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Weed Management, Training, and Irrigation Practices for Organic Production of Trailing Blackberry: III. Accumulation and Removal of Aboveground Biomass, Carbon, and Nutrients

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Abstract*. Relatively little is known about aboveground nutrient content of organic blackberry, and there is no published work on total carbon (C) content. Treatment effects on biomass, C, and nutrient content, accumulation, and removal were assessed over 2 years in a mature organic trailing blackberry (*Rubus* L. subgenus *Rubus,* Watson) production system that was machine harvested for the processed market. Treatments included two irrigation options (no irrigation after harvest and continuous summer irrigation), three weed management strategies (weed mat, hand-weeded, and nonweeded), and two primocane training times (August and February) in two cultivars (Black Diamond and Marion). Floricanes comprised an average of 45% of the total aboveground plant dry biomass, while primocanes and fruit comprised 30% and 25%, respectively. Depending on the treatment, the total aboveground dry biomass accumulation over the course of the season was 5.0–6.5 t·ha^{-1} per year, while C stock of the planting was an estimated 0.4–1.1 t·ha^{-1} in late winter. Carbon accounted for ≈50% of the dry biomass of each aboveground plant part, including primocanes, floricanes, and fruit. Weed management had the largest impact on plant biomass and nutrient content. No weed control reduced aboveground dry biomass, the content of nutrients in the primocanes, floricanes, and fruit, and the annual accumulation of dry biomass and nutrients, whereas use of weed mat resulted in the most dry biomass and nutrient content. Nutrient accumulation was similar between the cultivars, although February-trained 'Marion' plants had a greater removal of most nutrients in 2014 than the year prior. The amount of nitrogen (N) removed in the fruit was 22, 18, and 12 kg·ha^{-1} for weed mat, hand-weeded, and nonweeded plots, respectively, in 2013. In 2014, 'Marion' and 'Black Diamond' differed in N removed in harvested fruit when grown with weed mat at 18 and 24 kg·ha^{-1}, respectively, whereas there was no cultivar effect when plants were grown in hand-weeded or nonweeded plots. Plots with weed mat tended to have the most nutrients removed through harvested fruit in both years. In 2014, N removal from August-trained 'Marion' was 5 kg·ha^{-1} N less than the other training time and cultivar combinations. Plants that were irrigated throughout the summer accumulated more dry biomass, N, potassium (K), magnesium (Mg), sulfur (S), boron (B), and copper in one or both years than those that received no irrigation after fruit harvest. The irrigation treatment had inconsistent effects on nutrient content of each individual plant part between the two years. Removal of nutrients was often higher than what was applied through fertilization, especially for N, K, and B, which would eventually lead to depletion of those nutrients in the planting.

Organic blackberry (*Rubus* L. subgenus *Rubus*, Watson) production is an important niche market in Oregon, which produces a significant portion of the organic and conventional crop in the United States [U.S. Department of Agriculture (USDA), 2010, 2014]. Blackberry is a perennial plant that produces biennial canes from the crown. When canes emerge the first year, they are vegetative and called primocanes. In their 2nd year, they produce fruiting laterals and fruit on what are then called floricanes. Following fruit production, the floricanes senesce and are removed. In an annual or every-year fruit production system, primocanes and floricanes exist on the plant at the same time (Strik and Finn, 2012).

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

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

A high percentage of plant dry biomass is composed of C (Dixon, 2015), but the C content and allocation of blackberry has not been studied. There has been work in other *Rubus* sp. on photosynthetic rate (Bowen and Freyman, 1995; Fernandez and Pritts, 1993; Percival et al., 2001), radiolabeling of $^{14}CO_2$ (Fernandez and Pritts, 1994; Gauci et al., 2009; Privé et al., 1994), and reduction in C supply (Fernandez and Pritts, 1996). Mature blueberry (*Vaccinium corymbosum* L.) was found to contain 8.3 t·ha^{-1} C during dormancy (Nemeth, 2013), while mature grape (*Vitis vinifera* L.) was estimated to have 1.9 t·ha^{-1} of C (Keightley, 2011). Carbon sequestration has become increasingly important in light of climate change and the ability to estimate the C stock of agricultural land could be important for gauging offsets to C emissions.

The objective of this study was to continue the work by Harkins et al. (2013, 2014) and Dixon et al. (2015a, 2015b) and examine the effects of cultivar (Black Diamond and Marion), postharvest irrigation, weed management (weed mat, hand-weeded, and nonweeded), and primocane training time (August and February) on aboveground accumulation and removal of dry biomass, C,

Table 1. Dry biomass and total nutrient content in the dormant primocanes in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, 2013.[z]

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

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

[y]NS = nonsignificant; P values provided for significant factors.

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

[w]All other higher order interactions were nonsignificant and are not shown.

and nutrients in a mature planting of organic trailing blackberry.

Materials and Methods

Study site. The study was conducted in a mature planting at the North Willamette Research and Extension Center in Aurora, OR [lat. 45°16′47″N, long. 122°45′23″W; USDA plant hardiness zone 8b (U.S. Department of Interior, 2013)] from 2012 through 2014. The soil type at the site is Willamette silt loam (fine silty, mixed, superactive mesic Pachic Ultic Argixeroll). The field was certified organic by Oregon Tilth (Corvallis, OR), a USDA accredited agency, in 2012 (first fruiting year). See Harkins et al. (2013, 2014) for detailed information on site preparation and establishment and Dixon et al. (2015a, 2015b) for details on mature production.

Experimental design. Treatments included cultivar (Marion and Black Diamond), irrigation (postharvest and no postharvest), weed management [nonweeded, hand-weeded, and weed mat (a porous, polyethylene groundcover)], and primocane training time (August and February). Treatments were arranged in a split-split-split plot design with five replicates. See Dixon et al. (2015b) for details of experimental plot layout. Plots were 1.5 × 3 m in size and contained four plants.

Weed management. The three weed management strategies were applied to each plot individually. In nonweeded plots, weeds were allowed to grow after the first year (2010) and cut to soil level just before machine harvest (early July) during each harvest year (2012–14) to avoid any interference with the catcher plates on the machine harvester; the biomass removed was left in the row. In hand-weeded plots, weeds were removed as needed by hoeing throughout each growing season. The weed mat plots were covered with a 1.4-m-wide strip of black, woven, polyethylene groundcover (TenCate Protective Fabrics; OBC Northwest Inc., Canby, OR) centered on the row. Weeds were removed from the planting hole area and seams in the weed mat as required. More information on weed management strategies is provided in Dixon et al. (2015b).

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

Irrigation was scheduled weekly based on estimates of crop evapotranspiration but was adjusted as needed each week to maintain similar leaf water potentials (LWP) among treatments (Dixon et al., 2015b). Irrigation was applied from 9 May to 8 Oct. 2012, 17 May to 27 Sept. 2013, and 28 May to 23 Sept. 2014 in the postharvest irrigation treatment. In the no postharvest irrigation treatment, irrigation was initiated on the same dates but withheld after the last fruit harvest date on 30 July 2012, 19 July 2013, and 15 July 2014. Thus, these plots received no effective water until the rainy season began on 12 Oct. 2012, 21 Sept. 2013, and 23 Sept. 2014.

Fertilization. An Organic Materials Review Institute -approved fish hydrolysate and fish emulsion blend were diluted 1:3 (v/v) with water and applied through the drip system. In 2012, TRUE 402 (4N–0P–2K; True Organic Products, Inc., Spreckels, CA) was applied in four equal applications at a rate of 56 kg·ha⁻¹ N (Harkins et al., 2013). Converted Organics 421 (4N–2P–1K; Converted Organics of California LLC, Gonzales, CA) was used for the first four applications in 2013, and True Organics 512 (5N–0.4P–1.7K) was used for the last four applications in 2013 and all applications in 2014. The fertilizer(s) was split into eight equal applications (about every 2 weeks from 5 Apr. to 12 July 2013 and 19 Mar. to 25 June 2014) and applied

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Table 2. Dry biomass and total nutrient content in the dormant primocanes in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, 2014.[z]

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

[z]Primocane dry biomass was estimated using the relationship found between primocane number and dry biomass at the end of the study in Dec. 2014 [primocane biomass = 0.13 × (primocane number) – 0.043; $r^2 = 0.36$; $P < 0.0001$]. Primocanes were sampled in Feb. 2014.

[y]NS = nonsignificant; P values provided for significant factors.

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

[w]All other higher order interactions were nonsignificant and are not shown.

at a total rate of 90 $kg\cdot ha^{-1}$ N per year in 2013 and 2014 (based on the percentage of N listed on the label). Additional B fertilizer and lime and dolomite amendments were applied in 2013 and 2014 to correct nutritional deficiencies seen in soil tests and primocane leaf analyses (Dixon et al., 2015a). The total amount of nutrients applied to the planting are presented in Dixon et al. (2015a).

