Weed Management Practices for Organic Production of Trailing Blackberry, II. Accumulation and Loss of Biomass and Nutrients

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Abstract. A study was conducted in western Oregon to assess the impact of cultivar and weed management strategy on accumulation and loss of plant biomass and nutrients during the first 3 years of establishment when using organic fertilizer. The study was conducted in trailing blackberry (Rubus L. subgenus Rubus Watson) planted in May 2010 and certified organic in May 2012. Treatments included two cultivars, Marion and Black Diamond, each with either no weed control after the first year after planting or with weeds managed by hand-weeding or the use of weed mat. Each treatment was amended with organically approved fertilizers at pre-plant and was drip-fertigated with fish emulsion each spring. Most primocane leaf nutrient concentrations were within the range recommended for blackberry. However, leaf nitrogen (N) was low in ‘Black Diamond’, especially when grown without weed control, whereas leaf boron (B) was low in all treatments. In many cases, leaf nutrient concentrations were affected by cultivar and weed management in both the primocanes and the floricanes. The concentration of several nutrients in the fruit differed between cultivars, including calcium (Ca), magnesium (Mg), sulfur (S), B, and zinc (Zn), but only fruit Ca was affected by weed management and only in ‘Marion’. In this case, fruit Ca was higher when the cultivar was grown with weed mat than with hand-weeding or no weeding. Total biomass production of primocanes increased from an average of 0.3 t·ha⁻¹ dry weight (DW) during the first year after planting to 2.0 t·ha⁻¹ DW the next year. Plants were first cropped the third year after planting and gained an additional 3.3 t·ha⁻¹ DW in total aboveground biomass (primocanes, floricanes, and fruit) by the end of the third season. Fruit DW averaged 1.4 t·ha⁻¹ in non-weeded plots, 1.9 t·ha⁻¹ in hand-weeded plots, and 2.3 t·ha⁻¹ in weed mat plots. Biomass of senesced floricanes (removed after harvest) averaged 3.2 t·ha⁻¹ DW and was similar between cultivars and among the weed management treatments. ‘Marion’ primocanes accumulated a higher content of N, phosphorus (P), potassium (K), Mg, S, iron (Fe), B, copper (Cu), and aluminum (Al) than in ‘Black Diamond’. Weeds, however, reduced nutrient accumulation in the primocanes in both cultivars, and accumulation of nutrients was greater in the floricanes than in the previous year’s primocanes. Total nutrient content declined from June to August in the floricanes, primarily through fruit removal at harvest and senescence of the floricanes after harvest. Depending on the cultivar and weed management strategy, nutrient loss from the fruit and floricanes averaged 34 to 79 kg·ha⁻¹ of N, 5 to 12 kg·ha⁻¹ of P, 36 to 84 kg·ha⁻¹ of K, 23 to 61 kg·ha⁻¹ of Ca, 5 to 15 kg·ha⁻¹ of Mg, 2 to 5 kg·ha⁻¹ of S, 380 to 810 g·ha⁻¹ of Fe, 70 to 300 g·ha⁻¹ of B, 15 to 36 g·ha⁻¹ of Cu, 610 to 1350 g·ha⁻¹ of manganese (Mn), 10 to 260 g·ha⁻¹ of Zn, and 410 to 950 g·ha⁻¹ of Al. Overall, plants generally accumulated (and lost) the most biomass and nutrients with weed mat and the least with no weed control.

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Recent surveys show a shift toward more organic blackberry production worldwide (Strik et al., 2007). Approximately 200 ha of organic blackberry are currently planted in the United States, 74% of which are located in California and Oregon (National Agricultural Statistical Service, 2010). Some of the challenges to increased organic blackberry production include costly fertilization practices and limited options for control of weeds, insects, and plant diseases. Management practices that minimize fertilizer inputs and sustain good plant growth and yield without use of chemicals not certified as organic are therefore needed for continued expansion of organic production of blackberries. The common weed management methods used in organic blackberry fields include hand-weeding, use of woven landscape fabric (often referred to as “weed cloth” or “weed mat”), and no or limited weeding. In the latter case, weeds are typically removed during the first few months after planting to help establish the plants and then only mowed or removed just before fruit harvest.

