

Seasonal Variation in Mineral Nutrient Content of Primocane-fruiting Blackberry Leaves

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Abstract. Primocane-fruiting blackberry (*Rubus* L. subgenus *Rubus*, Watson) cultivars, Prime-Jan[®] and Prime-Jim[®], grown only for a primocane crop, were studied for 2 years to evaluate whether this type of blackberry should be sampled at a certain stage of development or time of season to best evaluate plant nutrient status. Leaves were sampled every 2 weeks from a primocane height of ≈ 0.75 m in spring through fruit harvest in autumn and were analyzed to determine concentration of macro- and micronutrients. Primocanes were summer pruned at 1.4 m, by hedging to a height of 1.0 m, to induce branching, a standard commercial practice. Leaf nutrient concentration was related to stage of primocane growth and development and whether the leaves originated on the main cane or on the branches that resulted from summer pruning. Nutrient concentration of leaves sampled on the main primocane from early growth in spring until early branch growth in summer was significantly affected by cultivar, year, and week for most nutrients. When leaf sampling occurred on the older leaves of the main cane (for 4 weeks after hedging), the concentration of Ca, Mg, B, Fe, Mn, and Al increased, likely a result of the relative immobility of most of these nutrients. When samples were taken on primocane branches, leaf N, Mg, S, B (2009 only), Fe, Mn, Cu (2009 only), Zn, and Al concentrations did not differ between samples taken 6–8 weeks after summer pruning or hedging. Leaf K and Ca were more stable when sampling was done from weeks 8 to 10 (early bloom to green/early red fruit). There was a significant difference in leaf P among all weeks sampled during this period. A sample date corresponding to early green fruit stage (week 8) would thus likely provide the best compromise for assessing plant nutrient status in this crop. During this stage of development the nutrient concentrations measured for both cultivars and years, were within the present recommended nutrient sufficiency levels for other blackberry and raspberry crops for all except leaf K and P which were below current standards. The results suggest leaf sampling primocane-fruiting blackberry at the early green fruit stage (about 8 weeks after summer pruning) rather than a particular calendar date. The present leaf sufficiency range for P and K may need to be lowered for this crop. In addition, sampling cultivars separately for tissue analysis would still be advised to better manage nutrient programs.

The commercial cultivation of primocane-fruiting blackberries is relatively recent, following the release of the first commercial cultivars in 2005 (Clark et al., 2005). Nutrient management programs specific to primocane-fruiting blackberry have not yet been published. Commercial berry crop growers are encouraged to develop fertilization programs based on recommended starting rates of nitrogen (N) fertilizer, which depend on berry type and planting age, with adjustments of N and other macro- and micronutrients based on periodic

soil nutrient analysis and annual leaf tissue analysis (Bolda et al., 2012; Bushway et al., 2008; Fernandez and Ballington, 1999; Hart et al., 2006a, 2006b; Krewer et al., 1999).

Primocane leaf nutrient status, as compared with published sufficiency levels (Bolda et al., 2012; Bushway et al., 2008; Hart et al., 2006a), coupled with observations of plant growth and yield are presently used to develop nutrient management programs in all caneberry (raspberry and blackberry) types. Leaf sampling is recommended for primocanes from May to August (Bolda et al., 2012), “following harvest” (Fernandez and Ballington, 1999), the first week of August (Bushway et al., 2008), or late July to early August (Hart et al., 2006a), regardless of type of caneberry crop or the fruiting season of the cultivar. The recommended nutrient sufficiency levels are similar among these currently available nutrient management guides and all have the same standards regardless of caneberry type.

Primocane leaf nutrient levels have been shown to vary over the growing season in floricane-fruiting blackberry (Clark et al., 1988; Mohadjer et al., 2001), floricane-fruiting raspberry (Hughes et al., 1979; John and Daubeny, 1972; John et al., 1976; Kowalenko, 1981, 1994; Wright and Waister, 1980), and in other fruit crops (e.g., Bailey et al., 1962; Buwalda and Meekings, 1990; Chuntanaparb and Cummings, 1980; Clark and Smith, 1990; Dominguez et al., 2009; Kucukyumuk and Erdal, 2011). 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. However, no standards have been published specifically for primocane-fruiting types of raspberry or blackberry, which differ in their growth and development relative to floricane-fruiting types. In addition, the best time to sample in primocane-fruiting blackberry is not known.

