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Seasonal Variation in Mineral Nutrient Concentration of Primocane and Floricane Leaves in Trailing Blackberry Cultivars Produced in an Organic System

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Abstract

The impact of floricane-fruiting trailing blackberry (*Rubus* L. subgenus *Rubus,* Watson) cultivar ('Black Diamond', 'Marion', 'Obsidian', and 'Onyx') and leaf sampling time during the growing season were studied for 2 years in an organic production system to evaluate impacts on leaf nutrient concentration in primocane and floricane leaves. Primocane leaves were sampled every 2 weeks from late May through early October, whereas leaves on fruiting laterals (floricane) were sampled every 2 weeks from bloom (early May) through fruit harvest (late July) and were analyzed to determine concentration of macro- and micronutrients. Sampling date through the season, cultivar, and year had an effect on the concentration of all nutrients in the primocane leaves, though patterns of change were similar between years and cultivars. Primocane leaf N, S, and Cu concentration generally declined over the season while P, K, and Zn generally increased. Primocane leaf Mg, Ca, B, Fe, Mn, and Al concentrations peaked during the harvest season. The concentration of nutrients in floricane leaves generally decreased (N, P, K), remained steady (Mg, S, Cu), or increased (Ca, B, Fe, Mn, Zn, Al) from bloom through fruit harvest. 'Black Diamond' tended to have lower primocane but higher floricane leaf nutrient concentrations than the other cultivars. 'Obsidian' tended to have among the highest concentrations in both primocane and floricane leaves for many nutrients. Our results confirm the need to sample cultivars separately. The primocane leaf nutrient concentrations measured in this study were below the published recommended sufficiency levels for N (in 'Black Diamond'), Mg (in 2014), K (in 'Onyx'), Ca, and B, indicating the sufficiency levels for these nutrients and cultivars may need to be revised for this region.

Oregon is the leading producer of trailing blackberry (*Rubus* L. subgenus *Rubus*, Watson) in the USA, with about 2500 ha harvested mainly for processed markets in 2016 (Oregon Department of Agriculture, 2017). The primocanes of these floricane-fruiting cultivars are vegetative in their first year of growth. In their second year, when they are called floricanes, they flower, fruit, and then senesce. The primocanes of trailing types are not self-supporting and they are kept on the ground, under the floricane canopy, until trained to the trellis after fruit harvest and floricane pruning (typically done in late August) (Strik and Finn, 2012).

The nutrient status in trailing blackberry plants and fields is monitored by commercial growers using soil nutrient analysis, observations of plant growth, and annual primocane leaf tissue analysis. Fertilizer programs are developed based on recommended starting rates of nitrogen (N), which depend on planting age, and are adjusted for N and other macro- and micronutrients based on field observation and plant tissue nutrient testing (Bolda et al., 2012; Bushway et al., 2008; Fernandez and Ballington, 1999; Hart et al., 2006; Krewer et al., 1999). A review of plant nutrient uptake and plant assessment of nutrient status is provided in Strik and Bryla (2015). In floricane-fruiting blackberry and raspberry, leaf sampling of primocanes in mid- to late-season informs growers of plant nutrient requirements for fruit production the following season.

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Primocane leaf nutrient concentrations varied over the growing season in erect (Clark et al., 1988; Strik and Vance, 2017) and trailing (Mohadjer et al., 2001; Strik and Vance, 2017) floricane-fruiting blackberry, primocane-fruiting blackberry (Strik, 2015), and floricane-fruiting raspberry (Hughes et al., 1979; John and Daubeny, 1972; John et al., 1976; Kowalenko, 1981, 1994; Wright and Waister, 1980). While nutrients in floricane leaves in blackberry changed over the fruiting season (Pereira et al., 2015; Strik and Vance, 2017) standards for this leaf tissue type have only recently been developed in Brazil (Pereira et al., 2015).

In Oregon, leaf sampling for tissue analysis is recommended for primocanes from late July to early August with values compared to published sufficiency levels (Hart et al., 2006), though Strik and Vance (2017) found that mid- to late-August provided a more consistent sampling time when most nutrients were not changing rapidly. Sufficiency levels in Oregon were developed based on 15 years of tissue samples submitted by growers of 'Marion' blackberry (Hart et al., 2006). However, there are many more cultivars currently being grown. Cultivars of blackberry (Fernandez-Salvador et al., 2015a, b, c; Dixon et al., 2016; Harkins et al., 2014; Strik, 2015; Strik and Vance, 2017) and raspberry (John and Daubeny, 1972; John et al., 1976) differed in primocane leaf nutrient levels when sampled in mid-season. In addition, nutrient sufficiency levels may need to differ between conventional and organic production systems, as was suggested in blueberry by Strik and Vance (2015). Organic sources of N and other nutrients are often more slowly released to the plants as they may come from sources such as compost, cover crops, and animal-based manures and fertilizers (Archer et al., 2016). This requires careful management to ensure adequate nutrients are available at the correct times. Organic fertilizer sources often contain nutrients other than N. For example, the high level of potassium (K) in yard-debris compost and fish emulsion fertilizer has led to high rates of K application when these fertilizer sources were used (Fernandez-Salvador et al., 2015a, Harkins et al., 2014; Strik et al., 2017), potentially impacting plant nutrient uptake. Other practices such as the use of permeable polyethylene ground cover as a weed barrier in organic systems rather than maintaining bare soil with herbicides has been suggested to impact nutrient uptake and plant nutrient status in blackberry (Dixon et al., 2016). There are no existing standards for leaf aluminum (Al), but it can be useful as an indicator of low soil pH, in which Al uptake increases and inhibits the uptake of other cations, and can eventually cause toxicity resulting in improper root growth and insufficient nutrient and water uptake (Foy et al., 1978; Ryan and Kochian, 1993; Vitorello et al., 2005).