Trailing blackberry is a perennial crop, but like other caneberry species, the shoots or canes of the plant are biennial. Vegetative canes, referred to as primocanes, emerge from the plant crown each spring and become floricanes with flowers and fruit the next spring. Mature plants will have both primocanes and floricanes in the same year in a typical annual or every-year production system and during the “on-year” of an alternate-year production system (Julian et al., 2009; Strik and Finn, 2012). Fruit ripen in the summer and are usually machine-harvested for processing. Primocanes rely primarily on soil nutrients and fertilizers for growth, whereas floricanes rely largely on current nutrient reserves (Malik et al., 1991; Mohadjer et al., 2001). Partitioning and accumulation of nutrients is a function of sink strength, and most nutrients accumulate in the floricanes in the spring and in the primocanes (and below ground in the crown and roots) in the summer and fall (Cortell and Strik, 1997; Mohadjer et al., 2001). Fertilizer applications are split; half is applied in early spring, primarily for growth of primocanes and development of fruiting laterals and fruit, and the other half is applied in late spring or early summer for continued primocane growth (Hart et al., 2006). Some growers, however, including those producing organic blackberries, fertilize with liquid fertilizers and inject the fertilizer through the drip irrigation system (Kafkafi and Tarchitzky, 2011). In this case, fertilizer is typically applied more frequently from early spring to midsummer.

Nitrogen is the primary nutrient applied to blackberry in Oregon, although P, K, and B are sometimes applied as well. In conventional plantings, Hart et al. (2006) recommend 35 to 55 kg·ha⁻¹ of N during the first year or two of establishment and 55 to 80 kg·ha⁻¹ of N once the planting matures. They also recommend as much as 90 kg·ha⁻¹ of P (P₂O₅), 45 to 110 kg·ha⁻¹ of K₂O, and 1 to 3 kg·ha⁻¹ of B based on soil and leaf tissue tests. Organic fertilizers are also applied at similar rates of N, although most are comprised of many nutrients, and therefore other nutrients are added inadvertently. Two of the most common sources of organic fertilizers used in blackberry include dry poultry litter and liquid fish products. Information on the effects of using these organic fertilizers on nutrient balance and plant nutrition is limited in most crops, including blackberry.
The objective of the present study was to assess the impact of cultivar and weed management strategies on the accumulation and loss of plant biomass and nutrients during the first 3 years of establishment when using organic fertilizers. The study included three methods of weed management (hand-weening, weed mat, and no weeding) and two cultivars (Marion and Black Diamond) commonly used for processing in Oregon. Previously, we found that weeds reduced yield during the establishment years in both cultivars by 40% relative to hand-weening, whereas weed mat increased yield by 20% relative to hand-weening (Harkins et al., 2013). We hypothesized that the treatment effects on yield were attributable, at least in part, to differences in plant nutrition, whereby weeds reduced availability of soil nutrients as a result of competition with the blackberry plants, whereas weed mat, which was black in color, resulted in warmer soil temperatures and increased availability of soil nutrients (Julian et al., 2012; Larco et al., 2013; Makus, 2011; Percival et al., 1998; Strik et al., 2006; Willard and Valenti, 2008), possibly a result of increased mineralization rates and root distribution and development, for example.

Materials and Methods

Study site. The study was conducted at the Oregon State University, North Willamette Research and Extension Center in Aurora, OR [lat. 45°17′ N, long. 122°45′ W; U.S. Dept. of Agriculture Plant Hardiness Zone 8 (2012); elevation 46 m]. Soil at the site is a Willamette silt loam (fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll) that had a pH of 5.3 before planting and contained 3.6% organic matter, 1.5 ppm NO$_3$-N, 2.3 ppm NH$_4$-N, 188 ppm P (Bray I), and 295 ppm K. Soil pH and K were low and below the ppm NH$_4$-N, 188 ppm P (Bray I), and 295 ppm K. Soil pH and K were low and below the

