may have been grossly underestimated as we did not measure growth of the roots or crown. Blackberry roots have been found to account for 26% (Naraguma et al., 1999) to 41% (Malik et al. 1991) of total plant biomass and serve as an important source of nutrient reserves. For example, blackberry and raspberry have been shown to use up to 30% and 40% of N stored in the crown and roots, respectively, for new growth (Mohadjer et al., 2001; Rempel et al., 2004). In addition, we did not estimate the amount of nutrients lost at leaf senescence. In trailing blackberry grown in the mild climate of Oregon's Willamette Valley, not all primocane leaves senesce prior to spring growth (then floricanes).

While nutrients applied (Table 1) exceeded accumulation in 2010-2011, this was not the case in 2012 considering likely inefficiencies in fertilizer uptake (e.g. Bañados et al., 2012; Malik et al. 1991; Mohadjer et al., 2001; Naraguma et al., 1999; Rempel et al., 2004). Nitrogen in particular, as it is required for early primocane growth (Mohadjer et al., 2001), may have been deficient early in the season as fertilization started after primocane emergence in 2012, 12 d later than in 2011. It is likely that N was particularly deficient in non-weeded plots, based on leaf %N and declining soil N over the length of the study. Since all of the weed management treatments during establishment received the same rate of fertilizer N, we do not know if growth and production in the non-weeded plots could have been improved if this weed management strategy had received higher rates of fertilizer N relative to the weed control treatments.

The amount of B applied during fertilization was insufficient considering the below recommended soil B concentration and primocane leaf %B. Additional fertilization with B would be required to avoid B deficiency symptoms. The long-term effects of high rates of K applied in the hydrolyzed fish fertilizer will need further study, particularly as high soil K may interfere with Ca uptake. While we found that blackberry have a relatively large requirement for K, the net gain and loss in Ca was also relatively high.

Summary. Total biomass production increased during planting establishment. Above-ground gain in biomass was greater in 'Marion' than in 'Black Diamond' in 2011 when only primocanes were produced, but there was no cultivar effect on DW biomass accumulation and loss in the fruiting year. Weed control increased cane and fruit biomass, tissue nutrient concentration, and nutrient accumulation and loss. Floricanes were a sink, reducing primocane biomass and nutrient concentration. 'Black Diamond' may have greater production efficiency, allocating a greater proportion of biomass to fruit production. Production efficiency was also greatest in non-weeded plots and least in weed mat plots. While nutrient concentration did differ among tissues, biomass had the largest impact on nutrient accumulation and loss. In all treatments in 2012, the mean accumulation of nutrients was greater in the floricanes than the primocanes. Nutrient concentration declined from June to August in the floricane tissue through loss in harvested fruit and remobilization during senescence. The blackberry cultivars studied accumulated relatively high quantities of N, K, and Ca for growth and fruit production. Nutrient gains may have exceeded fertilizer nutrients available in the fruit production year. Our findings suggest more biomass production and nutrient uptake was required per unit of DW fruit production in 'Marion' than in 'Black Diamond'. The response of plants grown in hand weeded plots was intermediate to that of non-weeded and weed mat plots. More research is needed to assess and understand the effects of weed mat on blackberry plant growth and nutrient accumulation.

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Table 3.1. The main effects of cultivar and weed management on aboveground biomass percent dry weight (DW) and nutrient concentration of primocane and floricane tissues in organic trailing blackberry, 2010-2012.