The objectives of this study were to evaluate the changes in primocane leaf nutrient concentrations in trailing, floricane-fruiting blackberry cultivars grown in an organic production system over two seasons, with a goal of comparing actual nutrient levels in each cultivar to published sufficiency levels for this crop. In addition, we evaluated the nutrient concentration of fruiting lateral leaves to better understand changes in nutrient allocation within the floricane during fruiting and whether this may provide another method of assessing nutrient needs in this type of blackberry.

Materials and Methods

Study sites. The study was conducted in 2013 and 2014, in a mature field planting at Oregon State University's North Willamette Research and Extension Center, Aurora, OR [lat. 45°16'47"N, long. 122°45'23"W; USDA hardiness zone 8b (U. S. Department of Agriculture, Agricultural Research Service, 2014); the weather records for this site can be viewed at U.S. Department of Interior (2014)]. The soil is mapped as a Willamette silt loam, classified as a fine-silty, mixed, superactive mesic Pachic Ultic Argixeroll.

The site was planted in spring 2010 and was certified organic by a USDA accredited agency (Oregon Tilth, Certified Organic, Corvallis, OR). Plants were spaced 1.5 m in the row with 3 m between rows (2222 plants/ha). The in-row area was covered with a 1.4-m-wide strip of black, woven polyethylene ground cover (TenCate Protective Fabrics; OBC Northwest Inc., Canby, OR) centered on the row and secured using 0.1-m-long nails. According to the manufacturer, the weed mat had a density of 0.11 $kg \cdot m^{-2}$ and a water flow rate of 6.8 $L \cdot h^{-1} \cdot m^{-2}$. The ground cover (referred to hereafter as weed mat) was placed on top of the row just prior to planting, and openings were cut for each plant (planting hole). Weeds were manually removed from the planting hole area and seams in the weed mat, as required throughout the study. The between row area was planted to a grass cover crop ('Aurora Gold' hard fescue, *Festuca brevipila* Tracey) that was mowed as needed.

Plants were irrigated with a single line of drip tubing (UNIRAM; Netafim USA, Fresno, CA) containing pressure-compensating emitters (1.9 $L \times h^{-1}$ in-line) spaced every 0.6 m. The drip tubing was placed along the ground at the base of the plants under the weed mat. More information on planting establishment is available from Fernandez-Salvador et al. (2015b).

Fertilization in both years was done through the drip irrigation system (fertigation). In 2013, a total target rate of 90 $kg \cdot ha^{-1}$ of N was applied, half using a soluble grain fermentation and nitrate of soda blend (4N–0.9P–0.8K; Converted Organics of California, LLC, Gonzales, CA) and half as a fish hydrolysate and fish emulsion blend combined with molasses (TRUE 512; 5N–0.4P–1.7K; True Organic Products, Inc., Spreckels, CA). In 2014, the same rate of N was applied using only TRUE 512 as a source. The fertilizers were applied in eight equal portions from early April to early July of each year. Additionally, 2.2 $kg \cdot ha^{-1}$ of boron (B; Solubor, 20 Mule Team Borax, Englewood, CO), 560 $kg \cdot ha^{-1}$ of pelletized dolomitic lime [62 $kg \cdot ha^{-1}$ magnesium (Mg) and 112 $kg \cdot ha^{-1}$ of calcium (Ca; Pro-Pell_it! Pelletized Dolomite; Marion Ag Service Inc., St. Paul, OR)], and 2242 $kg \cdot ha^{-1}$ of pelletized lime [717 $kg \cdot ha^{-1}$ of Ca (Pro-Pell-it! Pelletized Lime; Marion Ag Service Inc., St. Paul, OR)] were broadcast applied to the plots and aisles on 8 Mar. 2013. An additional 2.2 $kg \cdot ha^{-1}$ of B was applied in early Mar. 2014. Ground covers, as used in our study, have been shown to be permeable to fertilizers applied on top (Zibilske, 2010). A copper (Cu) fungicide (Nu-Cop; Albaugh Inc., Ankeny, IA) was applied to all plants (1.1 $kg \cdot ha^{-1}$ of Cu) on 24 Mar. 2014 to control for the cane diseases purple blotch [*Septocyta ruborum* (Lib.) Petr.] and cane rust [*Kuehneola uredines* (Link) Arthur].

Plants were grown in an every-year production system (Strik and Finn, 2012). New primocanes were bundled and tied to a 0.3-m-high trellis wire, below the floricane canopy, until Aug. each year. Primocanes were then trained to the upper trellis wires in mid- to late-Aug. by dividing the primocanes produced by each plant into two bundles and looping half in one direction from the upper to middle trellis wire and bringing it back towards the plant with one or two twists; the other half was looped in the opposite direction. Plants were trained on a two-wire vertical trellis system in each row with the wires attached to steel posts at 1.0 m and 1.6 m above the ground.

Cultivars. The cultivars studied were 'Black Diamond', 'Marion', 'Obsidian' and 'Onyx' trailing blackberry. More information on the fruiting season, growth and yield of the cultivars grown at this site was reported by Fernandez-Salvador et al. (2015b).

Leaf sampling. Tissue samples for nutrient testing were collected approx. every 2 weeks by choosing the most recent fully expanded leaves of primocanes (19 May to 6 Oct. 2013 and 2014) and fruiting laterals on floricanes (6 May to 29 July 2013 and 2014) for a total of 11 and 7 samples in each year for primocanes and floricanes, respectively. Stage of plant development and fruiting season was recorded for each cultivar. Yield data were not recorded, but the field had a good, typical commercial yield for this production region (Fernandez-Salvador et al., 2015b).

