Journal of the American Pomological Society 75(1): 17-30 2021

Alignment between University Nutrient Guidelines and Grower Practices for Blackberry and Red and Black Raspberry in Oregon

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Additional index words: *Rubus idaeus*, *Rubus occidentalis*, fruit nutrients, leaf tissue sampling, soil sampling

Abstract

Information was gathered from 13 caneberry (blackberry and red and black raspberry; *Rubus* spp.) growers in Oregon's Willamette Valley in 2018 to learn which nutrient management tools growers were using and to determine relationships between plant (leaf and fruit) and soil nutrient status and planting performance for various cultivars. The floricane-fruiting caneberry cultivars studied were 'Meeker' red raspberry, 'Munger' black raspberry; 'Black Diamond', 'Columbia Star', 'Marion', and 'Obsidian' trailing blackberry; and 'Triple Crown' semi-erect blackberry. Our goal was to understand key challenges and questions that remain after many years of nutrient management research and extension outreach. Considerable variation in fertilization practices among grower sites was found. Several growers were applying fertilizer within the recommended rates and had good plant growth and yield, but many sites in this study included fields that were not performing to their full potential. Key problems identified that may have reduced plant performance and yield included soil pH lower than the recommended range of 5.6–6.5, likely reducing nutrient availability; in the study, 28% had a soil pH below 5.6 and some had a pH as low as 4.6. Soil levels of P, K, and Mg were generally high across grower sites indicating no fertilizer was needed, yet many growers fertilized with P and K regardless. Many growers applied excessive rates of N fertilizer from sources that would exacerbate low pH, and timed applications improperly based upon existing extension recommendations. Site or grower management impacted the concentration of almost all leaf nutrients within cultivars, with deficient levels for N, P, K, and Ca at many sites. Site had a significant impact on the concentration of many fruit nutrients. Fruit %P, K, Ca, Mg, and S were positively correlated with their respective leaf concentrations. Percent moisture content of fruit ranged from 72–86% and was affected by grower management for 'Black Diamond', 'Munger', 'Obsidian', and 'Triple Crown'. Despite adequate to high N fertilizer rates being applied, leaf %N was low or just sufficient, supporting the hypothesis that management practices were limiting fertilizer uptake. Some growers applied granular product while drip irrigating, likely reducing availability of nutrients during periods of demand. Insufficient irrigation at key times of the season or stages of plant development may have limited plant uptake of N and K. While current recommendations are to collect soil samples every few years and leaf tissue samples annually to assess nutrient management programs, many growers were not doing so. Growers most frequently relied on fertilizer company field representatives regarding best nutrient management practices rather than using free extension resources for sampling and fertilization methods. Improved outreach to company representatives and revising nutrient management publications to incorporate new research-based information will be key in helping the industry better monitor soil and leaf nutrient status and manage fertilizer requirements in their caneberry crops.

Caneberries (blackberries and red and black raspberries) are an important crop in the United States. Blackberries (*Rubus L.* subgenus *Rubus*, Watson) are in the top 20 agricultural commodities in the Willamette Valley of Oregon with 18 million kg of fruit harvested from 2,550 ha in 2017 (NASS, 2018). Oregon leads the country in black raspberry (*R. occidentalis* L.) production and red raspberries (*R. idaeus* Arrhen.) are an important crop for many fresh-market growers and small farmers. Nutrient research

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on caneberries in Oregon led by B. Strik (Mohadjer et al., 2001; Rempel et al., 2004; Strik et al., 2006) was used to develop a caneberry nutrient management guide for growers (Hart et al., 2006); regional research on this topic conducted since this guide was published has been presented to industry and will be used to revise the guide (Dixon et al., 2016a, 2016b; Fernandez-Salvador et al., 2015; Harkins et al., 2014; Strik, 2015; Strik and Bryla, 2015; Strik and Vance, 2017, 2018; Vance et al., 2017).

Macro- and micronutrient fertilizer recommendations are often based on published research studies and grower experience. Recommended N application rates for red raspberry depend on raspberry type and production region. In Oregon, the recommendation is to apply 34–56 $kg{\cdot}ha^{-1}$ of N during the establishment year of floricane-fruiting raspberry and 56–90 $kg{\cdot}ha^{-1}$ in subsequent years (Hart et al., 2006). For black raspberry, N rates of 22–45 $kg{\cdot}ha^{-1}$ and 45–67 $kg{\cdot}ha^{-1}$ are recommended for the establishment and subsequent years, respectively. Recommendations for blackberry also depend on planting age and the type grown; 28–56 $kg{\cdot}ha^{-1}$ N in the establishment year and 56–90 $kg{\cdot}ha^{-1}$ in subsequent years are common ranges.

Research studies using ^{15}N confirmed that splitting N fertilizer applications in the spring is key to improving efficiency of N fertilizer uptake in red raspberry (Reickenberg and Pritts, 1996; Rempel et al., 2004), trailing blackberry (Mohadjer et al., 2001), erect blackberry (Naraguma et al., 1999) and semi-erect blackberry (Malik et al., 1991).

Fertilizer programs should be routinely adjusted based on leaf tissue and soil analysis. However, some growers rely on fertilizer company field sales representatives and product distributors for fertilizer recommendations and leaf and soil sampling. Soil in the regions of Oregon where most caneberries are grown is generally sufficient in phosphorus (P), while applications of N, potassium (K), and boron (B) fertilizers are typically needed for optimum growth and yield. Organic fertilizers, unlike most conventional inorganic fertilizers, frequently contain varying levels of macro- and micronutrients other than those growers are intending to apply (Dixon et al., 2016a; Fernandez-Salvador et al., 2015), many of which are unreported unless submitted to a lab for analysis. Proper soil sampling, including location of sampling in the row relative to an emitter if drip irrigation is used, depth, and consistent time of the year, is important to assess trends over the life of a caneberry planting (Hart et al., 2006; Horneck et al., 2011). Leaf tissue sampling must be done at the correct time of the growing season for leaf standards (Hart et al., 2006) to be applicable for assessing the nutrient status of each caneberry crop and cultivar (Strik, 2015; Strik and Bryla, 2015; Strik and Vance, 2017, 2018).