Primocane training. Primocanes in the August-trained treatment were trained to the upper trellis wires on 13–14 Aug. 2012, 27–29 Aug. 2013, and 14 Aug. 2014, using the method described by Dixon et al. (2015b). In the February-trained treatment, primocanes were left on the wire for the drip irrigation lines, just aboveground level, throughout the growing season and the subsequent winter, until they were wrapped and tied to the upper two trellis wires on 21–25 Feb. 2013 and 21–28 Feb. 2014. Primocane training was done by replicate to avoid any possible date effects within treatment over the days required to train.

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

One primocane was randomly cut from two plants per plot in Dec. 2014, weighed to determine the average individual fresh weight per cane in each plot, and then multiplied by cane number to estimate the total primocane fresh weight per plant in each plot. Subsamples that included tissue from the base, middle, and tip of the canes were analyzed for moisture content, C, N, phosphorus (P), K, calcium (Ca), Mg, S, iron (Fe), B, copper (Cu), manganese (Mn), zinc (Zn), and aluminum (Al) concentration (Dixon, 2015). A set of subsamples was also collected and analyzed for nutrients in Feb. 2014. Cane production was too low in 2014 to allow for destructive sampling, so cane fresh weight was not collected and subsamples were taken from near the end of the canes. The 2013 primocane nutrient concentrations were estimated as the average of the February and Dec. 2014 values. Percent moisture content was used to estimate dry biomass of the primocanes. The relationship between primocane number and dry biomass was determined in Dec. 2014: [primocane dry biomass = 0.13 × (no. of primocanes per plant) – 0.043; $r^2 = 0.36$; $P < 0.0001$] (Dixon, 2015). Primocane dry biomass was then calculated from the number of primocanes counted in Feb. 2013 and 2014. Primocane C and nutrient content were calculated from primocane nutrient concentrations and dry biomass in late winter. The 2013 primocane nutrient content refers to primocanes that grew in 2012 and then fruited as floricanes in 2013; 2014 primocane nutrient content refers to primocanes that grew in 2013 and then fruited as floricanes in 2014; and primocane nutrient content was calculated a final time in Dec. 2014 for primocanes that grew in 2014 and would have fruited as floricanes in 2015 (referred to as "2015 primocane nutrient content").

Ripe fruit were harvested twice weekly from 24 June to 18 July in 2013 and 2014, using an over-the-row rotary harvester (Littau Harvesters Inc., Stayton, OR). Total yield was calculated from the weight of machine-harvested fruit on each date. A 25-berry subsample per treatment plot was shipped overnight to Brookside Laboratories (New Bremen, OH) on 8 July 2013 and 7 July 2014 and analyzed for C and nutrient concentrations and for percent moisture (Dixon et al., 2015a).

Senescing floricanes were removed by pruning at the base of the plant (≈0.1 m high) after fruit harvest on 29 July–5 Aug. 2013 and 30 July–1 Aug. 2014, per standard commercial practice (Strik and Finn, 2012). The total fresh biomass of the pruned floricanes was determined per plot, and a subsample of the pruned canes (comprised of cane, lateral, and node tissue from the lower, middle, and upper portion of the cane) was shipped overnight to Brookside Laboratories for analysis of total

Table 3. Dry biomass and total nutrient content in the dormant primocanes in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, 2015.[z]

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

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

nutrient concentration and percent moisture content (Dixon et al., 2015a). Floricane dry biomass and C and nutrient content were then calculated. After pruning and data collection, the floricanes were left between the rows and flail-mowed (chopped), per standard commercial practice.

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

Data analysis. Data were analyzed by year due to large differences in weather and winter damage observed in Dec. 2013 (Dixon et al., 2015b). Within year, data were analyzed for a split-split-split plot design with cultivar as the main plot factor, postharvest irrigation as the subplot factor, and weed management and training time as sub-subplots, using PROC MIXED in SAS (version 9.3; SAS Institute Inc., Cary, NC). Normality was assessed using a histogram of the residuals. Residuals were plotted to assess homogeneity of variance (residual by fitted value plot). Strong fanning or skewedness in the residual plots led to the data being log transformed for analysis to improve homogeneity of variance and to assess proportional effects. Data were back transformed for presentation. Means were compared for treatment effects using a Tukey's honestly significant difference test at $\alpha = 0.05$. Mean comparisons within significant interactions were done for treatments using least square means at $\alpha = 0.05$.

Results

Dry biomass production. There were no main effects of cultivar or irrigation on the dry biomass of the dormant primocanes during the study. However, primocane dry biomass was significantly affected by an interaction between cultivar and irrigation in 2015, as well as by weed management each year, and by interactions between irrigation and training date in 2013 and cultivar and training date in 2015 (Tables 1–3). In 2013, the plants from the postharvest irrigation treatment had more dry biomass in the primocanes when the primocanes were trained in August than when they were trained in February. The plants also had more dry biomass in the primocanes with hand-weeding than with no weeding in 2 out of 3 years (2014 and 2015) and with weed mat each year. In 2015, 'Marion' had more primocane dry biomass than 'Black Diamond', particularly with

Table 4. Dry biomass and total nutrient content in the floricane prunings in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, July 2013.

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

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

postharvest irrigation, while 'Black Diamond' produced more primocane dry biomass when the primocanes were trained in February rather than in August.

'Marion' produced more floricane dry biomass than 'Black Diamond' in 2013, regardless of weed management strategy (Table 4). In 'Marion', however, both weed control strategies increased floricane dry biomass compared with no weed control, whereas in 'Black Diamond', there was no difference between hand-weeded and no weed control. In 2014, floricane dry biomass was affected by all treatments (Table 5). Plants produced more floricane dry biomass when grown with postharvest irrigation than with no postharvest irrigation the previous year. 'Marion' continued to produce more floricane dry biomass than 'Black Diamond', but it was especially greater in 'Marion' when the primocanes were trained in February. In addition, training time only had an effect on floricane dry biomass in 'Marion'. Weed control led to greater floricane dry biomass compared with no weeding when plants were trained in February. However, when plants were August-trained, there was no difference between hand-weeded and no weed control plots.

In 2013, 'Black Diamond' produced more fruit dry biomass without than with postharvest irrigation the previous year, whereas the opposite was found in 'Marion' (Table 6). The plants also produced more fruit dry biomass with weed mat than with hand-weeding that year, and the least amount of fruit dry biomass without weed control. In 2014, 'Marion' produced more fruit dry biomass when the plants were trained in February rather than in August, while 'Black Diamond' produced the same amount of fruit dry biomass with either training treatment (Table 7). Both cultivars produced more fruit dry biomass with weed mat than with no weed control, although there was a larger difference between the weed mat treatment and the nonweeded treatment in 'Black Diamond' than 'Marion' (Table 7). Similarly to what was observed in 2013, 'Black Diamond' plants grown with weed mat produced the most fruit dry biomass, but August training resulted in a larger difference between weed control treatments. Fruit dry biomass was greater in weed mat than in hand-weeded plots only when plants were trained in August.

In 2013, the annual accumulation in total aboveground plant dry biomass (new primocane growth and floricane and fruit growth) was greatest, on average, in both cultivars with postharvest irrigation, weed mat, and February training (Table 8). In 2014, February training still led to the greatest accumulation in dry biomass, on average (Table 9). However, weed management only had an effect on dry biomass accumulation in August-trained plants, where plants grown with weed mat accumulated more than with other weed management strategies. The two cultivars accumulated similar amounts of dry biomass, averaging 4.1 and 4.7 t·ha⁻¹ in 2013 and 2014, respectively.

Table 5. Dry biomass and total nutrient content in the floricanes prunings in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, July 2014.

