Leaf nutrient concentration in blackberry – recommended standards and sampling time should differ among blackberry types

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Abstract

Leaf tissue sampling is a critical aspect of a nutrient management program in commercial blackberry production. Current, published recommendations for time of sampling and nutrient sufficiency levels are generally defined for all caneberries (raspberry and blackberry), including floricane- and primocane-fruiting types. In blackberry, floricane-fruiting trailing, erect, and semi-erect cultivars and primocane-fruiting erect cultivars differ in fruiting season and pruning or training method. Thus, tissue nutrient levels and sampling requirements may differ among these blackberry types. Two studies were conducted to assess the impact of blackberry type and cultivar on tissue nutrient concentration of leaves sampled every 2 weeks over two growing seasons. In 'Prime-Jan'® and 'Prime-Jim'®, primocane-fruiting blackberry, the best time to sample primocane leaves coincided with a phenological stage (green fruit on the primocane) rather than on a given calendar date (standard method). In the second study, we examined leaf nutrient levels in trailing, erect, and semi-erect cultivars. Blackberry types differed in leaf nutrient concentrations. Within each type of blackberry studied, cultivars frequently differed in nutrient concentration throughout the season. We thus confirmed the importance of sampling cultivars separately. In many cultivars, primocane leaf nitrogen, phosphorus, potassium, calcium, magnesium, and copper were consistently below the current published sufficiency levels. New sufficiency levels and recommended sampling times based on blackberry type are presented. Fertilizer recommendations based on leaf nutrient sufficiency levels specific to the diverse types of blackberry grown will aid growers, potentially reducing over application of fertilizer nutrients.

Keywords: *Rubus*, tissue sampling, nutrient standards, nutrient management

INTRODUCTION

Approximately 6000 ha of blackberry (*Rubus* L. subgenus *Rubus*, Watson) were harvested in the United States in 2012 (US Department of Agriculture, 2014). Approximately, 2500 ha of blackberry were grown in Oregon in 2012, with the predominant type being the trailing blackberry which is grown mainly for processed markets. Erect and semi-erect types of blackberry are grown throughout many regions of the United States, mainly for the fresh market. The growth habit and fruiting season of trailing, erect, and semi-erect blackberry differ considerably (Strik and Finn, 2012). In Oregon, the fruiting season of trailing cultivars ranges from late June through July. Erect cultivars produce fruit from late July through August, and semi-erect cultivars from early August through early October. Primocane-fruiting blackberry are harvested from approximately mid-September to frost in the autumn for the primocane crop.

The primocanes of trailing types are not self-supporting and are trained along the ground under the floricane canopy. After fruit harvest and floricane senescence, the floricanes are pruned and the new primocanes are trained in either August or February. In contrast, the primocanes of erect and semi-erect types are self-supporting and are summer pruned (tipped) to encourage branching. This increases yield of the floricanes in the following year (e.g., Strik and Finn, 2012) and in the current season on primocane-fruiting types (Strik et al., 2008, 2012; Thompson et al., 2009).

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Commercial blackberry growers are encouraged to develop fertilization programs based on recommended starting rates of nitrogen (N) fertilizer, which depend on planting age, with adjustments of N and other macro- and micro-nutrients based on periodic soil nutrient analysis, observations of plant growth, and annual leaf tissue analysis (Bolda et al., 2012; Bushway et al., 2008; Fernandez and Ballington, 1999; Hart et al., 2006; Krewer et al., 1999). Leaf sampling for tissue analysis of raspberry and blackberry 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., 2006). The recommended nutrient sufficiency levels are similar among these currently available nutrient management guides and all have the same standards and sampling time recommendations regardless of caneberry type. 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. The nutrient concentration of fruiting lateral leaves has been shown to change during the fruit development period for blackberry types and cultivars (Strik and Vance, 2016a, b). However, in primocane-fruiting types, leaf nutrient levels may be significantly affected by yield as sampling may be during fruit development (Strik, 2015).

Primocane leaf nutrient levels have been shown to vary over the growing season in erect (Clark et al., 1988; Strik and Vance, 2016b), semi-erect (Strik and Vance, 2016b), and trailing (Mohadjer et al., 2001) floricane-fruiting blackberry, primocane-fruiting blackberry (Strik, 2015), and floricane-fruiting raspberry (e.g., John and Daubeny, 1972; Kowalenko, 1994).