Recommended caneberry fertilization programs have been published for multiple regions within the United States (Bolda et al., 2012; Bushway et al., 2008; Hart et al., 2006; Krewer et al., 1999; Kuepper et al., 2003). While results of published research studies have been shared with growers in presentations, the widespread level of adoption of best practices by growers has not been assessed. The relationship between yield, fruit nutrient concentration, and leaf and soil nutrient status has not yet been described for commercial caneberry grower fields in Oregon. More information on current grower practices and potential nutrient management problems is needed to inform future research and to provide a broader perspective for revision of the current nutrient management guide for Oregon (Hart et al., 2006). The objective of this project was to use information gathered from commercial red and black raspberry and blackberry growers to learn which nutrient management tools growers are using, establish relationships between plant and soil nutrient status and yield of various cultivars, and understand key challenges and questions that remain after many years of nutrient management research.

Materials and Methods

This study was conducted in 2018 across Oregon's Willamette Valley, encompassing an area of approximately 4,400 km^2. Commercial caneberry growers were asked to volunteer their information with the incentive of receiving free nutrient analyses of soil and fruit and leaf tissue as well as recommendations for future management practices if necessary. Caneberry types and cultivars included red raspberry ('Meeker'), black raspberry ('Munger'), trailing blackberry ('Black Diamond', 'Columbia Star', 'Marion', and 'Obsidian') and semi-erect blackberry ('Triple Crown'). All cultivars in the study were floricane-fruiting types, producing fruit only in the second year of cane growth. Many sites or growers had more than one cultivar (Table 1). Growers provided information on irrigation and fertilizer program (2017 and 2018), and estimated yield from two growing seasons (2016 and 2017) (Table 1) as well as field age (not shown). Only macronutrient fertilizer products and rates were provided; most did not apply any micronutrients as foliar products. While some growers were confident in yield data provided, many gave gross estimates. All sampled trailing blackberry fields were harvested every year as opposed to alternate years. Leaf and soil samples were collected once in 2018 using standard methods and timing (described below, Hart et al., 2006), and ripe fruit were sampled once just prior to a commercial harvest. There were three replications per site per cultivar for each sample type (fruit, leaf, soil) in a completely random design. Recommendations were provided to each grower based on the specific information and test results from their farm relative to current production standards with the goal of increasing field productivity.

Leaf sampling. Leaves were sampled from all cultivars during the last week of Aug., 2018. Strik and Vance (2017) found that mid- to late-August sampling provided more consistency in blackberry leaf nutrient concentration compared to earlier or later sampling. Approximately 6 to 12 of the most recent, fully expanded primocane leaves, including petioles, were sampled and shipped to Brookside Laboratories (New Bremen, OH) for analysis of macro- and micronutrient concentrations. Leaves were not washed prior to tissue analysis (Hart el al., 2006). 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, Fe and Zn were determined using an inductively coupled plasma atomic emission (ICP-AES) spectrophotometer after wet ashing the samples in nitric/perchloric acid (Gavlak et al., 1994).

Soil sampling. Soil samples were collected in mid-Nov. 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, approximately 0.3 m from the crown between plants and within the water emitter drip zone, if applicable, and fertilization area. Samples were analyzed by Brookside Laboratories for macro- and micronutrients using ICP-AES and cation exchange capacity (CEC $meq \cdot 100g^{-1}$) by summation (Ross, 1995). Soil P was analyzed using the Bray-1 method and then determined by ICP-AES. Soil NO_3-N and NH_4-N were determined using automated colorimetric methods after extraction with 1 M KCl (Dahnke, 1990). Soil organic matter and pH were measured using Loss-On-Ignition at 360 °C (Nelson and Sommers, 1996) and the 1:1 soil:water method (McLean, 1982), respectively.

Soil type was determined with Web Soil Survey, a soil mapping service provided by the United States Department of Agriculture Natural Resource and Conservation Service (Soil Survey Staff, Natural Resources Conservation Service, United States

Department of Agriculture. Web Soil Survey).

Fruit sampling. Ripe fruit samples were harvested in the middle of the fruiting season for each cultivar, from 21 June to 10 Aug., prior to a commercial harvest, and were refrigerated prior to analysis. Samples were priority shipped to Brookside Laboratories for analysis of moisture content and macro- and micronutrients.

Data analysis. Data were analyzed by analysis of variance for site (by cultivar) and cultivar (by site) effects using PROC MIXED in SAS version 9.4 (SAS Institute, Cary, NC). Mean separations were performed using LSMeans (PDIFF). PROC CORR was

Table 1. Sites and cultivars of blackberry and red and black raspberry studied and associated soil type, soil cation exchange capacity (CEC), irrigation method, total fertilizer rate applied in 2018 and estimated yield (2016–2018, Willamette Valley, Oregon, USA).

					Fertilizer applied (kg·ha^{-1})			
Cultivar	Site	Soil type[z]	CEC[y]	Irrigation	N	P_2O_5	K_2O	Yield (t·ha^{-1})
Black Diamond	9	Chehalis	17.9	Drip	127	18	112	11.4
	8	Woodburn	12.6	Drip	121	208	0	14.2
	13	Latourell	14.6	Drip	121	0	0	18.4
Columbia Star	10	Mershon	11.3	Drip	121	139	146	8.5
	8	Woodburn	12.8	Drip	121	208	0	14.5
	11	Helvetia	13.0	Drip	178	0	31	15.9
	9	Chehalis	19.7	Drip	127	18	112	16.1
	13	Latourell	15.2	Drip	121	0	0	22.0
Marion	4	Cazadero	12.1	Drip	232	532	280	6.7
	12	Concord	19.5	Drip	267	226	251	6.9
	11	McBee	22.0	Overhead	178	0	31	9.0
	13	Latourell	15.0	Drip	121	0	0	16.0
	9	Chehalis	17.9	Drip	127	18	112	NA
Obsidian	4	Cazadero	10.5	Drip	194	444	233	4.5
	5	Willamette	12.6	Drip	85	0	128	8.7
	12	Concord	14.3	Drip	267	226	251	11.8
	7	Cloquato	33.6	Drip, Overhead	186	0	75	16.9
	13	Latourell	13.0	Drip	121	0	0	22.4
Triple Crown	10	Mershon	6.6	Drip	121	139	146	7.2
	4	Cazadero	10.1	Drip	232	532	280	9.0
	5	Willamette	10.7	Drip	121	0	128	11.2
	13	Latourell	13.5	Drip	121	0	0	30.9
Meeker	3	Mershon	NA	Overhead	87	200	105	NA[x]
	4	Cazadero	12.4	Drip	194	444	233	5.6
	13	Latourell	12.4	Drip	121	0	0	7.8
	1	Bornstedt	7.4	Unirrigated	95	82	143	NA
Munger	9	Chehalis	23.8	Drip	62	19	19	1.5
	2	Woodburn	15.4	Overhead	120	0	66	2.8
	10	Mershon	11.9	Drip	126	139	146	3.7
	13	Latourell	15.3	Drip	121	0	0	5.2
	6	Quatama	13.6	Overhead	121	0	0	10.3
	1	Bornstedt	10.5	Overhead	95	82	143	NA

[z] Soil type scientific classifications are available at: https://soilseries.sc.egov.usda.gov/osdname.aspx
[y] CEC = cation exchange capacity (meq · 100g^{-1})
[x] NA indicates data not available

used to describe any relationships between leaf, soil, and fruit nutrient levels across cultivars and sites.