	(t·ha⁻¹)				Macronutrients (kg·ha⁻¹)											Micronutrients (g·ha⁻¹)													
	Dry biomass		C		N		P		K		Ca		Mg	S		Fe			B		Cu		Mn		Zn		Al		
Treatment																													
Cultivar (C)	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.			Aug.	Feb.	Aug.	Feb.		Aug.	Feb.				Aug.	Feb.	+Irrig.	–Irrig.	Aug.	Feb.					
Black Diamond (B. Dia.)	2.5 c[y]	2.8 c	1.1 c	1.2 c	48 b	50 b	5.8		48 b	51 b	37 b	38 b	7 b	2.7 b	2.8 b	701 b			156 c	158 c	252 a	166 b	900 b	962 b	87 b		612 b		
Marion	3.4 b	4.4 a	1.5 b	2.0 a	56 b	73 a	5.6		49 b	65 a	47 b	63 a	11 a	3.2 b	4.2 a	887 a			302 b	396 a	366 a	348 a	987 b	1,424 a	104 a		814 a		
Irrigation (I)																													
Postharvest (+Irrig.)	3.4 a		1.5 a		60 a		5.9		55		49		10	3.4		807			268 a		309 a		1,145		100		729		
No postharvest (–Irrig.)	3.1 b		1.4 b		54 b		5.5		52		43		9	3.1		781			238 b		257 b		991		91		697		
Weed management (W)	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.						Aug.	Feb.	B. Dia.		Marion	Aug.	Feb.	+Irrig.	–Irrig.			Aug.	Feb.	B. Dia.		Marion
Nonweeded	2.2 b	2.9 b	1.0 b	1.3 b	37 b	50 b	3.9 d	5.1 bcd	41 c		39 b		8 b	2.1 b	2.8 b	491 b		658 b	171 c	258 ab	324 ab	134 c	828 c		56 d	93 bc	431 b		604 b
Hand-weeded	2.6 b	3.8 a	1.1 b	1.7 a	45 b	63 a	4.5 cd	6.3 abc	50 b		43 b		9 b	2.6 b	3.6 a	669 b		1,027 a	200 bc	269 a	237 bc	241 ab	1,035 b		80 c	109 abc	587 b		940 a
Weed mat	4.1 a	4.1 a	1.8 a	1.8 a	75 a	72.a	7.3 a	6.8 ab	69 a		57 a		12 a	4.2 a	4.0 a	944 a		980 a	316 a	304 a	366 a	397 a	1,342 a		120 a	111 ab	818 a		898 a
Training (T)																Nonweeded	Hand-weeded	Weed mat									Nonweeded	Hand-weeded	Weed mat
August (Aug.)	3.0 b		1.3 b		52 b		5.2 b		49 b		42 b		8 b	3.0 b		493 d	735 bc	987 a	229 b		251		943 b		86 b		449 d	655 bc	875 a
February (Feb.)	3.6 a		1.6 a		61 a		6.1 a		58 a		50 a		10 a	3.5 a		655 cd	960 a	935 ab	277 a		316		1,193 a		105 a		587 cd	871 a	840 ab
Significance[z]																													
C	0.0007		0.0005		0.0036		NS		NS		0.0131		0.0043	0.0049		0.0059			0.0001		0.0408		0.0026		0.0248		0.0023		
I	0.0146		0.0283		0.0139		NS		NS		NS		NS	NS		NS			0.0486		0.0014		NS		NS		NS		
W	<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001	<0.0001		<0.0001			<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		
T	<0.0001		<0.0001		0.001		0.0213		0.0021		0.002		0.0009	0.0008		0.0106			0.0005		NS		0.0016		0.0027		0.006		
C × I	NS		NS		NS		NS		NS		NS		NS	NS		NS			NS		0.0336		NS		NS		NS		
C × W	NS		NS		NS		NS		NS		NS		NS	NS		0.0106			NS		NS		NS		NS		0.0139		
I × W	NS		NS				NS		NS		NS		NS	NS		NS			NS		0.001		NS		NS		NS		
C × T	0.0116		0.0106		0.0044		NS		0.0312		0.0082		NS	0.0107		NS			0.0007		NS		0.0173		NS		NS		
I × T	NS		NS		NS		NS		NS		NS		NS	NS		NS			NS		NS		NS		NS		NS		
W × T	0.0088		0.0073		0.0033		0.0334		NS		NS		NS	0.0082		0.0247			0.0096		NS		NS		0.0062		0.0226		
C × I × W	NS		NS		NS		NS		NS		NS		NS	NS		NS			NS		NS		NS		NS		NS		
C × I × T	NS		NS		NS		NS		NS		NS		NS	NS		NS			NS		NS		NS		NS		NS		
C × W × T	NS		NS		NS		NS		NS		NS		NS	NS		NS			NS		NS		NS		NS		NS		
I × W × T[x]	NS		NS		NS		NS		NS		NS		NS	NS		0.0251			NS		NS		NS		NS		0.0374		

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

In 2013, more dry biomass (harvested fruit and floricane prunings) was removed from 'Marion' than 'Black Diamond' when the plants were irrigated postharvest but not when there was no postharvest irrigation (Table 10). In addition, more dry biomass was removed from plants grown with weed mat, whereas the least was removed from those grown without weed control. In 2014, there was no effect of training time on dry biomass removal in 'Black Diamond', whereas more dry biomass was removed from 'Marion' when February-trained (Table 11). More dry biomass was also removed from 'Marion' than from 'Black Diamond' within each training time. Plants grown with weed mat had the greatest removal of dry biomass with August training; however, when plants were trained in February, there was no difference between dry biomass removal for weed mat and the hand-weeded treatment. The average removal in dry biomass was 3.5 t·ha⁻¹ in 2013 and 4.6 t·ha⁻¹ in 2014.

In 2013, net change in aboveground dry biomass ranged from 0.4 to 0.7 t·ha⁻¹ among the treatments, with the greatest increase observed in plants that were irrigated postharvest ($P = 0.0156$) and those that were February-trained ($P = 0.0168$; data not shown). In 2014, net change ranged from –0.3 to 0.3 t·ha⁻¹, although there were no significant treatment effects (data not shown).

Primocane nutrient content. Treatment effects and interactions on dormant primocane macro- and micronutrient content varied among years (Tables 1–3). Cultivar and irrigation had limited direct effects on primocane nutrient content. In 2013, 'Marion' primocanes trained in February had less Cu in the tissue than those trained in August, or than 'Black Diamond' primocanes trained at either time (Table 1). In 2014, 'Black Diamond' primocanes contained less P and more S and Zn than 'Marion' primocanes (Table 2). In 2015, 'Black Diamond' primocanes had less K and B than 'Marion' primocanes trained in August, and less Mg, Fe, Cu, and Al than 'Marion' primocanes trained on either date (Table 3).

The impact of withholding irrigation after fruit harvest on primocane nutrient content often was affected by training time. In 2013, plants that received irrigation postharvest had less Ca and Zn in the primocanes trained in February as compared with August, whereas there was no effect of training time when the plants received no irrigation after fruit harvest (Table 1). In 2015, 'Black Diamond' plants that received postharvest irrigation had less S and Al in the primocanes than those that were not irrigated after harvest, whereas there was no difference in S or Al between the irrigation treatments in 'Marion'.

In 2013, plants grown with weed mat had more primocane N, K (only when February-trained), Ca, S, and Cu than the nonweeded treatment. Plants in hand-weeded plots also contained more primocane Ca and Cu than the nonweeded treatment (Table 3). In 2014 and 2015, weed management affected all measured primocane nutrients. Both years,

Table 6. Dry biomass and total nutrient content in the fruit of a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, 2013.

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

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

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

[x]All other higher order interactions were nonsignificant and are not shown.

the plants with weed mat had a higher content of most nutrients in the primocanes than those in nonweeded plots, except for N and K in 2014 when the primocanes were August-trained, and a higher content of N and K (in February-trained only), P, and S than those in hand-weeded plots in 2014, but not in 2015 (Tables 4 and 5). In addition to the interactions mentioned previously, the 2013 primocanes that were trained in August had higher N, P, Ca, Mg, S, B, Cu, Mn, and Zn than when trained in February, while the opposite was found for Fe and Al content. In 2014, direct training effects were more limited, with only a similar response to training in the Fe and Al content. In addition, primocanes trained in February had a higher K content than those trained in August (Table 2). Only primocane Al was directly affected by training time in 2015, with a similar pattern as was seen in the previous 2 years.

Floricane nutrient content. The nutrient content in the pruned floricanes was mostly affected by cultivar and weed management in 2013 (Table 4) and by cultivar, weed management, and training time in 2014 (Table 5). In both years, floricane nutrient content was higher in 'Marion' than 'Black Diamond' (except for P) and generally greater with weed control, although in 2014, plants in nonweeded and hand-weeded plots did not differ in floricane N and S (when August-trained), Zn (February-trained), Fe and Al (in 'Black Diamond'), Cu (when irrigated postharvest), and P, Ca, Mg, and B. Use of weed mat led to higher floricane N, P, S, and Zn content than hand-weeding in 2013 and all nutrients in 2014, although only when August-trained for N, S, B, Zn, and Al, only when irrigated postharvest for Cu, and only in 'Black Diamond' for Fe.

The effect of training time, on average, was limited in 2013, with Mn content in floricane prunings only being higher when plants were trained in February (Table 4). However, in 2014, February training increased the content of all nutrients in the subsequent floricane prunings (Fe and Al only in hand-weeded plots) (Table 5). Floricane N, K, Ca, S, B, and Mn content were particularly high in 'Marion' for canes that were trained in February.

Fruit nutrient content. Treatment effects on fruit nutrient content varied between 2013 and 2014 (Tables 6 and 7). In 2013, there was a direct effect of weed management on every nutrient. In general, plants growing in nonweeded plots had the lowest content of each nutrient in the harvested fruit, whereas plants in weed mat plots had the greatest, although hand-weeded and weed mat plots were not different for Ca, Mn, or Al. No other treatment had a direct effect on any nutrient in 2013 except plants that received postharvest irrigation had more fruit Al than those that did not. However, there was a cultivar × irrigation interaction on all fruit nutrients except N, Ca, Fe, and Cu. When plants received no postharvest irrigation, 'Black Diamond' fruit contained more P, K, Mg, S, B, Mn, and Al than did 'Marion'. In plants irrigated postharvest, either the opposite was found (i.e., Mg, Mn, and Zn) or there was no difference between the cultivars (Table 6).