Recently, Strik (2015) recommended that primocane-fruiting blackberry be sampled at the early green fruit stage (about 8 weeks after summer pruning) rather than a particular calendar date and suggested the leaf sufficiency range for phosphorus (P) and potassium (K) may need to be lowered for this crop.

Cultivars of blackberry (Fernandez-Salvador et al., 2015a, b; Harkins et al., 2014; Strik, 2015; Strik and Vance, 2016a, b) and raspberry (John and Daubeny, 1972) have been shown to differ in primocane leaf nutrient levels when sampled in mid-season. 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 due to possible cultivar effects on leaf nutrient concentrations (Hart et al., 2006).

The objectives of this study were to evaluate the results of primocane leaf sampling date and tissue nutrient concentrations for trailing, erect, and semi-erect, floricane-fruiting and erect, primocane-fruiting blackberry cultivars and provide recommendations for sampling time and tissue nutrient standards to inform growers for nutrient management programs.

MATERIALS AND METHODS

Study sites

The studies were conducted in 2008-2009 and 2013-2014 for primocane-fruiting and floricane-fruiting cultivars, respectively at Oregon State University's North Willamette Research and Extension Center, Aurora, OR (lat. 45.2797, long. -122.7563). The plantings were mature during the study. Trailing blackberry cultivars were evaluated at a certified organic site [USDA accredited agency (Oregon Tilth, Certified Organic, Corvallis, OR)] and a conventionally-managed site. The primocane-fruiting blackberry cultivars were conventionally managed. Plants were drip irrigated, were pruned and trained per standard commercial practice (Strik and Finn, 2012), and weeds were managed using pre-emergent herbicides (conventionally managed) or a black, woven polyethylene ground cover in the organic planting (TenCate Protective Fabrics; OBC Northwest Inc., Canby, OR). More information on site establishment, irrigation, pruning, training, and fertilization can be found in Strik (2015) for primocane-fruiting blackberry and Strik and Vance (2016a, b) for floricane-fruiting blackberry.

In the floricane-fruiting blackberry cultivars grown in the organic planting, plants were fertilized with a target rate of 90 kg ha^{-1} of N through the drip irrigation system (fertigated) in eight equal portions from early April to early July of each year. In the conventionally managed planting 78 kg·ha^{-1} N was applied in a split application on April 3 and May 28, 2013. In 2014, 90 kg ha^{-1} N was applied in two equal portions on March 27 and June 5, and an additional 28 kg ha^{-1} N was applied to erect and semi-erect cultivars on July 7. These granular fertilizers were broadcast within the in-row area and were washed into the soil through rainfall (Strik and Vance, 2016a, b). In the primocane-fruiting cultivars, plants were fertilized with 34 kg ha^{-1} N in mid-April and an additional 45 kg ha^{-1} N in mid-May of each year. Information on other nutrients applied can be found in Strik and Vance (2016a, b) and Strik (2015).

Cultivars

For the floricane-fruiting types, the cultivars grown and studied at the organic site were all trailing types ('Black Diamond', 'Marion', 'Obsidian' and 'Onyx'). More information on their fruiting season, growth and yield is reported by Fernandez-Salvador et al. (2015b). At the conventional site, five trailing blackberry cultivars ('Black Diamond', 'Columbia Star', 'Marion', 'Obsidian' and 'Onyx'), one erect type ('Ouachita') and two semi-erect types ('Chester Thornless' and 'Triple Crown') were studied (Strik and Vance, 2016b). The primocane-fruiting cultivars studied were 'Prime-Jan'® and 'Prime-Jim'® (Strik, 2015).

Leaf sampling

Primocane leaf tissue samples for nutrient testing were collected approximately every 2 weeks from early May to early October of each year. Stage of plant development and fruiting season was recorded for each cultivar at each site. The rate of plant development and fruiting season did not appear to differ between years in each study (data not shown). The primocane-fruiting blackberry was hedged (summer pruned) and the weeks relative to hedge date recorded. Yield data were not recorded, but the fields were observed to have a good, typical commercial yield for this production region.