**Fig. 1.** A new planting of organic trailing blackberry, 2010–12: (A) tissue-cultured plug plants at planting, May 2010; (B) primocane growth in 2010; (C) primocanes cut back to crown, Feb. 2011; (D) primocane growth in 2011; (E) floricane growth in 2012 (with new primocanes left on the ground); and (F) new primocanes trained to a trellis (after senesced floricanes were removed), Aug. 2012. Cultivars in the planting included ‘Black Diamond’ and ‘Marion’, and three weed management strategies included hand-weening or weed mat in Year 1 and no weeding, hand-weening, and weed mat in Years 2 and 3. Plant dry weight (DW) data were adapted from Harkins et al. (2013). Plant DW was measured in Feb. 2011 (Year 1), Jan. 2012 (Year 2), and July 2012 (floricanes and fruit in Year 3); each measurement includes the average of two cultivars (‘Black Diamond’ and ‘Marion’) and three weed management strategies (no weeding, hand-weening, and weed mat); an asterisk after DW indicates a significant difference between cultivars ($P < 0.05$) and a dagger indicates a significant difference among the weed management strategies ($P < 0.01$). All interactions between cultivar and weed management on DW were nonsignificant.
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 and 2012 TRUE 402 53 7 62 1 1 26 11 6 18 79

*Nutra-Rich and TRUE 402 were analyzed by Brookside Laboratories, Inc. (New Bremen, OH). Values for Fish-Agra were obtained from the product label. Nutra-Rich was a pelleted poultry litter product incorporated in the soil along the row just before 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 before application. Nutra-Rich had a pH of 7.3 and TRUE 402 had a pH of 5.5. Fish-Agra was applied by hand around the base of the plants in seven equal applications of 4 kg ha⁻¹ nitrogen (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.

Weed management. Weeds were removed with a hoe from hand-weeded plots and from the planting hole, by hand, of weed mat plots. Weeds were also hand-hoed from non-weeded plots during the first year after planting in 2010 to encourage growth and establishment of the treatment, but left unchecked until harvest the next years, when weeds were mowed to the ground in the plots with a string trimmer in late June to avoid any interference with the machine harvester and avoid potential contamination of the fruit with weed seed (standard commercial practice). Primocane was randomly selected from two plots per plot each year and oven-dried at 70 °C to a constant weight to determine the average individual DW of the primocanes in each treatment. Primocane individual DW was then multiplied by the total number of primocanes counted in each plot and divided by plot area to calculate total primocane DW per hectare. Total primocane DW was also estimated after the third season by counting the number of primocanes in each treatment. Primocane individual DW was determined from each plot on each sample date. Total N content was determined in each sample using a combustion analyzer, and P, K, Ca, Mg, Na, B, Cu, Mn, Zn, and Al were determined using an inductively coupled plasma spectrophotometer after wet-ashing the samples in nitric/perchloric acid (Gavlak et al., 1994). The primocanes, fruit, and floricanes harvested for DW were also ground and analyzed for nutrient concentration and used to calculate total aboveground plant nutrient content per hectare each year. See Harkins et al. (2013) for a complete summary of primocane and florican nutrient concentrations in each treatment.

Results and Discussion

Leaf and fruit nutrient concentrations. Most primocane and florican leaf nutrient concentrations differed between cultivars and, in many cases, were affected by the method of weed management (Table 2). In general, ‘Marion’ had higher concentrations of macronutrients in the primocane leaves than ‘Black Diamond’—in both the second summer after planting when the plants had no fruit and the third summer after planting when the plants were cropped—but had a lower concentration of all but K in the florican leaves. ‘Black Diamond’, on the other hand, had similar or higher concentrations of most micronutrients, except Zn in the primocane leaves and B in the florican leaves. In the latter case, a significant interaction between cultivar and weed management revealed that florican leaf B was only higher in ‘Marion’ than in ‘Black Diamond’ when plants were grown in non-weeded plots (Fig. 2).