In 2014, there was no effect of irrigation on fruit nutrient content, but there was an effect of cultivar or a cultivar × training time interaction on the fruit content of each nutrient (Table 7). Fruit produced by August-trained 'Marion' plants had particularly low N, P, K, S, B, and Cu content than the other training time and cultivar combinations, whereas February-trained 'Marion' had a high P, Ca, Mg, Fe, Mn, and Zn content in the fruit. 'Marion' plants trained in February had a greater content of all nutrients, except for Al.

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

A three-way interaction among irrigation, weed management, and training time revealed that fruit Ca content in 2014 was particularly low when the plants were not weeded, not irrigated after harvest, and trained in August when compared with those that were irrigated postharvest, trained in February, and had weed mat, or those that were not irrigated postharvest and were either trained in February and hand-weeded or trained in August and grown with weed mat ($P = 0.0347$; Fig. 1A). Fruit Fe content was particularly high in plants trained in February and either grown with weed mat and irrigated postharvest or hand-weeded and not irrigated postharvest when compared with plants that were not weeded and trained in August with either irrigation treatment or those that were hand-weeded and trained in August with postharvest irrigation ($P = 0.0429$; Fig. 1B).

Nutrient accumulation and removal. In 2013, the annual accumulation (new primocane and floricane growth and fruit harvest) in macronutrients per hectare was affected mostly by irrigation and weed management, whereas training time also affected micronutrient accumulation (Table 8). Postharvest irrigation increased the total accumulation of N in 'Marion' and of K, Mg, and S in both cultivars relative to no irrigation after harvest (Table 8). Weed control, particularly with

Table 7. Dry biomass and total nutrient content in the fruit of a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, 2014.

	(t·ha^{-1})						Macronutrients (kg·ha^{-1})															
	Dry biomass			C			N		P			K			Ca			Mg			S	
Treatment																						
Cultivar (C)	Aug.	Feb.		Aug.	Feb.		Aug.	Feb.	Aug.	Feb.		Aug.	Feb.		Aug.	Feb.		Aug.	Feb.		Aug.	Feb.
Black Diamond (B. Dia.)	1.3 b[y]	1.3 b		0.6 b	0.6 b		17 a	18 a	3.1 ab	2.9 b		16 a	16 a		2.4 b	2.3 b		1.7 b	1.6 b		1.3 a	1.3 a
Marion	1.1 b	1.5 a		0.5 b	0.7 a		13 b	18 a	2.4 e	3.4 a		11 b	16 a		2.5 b	3.5 a		14 b	2.0 a		0.9 b	1.3 a
Irrigation (I)																						
Postharvest	1.3			0.6			16		2.9			15			2.6			1.7			1.2	
No postharvest	1.3			0.6			17		3.0			15			2.7			1.7			1.2	
Weed management (W)	B. Dia.	Marion		B. Dia.	Marion		B. Dia.	Marion	B. Dia.	Marion		B. Dia.	Marion								B. Dia.	Marion
Nonweeded	1.0 d	1.2 cd		0.4 c	0.5 bc		12 c	14 c	2.2 c	2.5 c		12 c	11 c		2.3 b			1.4 c			1.0 b	0.9 b
Hand-weeded	1.2 bcd	1.3 bc		0.5 bc	0.6 b		16 bc	15 bc	2.8 bc	2.8 bc		15 b	13 bc		2.7 a			1.6 b			1.2 b	1.0 b
Weed mat	1.7 a	1.5 ab		0.7 a	0.6 ab		24 a	18 b	3.9 a	2.2 ab		20 a	15 b		3.0 a			2.0 a			1.7 a	1.2 b
Training (T)	Non-weeded	Hand-weeded	Weed mat	Non-weeded	Hand-weeded	Weed mat			Non-weeded	Hand-weeded	Weed mat	Non-weeded	Hand-weeded	Weed mat	Non-weeded	Hand-weeded	Weed mat	Non-weeded	Hand-weeded	Weed mat		
August (Aug.)	0.9 d	1.1 cd	1.6 a	0 4 d	0.5 cd	0.7 a	15 b		2.0 d	2.5 dc	3.7 a	10 c	12 c	18 a	2.0 b	2.4 ab	3.0 a	1.2 c	1.4 c	2.1 a	1.1 b	
February (Feb.)	1.2 bc	1.5 ab	1.6 a	0.5 bc	0.6 ab	0.7 a	18 a		2.7 bc	3.2 ab	3.6 a	13 bc	16 ab	17 a	2.7 a	3.1 a	2.9 a	1.6 bc	1.8 ab	2.0 a	1.3 a	
Significance[z]																						
C	NS			NS			NS		NS			0.0164			0.0157			NS			0.0088	
I	NS			NS			NS		NS			NS			NS			NS			NS	
W	<0.0001			<0.0001			<0.0001		<0.0001			0.0001			0.0021			<0.0001			<0.0001	
T	0.0004			0.0005			0.0058		0.0018			0.0036			0.0024			0.0029			0.0052	
C × I	NS			NS			NS		NS			NS			NS			NS			NS	
C × W	0.0191			0.0071			0.0075		0.0306			0.0274			NS			NS			0.0044	
I × W	NS			NS			NS		NS			NS			NS			NS			NS	
C × T	0.0004			0.0004			0.0134		<0.0001			0.0004			0.0002			<0.0001			0.0005	
I × T	NS			NS			NS		NS			NS			NS			NS			NS	
W × T[x]	0.0237			0.011			NS		0.0207			0.0101			0.0182			0.011			NS	

(*Continued on next page*)

Table 7. *(Continued)* Dry biomass and total nutrient content in the fruit of a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, 2014.

	Macronutrients (g·ha^{-1})														
	Fe		B			Cu			Mn		Zn			Al	
Treatment															
Cultivar (C)	Aug.	Feb.	Aug.	Feb.		Aug.	Feb.		Aug.	Feb.	Aug.	Feb.			
Black Diamond (B. Dia.)	43 bc	45 ab	16 a	16 a		11 a	11 a		43 b	42 b	24 b	22 b		123 a	
Marion	36 c	52 a	11 b	16 a		8 b	12 a		39 b	53 a	20 b	28 a		88 b	
Irrigation (I)															
Postharvest	42		14			10			44		23			106	
No postharvest	46		15			11			44		24			105	
Weed management (W)											B. Dia.	Marion		B. Dia.	Marion
Nonweeded	36 c		12 c			9 b			36 c		16 d	20 dc		76 c	76 c
Hand-weeded	43 b		14 b			10 b			46 b		22 dc	24 bc		131 ab	96 bc
Weed mat	53 a		18 a			13 a			52 a		31 a	29 ab		162 a	96 bc
Training (T)			Non-weeded	Hand-weeded	Weed mat	Non-weeded	Hand-weeded	Weed mat			Non-weeded	Hand-weeded	Weed mat		
August (Aug.)	40 b		10 c	12 bc	18 a	7 c	8 bc	13 a	41 b		16 c	20 bc	30 a	96 b	
February (Feb.)	48 a		14 ab	16 a	18 a	10 ab	11 a	13 a	48 a		21 b	25 ab	30 a	115 a	
Significance[z]															
C	NS		NS			NS			NS		NS			0.0373	
I	NS		NS			NS			NS		NS			NS	
W	<0.0001		<0.0001			<0.0001			<0.0001		0.0001			0.0001	
T	0.0006		0.0006			0.001			0.0114		0.0035			0.0299	
C × I	NS		NS			NS			NS		NS			NS	
C × W	NS		NS			NS			NS		0.0397			0.0127	
I × W	NS		NS			NS			NS		NS			NS	
C × T	0.0042		0.0008			0.0001			0.0056		0.0002			NS	
I × T	NS		NS			NS			NS		NS			NS	
W × T[x]	NS		0.0298			0.0166			NS		0.0451			NS	

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

weed mat, also increased the accumulation of many nutrients relative to no weeding, including N, P (weed mat only), K, Ca, Mg, S, Fe, B, Cu, Mn, Zn, and Al. Finally, February training increased the accumulation of Fe (particularly in plants that were irrigated postharvest), Cu, Mn, and Al relative to August training.

In 2014, ‘Marion’ plants accumulated more Mg, B, Cu, and Mn than ‘Black Diamond’ (Table 9). Plants grown with weed mat accumulated more Ca, Mg, Mn, and Zn than the other weed management strategies, regardless of training time. However, plants with weed mat only accumulated more N, P, K, S, and B than the other weed management treatments when August-trained; weed management did not affect nutrient accumulation in February-trained plants. Plants that were irrigated after harvest accumulated more B and Cu than those that were not irrigated.