Approximately 6 to 12 of the most recent, fully expanded primocane and fruiting lateral leaves, respectively, including petioles, were sampled per plot on each date. Leaves were not washed prior to tissue analysis (Hart et al., 2006). Sampled leaves were priority shipped to Brookside Laboratories, Inc. in New Bremen, OH for analysis. Leaf N was determined using a combustion analyzer with an induction furnace and a thermal conductivity detector (Gavlak et al., 1994). Other nutrients, including phosphorus (P), K, Ca, Mg, Al, B, Cu, manganese (Mn), iron (Fe) and zinc (Zn) were determined using an inductively coupled plasma (ICP) spectrophotometer after wet ashing the samples in nitric/perchloric acid (Gavlak et al., 1994).

Soil testing. Soil samples were collected on 12 Nov. 2013 and 21 Oct. 2014 using a 2.4-cm-diam., 0.5-m-long, slotted, open-side, chrome-plated steel soil probe (Soil Sampler Model Hoffer, JBK Manufacturing, Dayton, OH). Soil was sampled to a depth of 0.2 m at the center of the row, approx. 0.3 m from the crown between plants and within the water emitter drip zone or fertilization area. Only one, combined sample (unreplicated) was sent for analysis of macro- and micronutrient content and pH to Brookside Laboratories each year.

Data analysis. Cultivars were arranged as a randomized complete block design with four replicates for each of the four cultivars. Each experimental unit consisted of a four-plant plot. Data were analyzed by tissue type (primocane or floricane) separately, as our goal was to observe nutrient changes throughout the season rather than to compare canes. Research has suggested that floricanes and primocanes act independently in blackberry as well (Bryla and Strik, 2008). Leaf nutrient data were analyzed by sample date for the effect of year using PROC MIXED (SAS version 9.3) with year as the main effect (n=2), and cultivar as the subplot effect (n=4) using a Satterthwaite approximation, as needed, for main effect comparisons. Mean comparison was performed using a protected LSMEANS.

PROC UNIVARIATE and the Shapiro-Wilk procedure were used to assess normality of the data for all the aforementioned analyses. As the tissue nutrient concentration of many nutrients was not normal, a log transformation was used to improve homogeneity of variance and to assess proportional effects. Data were back transformed for presentation.

Results and Discussion

Phenological development. Key phenological stages and harvest season for the four cultivars studied are shown in Table 1. Fruiting season and plant development were quite similar for the two years of the study (data not shown). 'Black Diamond' and 'Obsidian' had similar harvest dates, which were earlier than 'Marion' and 'Onyx'. By the end of July, all fruit harvest was complete and floricanes were removed ("caned-out") in mid-August.

Soil properties. Soil pH and all nutrients were within recommended levels in both years (Table 2), other than soil B (0.5 to 1.0 ppm; Hart et al., 2006); there are no published recommended levels for soil Fe, Cu, Zn, and Al for blackberries in this region.

Year effect. Year had a significant main effect on primocane and floricane leaf nutrient concentration on several sample dates throughout the season and for many nutrients on at least one sample date. In primocane leaves, the concentrations of most nutrients (N, Mg, Ca, S, Fe, Zn, and Al) were similar, higher, or lower in 2014 than 2013 depending on the time of the season. Leaf B and Mn concentrations were generally lower in 2014 than 2013, while the concentrations of P, K, and Cu were higher in 2014 for most

Table 1. Development stages for primocanes and floricanes through the season (2013 and 2014 averaged) for floricane-fruiting trailing blackberry cultivars grown in an organic production system at Oregon State University's North Willamette Research and Extension Center. Show in approximate order of fruit ripening.

Cultivar	Approximate stage of development on each date[z]										
	15 May	1 June	15 June	1 July	15 July	1 Aug.	15 Aug.	1 Sept.	15 Sept.	1 Oct.	15 Oct.
'Black Diamond'	late fruit set	mid green fruit	begin harvest	harvest	end of harvest	P[y] growing	P growing	P growing	P growing	P growing	P growing
'Marion'	mid bloom	early green fruit	red fruit	begin harvest	late harvest	P growing	P growing	P growing	P growing	P growing	P growing
'Obsidian'	late fruit set	mid green fruit	begin harvest	harvest	end of harvest	P growing	P growing	P growing	P growing	P growing	P growing
'Onyx'	early bloom	early green fruit	red fruit	begin harvest	harvest	P growing	P growing	P growing	P growing	P growing	P growing

[z] Approximate stage of development is provided. The beginning and end of fruit harvest for a particular cultivar may have occurred between the dates provided. Primocane leaves were sampled for tissue analysis on 6 May, 19-20 May, 2-3 June, 16-17 June, 30 June-1 July, 14-15 July, 28-29 July, 12 Aug., 25-27 Aug., 8-10 Sept., 22-23 Sept., and 6-7 Oct. (depending on year). Leaves on fruiting laterals were sampled for tissue analysis on 6 May, 19-20, May, 2-3 June, 16-17 June, 30 June-1 July, 14-15 July, and 28-29 July.

[y] "P"=primocanes. Primocane growth would have slowed toward the end of the season (e.g. 1 Oct.) as temperatures declined in autumn.

of the season (Figures 1 and 2). Leaf Cu was likely higher in 2014 as a result of the Cu-based fungicide applied in late winter of that year.

In floricane leaves, N, S, Fe, Mn, and Zn were lower in 2014 than in 2013 on at least one date while leaf B and Cu were higher in 2014 on at least one date (data not shown). Floricane leaf Cu concentrations spiked in the early part of 2014 due to the application of a copper-based fungicide used for disease control and remained higher for the duration of the season. Concentrations of K and Ca were either higher or lower in 2014 depending on the time of the season.