Results and Discussion

Grower sites and management. Sites differed considerably in soil type (Table 1) and CEC (ranged from 6.6 to 33.6 $meq \cdot 100g^{-1}$) as each of these farms represents a unique geographical location within Oregon's Willamette Valley. The rate of N fertilizer applied varied considerably among sites (62–267 $kg \cdot ha^{-1}$) with many growers exceeding Oregon State University (OSU) published recommendations (Hart et al., 2006). In addition, the rate of phosphate (P_2O_5) and potash (K_2O) applied varied from 0–532 $kg \cdot ha^{-1}$ and 0–280 $kg \cdot ha^{-1}$, respectively, with fertilizer often applied despite sufficient levels in the soil (see below). While most fields were irrigated by drip, overhead irrigation was used by some and one field was un-irrigated. Most growers used granular sources of fertilizer even when drip irrigating, potentially limiting availability of applied N fertilizer. In this region, rain in late spring or early summer may be sufficient to dissolve granular fertilizer if the application is timed appropriately, but if insufficient rain occurs then fertilizer can remain on the soil surface, and nutrients remain unavailable to the plants in the early season. Some growers expressed difficulty estimating yield for their fields and there was considerable variability in the reported yield for each cultivar. However, the average yield for the trailing blackberries seemed to be typical for the cultivars based on published findings and experience: 'Black Diamond' (average 14.7 $t \cdot ha^{-1}$), 'Columbia Star' (15.4 $t \cdot ha^{-1}$), 'Marion' (10.2 $t \cdot ha^{-1}$), and 'Obsidian' (12.9 $t \cdot ha^{-1}$) (Finn et al., 1997, 2005a, 2005b, 2014). However, the yield for 'Triple Crown' semi-erect blackberry (14.6 $t \cdot ha^{-1}$), 'Meeker' red raspberry (4.5 $t \cdot ha^{-1}$), and 'Munger' black raspberry (4.7 $t \cdot ha^{-1}$) would be considered lower than average for well-managed fields (Galletta et al., 1998; Moore and Daubeny, 1993; B. Strik, personal observation); in this region, yields of 25–30, 12–17, and 7–10 $t \cdot ha^{-1}$ for 'Triple Crown', 'Meeker', and 'Munger', respectively, are more typical.

Soil analysis. There was considerable variation in soil pH among sites within each cultivar studied (Table 2). All or most of the 'Marion', 'Black Diamond', and 'Columbia Star' fields had a soil pH within the recommended range of 5.6–6.5 (Hart et al., 2006). In contrast, there were fields of 'Munger', 'Meeker', 'Obsidian', and 'Triple Crown' that had a low soil pH. Of the study fields, 28% had a soil pH below 5.6 (data not shown) with some measured as low as 4.6 (Table 2). Soil pH affects soil and fertilizer nutrient availability to plants (Hart et al., 2006; Horneck et al., 2011).

Soil organic matter (SOM) ranged from 2.6–7.4% with significant differences among fields (Table 2). The level of SOM is related to the total N or "N release" in the soil which ranged from 71–112 $kg \cdot ha^{-1}$ of N. However, the SOM and N release estimates of the soils are not good indicators of the capacity of the soil at these sites to supply plant available N (PAN). Caneberries require available N in spring for new primocane growth (Malik et al., 1991; Mohadjer et al., 2001; Naraguma et al., 1999; Rempel et al., 2004); this needed N must be applied through fertilization because N is not released from PAN when soils are cool in the spring, as is typical for this region (Horneck et al., 2011). The soil nitrate-N (NO_3-N) and ammonium-N (NH_4-N) levels also varied considerably among cultivars and sites (Table 2). These levels in autumn, along with plant growth and leaf levels, may be used as an indicator of excessive or late applications of fertilizer N (see below).

Soil levels of multiple nutrients were high to excessive in many fields, including P (levels greater than 40 ppm using Bray-1 indicate no fertilizer needed), K (>350 ppm), and Mg (>120 ppm) (Hart et al., 2006; Horneck et al., 2011). For many fields, soil levels of P would be considered excessive (>100 ppm), increasing risk of groundwater

Table 2. Analysis of site effect on the range of soil properties and nutrient levels by cultivar for blackberry and red and black raspberry grown across the Willamette Valley of Oregon, USA.