Leaf nutrient concentrations were often higher with weed control than without it, including N, P, K, S, Cu, and Zn in the primocane leaves during the second year after planting and N (weed mat only) and S in the primocane leaves and N, P, Ca (hand-weeding only), Mg (hand-weeding only), S, and Cu in the florican leaves during the third year (Table 2). Some nutrient concentrations were also higher with weed mat than with hand-weeding such as P, S, Cu, and Zn in the primocane leaves during the second year and S in the primocane leaves during the third year, whereas others such as Fe and Al in the primocane leaves and P in the florican leaves were higher the third year with hand-weeding than with weed mat. Significant interactions between cultivar and weed management indicated that primocane leaf Fe and florican leaf P were only higher with hand-weeding in ‘Black Diamond’ with no effect of weed management in ‘Marion’ (Fig. 3A–B). Likewise, leaf S in the floricanes was higher with weed control than without it, but only in ‘Black Diamond’ (Fig. 3C). The only nutrient concentration that was significantly higher with no weeding than with either method of weed control was leaf Mn in the primocanes—and only during the second year (Table 2). Treatment effects on soil nutrient content and pH were also measured during the study but were inconsistent and unrelated to plant nutrient content (Harkins, 2013).

Currently, nutrient recommendations for conventional blackberry are based on tissue testing of primocane leaves collected in late July to early August (Hart et al., 2006). As already mentioned, the primary nutrients of
concern in the northwestern United States are N, P, K, and B. In the plants grown organically in the present study, primocane leaf P and K were well above the recommended levels of 0.19% and 1.25%, respectively, during the second and third years of the study (Table 2). Primocane leaf N was also within the recommended range of 2.3% to 3.0%, regardless of weed management strategy. ‘Marion’ each year, but was below the range in ‘Black Diamond’ grown in non-weeded plots during the second year after planting and all plots during the third year. ‘Black Diamond’ may therefore either require more N (fish emulsion) fertilizer than ‘Marion’, particularly when grown with limited or no weed control, or ‘Black Diamond’ may have lower N requirements. Current nutrient recommendations are based primarily on work done in ‘Marion’, but optimum levels likely vary among cultivars. Total marketable yield was in fact higher in ‘Black Diamond’ than in ‘Marion’, suggesting that N availability was not limiting to early production in the cultivar (Harkins et al., 2013). Low N levels may begin to reduce yield in ‘Black Diamond’ as the planting matures, and the cultivar may require more N fertilizer than ‘Marion’ to maintain adequate plant tissue levels. Better timing of fertilizer application may also improve N uptake, but information on the optimum time to apply organic fertilizers, non-weeded 2.2 by 0.23 c 1.4 b 0.5 0.29 0.11 c 81 23 8.5 c 142 a 26 c 53
Hand-weeded 2.9 a 0.28 b 1.6 a 0.4 0.28 0.14 b 108 21 9.4 b 108 b 31 b 71
Weed mat 3.0 a 0.31 a 1.6 a 0.4 0.29 0.15 a 76 21 10.6 a 97 b 35 a 38
Significance <0.0001 <0.0001 <0.0001 NS NS <0.0001 NS NS <0.0001 <0.0001 NS NS
Interaction C × W NS NS NS NS NS NS NS NS NS NS NS NS
Year 3 (2012)
Primocane leaves
Cultivar (C)
Black Diamond 1.96 0.26 1.35 0.39 0.30 0.13 101 18 8.4 174 26 68
Marion 2.59 0.35 1.56 0.47 0.32 0.14 75 15 6.5 140 31 42
Significance <0.0001 <0.0001 <0.0001 0.0003 0.0004 <0.0001 <0.0001 <0.0001 <0.0001 0.0003 <0.0001 <0.0001
Weed management (W)
Non-weeded 2.19 b 0.30 1.43 0.42 0.31 0.13 c 76 b 17 7.3 173 28 44 b
Hand-weeded 2.27 ab 0.30 1.47 0.43 0.30 0.137 b 102 a 16 7.6 147 28 71 a
Weed mat 2.38 a 0.31 1.47 0.44 0.31 0.144 a 86 b 16 7.4 152 29 50 b
Significance 0.02 NS NS NS NS NS 0.0001 NS NS NS NS NS 0.001
Interaction C × W NS NS NS NS NS NS 0.03 NS NS NS NS NS
Floricane leaves
Cultivar (C)
Black Diamond 2.53 0.23 1.18 1.62 0.33 0.14 139 47 6.3 577 26 118
Marion 1.48 0.15 1.18 0.99 0.26 0.09 88 58 4.3 268 18 74
Significance <0.0001 <0.0001 ns <0.0001 0.0002 <0.0001 <0.0001 0.001 <0.0001 <0.0001 0.01 0.0001
Weed management (W)
Non-weeded 1.79 b 0.16 c 1.16 1.20 b 0.27 b 0.10 b 127 52 4.8 b 446 22 99
Hand-weeded 2.08 a 0.22 a 1.16 1.44 a 0.31 a 0.12 a 105 54 5.5 a 462 23 104
Weed mat 2.15 a 0.19 b 1.22 1.28 ab 0.29 ab 0.12 a 110 51 5.6 a 359 21 84
Significance 0.01 0.0003 NS 0.03 0.04 0.001 NS NS 0.01 NS NS NS NS
Interaction C × W NS 0.003 NS NS NS NS NS NS NS 0.02 NS NS NS NS
zPlants had primocanes only in Year 2 (see Fig. 1). Primocane leaves were collected on 18 Aug. 2011 and 31 July 2012. Floricane leaves were collected on 3 July 2012 at 1 week before fruit harvest.
'yMeans were separated at the 0.05 level using Fisher’s protected least significant difference test.
NS = nonsignificant.