The patterns of change in leaf nutrients for both primocanes and floricanes were relatively similar through the season between years (primocanes: Figures 1 and 2; floricanes: data not shown), despite the above-noted differences between years. There was a year x cultivar interaction on several dates for multiple nutrients. An example of these interactions can be seen for one sample date within the recommended sampling time suggested by Strik and Vance (2017), in Table 3. The data presented herein support their recommendation of mid- to late-August as a good time to conduct primocane leaf tissue nutrient sampling based on the relative stability of many nutrients during that period (Figures 3 and 4). We have chosen to present only 2013 data here in order to more clearly show seasonal changes for these four cultivars.

Primocane leaf nutrient concentration. Primocane leaf N fluctuated throughout the season for all cultivars, but decreased overall in 'Black Diamond' whereas in 'Marion', 'Obsidian', and 'Onyx', leaf N was similar at the end of the season as in the spring (Figure 3). Primocane leaf N was significantly affected by cultivar. 'Obsidian' had higher leaf N than the other cultivars on several sampling dates, particularly early and late season, while 'Black Diamond' had lower leaf N than the other cultivars for most of July through the end of the season. Fewer differences among trailing cultivars were reported by us (Strik and Vance, 2017) in primocane leaf N in conventional production.

Leaf P concentration was either steady ('Marion') or declined slightly ('Black Diamond', 'Obsidian', 'Onyx') until the end of the fruiting season (late July, Figure 3), after which it increased in all cultivars through early September. Leaf P declined in all cultivars from September into October.

Table 2. Soil pH, organic matter and nutrient content in the organic production system at Oregon State University's North Willamette Research and Extension Center, 12 Nov. 2013 and 21 Oct. 2014.

		Organic	ppm												
Year	pH	matter (%)	NH_4-N	NO_3-N	P[z]	K	Ca	Mg	S	B	Fe	Mn	Cu	Zn	Al
2013	6.4	3.1	10.3	0.9	234	228	1127	132	12	0.23	337	51	0.8	1.9	1201
2014	6.1	3.0	3.8	1.4	218	289	1306	176	21	0.41	327	29	1.6	2.3	1297

[z] P as determined by Bray I.

During the fruiting season, leaf K concentration declined in 'Marion' and 'Obsidian', while it increased in 'Black Diamond' or remained relatively steady in 'Onyx' (Figure 3). However, leaf K increased in all cultivars from mid-Aug. until early Sept.. Blackberry fruit are high in K (Harkins et al., 2014), which may be why leaf K was lower during the portion of the season when fruit were present. Similar patterns in leaf K concentration during the fruiting season were reported for conventional production (Strik and Vance, 2017), except 'Marion' had considerably higher leaf K in late season than 'Black Diamond' in the present study.

Leaf Ca and Mg showed opposite patterns to leaf K, as concentrations were highest during the harvest season for all cultivars (Fig. 3). After fruiting, leaf Ca and Mg declined to levels similar to those measured in the spring, except for leaf Mg in 'Obsidian', which was high at the end of the season. The decline in

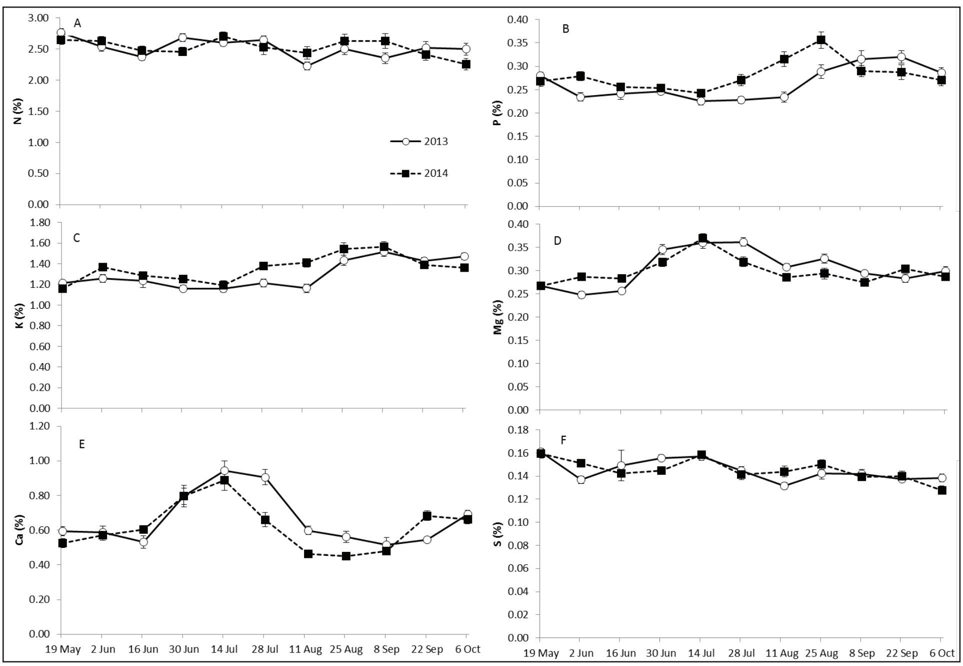

Figure 1. Effects of year and sample date on the concentration of macronutrients in primocane leaves of floricane-fruiting, trailing blackberry when sampled over the growing season in 2013 and 2014. Values are the means of four cultivars grown in an organic production system at Oregon State University's North Willamette Research and Extension Center, Aurora, Ore. **A** = nitrogen; **B** = phosphorus; **C** = potassium; **D** = magnesium; **E** = calcium; **F** = sulfur. Bars indicate standard error for cultivar (n = 16).

Table 3. Effect of year and cultivar on primocane leaf nutrient concentration of floricane-fruiting, trailing blackberry cultivars when grown in an organic production system at Oregon State University's North Willamette Research and Extension Center, Aurora, Ore. and sampled on 27 Aug. 2013 and 25 Aug. 2014.