Cultivar		pH	OM[z] (%)	N release[y] (kg·ha⁻¹)	ppm												
					NO_3-N	NH_4-N	P	K	Ca	Mg	S	B	Fe	Zn	Cu	Mn	Al
Black Diamond	Range	5.6-6.1	2.9-3.4	78-84	1.7-58.6	6.7-20.0	54-301	167-339	1170-2305	133-347	13-21	0.3-0.8	187-220	3.6-6.1	1.2-4.7	7-18	798-1170
	Significance[x]	0.0045	0.0500	0.0207	<0.0001	NS	0.0300	0.0406	0.0080	<0.0001	0.0122	0.0007	0.0258	<0.0001	<0.0001	0.0024	<0.0001
Columbia Star	Range	5.6-6.7	3.0-4.4	79-94	0.9-44.9	5.5-10.1	46-397	149-427	1137-2656	95-388	11-75	0.4-1.6	114-262	3.1-10.2	1.0-6.2	11-38	702-1305
	Significance	NS	0.0074	0.0085	NS	NS	0.0254	NS	0.0005	<0.0001	NS	0.0048	0.0037	0.0004	<0.0001	0.0251	<0.0001
Marion	Range	5.5-6.4	2.6-5.4	71-102	4.2-103.1	5.1-10.0	46-222	90-445	1201-3134	119-516	11-26	0.4-0.8	90-323	2.9-10.4	1.0-10.0	10-60	746-1170
	Significance	0.0005	<0.0001	0.0001	0.0018	NS	0.0041	0.0004	<0.0001	<0.0001	<.0001	0.0079	<0.0001	0.0003	<0.0001	<.0001	<0.0001
Obsidian	Range	4.7-6.5	3.1-5.9	81-105	2.2-70.2	4.2-13.5	68-226	184-517	446-2168	71-655	13-49	0.6-1.2	98-291	4.0-13.1	1.2-13.4	17-98	713-1329
	Significance	0.0006	<.0001	<0.0001	NS	NS	<0.0001	0.0006	0.0002	<0.0001	0.0035	NS	<0.0001	0.0004	<0.0001	<.0001	<0.0001
Triple Crown	Range	4.9-6.0	2.6-7.4	71-112	1.0-24.3	4.6-14.0	104-368	189-456	395-1591	46-225	13-29	0.4-0.9	114-248	3.9-14.5	1.2-7.6	16-68	1020-1431
	Significance	0.0035	<0.0001	<0.0001	NS	0.0147	0.0122	0.0020	0.0001	<0.0001	0.0285	NS	<0.0001	0.0519	<0.0001	0.0012	<0.0001
Meeker	Range	5.2-6.0	3.6-5.0	86-100	2.9-78.3	5.7-9.5	93-242	251-426	1120-1439	138-196	17-30	0.4-0.7	72-239	3.0-4.8	2.1-2.9	13-71	1165-1256
	Significance	NS	0.0203	0.0237	NS	NS	0.0014	0.0018	NS	NS	0.0327	NS	<0.0001	0.0041	NS	0.0160	0.0204
Munger	Range	4.6-6.8	3.2-5.8	82-104	1.9-79	5.0-62.9	31-345	72-592	476-2446	52-533	12-78	0.5-1.5	93-341	3.1-13.1	0.7-4.4	9-93	717-1511
	Significance	<0.0001	<0.0001	<0.0001	<0.0001	NS	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	NS	<0.0001	0.0004	<0.0001	0.0007	<0.0001

[z] OM = organic matter
[y] N release = estimated N release rate of soil from an autumn sample to a depth of about 0.3 m
[x] *P*-value provided when $P<0.05$. NS indicates not significant for the analysis of site effect within cultivar.

contamination (Horneck et al., 2011) as well as possible interference with micronutrient uptake and activity (May and Pritts, 1993; Sparks, 1988). Some growers of 'Munger' and 'Obsidian' had fields with very high levels of soil K (as high as 592 ppm). In some fields, growers were applying fertilizer P and K (Table 1), despite high levels of soil P and K (specific site data not shown). In blueberry (*Vaccinium corymbosum* L), high applications of fertilizer K were found to increase leaf K concentration (%K) and reduce leaf %Ca, and leaf %K was negatively correlated with yield of 'Duke' (Strik et al., 2019). Similarly in strawberry (*Fragaria* x *ananassa* Duch.), yield was found to increase with increasing B at high soil P levels (May and Pritts, 1993). It is not known if this same relationship would occur in caneberries.

Soil Ca ranged from 395–2656 ppm and was typically related to soil pH with highest levels in soils within the required pH range for caneberries (Table 2). Recommended levels for caneberries are soil Ca levels higher than 1000 ppm (Hart et al., 2006). Some grower fields also had low soil Mg, whereas others had levels higher than 120 ppm, requiring no fertilization of Mg. At one site, soil Mg was considered high for all tested cultivars (>300 ppm; Horneck et al., 2011). Growers with low soil pH and low Ca would need to consider whether to use agricultural or dolomitic lime to increase pH, considering their soil Mg levels (Hart et al., 2006). Soil S ranged from 11–78 ppm with higher levels associated with use of ammonium sulfate or blends of fertilizer with S added (see below). Levels of soil S greater than 20 ppm are considered high for our region (Horneck et al., 2011).

The levels of soil micronutrients were sufficient (Zn, Cu, and Mn) or are not recommended as a guide for plant needs (Fe and Al; Horneck et al., 2011). Only one field had soil B considered sufficient for caneberries (>1.5 ppm; Hart et al., 2006), especially of concern when B deficiency in raspberry has been shown to reduce yield and quality in this region (Chaplin and Martin, 1980). In strawberry, leaf P increased at lower soil B levels, suggesting that high B levels may be detrimental to P uptake (May and Pritts, 1993), In addition, leaf B did not respond to soil applications of B.

Leaf analysis. The concentration of most leaf nutrients differed among cultivars, within a site (data not shown). This confirmed the importance of sampling cultivars separately when doing tissue analysis (Hart et al., 2006; Strik, 2015; Strik and Vance, 2017, 2018). Site or grower management impacted the concentration of almost all macro- and micronutrients within the cultivars studied (Table 3).

Leaf N concentration (%N) was below published sufficiency standards for most sites growing 'Black Diamond' and 'Meeker', some sites growing 'Columbia Star', 'Munger', and 'Triple Crown', and for one site each growing 'Marion' and 'Obsidian' (Table 3). It is possible that leaf %N was lower in some cultivars because sampling was toward the end of Aug.; while this may work well for some blackberry cultivars, later sampling may lead to a reduction in leaf %N (Strik and Vance, 2017) and earlier sampling, in late-July to early-Aug., is recommended for raspberry (Hart et al., 2006; Strik and

Table 3. Analysis of site effect on leaf nutrient concentrations by cultivar for blackberry and red and black raspberry grown across the Willamette Valley of Oregon, USA.