Fig. 2. Effects of three different weed management strategies on leaf boron (B) concentration in the floricanes during the first year of fruit production (Year 3) in ‘Black Diamond’ and ‘Marion’ blackberry. Each bar represents the mean of three replicates. Cultivars were compared within each weed management strategy using the t test. NS, **Nonsignificant or significant at P ≤ 0.01, respectively.
particularly to perennial crops, is limited (Mattson and van Iersel, 2011). Primocane leaf B was also below the recommended level of 30 ppm (Hart et al., 2006), but in this case, it was low in both cultivars each year and in all weed management treatments (Table 2). Soil B was also below recommended levels for blackberry at the site (Harkins, 2013; Hart et al., 2006). Boron deficiency is common in the region and may result in reduced yield, small fruit, and, in severe instances, cane dieback. Fortunately, boric acid is an Organic Materials Research Institute-approved source of B fertilizer that is easily applied to blackberry and can be used in organic plantings with B deficiency. Weed mat may be permeable enough to allow for granular fertilizer application to the top of the mulch (Zibilske, 2010).

Fruit nutrient concentrations differed less between cultivars than leaf nutrients and were little affected by the method of weed management (Table 3). In this case, ‘Marion’ had higher concentrations of Ca, Mg, and Zn in the ripe fruit than ‘Black Diamond’ but had lower concentrations of S and B. Only fruit Ca concentration was affected by weed control and only in ‘Marion’ where levels were higher with weed mat than with hand-weeding or no weeding (Fig. 4). Calcium is primarily transported into plants and plant parts through the transpiration stream (Hanger, 1979; McLaughlin and Wimmer, 1999). Although fruit are low-transpiring organs relative to leaves, fruit transpiration accounts for a large percentage of the total Ca that enters the fruit (Ho and White, 2005; Montanaro et al., 2006, 2010). Although we did not measure fruit transpiration specifically in our study, we did find that weed mat increased water use in ‘Marion’, but not in ‘Black Diamond’, and therefore may have led to higher fruit Ca levels in the cultivar (Harkins et al., 2013). Currently, the impact of fruit nutrient concentration on fruit quality, particularly fruit Ca level and associated firmness, is unknown in blackberry.