Cultivars of blackberry (Fernandez-Salvador et al., 2015a, 2015b; Harkins et al., 2014) and raspberry (John and Daubeny, 1972; John et al., 1976) have been shown to differ in primocane leaf nutrient levels when sampled in midseason. In contrast, Clark et al. (1988) found no difference among three erect blackberry cultivars in leaf nutrient levels, and speculated that this was because of their similar parentage. Sampling cultivars separately for tissue analysis is recommended in Oregon due to possible cultivar effects on leaf nutrient concentrations (Hart et al., 2006a). The effect of cultivar on primocane-fruiting blackberry primocane leaf nutrient levels is not known.

The most common commercial production system used in primocane-blackberry includes a single (Strik et al., 2008, 2012) or a double-tip (Thompson et al., 2009) of the primocanes to encourage branching and increase primocane-fruiting. Hedging primocanes to facilitate primocane tipping (Strik and Buller, 2012) is also done commercially to reduce labor costs. The influence of summer pruning on leaf nutrient levels and optimal sampling time is not known.

The objectives of this study were to evaluate the impact of sample date on primocane leaf nutrient levels in two cultivars of primocane-fruiting blackberry, assess how tissue nutrient levels are related to pruning or hedging time over two seasons, and to evaluate whether this type of blackberry should be sampled at a certain stage of development or time of season to best evaluate plant nutrient status.

Materials and Methods

The study was conducted in 2008 and 2009, in a mature field planting established in Spring 2003 at Oregon State University’s North Willamette Research and Extension Center, Aurora, OR [NWREC; lat. 45°17' N, long. 122°45' W; U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS) hardiness zone 8b (USDA-ARS, 2014); elevation 46 m above sea level; average last freeze date 17 Apr.; average first freeze date

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25 Oct.; the weather records for this site can be viewed at U.S. Department of Interior (2014)]. The soil type was a Quatama loam (fine-loamy, mixed, mesic Aqualtic Haploxeralfs). Plants were spaced 0.6 m in the row with 3 m between rows.

Plants were fertilized with 34 kg·ha⁻¹ N, 31 kg·ha⁻¹ P, and 53 kg·ha⁻¹ K in mid-April and an additional 45 kg·ha⁻¹ N in mid-May of each year. The field was drip irrigated (3.8 L·h⁻¹ emitters at 0.6 m spacing) as required, typically 30 min. twice daily from June through September. Weeds were controlled with preemergent herbicides and mechanical methods. Blackberry row width was maintained at 0.45 m using cultivation. Canes were trained between double sets of trellis wires located at 0.3 and 1.7 m high, but were not tied to the wires.

Plants were grown for a primocane crop only and were pruned to ground level in late winter of each year starting in 2004. During the subsequent growing season, primocanes were tipped using a hedging method to 1.0 m high, by removing about 0.4 m of growth with hand-held shears—a “hard-tip” as has been shown to be a very effective pruning method in this type of blackberry (Strik and Buller, 2012). Hedging was done on 2 July 2008 and 24 June 2009. The number of growing degree days (GDD) were recorded using a base of 50 °F (10 °C) and an upper cap of 86 °F (30 °C) (U.S. Department of Interior, 2014).

There were four replicates of each of the cultivars, Prime-Jan[®] and Prime-Jim[®], arranged as a randomized complete block design. Each experimental unit consisted of a five-plant, 3-m long plot with 3 m separating plots. Tissue samples for nutrient testing were collected approximately every 2 weeks from 4 June to 22 Oct. in 2008 and 13 May to

28 Oct. 2009 for a total of 11 and 13 samples in 2008 and 2009, respectively (Table 1). Stage of plant development was recorded for each sampling date ranging from a primocane height of ≈0.75 m to well into the fruit harvest season on the primocanes in October. Yield data were not recorded; performance of this research plot was reported by Strik et al. (2012) and the field was observed to have a good, typical commercial yield for this production region.

About 50 of the most recent, fully expanded primocane leaves, including petioles, were sampled per plot on each date per standard recommendation (Hart et al., 2006a). Leaves were sampled from the main cane when average primocane height increased from ≈0.75 to 1.4 m, at which point the canes in the plot were hedged to 1.0 m tall (Table 1). For the first two sample dates immediately after hedging, primocane leaves were sampled from the main cane just under the recently tipped portion of the cane. Once branches were ~0.3 m long, leaf tissue sampling was done on the primocane branches selecting the most recent fully expanded leaves (Table 1). Based on the growth habit and summer pruning practices performed in this type of blackberry, this leaf sampling procedure would be expected in a commercial planting. No fungicides, insecticides, or foliar fertilizers were applied to the planting. Leaves were not washed before tissue analysis (Hart et al., 2006a).