More N, Ca, Mg, Fe, B, Cu, and Zn were removed from ‘Marion’ as a result of fruit harvest and floricane pruning than ‘Black Diamond’ in 2013 (Table 10). Removal of P and Al was also higher in ‘Marion’ plants irrigated after harvest than in ‘Black Diamond’ or in ‘Marion’ plants that were not irrigated after harvest. Nitrogen, P, K, S, Cu, and Zn removal was highest from plants grown with weed mat, whereas removal was lowest from those in nonweeded plots. In addition, either method of weed control increased the annual removal of Ca, Mg, Fe, B, Mn, and Al compared with nonweeded plants.

In 2014, removal was higher in ‘Marion’ plants that were trained in February for N, K, Ca, S, B, and Mn than in the other cultivar and training time combinations (Table 11). Phosphorus removal in ‘Marion’ was also higher when February-trained than when August-trained, although P removal was not higher than ‘Black Diamond’ for either training time. There was no effect of training time on nutrient removal in ‘Black Diamond’, which had less Mg, Fe, B, Zn, and Al (except in nonweeded plots) removed than ‘Marion’, irrespective of training time. Withholding irrigation after harvest decreased removal of N in both cultivars and of Cu in ‘Black Diamond’.

Less N and S was removed from ‘Black Diamond’ than ‘Marion’ when grown in nonweeded and hand-weeded plots, but there was no difference among cultivars when weed mat was used (Table 11). Plants grown with weed mat had a greater removal of Ca, Mg, and Mn than those in nonweeded and hand-weeded plots in both cultivars. Weed mat also led to greater removal of P, K, B, Zn, and Al when primocanes were trained in August, whereas there was generally no difference between weed mat and hand-weeded plots in the removal of these nutrients when primocanes were trained in February. In general, plants grown without weed control had the least nutrient removal.

In 2013, net change in aboveground nutrient content (annual accumulation minus annual removal) was 11–15 kg·ha^{-1} N, 1–2 kg·ha^{-1} P, 5–10 kg·ha^{-1} K, 0–2 kg·ha^{-1} Ca,

Table 8. Annual dry biomass and nutrient accumulation in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center, Aurora in OR, in 2013.

	(t·ha^{-1})		Macronutrients (kg·ha^{-1})						Micronutrients (g·ha^{-1})					
	Dry biomass	C	N	P	K	Ca	Mg	S	Fe	B	Cu	Mn	Zn	Al
Treatment														
Cultivar (C)														
Black Diamond (B. Dia.)	3.4	1.6	60	7	52	30	7	3.6	822	120	21	871	102	991
Marion	4.7	2.2	74	8	62	47	11	4.4	1,084	316	24	1,199	131	1,099
Irrigation (I)		B. Dia. Marion	B. Dia. Marion						Aug. Feb.					
Postharvest	4.4 a	1.7 bc[y] 2.4 a	64 b 84 a	8	60 a	42	10 a	4.4 a	820 b 1,140 a	233	24	1,085	127	1,081
No postharvest	3.7 b	1.5 c 1.9 b	56 b 65 b	7	53 b	35	8 b	3.7 b	929 ab 922 ab	203	21	984	106	1,009
Weed management (W)														
Nonweeded	3.3 c	1.5 c	52 c	6 b	43 c	30 b	8 c	3.1 c	750 b	169 b	17 c	790 b	89 c	826 b
Hand-weeded	4.1 b	1.9 b	67 b	7 b	56 b	41 a	9 b	4.0 b	1,053 a	227 a	23 b	1,191 a	119 b	1,126 a
Weed mat	4.8 a	2.2 a	82 a	10 a	71 a	44 a	11 a	4.9 a	1,055 a	258 a	27 a	1,124 a	142 a	1,183 a
Training (T)														
August (Aug.)	3.8 b	1.7 b	64	7	55	37	9	3.8	874 b	209	21 b	915 b	115	950 b
February (Feb.)	4.4 a	2.0 a	70	8	58	39	9	4.2	1,032 a	227	24 a	1,155 a	119	1,139 a
Significance[z]														
C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I	0.0074	0.01	0.0079	NS	0.0247	NS	0.0218	0.0267	NS	NS	NS	NS	NS	NS
W	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0006	0.0003	<0.0001	0.0004	<0.0001	<0.0001	0.0062	0.0002	0.0008
T	0.0087	0.0115	NS	NS	NS	NS	NS	NS	0.0143	NS	0.0399	0.0213	NS	0.0121
C × I	NS	0.042	0.0425	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C × W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I × W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C × T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I × T	NS	NS	NS	NS	NS	NS	NS	NS	0.012	NS	NS	NS	NS	NS
W × T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C × I × W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C × I × T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C × W × T	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0235	NS	NS	NS	NS
I × W × T[x]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

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

1–2 kg·ha^{-1} Mg, 0–1 kg·ha^{-1} S, 94–289 g·ha^{-1} Fe, 6–11 g·ha^{-1} B, 2–4 g·ha^{-1} Cu, 33–68 g·ha^{-1} Mn, 13–28 g·ha^{-1} Zn, and 94–292 g·ha^{-1} Al, depending on treatment (data not shown). Net nutrient content change was affected by irrigation and training time in 2013, but not by cultivar or weed management. Plots receiving postharvest irrigation accumulated more dry biomass and N, K, Ca, Mg, S, B, and Zn than those not receiving postharvest irrigation. February-trained plots accumulated more dry biomass, N, P, K, Ca, S, Fe, Cu, Mn, and Al than August-trained plots. There was a significant cultivar × irrigation effect on accumulation in aboveground Ca (P = 0.0428). All 'Marion' plots and postharvest-irrigated 'Black Diamond' plots accumulated an average of 1.7 kg·ha^{-1} of Ca in 2013, whereas 0.4 kg·ha^{-1} Ca was removed from 'Black Diamond' plots without postharvest irrigation.

There were few treatment effects on change in aboveground nutrients in 2014 (data not shown). The net aboveground change of K and S was greater in 'Black Diamond' (–8 and –0.6 kg·ha^{-1}, respective removal) than 'Marion' (–3 and –0.2 kg·ha^{-1}, respective removal). In addition, there was a net accumulation of Cu (8 g·ha^{-1}) in 'Marion', whereas there was a removal in 'Black Diamond' (–4 g·ha^{-1}). More Fe and Al were removed from plants that were trained in February (–390 and –389 g·ha^{-1}, respectively) than those trained in August (–112 and –114 g·ha^{-1}, respectively). Aboveground net nutrient change ranged from –8 to –13 kg·ha^{-1} N, 0 to –1 kg·ha^{-1} P, –3 to –8 kg·ha^{-1} K, 0 to 2 kg·ha^{-1} Ca, 0 to –1 kg·ha^{-1} Mg, 0 to –1 kg·ha^{-1} S, –112 to –390 g·ha^{-1} Fe, –9 to 4 g·ha^{-1} B, –4 to 8 g·ha^{-1} Cu, –38 to 8 g·ha^{-1} Mn, –25 to 10 g·ha^{-1} Zn, and –114 to –478 g·ha^{-1} Al, depending on treatment.

Carbon. Carbon content of the primocanes, floricanes, and fruit varied between years and followed the same pattern as dry biomass in almost every case, so specific results are not presented in detail here (Tables 1–5). Aboveground accumulation and removal in C content was similar in 2013 (Tables 8 and 10) and 2014 (Tables 9 and 11). Treatment effects differed from dry biomass in two cases. In 2013, irrigation only affected 'Marion' plants, which accumulated more C with postharvest irrigation than without, and in 2014, 'Marion' accumulated more C than 'Black Diamond', regardless of irrigation strategy.

In 2013, irrigation and training time had direct effects on net change in aboveground C (data not shown). Plots that received irrigation after harvest accumulated 0.4 t·ha^{-1} C compared with 0.2 t·ha^{-1} C when not irrigated postharvest. The net accumulation of February-trained plots was 0.4 t·ha^{-1} C, whereas August-trained plots accumulated 0.2 t·ha^{-1} C. There were no treatment effects on net aboveground C in 2014, with an average measured net removal of 0.03 t·ha^{-1} of C (data not shown).

The aboveground C stock of the treatments averaged 0.4–1.1 t·ha^{-1} during dormancy in late winter. The greatest C stock

Table 9. Annual dry biomass and nutrient accumulation in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, in 2014.