Accumulation and loss of plant biomass and nutrients. Plant growth was similar regardless of cultivar or method of weed management during the first year after planting, and by the end of the season, primocane tissue DW in each treatment averaged 0.3 t·ha⁻¹ (Fig. 1A–B). Because the plants were still small at this point, the primocanes were cut to the ground and removed in February (Fig. 1C) to prevent fruiting the next season and to encourage more primocane growth (Fig. 1D), the standard commercial practice. Nutrient levels measured in the primocanes just before cutting indicated that more Ca, Mn, Zn, and Al were removed in ‘Black Diamond’ than in ‘Marion’, and more Fe, Cu, and Al were removed in hand-weeded plots than in those with weed mat (Table 4). Total removal of other nutrients was similar among treatments and averaged 5.5 kg·ha⁻¹ of N, 0.5 kg·ha⁻¹ of P, 2.0 kg·ha⁻¹ of K, 0.5 kg·ha⁻¹ of Mg, 0.3 kg·ha⁻¹ of S, and 7 g·ha⁻¹ of B.

Dry weight production of primocanes was four to eight times higher among treatments the second year after planting than the previous year (Fig. 1D). By the end of the second season, total primocane DW averaged 1.8 t·ha⁻¹ in ‘Black Diamond’ and 2.2 t·ha⁻¹ in ‘Marion’ and was greater in both cultivars with hand-weeding (2.2 t·ha⁻¹) or weed mat (2.5 t·ha⁻¹) than with no weeding (1.3 t·ha⁻¹) (data not shown; adapted from Harkins et al., 2013). As a result of differences in DW, ‘Marion’ primocanes contained a higher content of most nutrients than ‘Black Diamond’ after the second season, including all but Ca among the macronutrients and all but Mn and Zn among the micronutrients (Table 4). Primocanes also contained more nutrients with weed control than with no weeding but were similar regardless of the method of weed control. With hand-weeding or weed mat, ‘Black Diamond’ and ‘Marion’ accumulated an average of 22 and 31 kg·ha⁻¹ of N, 3 and 4 kg·ha⁻¹ of P, 15 and 19 kg·ha⁻¹ of K,
Table 3. Fruit nutrient concentrations during the first year of production (Year 3) in two cultivars of organic trailing blackberry.

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<thead>
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<th>Treatment</th>
<th>Cultivar (C)</th>
<th>Significance</th>
<th>Weed management (W)</th>
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Means were separated at the 0.05 level using Fisher’s protected least significant difference test. ns = nonsignificant.

Fig. 4. Effects of three different weed management strategies on fruit calcium (Ca) concentration during the first year of fruit production (Year 3) in ‘Black Diamond’ and ‘Marion’ blackberry. Each bar represents the mean of three replicates. Means were separated within cultivars using Tukey’s honestly significant difference test (P = 0.05). ns Nonsignificant.

11 and 12 kg ha⁻¹ of Ca, 2 and 3 kg ha⁻¹ of Mg, 1 and 2 kg ha⁻¹ of Mn, 61 and 74 g ha⁻¹ of Zn, and 125 and 310 g ha⁻¹ of Al, respectively, in the primocanes during the second year after planting. No weed control, on the other hand, reduced uptake of each nutrient anywhere from 60% to 138% in ‘Black Diamond’ and from 61% to 232% in ‘Marion’ (data not shown).

Plants were first cropped during the third year after planting and therefore had both primocanes and floricanes present by harvest. The floricanes produced 1.2 t ha⁻¹ DW of fructifying laterals and 1.9 t ha⁻¹ DW of fruit (Fig. 1E), which was comparable to that produced by mature ‘Kotata’ blackberry plants grown conventionally (Mohadjer et al., 2001). Fruit DW was similar between cultivars but averaged 1.9 t ha⁻¹ with hand-weeding, 2.3 t ha⁻¹ with weed mat, and only 1.4 t ha⁻¹ with no weeding (data not shown; adapted from Harkins et al., 2013). Consequently, total content of most nutrients in the fruit was also similar between cultivars—except S and B, which were higher in ‘Black Diamond’, and Mg and Zn, which were higher in ‘Marion’. Total fruit nutrient content was higher with weed control than without it and, in most cases (i.e., all except Fe, Cu, Al), were higher with weed mat than with hand weeding (Table 5). The total amount of nutrients removed with the fruit in each treatment averaged 11 to 26 kg ha⁻¹ of N, 3 t to 5 kg ha⁻¹ of P, 12 to 27 kg ha⁻¹ of K, 2 to 6 kg ha⁻¹ of Ca, 1 to 3 kg ha⁻¹ of Mg, 1 to 2 kg ha⁻¹ of S, 44 to 82 g ha⁻¹ of Fe, 11 to 30 g ha⁻¹ of B, 6 to 12 g ha⁻¹ of Cu, 56 to 110 g ha⁻¹ of Mn, 18 to 40 g ha⁻¹ of Zn, and 93 to 240 g ha⁻¹ of Al.