	DW	Macronutrients (%)						Micronutrients (ppm)					
2010 Primocanes[z]	(%)	N	P	K	Mg	Ca	S	B	Fe	Mn	Cu	Zn	Al
Cultivar (*C*)													
Black Diamond	59.5	1.9	0.2	0.7	0.16	0.8	0.10	22.7	926.3	542.8	9.2	78.6	861.7
Marion	56.8	1.7	0.2	0.6	0.17	0.4	0.08	23.5	516.9	290.3	8.7	61.7	481.7
Significance	0.01	0.01	NS[y]	<.0001	0.003	<.0001	<.0001	NS	NS	<.0001	NS	<.0001	0.04
Weed management (*W*)													
Hand weed	56.8	1.8	0.2	0.6	0.2	0.6	0.1	23.1	966.0	424.9	9.3	71.5	894.9
Weed mat	61.0	1.8	0.2	0.7	0.2	0.6	0.1	23.0	232.9	399.9	8.2	67.3	225.3
Significance	0.001	NS	NS	0.005	NS	NS	NS	NS	<.0001	NS	0.02	NS	<.0001
Interactions													
CxW	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2011 Primocanes[x]													
Cultivar (*C*)													
Black Diamond	51.0	1.0	0.13	0.65	0.11	0.53	0.06	13.9	69.0	139.3	3.8	31.3	61.1
Marion	57.6	1.2	0.15	0.71	0.13	0.47	0.06	17.7	107.8	138.8	5.6	30.6	101.3
Significance	0.0001	0.04	<.0001	0.002	<.0001	0.0001	NS	<.0001	0.001	NS	<.0001	NS	0.002
Weed management (*W*)													
Non-weeded	55.1	1.0 b[w]	0.14 b	0.61 b	0.12	0.51	0.05 b	15.7	70.8 b	126.5	5.2 a	35.9 a	63.6 b
Hand weed	53.3	1.1 a	0.14 b	0.70 a	0.11	0.52	0.06 a	15.5	117.6 a	149.1	4.3 b	28.7 b	113.3 a
Weed mat	54.5	1.2 a	0.15 a	0.74 a	0.12	0.48	0.06 a	16.2	76.8 b	141.5	4.7 b	28.3 b	66.7 b
Significance	NS	0.003	0.003	<.0001	NS	NS	0.0003	NS	0.002	NS	0.004	0.02	0.002
Interactions													
CxW	NS	0.049	NS	NS	NS	NS	NS	NS	0.02	NS	NS	NS	0.01
2012 Floricanes[v]													
Cultivar (*C*)													
Black Diamond	48.5	1.0	0.2	1.3	0.16	0.9	0.07	26.5	159.7	266.3	4.0	50.0	153.3
Marion	52.7	0.9	0.1	0.9	0.19	0.9	0.06	44.1	145.1	197.9	3.8	37.6	146.3
Significance	<.0001	NS	0.03	<.0001	0.01	NS	0.046	<.0001	NS	0.03	NS	NS	NS
Weed management (*W*)													
Non-weeded	51.4 b	0.9	0.1	1.0	0.17	0.9	0.06	33.8	160.3	260.0	3.7	43.3	153.3
Hand weed	50.5 ab	1.0	0.1	1.1	0.18	0.9	0.06	36.5	159.2	230.5	4.0	52.0	158.6
Weed mat	49.5 a	1.0	0.1	1.1	0.17	0.9	0.06	35.6	137.7	205.8	4.0	36.2	137.4
Significance	0.047	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interactions													
CxW	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fruit 2012[u]													
Cultivar (*C*)													
Black Diamond	13.5	1.1	0.2	1.1	0.10	0.17	0.07	12.3	35.7	44.3	5.2	13.4	89.6
Marion	16.1	0.9	0.2	1.0	0.12	0.23	0.06	9.2	37.2	45.4	5.1	15.5	86.1
Significance	0.0001	NS	NS	NS	0.018	<.0001	0.001	0.002	NS	NS	NS	0.017	NS
Weed management (*W*)													
Non-weeded	15.7 b	0.9	0.2	1.0	0.11	0.19 b	0.06	10.1	32.7	46.0	4.9	13.7	74.2
Hand weed	14.3 a	1.0	0.2	1.0	0.11	0.19 b	0.07	10.6	41.3	44.6	5.3	14.4	97.9
Weed mat	14.2 a	1.1	0.2	1.1	0.11	0.21 a	0.07	11.6	35.3	43.9	5.3	15.1	91.5
Significance	0.02	NS	NS	NS	NS	0.01	NS	NS	NS	NS	NS	NS	NS
Interactions													
CxW	NS	NS	NS	NS	NS	0.02	NS	NS	NS	NS	NS	NS	NS

[z]Collected Feb. 2011.
[y]NS=non significant
[x]Collected Feb. 2012.
[w]Mean separation (in columns) by LSD test at $P \leq 0.05$ (lowercase letters)
[v]Collected July 2012.
[u]Collected 9 Aug. 2012.