Recent, fully expanded primocane leaves, including petioles, were sampled per plot on each date and were not washed per standard recommendation (Hart et al., 2006). Sampled leaves were priority shipped to Brookside Laboratories, Inc. in New Bremen, OH for analysis of macro- and micro-nutrient concentration.

Information on data analysis is available in Strik (2015) and Strik and Vance (2016a, b). The data were interpreted to assess whether recommended tissue nutrient standards and sampling should vary among blackberry types and cultivars.

RESULTS AND DISCUSSION

In primocane-fruiting blackberry, and all types of floricane-fruiting blackberry studied, primocane leaf nutrient concentration differed over the growing season. This was true for most macro- and micro-nutrients and was often affected by year, site, and cultivar (Strik, 2015; Strik and Vance, 2016a, b). Within blackberry type, cultivars were found to vary in the concentration of many macro- and micro-nutrients within primocane leaves when sampled at the current recommended time of late-July to early-August (Strik, 2015; Strik and Vance, 2016a, b). Based on these findings, we recommend that cultivars continue to be sampled separately when monitoring plant nutrient status.

In primocane-fruiting blackberry, the pattern of nutrient changes over the season was more related to summer tipping or hedging date than sampling date (Strik, 2015). Thus sampling for nutrient analysis at the currently recommended time of late-July to early-August would be a time when some nutrients such as calcium are rapidly changing in the primocane. When tissue nutrients were related to date of hedging, changes in nutrient concentration over time were much more consistent among years and cultivars. Based on these results, we now recommend sampling the leaves of primocane-fruiting blackberry for tissue analysis 8 to 10 weeks after hedging or at the early green fruit stage (Strik, 2015).

In floricane-fruiting blackberry, stage of plant development in the late-July to early-

August recommended primocane leaf sampling period varies from harvest being complete or finishing up and primocanes actively growing (trailing types), during fruit harvest (erect type), and from fruit development to just starting harvest (semi-erect types) (Table 1). One might expect primocane leaf nutrient concentration to vary greatly among these types of blackberry as a result of this range in stage of development. Strik and Vance (2016b) found that the trailing blackberry cultivars differed from the erect or semi-erect cultivars for leaf N, Mg, S, B, Fe, Cu, and Al when sampled on either the end of July or mid-August. Leaf P, Ca, and Zn differed between trailing and the other types when sampled in mid-August. There were fewer differences found among 'Ouachita' (erect) and the semi-erect types ('Triple Crown' and 'Chester Thornless'), but these did differ in leaf P (mid-August), K (late July), S, B (mid-August), Cu, and Zn (late July). In all types, only leaf P, K, and Fe were stable during the currently recommended sampling period, whereas leaf Mg, Ca, B, Mn, and Zn were more stable the last 2 weeks of August (Strik and Vance, 2016b). Leaf N, S, Cu, and Al were more variable among dates depending on blackberry type, year and site. There is a lot of N and K in blackberry fruit (Harkins et al., 2014; Strik and Bryla, 2015) perhaps accounting for the variability seen among sampling dates and cultivars in leaf N and K. For example, in the trailing blackberry cultivars, primocane leaf K generally increased during the late July to late August sampling dates, after fruit harvest. However, leaf K declined during this period in the erect, semi-erect (Strik and Vance, 2016b) and primocane-fruiting cultivars (Strik, 2015) during fruit development.

The current published primocane leaf nutrient sufficiency levels are provided in Table 2 as well as the proposed new recommendations for Oregon. These new recommendations are based on the findings of Strik (2015) and Strik and Vance (2016a, b). For primocane leaf N they found that 'Black Diamond', 'Triple Crown', and 'Prime-Jan®' had levels lower than 2.3% (current standard) despite having good growth and high yield. Thus the lower end of the range has been reduced to 2.0%. We leave the upper end of the range at 3.0%, because leaf N was higher in organically-grown blackberry with no apparent adverse effect (Strik and Vance, 2016a).

We propose lowering the range for sufficiency for leaf P, because 'Ouachita', 'Triple Crown', 'Prime-Jan'®, and 'Prime-Jim'® commonly had a lower leaf P than the published sufficiency levels without any symptoms of deficiency or negative effects on yield. The upper limit is not changed because blackberry grown organically had greater leaf P with no adverse effects.