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 P, K, Ca, Mg, Al, B, Cu, Mn, and Zn were determined using an inductively

coupled plasma (ICP) spectrophotometer after wet ashing the samples in nitric/perchloric acid (Gavlak et al., 1994).

Stage of plant development was recorded for each cultivar, including taking photos on each sample date. The cultivars were not observed to differ in rate of development. However, the rate of plant development differed between years. Primocane growth and development, and thus hedging date was more than 1 week delayed in 2009 compared with 2008, likely a result of differences in cumulative GDD (Table 1). The effect of GDD on rate of development in primocane-fruited blackberry has been reported previously (Strik et al., 2012). When the leaf tissue nutrient data were graphed by year and cultivar, it appeared that shifts in nutrient concentration were related to hedging or tipping date rather than the calendar date on which samples were collected. Data were thus graphed and analyzed with sampling time measured as weeks before or after hedging (Table 1). Years were compared for samples collected 4 weeks prior (week -4) to hedging (week 0) through 16 weeks after hedging (week 16).

Data for nutrient concentration over the entire sample season were analyzed as a split-split plot with cultivar as the main effect ($n = 2$), year as the split plot effect ($n = 2$), and sample week as the split-split plot effect ($n = 11$) using PROC MIXED (SAS version 9.3). Data were first analyzed to see if year should have its own separate error term (rep x year); results confirmed that this was not necessary. Residuals were plotted to assess homogeneity of variance (residual by fitted value plot). Strong fanning in the residual plots led to the tissue nutrient concentration of all nutrients (except for N and K) being log transformed for analysis to improve homogeneity of

Table 1. Dates on which primocane leaf tissue samples were collected as related to stage of plant development and date of hedging of ‘Prime-Jan’[®] and ‘Prime-Jim’[®] primocane-fruited blackberry plants grown at Oregon State University’s North Willamette Research and Extension Center, Aurora, OR. The cultivars were not observed to differ in rate of development so averages are presented.

Stage of development	Sample dates		Sample week relative to hedge date ^x	Growing degree days ^w	
	2008	2009		2008	2009
Primocanes at ≈0.3 m ^z	NA	13 May		NA	340
Primocanes at ≈0.75 m	4 June	27 May	-4	518	505
Primocanes at ≈1 m	18 June	10 June	-2	627	724
Primocanes at ≈1.4 m (hedge date)	2 July	24 June	0	871	913
Branches emerging (≈2.5 cm)	16 July	8 July	+2	1138	1133
Branches growing (≈15 cm)	30 July	22 July	+4	1353	1385
Branches ≈0.3 m long; first leaf sample on branches (early bloom in 2009) ^y	13 Aug.	5 Aug.	+6	1599	1699
Branches ≈0.4 m long (early bloom in 2008; green fruit stage in 2009) ^y	27 Aug.	19 Aug.	+8	1851	1931
Green fruit stage in 2008; beginning of red fruit stage in 2009	10 Sept.	2 Sept.	+10	2067	2165
Beginning of red fruit stage in 2008; early black fruit in 2009	24 Sept.	16 Sept.	+12	2264	2386
Early black fruit stage in 2008; harvest season in 2009	8 Oct.	30 Sept.	+14	2421	2558
Harvest season	22 Oct.	14 Oct.	+16	2499	2650
Harvest season	NA	28 Oct.	NA	NA	2731

^zAverage primocane height.

^yIn 2008, branches bloomed 14 d after first tissue sampling on branches, whereas in 2009 early bloom coincided with first fully expanded leaf and first date of tissue sampling on branches.

^xFor example, -4 = 4 weeks before hedging; 0 = date of hedging; 2 = 2 weeks after hedging.

^wGrowing degrees days were calculated with a base of 50 °F (10 °C) and a cap of 86 °F (30 °C; U.S. Department of Interior, 2014).

NA = not available.

variance and to assess proportional effects. Data were back transformed for presentation.

The data for each nutrient were then separated into “early” season (leaves collected on the main cane; weeks -4 through 4; $n = 5$) and “late” season (leaves collected from branches; weeks 6 through 16; $n = 6$) to account for origin of the leaf tissue sampled. Early and late-season samples were each analyzed as a split-split plot, as described above, with a Satterthwaite approximation used, as needed, for main effect comparisons.