Table 3.2. The main effects of cultivar and weed management on primocane leaf macro- and micronutrient concentration on 18 Aug. 2011 and 31 July 2012.

	Macronutrients (%)						Micronutrients (ppm)					
	N	P	K	Mg	Ca	S	B	Fe	Mn	Cu	Zn	Al
2011												
Cultivar (*C*)												
Black Diamond	2.3	0.24	1.3	0.26	0.3	0.12	19.9	93.2	117.5	10.3	28.4	58.7
Marion	3.0	0.31	1.8	0.31	0.5	0.15	23.7	84.2	113.4	8.7	32.9	50.0
Significance	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	NS[z]	NS	<.0001	0.0001	NS
Weed management (*W*)												
Non-weeded	2.2 b[y]	0.23 c	1.4 b	0.29	0.5	0.11 c	22.8	81.2	141.7 a	8.5 c	26.5 c	52.9
Hand weed	2.9 a	0.28 b	1.6 a	0.28	0.4	0.14 b	21.3	108.3	107.8 b	9.4 b	30.6 b	71.8
Weed mat	3.0 a	0.31 a	1.6 a	0.29	0.4	0.15 a	21.3	76.5	96.8 b	10.6 a	34.9 a	38.4
Significance	<.0001	<.0001	<.0001	NS	NS	<.0001	NS	NS	<.0001	<.0001	<.0001	NS
Interactions												
C x *W*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2012												
Cultivar (*C*)												
Black Diamond	2.0	0.26	1.4	0.30	0.4	0.130	18.3	101.5	174.4	8.4	25.5	68.0
Marion	2.6	0.35	1.6	0.32	0.5	0.144	14.7	74.8	140.1	6.5	31.3	42.1
Significance	<.0001	<.0001	<.0001	0.0004	0.0003	<.0001	<.0001	<.0001	0.0003	<.0001	<.0001	<.0001
Weed management (*W*)												
Non-weeded	2.2 b	0.30	1.4	0.31	0.4	0.131 c	17.3	76.5 b	172.9	7.3	27.7	44.4 b
Hand weed	2.3 ab	0.30	1.5	0.30	0.4	0.137 b	16.1	102.2 a	147.0	7.6	28.4	70.8 a
Weed mat	2.4 a	0.31	1.5	0.31	0.4	0.144 a	16.1	85.7 b	151.9	7.4	29.1	50.0 b
Significance	0.02	NS	NS	NS	NS	0.0001	NS	0.001	NS	NS	NS	0.001
Interactions												
C x *W*	NS	NS	NS	NS	NS	NS	NS	0.03	NS	NS	NS	NS

[z]NS=Non significant

[y]Mean separation (in columns) by LSD test at $P \leq 0.05$ (lowercase letters)

Table 3.3. The main effects of cultivar and weed management on floricane leaf macro- and micronutrient concentration, on 3 July 2012.

	Macronutrients (%)						Micronutrients (ppm)					
	N	P	K	Mg	Ca	S	B	Fe	Mn	Cu	Zn	Al
Cultivar (*C*)												
Black Diamond	2.5	0.23	1.2	0.33	1.6	0.14	46.8	139.3	577.0	6.31	26.5	117.7
Marion	1.5	0.15	1.2	0.26	1.0	0.09	57.8	88.4	268.0	4.31	18.0	73.5
Significance	<.0001	<.0001	NS[z]	0.0002	<.0001	<.0001	0.001	<.0001	<.0001	<.0001	0.01	0.0001
Weed management (*W*)												
Non-weeded	1.8 b[y]	0.16 b	1.2	0.27 b	1.2 b	0.10 b	52.0	127.2	446.3	4.8 b	22.5	99.2
Hand weed	2.1 a	0.22 a	1.2	0.31 a	1.4 a	0.12 a	53.9	104.8	461.8	5.5 a	22.8	103.8
Weed mat	2.2 a	0.19 c	1.2	0.29 ab	1.3 ab	0.12 a	51.0	109.7	359.3	5.6 a	21.4	83.8
Significance	0.01	0.0003	NS	0.04	0.03	0.001	NS	NS	NS	0.01	NS	NS
Interactions												
C x *W*	NS	0.003	NS	NS	NS	0.03	0.02	NS	NS	NS	NS	NS