		%						ppm					
		N	P	K	Ca	Mg	S	B	Fe	Mn	Cu	Zn	Al
Tissue Standards[z]		2.3-3.0	0.19-0.45	1.3-2.0	0.6-2.0	0.3-0.6	0.1	30-70	60-250	50-300	6.0-20.0	15-50	n/a
Cultivar	*Site*												
Black Diamond	8	2.3 a[y]	0.19	0.89 ab	0.61 a	0.29	0.14 a	42 a	218 b	247 a	6.3	28 a	219 b
	9	2.1 ab	0.17	0.73 b	0.37 b	0.25	0.12 b	22 b	558 a	84 b	-	23 ab	546 a
	13	1.8 a	0.17	0.93 a	0.44 ab	0.29	0.11 b	30 ab	319 b	56 b	5.6	20 b	338 b
	Significance[x]	0.0361	NS	0.0214	0.0212	NS	0.0008	0.0076	0.0020	0.0002	NS	0.0345	0.0030
Columbia Star	8	2.3 ab	0.20 ab	1.10	0.51	0.26 bc	0.12 ab	42 a	219 ab	99 bc	5.7	24	198 ab
	9	2.5 a	0.22 a	1.14	0.56	0.33 a	0.14 a	26 b	348 a	101 abc	-	27	377 ab
	10	2.2 ab	0.21 ab	1.16	0.41	0.30 ab	0.11 ab	34 ab	112 ab	135 ab	5.4	20	117 b
	11	2.3 ab	0.18 bc	1.18	0.42	0.23 c	0.12 ab	31 ab	83 b	195 a	5.2	20	70 b
	13	1.9 b	0.16 c	1.04	0.55	0.32 ab	0.11 b	38 a	284 ab	71 c	5.5	22	299 ab
	Significance	0.0380	0.0013	NS	NS	0.0013	0.0359	0.0108	0.0248	0.0047	NS	NS	0.0101
Marion	4	2.2 bc	0.26 a	1.43 a	0.45 b	0.27 b	0.12	24 c	119 b	306 a	5.6 b	26 b	135 b
	9	2.9 a	0.22 ab	1.00 b	0.65 ab	0.37 a	0.14	25 c	220 b	83 b	-	27 ab	232 b
	11	2.6 ab	0.17 bc	0.98 b	0.82 ab	0.35 ab	0.13	38 b	191 b	102 b	5.8 b	27 ab	198 b
	12	2.6 ab	0.23 ab	1.15 ab	0.85 ab	0.38 a	0.14	17 c	318 ab	230 a	7.1 a	34 a	320 ab
	13	1.9 c	0.16 c	0.86 b	0.96 a	0.36 a	0.11	60 a	464 a	83 b	5.6 b	28 ab	461 a
	Significance	0.0027	0.0014	0.0048	0.0153	0.0164	NS	0.0042	0.0024	<0.0001	0.0009	0.0323	0.0065
Obsidian	4	1.8 d	0.20	1.04	0.51 d	0.20 c	0.12 c	40 b	176 b	583 a	4.9 d	19 b	206 bc
	5	3.1 b	0.25	1.08	0.69 cd	0.32 b	0.16 b	42 b	94 c	217 bc	5.5 cd	27 ab	58 d
	7	3.7 a	0.22	1.17	0.92 bc	0.47 a	0.19 a	39 b	139 bc	128 c	8.2 a	29 ab	121 cd
	12	2.8 bc	0.21	0.96	1.05 b	0.43 a	0.16 ab	36 b	328 a	409 ab	7.5 ab	38 ab	290 b
	13	2.5 c	0.22	0.97	1.39 a	0.43 a	0.15 b	73 a	446 a	121 c	6.4 bc	41 a	454 a
	Significance	<0.0001	NS	NS	<0.0001	<0.0001	0.0005	0.0016	<0.0001	<0.0001	<0.0001	0.0454	<0.0001
Triple Crown	4	1.8 b	0.14 a	1.00	0.57 b	0.35 c	0.13 b	35 b	127 b	459 a	7.6 a	21 b	146 b
	5	2.5 a	0.19 a	0.84	0.96 a	0.48 ab	0.19 a	66 a	124 b	520 a	4.3 b	29 a	102 bc
	10	2.1 ab	0.14 a	0.89	0.62 b	0.41 bc	0.14 b	39 b	102 b	119 b	6.5 a	27 a	93 c
	13	2.2 ab	0.15 a	0.77	0.98 a	0.56 a	0.16 ab	71 a	248 a	97 b	5.8 ab	28 a	273 a
	Significance	0.0080	0.0469	NS	0.0004	0.0009	0.0064	0.0030	0.0003	0.0001	0.0050	0.0447	0.0001
Meeker	1	2.0 ab	0.20 b	1.15	0.72 a	0.27 b	0.11 b	29 a	368 a	297 b	4.7 ab	23 b	512 a
	3	2.1 ab	0.19 b	1.10	0.62 b	0.38 a	0.11 b	28 a	137 b	91 c	4.2 b	18 b	136 b
	4	1.9 b	0.20 b	1.12	0.71 a	0.31 ab	0.12 b	27 a	138 b	384 a	5.9 ab	21 b	155 b
	13	2.1 a	0.29 a	1.28	0.60 b	0.30 ab	0.15 a	18 b	401 a	105 c	6.7 a	32 a	402 ab
	Significance	0.0496	0.0009	NS	0.0488	0.0262	0.0096	0.0058	0.0192	<0.0001	0.0174	0.0019	0.0180
Munger	1	1.6 c	0.10 c	0.83 c	0.56 c	0.29 c	0.10 b	25 b	656 a	217 a	4.8 c	16 c	931 a
	2	2.5 a	0.19 b	1.24 a	0.89 ab	0.36 ab	0.15 a	42 a	122 b	135 abc	5.0 c	20 bc	84 c
	6	2.3 ab	0.20 b	0.88 bc	0.93 a	0.37 ab	0.15 a	33 ab	192 ab	125 bc	5.8 b	33 a	153 bc
	9	2.4 a	0.24 a	1.13 ab	0.97 a	0.39 a	0.14 a	34 ab	411 ab	182 ab	-	32 a	341 ab
	10	2.4 ab	0.18 b	1.36 a	0.47 c	0.30 c	0.13 a	44 a	180 b	101 bc	6.1 ab	21 bc	162 bc
	13	1.9 bc	0.20 b	1.15 a	0.65 bc	0.32 bc	0.14 a	31 ab	270 ab	84 c	6.2 a	26 ab	261 abc
	Significance	0.0004	<0.0001	0.0001	0.0002	0.0011	0.0003	0.0065	0.0089	0.0019	0.0375	<0.0001	0.0018

[z] Recommended sufficiency range for caneberries (Hart et al., 2006) when sampled in late July to early August; no sufficiency levels are available for aluminum (n/a).

[y] Means followed by the same letter within treatment are not significantly different (LSMeans) ($P > 0.05$).

[x] P-value provided when $P < 0.05$. NS indicates not significant ($P > 0.05$).