	(t·ha⁻¹)		Macronutrients (kg·ha⁻¹)						Micronutrients (g·ha⁻¹)					
	Dry biomass	C	N	P	K	Ca	Mg	S	Fe	B	Cu	Mn	Zn	Al
Treatment														
Cultivar (C)														
Black Diamond	3.8	1.6 b	57	8	63	43	8 b	4	539	179 b	160 b	1,017 b	98	522
Marion	5.6	2.4 a	75	9	70	64	13 a	5	736	380 a	187 a	1,301 a	147	721
Irrigation (I)														
Postharvest (+Irrig.)	4.8	2.1	69	9	68	58	11	4	693	297 a	242 a	1,241	125	679
No postharvest (–Irrig.)	4.6	2.0	64	8	65	50	10	4	582	263 b	205 b	1,077	120	564
Weed management (W)	Aug. Feb.	Aug. Feb.	Aug. Feb.	Aug. Feb.	Aug. Feb.			Aug. Feb.		Aug. Feb.	+Irrig. –Irrig.			
Nonweeded	3.4 c[y] 4.1 bc	1.4 c 1.8 bc	44 d 59 bcd	6 b 8 ab	47 c 61 bc	47 b	9 b	3 d 4 bcd	519	209 c 271 abc	290 a 157 b	978 b	94 b	488
Hand-weeded	3.6 c 5.6 ab	1.5 c 2.3 ab	50 cd 77 ab	6 b 10 ab	50 bc 75 ab	49 b	10 b	3 cd 5 abc	601	222 bc 300 abc	170 ab 219 ab	1,098 b	116 b	604
Weed mat	6.1 a 5.6 ab	2.6 a 2.4 ab	93 a 74 abc	12 a 9 ab	91 a 75 ab	65 a	13 a	6 a 5 ab	791	362 a 316 ab	267 a 238 ab	1,401 a	157 a	772
Training (T)														
August (Aug.)	4.3 b	1.9 b	62	8	63	51	10	4	699	264	201	1,054	105 b	687
February (Feb.)	5.1 a	2.2 a	70	9	71	57	11	4	575	295	246	1,264	140 a	557
Significance[z]														
C	NS	0.0437	NS	NS	NS	NS	0.0458	NS	NS	0.0099	0.0477	0.0364	NS	NS
I	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.024	0.0487	NS	NS	NS
W	<0.0001	<0.0001	<0.0001	0.0033	<0.0001	0.0003	0.0097	<0.0001	NS	0.0007	NS	0.0059	0.0074	NS
T	0.0384	0.0448	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0321	NS
C × I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C × W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I × W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0086	NS	NS	NS
C × T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I × T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
W × T	0.0221	0.0236	0.0021	0.0054	0.0048	NS	NS	0.0154	NS	0.0311	NS	NS	NS	NS
C × I × W	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C × I × T	NS	NS	NS	NS	NS	NS	NS	NS	0.004	NS	NS	NS	NS	0.0049
C × W × T	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I × W × T[x]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

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

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

[x]All other higher order interactions were nonsignificant and are not shown.

was measured in ‘Black Diamond’ grown without postharvest irrigation, with weed mat, and when trained in February, whereas the lowest was measured in ‘Black Diamond’ grown without postharvest irrigation, without weed control, and when trained in August. In ‘Marion’, the highest aboveground C stock occurred when plants received no irrigation after harvest, were grown with weed mat, and were August-trained, whereas the lowest occurred with postharvest irrigation, no weed control, and February training.

Discussion

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

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

Table 10. Annual dry biomass and nutrient removal in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, in 2013.

	($t \cdot ha^{-1}$)				Macronutrients ($kg \cdot ha^{-1}$)							Micronutrients ($g \cdot ha^{-1}$)						
	Dry biomass		C		N	P		K	Ca	Mg	S	Fe	B	Cu	Mn	Zn	Al	
Treatment																		
Cultivar (C)																		
Black Diamond (B. Dia.)	2.8 b		1.3 b		48 b	6		41	27 b	6 b	2.9	657 b	102 b	16 b	786	73 b	807	
Marion	4.1 a		1.9 a		61 a	6		53	42 a	9 a	3.8	919 a	286 a	22 a	1,047	105 a	961	
Irrigation (I)	B. Dia.	Marion	B. Dia.	Marion		B. Dia.	Marion										B. Dia.	Marion
Postharvest	2.7 c[y]	4.3 a	1.2 c	2.0 a	56	6 b	7 a	48	36	8	3.4	801	204	19	977	92	789 b	1,033 a
No postharvest	2.9 bc	3.8 ab	1.3 bc	1.7 ab	53	6 b	6 b	46	33	7	3.2	775	183	19	856	86	824 b	889 b
Weed management (W)																		
Nonweeded	2.6 c		1.2 c		38 c	4 c		33 c	26 b	6 b	2.4 c	595 b	141 b	14 c	638 b	62 c	664 b	
Hand-weeded	3.7 b		1.7 b		58 b	6 b		50 b	38 a	8 a	3.6 b	851 a	211 a	20 b	1,047 a	93 b	951 a	
Weed mat	4.1 a		1.9 a		66 a	8 a		58 a	40 a	9 a	4.1 a	919 a	229 a	23 a	1,065 a	112 a	1,036 a	
Training (T)																		
August	3.4		1.5		54	6		47	34	8	3.3	785	193	19	856	88	875	
February	3.5		1.6		55	6		47	35	8	3.4	791	195	19	977	90	892	
Significance[z]																		
C	0.0139		0.0125		0.0486	NS		NS	0.0209	0.0122	NS	0.0262	0.0006	0.0335	NS	0.0355	NS	
I	NS		NS		NS	NS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
W	<0.0001		<0.0001		<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	
T	NS		NS		NS	NS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
C × I	0.0228		0.0246		NS	0.0386		NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0254	
C × W	NS		NS		NS	NS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
I × W	NS		NS		NS	NS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
C × T	NS		NS		NS	NS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
I × T	NS		NS		NS	NS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
W × T[x]	NS		NS		NS	NS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	

[z]NS = nonsignificant; P values provided for significant factors.

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

[x]All other higher order interactions were nonsignificant and are not shown.

nutrient levels, which were lowest in the nonweeded and hand-weeded plots and higher under the weed mat (Dixon et al., 2015a).

'Black Diamond' and 'Marion' did not differ in primocane N content despite the former having a lower primocane leaf N concentration (Dixon et al., 2015a), leading to the possibility that the lower leaf %N was sufficient in this cultivar. Perhaps 'Black Diamond' was allocating more newly acquired N to primocane tissue than to primocane leaf tissue, leading to the appearance of N deficiency in leaf tissue samples. Leaf samples were taken in midsummer, whereas the primocane tissue was sampled in winter, so N may also have been remobilized from leaves to cane tissue between the two sample dates.

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

Fruit dry biomass was 0.4–0.7 $t \cdot ha^{-1}$ lower in each year of the present study than what was measured during the first fruiting year by Harkins et al. (2014). Consequently, nutrient content removed in the fruit was also lower for most macro- and micronutrients. However, N removal in fruit was about the same, and fruit Al content was much higher in 2013, although values in 2014 were similar to 2012. Fruit from weed mat plots contained more N, K, Mg, S, Mn, and Zn in 2013 or 2014 than either the hand-weeded or nonweeded plots, a response that may have been due to the higher soil nutrient levels under the weed mat (Dixon et al., 2015a). However, soil Ca was also higher under weed mat than in hand-weeded plots, but Ca was not higher in the fruit. In contrast, other nutrients, such as P, were higher in the fruit from weed mat plots and not in the soil (Dixon et al., 2015a). Fertilizer studies in raspberry and blackberry have shown that higher rates of N, P, K, Ca, and Mg increased plant levels of those nutrients; however, often this response did not result in an increase in yield (Kowalenko, 1981a, 1981b; Nelson and Martin, 1986; Spiers and Braswell, 2002).

Floricane dry biomass at floricane senescence or pruning in 2014 was similar to that reported by Harkins et al. (2014) in 2012, but it was ≈1 $t \cdot ha^{-1}$ less in 2013; a response that reflected the planting's transition into mature every-year production from 2013 to 2014. Despite the higher floricane dry biomass in 2014, fruit production did not increase from 2013 to 2014, so it appears that floricane dry biomass is not directly related to yield. An infestation of crown borer (*Pennisetia marginata* Harris) was discovered in 2013 that affected 'Black Diamond' primarily. There was also an extreme cold event in Dec. 2013 that caused cold injury to 'Marion' (Dixon et al., 2015b). Either of these problems could have reduced fruit production the following year. In fact, yield did appear to increase from 2013 to 2014 in February-trained 'Marion', which had much less winter cold damage than August-trained 'Marion' (Dixon et al., 2015b). 'Black Diamond' also had almost 20% lower budbreak in 2014 than was seen in 2013 (Dixon et al., 2015b), which may have been the reason that we did not see an increase in fruit dry biomass during this study.