[z]NS=non significant

[y]Mean separation (in columns) by LSD test at $P \leq 0.05$ (lowercase letters)

Table 3.4. Main effects of cultivar and weed management on soil pH, organic matter, and nutrient concentration. Soil was sampled (0-0.3 m) on 7 Oct. 2011 and 20 Oct. 2012.

	Soil		Soil nutrients													
			--------------------ppm--------------------				---------------meq·100g soil^{-1}-------------				--------------------------------ppm--------------------------------					
	pH	Organic matter (%)	NO_3	NH_4	P	S	K	Ca	Mg	Na	Fe	B	Cu	Mn	Zn	Al
2011																
Cultivar (*C*)																
Black Diamond	5.7	2.6	1.4	1.3	258.5	19.6	0.64	5.10	1.20	0.22	294.7	0.4	0.8	19.9	2.0	1391.1
Marion	5.6	2.6	1.3	1.6	270.6	20.4	0.62	4.86	1.09	0.21	305.0	0.4	0.8	19.8	2.1	1407.7
Significance	NS[z]	NS	NS	NS	NS	NS	NS	NS	0.04	NS	NS	NS	NS	NS	NS	NS
Weed management (*W*)																
Non-weeded	5.5	2.5	1.2	1.3 b[y]	249.7 b	19.6	0.62	4.72 b	1.08 b	0.20	298.8	0.4	0.8	18.4 b	1.7 b	1402.9
Hand-weed	5.6	2.6	1.4	1.3 b	267.2 ab	18.8	0.63	4.90 b	1.07 b	0.22	298.9	0.4	0.8	17.8 b	2.0 b	1415.3
Weed mat	5.7	2.7	1.5	1.9 a	276.8 a	21.6	0.65	5.32 a	1.28 a	0.22	302.0	0.4	0.8	23.3 a	2.5 a	1380.0
Significance	NS	NS	NS	0.01	0.02	NS	NS	0.005	0.002	NS	NS	NS	NS	<.0001	0.003	NS
Interactions																
C x *W*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2012																
Cultivar (*C*)																
Black Diamond	5.6	2.8	0.8	2.7	415.1	16.0	0.62	4.94	1.09	0.12	303.2	0.6	0.8	20.8	2.6	1360.3
Marion	5.7	2.7	0.7	2.8	423.3	16.4	0.58	4.92	1.08	0.15	307.0	0.5	0.7	19.6	2.3	1376.4
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.03	NS	<.0001	NS	NS	NS	NS
Weed management (*W*)																
Non-weeded	5.6	2.7	0.7	2.7	408.6	15.4 b	0.59 b	4.94	1.06 b	0.14	304.8	0.6	0.7	19.1 b	2.2	1373.8 ab
Hand-weed	5.6	2.7	0.6	2.5	419.1	14.9 b	0.55 b	4.86	1.01 b	0.12	305.1	0.5	0.7	18.2 b	2.4	1394.6 a
Weed mat	5.7	2.8	0.9	3.0	429.9	18.3 a	0.66 a	5.00	1.19 a	0.14	305.4	0.5	0.8	23.3 a	2.8	1336.8 b
Significance	NS	NS	NS	NS	NS	0.008	0.0002	NS	0.03	NS	NS	NS	NS	0.0002	NS	0.04
Interactions																
C x *W*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]NS=Non significant

[y]Mean separation (in columns) by LSD test at P ≤ 0.05 (lowercase letters)

Table 3.5. The main effects of cultivar and weed management on plant dry weight (DW) and macro- and micronutrient gains in organic trailing blackberry during establishment, 2010-2012.