	%							ppm									
	N[z]	P		Mg		K	Ca	S	B	Fe		Mn	Cu		Zn	Al	
Tissue Standards[y]	2.3–3	0.19–0.45		0.3–0.6		1.3–2.0	0.6–2.0	0.1	30–70	60–250		50–300	6–20		15–50	n/a	
Year																	
2013	2.50	0.29 b[x]		0.33		1.43 b	0.56 a	0.14	23.1	156 a		163 a	8.0 b		34.9	115 a	
2014	2.62	0.36 a		0.29		1.54 a	0.45 b	0.15	22.0	115 b		123 b	11.7 a		35.6	89 b	
Cultivar		2013	2014	2013	2014					2013	2014		2013	2014		2013	2014
Black Diamond	2.11 d	0.27 e	0.28 de	0.29 bc	0.26 c	1.33 b	0.46 b	0.13 c	21.9 b	144 ab	157 a	137 ab	8.9 c	11.3 b	31.3 ab	103 bc	140 a
Marion	2.76 b	0.33 c	0.39 b	0.36 a	0.29 bc	1.64 a	0.60 a	0.15 b	24.1 b	158 a	91 c	131 b	7.3 d	11.5 b	37.2 bc	124 ab	68 e
Obsidian	3.01 a	0.35 c	0.45 a	0.35 a	0.36 a	1.72 a	0.52 ab	0.17 a	27.1 a	150 ab	124 b	165 a	8.9 c	13.3 a	43.0 a	97 bcd	80 cde
Onyx	2.37 c	0.21 f	0.31 cd	0.30 b	0.26 c	1.27 b	0.46 b	0.13 c	17.1 c	172 a	90 c	139 ab	6.9 d	10.8 b	29.4 c	135 a	69 de
Significance[w]																	
Year	NS	0.0031		NS		0.0467	0.007	NS	NS	0.0225		0.0435	<0.0001		NS	0.0176	
Cultivar	<0.0001	<0.0001		<0.0001		<0.0001	0.025	<0.0001	<0.0001	NS		NS	<0.0001		<0.0001	0.0119	
Year*Cultivar	NS	0.0161		0.0086		NS	NS	NS	NS	0.0006		NS	0.0059		NS	0.0001	

[z] N=nitrogen; P=phosphorus; Mg=magnesium; K=potassium; Ca=calcium; S=sulfur; B=boron; Fe=iron; Mn-manganese; Cu=copper; Zn=zinc; Al=aluminum.
[y] Recommended sufficiency range for blackberry when sampled in late July to early August (Hart et al., 2006); no sufficiency levels are available for aluminum (n/a).
[x] Means followed by the same letter within treatment or the interaction are not significantly different (LSMeans) ($P > 0.05$).
[w] Non-significant ("NS") or actual P value provided when significant by analysis of variance.

leaf Ca after fruiting may have been related to the relatively high rate of primocane growth that occurs during the latter part of the season in trailing blackberry (Cortell and Strik, 1997). Similar patterns and levels were reported in conventional production (Strik and Vance, 2017). Primocane leaf S fluctuated throughout the season, but all cultivars ended the season with slightly lower leaf S than in spring.

Primocane leaf B, Fe, Mn, and Al concentrations increased or reached their highest levels during fruiting and declined into Aug. and Sept., ending the season at levels that were similar (B) or higher (Fe, Mn, Al) than those in the spring (Figure 4). Leaf Zn increased during fruiting and ended the season with higher concentrations than in spring (except 'Onyx', which had similar leaf Zn at the beginning and end of the season). 'Black Diamond' and 'Obsidian' had significantly higher leaf Cu than 'Marion' and 'Onyx' for the majority of the season. Leaf Cu concentration fluctuated in all cultivars and was lower at the end of the season than in spring. We found less variability in primocane leaf micronutrient concentrations over the season in this study as compared to conventionally-grown trailing blackberry where canes were on bare soil through much of the season (Strik and Vance, 2017).

Comparison to standards. Many of the primocane leaf nutrient concentrations measured were within the recommended sufficiency range during the mid- to late-August sampling period