'Black Diamond', 'Onyx', 'Ouachita', 'Triple Crown', 'Chester Thornless', and 'Prime-Jan'® all had a leaf K lower than the 1.3% at the currently published sufficiency level (Strik, 2015; Strik and Vance, 2016b; Table 2). Blackberry plants tend to have a high yield and there is significant removal of K in harvested fruit (Strik and Bryla, 2015). The high demand of fruit for K may thus reduce the K concentration in primocane leaves. We thus are lowering the sufficiency range (Table 2).

'Columbia Star', 'Marion', 'Black Diamond', and 'Onyx' had a leaf Ca lower than the published sufficiency level of 0.6% and thus we have lowered this value. We have also lowered the upper end of the sufficiency range to 1.5% (Table 2).

'Black Diamond', 'Onyx', and 'Marion' had a leaf Mg less than the 0.3% currently at the lower end of the sufficiency range. We thus have reduced this lower end to 0.25%. We do not recommend changing the upper end of the range because the semi-erect cultivars had higher leaf Mg than the trailing types (Strik and Vance, 2016a, b).

Table 1. Phenological stages for trailing, erect, and semi-erect blackberry throughout the growing season in approximate order of fruit ripening. Adapted from Strik (2015) and Strik and Vance (2016a, b).

Blackberry type and cultivar	Approximate stage of development on each date[1]											
	1 May	15 May	1 Jun	15 Jun	1 Jul	15 Jul	1 Aug	15 Aug	1 Sep.	15 Sep	1 Oct	15 Oct
Floricane-fruiting trailing												
Obisidian	P growing; bloom	Early green fruit	Late green fruit	Black fruit	Harvest	End of harvest	P growing	P growing	P growing	P growing	P growing	P growing
Black Diamond	P growing; bloom	Late fruit set	Mid green fruit stage	Late red fruit	Harvest	Harvest	End of harvest	P growing	P growing	P growing	P growing	P growing
Columbia Star	P growing; early bloom	Late fruit set	Late green fruit	Mid red fruit	Harvest	Harvest	End of harvest	P growing	P growing	P growing	P growing	P growing
Marion	P growing	Late bloom	Early green fruit	Early red fruit	Begin harvest	Late harvest	P growing	P growing	P growing	P growing	P growing	P growing
Onyx	P growing	Mid bloom	Late bloom to green fruit	Late green	Late red to first black	Harvest	Late harvest	P growing	P growing	P growing	P growing	P growing
Floricane-fruiting erect												
Ouachita	P growing	Very early bloom	Late bloom to early green	Late green fruit	Late green to first red	Late red to shiny black	Harvest	Harvest	Late harvest	P growing	P growing	P growing
Floricane-fruiting semi-erect												
Triple Crown	P growing	P growing	Early bloom	Late bloom to early green	Mid green fruit	Late red to shiny black	Late red to shiny black	First harvest	Harvest	Harvest	End of harvest	P growing
Chester Thornless	P growing	P growing	Early bloom	Early green	Late green to first red	Late red fruit	Late red to shiny black	Late red to shiny black	Harvest	Harvest	Late harvest	P growing
Primocane-fruiting erect												
Prime-Jan and Prime-Jim[2]	P at <0.3 m	P ~0.3 m	P ~0.75 m	P ~1 m	P ~1.4 m (hedge date)	P branches emerging	P branches <0.3 m	P branches ~0.35 m to green fruit	Green to red fruit	Red to black fruit	Black fruit to harvest	Harvest

[1]Approximate stage of development is provided. The beginning and end of fruit harvest for a particular cultivar may have occurred between the dates provided. Years (2013 and 2014) were not found to differ in rate of development. P = primocane; primocane growth would have slowed toward the end of the season (e.g., 1 Oct.) as temperatures declined in autumn.

[2]Cultivars were not found to differ in rate of development. Average stage of development for 2008 and 2009 provided as years differed considerably (Strik, 2015).

Table 2. Currently published recommended primocane leaf nutrient sufficiency levels for raspberry and blackberry in Oregon, California, and the northeastern United States and the proposed, new sufficiency levels recommended for all blackberry types in Oregon.