Results and Discussion

When all sampling dates (weeks -4 through 16) were analyzed, there was a significant effect ($P < 0.05$) of cultivar, year, and week of sampling (“week”) on the concentration of

all primocane leaf nutrients except for Ca (no cultivar or year effect) and B, Mn, Fe, and Al where there was no cultivar effect (data not shown). The data for the full sampling period are presented by year and cultivar for each nutrient in Figures 1 and 2.

When data were analyzed for the early period of leaf sampling on the main primocane from early growth until early branch growth (weeks -4 to 4), cultivar, year, and week significantly affected the concentration of all nutrients except for Ca, B, Mn, and Fe (no cultivar effect), and Zn (no cultivar or year effect) (data not shown).

Leaf Ca, Mg, B, Fe, Mn, and Al concentrations were relatively stable when the most recent fully expanded leaf was sampled on the main primocane (weeks -4 through 0; before hedging in spring) (Figs. 1 and 2).

However, when leaf sampling occurred on the older leaves of the main cane (weeks 2 and 4), below the tip site, the concentration of these nutrients increased, likely a result of the relative immobility of Ca, B, Mn, Fe, and Al within the plant. Although Mg is mobile, our results seem to indicate that Mg was accumulating in older primocane leaves. Hughes et al. (1979) reported a higher leaf Mg, Ca, and Mn on older primocane leaves than on the most recent, fully expanded leaves in floricanne-fruited raspberry. The concentration of N and P in leaves declined during this early sampling period. There were relatively large differences among cultivars and years in leaf K, S, Zn, and Cu concentrations during this spring—early summer sampling period on the main primocane (Figs. 1 and 2). It would thus be difficult to monitor plant