Bryla, 2015). Leaf N was not correlated with soil N (nitrate or ammonium) levels in autumn (data not shown).

Leaf %P was at the low end of the sufficiency range or below sufficiency, depending on cultivar and site (Table 3). Levels were low despite some growers fertilizing with P (Table 1) and high or very high levels in the soil (Table 2). In fact, we observed a negative correlation between leaf %P and soil P levels (Fig. 1A). The sufficiency levels for leaf %P may need to be lowered, as suggested by Strik and Vance (2017), to reduce likelihood of growers applying P fertilizers when not needed.

Leaf %K was below sufficiency levels with the exception of one field each of 'Marion', 'Meeker', and 'Munger' (Table 3). Levels were low despite many growers fertilizing with K (Table 1) and high levels in the soil (Table 2). There was no significant correlation between leaf and soil K (data not shown). It is possible that insufficient irrigation at some sites limited plant nutrient uptake, reducing leaf %K (Hart et al., 2006; specific grower data not shown). A high yield may also reduce leaf %K, because fruit levels of K are high in caneberries (see below; e.g., Dixon et al., 2016a). In addition, the sufficiency levels for leaf %K may need to be lowered, as suggested by Strik and Vance (2017).

In general, leaf %Mg was within sufficiency levels, although there was an effect of site for all cultivars except 'Black Diamond'. Considering all cultivars, there was a trend for leaf %Mg to be positively correlated with soil Mg (Fig. 1B). However, there were large differences in the strength of this relationship among cultivars. Leaf %Ca was below sufficiency for two sites each of 'Black Diamond', 'Columbia Star', and 'Munger', and one site each for 'Marion' and 'Obsidian' (Table 3). In this study, low leaf %Ca was related to low soil Ca (Fig. 1C), but cultivars appeared to differ in the strength of this relationship.

Leaf B concentration was deficient for one site each of 'Black Diamond', 'Columbia Star', and 'Munger', but three sites each for 'Marion' and 'Meeker' (Table 3). Soil B was low and it is difficult to improve plant B status without using foliar applications (Hart et al., 2006), but none of the growers used this method. Leaf Fe concentrations were high, likely because Fe is high in soil and the leaves were not washed (Strik and Vance, 2017). Leaf Fe concentration was positively correlated with soil Fe (data not shown). Leaf Cu was lower than recommended but this may be because the sufficiency levels that are published (Hart et al., 2006) are too high because they were developed at a time when use of Cu fungicides was much more common (Strik and Vance, 2017, 2018). Leaf Cu was negatively correlated with soil Cu levels, mainly because of low leaf Cu in 'Triple Crown' despite high soil Cu levels (Fig. 1D). Leaf Mn concentration was negatively correlated with soil pH (Fig. 1E), as expected because Mn becomes more available to plants at a low pH (Hart et al., 2006). Little information has been published on leaf Al in caneberries. There was considerable range in leaf Al concentration, but the observed range encompassed what has been published for blackberry in Oregon (Strik and Vance, 2017, 2018). Leaf Zn concentration was negatively correlated with soil P levels (Fig. 1E). In strawberry, high soil P has influenced levels of B and Zn (May and Pritts, 1993).

Fruit analysis. The concentration of most fruit nutrients differed among cultivars within a site (data not shown). Site or grower management impacted the concentration of all macro- and micronutrients in 'Munger', most nutrients in 'Obsidian', some in 'Black Diamond' and 'Columbia Star', only %P and %Mg in 'Meeker' and %K in 'Marion', but had no impact in 'Triple Crown' fruit (Table 4). Nitrogen and K were the major nutrients in the fruit for all the cultivars studied, confirming what has been reported by others (Dixon et al., 2016a; Harkins et al., 2014; Rempel et al., 2004; Strik and Bryla, 2015). While fruit %N was not correlated with leaf %N, fruit %K was correlated with leaf

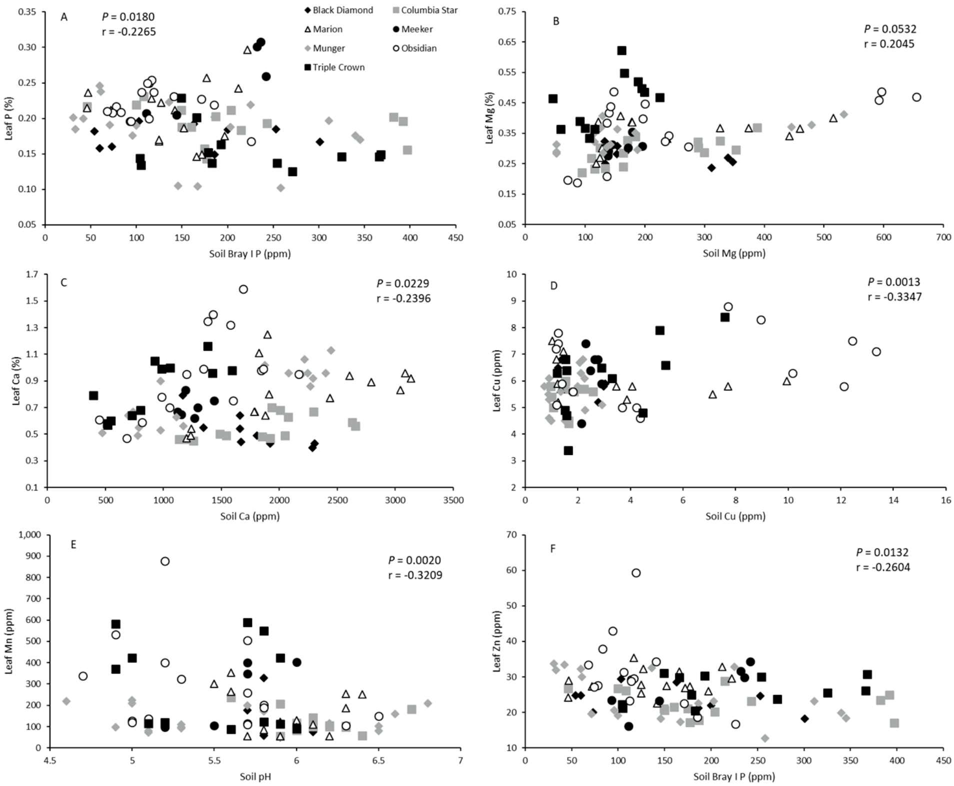

Figure 1. Scatter plots and correlation analysis of leaf nutrient concentration and soil properties and nutrient levels across cultivars of blackberry and red and black raspberry and grower locations in the Willamette Valley of Oregon, USA.