Nutrient	Published sufficiency levels in North America[1]			New sufficiency levels Oregon[2]
	Oregon	California	Northeastern US	
Nitrogen (%)	2.3 to 3.0	2.0 to 3.0	2.0 to 3.0	2.0 to 3.0
Phosphorus (%)	0.19 to 0.45	0.25 to 0.40	0.25 to 0.40	0.15 to 0.40
Potassium (%)	1.3 to 2.0	1.5 to 2.5	1.5 to 2.5	0.9 to 1.8
Calcium (%)	0.6 to 2.0	0.6 to 2.5	0.6 to 2.0	0.5 to 1.5
Magnesium (%)	0.3 to 0.6	0.3 to 0.9	0.6 to 0.9	0.25 to 0.60
Sulfur (%)	0.1	na	0.4 to 0.6	0.1 to 0.2
Managanese (ppm)[3]	50 to 300	50 to 200	50 to 200	50 to 300
Boron (ppm)	30 to 70	30 to 50	30 to 70	30 to 70
Iron (ppm)	60 to 250	50 to 200	60 to 250	70 to 500
Zinc (ppm)	15 to 50	20 to 50	20 to 50	20 to 50
Copper (ppm)	6 to 20	7 to 50	6 to 20	5 to 15
Aluminium (ppm)	na[w]	na	na	50 to 400

[1] Currently published sufficiency levels for caneberries (raspberry and blackberry) for: a) Oregon: washed leaves, including petioles (Hart et al., 2006) collected in late July to early August; b) California: for whole leaves (petioles and washing not specified collected from May to August (Bolda et al., 2012); and c) Northeastern United States: for leaves with petioles removed and washed in distilled water in mid-summer or the first week of August (Bushway et al., 2008).

[2] Proposed new sufficiency levels for blackberry in Oregon based on new research by Strik (2015) and Strik and Vance (2016a, b) for leaves (including petioles) that are not washed and are collected in late-July to late-August. Sample primocane-fruiting blackberry cultivars at the early-green fruit stage, about 8 to 10 weeks after hedging in Oregon. Sample leaves from primocane branches.

[3] 1 ppm = 1 mg kg^{-1}.

We recommend changing the leaf sufficiency levels for Fe (Table 2) to account for dust that could distort leaf values for Fe in our soils; recommendations are to not wash leaves prior to sending for analysis (Hart et al., 2006). For leaf Zn, we recommend increasing the lower end of the sufficiency range (Table 2). The current sufficiency range for primocane leaf Cu was likely established when use of copper fungicides was common for control of various cane diseases. However, leaf Cu is lower than these levels when these fungicides are not used, without any apparent effect on yield or plant growth. The lowest leaf Cu observed was 5.9 ppm and the highest 9.4 ppm (Strik, 2015; Strik and Vance, 2016a, b). We are thus lowering the sufficiency range for this nutrient (Table 2). We are not aware of any sufficiency levels published for leaf aluminum (Al). Based on the leaf Al observed in Strik (2015) and Strik and Vance (2016a, b) where there was a range from a low of 87 ppm (primocane-fruiting blackberry and 'Onyx') to 379 ppm (also in 'Onyx') we have proposed the sufficiency levels presented in Table 2. We are not proposing any changes to the existing sufficiency levels for S, Mn, or B (Table 2).

While the current published standards are intended to be suitable for all raspberries and blackberries, including primocane- and floricane-fruiting types, we are proposing new standards for blackberry that are inclusive of all blackberry types. All floricane-fruiting blackberry types studied can be sampled during the current recommend time of late-July to early-August. However, for some nutrients, such as Ca, Mg, B and Zn, the best time to sample is the latter part of August. In primocane-fruiting blackberry a calendar date is not recommended as these types are best sampled during the green fruit stage.

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Literature cited

Bolda, M., Gaskell, M., Mitcham, E., and Cahn, M. (2012). Fresh Market Caneberry Production Manual, Pub. 3525 (USA: Univ. Cal. Agr. Nat. Res.).

Bushway, L., Pritts, M., and Handley, D., eds. (2008). Raspberry & Blackberry Production Guide for the Northeast, Midwest, and Eastern Canada (Ithaca, NY, USA: Plant and Life Sci. Pub. Coop. Ext., NRAES-35).

Clark, J.R., Buckley, J.B., III, and Hellman, E.W. (1988). Seasonal variation in elemental concentration of blackberry leaves. HortScience *23*, 1080.