	DW	Macronutrient gains (kg·ha^{-1})						Micronutrient gains (g·ha^{-1})					
	(t·ha^{-1})	N	P	K	Mg	Ca	S	B	Fe	Mn	Cu	Zn	Al
2010													
Primocanes													
Cultivar (*C*)													
Black Diamond	0.3	5.5	0.5	2.1	0.5	2.5	0.3	6.7	274.9	160.8	2.7	23.0	255.3
Marion	0.3	5.4	0.6	1.9	0.5	1.3	0.2	7.4	141.7	87.3	2.7	18.9	132.9
Significance	NS[z]	NS	NS	NS	NS	<.0001	0.01	NS	NS	<.0001	NS	0.01	0.04
Weed management (*W*)													
Hand weed	0.3	5.6	0.6	2.0	0.5	2.0	0.3	7.3	280.4	128.0	2.9	21.9	260.1
Weed mat	0.3	5.2	0.5	2.0	0.5	1.8	0.3	6.6	64.2	116.1	2.3	19.0	62.2
Significance	NS	NS	NS	NS	NS	NS	NS	NS	0.0001	NS	0.03	NS	<.0001
Interactions													
CxW	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2011													
Primocanes													
Cultivar (*C*)													
Black Diamond	1.8	18.4	2.3	11.9	1.9	9.4	1.0	24.6	118.0	244.9	6.7	53.0	103.6
Marion	2.2	25.7	3.4	16.1	2.8	10.1	1.3	38.2	249.6	296.9	12.3	64.3	237.3
Significance	0.047	0.01	0.00	0.01	0.00	NS	0.03	0.0001	0.002	NS	<.0001	NS	0.004
Weed management (*W*)													
Non-weeded	1.3 b	12.3 b	1.7 b	7.9 b	1.4 b	6.3 b	0.7 b	20.1 b	86.4 b	184.2 b	5.5 b	41.7 b	76.8 b
Hand weed	2.2 a	24.7 a	3.1 a	15.8 a	2.7 a	11.3 a	1.3 a	35.9 a	268.1 a	312.8 a	10.6 a	64.4 a	260.7 a
Weed mat	2.5 a	29.2 a	3.7 a	18.2 a	2.9 a	11.5 a	1.5 a	38.2 a	196.9 a	315.7 a	12.6 a	69.9 a	173.8 ab
Significance	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.003	0.003	<.0001	0.002	0.01
Interactions													
CxW	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2012													
Floricanes (fruit & laterals)[x]													
Cultivar (*C*)													
Black Diamond	3.3	33.2	6.3	50.3	4.9	23.2	2.5	81.3	458.3	646.3	15.8	125.9	562.5
Marion	4.3	32.7	5.9	44.6	8.3	15.7	2.6	187.4	449.4	750.2	14.9	138.3	551.0
Significance	0.0004	NS	NS	NS	<.0001	0.00	NS	<.0001	NS	NS	NS	NS	NS
Weed management (*W*)													
Non-weeded	2.0 c	22.5 c	3.8 c	28.8 c	4.3 c	18.4 c	1.6 c	80.9 c	338.6 b	511.4 b	10.0 c	76.6 b	387.6 c
Hand weed	4.1 b	32.1 b	6.3 b	49.3 b	6.8 b	29.4 b	2.6 b	141.7 b	451.2 ab	709.0 ab	16.0 b	170.8 a	550.6 b
Weed mat	5.3 a	44.2 a	8.3 a	64.2 a	8.7 a	39.3 a	3.4 a	180.4 a	571.9 a	874.3 a	19.9 a	148.7 a	732.1 a
Significance	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0001	0.01	NS	<.0001	0.02	0.001
Interactions													
CxW	0.004	NS	NS	NS	0.04	NS	NS	0.02	NS	NS	NS	NS	NS
Primocanes													
Cultivar (*C*)													
Black Diamond	0.2	2.5	0.3	1.6	0.27	1.3	0.1	3.4	16.7	33.8	0.9	7.6	14.8
Marion	0.2	2.7	0.4	1.7	0.31	1.1	0.1	4.2	24.9	32.7	1.3	7.3	23.3
Significance	NS	NS	0.02	NS	0.002	0.01	NS	0.0003	<.0001	NS	<.0001	NS	<.0001
Weed management (*W*)													
Non-weeded	0.3	2.4	0.4	1.6	0.29	1.3	0.1	3.9	17.9 b	37.6 a	1.1 ab	9.0 a	16.1 b
Hand weed	0.2	2.6	0.3	1.6	0.29	1.2	0.1	3.7	26.4 a	32.2 b	1.0 b	6.6 b	25.3 a
Weed mat	0.2	2.8	0.4	1.8	0.29	1.1	0.1	3.7	18.2 b	30.0 b	1.2 a	6.7 b	15.8 b