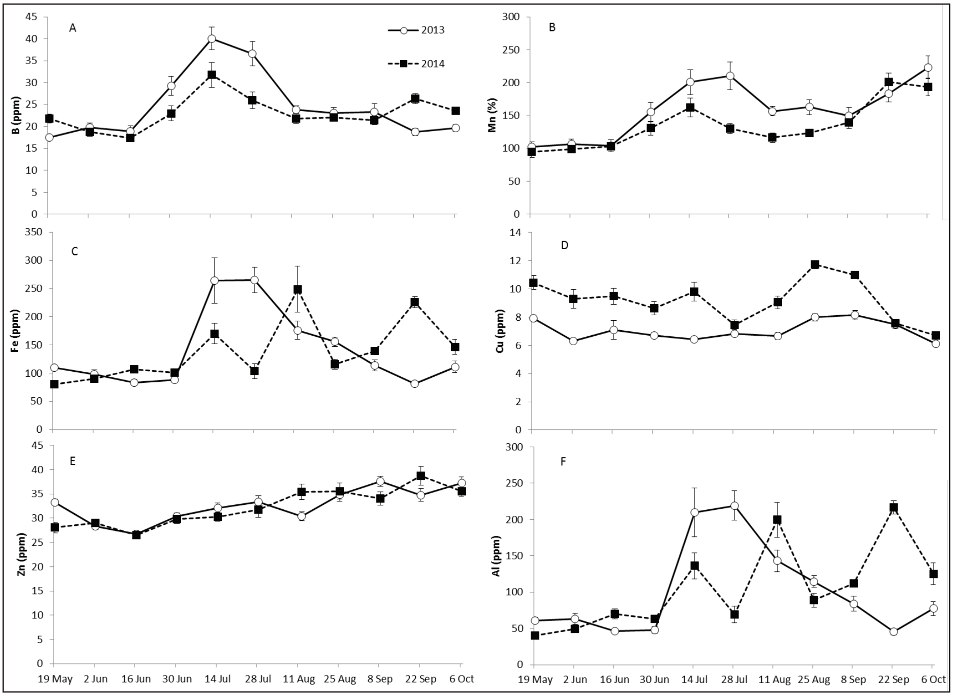

Figure 2. Effect of year and sample date, averaged over cultivar, on the concentration of macronutrients in primocane leaves of floricane-fruiting, trailing blackberry when sampled over the growing season in 2013 and 2014. Values are the means of four cultivars grown in an organic production system at Oregon State University's North Willamette Research and Extension Center, Aurora, Ore. **A** = boron; **B** = manganese; **C** = iron; **D** = copper; **E** = zinc; **F** = aluminum. Bars indicate standard error for cultivar (n = 16).

recommended by Strik and Vance (2017), including leaf P, S, Fe, Mn, Cu, and Zn. 'Black Diamond' had low leaf N compared to the other cultivars and was below the recommended range, as was found previously in both organic (Dixon et al., 2016, Harkins et al., 2014) and conventional (Strik and Vance, 2017) production systems. Leaf Mg was low in all cultivars except 'Obsidian' in 2014, while all cultivars except 'Black Diamond' were within (but at the low end) of the range in 2013. 'Onyx' had particularly low leaf K, while 'Black Diamond' was just within the recommended range in late Aug. and below it in mid-Aug.. All cultivars were below the existing tissue standard for leaf Ca and B, though it is typical in this region for leaf B to be low unless supplemental foliar B is applied. Soil B was also below recommended levels at this site (Table 2). Clearly, cultivars vary in leaf nutrient levels, even when fertilized the same, indicating differences in nutrient requirements or uptake. We thus confirm that cultivars should be sampled separately for leaf tissue analysis. The proposed new sufficiency standards proposed by Strik and Vance (2016) for blackberries in Oregon would encompass the ranges of nutrients observed in this study.

Floricane leaf nutrient concentration. While floricane leaf nutrient concentrations changed similarly from spring through the fruiting season in all cultivars (Figures 5 and 6), there was a significant cultivar effect on many sampling dates. Whereas 'Black Diamond' had the lowest primocane leaf N

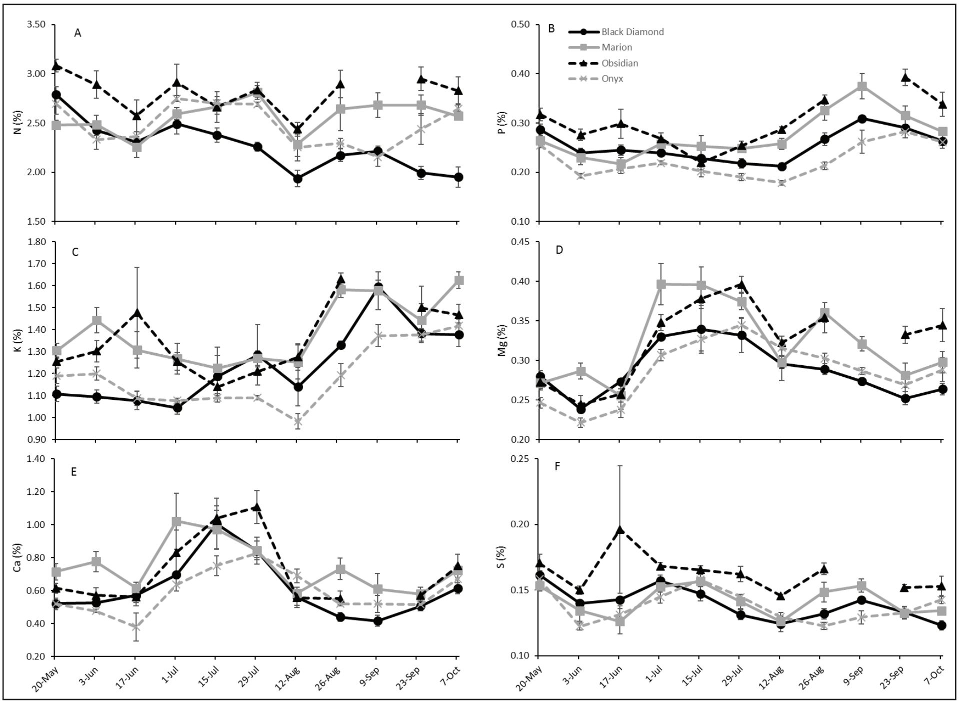

Figure 3. Effect of sample date and cultivar on the concentration of macronutrients in primocane leaves of floricane-fruiting, trailing blackberry when sampled over the growing season in 2013 in an organic production system at Oregon State University's North Willamette Research and Extension Center, Aurora, Ore. **A** = nitrogen; **B** = phosphorus; **C** = potassium; **D** = magnesium; **E** = calcium; **F** = sulfur. Bars indicate standard error for cultivar (n = 4). No data were collected for 'Obsidian' on Sept 9 due to insufficient leaf tissue after primocane training.

on many dates, it had the highest floricane leaf N concentration for most of the season. 'Marion' had much lower floricane leaf N than the other three cultivars. 'Obsidian' and 'Onyx' had similar floricane leaf N concentrations, but 'Obsidian' had higher levels on several dates. Differences in floricane leaf N concentration may be related to vigor of the fruiting lateral or yield. For example, 'Black Diamond' has very short fruiting laterals with dark green leaves, as compared to relatively long laterals with lighter green leaves in 'Marion' (Finn et al., 1997, 2005). In addition, the concentration of N in the floricane leaves may have declined as N was mobilized to the developing fruit which, in these cultivars, ranges from 0.9 to 1.4% of dry weight (Dixon et al., 2016; Harkins et al., 2014; Strik and Vance, 2017). Leaf S followed much the same pattern by cultivar as leaf N.