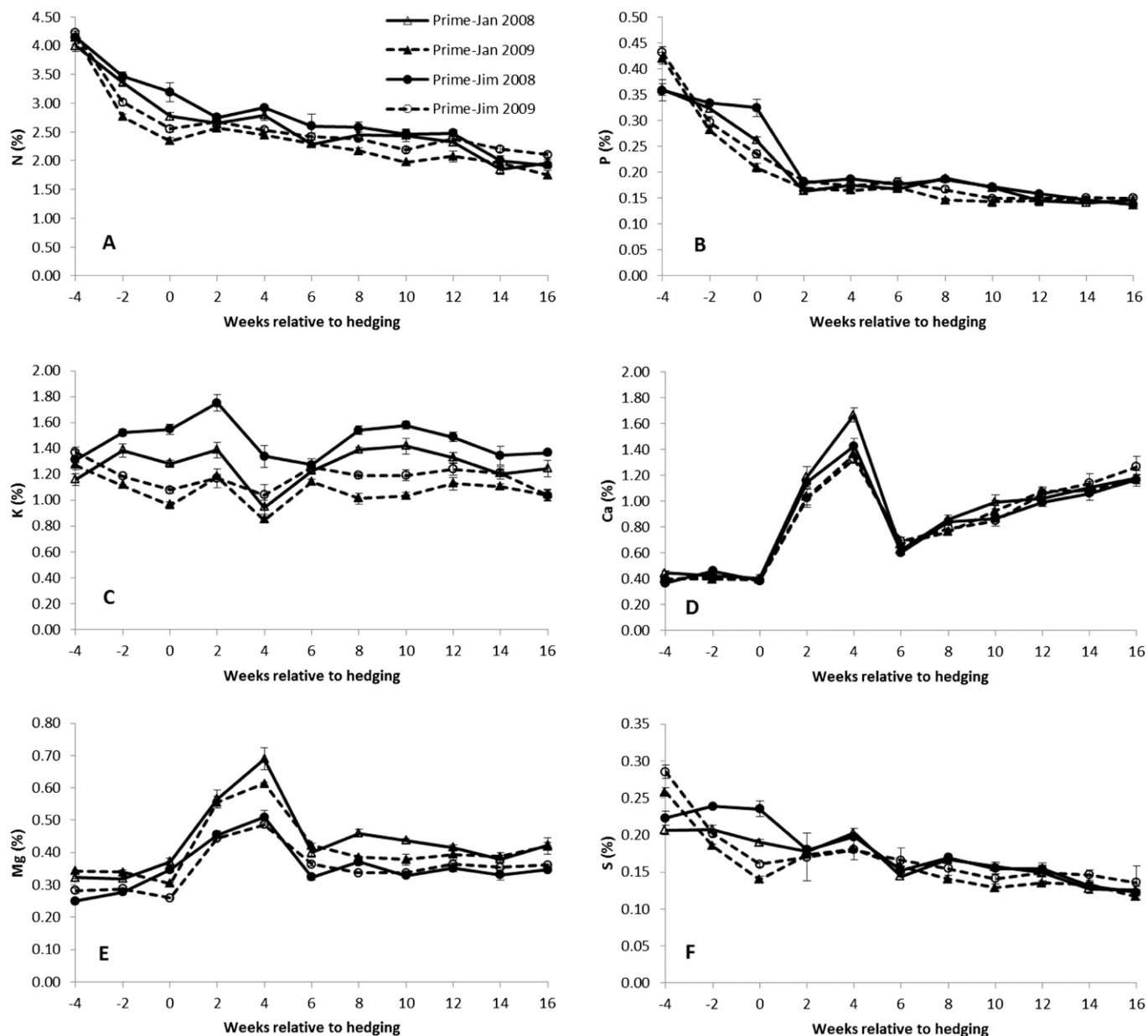


Fig. 1. Concentration of (A) nitrogen; (B) phosphorus; (C) potassium; (D) calcium; (E) magnesium; and (F) sulfur in primocane leaves sampled from 4 weeks before hedging (week -4) through 16 weeks after hedging of ‘Prime-Jan’[®] and ‘Prime-Jim’[®] primocane-fruited blackberry plants grown at Oregon State University’s North Willamette Research and Extension Center, Aurora, OR, in 2008 and 2009 ($n = 5$; mean \pm SE).