Significance	NS	NS	NS	NS	NS	NS	NS	NS	<.0001	0.003	0.04	<.0001	<.0001
Interactions													
CxW	NS	NS	NS	NS	NS	NS	NS	NS	<.0001	NS	NS	NS	<.0001
Gains 2012													
Cultivar (*C*)													
Black Diamond	3.5	35.7	6.6	51.9	5.2	24.5	2.6	84.7	475.1	680.1	16.7	133.4	577.4
Marion	4.6	35.4	6.3	46.2	8.6	36.0	36.0	191.5	474.3	782.9	16.2	145.5	574.3
Significance	0.0004	NS	NS	NS	<.0001	0.001	NS	<.0001	NS	NS	NS	NS	NS
Weed management (*W*)													
Non-weeded	2.3 c	24.9 c	4.1 c	30.3 c	4.6 c	19.7 c	1.8 c	84.8 c	356.5 b	549.0	11.1 c	85.7 b	403.7 c
Hand weed	4.3 b	34.7 b	6.7 b	50.9 b	7.1 b	30.6 b	2.7 b	145.4 b	477.5 ab	741.2	17.1 b	177.4 a	575.9 b
Weed mat	5.5 a	47.1 a	8.6 a	65.9 a	9.0 a	40.4 a	3.6 a	184.1 a	590.1 a	904.3	21.2 a	155.4 a	747.9 a
Significance	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0001	0.01	NS	<.0001	0.03	0.001
Interactions													
CxW	0.01	NS	NS	NS	0.04	NS	NS	0.02	NS	NS	NS	NS	NS

[z]NS=Non Significant

[y]Mean separation (in columns) by LSD test at P ≤ 0.05 (lowercase letters)

[x]Calculated by: Net floricane accumlation = ([Floricanes 2012 - Primocanes 2011] + Fruit 2012)

Table 3.6. The main effects of cultivar and weed management on plant dry weight (DW) and macro- and micronutrient losses in organic trailing blackberry during establishment, 2010-2012.