%K (Fig. 2A). Also, fruit %Ca was highly correlated with leaf %Ca indicating that promoting good uptake of Ca from the soil, in general, is a good way to increase fruit %Ca. Growers are concerned about improving fruit Ca to increase firmness and quality. However, applications of foliar products have not been effective to improve fruit %Ca in caneberries (Vance et al., 2017). Fruit P, Mg, S, and Mn concentrations were also significantly correlated with their respective leaf concentrations (Fig. 2C–F).

Percent moisture content of fruit ranged from 72–86% and was affected by site for 'Black Diamond', 'Munger', 'Obsidian', and 'Triple Crown' (Table 4). The upper values in this study were similar to those reported for well-irrigated, mature 'Black Diamond' and 'Marion' by Dixon et al. (2015). The percent dry weight (calculated from percent moisture content) coupled with fresh yield per hectare and concentrations of the nutrients may be used to calculate the nutrients removed from the field (Strik and Bryla, 2015). While a lot of nutrient biomass is in the prunings (dead floricanes) in caneberries (e.g. Dixon et al., 2016b; Strik and Bryla, 2015), growers typically chop their prunings between the rows. These decompose relatively quickly and there is evidence that at least the N in these dead canes is available to caneberry plants (Strik et al., 2006).

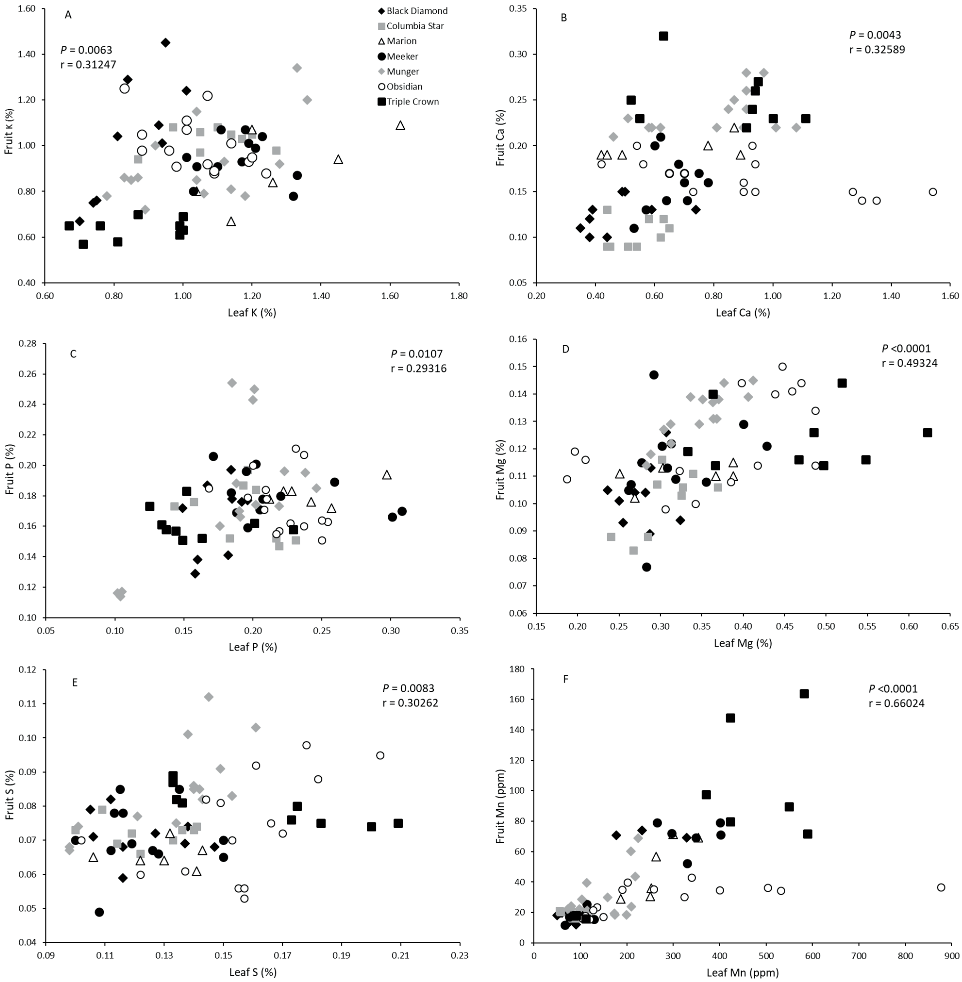

Figure 2. Scatter plots and correlation analysis of fruit and leaf nutrient concentration across cultivars of blackberry and red and black raspberry and grower locations in the Willamette Valley of Oregon, USA.

Fertilization and nutrient analysis results. All growers except three applied N fertilizer at rates higher than recommended by Hart et al. (2006) (Table 1). However, higher N rates may be needed if plant growth and tissue test results warrant it. Some growers, however, were applying extraordinarily high rates of N (>178 $kg \cdot ha^{-1}$). Long-term fertilization with excessive rates of N lead to a significant decline in soil pH over time (Kowalenko, 1981); for example, fertilizing with 112 $kg \cdot ha^{-1}$ of N per year (as urea) would decrease soil pH 1 unit in 10 years (e.g. 5.6 to 4.6) in the soils typical for this region (Hart et al., 2006). Since these caneberry crops, especially blackberry, can be very long-lived, this reduction of soil pH could be quite detrimental if not monitored and adjusted over time (see below). Spiers (1993a) also found that there was a threshold for N

Table 4. Analysis of site effect on the range in fruit nutrient concentrations and percent fruit moisture content by cultivar for blackberry and red and black raspberry grown across the Willamette Valley of Oregon, USA.