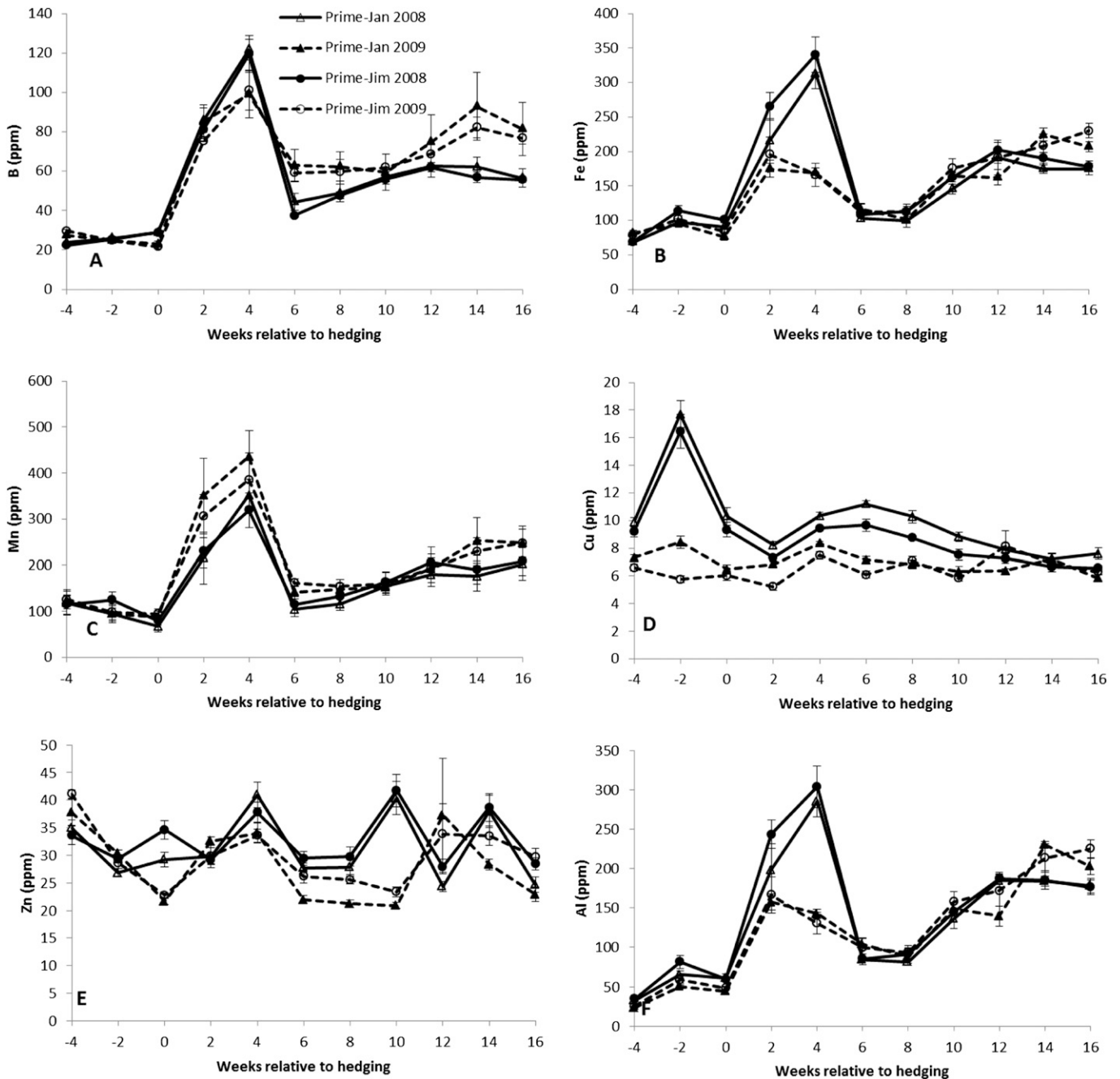


Fig. 2. Concentration of (A) boron; (B) iron; (C) manganese; (D) copper; (E) zinc; and (F) aluminum in primocane leaves sampled from 4 weeks before hedging (week -4) through 16 weeks after hedging of 'Prime-Jan'® and 'Prime-Jim'® primocane-fruited blackberry plants grown at Oregon State University's North Willamette Research and Extension Center, Aurora, OR, in 2008 and 2009 ($n = 5$; mean \pm SE).

performance over time or develop leaf nutrient standards for this period of growth in primocane-fruited blackberry.

When data were analyzed for the late period of leaf sampling on the primocane branches in late summer and autumn (weeks 6 to 16), there was still a cultivar and year effect on leaf N, K, and Zn, a year effect on P, B, Cu, Fe, and Al, and a cultivar effect on leaf Mg and S (Tables 2 and 3). There was only a cultivar \times year interaction on leaf Cu concentration. Week of sampling significantly affected the concentration of all nutrients in the leaves during this sampling period (Tables 2 and 3). Leaf Ca, B, Fe, Mn, and Al

concentration increased on branch leaves when sampled from early bloom through fruit harvest, whereas leaf Mg levels remained relatively stable during this period (Figs. 1 and 2). Clark et al. (1988) reported an increase in leaf blade Ca and Mg with sample date through the season in floricanefruited blackberry, but no mention was made of primocane management or summer pruning date.

Leaf N and S levels declined throughout the season (Fig. 1; Table 2). Leaf N was also found to decline through the sampling season in floricanefruited blackberry (Alleyn and Clark, 1997; Clark et al., 1988; Mohadjer

et al., 2001). Leaf N may have declined due to dilution, but was also likely translocated to fruit which is relatively high in N (Harkins et al., 2014; Mohadjer et al., 2001).

In 2008, leaf K concentration increased on the primocane branch leaves from early growth through green to red fruit stage and was relatively stable during the fruit harvest period (Table 2; Fig. 1). Leaf Cu increased during early branch development, but declined for the remainder of the season. In 2009, leaf K and Cu were relatively stable throughout the season. The concentration of Zn varied throughout the season and between years (Fig. 2).

Table 2. Concentration of macronutrients in primocane branch leaves sampled from 6 to 16 weeks after hedging of 'Prime-Jan'[®] and 'Prime-Jim'[®] primocane-fruited blackberry plants grown at Oregon State University's North Willamette Research and Extension Center, Aurora, OR, in 2008 and 2009 (*n* = 5).