	DW	Macronutrient removal (kg·ha^{-1})						Micronutrient removal (g·ha^{-1})					
	(t·ha^{-1})	N	P	K	Mg	Ca	S	B	Fe	Mn	Cu	Zn	Al
2012													
Fruit													
Cultivar (*C*)													
Black Diamond	1.9	19.9	3.7	20.8	1.9	3.1	1.4	22.9	66.5	80.7	9.9	25.1	173.4
Marion	1.9	17.1	3.7	18.0	2.2	4.3	1.2	17.5	69.7	86.7	9.5	29.3	159.3
Significance	NS	NS	NS	NS	NS	0.000	0.041	0.005	NS	NS	NS	0.04	NS
Weed management (*W*)													
Non-weeded	1.4	12.6 c	2.7 c	13.3 c	1.4 c	2.6 c	0.9 c	13.9 c	44.6 b	64.0 c	6.7 b	18.8 c	98.4 b
Hand weed	1.9	17.8 b	3.7 b	19.5 b	2.0 b	3.7 b	1.3 b	19.8 b	77.7 a	84.6 b	10.0 a	27.2 b	188.5 a
Weed mat	2.3	25.2 a	4.7 a	25.2 a	2.7 a	5.0 a	1.7 a	26.9 a	82.0 a	102.4 a	12.4 a	35.5 a	212.2 a
Significance	0.01	0.0003	0.0003	0.0002	0.0003	<.0001	0.001	0.0002	0.003	0.002	0.01	0.0001	0.03
Interactions													
CxW	NS	NS	NS	NS	NS	0.006	NS	NS	NS	NS	NS	NS	NS
Floricanes													
Cultivar (*C*)													
Black Diamond	3.2	31.4	4.9	41.1	4.8	29.1	2.1	82.3	505.0	802.9	12.6	152.7	488.4
Marion	4.6	40.9	5.5	42.6	8.9	40.3	2.7	206.4	623.5	951.5	17.6	171.8	623.3
Significance	<.0001	0.001	NS	NS	<.0001	0.001	0.004	<.0001	0.048	NS	NS	NS	0.03
Weed management (*W*)													
Non-weeded	2.5 c	21.9 c	2.8 c	23.2 c	4.2 b	22.0 c	1.4 c	86.3 b	376.7 b	625.6 b	8.8 c	98.8 b	362.6 b
Hand weed	4.1 b	38.7 b	5.6 b	45.1 b	7.4 a	36.7 b	2.6 b	156.4 a	635.6 a	928.4 a	16.3 b	206.4 a	617.5 a
Weed mat	5.2 a	47.8 a	7.2 4	56.7 a	8.9 a	45.5 a	3.2 a	190.2 a	680.5 a	1077.6 a	20.2 a	181.6 a	687.5 a
Significance	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.001	0.01	0.001	0.02	0.001
Interactions													
CxW	NS	0.04	NS	NS	0.04	NS	NS	NS	NS	NS	NS	NS	NS
Losses 2012													
Cultivar (*C*)													
Black Diamond	5.0	51.6	8.6	62.2	6.7	32.5	3.5	106.0	576.0	890.8	22.5	179.1	666.1
Marion	6.5	58.4	9.3	60.6	11.1	45.0	3.9	225.8	698.8	1047.3	27.3	202.6	788.2
Significance	0.004	0.01	NS	NS	<.0001	0.0003	0.049	<.0001	0.04	NS	0.002	NS	0.04
Weed management (*W*)													
Non-weeded	3.9 c	34.8 c	5.5 c	36.7 c	5.7 c	24.8 c	2.3 c	101.0 c	424.7 b	695.2 b	15.6 c	118.5 c	464.2 b
Hand weed	6.0 b	56.8 b	9.3 b	65.1 b	9.5 b	40.7 b	3.9 b	177.6 b	719.0 a	1021.4 a	26.5 b	235.5 a	811.4 a
Weed mat	7.5 a	73.4 a	12.0 a	82.4 a	11.6 a	50.8 a	4.9 a	218.9 a	768.5 a	1189.7 a	32.7 a	218.7 a	905.7 a
Significance	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0002	0.010	<.0001	0.004	<.0001
Interactions													
CxW	NS	0.05	NS	NS	0.03	NS	NS	0.02	NS	NS	NS	NS	NS

[z]NS=Non Significant

[y]Mean separation (in columns) by LSD test at P ≤ 0.05 (lowercase letters)