Nutrients were also removed with pruning of senescing floricanes after harvest, which likewise differed with cultivar in many cases and was always affected by weed management (Table 5). ‘Marion’ had more N, Ca, Mg, S, Fe, B, and Al in the floricanes at pruning than ‘Black Diamond’, although significant interactions between cultivar and weed management indicated that N and Mg were only higher in ‘Marion’ when plants were grown with weed control (Fig. 5). Both methods of weed control increased nutrient content in the floricanes, but some nutrients, including N, P, K, Ca, S, and Cu, were also higher with weed mat than with hand-weeding. Total removal of nutrients in the floricanes was often at least twice that of the fruit—and sometimes much higher (e.g., Ca, Mg, Fe, B, Mn, Zn, and Al)—and depending on the treatment averaged 22 to 55 kg ha⁻¹ of N, 2 to 7 kg ha⁻¹ of P, 23 to 58 kg ha⁻¹ of K, 20 to 54 kg ha⁻¹ of Ca, 3 to 12 kg ha⁻¹ of Mg, 1 to 4 kg ha⁻¹ of S, 330 to 730 g ha⁻¹ of Fe, 56 to 280 g ha⁻¹ of B, 8 to 23 g ha⁻¹ of Cu, 550 to 1240 g ha⁻¹ of Mn, 89 to 200 g ha⁻¹ of Zn, and 310 to 760 g ha⁻¹ of Al.

The total amount of N removed in the floricanes and fruit exceeded the amount applied as fertilizer in the third year in most treatments. For example, 65 kg ha⁻¹ of N was removed from ‘Black Diamond’ plots with weed mat and 75 kg ha⁻¹ of N was removed from ‘Marion’ plots with weed mat, but only 53 kg ha⁻¹ of N was applied the third year (Table 1). Likewise, 35 to 85 kg ha⁻¹ of K was removed in each treatment, which for some treatments was more than the 62 kg ha⁻¹ of K applied in each treatment. The available nutrients in the soil may be sufficient. In addition, most commercial growers flail (chop) the prunings in the row middles, and thus any nutrients in the spent floricanes are returned to the soil and potentially available to the plants the next years (Ledgard et al., 1992; Rempel et al., 2004). Using ¹⁵N as a tracer, Strik et al. (2006) calculated that up to 8% of the N in raspberry floricanes prunings was available for plant uptake with 1.5 years. In our case, 66% to 74% of the N and 47% to 93% of other nutrients considered removed or “lost” would be returned to the field by flailing the prunings and potentially be available to the blackberry plants.

New primocane growth was limited during the third season and based on primocane number was estimated to average only 0.2 to 0.3 t ha⁻¹ DW in each treatment, which was only 10% of total primocane DW produced the previous year (Fig. 1F). The estimated nutrient gain was thus likewise low and, based on primocane nutrient concentrations from the previous year, averaged 2 to 3 kg ha⁻¹ of N; 1
to 2 kg·ha⁻¹ of Ca and K; less than 1 kg·ha⁻¹ of P, Mg, and S; 16 to 34 g·ha⁻¹ of Fe; 3 to 5 g·ha⁻¹ of B; 1 to 2 g·ha⁻¹ of Cu; 29 to 40 g·ha⁻¹ of Mn; 6 to 9 g·ha⁻¹ of Zn; and 14 to 34 g·ha⁻¹ of Al. Mohadjer et al. (2001) compared primocane growth in ‘Kotata’ blackberry grown in an alternate-year production system and similarly found that primocane growth during an “on year,” when floricanes and primocanes were present, was only 30% of what was produced during an “off year,” when plants had only primocanes. Floricanes compete with the primocanes for resources in caneberry plants and therefore may reduce not only primocane growth but nutrient uptake by the primocanes as well (Bryla and Strik, 2008; Cortell and Strik, 1997; Malik et al., 1991; Mohadjer et al., 2001; Naraguma et al., 1999; Rempel et al., 2004; Wright and Waister, 1982).