Fernandez, G., and Ballington, J. (1999). Growing Blackberries in North Carolina (North Carolina State Univ. Ext. Serv. Pub. AG-401). http://www.ces.ncsu.edu/depts/hort/hil/pdf/ag-401.pdf.

Fernandez-Salvador, J.A., Strik, B.C., and Bryla, D. (2015a). Response of blackberry cultivars to fertilizer source in an organic fresh market production system. Horttechnology *25* (*3*), 277–292.

Fernandez-Salvador, J., Strik, B.C., Zhao, Y., and Finn, C.E. (2015b). Trailing blackberry genotypes differ in yield and post-harvest fruit quality during establishment in an organic production system. HortScience *50*, 240–246.

Harkins, R., Strik, B.C., and Bryla, D. (2014). Weed management practices for organic production of trailing blackberry. II. Accumulation and loss of biomass and nutrients. HortScience *49*, 35–43.

Hart, J., Strik, B.C., and Rempel, H. (2006). Caneberries. Nutrient Management Guide (USA: Ore. State Univ. Ext. Serv., EM8903-E). http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20427/em8903-e.pdf.

John, M.K., and Daubeny, H.A. (1972). Influence of genotype, date of sampling, and age of plant on leaf chemical composition of red raspberry (*Rubus idaeus* L.). J. Am. Soc. Hortic. Sci. *97*, 740–742.

Kowalenko, C.G. (1994). Growing season changes in the concentration and distribution of macroelements in Willamette red raspberry plant parts. Can. J. Plant Sci. *74* (*4*), 833–839 http://dx.doi.org/10.4141/cjps94-151.

Krewer, G., Smith, B., Brannen, P., and Horton, D. (1999). Commercial Bramble Culture, Bull. 964 (USA: Coop. Ext. Serv. Univ. Georgia). http://www.smallfruits.org/Bramble/production/BRAMBLE.pdf.

Mohadjer, P., Strik, B.C., Zebarth, B.J., and Righetti, T.L. (2001). Nitrogen uptake, partitioning and remobilization in 'Kotata' blackberries in alternate year production. J. Hortic. Sci. Biotechnol. *76* (*6*), 700–708 http://dx.doi.org/10.1080/14620316.2001.11511434.

Strik, B.C. (2015). Seasonal variation in mineral nutrient content of primocane-fruiting blackberry leaves. HortScience *50*, 540–545.

Strik, B.C., and Bryla, D.R. (2015). Uptake and partitioning of nutrients in blackberry and raspberry and evaluating plant nutrient status for accurate assessment of fertilizer requirements. Horttechnology *25* (*4*), 452–459.

Strik, B.C., and Finn, C.E. (2012). Blackberry production systems – a worldwide perspective. Acta Hortic. *946*, 341–347 http://dx.doi.org/10.17660/ActaHortic.2012.946.56.

Strik, B.C., and Vance, A.J. (2016a). Seasonal variation in mineral nutrient content of primocane and floricane leaves in blackberry. I. Impact of conventional and organic production in trailing blackberry cultivars. HortScience.

Strik, B.C., and Vance, A.J. (2016b). Seasonal variation in mineral nutrient content of primocane and floricane leaves in blackberry. II. Comparison of trailing, erect, and semi-erect cultivars. HortScience.

Strik, B.C., Finn, C.E., Clark, J.R., and Buller, G. (2008). Management of primocane-fruiting blackberry to maximize yield and extend the fruiting season. Acta Hortic. *777*, 423–428 http://dx.doi.org/10.17660/ActaHortic.2008.777.63.

Strik, B.C., Clark, J.R., Finn, C.E., and Buller, G. (2012). Management of primocane-fruiting blackberry – Impacts on yield, fruiting season, and cane architecture. HortScience *47*, 593–598.

Thompson, E., Strik, B.C., Finn, C.E., Zhao, Y., and Clark, J.R. (2009). High tunnel vs. open field: management of primocane-fruiting blackberry using pruning and tipping to increase yield and extend the fruiting season. HortScience *44*, 1581–1587.

US Department of Agriculture. (2014). Table 33: Berries: 2012 and 2007. In 2012 Census of Agriculture (Washington DC, USA: US Dept. Agr., Natl. Agr. Statistical Serv.).