Sufficiency range ^z	N (%)		P (%)		K (%)			Ca (%)	Mg (%)		S (%)		
	2.3–3.0		0.19–0.45		1.3–2.0			0.6–2.0	0.3–0.6		0.1–0.2		
Sample week	Prime-Jan	Prime-Jim	2008	2009	Prime-Jan	Prime-Jim	2008	2009	0.6–2.0	Prime-Jan	Prime-Jim	Prime-Jan	Prime-Jim
6	2.29	2.51	0.17	0.18	1.19	1.27	1.25	1.20	0.64	0.41	0.34	0.15	0.16
8	2.31	2.48	0.19	0.16	1.20	1.37	1.46	1.10	0.81	0.42	0.35	0.15	0.16
10	2.21	2.32	0.17	0.15	1.23	1.39	1.50	1.11	0.91	0.41	0.33	0.14	0.15
12	2.20	2.43	0.15	0.15	1.23	1.36	1.41	1.18	1.04	0.41	0.36	0.14	0.15
14	1.90	2.10	0.14	0.15	1.16	1.28	1.28	1.16	1.09	0.38	0.34	0.13	0.14
16	1.85	2.01	0.14	0.14	1.14	1.20	1.31	1.04	1.19	0.42	0.35	0.12	0.13
LSD week ^y	0.087		0.0074		0.046				0.062	0.014		0.005	
LSD cultivar	0.055		—		0.056				—	0.019		0.0027	
Significance ^x													
Cultivar	0.0061		NS		0.022				NS	0.0078		0.0095	
Year	NS		0.016		<0.0001				NS	NS		NS	
Week	<0.0001		<0.0001		<0.0001				<0.0001	0.0048		<0.0001	
Cultivar × year	NS		NS		NS				NS	NS		NS	
Cultivar × week	NS		NS		NS				NS	NS		NS	
Year × week	<0.0001		<0.0001		<0.0001				NS	NS		NS	
C × Y × W	0.042		NS		NS				NS	NS		NS	

^zRecommended sufficiency range for caneberry crops (Hart et al., 2006a).

^yLSD provided for comparison of means when significant (*P* > 0.05); "—" indicates nonsignificant treatment effect.

^xNonsignificant (ns) or actual *P* value provided when significant by analysis of variance.

Table 3. Concentration of micronutrients in primocane branch leaves sampled from 6 to 16 weeks after hedging of 'Prime-Jan'[®] and 'Prime-Jim'[®] primocane-fruited blackberry plants grown at Oregon State University's North Willamette Research and Extension Center, Aurora, OR, in 2008 and 2009 (*n* = 5).

Sufficiency range ^z	B (ppm)		Fe (ppm)		Mn (ppm)	Cu (ppm)		Zn (ppm)				Al (ppm)		
	30–70		60–250		50–300	6–20		15–50				NA		
Sample week	2008	2009	2008	2009		2008	2009	Prime-Jan	Prime-Jim	2008	2009	2008	2009	
6	41.0	61.0	105.5	113.7	130.5	10.4	6.6	24.8	27.8	28.6	24.1	85.2	101.9	
8	48.3	61.1	106.3	107.1	137.6	9.5	7.0	24.5	27.7	28.8	23.4	86.6	90.6	
10	56.6	60.7	154.0	170.1	157.6	8.2	6.1	30.6	32.6	41.1	22.1	140.7	153.3	
12	62.2	71.8	196.5	176.9	192.7	7.6	7.3	30.8	30.9	26.1	35.6	186.1	155.9	
14	59.5	87.5	182.4	216.3	212.1	6.9	7.1	33.1	36.1	38.3	30.9	184.9	222.0	
16	56.0	79.1	176.5	218.6	226.7	7.1	6.1	23.8	29.1	26.5	26.3	177.3	214.0	
LSD week ^y	5.5		13.1		24.7	0.5			3.6				12.8	
LSD cultivar	—		—		—	—			1.3				—	
Significance ^x														
Cultivar	NS		NS		NS	NS			0.024				NS	
Year	0.0093		0.036		NS	<0.0001			0.0004				0.047	
Week	<0.0001		<0.0001		<0.0001	<0.0001			<0.0001				<0.0001	
Cultivar × year	NS		NS		NS	0.014			NS				NS	
Cultivar × week	NS		NS		NS	0.0107			NS				NS	
Year × week	0.0004		0.0002		NS	<0.0001			<0.0001				<0.0001	
C × Y × W	NS		NS		NS	NS			NS				NS	

^zRecommended sufficiency range for caneberry crops (Hart et al., 2006a); no sufficiency levels are available for aluminum (Al).

^yLSD provided for comparison of means when significant (*P* > 0.05); "—" indicates nonsignificant treatment effect.

^xNonsignificant (ns) or actual *P* value provided when significant by analysis of variance.

NA = not available.