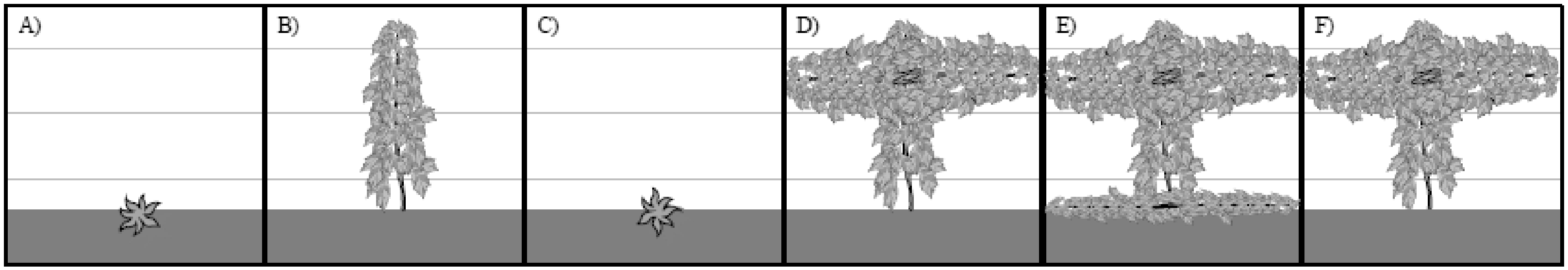

Fig. 3.1. Blackberry plant establishment 2010-2012: **A**) tissue-cultured plug plants at planting, May 2010; **B**) primocane growth 2010; **C**) primocanes cut back to crown, Feb. 2011; **D**) primocane growth 2011; **E**) primocane and floricane growth, July 2012, **F**) new primocanes trained to trellis after harvest, Aug. 2012, after floricane pruning.

CHAPTER 5: General Conclusions

During the establishment years of this study, 'Marion' and 'Black Diamond' trailing blackberry appeared well suited to the organic production systems for processing trialed. There were several advantages to growing 'Black Diamond' including plants produced less above-ground DW, consisting of fewer and shorter canes than 'Marion' plants, favoring easier trellising of the canes. In addition, despite the lesser growth of 'Black Diamond' plants, they had greater yield efficiency, with harvest over a longer fruiting season, and produced a lower cull weight/plant. Differences in growth and yield did not result in large differences in nutrient usage, as net nutrient accumulation and removal was similar between cultivars. 'Black Diamond' plants thus appeared to have a greater production efficiency than 'Marion' plants. The impact of this on profitability as the planting matures needs to be evaluated.

We established that the presence of weeds in the row, reduced growth, production, nutrient accumulation and loss in both cultivars. In contrast, the use of weed mat improved plant growth, yield, and nutrient accumulation relative to non-weeded plots, but often related to hand weeded plots. The positive effects of weed mat are attributed to greater availability of some soil nutrients and favorable soil and canopy temperatures, fostering vigorous plant growth and yield. Additionally, weed mat reduced labor costs to negligible levels relative to hand weeded plots. Therefore, even though the initial installation costs of weed mat were high, the returns associated with high yields and the reduced management costs suggest that weed mat is the most advantageous form of weed control for organic blackberry systems. Future work is necessary to determine whether additional fertilizer may mitigate nutrient losses to competitive weeds in non-weeded plots thereby enabling better plant growth and yield.

Investigations regarding soil nutrient availability in the fertigated system indicated that soil pH, organic matter, and nutrients were not significantly affected by the cultivar grown or the weed management strategy used. However location from the emitter and sampling depth influenced these soil properties. Due to this spatial influence on fertigated soils, it was found that soil samples should be collected to a 0.15 m depth, in the row, under the drip emitters, where fertilizer is applied and nutrients may be more precisely managed. However analysis of soil properties should not be the sole indicator of nutrient availability and adequate pH and organic matter for crop growth, because effects on soil properties often take many years to become apparent. Given that soil nutrients were not affected by weed management, but nutrient uptake clearly differed across weed management treatments, it is possible nutrient reserves in the soil are large and or the timing of soil sampling did not capture differences in soil, particularly for soil N. Therefore, additional work may be necessary to determine optimum sample time and frequency to more accurately evaluate soil nutritive status.

In summary, this study affirmed that weed management, like in many other berry crops, is critical to obtain good yields and vigorous plant growth in blackberry. While yield of plants grown with in-row weeds were equivalent to what is often observed in establishing conventional ‘Marion’ blackberry systems, yield in the weed mat system far exceeded what was observed for non-weeded plots. During the establishment years of this study, the best treatment combination was ‘Black Diamond’ grown with weed mat. However, future work is necessary to determine whether these findings will be consistent as the planting matures.

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