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

Both fruit and floricanes were removed from the plants and were considered nutrient removal. Between 40% and 55% of the aboveground N was removed by floricane pruning and fruit harvest in semierect blackberry, trailing blackberry, and red raspberry (Malik et al., 1991; Mohadjer et al., 2001; Rempel et al., 2004). Delaying floricane pruning reduced N removal in 'Kotata' blackberry by almost 65% (Mohadjer et al., 2001) and in red raspberry by almost 40% (Rempel et al., 2004). Growers could use this tactic to reduce N fertilizer applications in the spring. Because the floricanes in our study were placed in the aisles after pruning and were chopped, their nutrients would have returned to the soil and would thus not represent a true removal from the system. Strik et al. (2006) found that the

Table 11. Annual dry biomass and nutrient removal in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, in 2014.

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

(*Continued on next page*)

Table 11. *(continued)* Annual dry biomass and nutrient removal in a mature planting of organic trailing blackberry located at the North Willamette Research and Extension Center in Aurora, OR, in 2014.

	Micronutrients ($g\cdot ha^{-1}$)													
	Fe			B		Cu		Mn		Zn		Al		
Treatment														
Cultivar (C)				Aug.	Feb.	+Irrig.	–Irrig.	Aug.	Feb.			Nonweeded	Hand-weeded	Weed mat
Black Diamond (B. Dia.)	745 b			171 c	173 c	264 a	178 b	942 b	1,004 b	110 b		507 c	718 b	978 a
Marion	934 a			313 b	413a	376 a	360 a	1,027 b	1,478 a	128 a		678 bc	1,035 a	993 a
Irrigation (I)														
Postharvest (+Irrig.)	852			282		320 a		1,189		122		835		
No postharvest (–Irrig.)	827			253		268 b		1,036		115		802		
Weed management (W)	B. Dia.	Marion		Aug.	Feb.	+Irrig.	–Irrig.			Aug.	Feb.	+Irrig.	–Irrig.	
Nonweeded	524 b	702 b		182 c	271 ab	334 ab	142 c	864 c		73 d	116 bc	649 cd	537 d	
Hand-weeded	711 b	1,069 a		213 bc	284 a	246 bc	252 ab	1,080 b		100 c	133 abc	815 bc	938 ab	
Weed mat	1,000 a	1,029 a		333 a	322 a	379 a	410 a	1,394 a		151 a	140 ab	1,041 a	931 ab	
Training (T)	Nonweeded	Hand-weeded	Weed mat			B. Dia.	Marion					Nonweeded	Hand-weeded	Weed mat
August (Aug.)	524 d	771 bc	1,038 a	242 b		216 b	304 b	984 b		108 b		513 c	755 b	1,000 a
February (Feb.)	704 cd	1,009 a	989 ab	293 a		224 b	429 a	1,241 a		130 a		673 bc	998 a	971 a
Significance[z]														
C	0.0056			0.0001		0.0438		0.0028		0.0263		0.0036		
I	NS			NS		0.0014		NS		NS		NS		
W	<0.0001			<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		
T	0.0063			0.0004		NS		0.0016		0.0017		0.0028		
C × I	NS			NS		0.0306		NS		NS		NS		
C × W	0.0114			NS		NS		NS		NS		0.0128		
I × W	NS			NS		0.0009		NS		NS		0.0295		
C × T	NS			0.0005		0.0437		0.0158		NS		NS		
I × T	NS			NS		NS		NS		NS		NS		
W × T	0.0219			0.0089		NS		NS		0.0048		0.0235		
C × I × W	NS			NS		NS		NS		NS		NS		
C × I × T	NS			0.0496		NS		NS		NS		NS		
C × W × T	NS			NS		NS		NS		NS		NS		
I × W × T[x]	0.022			NS		NS		NS		NS		0.0458		

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

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

[x]All other higher order interactions were nonsignificant and are not shown.

organic form of N in red raspberry prunings left in the row was as readily taken up as a granular, inorganic form applied at the same time.

In many cases, in both years of our study, nutrient removal was higher than what was applied in fertilizer, which would eventually lead to depletion in the soil. In 2013, K fertilizer application (31 $kg\cdot ha^{-1}$) (Dixon et al., 2015a) was notably lower than the removal seen in the field (33–58 $kg\cdot ha^{-1}$, depending on the treatment). Calcium, Mg, and B applications were also lower than the amount removed for some treatments, but lime, dolomite lime, and B fertilizers were applied in addition to the fertigation treatments (Dixon et al., 2015a). Despite fertilization, soil Ca, Mg, and B did not increase from 2013 to 2014. Similar results were seen in 2014, except in that year, N was also removed at a higher rate than it was applied for the most vigorous treatments, e.g., February-trained 'Marion' and weed mat plots, irrespective of cultivar or training time. Withholding irrigation after harvest reduced aboveground plant accumulation of B. Thus, plants in fields receiving no irrigation postharvest over many seasons might eventually be deficient in B if availability is limited during primocane growth and uptake. If we assume that floricane nutrients were actually returning to the system through uptake by blackberry roots in the row middles, true nutrient removal through fruit harvest was not higher than the fertilizer applied. However, it is unknown if nutrients other than N become readily available for plant uptake through this same pathway.

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

Cane C content increased in both years from when primocanes were sampled in late winter until they were removed and sampled as floricanes in August. Research in raspberry has shown that roots are a strong sink of C, which is remobilized into the floricanes for lateral and fruit production the following year (Fernandez and Pritts, 1996; Waister and Wright, 1989). Studies with ^{14}C in red

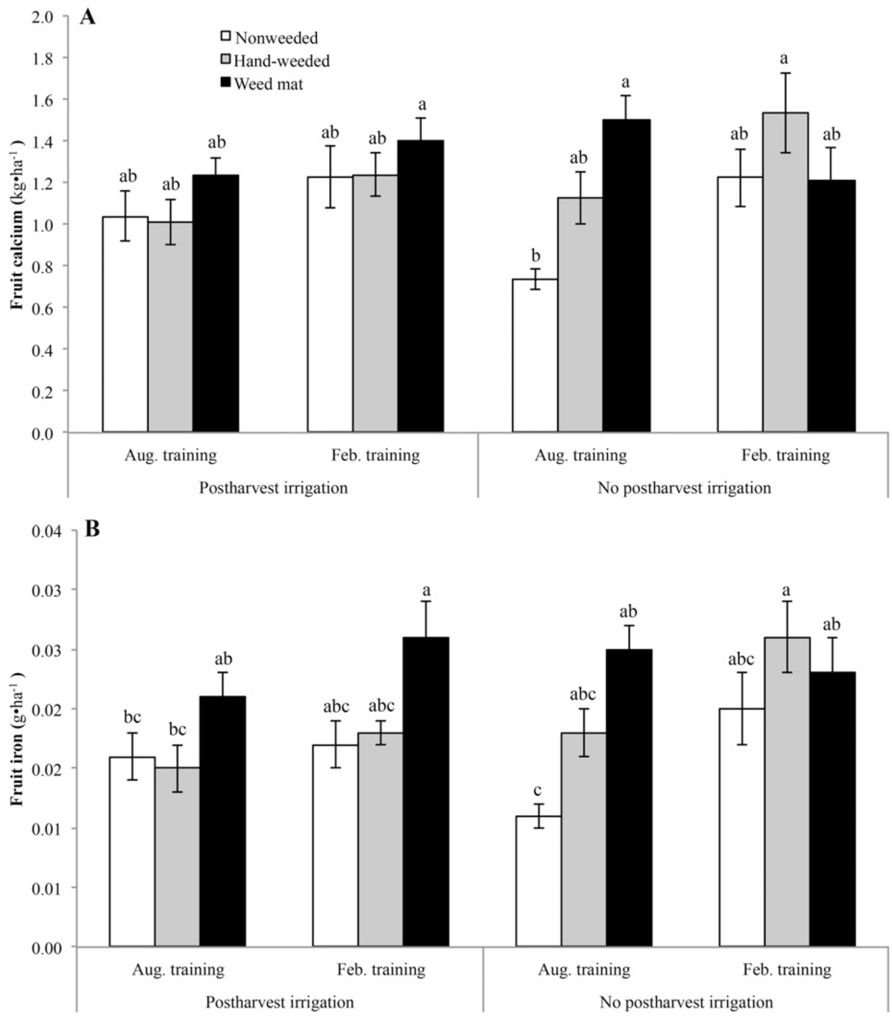

Fig. 1. Effects of irrigation, weed management, and training time on mature organic 'Black Diamond' and 'Marion' trailing blackberry fruit (**A**) calcium ($P = 0.0347$) and (**B**) iron ($P = 0.0429$) content. The plants were grown at the North Willamette Research and Extension Center in Aurora, OR, in 2014. Mean ± SE; means followed by the same letter within the interaction presented are not significantly different ($P > 0.05$).

raspberry have shown that fruit is the largest sink for C produced in floricane leaves, whereas the new primocane growth is the strongest sink for primocane leaves, and both types of canes send C to the roots as a secondary sink (Fernandez and Pritts, 1994; Privé et al., 1994; Waister and Wright, 1989). In blackberry, greater dry matter accumulation in the floricanes seems to suggest floricanes and fruit are the largest sink (Mohadjer et al., 2001). Floricanes and primocanes do not share fixed C products in other *Rubus* sp. (Fernandez and Pritts, 1993; Gauci et al., 2009), so it is probable that vegetative and reproductive canes in blackberry are also independent. The floricanes and fruit in our study would then have been receiving C from floricane leaves or root remobilization, not primocanes.