Net biomass or nutrient gains may have been grossly underestimated in the present study because the plants were not measured below ground. Blackberry roots account for 26% to 41% of the total plant biomass and serve as an important reserve of nutrients (Malik et al., 1991; Naraguma et al., 1999). Blackberry and red raspberry use up to 40% of the N stored in the crown and roots for new shoot growth (Mohadjer et al., 2001; Rempel et al., 2004). Nutrients lost during leaf senescence were also not estimated, although when trailing blackberry is grown in a mild climate such as Oregon’s Willamette Valley, where the majority of the crop is produced, not all primocane leaves senesce before the plants resuming growth the next spring.

### Table 4. Total nutrient content in the primocanes after the first 2 years after planting in two cultivars of trailing blackberry in transition to organic.※

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Macronutrients (kg·ha⁻¹)</th>
<th>Micronutrients (g·ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>Year 1 (2010) Primocanes (removed) Cultivar (C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black Diamond</td>
<td>5.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Marion</td>
<td>5.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Significance</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Weed management (W)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand-weeded</td>
<td>5.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Weed mat</td>
<td>5.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Significance</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Interaction C × W</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Year 2 (2011) Primocanes Cultivar (C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black Diamond</td>
<td>18.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Marion</td>
<td>25.7</td>
<td>3.4</td>
</tr>
<tr>
<td>Significance</td>
<td>0.01</td>
<td>0.001</td>
</tr>
<tr>
<td>Weed management (W)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-weeded</td>
<td>12.3 b</td>
<td>1.7 b</td>
</tr>
<tr>
<td>Hand-weeded</td>
<td>24.7 a</td>
<td>3.1 a</td>
</tr>
<tr>
<td>Weed mat</td>
<td>29.2 a</td>
<td>3.7 a</td>
</tr>
<tr>
<td>Significance</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Interaction C × W</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

※Weeds were controlled by hand-weeding or weed mat each year or by hand-weeding the first year (2010) but no weeding the next years.

Because the non-weeded treatment was hand-weeded during the first year after planting, means of the hand-weeded treatment include the average of hand-weeded and non-weeded plots in 2010.

※Means were separated at the 0.05 level using Fisher’s protected least significant difference test. NS = nonsignificant.

Fig. 5. Effects of three different weed management strategies on (A) nitrogen (N) and (B) magnesium (Mg) content in senescing floricanes after harvest during the first year of fruit production (Year 3) in ‘Black Diamond’ and ‘Marion’ blackberry. Each bar represents the mean of three replicates. Cultivars were compared within each weed management strategy using the t test. NS, **Nonsignificant or significant at P ≤ 0.01, respectively.
Year 3 (2012)

Weed control, however, increased cane and therefore relied on plant growth was greater in ‘Marion’ than in ‘Diamond’ may have a need for more fertilizer than the 3 kg ha⁻¹ N applied per year but limited or no weed control, although additional application may likewise increase weed growth. Low B is easily resolved with a broadcast application of boric acid in the fall or before budbreak in the spring. Hart et al. (2006) recommended applying no more than 3 kg ha⁻¹ of B in any given year and to avoid further application once primocane leaf B levels are adequate (greater than 30 ppm).

In terms of gains in biomass, aboveground plant growth was greater in ‘Marion’ than in ‘Black Diamond’ during the second year after planting when only primocanes were present but was similar between cultivars the next year when plants were first cropped. Weed control, however, increased cane and fruit biomass, leaf tissue nutrient concentrations, and nutrient accumulation and loss in both cultivars. Nutrient gains exceeded nutrients applied in the organic fertilizer during the first year of fruit production (with weed control) and therefore relied on plant tissue reserves and or soil nutrients to meet plant demands. Nutrient management practices for organic production of high-bush blackberries. II. Impact on plant and soil nutrients during establishment. HortScience 48:1484–1495.