Leaf P concentration declined more rapidly in the early season compared to leaf N, but mostly leveled out through the fruiting season. 'Black Diamond' and 'Marion' had the highest and lowest leaf P, respectively, relative to the other cultivars for most of the season. Floricane leaf K, Mg, and Ca were similar between 'Black Diamond' and 'Marion', while concentrations in 'Obsidian' were either lower (K) or higher (Mg and Ca) than the other cultivars for much of the season. Floricane leaf K remained at a more consistent, higher concentration in our study

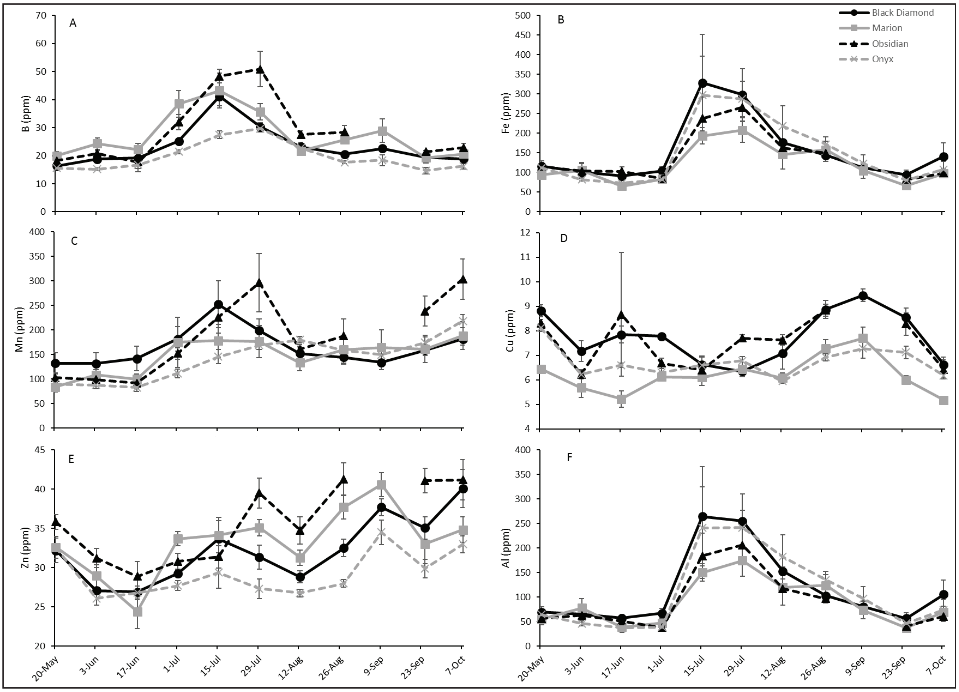

Figure 4. Effect of sample date and cultivar on the concentration of macronutrients in primocane leaves of floricane-fruiting, trailing blackberry when sampled over the growing season in 2013 in an organic production system at Oregon State University's North Willamette Research and Extension Center, Aurora, Ore. **A** = boron; **B** = iron; **C** = maganese; **D** = copper; **E** = zinc; **F** = aluminum. Bars indicate standard error for cultivar (n = 4). No data were collected for 'Obsidian' on Sept 9 due to insufficient leaf tissue after primocane training.

than many of the same cultivars grown in a conventional production system with bare soil in the row (Strik and Vance, 2017). The differences observed between these two studies may be because plants in this study were being fertigated, including applications later in the season (as opposed to granular fertilizer applications used by Strik and Vance, 2017), or were due to differences in nutrient availability related to production method (weed mat in the row as compared to bare soil). Dixon et al. (2016) showed that trailing blackberries grown with weed mat (which is commonly used in organic blackberry production in this region) had higher K in floricanes than plants grown with bare soil.

Floricane leaf Mg concentration peaked just prior to fruit harvest in 'Obsidian' and 'Black Diamond' and again at the end of the floricane season, but remained relatively stable all season with a slight increase toward the end of harvest in 'Marion' and 'Onyx' (Figure 5). Leaf Ca increased for the majority of the floricane season in all cultivars, with the highest levels in 'Obsidian' (Figure 5). Leaf Ca and Mg concentrations likely increased because these fruiting lateral leaves were aging, as has been reported in older primocane leaves of raspberry (Hughes et al., 1979), and there are relatively low concentrations of these nutrients in trailing blackberry fruit (Dixon et al., 2016; Harkins et al., 2014).