Leaf N, Mg, S, B (2009 only), Fe, Mn, Cu (2009 only), Zn, and Al concentrations did not differ between samples taken 6–8 weeks after hedging on the primocane branches (Tables 2 and 3). This sample period corresponded to a branch length of ≈0.3 m (before bloom) through the early green fruit stage (Table 1). Leaf K and Ca were affected by sampling week during this period, but were more stable when sampling was done from weeks 8 to 10 (early bloom to green/early red fruit) (Tables 1 and 2). There was a significant difference in leaf P among all weeks sampled during this period. A sample date corresponding to early green fruit stage (week 8) would thus likely provide the best compromise for assessing plant nutrient status in this crop. Our findings indicate that the recommended tissue sampling period of late-July to early

August for other caneberry types (Hart et al., 2006a) would not be a good time to assess plant nutrient status in primocane-fruited blackberry considering the high variability among sampling weeks relative to hedge date, years, and cultivars (Figs. 1 and 2).

The primocane leaf nutrient concentrations measured in this study, for both cultivars and years, were within the current recommended nutrient standards (Bolda et al., 2012; Bushway et al., 2008; Hart et al., 2006a) (Tables 2 and 3) for all nutrients except K ('Prime-Jan' and 2009; Table 2) and P for our recommended sampling period of week 8 on primocane branches; there are currently no published standards for Al. While leaf P was just below the lower end of the sufficiency range, there was no evidence of P deficiency and soil P was well

above recommended levels (data not shown). Some florican-fruited blackberry cultivars were reported to have a leaf P below recommended sufficiency levels when sampled in late-July/early August (Archbold et al., 1989; Clark et al., 1988; Naraguma and Clark, 1988), whereas others were within the recommended range (Nelson and Martin, 1986). It is possible that the leaf sufficiency range for P should be lowered for this crop.

Leaf K declined during the fruit development period and was lower than the present sufficiency range for caneberries (1.3% to 2.0% by Hart et al., 2006a; and 1.5% to 2.5% by Bolda et al., 2012; Bushway et al., 2008) on many sample dates during branch development and fruiting. Erect, florican-fruited blackberry cultivars had a primocane leaf blade K concentration below

current sufficiency levels also (Clark et al., 1988); however, they measured petiole and leaf blades separately and noted that K concentration was higher in the petiole than the leaf blade. The K concentration of the entire leaf would thus have been higher in their study. Archbold et al. (1989) reported a leaf blade K concentration well below sufficiency levels in mid-August (0.85%) in 'Hull Thornless' semierect blackberry. However, they washed the leaves in tap water which may have leached K before analysis. In many floricanne-fruiting blackberry cultivars, primocane leaf K was within sufficiency levels (Harkins et al., 2014; Fernandez-Salvador et al., 2015a, 2015b; Nelson and Martin 1986). Blackberry fruit have a high concentration of K (Harkins et al., 2014) and thus the sufficiency range for primocane leaf K may be lower in a primocane-fruiting blackberry where leaves are sampled on the fruiting cane as compared with a floricanne-fruiting type where the vegetative and fruiting canes are separated.

While the cultivars did differ in primocane leaf N, K, Mg, S, and Zn, differences during our recommended sampling period of 8 weeks after hedging (early green fruit stage) were relatively small except for leaf K and Mg (Tables 2 and 3). Cultivars of floricanne-fruiting blackberry have been shown to differ in many primocane leaf nutrient levels in some studies (Fernandez-Salvador et al., 2015a, 2015b; Harkins et al., 2014). Differences among cultivars may depend on how different they are genetically (Clark et al., 1988). The cultivars studied here are half-sibs (Clark et al., 2005), which may have reduced variability. Sampling cultivars separately for tissue analysis would still be advised to better manage nutrient programs (Hart et al., 2006a).

Conclusions

The findings of this study indicate that the recommended sampling time to determine plant nutrient status should be changed for primocane-fruiting blackberry. If this crop were sampled at the commonly recommended time of late July to early August (weeks 4–6 in this study; Bolda et al., 2012; Bushway et al., 2008; Hart et al., 2006a), the tissue levels for most nutrients would have been highly variable making interpretation and monitoring changes over the years difficult. Based on these results, a sampling period correlating with early green fruit stage is recommended. Sampling at a clear stage of development (rather than a recommended calendar date) would necessitate sampling leaves on primocane branches thus reducing the variability that would occur when sampling earlier and collecting leaves from the primocane main cane and the branches. The present nutrient sufficiency levels for P and K for caneberries may need to be lowered for primocane-fruiting blackberry.

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