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

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

Conclusions

Dry biomass production in organic trailing blackberry was negatively affected by weeds, and often by training the primocanes in August. The aboveground C stock of the planting in winter reached a maximum of 1.1 t·ha^{-1} and was negatively impacted by weeds, postharvest irrigation, and February training. Although this C stock is relatively low compared with what has been reported in some other crops, this value does not include the roots or crowns. Nutrient content accumulation and removal in the aboveground portions of the plants were directly related to dry biomass accumulation. The use of weed mat led to a particularly high fruit nutrient content, even when compared with hand-weeding. 'Black Diamond' had lower floricane nutrient content than 'Marion', but a similar primocane nutrient content. The nutrient deficiencies found by Dixon et al. (2015a) in 'Black Diamond' primocane leaf N concentrations may have reflected only a difference in allocation between the two cultivars, not a true plant deficiency in N. The current caneberry nutrient standards (Hart et al., 2006) may need to be revised for cultivars other than Marion. The organic fertilizer applied to the planting often contained fewer nutrients than what was removed from the planting in floricane prunings and fruit. Although, since the floricanes were left in the field, true removal in the form of fruit was lower than the fertilizers applied. Fertilization rates may also need to be adjusted for some of these organic production systems, and it is unknown if other less mobile nutrients would be as readily available to plants as N is in the floricane prunings.

Literature Cited

Alvarado-Raya, H.E., R.L. Darnell, and J.G. Williamson. 2007. Root to shoot relations in an annual raspberry (*Rubus idaeus* L.) production system. HortScience 42:1559–1562.

Bowen, P. and S. Freyman. 1995. Ground covers affect raspberry yield, photosynthesis, and nitrogen nutrition of primocanes. HortScience 30:238–241.

Darnell, R.L., H.E. Alvarado-Raya, and J.G. Williamson. 2008. Root pruning effects on growth and yield of red raspberry. HortScience 43:681–684.

Dean, D.M., B.J. Zebarth, C.G. Kowalenko, J.W. Paul, and K. Chipperfield. 2000. Poultry manure effects on soil nitrogen processes and nitrogen accumulation in red raspberry. Can. J. Plant Sci. 80:849–860.

Dixon, E.K. 2015. Weed management, training, and irrigation practices for organic production of trailing blackberry: Plant growth, yield, and nutrients. MS thesis, Ore. St. Univ., Corvallis, OR 15 Oct. 2015. <http://ir.library.oregonstate.edu/xmlui/handle/1957/57654>.

Dixon, E.K., B.C. Strik, and D.R. Bryla. 2015a. Weed management, training, and irrigation practices for organic production of trailing

blackberry: II. Soil and aboveground plant nutrient concentrations. HortScience 51:36–50.
Dixon, E.K., B.C. Strik, L.R. Valenzuela-Estrada, and D.R. Bryla. 2015b. Weed management, training, and irrigation practices for organic production of trailing blackberry: I. Mature plant growth and fruit production. HortScience 50:1165–1177.
Fernandez, G.C. and M.P. Pritts. 1993. Growth and source-sink relationships in 'Titan' red raspberry. Acta Hort. 352:151–157.
Fernandez, G.C. and M.P. Pritts. 1994. Growth, carbon acquisition, and source-sink relationships in 'Titan' red raspberry. J. Amer. Soc. Hort. Sci. 119:1163–1168.
Fernandez, G.E. and M.P. Pritts. 1996. Carbon supply reduction has a minimal influence on current year's red raspberry (*Rubus idaeus* L.) fruit production. J. Amer. Soc. Hort. Sci. 121:473–477.
Fernandez-Salvador, J., B.C. Strik, and D.R. Bryla. 2015. Liquid corn and fish fertilizers are good options for fertigation in blackberry cultivars grown in an organic production system. HortScience 50:225–233.
Gauci, R., B. Otrysko, J.-G. Catford, and L. Lapointe. 2009. Carbon allocation during fruiting in *Rubus chamaemorus*. Ann. Bot. (Lond.) 104:703–713.
Harkins, R.H., B.C. Strik, and D.R. Bryla. 2013. Weed management practices for organic production of trailing blackberry: I. Plant growth and early fruit production. HortScience 48:1139–1144.
Harkins, R.H., B.C. Strik, and D.R. Bryla. 2014. Weed management practices for organic production of trailing blackberry: II. Accumulation and loss of biomass and nutrients. HortScience 49:35–43.
Hart, J., B. Strik, and H. Rempel. 2006. Caneberries. Nutrient management guide. Ore. State Univ. Ext. Serv., EM8903-E, Corvallis, OR.
Keightley, K.E. 2011. Applying new methods for estimating in vivo vineyard carbon storage. Amer. J. Enol. Viticult. 62:214–218.
Kowalenko, C.G. 1981a. The effect of nitrogen and boron soil applications on raspberry leaf N, B and Mn concentrations and on selected soil analyses. Commun. Soil Sci. Plant Anal. 12:1163–1179.
Kowalenko, C.G. 1981b. Affects of magnesium and potassium soil applications on yields and leaf nutrient concentrations of red raspberries and on soil analyses. Commun. Soil Sci. Plant Anal. 12:795–809.
Malik, H., D.D. Archbold, and C.T. MacKown. 1991. Nitrogen partitioning by 'Chester Thornless' blackberry in pot culture. HortScience 26:1492–1494.
Mohadjer, P., B.C. Strik, B.J. Zebarth, and T.L. Righetti. 2001. Nitrogen uptake, partitioning and remobilization in 'Kotata' blackberry in alternate-year production. J. Hort. Sci. Biotechnol. 76:700–708.
Naraguma, J., J.R. Clark, R.J. Norman, and R.W. McNew. 1999. Nitrogen uptake and allocation by field-grown 'Arapaho' thornless blackberry. J. Plant Nutr. 22:753–768.
Nelson, E. and L.W. Martin. 1986. The relationship of soil-applied N and K to yield and quality of 'Thornless Evergreen' blackberry. HortScience 21:1153–1154.
Nemeth, D.A. 2013. Patterns of carbon storage within a mature northern highbush blueberry production system. PhD Diss., Ore. St. Univ., Corvallis, OR. 10 June 2013. <http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/41676/THESIS2013.pdf?sequence=1>.
Percival, D.C., J.T.A. Proctor, and J.A. Sullivan. 2001. Cultivar differences in carbon assimilation and partitioning of primocane-fruiting raspberry. J. Amer. Pomolog. Soc. 55:82–89.
Privé, J.-P., J.A. Sullivan, and J.T.A. Proctor. 1994. Carbon partitioning and translocation in primocane-fruiting red raspberries (*Rubus idaeus* L.). J. Amer. Soc. Hort. Sci. 119:604–609.
Rempel, H.G., B.C. Strik, and T.L. Righetti. 2004. Uptake, partitioning, and storage of fertilizer nitrogen in red raspberry as affected by rate and timing of application. J. Amer. Soc. Hort. Sci. 129:439–448.
Spiers, J.M. and J.H. Braswell. 2002. Influence of N, P, K, Ca, and Mg rates on leaf macronutrient concentration of 'Navaho' blackberry. Acta Hort. 585:659–663.
Strik, B.C. and C.E. Finn. 2012. Blackberry production systems—a worldwide perspective. Acta Hort. 946:341–348.
Strik, B., T. Righetti, and H. Rempel. 2006. Black plastic mulch improved the uptake of ^{15}Nitrogen from inorganic fertilizer and organic prunings in summer-bearing red raspberry. HortScience 41:272–274.
U.S. Department of Agriculture (USDA). 2014. Table 33: Berries: 2012 and 2007. In: 2012 Census of Agriculture. U.S. Dept. Agr., Natl. Agr. Statistical Serv., Washington, DC.
U.S. Department of Agriculture (USDA). 2010. Table 4: Organic berries harvested from certified and exempt organic farms: 2008. In: Organic production survey (2008), 2007 Census of agriculture. U.S. Dept. Agr., Natl. Agr. Statistical Serv., Washington, DC.
U.S. Department of the Interior. 2013. U.S. Department of the Interior, Bureau of Reclamation, AgriMet. Boise, ID. 5 Apr. 2015. <http://www.usbr.gov/pn>.
Waister, P.D. and C.J. Wright. 1989. Dry matter partitioning in cane fruits, p. 51–61. In: C.J. Wright (ed.). Manipulation of fruiting. Butterworth & Co. Ltd., London.
Whitney, G.G. 1982. The productivity and carbohydrate economy of a developing stand of *Rubus idaeus*. Can. J. Bot. 60:2697–2703.