In general, floricane leaf B, Fe, Mn, and

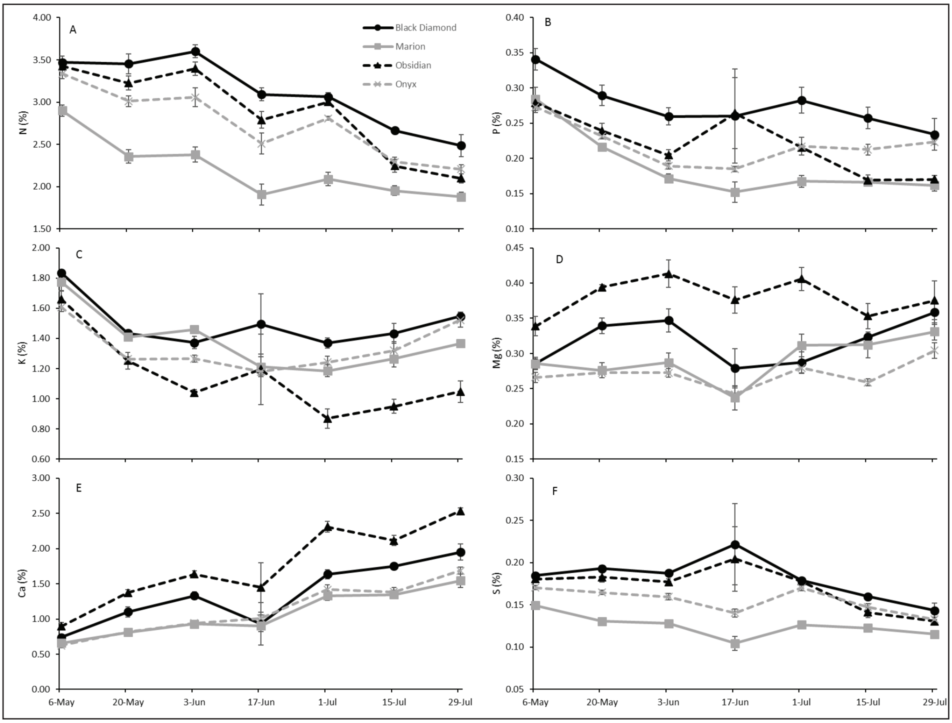

Figure 5. Effect of sample date and cultivar on the concentration of macronutrients in floricane leaves of floricane-fruiting, trailing blackberry when sampled over the growing season in 2013 in an organic production system at Oregon State University's North Willamette Research and Extension Center, Aurora, Ore. **A** = nitrogen; **B** = phosphorus; **C** = potassium; **D** = magnesium; **E** = calcium; **F** = sulfur. Bars indicate standard error for cultivar (n = 4).

Zn, and Al concentrations increased during the floricane season, with the exception of lower values of each nutrient for 'Black Diamond' just prior to fruit harvest (Figure 6). Leaf Cu concentration was relatively stable in the fruiting lateral leaves of most cultivars, except for an increase before fruit harvest in 'Obsidian' and a slight decrease at this time in 'Marion' and 'Onyx'. 'Black Diamond' had higher floricane leaf Fe and Al (all season except just prior to fruit harvest), leaf Mn (to mid-June), and Cu in spring than the other cultivars, as has been reported in other studies (Dixon et al., 2016; Harkins et al., 2014; Strik and Vance, 2017). 'Marion' had the lowest concentrations for all or the majority of the season for all micronutrients except B.

Summary

Primocane leaf nutrient concentrations changed through the growing season and were often affected by year and cultivar. Sampling cultivars separately, as currently recommended (Hart et al., 2006; Strik and Vance, 2016), is thus important in addition to keeping records to monitor variability among years. The primocane leaf nutrient concentrations measured in this study were below the published recommended sufficiency levels for N (in 'Black Diamond'), Mg (in 2014), K (in 'Onyx'), Ca, and B, indicating the sufficiency levels for these nutrients and cultivars may need to be revised for this region (Hart et al., 2006; Table 3), as we have suggested for conventional production (Strik and Vance, 2016, 2017).

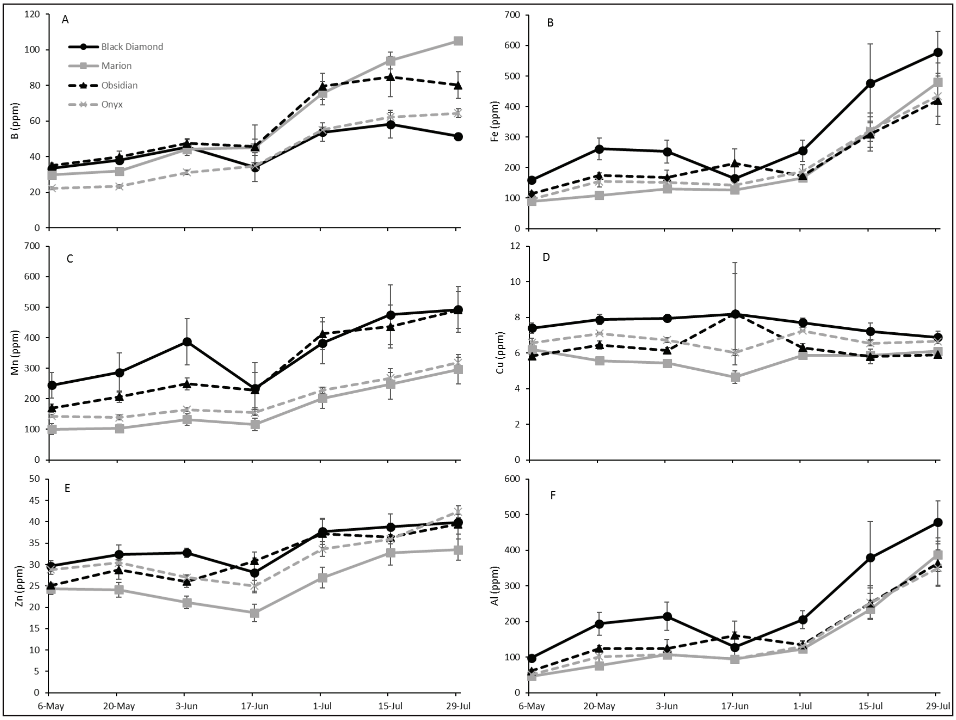

Figure 6. Effect of sample date and cultivar on the concentration of macronutrients in floricane leaves of floricane-fruiting, trailing blackberry when sampled over the growing season in 2013 in an organic production system at Oregon State University's North Willamette Research and Extension Center, Aurora, Ore. **A** = boron; **B** = iron; **C** = maganese; **D** = copper; **E** = zinc; **F** = aluminum. Bars indicate standard error for cultivar (n = 4).

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