		%						
Cultivar		N	P	K	Ca	Mg	S	Moisture
Black Diamond	Range	1.08-1.47	0.14-0.19	0.73-1.33	0.11-0.14	0.09-0.11	0.07-0.08	82.4-85.3
	Significance[z]	0.0078	0.0006	0.0002	NS	NS	NS	0.0030
Columbia Star	Range	1.13-1.28	0.15-0.19	1.00-1.06	0.09-0.12	0.09-0.11	0.071-0.073	81.9-83.2
	Significance	NS	0.0042	NS	0.0077	0.0003	NS	NS
Marion	Range	0.84-0.89	0.18	0.77-1.03	0.19-0.20	0.109-0.112	0.06-0.07	82.6-83.8
	Significance	NS	NS	0.0194	NS	NS	NS	NS
Obsidian	Range	0.91-1.53	0.16-0.21	0.92-1.19	0.15-0.19	0.10-0.14	0.06-0.09	81.4-85.5
	Significance	0.0012	0.0004	0.0036	NS	<0.0001	<0.0001	<0.0001
Triple Crown	Range	0.91-1.16	0.16-0.17	0.60-0.67	0.23-0.27	0.12-0.13	0.076-0.083	79.9-83.4
	Significance	NS	NS	NS	NS	NS	NS	0.0020
Meeker	Range	0.95-1.25	0.17-0.21	0.89-1.02	0.14-0.18	0.10-0.13	0.06-0.08	79.8-81.2
	Significance	NS	0.0166	NS	NS	0.0302	NS	NS
Munger	Range	0.91-1.43	0.12-0.25	0.79-1.23	0.22-0.26	0.12-0.14	0.07-0.11	72.2-79.3
	Significance	0.0006	<0.0001	0.0001	0.0408	<0.0001	<0.0001	<0.0001

[z] *P*-value provided when $P < 0.05$. NS indicates not significant ($P > 0.05$).

fertilization with increased rates improving growth and yield of red raspberry compared to no fertilizer N but with higher rates leading to reduced growth and yield; similar results were reported for trailing blackberry in Oregon (Nelson and Martin, 1986).

Three management factors may have been related to insufficient fertilizer N being available to the various cultivars grown. Caneberry plants take up the nitrate form of N, but many growers were using less-expensive sources of N including urea (ammonium-N). While ammonium-N will rapidly nitrify to nitrate-N at a soil pH suited to caneberries (5.6–6.5), nitrification is greatly reduced or slowed at a lower soil pH (Hart et al., 2006). Growers that were fertilizing with ammonium-N fertilizers and had low soil pH likely had plants deficient in N in spring, a time when fertilizer N is critical for good primocane growth (Mohadjer et al., 2001; Rempel et al., 2004). Nitrification would, however, hasten as soil temperatures increased, potentially leading to undesirable late growth and higher soil nitrate levels in autumn, as was noted for some sites (Table 2).

Secondly, many growers were only applying a granular fertilizer product while exclusively using drip irrigation (Table 1). This combination would be expected to reduce fertilizer uptake efficiency through increased volatilization of urea remaining on the surface of the soil and decreased movement of fertilizer N into the root zone with insufficient rainfall or drip irrigation; often growers do not turn on drip irrigation systems until after the first application of fertilizer in late March/early April because they expect sufficient rain – this does not always occur. Kowalenko et al. (2000) found that yield was higher in red raspberry in British Columbia, Canada when N fertilizer was applied as a granular product rather than distributed in smaller quantities during fertigation. They concluded that there was insufficient available N for primocane growth from fertigation alone. In this region, a combination of granular application of N in the spring with fertigation for those growers using drip irrigation is likely the best option. Finally, half of the growers in this study applied all of the N fertilizer in one application (late March/early April) rather than in the recommended split applications (50:50; late March:mid-June) that improve fertilizer uptake efficiency (Hart et al., 2006). In erect blackberry, doubling N fertilization rate (56–112 $kg \cdot ha^{-1}$) had no effect on leaf %N except when the N was split into two applications; this increased leaf %N, but had no effect on yield (Naraguma and Clark, 1998). In 'Meeker' red raspberry, Rempel et al. (2004) noted that increased rates of a single application of N fertilizer or a split application increased leaf %N and yield.

Higher rates of N typically have increased leaf %N, and often fruit %N in caneberries (Chaplin and Martin, 1980; Nelson and Martin, 1986; Rempel et al., 2004). However, in this study, despite adequate to high N fertilizer rates being applied, leaf %N was low or just sufficient, supporting the hypothesis that management practices limited fertilizer uptake. At some sites, particularly with later-season blackberry cultivars, it appeared that fruit %N was higher when growers applied high rates of N fertilizer (data not shown). The impact of N fertilizer rate on fruit %N has been mixed with a positive correlation found in red raspberry (Rempel et al., 2004), but no effect in blackberry (Alleyne and Clark, 1997).

Many growers were applying very high rates of phosphate (>82 $kg \cdot ha^{-1}$) and potash (>75 $kg \cdot ha^{-1}$) (Table 1) even though test analysis showed sufficient or high levels in soil (Table 2). Spiers (1993b) found that higher rates of K fertilization in erect blackberry increased leaf %K and reduced leaf %Ca. In trailing blackberry, higher rates of K fertilizer increased soil K, and while there was no impact on leaf %K there was a negative correlation with leaf %Ca (Nelson and Martin, 1986). In this study, higher levels of soil K were not related to leaf %K but it appeared that fruit %K was higher when growers applied high rates of K fertilizer (data not shown). While we were unable to correlate yield with soil or plant tissue nutrients due to the reliance on grower reported yield for prior years and the wide range of crops and cultivars included in this survey, additional study of those relationships within caneberry crops would be beneficial to further understanding any risks associated with K fertilization. In blueberry, Strik et al. (2019) found high levels of soil K were associated with reduced yield, but cultivars differed in this response.

There was considerable variation in fertilizer practices and products used among grower sites. Several growers were applying fertilizer at recommended rates and timings and had higher yields. However, several sites in this study included fields that were not performing to their full potential based on observed plant growth and yield. While some growers regularly used soil and leaf samples collected by fertilizer company field representatives to help inform their nutrient management program, few did their own sampling and some growers did no consistent leaf sampling. The amount of variability observed suggests that growers are either unaware of the resources available, prefer to use their own "real world" experiences, or rely on the companies from which they purchase fertilizer products. In cases where growers were applying more N, P, and K fertilizer than needed, there are opportunities for cost savings and reduced risk of leaching or environmental concerns with reducing application rates and/or improving timing of N applications. We need to improve our outreach to growers and chemical company representatives regarding best nutrient management practices and consider best methods of conveying new knowledge as we update our nutrient management resources for caneberry growers. Any needed changes in grower practices may be influenced by sharing risks associated with excessive application of some fertilizer nutrients and improper timing.

Acknowledgements

The authors appreciate the grower collaborators involved in this study and funding from the Clackamas Innovative Fund.

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